12 HAZARD TO LIFE

Introduction

12.1 Background

12.1.1 ERM-Hong Kong Ltd (ERM) has been commissioned to conduct a Hazard to Life Assessment (HA) for the In-Situ Reprovisioning of Sha Tin Water Treatment Works (Sha Tin WTW) South Works Project (hereinafter referred to as “the Project”). The hazard assessment is a part of the Environmental Impact Assessment for the Project conducted under the EIAO. The EIA Study Brief is registered as "In-situ Reprovisioning of Sha Tin Water Treatment Works – South Works” (Reference No. ESB-220/2011) and was issued on 9 March 2011.

12.1.1 Requirements for assessment of hazards to life are presented in Section 3.4.3 of the Study Brief. Section 3.4.3.2 stipulates that:

The Applicant shall investigate alternative construction methods to avoid the use of explosives. If there is use of explosives for the construction activities and the storage or blasting location is in close proximity to populated areas and/or Potentially Hazardous Installation site (i.e. STWTW), the Applicant shall carry out hazard assessment as follows:

(i) Identify hazardous scenarios associated with the transport, storage and use of explosives (including possible damage scenarios to gas and chlorine facilities) and then determine a set of relevant scenarios to be included in a Quantitative Risk Assessment (QRA);

(ii) Execute a QRA of the set of hazardous scenarios determined in (i), expressing population risks in both individual and societal terms;

(iii) Compare individual and societal risks with the criteria for evaluating hazard to life stipulated in Annex 4 of the TM; and

(iv) Identify and assess practicable and cost-effective risk mitigation measures.

The methodology to be used in the hazard assessment should be consistent with previous studies having similar issues (e.g. Shatin-to-Central Link (Tai Wai to Hung Hom Section) (ESB-191/2008), and Central Kowloon Route (ESB-156/2006).

12.1.2 Section 3.4.3.3 of the Study Brief stipulates that:

The Applicant shall investigate methods to avoid and/or minimize chlorine risks. The Applicant shall carry out hazard assessment to evaluate potential hazard to life during construction and operation stages of the Project due to STWTW. The hazard assessment shall include the following:

(i) Identify hazardous scenarios associated with the transport, storage and use of chlorine at STWTW (including possible damage scenarios associated with construction activities, storage of liquid oxygen) and then determine a set of relevant scenarios to be included in a QRA;

(ii) Execute a QRA of the set of hazardous scenarios determined in (i), expressing population risks in both individual and societal terms;

(iii) Compare individual and societal risks with the criteria for evaluating hazard to life stipulated in Annex 4 of the TM; and

(iv) Identify and assess practicable and cost-effective risk mitigation measures.

The methodology to be used in the hazard assessment should be consistent with previous studies having similar issues (e.g. Shatin-to-Central Link (Tai Wai to Hung Hom Section) (ESB-191/2008), and Integration of Siu Ho Wan and Silver Mine Bay Water Treatment Works (ESB-150/2006)).

12.1.3 The scope section of the Study Brief also states (Section 3.2.2 (vi)):

Potential hazard to life on construction workers, operational staff and other sensitive receivers to be identified, with STWTW is Potentially Hazardous Installations (PHI) due to the use of liquid chlorine on site and the Beacon Hill North Offtake Station and its associated 750mm diameter high pressure gas *pipeline that runs through the old Beacon Hill Tunnel, and the possible use of explosives for blasting if applicable.*

12.1.4 As required by the Study Brief, this assessment concerns hazards related to transport, storage and use of chlorine at Sha Tin WTW (STWTW) during the Construction Phase (South Works reprovisioning works) and Operational Phase of the Project (after the project completion). The approach adopted follows that of previous studies having similar issues.

12.1.5 Hazards relating to liquid oxygen are not included in the assessment as it has been confirmed that there will be no storage of liquid oxygen at Sha Tin WTW. Also, there will be no use of explosives and hence this is not considered further in the assessment. Further, it has been confirmed by HKCG that there are no high pressure gas pipelines running through the old Beacon Hill Tunnel.

12.1.6 Additional hazard to life requirements are also formulated in Section 2.1 (v) of the Study Brief, which as one of the objectives of the EIA Study specifies:

To identify and assess the potential risk to human life due to the construction works impact on the operation of the existing PHI (Chlorine Store), the 400kV overhead power line and other notifiable gas installations (NGIs), e.g. Beacon Hill North Offtake Station present or in the vicinity of Project site and to propose measures to mitigate these impacts.

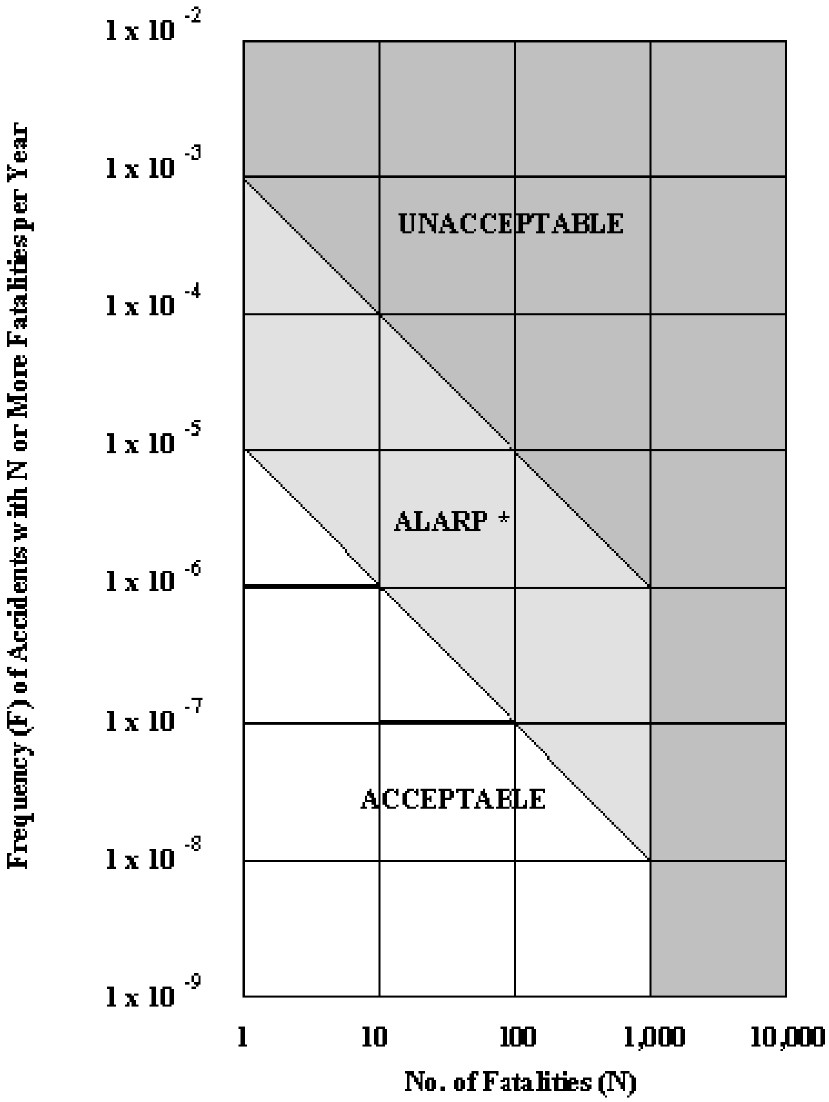
These issues are also addressed in relevant sections of this assessment.

12.2 Hong Kong Risk Guidelines and Other Relevant Legislation

12.2.1 Hong Kong Risk Guidelines (HKRG) for Designated Projects are defined in *Annex 4* of the *Technical Memorandum to Environmental Impact Assessment Process* (EIAO-TM) in terms of individual and societal risks as follows:

- Maximum level of off-site individual risk should not exceed 1 in 100000 per year, i.e. 1×10^{-5} per year; and
- Societal Risk Guidelines as stipulated in EIAO-TM are shown in *Figure 12.1*. For definitions of the individual and societal risk measures see *Section 12.12.*

Figure 12.1 Societal Risk Guidelines for Acceptable Risk Levels (EIAO-TM)



* ALARP means As Low As Reasonably Practicable. Risk within ALARP Region Should Be Mitigated To As Low As Reasonably Practicable

12.2.2 The Sha Tin WTW is designated as a Potentially Hazardous Installation (PHI) owing to its use and storage of chlorine in 1-tonne (1t) drums. A Consultation Zone (CZ), centred at the Chlorination House, of 1000m radius but excluding the areas located at over 150 m above sea level is established around the WTW (*Figure 12.2*). The *Hong Kong Planning Standards and Guidelines* (HKPSG), Chapter 12, require that PHIs comply with Hong Kong Risk Guidelines as described above.

Figure 12.2 Sha Tin WTW Location and Consultation Zone

12.3 Sha Tin Water Treatment Works: Location and Operations

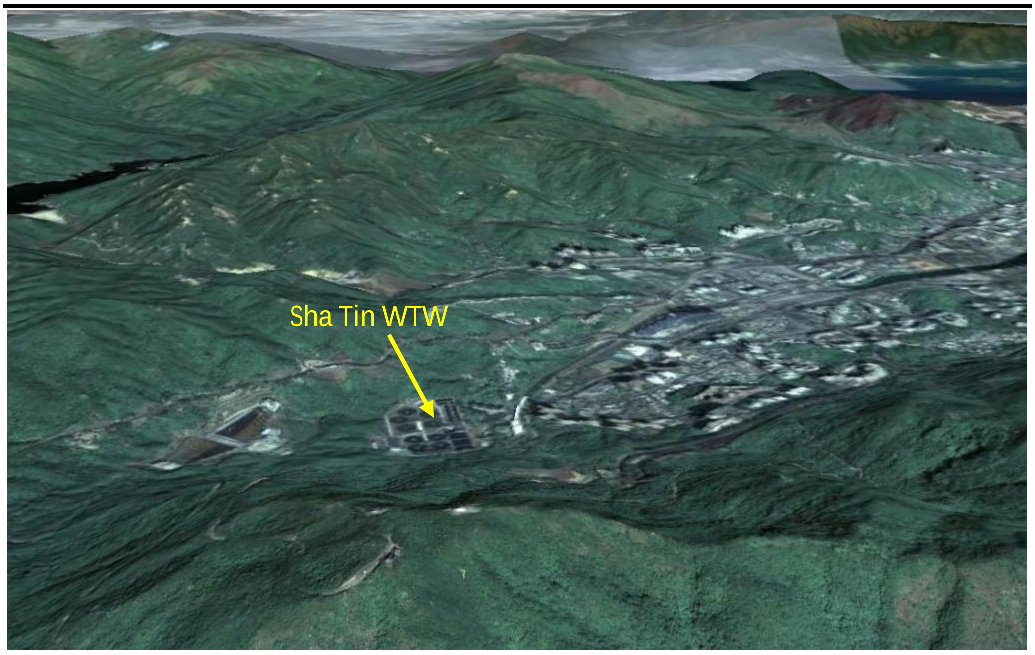
Location

12.3.1 Sha Tin WTW lies at the head of a valley on Keng Hau Road, Hin Tin to the south-west of Sha Tin new town. The site is approximately rectangular in shape and measures 400 m north to south by 300 m east to west. The treatment plant comprises a South Works and a North Works. The Chlorination House is located in the south-west corner of the site. The site location is shown in *Figure 12.2* and the existing site layout in *Figure 12.3*.

12.3.2 Sha Tin WTW is located at 30 m above the Principal Datum (PD) and is surrounded on three sides by hills rising to approximately 300 m. To the north-east the land slopes gently downwards towards the town of Sha Tin. The topography is of particular relevance; since chlorine is a dense gas, the spread of a chlorine cloud from any large release would be restricted by the neighbouring hills and directed towards the populated areas. The topography of the site is shown in *Figure 12.4*.

Figure 12.3 Existing Layout of Sha Tin WTW

Figure 12.4 Topography of the Sha Tin WTW Area (not to scale)



Delivery, Storage and Handling of Chlorine

12.3.3 Chlorine is delivered to Sha Tin WTW in batches of up to 6×1-tonne drums. Unloading takes place inside the Chlorination House, with the doors closed, in a designated truck unloading bay. The movement of drums within the storage area and 'drive-through' unloading bay is carried out using a hoist/monorail system with a purpose-built lifting beam. Prior to usage, the drums are stored on cradles within the chlorine storage area.

12.3.4 The on-site chlorine delivery route is shown in *Figure 12.6*.

Chlorination System

12.3.5 The draw-off units comprise of pairs of drums, one drum on duty, the other serving as standby. The number of drums on line is subject to the raw water quality. Changeover panels automatically change the draw-off from duty to standby when the draw-off pressure falls below a preset level. The changeover is achieved by electrically-actuated isolating valves provided for each drum.

12.3.6 Liquid chlorine is drawn from the 1-tonne drums and is passed to the evaporators for conversion into the gaseous state. The gaseous chlorine passes through the chlorinators and dissolves in water at ejectors to form chlorinated water for feeding into the bulk water stream during the treatment process.

12.3.7 The chlorinators are of vacuum venturi type and thus the section of line between the regulator and the chlorinator is at negative pressure. This reduces the chances of chlorine leaks. Double non return valves are provided within the chlorinator units.

Ventilation System

12.3.8 The chlorine drum storage area, evaporator and chlorinator rooms are normally ventilated via a supply of fresh air at high level which is extracted at low level. On detection of chlorine levels above 3 ppm there are visual and audible alarms, the ventilation fans stop and the normally-open motorised louvres shut.

Chlorine Scrubbing System

12.3.9 An emergency chlorine scrubbing system is installed to remove any leaked chlorine in the chlorine handling and storage areas. The system is a packed tower utilising sodium hydroxide as the neutralising agent. The plant and equipment are installed in a separate scrubber room.

12.3.10 On detection of chlorine at a concentration of 3 ppm or above in the chlorine handling or storage areas, the scrubbing system will activate automatically. The air/chlorine mixture in the affected areas is drawn into the scrubber by the scrubber fan via ducting connected to the normal ventilation system. An electrically-operated isolating damper is provided in the scrubber intake which opens automatically when the scrubber fan starts up.

12.3.11 The scrubber system is normally set at auto standby mode and is activated if the chlorine concentration rises above 3 ppm. A continuous chlorine monitor is installed at a point downstream of the packed tower and upstream of the vent/recycle changeover dampers to monitor the scrubber performance; a “Chlorine concentration high” alarm will be initiated if the concentration of chlorine in the tower exhaust exceeds the preset value.

12.3.12 The sodium hydroxide solution is of 10-12% concentration and is held in a solution tank beneath the packed tower. When the system is in operation, the sodium hydroxide is re-circulated by a pump to the distributor at the top of the packed tower to provide adequate irrigation to the packing. Sufficient solution is provided to absorb 1 tonne of chlorine. A mist eliminator is provided at the top of the packed tower to prevent entrainment of liquid into the treated air.

12.3.13 The scrubber is provided with the following additional features: a sampling point, a top entry mixer (for preparation of the sodium hydroxide solution), a direct reading transparent level gauge, an inspection window and level indication with high and low level alarms and a temperature measurement device for monitoring the temperature of caustic solution during the preparation process.

Emergency Repair/Stoppage Kit for Chlorine Spillage/Leakage

12.3.14 According to the Fire Services Department’s fire safety requirements, an emergency repair/stoppage kit for chlorine spillage/leakage is provided and maintained in good working condition at all times for use by the trained persons and stowed adjacent to but outside the store/plant room. Regular drills are conducted to train personnel on the proper use of the breathing apparatus and protective clothing.

12.4 South Works Reprovisioning

12.4.1 This project concerns a major reprovisioning of the Sha Tin WTW South Works. During the reprovisioning, since parts of the plant (i.e. the South Works) will have to be temporarily shut down, the water throughput will decrease and accordingly, chlorine storage and usage levels will be significantly reduced. Following completion of the reprovisioning water throughput will return to 1,227 Mld.

12.4.2 The reprovisioning will involve introduction of new treatment technologies for the South Works and construction of a number of new facilities. Details are shown in *Figure 12.5*.

12.4.3 The current chlorine dosage levels are at or below 2 mg/l. This will be reduced to 1.7 mg/l following the reprovisioning, due to the introduction of new treatment technologies. This will result in a permanent reduction in chlorine usage once reprovisioning is completed. Therefore, it is worth highlighting that this is an improvement project that will lead to a reduction in risks associated with the Sha Tin WTW. The operational parameters of the WTW during and after the reprovisioning are presented in *Table 12.1*.

12.4.4 Before the start of the construction of reprovisioning of South Works, 31 excess storage castors for storage of chlorine drums will be carefully selected and to be removed from the chlorination house (i.e. reduced from 221 castors to 190 castors before the start of the construction works).

12.4.5 During and after the reprovisioning, the existing on-site chlorine delivery route along the east & south & west boundaries of the site will be replaced by the route along the east & north & west site boundaries. Details are shown in *Figure 12.6*. The purpose of this is to separate the existing North Works and the construction activities in order to maintain continuous operation, maintenance and security of the existing North Works and in particular to separate chlorine deliveries from the construction activities.

