“NEXT LEVEL” RISK MANAGEMENT AT HAMILTON’S WATER TREATMENT PLANT

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ABSTRACT

Increased standards for risk management and a desire to improve health and safety provisions for its workers and community has resulted in the implementation of an Emergency Gas Scrubber (EGS) to manage the risks posed through the accidental release of chlorine gas at the Hamilton water treatment plant.

Although such an event is highly unlikely, this outcome is similar to work recently undertaken in Australia by major city water agencies there. Currently, there are no other known installations that utilise this specific type of EGS equipment anywhere else in New Zealand municipal water or wastewaster treatment facilities.

A key driver for this project is not only the size of the treatment facility at Hamilton (it is Hamilton’s sole source of water supply), but the plant’s location adjacent to an urban community .

The paper provides an overview of the process that were undertaken from start to finish which commenced with a risk mitigation options assessment that considered not only the “do nothing”, but also options involving an improved public awareness campaign, application of both dry and wet scrubber technology and also conversion of the disinfection system from a gas to a hypochlorite-based solution.

Of particular interest is the formal Quantitative Risk Analysis (QRA) that was carried out to quantify the risk posed by a myriad of failure modes of the existing chlorine system that could lead to an accidental chlorine gas discharge. A formal risk assessment criteria used for this application is in common use in New Zealand and this was supplemented with a set of risk framework criteria used for similar projects in Australia . The outcome of the QRA was a series of risk profiles for various failure scenarios. This analysis was able to inform HCC’s decision making about type of risk mitigation and the extent of the system that was appropriate to implement.

Various steps in the implementation of the system through design and construction to testing/commissioning are discussed, including an overview of the actual EGS technology.

Given this project involves application of anew and rigorous approach to risk management and the implementation of associated technology, this paper should be of interest to a wide range of conference delegates involved in risk assessments and also the operation, maintenance and management of hazardous environments and facilities at municipal treatment plants.

Keywords- Chlorine, risk management, scrubber, emergency, water treatment

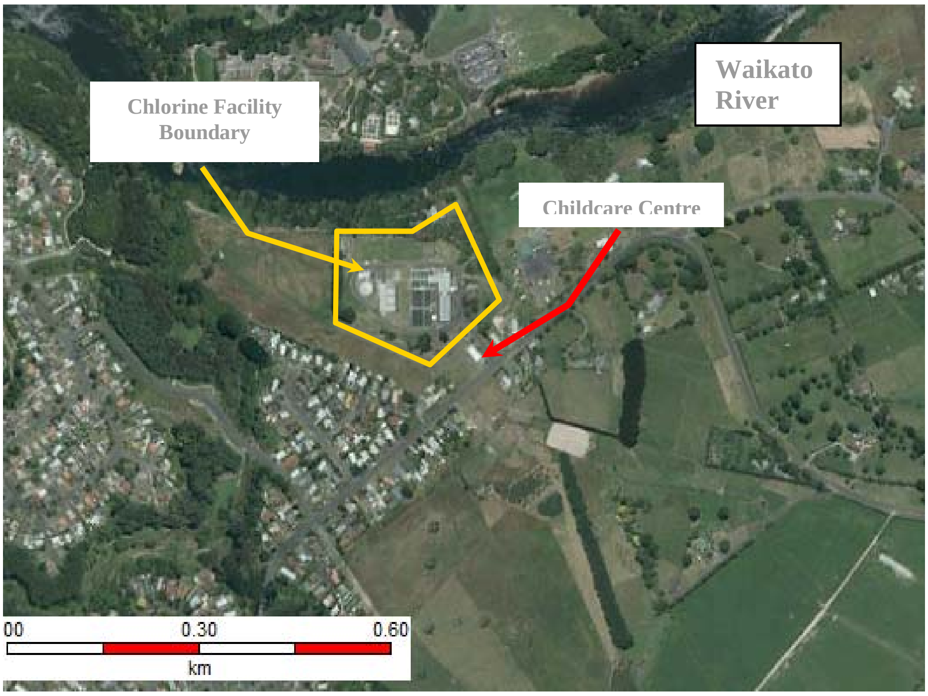
1. BACKGROUND

1.1 HAMILTON WTS LOCATION

The Hamilton Water Treatment Station (WTS) is Hamilton’s only source of treated drinking water and has a peak flow design capacity of 106ML/day. Water sourced from the Waikato River is pumped into a conventional clarification/filtration process before passing through a further carbon media filtration process. Ultra violet light and chlorine then complete the disinfection process.

The site is located at Waiora Terrace off Peacockes Road in Hamilton as shown in Figure1. It is bounded on the northern boundary by the Waikato River which lies within the 200 metre radius of the WTS. The facility is surrounded by occupied residential allotments (predominantly to the south or south east direction)with the closest property within 140m of the chlorine drum room .

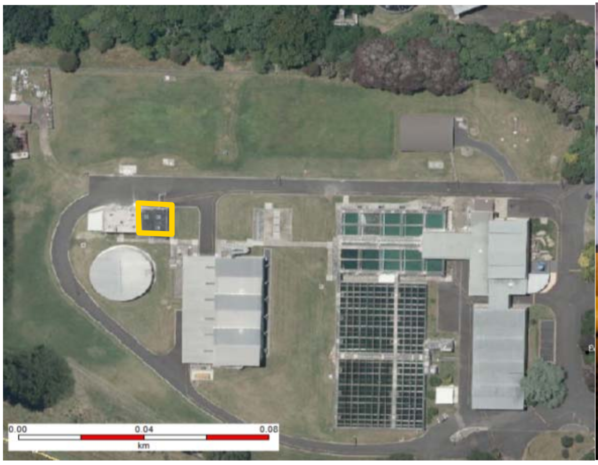
Figure 1. Hamilton WTS Location



The current chlorine dosing system was designed and installed as part of an upgrade of the WTS that was completed in 2006. The WTS layout is shown in Figure 2.

It utilises a continuous gas chlorination dosing system operating with five 920 kg cylinders on site with the option to add a sixth (currently being considered). Figure 2 shows the Chlorine Cylinder Room's location within the WTS and also inside the Chlorine Drum Store.

Figure 2: Existing WTS Layout and Chlorine Drum Store Room



Whilst the chlorine cylinders are stored in a single room, the actual chlorinator is in a separate adjacent Chlorinator Room. Passive and forced ventilation systems located at low levels are installed in the Chlorine Cylinder Room. The Chlorine Cylinder Room has an overhead gantry and door for removal/installation of cylinders.

Operationally, up to two chlorine cylinders are replaced at a time, with only a single tank being moved, disconnected/connected at any given time. During peak water production during the summer months, chlorine demand reaches 150 kg per day. Commissioning and decommissioning a single cylinder and connection thereto is considered to present the major risk source of a chlorine leak. It is this scenario, i.e accidental discharge of a single chlorine cylinder, that is the therefore the maximum foreseeable discharge scenario upon which this investigation is based.

1.2 CHLORINE GAS HAZARD

Chlorine gas is a respiratory irritant. Symptoms that may be caused by inhalation include headache, painful and difficult breathing, burning sensation of the chest, nausea and watering of the eyes. Chlorine has the potential to disperse outside the site boundary and cause an impact to the off-site population. Exposure to chlorine through inhalation, ingestion and direct contact can result in injury and fatality. Exposure effects of chlorine to humans are shown in Table 1.