12.4.6 Details of the construction programme are provided in *Appendix 2.1*. In general, the existing on-site chlorine delivery route along the east & south & west boundaries of the site will be used during Stage 1 of the reprovisioning and that along the east & north & west boundaries of the site as shown in *Figure 12.6* will be used for Stage 2; the intent being to segregate chlorine delivery trucks from construction activities. Description and locations of different construction activities are also provided in *Appendix 12.8*.

Figure 12.5 New Treatment Facilities and Sha Tin WTW Layout following the Reprovisioning of South Works

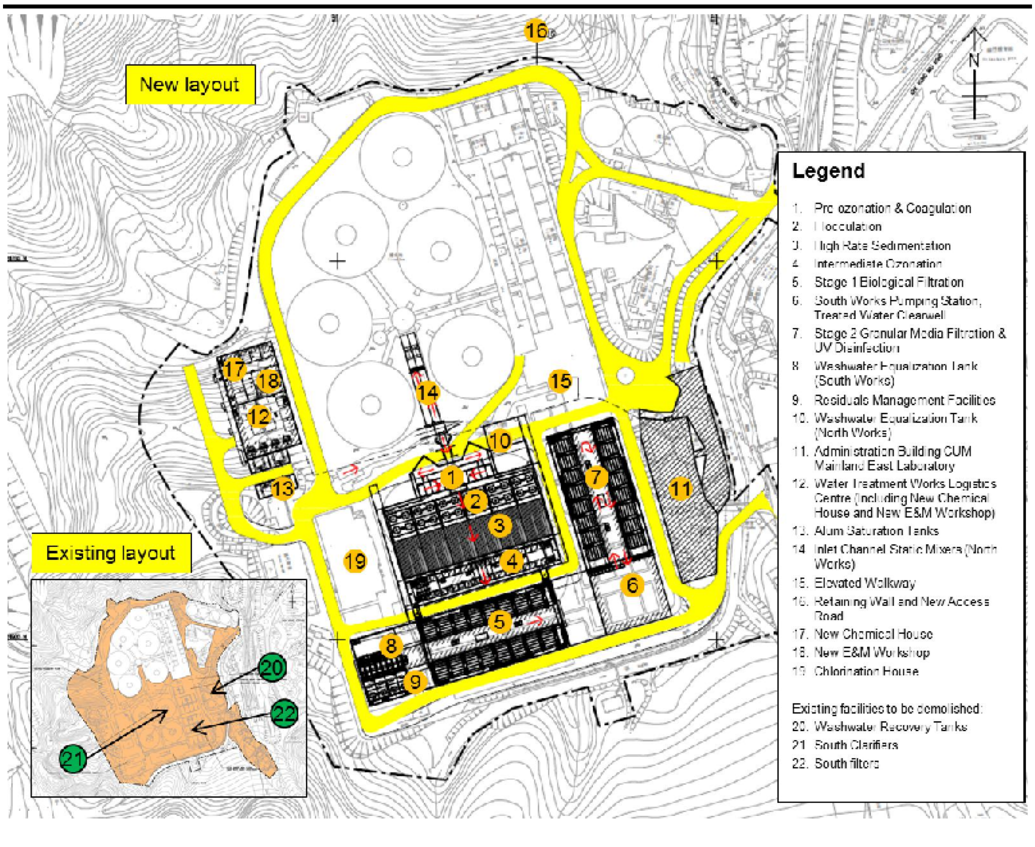
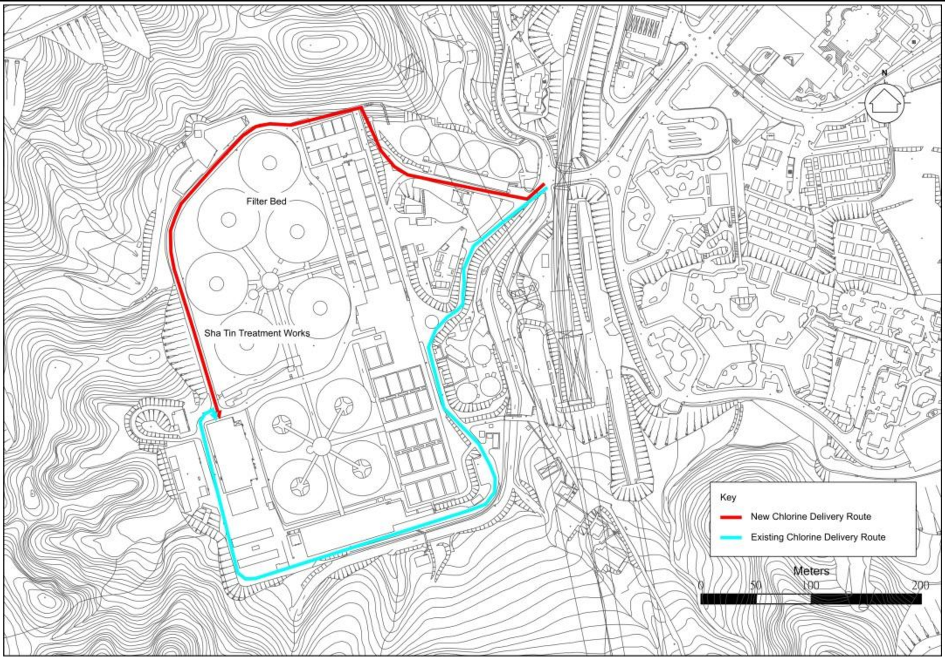


Figure 12.6 Existing Chlorine Delivery Route at Sha Tin WTW and the New Route to be used during and after the Reprovisioning of South Works



12.5 Scenarios Considered in the QRA

12.5.1 Based on the South Works reprovisioning schedule, two scenarios have been considered in the QRA. These are the Construction Phase of this project and the Operational Phase following the completion of the reprovisioning. The main assumptions used for each scenario, based on WTW operational data provided by WSD, are listed in *Table 12.1*. Population data for the construction and operational phase scenarios are projected to years 2016 and 2031, respectively. Details of the population data for each assessment year are provided in *Section 12.8* and *Table 12.3*.

12.5.2 The WTW operating data for these two scenarios are consistent with Scenarios 2 and 4 of ERM (2011a).

Table 12.1 Scenarios Considered in the QRA

Scenario	Assessment year	Maximum Chlorine Storage at WTW (tonnes)	Chlorine Storage Time Distribution Assumed in the QRA (tonnes, % of time)	Average Chlorine Usage at WTW (tonnes per year)
Scenario 1: Construction Phase	2016	158	158 (100%)	642
Scenario 2: Operational Phase	2031	190	190 (20%) 150 (80%)	761

12.6 Previous Hazard Assessments for Sha Tin WTW

2001 QRA

12.6.1 In 1997, the Water Supplies Department (WSD) commissioned ERM to carry out a *Reassessment of Chlorine Hazards for Eight Existing Water Treatment Works*. The WTWs considered were:

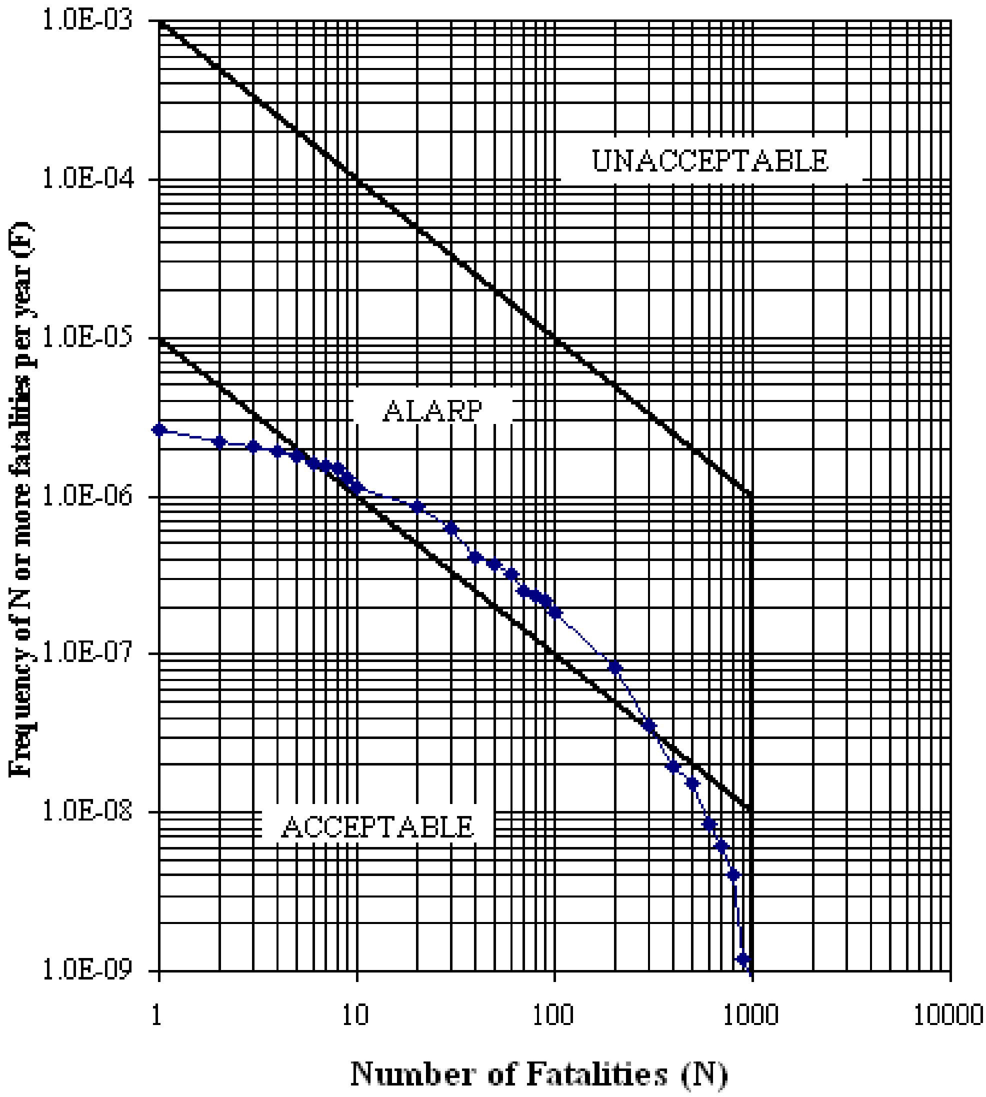
- Au Tau WTW;
- Pak Kong WTW;
- Sha Tin WTW;
- Sheung Shui WTW;
- Tai Po Tau WTW;
- Tsuen Wan WTW;
- Tuen Mun WTW; and
- Yau Kom Tau WTW.

12.6.2 The approved methodology for the above QRA studies is detailed in the 8 WTW Study *Methodology Report* (ERM, 1997).

12.6.3 Results for the Sha Tin WTW (ERM, 2001), illustrated here in *Figure 12.7* showed that:

- The risk was in the 'ALARP region'; and
- The maximum number N of fatalities was assessed at over 900.

Figure 12.7 FN curve from the 2001 Sha Tin WTW Hazard Assessment (ERM, 2001)



2011 QRA for Hin Keng Station and SCL Alignment

12.6.4 In 2008–2011, ERM conducted a QRA study on behalf of MTRCL to assess the chlorine hazards related to the Sha Tin WTW operations in connection with the proposed Sha Tin to Central Link (SCL) project. This study assessed the impact of increased population from SCL work areas, future SCL alignment and the proposed Hin Keng Station that will be located within the Sha Tin WTW Consultation Zone (ERM, 2011a). The SCL QRA also took into account the South Works reprovisioning that will proceed concurrently with the SCL construction and the modified WTW operational parameters (chlorine usage and storage quantities) during the reprovisioning and after its completion.

12.6.5 The present QRA for the on-site transport, storage and handling of chlorine at Sha Tin WTW follows the methodology of both previous studies.

12.7 Meteorological Data

12.7.1 For the sake of consistency, this study uses the same meteorological data set as was used in the previous QRAs (ERM 2001, 2011a), i.e. the data recorded at the Sha Tin weather station in the year 1996 by the Hong Kong Observatory.

12.7.2 The weather data have been rationalised into different combinations of wind direction, speed and atmospheric stability class. The probabilities of occurrence of each combination during day and night are presented in *Table 12.2*. The Pasquill-Gifford stability classes range from A through F. Class A represents extremely unstable conditions which typically occur under conditions of strong daytime insolation. Class F on the other hand represents stable conditions which typically arise on clear nights with little wind. Turbulent mixing, which affects the dispersion of a chlorine cloud, increases through the stability class range from F to A.

Table 12.2 Meteorological Data for Sha Tin Water Treatment Works

Direction		**DAY Probability**				**NIGHT Probability**			**TOTAL**
	Wind Speed (m/s):	**2.3**	**1.5**	**3.5**	**1.5**	**1.5**	**3.5**	**1.5**	
	Atmospheric Stability :	**B**	**D**	**D**	**F**	**D**	**D**	**F**	
N		0.0509	0.0380	0.0120	0.0153	0.0224	0.0045	0.0761	0.2191
NE		0.0458	0.0228	0.0253	0.0149	0.0107	0.0239	0.0529	0.1963
E		0.0450	0.0200	0.0299	0.0115	0.0116	0.0173	0.0774	0.2126
SE		0.0146	0.0065	0.0059	0.0027	0.0023	0.0029	0.0233	0.0581
S		0.0171	0.0106	0.0125	0.0042	0.0029	0.0050	0.0346	0.0868
SW		0.0247	0.0113	0.0429	0.0050	0.0034	0.0103	0.0528	0.1504
W		0.0023	0.0020	0.0004	0.0017	0.0018	0.0000	0.0139	0.0220
NW		0.0038	0.0048	0.0059	0.0039	0.0036	0.0032	0.0294	0.0546
Total		0.2042	0.1160	0.1346	0.0590	0.0587	0.0671	0.3604	1.0000

12.8 Population Data

General Approach

12.8.1 The approach to the population data for this study is the same as in the QRA for Sha Tin WTW for the SCL Project (ERM, 2011a). The population data from the 2011 study were updated where applicable based on more recent information.

12.8.2 The population data used in this study is summarised in *Table 12.3*. A definition of the time periods included in *Table 12.3* is provided in *Appendix 12.6*.

Sources of Information

12.8.3 Population data for the South Works reprovisioning workforce and Sha Tin WTW staff quarters were provided by WSD.

12.8.4 Railway-specific data such as SCL train and station loadings for the Operational Phase, population of the Tai Wai MTR Depot, number and locations of the SCL construction workers etc. were obtained from MTRCL.

12.8.5 The Planning Department provided the GIS coverage of Tertiary Planning Units (TPUs) further divided into Street Blocks (SB). Detailed TPU-based population data and their projections to the future are publicly available from the Plan-D website.

12.8.6 The Territory Population and Employment Data Matrix (TPEDM) population projections for different Planning Data Zones (PDZ) were also obtained from PlanD. These were used to obtain population projections up to the year 2031 and the average household size for different areas.

12.8.7 Hong Kong conducts a population census once every ten years and a by-census in the middle of the intercensal period. By-census differs from a full census in not having a complete headcount but enquiring on the detailed characteristics of the population on the basis of a large sample. Census data is presented on Centamap website [(1)] for most building groups and the population is further updated based on Territory Planning Unit (TPU) Large Street Block (SB) population from 2011 Census.

12.8.8 If the population data was not directly available, data on the number of floors and units of the residential developments were obtained from the Centamap website and, together with the TPEDM data on average household size, were used to estimate the current population of these developments.

12.8.9 The Centamap website was also used to verify the locations and/or further existence of the population units assumed in the previous assessments and to check for any new developments that may have been recently constructed.

12.8.10 Daily attendance data at Hin Tin Swimming Pool and the highest and average daily usage data for the Hin Tin Playground were obtained from Leisure and Cultural Services Department (LCSD).

12.8.11 Most of the road populations were estimated based on the Annual Average Daily Traffic (AADT) data from the Transport Department's (TD) Annual Traffic Census 2013 [(2)] which is the latest available data.

12.8.12 Recent data for the Tsing Sha Highway and Lion Rock Tunnel, such as Staff in administration building, toll plaza, etc. were obtained from TD in 2014 [(3)].

12.8.13 A site survey covering a large part of the area within the 1-km CZ considered in the study was conducted by ERM personnel on 28 April 2009. An additional site survey of the areas to be affected by the SCL project site was conducted in July 2011. Another site survey was conducted in Jan 2014 to further update the population.

12.8.14 Although site surveys indicated no population at the Beacon Hill North Offtake Station, Towngas has since advised that a number of their staff are located on this site from time to time. This population has therefore been included in this assessment taking into consideration both the site surveys and the Towngas information. However, this has no significant impact on the results.

12.8.15 For most kindergartens, primary and secondary schools and colleges, data from the Education Bureau website [(4)] was used. This included the number of classrooms and the capacity of each classroom.

12.8.16 For cases where population data were not available from publicly available data sources, the required information was obtained by telephone interviews and e-mail inquiries.