Table 1 Effects of Chlorine on Humans

Chlorine Concentration (ppm)	Effect
0.2 – 0.4	Odour threshold (decrease in odour perception occurs over time)
1 – 3	Mild mucous membrane irritation, tolerated for up to 1 hour
5 – 15	Moderate irritation of the respiratory tract. The gas is very irritating, and it is unlikely that any person would remain in such an exposure for more than a very brief time unless the person is trapped or unconscious
30	Immediate chest pain, vomiting, dyspnoea, cough
40 – 60	Toxic pneumonitis and pulmonary oedema
430	Lethal over 30 minutes
1000	Fatal within a few minutes

1.3 DISCHARGE EVENTS

It is worth noting that worldwide major leaks from chlorine drum systems are very rare and that in the case of release of the compressed gas the expansion is accompanied by a reduced temperature that can cause ice to develop at the release point. This freezing characteristic can markedly reduce the chlorine gas release rate.

Aside from published literature from scrubber suppliers of isolated cases of accidental discharge of chlorine in the USA, the single leak event known to the authors occurred at the Silvan Water Treatment Plant in Melbourne in the early 1990s. It was due to failure of a faulty gasket at a catchpot on the pressurized chlorine gas manifold. It resulted in the release of only about 80kg of chlorine before the rate of release slowed to a low rate due to this freezing effect. The operator entered the drum room after putting on the required protective equipment and was able to isolate the leak.

1.4 NEED FOR AN IMPROVED RISK MANAGEMENT APPROACH

The outcome of a site audit by Worksafe New Zealand recommended that HCC consider improvements to their emergency plans for the unlikely event of a substantive chlorine gas leak occurring at the Water Treatment Plant site. HCC decided the best way to improve emergency plans and minimise the risk to staff working on site and the surrounding community was to mitigate the effects of any chlorine gas leak within the site boundaries and started investigations into options to achieve that outcome.

2. CHLORINE DISCHARGE MITIGATION OPTIONS INVESTIGATED

HCC engaged GHD to carry out an assessment of systems and technologies available to further mitigate risks associated with chlorine gas discharges. Options investigated are in use elsewhere at facilities in Australia and New Zealand and included the following :

- Option 1 - Containment and controlled release to the environment;
- Option 2 - 'Wet' type EGS chlorine scrubber;
- Option 3 - 'Dry' type EGS chlorine scrubber;
- Option 4 - Conversion to sodium hypochlorite system for chlorination.

The first three of these options are reactive approaches aiming to limit chlorine escaping the facility during an accidental release. These options can be described as 'isolation' of the hazard. The fourth option – conversion to a sodium hypochlorite system aims to prevent an accidental release from occurring by removing chlorine gas from the system. This option can be described as 'elimination' of the hazard, although it was acknowledged that there are other hazards inherent to the use of Hypochlorite that would still need to be effectively managed

Option 2 - Wet scrubbers have historically been the only option for chlorine gas removal. Once chlorine gas is detected, forced ventilation extracts the gas which is then neutralised using a chemical reaction. Upon chlorine detection forced ventilation draws contaminated air through the device and caustic soda is sprayed into the airstream to react with and neutralise any chlorine gas Wet scrubber systems have the following features:

Caustic soda (25-30% w/w concentration) stored in quantities large enough to treat the flow from the largest reasonably foreseeable leak – generally > 5kL. The concentration range is chosen to minimise the risk of freezing which will occur if more concentrated sodium hydroxide solution is used;

Wet scrubbers have previously been installed throughout Australia and New Zealand with installations currently operational at only 1 installation in Auckland. Watercare's Onehunga Water Treatment Plant (the only known scrubber facility of any kind in New Zealand), the Victoria Eastern Sewage Treatment Plant in Melbourne and a number of Sydney Water's water treatment plants.

Option 3 - Dry scrubbers operate on the same principal as wet scrubbers; using mechanical ventilation in the event of a chlorine leak to extract chlorine gas, pass it through the device, neutralise and discharge the treated air. Where liquid caustic soda provides removal by chemical reaction in wet scrubbers, dry scrubbers use dry media (typically caustic impregnated 'beads' of activated carbon) and the chemisorptive processes to adsorb chemically react with the chlorine to discharge clean air.

Dry scrubbers have three main system components as shown in Fig 3 – ventilation piping, ventilation fan, and the dry media tank.

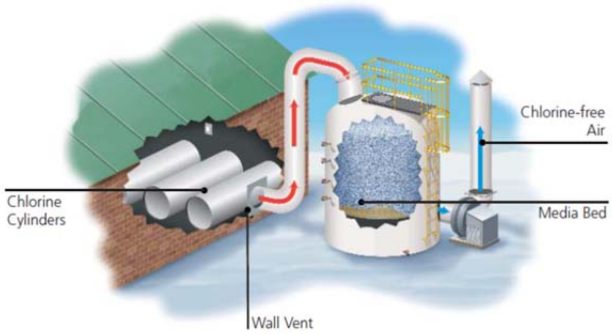


Figure 3: Typical Dry Scrubber Installation (Purafil®)

Table 2 documents a number of comparative criteria related to the four options described above.

Table 2: Comparison of Options

Option and NPV Estimate	Health & Safety, Residual Chlorine Risk	Operation, Maintenance & Reliability	Implementation at HWTP
Containment & Controlled Release ($1.7-$2M)	Containment allows the surrounding area to be evacuated prior to discharge of the chlorine gas to the environment. High residual risk associated with chlorine gas discharge. May not achieve regulatory compliance without formal Quantitative Risk Assessment	Simple, low maintenance. Reliable.	Easy implementation. Actuation of ventilation louvers and leak testing/sealing of building required.
Wet Scrubber ($3.1-$4.8M)	Large quantity of Dangerous Good Class 8 caustic soda stored on site. Residual chlorine risk eliminated through proper design of the scrubber.	More complicated system compared to dry scrubber. Moderate maintenance requirements, corrosive environment and several motors (pumps & fans). Good reliability if system is well maintained. Experience shows systems easy to fall into disrepair. Routine testing & replacement of caustic.	Easy implementation. Wet scrubber can be designed and constructed without impacting operations.
Dry Scrubber ($2.5-$3.1M)	Non-hazardous materials & waste. Residual chlorine risk eliminated through proper design of the scrubber.	Low maintenance requirements, only one motor (blower) – good reliability. Routine testing of scrubbing media to ensure integrity.	Easy implementation. Pre-designed system can be installed without impacting operations.
Sodium Hypochlorite Conversion ($2.8-$3.6M)	Risk of accidental chlorine gas release eliminated. Storage of liquefied chlorine gas replaced with Large quantities of sodium hypochlorite – hazardous material. Liquid hazardous material is easier to manage during a leak than gas – lower risk to surrounding residents.	Similar O&M costs as just replaces chlorine gas system. Higher chemical costs than chlorine gas. Hypochlorite degradation is light and temperature related.	Expensive to implement as HWTP is required to operate continually. Full detailed design of new system and construction staging plan. Requires construction of new hypochlorite storage & dosing building, bunded delivery bay if retrofit into existing chlorine gas storage building is too difficult.

2.1 IDENTIFICATION OF PREFERRED OPTION

Evaluation of local and international experience along with preliminary cost estimates was used to identify the preferred option. Achieving the optimum balance of suitability for this site, the key selection criteria are ;

1. Minimising the risk to staff and the surrounding community

2. Operability, including health and safety issues
3. Operational experience
4. Whole of life cost.

Whilst the Containment and Controlled Release option has the lowest capital and NPV costs and enables the risk to staff to be reduced, the risk to the surrounding community is not totally eliminated. .

Chlorine scrubbing (wet or dry) minimises the risk to both staff and surrounding community but some risk remains due to the possibility that the scrubber might fail during a chlorine leak. This means with these options there is still a need for community communication protocols to be included in emergency planning. The only way to fully satisfy the first of the above criteria is through conversion to a sodium hypochlorite dosing system.

Based on the above qualitative assessment and evaluation of the options available in conjunction with preliminary order-of-magnitude cost estimates, either Dry Scrubber technology or Sodium Hypochlorite Conversion were identified as the more favourable options.