12.8.17 The percentages of the maximum population present (occupancy) at different times of the day and the indoor/outdoor fractions for the total unit population are consistent with those used in the previous QRA (ERM, 2011a).

Population Units

12.8.18 The population units are defined for the QRA purposes in the form of GIS-based polygons, points and lines. Outside the WTW site the units used in this study are the same as in the previous QRA (ERM, 2011a) however more detailed population units for different South Works reprovisioning work areas are considered.

12.8.19 The full list of population units considered is provided in *Table 12.3* and their locations shown in *Figure 12.8 and Figure 12.9*. The population units within the 1-km Consultation Zone of the WTW are referenced with letters while those outside the CZ are denoted by numbers.

South Works Reprovisioning Work Areas and Workforce Population Data

12.8.20 Based on information provided by WSD, eight population polygons, T1 to T8 (see *Figure 12.8, Figure 12.9 and Figure 12.10*) have been defined for different project work areas at the WTW. Details on the construction activities within each of these areas are provided in *Appendix 12.8*.

[1] http://www.centamap.com/gc/home.aspx
[2] http://www.td.gov.hk/filemanager/en/content_4677/annual%20traffic%20census%202013.pdf
[3] Email communications dated 29th Jan2014
[4] http://www.edb.gov.hk/index.aspx?nodeID=163&langno=1

12.8.21 Since a different number of workers will be needed for each construction activity and the activities at different site areas will occur at different times, the total number of workers on site will be changing and there will be no period when the workforce will be present simultaneously in all locations. A conservative case was therefore selected with a relatively high total population of 198 construction workers and resident site staff (RSS) for supervision of the construction activities simultaneously present at areas T1, T2 and T5. The resulting total numbers of people at each site for this representative period are shown in *Table 12.3*. These 198 construction and RSS workers are conservatively assumed to be present year round.

12.8.22 It is assumed that 10% of the 85 construction workers and 50% of the 113 RSS will be located indoors. Thus, at each site, the average proportion of people indoors can be estimated at (8.5 + 56.5)/(85 + 113) = 33%.

12.8.23 It may be noted that the spatial distribution of the reprovisioning workers and number of workers are different from those assumed in the SCL QRA (ERM, 2011a). These have been revised based on updated information provided by WSD. The SCL QRA assumed a uniform density of workers over the southern works area whereas a more detailed spatial distribution is now available as adopted in the current assessment. The estimated number of workers has increased based on the latest project schedule. These changes, however, do not have a significant impact on the analysis.

12.8.24 The WTW has a reception facility for visitors as an integrated part of the WTW. The visitor reception facility is located within the boundary fence of the WTW, which walk-in visitors are not allowed. Only visitors permitted by WSD are allowed to enter into the boundary of the WTW. In addition, visitors will be briefed on the safety and emergency procedures in case of fire and chlorine leak. Visitors will also be escorted by WSD staff when they are within the WTW.

Figure 12.8 Population Units used in QRA (figure 1 of 2)

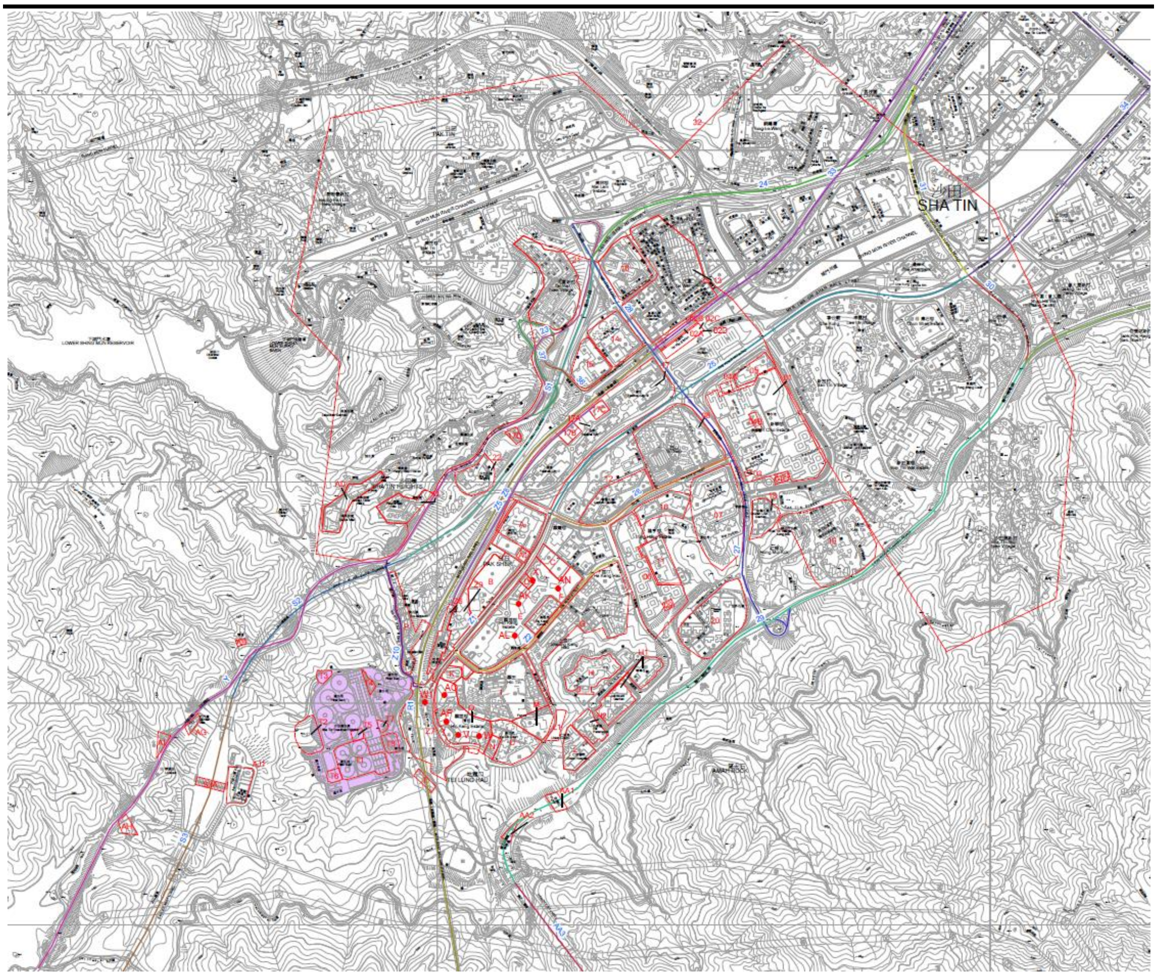


Figure 12.9 Population Units used in QRA (figure 2 of 2)

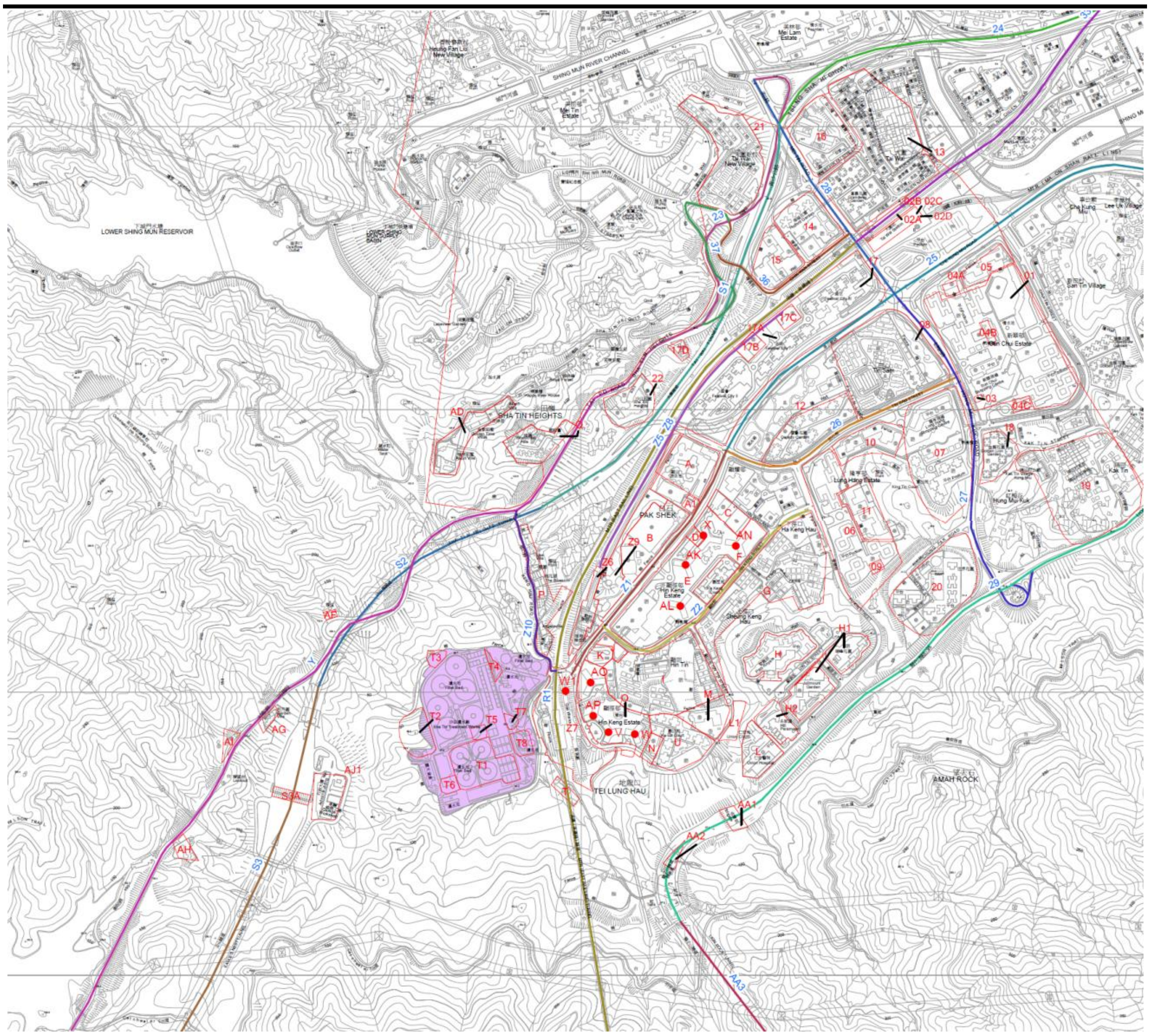
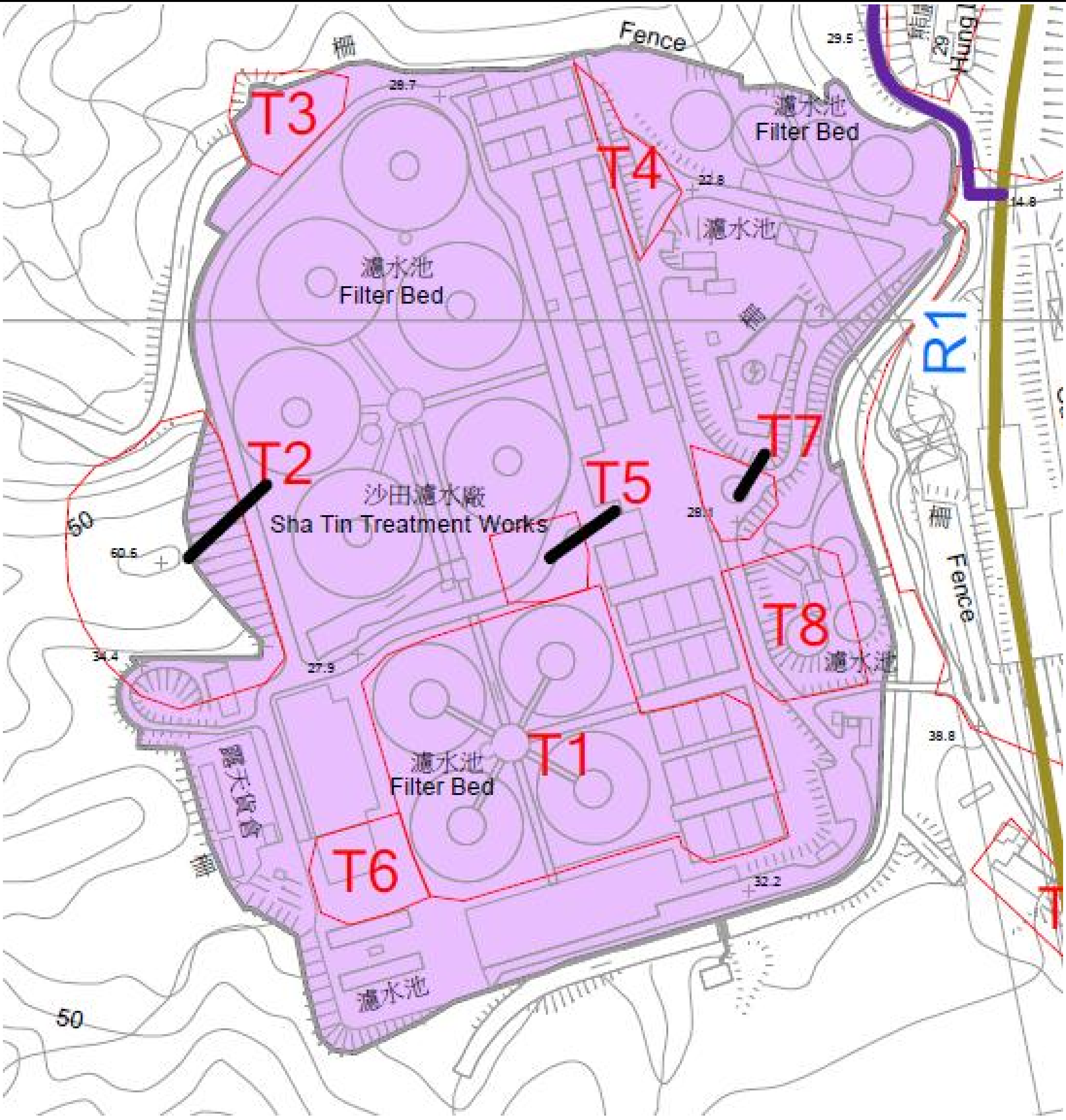


Figure 12.10 Population Units for the Reprovisioning Works



Population Forecast

12.8.25 The residential population levels determined as described above have been scaled up or down according to the population trends determined from the area-specific TPEDM PDZ-based projections. For construction phase, the maximum population between 2011 and 2016 will be used. For operational phase, the maximum population between 2011, 2016 and 2031 will be used. Relevant scaling factors are listed in *Appendix 12.6*.

12.8.26 The methodology of this scaling is consistent with that used in the SCL Project QRA (ERM 2011a) except population is update based on the latest available data.

12.8.27 As no information on the future traffic trends was available for the road population and the examination of past traffic data shows no significant upward traffic trend over recent years, the road population numbers derived from the 2013 Traffic Census were not further projected to the future years.