Each of the preferred options was taken through to a Concept Design Stage to refine NPV costs and issues so as to identify a preferred option for implementation.

The key conclusions of this concept design stage of this project were that :

a) Whilst they had similar capital costs, significantly higher (40%) operational costs of the hypochlorite system resulted in a 25% higher NPV cost with this option.

b) An MCA framework developed for the process suggests that the Scrubber option is more favourable than the Sodium Hypochlorite option on all selected criteria with the exception of the Risk Management criteria related to chlorine gas release.

c) To further reduce the chlorine gas release risk from the Scrubber Option would require the delivery truck bay to be covered and sealed during deliveries and include gantry crane and walkways etc which is likely to add at least another $300,000 + to the capital cost. This additional cost does not alter the more favourable outcomes for the Scrubber option on any of the criteria in the MCA.

It was then decided that to better understand the contribution of this Risk Management component to this decision of the Dry Scrubber as the preferred option, a formal and detailed Quantitative Risk Analysis be undertaken to determine whether the level of residual risk associated with the Dry Scrubber was appropriate good industry practice..

3. FORMAL QUANTITATIVE RISK ANALYSIS (QRA)

The scope of the QRA conducted included the following :

- Development of chlorine release scenarios covering drum transfers, stored drum, pigtail and manifold failure scenarios;
- Completion of failure frequency analysis for each of the release scenarios using event tree analysis (ETA);
- Consequence assessment based on the toxicity of chlorine;
- Risk assessment using the nominated risk criteria and development of fatality risk profiles;
- Identification of major risk contributors

The risk assessment process used in this study is a systematic approach to identifying and assessing hazardous events and is consistent with ISO 31000 - Risk management – Principles and guidelines.

The methodology covers the following steps:

- Hazard identification, in which site events and external events are identified which may lead to or contribute to the release of chlorine that impacts off-site;
- Frequency estimation, in which the frequency (i.e. likelihood per year of occurrence) of each of the release events is estimated, based on historical failure data;
- Consequence modelling, in which all the possible consequences of each event are estimated;
- Risk calculation, in which the frequencies and consequences of each event and information about the surrounding area are combined to determine levels of individual fatality risk; and
- Risk assessment, in which the risks calculated are assessed against nominated risk criteria.

3.1 HAZARD IDENTIFICATION

The three identified areas where there is potential for hazardous release scenarios to occur are associated with:

- Chlorine deliveries (drum unloading);
- Storage; and
- Chlorination.

Having identified all potentially significant scenarios, a list of failure cases was developed. This list was then analysed in detail in the frequency and consequence analysis steps.

3.2 FREQUENCY ANALYSIS

Failure cases were developed to represent the potential hazardous scenarios. The incidents were developed by considering all possible mechanisms for loss of containment.

The following types of failure cases were identified for further analysis:

- Leaks from pipe work and drums; and
- Catastrophic rupture of drums.

Each failure case is broken down into equipment items. The leak frequency of each item is based on historical data.

The two sources of historical leak frequency data used were:

- Orica failure frequencies for Chlorine Service; and
- Health, Safety and Environment (HSE) 2006 Offshore Leak Frequency Database

At Hamilton it was assumed that due to 4 drums being connected and online, the worst case scenario would be for the inventory for up to 4 full drums to be released in the event of a hole within the manifold. Therefore the maximum inventory available for release is 3680 kg. However, for this to occur there would need to be a simultaneous failure of all safeguards (four chlorguard valves and the chlorine scrubber) and this is not considered credible.

To assess effects, five different weather categories were used in the assessment. They all have different frequencies :

- day time with either sunny and light winds or overcast and moderate winds;
- day time with little sun and high wind or overcast/windy night;
- day time with overcast and strong winds or night time and strong winds;
- night time with light winds; and
- night time with moderate winds and little cloud or light winds and more clouds.

Night time is considered stable and is the worst case scenario as the weather conditions are the calmest (light wind with little cloud) leading to less mixing of the chlorine cloud.