Table 12.3 Detailed Population Data

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
01	Sun Chui Estate	18937	18937	20673	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
02A	East Rail Tai Wai Station	2000	2000	2083	20%	100%	100%	50%	50%	0%	1	1	Based on MTRCL data. SCL is under construction under Year 2014 and will operate at Year 2018 (1).
02B	East Rail Train at Tai Wai Station	1304	1304	1464	20%	100%	100%	50%	50%	100%	1	1	Based on MTRCL data. SCL is under construction under Year 2014 and will operate at Year 2018 (1).
02C	SCL Tai Wai Station	500	500	1250	20%	100%	100%	50%	50%	100%	1	1	Based on MTRCL data. SCL is under construction under Year 2014 and will operate at Year 2018 (1).
02D	Development atop Tai Wai Station	0	0	6752	100%	50%	50%	70%	50%	99%	1	39	Value from Planning Department. The residential and commercial development is now pending for approval. Population intake in Year 2019 tentatively. No. of building = 8 and no. of floor = 39 - 49 (conservatively assumed 39)
03	T.W.G.Hs. Mok Wong Fung Yee Home for the Elderly, G/F floor Sun Chui Estate	68	121	121	100%	100%	100%	100%	100%	95%	3.3	1	Base value from: http://www.swd.gov.hk/ (1). 75 bed space and 46 staff were considered in 2016 & 2031.
04A	Cheong Wong Wai Primary School	315	418	418	0%	50%	50%	0%	100%	95%	3.3	5	School capacity from: http://www.edb.gov.hk/ was taken as base value. (1) Assume 30 students per class. 13 classes, 28 staff. Numbers of class and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031.Time factor of 0.67 applied in modelling.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
04B	Free Methodist Bradbury Chun Lei Primary School	1087	829	829	0%	50%	50%	0%	100%	95%	3.3	5	School capacity from: http://www.edb.gov.hk/ was taken as base value. [(1)]. Assume 30 students per class. 26 classes, 49 staff. Numbers of class and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031. Time factor of 0.67 applied in modelling.
04C	KCBC Hay Nien (Yan Ping) Primary School	780	385	385	0%	50%	50%	0%	100%	95%	3.3	5	Base school capacity value was referenced: from 2001 QRA. [(1)] Assume 30 students per class. 12 classes, 25 staff. Numbers of class and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031. Time factor of 0.67 applied in the modelling.
05	Ng Yuk Secondary School and TWGHs Wong Fut Nam College	2386	2515	2515	0%	50%	50%	0%	100%	95%	1	5	Base school capacity value was referenced: http://www.edb.gov.hk/. [(1)] Shatin Tsung Tsin Secondary School moved to ref. 17B, TWGHs Wong Fut Nam College temporarily using the site as a decanting site. Information from http://www.chsc.hk/. Assume 45 students per class for Form 1-5 and 30 students per class for Form 6. 46 classes of Form 1-5, 10 classes of Form 6 and 145 staff. Numbers of class and staff numbers from http://www.chsc.hk/. Numbers are combined for the 2 schools were considered in 2016 & 2031. Time factor of 0.67 applied in modelling.
06	Lung Hang Estate	14020	18288	18288	100%	50%	50%	70%	50%	99%	1	12	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
07	King Tin Court	3836	5004	5004	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (updated based on 2011 Population Census Street Block data)., scaled according to 2011 based TPEDM projection.
08	Tin Sam Village	1537	2005	2005	100%	50%	50%	70%	50%	99%	1	3	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
09	Salvation Army - Hong Kong and Macau Command Lung Hang Residence for Senior Citizens (The) G/F Lung Hang Estate	134	134	134	100%	100%	100%	100%	100%	95%	3.3	1	Value from ERM (2001) report [(1)].
10.1	PLK C. H. Wong Primary School	1215	860	860	0%	50%	50%	0%	100%	95%	3.3	6	Base school capacity value was referenced: http://www.edb.gov.hk/ [(1)]. Assume 30 students per class. 27 classes, 50 staff. Numbers of class and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031. Time factor of 0.67 applied in modelling.
10.2	PLK C W Chu College	1035	1114	1114	0%	50%	50%	0%	100%	95%	1	5	Base school capacity value was referenced: http://www.edb.gov.hk/ [(1)].. Assume 45 students per class for Form 1-5 and 30 students per class for Form 6. 20 classes of Form 1-5, 5 classes of Form 6 and 64 staff. Numbers of class and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031. Time factor of 0.67 applied in modelling.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
11	Lok Sin Tong Young Ko Hsiao Lin Secondary School and Pok Oi Hospital Chan Kai Memorial College	2428	2413	2413	0%	50%	50%	0%	100%	95%	1	5	Base school capacity value was referenced: http://www.edb.gov.hk/ (1). Assume 45 students per class for Form 1-5 and 30 students per class for Form 6. 44 classes of Form 1-5, 10 classes of Form 6 and 133 staff. Numbers of class and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031. Numbers are combined for the 2 schools. Time factor of 0.67 applied in modelling
12	Carado Garden	6252	8155	8155	100%	50%	50%	70%	50%	99%	1	20	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
13	Misc. residential buildings	7786	7786	7786	100%	50%	50%	70%	50%	99%	1	10	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
14	Holford Garden	2184	2184	2184	100%	50%	50%	70%	50%	99%	1	25	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
15	Christian Alliance Cheng Wing Gee College and GCC&ITKD Lau Pak Lok Secondary School	2324	2277	2277	0%	50%	50%	0%	100%	95%	1	5	Base school capacity value was referenced: http://www.edb.gov.hk/ (1). Assume 45 students per class for Form 1-5 and 30 students per class for Form 6. 42 classes of Form 1-5, 9 classes of Form 6 and 117 staff. Numbers of class and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031. Numbers are combined for the 2 schools. Time factor of 0.67 applied in modelling.
16	Shatin Public School	220	523	523	0%	50%	50%	0%	100%	95%	3.3	1	Base school capacity value was referenced: http://www.edb.gov.hk/ (1). Special School for slightly mentally challenged students. Both primary and secondary students. Assume 30

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
													students per primary class. Assume 45 students per class for Form 1-5 and 30 students per class for Form 6. 7 classes of primary, 5 classes of Form 1-5, 1 class of Form 6 and 58 staff. Numbers of class and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031. Time factor of 0.67 applied in modelling.
17	Tai Wai MTR Depot	47	47	47	44%	50%	50%	55%	100%	80%	1	1	Following to information provided by MTRCL (QRA 2011). [(1)].
17A	Festival City Development being constructed in Tai Wai Depot area	6107	11932	11932	100%	50%	50%	70%	50%	99%	1	40	Values from Planning Department.
17B	Shatin Tsung Tsin Secondary School	1343	1343	1343	0%	50%	50%	0%	100%	95%	1	8	Assume 45 students per class for Form 1-5 and 30 students per class for Form 6. 25 classes of Form 1-5, 5 classes of Form 6 and 68 staff. Numbers of class and staff numbers from http://www.chsc.hk/. Time factor of 0.67 applied in modelling. Confirmed by site survey Jan 2014.
17C	Immaculate Heart of Mary School	860	860	860	0%	50%	50%	0%	100%	95%	3.3	8	Assume 30 students per class. 27 classes, 50 staff. Numbers of class and staff numbers from http://www.chsc.hk/. Time factor of 0.67 applied in modelling. Confirmed by site survey Jan 2014.
17D	Caltex Petrol Station	10	10	10	50%	100%	100%	100%	100%	0%	1	-	Confirmed by site survey Jan 2014. Assume no. of population is 10 conservatively.
18	Golden Lion Garden – Phase II	3664	3664	4000	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
19	Kak Tin Village	1013	1013	1106	100%	50%	50%	70%	50%	99%	1	1	Number of houses extracted from Centamap, scaled according to PDZ projection. Note that in the 2001 Report, unit 21 populations was listed together with unit 19, scaled according to 2011 TPEDM based projection.
20	Worldwide Garden	1268	1654	1654	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
21	Tai Wai Village	1350	1350	1350	100%	50%	50%	70%	50%	99%	1	3	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
22	Sha Tin Heights	279	290	290	100%	50%	50%	70%	50%	99%	1	5	Based on number of units extracted from Centamap and PDZ household size (3.46), scaled according to 2011-based TPEDM projection.
23	Tai Po Road (1 km from WTW to Mei Tin Rd)	724	724	724	2%	100%	33%	16%	18%	0%	1	-	Traffic data from 2013 Annual Traffic Census were considered in 2016 & 2031; length 0.8 km. Assume one direction jammed and the other free-flow at Jammed Peak.
24	Tai Po Road (Mei Tin Rd to 3 km from WTW)	836	836	836	1%	100%	16%	8%	9%	0%	1	-	Traffic data from 2013 Annual Traffic Census were considered in 2016 & 2031; length 1.4 km. Assume one direction jammed and the other free-flow at Jammed Peak.
25	Che Kung Miu Road (Lion Rock Tunnel Rd to 1 km from WTW)	322	322	322	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2013 Annual Traffic Census were considered in 2016 & 2031; length 1.8 km.
26	Tin Sam Street	107	107	107	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2013 Annual Traffic Census were considered in 2016 & 2031; length 0.7 km.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
27	Hung Mui Kuk Road	208	208	208	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2013 Annual Traffic Census were considered in 2016 & 2031; length 0.8 km.
28	Mei Tin Road	203	203	203	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2013 Annual Traffic Census were considered in 2016 & 2031; length 0.7 km.
29	Lion Rock Tunnel Road – Sha Tin Rd to Lion Rock Tunnel	2471	2471	2471	4%	100%	84%	42%	46%	0%	1	-	Traffic data from 2013 Annual Traffic Census were considered in 2016 & 2031. Road length ~2.6 km; Assumed one direction jammed and the other free-flow at Jammed Peak.
30	Lion Rock Tunnel Road – Che Kung Miu Rd to Sha Tin Rd	39	39	39	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2013 Annual Traffic Census were considered in 2016 & 2031; length 0.4 km.
31	Lion Rock Tunnel Road – Tai Po Rd to Che Kung Miu Rd	112	112	112	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2013 Annual Traffic Census were considered in 2016 & 2031; length 0.6 km.
32	Populated area 2–3km northeast of Sha Tin WTW	78044	84436	84436	100%	50%	50%	70%	50%	99%	1	20	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
33	East Rail Train near Shatin WTW (Outside 1-km CZ)	718	718	806	20%	100%	100%	50%	50%	100%	1	1	Following to the information provided by MTRCL (QRA 2011). Length = 1.5 km SCL is under construction under Year 2014 and will operate at Year 2018.
34	Sha Tin Rural Commetee Road	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Outside of consideration 2-km Zone
35	Shatin Wai Road to Sha Tin Road	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Outside of consideration 2-km Zone

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
36	Chik Wan Street	217	217	217	2%	100%	33%	16%	18%	0%	1	0	Assume population 30% of Tai Po Rd (Ref. 23)
37	Lower Shing Mun Road	217	217	217	2%	100%	33%	16%	18%	0%	1	0	Assume population 30% of Tai Po Rd (Ref. 23)
A	Hin Tin Swimming Pool	300	300	300	0%	50%	50%	100%	50%	30%	1	-	Based on the average daily usage data provided by LCSD and an interview with the pool staff, assuming each user would spend about 1.5 hours at the pool. 50% of maximum occupancy assumed. *Population for summer is 300. Population for rest of the year is 123. 30% of population is indoors in summer. 50% is indoors for rest of the year (1). The population data is verified in 2014 .
A1	Auxiliary Medical Service NTE Regional Office	10	10	10	0%	100%	100%	0%	100%	95%	1	2	2 storeys office, confirmed with observation during site survey Jan 2014. Assume no. of staff: 10 conservatively.
B1	Hin Tin Playground	133	0	128	0%	50%	50%	100%	50%	0%	1	-	Based on the average daily usage data provided by LCSD, assuming each user would spend about 1.5 hours at the playground. To be converted to the SCL Project works areas (unit Z9) during the SCL construction phases. Part of the Playground to be permanently used by the planned SCL Hin Keng Station (1).
B2	Hin Tin tennis court and Football field	87	87	87	0%	50%	50%	100%	50%	0%	1	-	Based on the average daily usage data provided by LCSD, assuming each user would spend about 1.5 hours at the playground(1). The population data is verified in 2014.
C	Carmel Alison Lam Primary School	1042	764	764	0%	50%	50%	0%	100%	95%	3.3	6	Base school capacity value was referenced: http://www.edb.gov.hk/ (1). Assume 30 students per class. 24 classes, 44 staff. Numbers of class

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
													and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031. Time factor of 0.67 applied in modelling.
D	Wong Wah San Hostel for the Elderly	140	0	0	100%	100%	100%	100%	100%	95%	3.3	1	Name changed (from Wong Wah San Hostel for the Elderly to SAGE Mrs. Wong Yee Jar Jat Memorial Home for the Elderly) and moved to Hin Yeung House (Ref. AK). This location is changed purpose of use and moved to Ref. AL (SAGE Mrs. Wong Yee Jar Jat Memorial Neighbourhood Elderly Centre).
E	Hin Keng Estate North	10229	10277	10277	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
F	Ka Keng Court	1083	1089	1089	100%	50%	50%	70%	50%	99%	1	41	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
G	Sheung/Ha Keng Hau Village	2045	2055	2055	100%	50%	50%	70%	50%	99%	1	3	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
H	Parc Royale	2570	2582	2582	100%	50%	50%	70%	50%	99%	1	20	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
H1	Julimount Garden	693	904	904	100%	50%	50%	70%	50%	99%	1	22	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
H2	Hill Paramount	443	578	578	100%	50%	50%	70%	50%	99%	1	27	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
I	Hin Tin Village Housing	1176	1181	1181	100%	50%	50%	70%	50%	99%	1	3	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
J	Market Place/Bazaar/Restaurant	400	400	400	0%	50%	50%	100%	50%	90%	1	4	2001 QRA population numbers increased, portion outdoors and time distribution slightly modified following the 2009 survey. Shops and sports centre across the street taken into account. (1) Confirmed to be still existing and applicable during site survey Jan 2014.
K	Bus Station	50	50	50	10%	100%	100%	50%	50%	0%	1	1	Value from 2001 QRA reduced following the 2009 survey (1). Confirmed to be still existing and applicable during site survey Jan 2014.
L	Union Hospital and Staff Quarters	473	473	473	100%	100%	100%	100%	100%	99%	3.3	13	Based on ERM (2001) (1).
L1	Proposed residential HOS development at Hin Tin St. (construction)	200	200	0	0%	50%	50%	0%	100%	0%	1	0	Based on information from Housing Authority
	HOS development at Hin Tin St. occupied	0	0	810	100%	50%	50%	70%	50%	99%	1	40	Based on information from Housing Authority
M	Helen Liang Memorial School	1040	1070	1070	0%	50%	50%	0%	100%	95%	1	6	Base school capacity value was referenced: http://www.edb.gov.hk/ (1). Assume 45 students per class for Form 1-5 and 30 students per class for Form 6. 20 classes of Form 1-5, 4 classes of Form 6 and 50 staff. Numbers of class and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031. Time factor of 0.67 applied in modelling.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
N	CUHK FAA Thomas Cheung Primary School	1116	606	606	0%	50%	50%	0%	100%	95%	3.3	6	Base school capacity value was referenced: http://www.edb.gov.hk/ (1). Assume 30 students per class. 19 classes, 36 staff. Numbers of class and staff numbers from http://www.chsc.hk/ were considered in 2016 & 2031. Time factor of 0.67 applied in modelling.
O	Hin Keng Estate South	8985	9027	9027	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
P	Residential Area (Keng Hau Road)	122	129	129	100%	50%	50%	70%	50%	99%	1	3	Based on number of units and PDZ household size (3.3).
Q	K. K. Terrace, Woodcrest Hills	171	178	178	100%	50%	50%	70%	50%	99%	1	1	Based on number of units extracted from Centamap and PDZ household size (3.46), scaled according to 2011-based TPEDM projection.
R1	East Rail Train near Sha Tin WTW	718	718	806	16%	100%	100%	41%	41%	100%	1	1	Based on MTRCL data. SCL is under construction in Year 2014 and will operate at Year 2018. (1).
S1	Tsing Sha Hwy (formerly Route 16: Northern Section)	540	559	559	1%	100%	17%	8%	9%	0%	1	-	Based on the traffic data provided by TD. Traffic in stationary on one direction during Jammed Peak was considered.
S2	Sha Tin Heights Tunnel (formerly Route 16: Sha Tin Tunnel)	1620	1676	1676	1%	100%	17%	8%	9%	100%	1	-	Based on the traffic data provided by TD. Traffic in stationary on one direction during Jammed Peak was considered. Shatin Heights Tunnel is 100% indoor.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
S3	Route 8 (formerly Route 16): Toll Plaza	693	731	731	3%	100%	55%	27%	34%	0%	1	-	Based on the traffic data provided by TD. Traffic in stationary on one direction during Jammed Peak was considered. Population in Toll Plaza is separated from Ref. S3 to S31
S3A	Tsing Sha Highway Toll Plaza	10	10	10	50%	90%	100%	100%	100%	0%	1	-	10 Booths was observed on site survey Jan 2014 and based on data provided by TD.
T	Staff Quarters of Sha Tin WTW	10	10	10	100%	50%	50%	70%	50%	99%	1	1	Based on WSD data [(1)].
T1	WTW reprovisioning workers, South Works	0	93	0	0%	50%	50%	0%	100%	33%	1	-	Based on WSD data [(1)].
T2	WTW reprovisioning workers, Chemical House	0	70	0	0%	50%	50%	0%	100%	33%	1	-	Based on WSD data [(1)].
T5	WTW reprovisioning workers, Washwater Recovery Tank	0	35	0	0%	50%	50%	0%	100%	33%	1	-	Based on WSD data [(1)].
U	Ka Tin Court	4707	4729	4729	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (updated based on 2011 Population Census Street Block data), scaled according to 2011 based TPEDM projection.
V	Assemblies of God Wa Wai Church Hin Keng Anglo-Chinese Kindergarten G/F of Hin Kwai House	90	0	0	0%	50%	50%	0%	100%	95%	3.3	1	Base value from: http://www.edb.gov.hk [(1)]. Confirmed to be shut down during site survey Jan 2014.
W	Po Leung Kuk District Support Centre (Shatin)	0	50	50	0%	100%	100%	100%	100%	95%	3.3	1	Based on site survey Jan 2014 and telephone interview, there is approximately 50 people including a dental care centre of 1 dental bed.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
	G/F of Hin Fu House												
W1	Beacon Hill North Gas Offtake Station	3	3	3	0%	50%	50%	0%	100%	95%	1	1	Based on the site surveys and Towngas information [(2)].
X	Kindergarten G/F of Hing Tak Lau	240	118	118	0%	50%	50%	0%	100%	95%	3.3	1	Base value from: http://www.edb.gov.hk [(1)]. confirmed with observation during site survey Jan 2014. 98 students in total with 20 staff, data from http://www.chsc.hk/ were considered in 2016 & 2031.
Y	Tai Po Road	1574	1574	1574	2%	100%	32%	16%	18%	0%	1	-	Traffic data from the 2013 annual traffic census. Length 1.5 km. Traffic in stationary on one direction during Jammed Peak was considered.
Z1	Che Kung Miu Road	300	300	300	5%	100%	100%	50%	55%	0%	1	-	Value from 2001 QRA, partially verified during 2009 ERM survey, population was updated from Site survey Jan 2014. 86 vehicles per 5 minutes in average. More conservative data (2011) were adopted [(1)].
Z2	Hin Keng Street	270	270	270	5%	100%	100%	50%	55%	0%	1	-	Value from 2001 QRA, partially verified during 2009 ERM survey, population was updated from Site survey Jan 2014. 30 vehicles per 5 minutes in average. More conservative data (2011) were adopted [(1)].
Z5	SCL train (moving)	0	0	501	16%	100%	100%	41%	41%	100%	1	-	Based on MTRCL data [(1)].
Z6	Hin Keng Station	0	0	372	16%	100%	100%	41%	41%	0%	1	4	Based on MTRCL data. SCL is under construction in Year 2014 and will operate at Year 2018 [(1)].
	Stationary train at HIK Station	0	0	607	16%	100%	100%	41%	41%	100%	1	-	Based on MTRCL data. SCL is under construction in Year 2014 and will operate at