3.3 MEASURES OF RISK- THE HIPAP RISK CRITERIA

In order to draw meaningful conclusions from the risk results, it is necessary to compare them against established criteria.

A search was conducted to determine if there are any existing New Zealand offsite risk criteria, however none could be found that are currently in place.

It was decided to utilise the Australian (NSW) Department of Planning (DoP) Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 and No. 4 as guidance. These are widely used across Australia.

The offsite risk assessment includes guidance on the fatality and injury risk as per the criteria given in HIPAP No 4. The offsite risk criteria cover:

- **Individual Fatality Risk (IFR)-** the risk of death to a person at a particular point. HIPAP 4 assigns different acceptable risk levels for hospital/schools, residential developments, commercial developments, sporting complexes, industrial sites.
- **Societal Risk** presented in the form of F-N curves; multiple fatalities are considered instead of single fatalities as assessed in IFR. For 10 fatalities, the target probability of $1x10^{-4}$ and 10^{-6} per year and for 1000 fatalities between 1×10^{-7} and 10^{-9} per annum.
- **Injury Risk** from toxic exposure; HIPAP 4 applies a lower level of effect from exposure to hazardous substances such as chlorine compared to that used in IFR assessment (target frequency is 1×10^{-5} per annum)

  Irritation Risk from toxic exposure. (Target frequency is 5×10^{-5} per annum)

3.4 QRA RESULTS

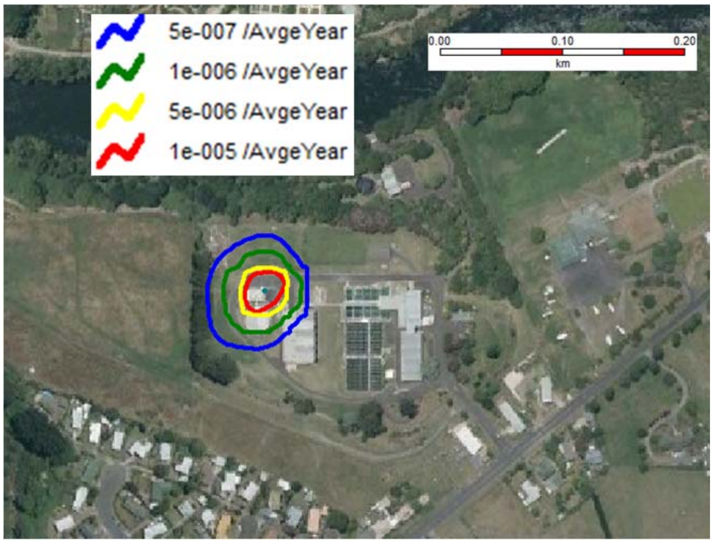
Release, dispersion and subsequent toxic effect calculations are performed using Software for the Assessment of Flammable, Explosive and Toxic Impact (SAFETI), a commercial software package. The SAFETI (formerly called PHAST Risk) package models have been extensively utilised in Australia and is designed to do risk and consequence modelling for the range of scenarios relating to toxic gas / liquid releases.

SAFETI analyses complex consequences from accident scenarios, taking into account the local population, the surface roughness (characterising the ground conditions over which a plume will travel) and weather conditions, to quantify the risk associated with the release of chlorine.

3.4.1 INDIVIDUAL FATALITY RISK

Figure 4 shows the Individual Fatality Risk (IFR) contours- one contour for each category.