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
													Year 2018 (1).
	HIK Station construction workers	0	140	0	0%	50%	50%	10%	100%	0%	1	-	Based on MTRCL data. SCL is under construction in Year 2014 and will operate at Year 2018 (1). SCL construction workers are conservatively included in 2016 scenario.
Z7	SCL Tunnel portal construction workers	0	120	0	0%	50%	50%	10%	100%	0%	1	-	Based on MTRCL data. SCL is under construction in Year 2014 and will operate at Year 2018 (1). SCL construction workers are conservatively included in 2016 scenario.
Z8	SCL Alignment construction workers	0	20	0	0%	50%	50%	10%	100%	0%	1	-	Based on MTRCL data. SCL is under construction in Year 2014 and will operate at Year 2018 (1). SCL construction workers are conservatively included in 2016 scenario.
Z9	SCL Construction Offices/yard	0	80	0	0%	50%	50%	10%	100%	50%	1	1	Based on MTRCL data. SCL is under construction in Year 2014 and will operate at Year 2018 (1).
Z10	Keng Hau Rd underpass below the SCL alignment	6	11	11	5%	100%	100%	50%	55%	0%	1	-	Based on ERM 2011 site survey (1), population taken from Site survey Jan 2014. 8 vehicles per 5 minutes in average were considered in 2016 & 2031.
AA1	Lion Rock Tunnel Toll Plaza	12	12	12	50%	100%	100%	100%	100%	0%	1	-	12 Booths as observed on site survey Jan 2014. Information provided by Transport Department. Assume no. of staff : 1 staff per booth
AA2	Lion Rock Tunnel Office (Transport Department)	63	63	63	50%	100%	100%	100%	100%	95%	1	2	2 storey, confirmed with observation during site survey Jan 2014. Information provided by Transport Department. No. of staff at LRT = 75; Assume no. of staff at toll plaza = 12
AA3	Lion Rock Tunnel (Inside the tunnel)	190	190	190	4%	100%	84%	42%	46%	100%	1	-	Traffic data from 2013 Annual Traffic Census. Road length ~200m; Traffic in stationary on one direction during Jammed Peak was considered. Lion Rock Tunnel is 100% indoor.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
AD	Ascot Villas, Golden Time Villas, Chase Villa and Albert Villas	135	135	135	100%	50%	50%	70%	50%	99%	1	3	Confirmed with observation during site survey Jan 2014. Ascot Villas: 3 3-storey blocks, 15 units in total, data from https://bmis.buildingmgt.gov.hk/, Golden Time Villas: 17 3-storey houses, 17 units in total, data from https://bmis.buildingmgt.gov.hk/, checked with view from aerial map, Chase Villa - 4 units data from https://bmis.buildingmgt.gov.hk/ and Albert Villas - 9 units confirmed during site survey. Population estimated from number of units.
AF	Luk Hop Village	6	6	6	100%	50%	50%	70%	50%	99%	1	2	Confirmed with observation during site survey Jan 2014. 2 blocks, confirmed with view from aerial map. Population estimated from number of units.
AG	Garden Villa	0	48	48	100%	50%	50%	70%	50%	99%	1	2	Confirmed with observation during site survey Jan 2014. 8 blocks low-rise (2 storey) Appears to be abandoned / under construction in google map, confirmed during site survey Jan 2014. Population estimated from number of units. Assume 2015 complete works. Assume 1 unit per floor, 3 people per units.
AH	Kothari House	9	9	9	100%	50%	50%	70%	50%	99%	1	3	Confirmed with observation during site survey Jan 2014. 3 Detached Houses (3 storey each), confirmed during site survey Jan 2014, assume 3 people per house.
AI	Shell Petrol Filling Station	10	10	10	50%	100%	100%	100%	100%	0%	1	-	Confirmed with observation during site survey Jan 2014. 3 staff observed during site survey Jan 2014. Conservatively assumed 10 people at Filling station.
AJ1	Tsing Sha Hwy Administration Building	370	370	370	14%	20%	38%	14%	38%	95%	1	3	3 storey building, confirmed with observation during site survey Jan 2014.
AK	"SAGE Mrs. Wong Yee Jar Jat Memorial	137	137	137	100%	100%	100%	100%	100%	99%	3.3	1	Confirmed with observation during site survey Jan 2014. In total 90 bed space and no. of staff : 47. Information from http://www.swd.gov.hk/.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
	Home for the Elderly, G/F of Hin Yeung House"												
AL	"SAGE Mrs. Wong Yee Jar Jat Memorial Neighbourhood Elderly Centre, G/F of Hin Hing House; Shatin Inhabitants Association Hin Keng Intergrated Service Centre G/F of Hin Hing House"	45	45	45	0%	100%	100%	100%	100%	95%	3.3	1	Confirmed with observation during site survey Jan 2014. Assume no. of population : 30 and no. of staff :15
AN1	Po Leung Kuk 82 Hin Keng Centre G/F of Hin Pui House	45	45	45	0%	100%	100%	100%	100%	95%	3.3	1	Confirmed with observation during site survey Jan 2014. Information on hostel on: http://www.swd.gov.hk/en/print/page_2595/ Assume no. of population : 30 and no. of staff: 15.
AN2	Po Leung Kuk 82 Hin Keng Hostel for Severely Mentally Handicapped Persons G/F of Hin Pui House	3	3	3	100%	100%	100%	100%	100%	99%	3.3	1	Confirmed with observation during site survey Jan 2014. Information on hostel on: http://www.swd.gov.hk/en/print/page_2595/ and http://www.hkscaa.org/download/disabled_resident_service.pdf/, Hostel has bedspace for 1. Assume no. of staff :2.
AO1	Hin Keng Estate Management Office, Incorporated Owners of Hin Keng Estate G/F of Hin Yau House	10	10	10	0%	100%	100%	50%	100%	95%	1	1	Confirmed with observation during site survey Jan 2014. Information from http://www.swd.gov.hk/ Assume no. of staff : 10.
AO2	Mental Health Association of Hong Kong Hin Keng House,	56	56	56	100%	100%	100%	100%	100%	95%	3.3	1	Confirmed with observation during site survey Jan 2014. Maximum capacity 42 bed space. Information from http://www.swd.gov.hk/ Assume no. of staff : 14.

Ref. (see Fig 12.8)	Name	Base data/ data used previously	Const. Phase (2016)	Oper. Phase (2031)	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
					Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
	G/F of Hin Yau House												
AP	Chinese YMCA of Hong Kong Hin Keng Centre (Integrated Team) G/F of Hin Wan House	45	45	45	0%	100%	100%	100%	100%	95%	1	1	Confirmed with observation during site survey Jan 2014. Assume no. of population : 30 and no. of staff :15.
	CZ total	44425	44461	46209									
	Total (inside & outside CZ)	214932	234986	246732									

Note 1: These values are consistent with those used in the QRA for the SCL Project. See ERM (2011a) for details.

Note 2: Working Day population of Beacon Hill North Gas Offtake Station has been estimated assuming 30 persons present for 5% of time, 15 for 5% of time, 2 persons for 30% of time and none during 60% of time.

Note 3: Population is assumed zero growth despite decreasing trend in population for certain well established areas after the base year (i.e. zero growth in year 2016 and 2031 despite decreasing trend in the areas where applicable).

Note *: The STWTW Reprovisioning Project construction workers are (on-site population) included to follow the approved SCL EIA methodology, despite that HKRG is meant to assess the potential off-site risk and the on-site population are considered as "voluntary risk takers".

12.9 Hazard Identification

Hazardous Characteristics of Chlorine

12.9.1 The following lines summarise some of the key hazardous characteristics of chlorine (Chlorine Handbook, ICI, 1995):

- Chlorine gas is heavier than air and as a result will tend to accumulate in low places when released to the atmosphere and flow downhill in still air. However, slight breezes or thermal turbulence will cause it to move upward, so people are not necessarily safe simply because they are above the point of release;
- Chlorine gas has a greenish-yellow colour which is only visible at high concentrations (above approximately 500 ppm) many times higher than the danger level (see *Table 12.4* below); and
- Chlorine gas is a respiratory irritant. Symptoms caused by inhalation of chlorine include: headaches, pain, difficult breathing, burning sensation of the chest, nausea and watering of the eyes.

12.9.2 The physiological effects of chlorine are summarised in *Table 12.4*.

Table 12.4 Physiological Effects of Chlorine

Concentration (ppm)	**Effects**
0.2–3.5	Threshold of odour perception in most individuals.
3–5	Tolerated without undue ill effect for half to one hour.
5–8	Slight irritation of the mucous membranes of the upper respiratory tract and the eyes.
15	Effects are immediate. Irritation of nose, throat and eyes with cough and lachrymation.
30	Immediate cough with a choking sensation, retrosternal chest pain and a sense of constriction in the chest.
40–60	Development of a chemical tracheo-bronchitis and pulmonary oedema.
1000	Concentration likely to be fatal after a few deep breaths.

Review of Past Incidents

12.9.3 In light of the recent judgement of the Court of Final Appeal (FACV 28/2005) the Hazard Identification results of ERM (2001) have been carefully reviewed for the purpose of the current assessment. In particular, the latest version of the world wide accident database MHIDAS has been independently reviewed in order to update the Hazard Identification conclusions. However, only a few relevant chlorine incidents occurred worldwide since the previous review, and after examination of their nature it has been concluded that no revisions of the previously identified hazard scenarios or their frequencies are necessary for this study.

12.9.4 The following reference data had been searched and consulted:

- MHIDAS Database (MHIDAS is a Major Hazard Incident Data Service developed by the Safety and Reliability Directorate of the UK Atomic Energy Authority. MHIDAS contains incidents from over 95 countries particularly the UK, USA, Canada, Germany, France and India. The database allows access to many other important sources of accident data, such as the Loss Prevention Bulletin);

- HSELine (The Library and Information Services of the UK Health and Safety Executive has accumulated in a computer database documents relevant to health and safety at work. HSELine contains citations to HSE and Health and Safety Commission publications, together with documents, journal articles, conference proceedings, etc.);
- Lees (1996);
- AQUALINE;
- Chlorine Institute; and
- Chlorine Transport Risk Studies (DNV, 1997; Atkins, 2006).

Hazard and Operability Study

12.9.5 A Hazard and Operability (HAZOP) study was conducted for Sha Tin WTW as part of the *Eight WTWs Study* (ERM, 2001) to provide a full and systematic identification of the hazards associated with the delivery, storage and handling of chlorine. The HAZOP technique provides a means of examining deviations from the design intent, their causes, consequences and safeguards, in a structured manner.

12.9.6 The HAZOP sessions considered each of the following aspects of the design and operation of the WTW:

- transport of chlorine containers along the site access road (including manoeuvring of the truck outside the entrance to the truck unloading bay);
- handling of containers within the Chlorination House;
- containers in storage;
- connection and disconnection of containers;
- chlorination system (including the liquid chlorine pipework, evaporators, chlorinators and ejectors); and
- Contain and Absorb system.

12.9.7 The HAZOP considered the various operating modes of the plant (auto/manual) as well as planned maintenance operations. Prior to the HAZOP study, previous HAZOP studies of WTWs and chlorine leak incidents were reviewed to provide additional input to the identification of the chlorine release scenarios.

12.9.8 HAZOP results presented in ERM (2001) show that the primary hazard arises from a loss of containment of chlorine with subsequent acute exposure of people leading to injuries or fatalities. Releases may range in size from a small leak (e.g. via a valve gland), through to dislodgement of a fusible plug or catastrophic failure of the container itself. The releases may be isolatable (i.e. via closure of the changeover valves or drum valve) or non-isolatable (i.e. a leak from the shell of the container).

12.9.9 The physical state of the release may be gas, liquid or two-phase depending on the precise location, e.g. a small leak downstream of the evaporator is likely to be gas, a leak from the 'pigtail' connection is likely to be two-phase (due to flashing in the line), whereas a leak from the container shell itself is likely to be liquid. The release may arise from failure of the chlorine equipment itself or failure induced by an external event such as an earthquake or landslide. The quantity of chlorine released may vary from a few kilograms to several tonnes released instantaneously, e.g. in the case of a severe external event such as an earthquake. For releases occurring within the Chlorination House a Contain and Absorb system is provided to minimise the likelihood of the release escaping to atmosphere.

Characterisation of Chlorine Release Scenarios

12.9.10 Following the HAZOP study, the next step in the Hazard Assessment is to characterise the release scenarios identified in HAZOP in terms of the releasing inventory, hole size and phase of release

(*Table 12.5*). This follows the approach outlined in the Consultants' Methodology Report for the *Eight WTWs Study* (ERM, 1997).

12.9.11 Chlorine release scenarios due to the construction activities are separately discussed in *Sections* 12.9.12–12.9.15 below.

Table 12.5 Characterisation of Chlorine Release Scenarios

Chlorine release scenario	**Outcome**	**Releasing inventory (tonnes)**	**Hole size (diameter)**	**Phase**
1. ACCESS ROAD				
1.1 Truck fire	Considered to result in melting of the fusible plugs on up to three drums (1).	3	3×6 mm	liquid
1.2 Fire on the roadside	Considered to present negligible risk as truck does not park on site other than within chlorine building	-	-	-
1.3 Manoeuvring accident	Considered to result in a single drum – small leak (e.g. valve gland failure)	1	3 mm	liquid
1.4 Rollover	Single drum – small leak(e.g. valve gland failure) Single drum – medium leak(e.g. guillotine failure of drum valve)	1 1	3 mm 8 mm	liquid liquid
	Three drums – medium leak (e.g. guillotine failure of drum valves on three drums)	3	3×8mm	liquid
	Fire (outcomes as item 1.1 above)			
1.5 Collision	Single drum – rupture Fire (outcomes as item 1.1 above)	1	-	liquid
1.6 Load-Shedding	Single drum – small leak	1	3 mm	liquid
	Single drum – medium leak	1	8 mm	liquid
1.7 Spontaneous drum failure	Single drum – medium leak	1	8 mm	liquid
	Single drum – large leak (eg. dislodgement of a fusible plug)	1	20 mm	liquid
	Single drum – rupture	1 (inst)	-	liquid
2. DRUM HANDLING				
2.1 Dropped drum	Single drum – medium leak	1	8 mm	liquid
	Single drum – large leak (e.g. dislodgement of fusible plugs)	1	20 mm	liquid
	Single drum – rupture	1 (inst)	-	liquid
2.2 Collision of drum with another object	Single drum – medium leak	1	8 mm	liquid
2.3 Accidental impact of drum on pigtail during setdown at standby position	Pigtail – guillotine failure	1	4.5 mm	two-phase
2.4 Dropped drum due to overextension of truck crane	Single drum – medium leak	1	8 mm	liquid
2.5 Dropped drum due to incorrect alignment of monorail track	As item 2.1 above			
3. CONTAINERS IN STORAGE				
3.1 Leaking chlorine drums	Single drum – medium leak	1	8 mm	liquid
	Single drum – large leak	1	20 mm	liquid
	Single drum – rupture	1 (inst)	-	liquid

Chlorine release scenario	Outcome	Releasing inventory (tonnes)	Hole size (diameter)	Phase
3.2 Overfilled drums leading to overpressurisation on thermal expansion	As item 3.1 above			
3.3 Impurities in chlorine drum leading to explosion or leak	As item 3.1 above			
3.4 Object falls onto chlorine containers	Considered to present negligible risk as there are no objects likely to fall which could cause significant damage to the drums.	-	-	-
3.5 Fire (external or internal)	Considered to present negligible risk as Chlorination House is 2 hour fire-rated structures. The most significant internal source of fire is considered to be the chlorine truck. However, pessimistically, all truck fires are modelled as occurring outdoors	-	-	-
3.6 External explosion	Single drum – medium leak	1	8 mm	liquid
3.7 Lightning strike	Considered to present negligible risk as the Chlorination House is lightning protected and a lightning, while it can result in electrical damage, is unlikely to cause a chlorine release	-	-	-
3.8 Extreme wind	Considered to present negligible risk as the Chlorination House is designed for typhoon loading	-	-	-
3.9 Flooding	Considered to pose negligible risk as could only affect empty drums	-	-	-
3.10 Construction activities	No construction activities inside the Chlorination House are anticipated during the construction and operational phases of this project.	-	-	-
3.11 Subsidence	Considered to present negligible risk, due to topographical and geological properties of the site	-	-	-
3.12 Earthquake (2)	Overhead crane dislodged from rails: Single drum – rupture Roof collapse: Multiple drum – rupture	1 (inst) 36 (inst) (5)	-	liquid
3.13 Aircraft crash	Roof collapse: Multiple drum – rupture (similar to earthquake)	36 (inst) (5)	-	liquid
3.14 Sabotage	Considered to present negligible risk (issues of site security were considered in the HAZOP studies and appropriate actions have been raised.)	-	-	-
3.15 Vehicle crash	Single drum – medium leak	1	8 mm	liquid
3.16	Considered to present negligible risk	-	-	-

Chlorine release scenario	**Outcome**	**Releasing inventory (tonnes)**	**Hole size (diameter)**	**Phase**
Electromagnetic interference	as precautions are adopted in the design of the electrical systems.			
4. CONNECTION AND DISCONNECTION OF CHLORINE CONTAINERS				
4.1 Human error or equipment failure during connection or disconnection of drums	Pigtail – guillotine failure	1	4.5 mm	two-phase
5. CHLORINATION SYSTEM				
5.1–5.5 Failures associated with the chlorination system pipework	Liquid chlorine pipework – guillotine failure	1.05 (3)	4.5 mm (4)	two-phase
5.6–5.7 Failure of evaporator	Evaporator – leak or rupture	1.05	4.5 mm	two-phase

Notes

(1) In the 2001 QRA a mixture of "old" and "new" chlorine drums was assumed (with 6 and 1 fusible plug, respectively). According to the recent WSD information, the "old" drums are no longer in use, so only the "new"-type drums are considered.