Figure 4   Individual Fatality Risk Contours

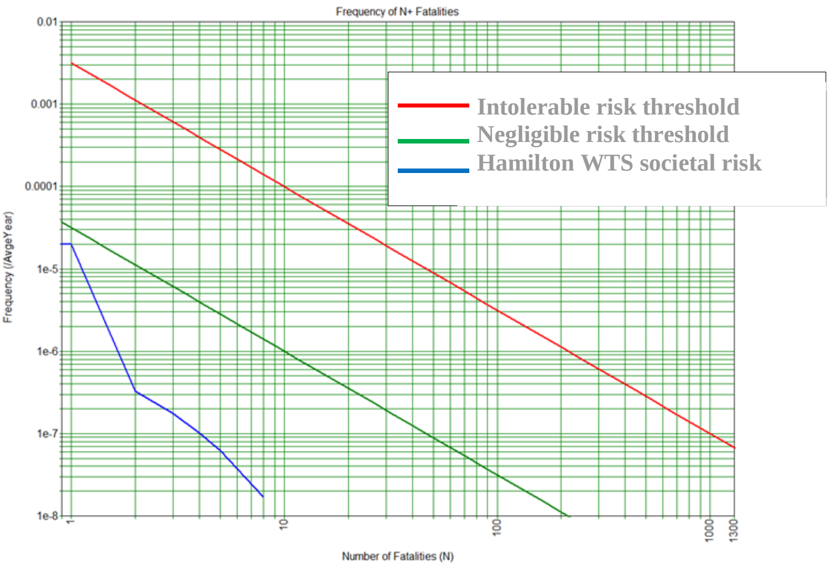


On the basis that all of the HIPAP 4 IFR contours remain within the site boundary and do not encroach on the respective sensitive receivers, the current chlorine facility at the Hamilton Water Treatment System complies with the suggested IFR criteria as specified in HIPAP 4**.**

3.4.1 SOCIETAL RISK

Figure 5 shows the societal risk for Hamilton. As can be seen from the figure the FN curve is well below the lower risk limit and for societal risk. The societal risk for Hamilton can be considered to be acceptable according to the HIPAP 4 criteria if risks are shown to be ALARP.

Figure 5   Societal Risk



3.5 INJURY CRITERIA

In this QRA, the toxic injury exposure is assessed with respect to ERPG 3 concentrations based on 60 minutes exposure time. The injury risk contour from exposure to chlorine is shown below in Figure 6. As can be seen, the toxic injury risk level remains within the site boundary and therefore meets the criterion as suggested in HIPAP 4.

Figure 6 Toxic Injury Risk Contour

3.6 IRRITATION CRITERIA

The irritation risk from exposure to toxic gases was been assessed using ERPG 2 concentrations. No irritation risk contours from exposure to chlorine of 50 x 10^{-6} per year are generated, therefore the toxic irritation risk level does not exceed the criterion as suggested in HIPAP 4.

3.7 SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to determine the effect of an enclosed delivery bay on the risk profile of the Hamilton WTS. Enclosing the deliver bay is a common mitigating control option at a chlorine installation, and works by capturing the chlorine release as to not release it to the surrounding environment.

Modelling was undertaken on the basis that all drum transfer cases were changed from outdoor releases in the base case results to being indoor releases in the sensitivity assessment.

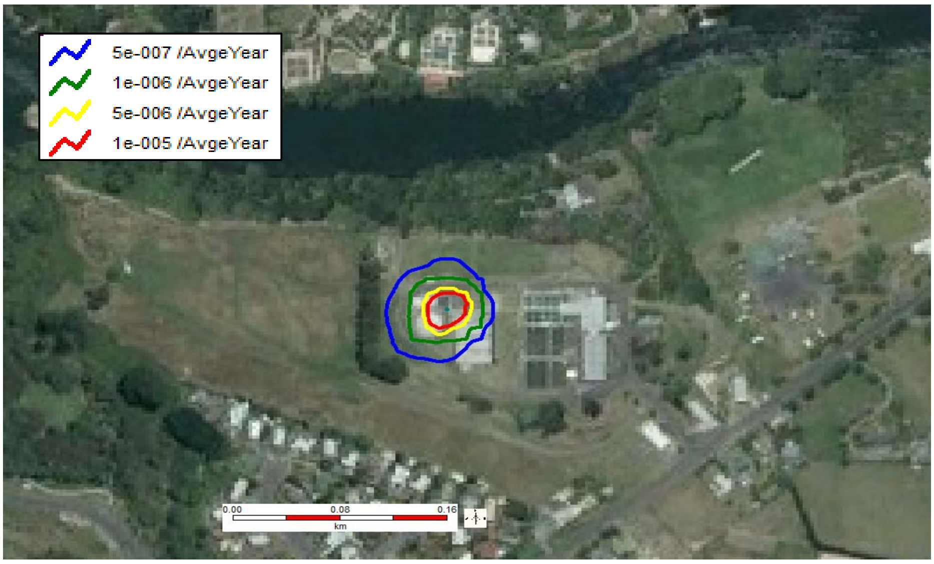
Risk modelling for the enclosed delivery bay sensitivity was completed using SAFETI and the QRA results are presented in Figure 6.

The above indicates that enclosing the delivery bay will slightly reduce (by approximately 11%) the IFR levels associated with the chlorine facility at the Hamilton WTS, however all contours are currently already within the site boundary. However, it was concluded that this risk reduction was not significant enough to justify the additional expenditure, expected to be approximately $350,000.

3.8 QRA OUTCOMES

The outcome of the QRA process was that HCC were able to proceed with the design, procurement and installation of the EGS system on the knowledge that it was doing so having applied detailed risk management process and with a residual risk profile that is commensurate with good practice elsewhere.

Figure 6 Individual Fatality Risk Contours – with Enclosed Delivery Bay



4. FURTHER RISK MANAGEMENT IN THE EGS DESIGN AND PROCUREMENT

Summarised briefly, HCC further mitigated project risks through the following key risk management tools

4.1 BUSINESS CASE PROCESS

As is the case with all projects of this type, HCC prepare Business Cases using guidelines derived from the Better Business Case process published by the NZ Treasury. This process ensures an appropriate strategic fit and that there is a robust case for change. The process requires consideration of the following key elements –

(a) The Strategic Case, including consideration of Current Position, Outcomes/Benefits, Strategic Alignment within HCC, The Organisational Context and Impact, Stakeholders, The Scope of Work, Qualitative and Quantitative Benefits,

(b) The Economic Case which includes consideration of Options and Value for Money

(c) The Commercial Case, which considers resourcing and procurement

(d) The Financial Case which documents all potential project costs

(e) The Management Case, which considers stakeholders and the implementation plan.

4.2 DESIGN PROCESS

Similar Dry Scrubber units installed recently in Australia such as those at SA Water near Adelaide have been procured and installed by a design-build process.

HCC saw an elevated risk profile in adopting a similar process given that its WTS is an operating plant and is the only source of water for Hamilton. By adopting a detailed design and separate construction contract with traditional contract management services, HCC was able to have its own detailed input into the design and its review processes, minimising the risks perceived with the design-build process.

4.3 PROCUREMENT PROCESS

Not being commonly-installed equipment (this is the first installation of its kind in NZ), HCC decided to further reduce risk in the supply of the equipment by sourcing the EGS equipment directly from the

Australian company, Airepure Australia Pty Ltd, that had previously supplied and installed these EGS units elsewhere, rather than instead of using the local agency.

A separate installation contract was procured to install the EGS system and its associated equipment. Aside from the installation works, various other mechanical , electrical and controls and minor civil works were required in this contract which was completed by Filtec. Given much of the installation work to be carried out installing the EGS system was with its electrical and controls, HCC decided to nominate its regular supplier for these works as a nominated subcontractor for the installation contract.

5. CONCLUSIONS

Hamilton City Council determined through advanced risk assessment processes that it was able to significantly reduce the risk to staff and the local community posed by an accidental chlorine discharge at its Water Treatment Station by the installation of an EGS Dry Scrubber.

Having implemented the new EGS Dry Scrubber, the level of residual risk to the community and HCC has been shown by a detailed Quantitative Risk Analysis to meet appropriate available industry risk guidelines.

Further risks on the project during the design, procurement and installation phases have been managed and reduced by having incorporated Business Case and targeted design and procurement processes.