(2) For assessment of effects of earthquake on Chlorination House see *Appendix 12.7*

(3) Inventory of drum (1 tonne) and evaporator (50 kg)

(4) Diameter of liquid chlorine pipework is 20mm but limiting orifice size is that of pigtail, i.e. 4.5 mm.

(5) The values listed are for the maximum 190 tonnes storage. For reduced storage scenarios they are reduced in proportion to the storage levels (see discussion in *Appendix 12.7*).

(6) Construction Phase only

Hazards Associated with Reprovisioning Works

12.9.12 Possible hazardous scenarios associated with reprovisioning works that might have potential to damage chlorine facilities/trucks and lead to a chlorine release were identified using a structured HAZID workshop approach, conducted on 11 November 2011 and attended by representatives of AECOM, WSD, MTRCL and ERM.

12.9.13 Following the workshop, a quantitative analysis was performed on each of the potential hazards identified. Details are provided in *Appendix 12.8*.

12.9.14 It was also concluded that while other reprovisioning activities may in some cases lead to potential chlorine releases (e.g. collision of a construction vehicle with chlorine truck), such events are already included in *Table 12.5* and therefore no additional chlorine release scenarios arising from construction activities need to be considered. The following points are particularly noteworthy:

- Reprovisioning works will be well segregated from the WTW operations. In particular, completely separate access routes will be used for construction trucks and chlorine delivery trucks. A new road will be constructed so that completely separate on-site roads will be used all the way up to the front entrance gate;
- Chlorine gas is dissolved into water within the Chlorination House prior to bulk dosing. All underground piping running across the site therefore contains chlorinated water and not chlorine gas. Any damage to this piping from reprovisioning works will not lead to a hazard; and
- Any tower cranes will be located at least 70 m away from the Chlorination House. Even if one of these cranes were to collapse, it cannot impact on the Chlorination House; they are simply too far away compared to the crane height. Similarly, the potential ground vibrations due to crane collapse or bore piling would be too weak to damage the Chlorination House.
- The construction activities involving mobile or tower crane usage are well separated from the chlorine delivery routes. The two tower cranes to be used during Stage 2 Activity 2 (see *Appendix 12.8*. for details of construction activities) will be placed more than 60 m away from the new chlorine delivery route. Therefore, a direct tower crane impact (either due to crane collapse and

dropped/ swinging loads) on chlorine truck is not credible taking into account sufficient separation between the proposed tower crane (used for Stage 2 Activity 2) locations and the new chlorine delivery route.

- For mobile crane impact, the possibility will be eliminated by suspending the chlorine deliveries during the short period of construction of the concerned section of elevated walkway under Stage 2 Activity 10, therefore mobile crane impacts on chlorine trucks are no longer considered.

12.9.15 Nevertheless, a number of good practice recommendations were formulated at the workshop. Subsequently a number of other good practice measures have also been recommended. These measures are further discussed in *Section 12.13* and listed in *Table 12.22*.

Hazards Associated with Liquid Oxygen

12.9.16 The South Works reprovisioning will introduce new treatment technologies including ozonation to reduce chlorine consumption. As liquid oxygen (LOX) was used in connection with ozonation process in other WTWs, the Study Brief requires the hazards associated with storage of liquid oxygen to be included in this QRA. However, as per the latest design, sufficient standby Vacuum Pressure Swing Adsorption (VPSA) units will be provided such that LOX is no longer required as a back-up oxygen supply for ozone generation [(1)]. The hazards associated with the LOX are therefore disregarded in this study. The primary function of Vacuum-Pressure Swing Adsorption (VPSA) units is to separate gases from a mixture, in this case to separate oxygen from air. VPSA units work on the principle that nitrogen tends to be adsorbed more strongly to certain materials. VPSAs can produce at least 90% pure oxygen with nitrogen and argon as the main impurities.

Potential Hazards to/from Other Projects and Installations

12.9.17 The only nearby installation handling hazardous material is the Towngas Beacon Hill North Gas Offtake Station located to the east of the WTW (*Figure 12.11*). Construction activities at the Sha Tin WTW are too far away (at a distance of at least 75 m) to have any impact on this offtake station as well as the underground gas pipes and the aboveground gas pipes installed through the Old Beacon Hill Tunnel. More details are provided in *Appendix 12.8*. Similarly, any chlorine releases from Sha Tin WTW, while affecting the surrounding population, will have no effect on the equipment at Beacon Hill. There is therefore no potential for events at Sha Tin WTW to escalate to the Beacon Hill North Gas Offtake Station and its associated pipelines.

12.9.18 There is potential for gas releases from the Beacon Hill North Gas Offtake Station and its associated 750mm diameter intermediate pressure pipeline and a new 500mm intermediate pressure gas pipeline to potentially impact on the chlorine facilities at the WTW. A gas release may, if ignited, lead to a fireball, flash fire or jet fire. Consequences of a gas release from the Beacon Hill North Offtake Station and adjacent pipeline were assessed as part of the recent SCL EIA and presented in *Appendix 13B* of the EIA report (ERM, 2011b). The Sha Tin WTW Chlorination House, some 300 m away from the nearest Towngas equipment cannot be affected by jet fires or fireballs, and lies beyond the consequence distance of a flash fire (maximum distance to 0.85 LFL for a full bore pipeline rupture is calculated at 196 m). Furthermore, since the building is fireproof and flash fires are of short duration with negligible radiation effects, an external flash fire cannot lead to a chlorine release inside the Chlorination House as stated in *Table 12.5*. While *Appendix 13B* of the SCL EIA report is limited to the hazardous scenarios due to the use of explosives, other external hazardous scenarios such as earthquake, aircraft crash will not result in more severe fire cases and worst case consequence remain as full-bore rupture. Hence the conclusion that the Chlorination House cannot be affected by jet fires or fire balls, which are the worst case consequences, remains valid.

12.9.19 It follows, that gas releases from the pipelines within the Old Beacon Hill Tunnel also cannot impact on the Chlorination House as the tunnel portal is a similar distance away at more than 300 m.

12.9.20 While parts of the new chlorine delivery road are within the hazard range of a jet fire or fireball originating at the off-take station, such jet could not reach the chlorine truck since it would be

[1] The Ngau Tam Mei Water Treatment Works, commissioned in 2000, adopted VPSA units for the production of pure oxygen with liquid oxygen (LOX) as back up for ozone generation. With technological advancement in the last decade, more reliable VPSA units are commonly available in the market and sufficient standby units instead of the inclusion of LOX has been adopted in this Project for ozone generation.

screened by the MTR East Rail track enclosure (see *Figure 12.11*). On the other hand, a flash fire from the off-take station or associated underground pipeline could affect the chlorine trucks on the WTW access road, leading to secondary fires and a chlorine release due to melting of fusible plugs on some chlorine drums.

12.9.21 The probability of such chlorine release is however extremely low. This may be estimated using the following data:

- typical failure frequency for the underground gas pipelines 10^{-5} per km-year [1]
- conservative delayed ignition probability of 40% [2]
- 300 m length of the relevant pipeline segment
- probability of wind blowing from the eastern direction of 20%
- fraction of the year when a chlorine truck is present on the access road: about 0.001, based on 127 trucks per year and 10 km/h speed on the access road

Based on the above, a probability of a flash fire affecting a chlorine truck on the access road can be estimated at 2.4×10^{-10} per year. This is a very conservative estimate, since the pipeline failure frequencies used here include all possible leak sizes, while only a full bore rupture with a conditional probability of about 1% has a potential to cause an extensive flash fire that could reach the access road.

12.9.22 A similar calculation may be performed for the above ground installations of the offtake station. The frequency of a flash fire with consequence distance of more than 100 m (the closest distance between off-take station and chlorine trucks is about 125 m) can be estimated at about 2.0×10^{-9} per year). This yields an impact frequency of $2.0 \times 10^{-9} \times 0.2 \times 0.001 = 4 \times 10^{-13}$ per year.

12.9.23 Both these frequencies are several orders of magnitude lower than the 3.0×10^{-7} per year frequency of chlorine release due to the truck fire adopted in this QRA (*Table 12.17*) and less than the 10^{-9} per year cut-off frequency adopted in Hong Kong. The risk of events at the Towngas facilities impacting on chlorine trucks is therefore not significant. The risk from the gas facilities to nearby population including operators and construction workers at STWTW is assessed taking into account the MTR East Rail track as stated in *Section 12.9.20*.

12.9.24 The Beacon Hill North Offtake Station will be relocated about 10 m to the west of the existing location. This is already taken into consideration in the above analysis, and the population at the offtake station will not exceed the levels assumed for that location in *Table 12.3* (30 persons present yearly for 5% of time, 15 for 5% of time, 2 persons for 30% of time and none during 60% of time).

12.9.25 As part of the SCL project, explosives will be transported through the Sha Tin WTW Consultation Zone on the Che Kung Miu Road. Explosives will be transported in quantities of up to 200 kg, an initiation of which may impact the Chlorination House or chlorine trucks. Based on the approved SCL QRA (ERM, 2011b) the probability of an explosion of an explosive delivery truck is 7.69×10^{-10} per km and the number of explosive deliveries using that road is 336 per year. The impact radius of an explosives truck explosion is only about 100 m (ERM, 2011b). It is conservatively assumed that about a 500m section of Che Kung Miu Rd may impact the on-site chlorine delivery truck. This leads to the relevant explosion probability near Sha Tin WTW of $336 \times 0.5 \times 7.69 \times 10^{-10} = 1.3 \times 10^{-7}$ per year. With the chlorine truck presence factor of 0.001 (see above), this leads to an event frequency of 1.3×10^{-10} per year, again below the 10^{-9} per year cut-off frequency adopted in Hong Kong. Note that this estimation conservatively assumed that the chlorine trucks on the whole length of the access road can be affected by a Che Kung Miu Road explosion, while in fact the impact radius of an explosives truck explosion is only about 100 m so only a small fraction of the Sha Tin WTW on-site chlorine delivery road can be affected.

12.9.26 Similarly, an explosives truck explosion cannot affect the Chlorination House. As shown in the approved QRA for the SIL(E) Project (ERM, 2010) an explosion of a truck with a load of 200 kg

[1] See *QRA for the HKCG Eastern Transmission Network*, ERM report for HKCG, 2005

[2] See *QRA for the HKCG Eastern Transmission Network*, ERM report for HKCG, 2005

explosives as used for the SCL project can affect concrete structures at a distance of not more than 62 m, while the Chlorination House is about 360 m away from Che Kung Miu Road.

12.9.27 As concluded in the assessment by AECOM (see *Appendix 12.9*), the construction activities at the Sha Tin WTW will have no effect on the nearby 400kV overhead power line. Due to the adequate separation distance there is also no potential for domino effect from this installation.

12.9.28 Therefore, escalation events to/from the Beacon Hill North Offtake Station, the gas pipelines, the SCL Project explosives transport on Che Kung Miu Road and the 400kV overhead power lines were not assessed further in this QRA.

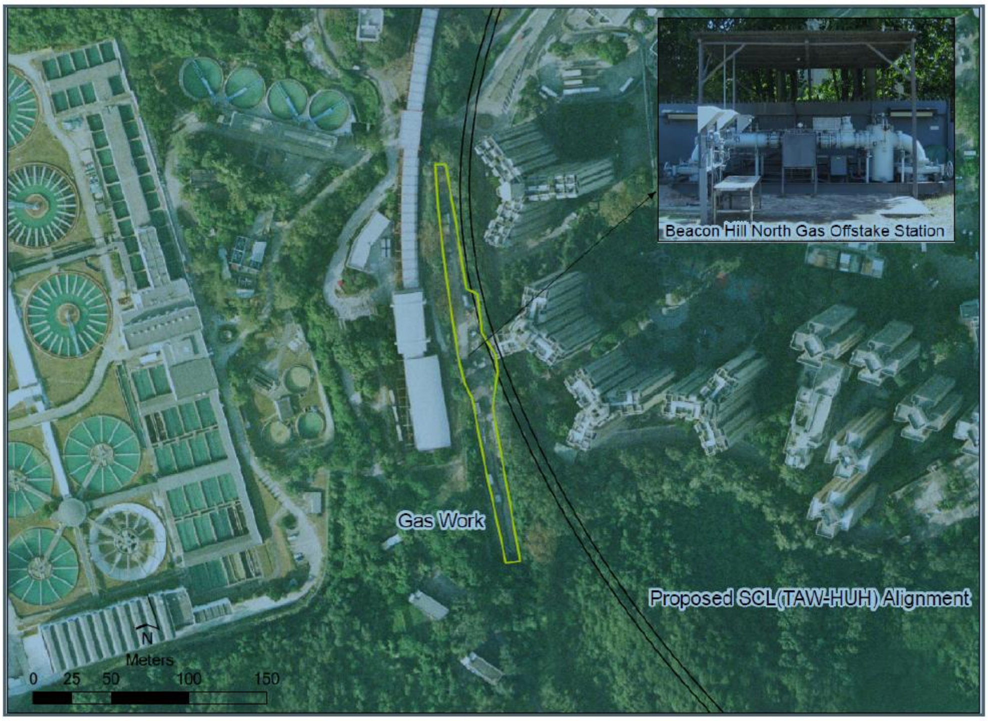
12.9.29 Apart from the normal operation of the north part of the WTW there will be no other projects at the site of Sha Tin WTW concurrent with South Works reprovisioning project.

12.9.30 A review of all committed and planned developments has been conducted as part of this EIA and, as stated in Section 2.8 of this report, the only relevant concurrent project outside the WTW is the SCL Project of MTRC. The construction workers and future passengers of the SCL have been included in this QRA.

12.9.31 It may be noted that that there will be a new 500mm diameter gas pipeline installation works within the Beacon Hill North Offtake Station area and the Old Beacon Hill Tunnel. However, according to the information from Towngas, all the installation works within Sha Tin WTW Consultation Zone will be completed before the start of the Sha Tin WTW reprovisioning project.

12.9.32 Apart from the effects on population, potential chlorine releases at the WTW will not lead to any other hazardous events. Similarly, while the chlorine release scenarios caused by external causes are considered in the QRA, no potential impact from other concurrent planned or committed project has been identified. Therefore, apart from the increase of population, there will be no potential domino effect from other projects.

Figure 12.11 Beacon Hill North Gas Offtake Station



12.10 Consequence Analysis

Overview

12.10.1 The assessment of the consequences of a chlorine release essentially involves three steps:

- modelling the initial release of chlorine (whether inside or outside the chlorine building);
- modelling the dispersion of chlorine in the atmosphere; and
- assessing the toxic impact to people (whether indoors or outdoors).

Initial Release of Chlorine

12.10.2 The initial release of chlorine or 'source term' is modelled using standard discharge rate formulae as detailed in (ERM, 1997). Releases direct from the chlorine container are the most significant and, in the case of chlorine drums, these are modelled as liquid releases.

12.10.3 The rapid flashing of chlorine which occurs following a liquid leak from a drum is conservatively assumed to result in 100% entrainment of the liquid as aerosol with no rain-out. For catastrophic (instantaneous) liquid releases, the rapid boiling of chlorine on contact with the ground is assumed to result in entrainment of twice the initial flash fraction as aerosol, following Lees (1996). The remainder of the liquid chlorine is modelled as a spreading, evaporating pool.

12.10.4 For releases of chlorine within the chlorine building, a simple 'perfect mixing' model is used to account for the initial dilution of chlorine. Instantaneous releases of 1 tonne of chlorine are assumed to result in pressurisation of the building to the extent that there could be a release of chlorine via weak points in the building structure, e.g. door seals. Continuous releases are assumed to be entirely contained, except in the event of failure of the Contain and Absorb system for which two modes of failure are considered: normal ventilation remains on or a door is left open.

12.10.5 The results of the 'source term' modelling of chlorine releases are summarised in *Table 12.6* below.

Table 12.6 Summary of Source Term Modelling Results for Sha Tin WTW

Release case	Hole size (mm)	Phase	Mode of release to atmosphere (for internal release cases only)	Release rate to atmosphere or instantaneous release quantity	Release duration (Note 1)
External releases (1-tonne drum)					
Small leak	3	Liquid	-	0.2 kg/s	83 min
Medium leak	8	Liquid	-	1.4 kg/s	12 min
Large leak	20	Liquid	-	8.8 kg/s	114 s
Rupture	-	Liquid	-	1000 kg	-
Internal releases (1-tonne drum or chlorine pipework)					
Pigtail–guillotine failure	4.5	Two-phase	Normal ventilation remains on	0.027 kg/s	10 min (Note 2)
			Door left open	0.013 kg/s	10 min
Medium leak from drum	8	Liquid	Normal ventilation remains on	0.30 kg/s	10 min
			Door left open	0.13 kg/s	10 min

Large leak from drum	20	Liquid	Normal ventilation remains on	0.55 kg/s	10 min
			Door left open	0.24 kg/s	10 min
Rupture	-	Liquid	Pressurisation of Chlorination House – release via weak points (Note 4)	1.62 kg/s	10 s (Note 3)

Note 1: assumes no intervention by operating staff

Note 2: upper limit of 10 min set for duration of releases from chlorine building (by which time action would be taken to shut-off ventilation, close doors etc.)

Note 3: assumed release duration for catastrophic failure of a drum, e.g. a split along a weld (QRA not sensitive to this assumption)

Note 4: 'Normal ventilation remains on' and 'Door left open' are not included for this mode of release since 'Pressurisation of Chlorination House – release via weak points' will be more dominant in the QRA.

12.10.6 It is also apparent that the chlorine building has a significant effect in modifying the release of chlorine to the atmosphere, given failure of the Contain and Absorb system. The rate of chlorine release is reduced dramatically (e.g. for a medium leak the rate of chlorine to atmosphere is reduced from 1.4 kg/s to 0.3 kg/s or 0.13 kg/s) and the chlorine becomes diluted in the building air.

12.10.7 The failure mode of the Contain and Absorb system 'Normal ventilation remains on' is a more severe case than 'Door left open' in terms of the chlorine release rate to atmosphere. This is because the normal ventilation (typically 2.6 air changes per hour) provides a more rapid release of chlorine to the environment than if a door is left open (normal ventilation shutdown, chlorine scrubber system in operation).

Toxic Impact Assessment

12.10.8 Similar to the previous QRAs (ERM 2001, 2011a), the following probit equation (TNO, 1992) has been used in this study to estimate the likelihood of fatality due to exposure to chlorine:

$Pr = -14.3 + \ln C^{2.3}t$

where

Pr = probit value

C = chlorine concentration (mg/m^3)

t = exposure time (minutes)

12.10.9 *Table 12.7* shows the relationship between the chlorine concentration and the probability of fatality for the TNO probit (assuming 10 minute exposure duration).

Table 12.7 Chlorine Toxicity Relationship

Chlorine concentration (ppm)	**Probit value for 10 min exposure (TNO probit)**	**Probability of fatality (LD = Lethal Dose)**
251	3.17	0.03 (LD03)
557	5.00	0.50 (LD50)
971	6.28	0.90 (LD90)

Dispersion of Chlorine in the Atmosphere

12.10.10 The *Eight WTWs Study* used advanced techniques for prediction of the dispersion of chlorine in the atmosphere. The effects of buildings and variable ground terrain on the dispersion of chlorine in the atmosphere are modelled. The modelling of the dispersion of chlorine in the atmosphere involves three elements.

- Wind tunnel simulations;
- Computational Fluid Dynamics (CFD); and
- Flat terrain dispersion modelling.

12.10.11 The wind tunnel and CFD studies represent the 'state of the art' in dense gas dispersion modelling and provide the only rigorous means of accounting for the effects of buildings and complex terrain. Wind tunnel testing has been used in the *Eight WTWs Study* to investigate a range of release conditions, wind directions and wind speeds in near-neutral atmospheric conditions. CFD has been used to determine the influence of atmospheric stability on the dispersion of chlorine and provide a broad comparison against the wind tunnel results for neutral stability. In the *Eight WTWs Study* wind tunnel simulations were undertaken for all eight sites, whereas CFD modelling was undertaken for two sites representing the extremes of topography (Sha Tin WTW and Tai Po Tau WTW). Both the wind tunnel testing and CFD modelling have included off-site high rise buildings as well as on-site buildings as these have a significant influence on the dispersion of the chlorine.

12.10.12 The role of the flat terrain dispersion modelling has been to provide the 'source term' for both the wind tunnel and CFD studies. The model used in the *Eight WTWs Study* was DRIFT (Webber et al, 1992), an integral dispersion model developed by AEA Technology under the sponsorship of the UK Health and Safety Executive. DRIFT contains the necessary thermodynamics and heat transfer sub-models to be able to simulate the dispersion of a cold, aerosol-laden cloud typical of the early stage of a chlorine release. As DRIFT runs in a matter of minutes, it has also been possible to use the code to simulate the full range of chlorine release rates and weather conditions. In conjunction with the wind tunnel and CFD, this provides all the data needed for input to the QRA.

12.10.13 The results of wind tunnel testing for Sha Tin WTW are summarised in *Table 12.8* and *Figures B1* to *B14* in *Appendix 12.2.*

Table 12.8 Summary of Wind Tunnel Tests Results for Sha Tin WTW

Release case	**Release location**	**Description**	**Weather class**	**Wind direction (Note 1)**	**Maximum extent of LD03 contour (m) (Note 2)**
0.2 kg/s (aerosol) Continuous	Access Road	Small leak (3 mm) from chlorine drum	D2	SW, W	No LD03 contour off-site
0.5 kg/s (vapour) continuous	Chlorinat ion House	Chlorine vapour release from store due to large leak (20 mm) from drum within store followed by failure of Contain and Absorb System	D2	SW, W, SE	No LD03 contour off-site
			D5	SW, SE	No LD03 contour off-site
1.4 kg/s (aerosol) continuous	Access road	Medium leak (8 mm) from chlorine drum	D2	S, SW, W NW, SE, NNE	No LD03 contour off-site
			D5	W, SE	No LD03 contour off-site
1 tonne (aerosol) instantaneous	Chlorinat ion House	Catastrophic failure of a chlorine drum	D2	SSW, WSW, SE,	350 650 250

Release case	**Release location**	**Description**	**Weather class**	**Wind direction (Note 1)**	**Maximum extent of LD03 contour (m) (Note 2)**
				NNE, WNW	285 No LD03 contour off-site
			D5	WSW, SE	315 250
1 tonne (aerosol) instantaneous	Access road	Catastrophic failure of a chlorine drum	D2	S SW W NW SE NNE	295 640 260 480 300 355
			D5	W SE	165 210

Note 1: Following standard meteorology notation, wind directions refer to the direction *from* where the wind blows.

Note 2: Downwind distance to 3% nominal outdoor fatality probability, i.e. not taking into account escape and assuming 10 min exposure duration or cloud passage time (whichever is shorter)

12.10.14 From the results in *Table 12.8*, *Appendix 12.2* and RWDI (1998), the key findings of the wind tunnel testing may be summarised as follows:

- The wind tunnel results show that the LD03 contour only exceeds the site boundary for 1 tonne instantaneous releases. For 1.4 kg/s and 0.5 kg/s continuous releases the LD03 does not extend off-site; and

- The LD contours for the 1 tonne instantaneous release cases are strongly influenced by the topography and buildings near Sha Tin WTW. In particular:
  - The chlorine clouds are constrained by the hills surrounding the WTW on three sides. However it is noted that the LD03 contour does extend to an elevation of 100m above Principal Datum (NNE wind direction) with significant concentrations of chlorine also present at greater elevations (e.g. 30 ppm at 200m above PD); and
  - The nearest high rise blocks of the Hin Keng Estate act as an effective barrier to chlorine dispersion in the WSW direction with the chlorine cloud instead diverting down the Sha Tin valley (i.e. following the path of least resistance).

12.10.15 The results of the CFD modelling for Sha Tin WTW and Tai Po Tau WTW are presented in *Appendix 12.3* and summarised in *Table 12.9*. Full details can be found in HSL (1998) and HSL (1999).

Table 12.9 Summary of CFD Modelling Results

Release case	**Weather Class**	**Maximum extent of LD contour (m)**		
		LD90	**LD50**	**LD03**
Sha Tin WTW				
1.4kg/s continuous	D2 F2	110 145	140 155	205 225
1 tonne instantaneous	D2 F2	170 220	200 255	255 275
Tai Po Tau WTW				
1.4kg/s continuous	D2 F2	135 130	165 180	265 330

Release case	**Weather Class**	**Maximum extent of LD contour (m)**		
		LD90	**LD50**	**LD03**
1 tonne instantaneous	D2 F2 B2	200 180 75	215 255 95	255 355 105

12.10.16 From *Table 12.9,* HSL (1998) and HSL (1999), the key findings of the CFD modelling may be summarised as follows:

- Atmospheric stability does not significantly influence the hazard range of either a 1.4 kg/s continuous release of chlorine or a 1 tonne instantaneous release of chlorine for the two weather conditions of most interest in this study (i.e. D – neutral stability and F – stable conditions). This is because, in the presence of buildings and complex, heavily-vegetated terrain, atmospheric stability has less of an influence on chlorine dispersion;
- For B (unstable conditions) the CFD results for Tai Po Tau WTW indicate that the chlorine hazard range is significantly reduced compared to neutral conditions (i.e. a factor of 2.5 shorter for a 1 tonne instantaneous release). HSL indicate that this is due to the unstable wind field which significantly enhances vertical dispersion of the chlorine. However, as B conditions account for no more than 20% of the weather in Hong Kong, this is not considered a significant factor for the QRA (i.e. risks are not considered to be significantly overestimated by ignoring B conditions); and
- For F (stable conditions) the CFD results for Tai Po Tau WTW indicate that, whilst the chlorine hazard range is not significantly affected by atmospheric stability, the direction of travel of the chlorine cloud may be affected. At Tai Po Tau WTW, the chlorine releases in F conditions more closely followed the topographic contours than the equivalent releases in D conditions, which followed the direction of the wind.

12.10.17 The results of the flat terrain dispersion modelling using DRIFT are presented in *Appendix 12.1* and summarised in *Table 12.10* below.

Table 12.10 Summary of DRIFT Results

Release case	**Weather Class**	**Maximum extent of LD contour (m)**		
		LD90	**LD50**	**LD03**
0.2 kg/s continuous	D2	86	119	182
1.4 kg/s continuous	D2	268	362	550
1 tonne instantaneous	D2	325	425	600
3 tonnes instantaneous	D2	586	735	1044
10 tonnes instantaneous	D2	1004	1286	1790

12.10.18 From the results in *Table 12.10* it is possible to derive a relationship between the chlorine release rate (or release quantity) and the downwind hazard range. The relationship is used in the QRA, as described below.

12.10.19 *Table 12.11* compares the key results from the wind tunnel testing, CFD modelling, and DRIFT flat terrain dispersion modelling.

Table 12.11 Comparison of Wind Tunnel, CFD and DRIFT Results (Neutral stability, 2m/s wind speed)

Release case	Maximum extent of LD03 contour (m)		
	Wind tunnel	CFD	DRIFT

0.2 kg/s continuous	<125	-	182
1.4 kg/s continuous	<125	260 (Note 1)	550
1 tonne instantaneous	250-650	255	600

Note 1: Result from higher order discretisation scheme used in CFD modelling (HSL, 1998)

12.10.20 From *Table 12.11* the following key points emerge:

- The chlorine hazard range predicted by the wind tunnel testing and CFD modelling is generally shorter than that predicted by the DRIFT flat terrain dispersion modelling, particularly for continuous-type releases. This highlights the importance of modelling the effects of buildings and complex terrain, which act to increase turbulence and cause greater mixing of the chlorine. (It should also be noted that there is an inherent limitation in models such as DRIFT, whereby the surface roughness chosen must be small in relation to the cloud height. For dense gas release this limits the scope of DRIFT-type simulations to relatively smooth terrain, which is not applicable to Hong Kong conditions);
- The hazard range predicted by the wind tunnel testing for the 1.4 kg/s continuous release case is significantly shorter than that predicted by the CFD modelling (less than half). The reason for this is not certain, however an independent technical review of the wind tunnel testing (Webber, 1998) highlighted the limitation of modelling this type of release in the wind tunnel (1:500 scale) due to the difficulty of accurately simulating turbulence close to the ground near the source of the release. It is possible, therefore, that in the wind tunnel the degree of turbulence was greater than would occur in practice for this type of release. In view of this, the QRA uses the CFD modelling results for this release, in preference to those generated by the wind tunnel; and
- The hazard range predicted by the wind tunnel for 1 tonne instantaneous releases are greater than those predicted by the CFD modelling. The reason for this is not clear; however, as the wind tunnel results err on the conservative side (whilst eliminating the pessimism in the DRIFT-type predictions for these releases) they have been used in preference in the QRA.

Rationalisation of Chlorine Dispersion Modelling Results

12.10.21 The preceding sections have discussed the results arising from the various strands of work on chlorine dispersion modelling. The following paragraphs summarise how these results have been applied in the QRA. More details are provided in *Appendix 12.4.*

12.10.22 *Wind tunnel testing*: the wind direction-specific cloud shapes generated in the wind tunnel have been used directly in the QRA. This has been achieved through use of Graphical Information Systems (GIS) software which is described in further detail below. Another output of the wind tunnel testing was the influence of wind speed on the chlorine hazard range. From the wind tunnel test results for all eight WTWs a simple scale factor was derived to modify the cloud contours for the 2m/s wind speed case to determine those for the 5m/s case.

12.10.23 *CFD modelling*: the CFD modelling results show no significant influence of atmospheric stability on the chlorine hazard range (for D and F conditions), therefore this parameter is not considered further in the QRA. However the CFD results for the 1.4 kg/s continuous release case (D2 weather conditions), which are consistent for Sha Tin WTW and Tai Po Tau WTW, are used in the QRA in preference to those from the wind tunnel.

12.10.24 *DRIFT modelling*: the DRIFT flat terrain dispersion modelling results are not used directly in the QRA. However the relationships derived from the DRIFT modelling for the chlorine release rate/quantity versus hazard range are used to scale the wind tunnel results for the complete range of release scenarios which need to be considered in the QRA. One further aspect which needs to be considered in applying the results of the wind tunnel testing in the QRA is the number of individual wind tunnel directions which are considered. In the wind tunnel testing up to eight wind directions were typically modelled for the most important release scenarios (e.g. a 1 tonne instantaneous release). However, in a QRA, it is usually necessary to consider a greater number of possible directions, in order to eliminate any spurious, numerical error in the risk results. The process of interpolating between the modelled wind directions is called 'wind smoothing' (achieved mathematically in software such as RISKPLOT the Consultants proprietary risk integration tool).

12.10.25 The application of wind smoothing in this study was considered in detail in *Technical Note 1* (ERM, 1998). It was concluded that for sites with relatively flat surrounding terrain, wind smoothing could be achieved by the simple method of cloud 'rotation' (i.e. rotation of clouds to fill the directional 'gaps' left by the wind tunnel). However for sites with complex terrain and/or high rise buildings it would be necessary to demonstrate that the important effects of the topography and buildings had been adequately captured in the raw wind tunnel data. For Sha Tin WTW it was demonstrated in *Technical Note 1* that sufficient number of wind directions were considered in the wind tunnel testing, such that further wind smoothing was either not necessary or could be achieved easily by the method of cloud rotation without introducing any significant additional error.

Chlorine Cloud Height

12.10.26 Information on the height of a chlorine cloud has been obtained from the wind tunnel simulations, CFD modelling and DRIFT flat terrain dispersion modelling. This is useful for determining the degree of protection of people inside high rise buildings. Details are presented in *Appendix 12.5*

12.10.27 The data in *Appendix 12.5* have been rationalised for use in the QRA as shown in *Table 12.12.*

Table 12.12 Chlorine Cloud Heights

Release case	Chlorine cloud height (m) (Note 1)	Equivalent number of storeys (Note 2)
1.4 kg/s continuous	30	10
1 tonne instantaneous	6	2
10 tonnes instantaneous	9	3

Note 1: Note that this is not the full height of the chlorine cloud. It is the height up to which the ground level chlorine concentration is assumed to apply for the purpose of calculating number of fatalities in tall buildings.
Note 2: Assumes 3 m per storey

Modelling of Escape from the Chlorine Cloud

12.10.28 In risk assessments for toxic gas releases it is common practice to take into account the possibility of escape of exposed persons. This is because at lower concentrations of the gas, people may be able to obtain protection by moving indoors or directly out of the cloud.

12.10.29 *Annex F1* of ERM (2001) provides details of the modelling of escape from a chlorine cloud which is also followed in this study. The methodology is similar to that developed by the UK Health and Safety Executive (Lees and Ang, 1989). It assumes that a person outdoors will have a probability of escape dependent on the chlorine cloud concentration, with escape occurring either directly out of the cloud or to a nearby building. The methodology takes into account the dose received during escape as well as the subsequent dose in the place of refuge. Suitable conservative assumptions are made for the time of escape bearing in mind the debilitating effect of the chlorine gas.

12.10.30 Incorporating all the above considerations it is possible to calculate an ‘effective’ outdoors fatality probability, i.e. the fatality probability that can be applied to the total outdoor population at any given location taking into account the probability of escape.

12.10.31 The consequence analysis gives three fatality probability contours for each release scenario, corresponding to 3%, 50% and 90% nominal outdoor fatality probability. The effective outdoors fatality probabilities corresponding to these levels of fatality are shown in *Table 12.13.*

Table 12.13 Effective Outdoors Probability of Fatality

Nominal outdoor fatality probability (for a person remaining outdoors)	% of population attempting escape	Effective outdoor fatality probability (taking into account the probability of escape)
90%	0%	90%
50%	80%	31%

Nominal outdoor fatality probability (for a person remaining outdoors)	% of population attempting escape	Effective outdoor fatality probability (taking into account the probability of escape)
3%	80%	0.7%

Protection for Persons Indoors

12.10.32 Following similar previous studies undertaken in Hong Kong and elsewhere, it is assumed that the probability of fatality for a person indoors is 10% of that for a person remaining outdoors, i.e. nominal outdoor fatality probability.

12.10.33 Protection is also considered for people on the upper floors of high rise buildings. This is based on data on the typical height of a chlorine cloud provided by the dispersion modelling.

Sensitive Populations

12.10.34 Certain groups of people, i.e. the young, the elderly and the infirm will be more sensitive to the effects of chlorine than others (ERM, 1997). This is taken into account in the QRA by increasing the fatality rate applied to certain sensitive receivers such as nurseries, primary schools, old people homes and hospitals (see *Table 12.3*).

12.10.35 In line with data published by Withers and Lees (1985) and risk criteria applied to sensitive developments in the UK and Australia, the fatality rate for these groups of people is set a factor of 3.3 higher than for the average population.

12.11 Rationalization of Chlorine Release Scenarios and Estimation of Scenario Frequencies

Release Scenarios Considered

12.11.1 The consequence analysis from wind tunnel testing and CFD modelling shows that it is only certain, severe types of chlorine release which could produce fatal off-site concentrations of *chlorine (Table 12.8 and Table 12.9*). The release cases which fall into this category are external continuous releases of 1.4 kg/s or more (equivalent to guillotine failure of a drum valve) and instantaneous releases of 1 tonne or more, either external or in which containment provided by the building is lost, e.g. due to an earthquake or aircrash.

12.11.2 These results mean that many of the chlorine release scenarios identified in *Section 12.9* (*Table 12.5*) can be eliminated from further consideration in the QRA.

12.11.3 *Table 12.14* considers each release scenario in turn and, based on the results of the consequence analysis, determines whether the scenario poses an off-site hazard. *Table 12.15* then summarises the results of the analysis in *Table 12.14* by grouping the release scenarios into 'events' having identical release characteristics (i.e. the same release rate, duration and phase of release).

Table 12.14 Rationalisation of Chlorine Release Scenarios

Chlorine release scenario	**Outcome**	**Hole size**	**Phase**	**Chlorine release rate from primary source (kg/s)**	**Chlorine release quantity (tonnes)**	**Chlorine release rate (or quantity) to atmosphere**	**Significant off-site hazard ? (Y/N)**	**Event Ref [(2)]**
1. ACCESS ROAD								
1.1 Truck fire	Considered to result in melting of the fusible plugs on up to three drums.	3×6mm	Liquid	2.4	3	2.4 kg/s	Y	RU1TMML
1.3 Manoeuvring accident	Single drum – small leak	3 mm	liquid	0.2	1	0.2 kg/s	N	-
1.4 Rollover	Single drum – small leak Single drum – medium leak Three drums – medium leak Fire (outcomes as item 1.1 above)	3 mm 8 mm 3×8mm	liquid liquid liquid	0.2 1.4 4.2	1 3	0.2 kg/s 1.4 kg/s 4.2 kg/s	N Y Y	- RU1TSML RU1TMML
1.5 Collision	Single drum – rupture Fire (outcomes as item 1.1 above)	-	liquid	-	1 (inst)	1 tonne	Y	RU1TSRU
1.6 Loadshedding	Single drum – small leak Single drum – medium leak	3 mm 8 mm	liquid liquid	0.2 1.4	1 1	0.2 kg/s 1.4 kg/s	N Y	- RU1TSML
1.7 Spontaneous container failure	Single drum – medium leak Single drum – large leak Single drum – rupture	8 mm 20 mm -	liquid liquid liquid	1.4 8.8 -	1 1 1 (inst)	1.4 kg/s 8.8 kg/s[(3)] 1 tonne	Y Y Y	RU1TSML RU1TSRU RU1TSRU
2. DRUM HANDLING								
2.1 Dropped drum	Single drum – medium leak Single drum – large leak Single drum – rupture	8 mm 20 mm -	liquid liquid liquid	1.4 8.8 -	1 1 1 (inst)	0.30 kg/s 0.55 kg/s 16 kg	N N N	- - -
2.2 Collision of drum with another object	Single drum – medium leak	8 mm	liquid	1.4	1	0.30 kg/s	N	-
2.3 Accidental impact of drum on pigtail during setdown at standby position	Pigtail – guillotine failure	4.5 mm	two-phase	0.12	1	0.027 kg/s	N	-

Chlorine release scenario	Outcome	Hole size	Phase	Chlorine release rate from primary source (kg/s)	Chlorine release quantity (tonnes)	Chlorine release rate (or quantity) to atmosphere	Significant off-site hazard ? (Y/N)	Event Ref [(2)]
2.4 Dropped drum due to overextension of truck crane	Single drum – medium leak	8 mm	liquid	1.4	1	0.30 kg/s	N	-
2.5 Dropped drum due to incorrect alignment of monorail track	As item 2.1 above							
3. CONTAINERS IN STORAGE								
3.1 Leaking chlorine drums	Single drum – medium leak Single drum – large leak Single drum – rupture	8 mm 20 mm -	liquid liquid liquid	1.4 8.8 -	1 1 1 (inst)	0.30 kg/s 0.55 kg/s 16 kg	N N N	- - -
3.2 Overfilled drums leading to overpressurisation on thermal expansion	As item 3.1 above							
3.3 Impurities in chlorine drum leading to explosion or leak	As item 3.1 above							
3.6 External explosion	Single drum – medium leak	8 mm	liquid	1.4	1	0.30 kg/s	N	-
3.12 Earthquake	Overhead crane dislodged from rails: single drum-rupture Roof collapse: multiple drum-rupture	- -	liquid liquid	- -	1 (inst) 36 [(4)] (inst)	16 kg 23 tonnes [(1,4)]	N Y	- EU1TMRU EU1TMRU1G
3.13 Aircraft crash	Roof collapse: multiple drum rupture (similar to earthquake)	-	liquid	-	36 [(4)] (inst)	23 tonnes [(1,4)]	Y	AU1TMRU
3.15 Vehicle crash	Single drum – medium leak	8 mm	liquid	1.4	1	0.30 kg/s	N	-
4. CONNECTION AND DISCONNECTION OF CHLORINE CONTAINERS								
4.1 Human error or equipment failure	Pigtail – guillotine failure	4.5 mm	two-phase	0.12	1	0.027 kg/s	N	-

Chlorine release scenario	Outcome	Hole size	Phase	Chlorine release rate from primary source (kg/s)	Chlorine release quantity (tonnes)	Chlorine release rate (or quantity) to atmosphere	Significant off-site hazard ? (Y/N)	Event Ref [(2)]
during connection/disconnection of drums								
5. CHLORINATION SYSTEM								
5.1–5.5 Failures associated with the chlorination system pipework	Liquid chlorine pipework – guillotine failure	4.5 mm	two-phase	0.12	1.05	0.027 kg/s	N	-
5.6–5.7 Failure of Evaporator	Evaporator – leak or rupture	4.5 mm	two-phase	0.12	1.05	0.027 kg/s	N	-

Note (1): For large instantaneous releases, 64% of the chlorine is estimated to be released instantaneously to atmosphere as vapour and entrained aerosol. This comprises the initial vapour flash fraction (19%) plus the entrained aerosol (2 × 19%) plus the contribution from the evaporating chlorine pool over the first minute (7%).

Note (2): Key to event ref

E	R (Road) or E (Earthquake) or A (Aircraft crash) or I (internal)
U	U (Unisolated) or I (Isolated)
1T	1T (1-tonne drums)
M	S (Single) or M (Multiple)
RU	RU (Rupture), LL (Large Leak), ML (Medium Leak) or SL(Small Leak)
1G	Earthquake of higher ground acceleration

Note (3): These releases treated as effectively instantaneous releases due to short release duration

Note (4): The values listed are for the maximum 190 tonnes storage. For reduced storage scenarios they are reduced in proportion to the storage levels (see discussion in *Appendix 12.7*)

Table 12.15 Release Scenarios Included in QRA

Event Ref	Component scenarios	Release rate (or quantity) to atmosphere	Type of release	Release location
RU1TSML	Rollover Loadshedding Spontaneous leak	1.4 kg/s	Continuous	Access road
RU1TMML	Rollover Truck fire	4.2 kg/s	Continuous	Access road
RU1TSRU	Truck impact Spontaneous failure	1 tonne	Instantaneous	Access road
EU1TMRU	Earthquake: roof collapse, ground acceleration 0.7g	23 (1) tonnes	Instantaneous	Chlorination House
EU1TMRU1G	Earthquake: roof collapse, ground acceleration 1g	23 (1) tonnes	Instantaneous	Chlorination House
AU1TMRU	Aircraft crash	23 (1) tonnes	Instantaneous	Chlorination House

Note (1): the values listed are for maximum 190 tonnes storage. For reduced storage scenarios they are reduced in proportion to the storage levels

Frequency Estimation

12.11.4 Next step in the Hazard Assessment is to determine the frequency of occurrence of scenarios listed in *Table 12.15*. This is based on the approach outlined in the Consultants' *Methodology Report* (ERM, 1997).

12.11.5 *Table 12.16* summarises the base data which has been used in the frequency calculations. Following the methodology described in ERM (2001) and also applied in ERM (2011a), actual frequencies are then determined based on these base failure data and the operational parameters of the WTW such as chlorine use, chlorine storage levels, and length of the access road or, in the case of the aircraft crash event, the Sha Tin WTW location in relation to the flight path, number of flights into CLK airport etc. The resulting total event frequencies are presented in *Table 12.17.*

Table 12.16 Base Failure Rate Data

Data item	Value	Units	Source
1*. Chlorination House*			
1.1(i) Spontaneous container failure frequency (ii) Conditional probability of catastrophic failure (iii) Conditional probability of medium leak (iv) Conditional probability of large leak	1.5E-4 2.7E-2 2.2E-1 8.1E-2	per year - - -	*Methodology Report* (ERM, 1997), based on review of worldwide failure data for chlorine containers and generic pressure vessel failure data
1.2 (i) Probability of dropped container	7.7E-6	per lift	*Methodology Report* (ERM, 1997) based on

Data item	Value	Units	Source
(ii) Conditional probability of catastrophic failure	1.0E-4	-	Hong Kong data for number of lifts which have occurred without incident
2. *Chlorine delivery vehicle*			
2.1(i) Frequency of loadshedding (ii) Conditional probability of a medium leak	1.1E-7 6.3E-2	per truck-km -	*Methodology Report* (ERM, 1997) based on Chlorine Transport Risk Study, DNV (1997)
2.2(i) Frequency of rollover (ii) Conditional probability of a small leak from a single drum (ii) Conditional probability of a medium leak of a single drum (iii) Conditional probability of medium leak of multiple drums	1.9E-7 2.4E-1 1.5E-1 1.1E-2	per truck-km - - -	*Methodology Report* (ERM, 1997) based on Chlorine Transport Risk Study, DNV (1997) (1)
2.3(i) Frequency of vehicle impact (ii) Conditional probability of drum rupture	4.0E-7 1.7E-2	per truck-km -	Chlorine Transport Risk Study, DNV (1997) (1)
2.4 Frequency of spontaneous truck fire	4.0E-9	per truck-km	Chlorine Transport Risk Study, DNV (1997)
3. *External events*			
3.1(i) Frequency of earthquake of 0.7g ground acceleration (ii) Probability of roof collapse in an earthquake of 0.7g ground acceleration	4.0E-7 0.1	per year -	Cook et al. (1993) *Water Treatment Works Seismic Hazard Assessment*, Ove Arup (2001)
3.2(i) Frequency of earthquake of 1.0g ground acceleration (ii) Probability of roof collapse in an earthquake of 1.0g ground acceleration	2.5E-8 0.5	per year -	Cook et al. (1993) *Water Treatment Works Seismic Hazard Assessment,* Ove Arup (2001)
3.3 Frequency of aircraft crash	1.2E-8	per landing	Based on US National Transportation Safety Board aircraft crash date 1982–1998 (*Annex H* of ERM, 2001)

Note 1: The DNV (1997) rollover and impact frequencies were derived from the general truck accident involvement rate on Hong Kong roads. This is a very conservative assumption considering the very low traffic volume and very low chlorine truck speed on the access road. Considering also the low traffic volume and low speed of construction vehicles on site, the

segregation of chlorine delivery route and construction traffic access roads as well as implementation of the relevant good practice measures recommended in this report, it is believed that even with the presence of construction vehicles and machinery on-site, this frequency remains valid for the Construction Phase of the Project and is still conservative.

Table 12.17 Event Frequencies

Event Ref	Component scenarios	Frequency (per year)	Time periods during which event could occur
RU1TSML[1]	Rollover Loadshedding Spontaneous leak *Total*	2.22E-6 5.23E-7 1.74E-7 *2.92E-6*	All except Night All except Night All except Night
RU1TMML[1]	Rollover Truck fire *Total*	1.59E-7 3.04E-7 *4.63E-7*	All except Night All except Night
RU1TSRU[1]	Truck impact Spontaneous drum failure *Total*	5.19E-7 8.44E-8 *6.03E-7*	All except Night All except Night
EU1TMRU	Earthquake	4.0E-8	All
EU1TMRU1G	Earthquake	1.25E-8	All
AU1TMRU	Aircraft crash	1.44E-9	All

Note 1: Frequencies for the access road events are proportional to the number of chlorine trucks per year and are shown here for the operational phase WTW chlorine usage of 761 tonnes (127 trucks) per year, assuming the on-site length of the access route of 0.6 km and the on-site chlorine truck speed of 10 km/h. Frequencies for the construction phase scenario with lower chlorine usage were reduced accordingly.

12.12 Quantitative Risk Assessment

Assessment Methodology

12.12.1 The QRA combines information on the consequences of chlorine releases with information on the likelihood of releases to generate two measures of risk - individual risk and societal risk. Individual risk is the chance of death per year to a specified individual at a specific location. Societal risk is the risk to the population as a whole.

12.12.2 The QRA has been undertaken using a GIS-based software GIS*Risk,* developed for the 8 WTW project. The GIS component of the software enables the complex cloud shapes generated by the wind tunnel to be input directly into the QRA. It also provides a graphical interface by which the population data, chlorine cloud (LD) contours and individual risk contours can be viewed on a base map of the area. GIS*Risk* is an application of standard, well-validated, commercial software, i.e. ESRI's ARCVIEW GIS software, Microsoft Access and Microsoft Excel.

12.12.3 Associated with the GIS software is a database containing all the relevant information relating to the WTW, the defined events, the meteorological data, the population data and the chlorine cloud coordinates. The database contains the routines for the calculation of individual and societal risk.

12.12.4 The main outputs from the software are as follows:

- *Individual risk* in the form of iso-risk contours overlaid on a base map of the area;
- *Societal risk* in the form of an *FN curve*, which is a graphical representation of the cumulative frequency (F) of N or more fatalities plotted against N on a log-log scale; and
- S*ocietal risk* in the form of a *Potential Loss of Life* (PLL) value, which expresses the risk to the population as a whole and for each scenario and its location. The PLL is an integrated measure of societal risk obtained by summing the product of each *f-N* pair, as below:

$$PLL = f_1N_1 + f_2N_2 + \ldots + f_nN_n$$

12.12.5 The individual and societal risk guidelines are described in *Section 12.2*.

Societal Risk Results for STWTW

12.12.6 The FN curves for the construction and operational phase scenarios for STWTW are presented in *Figure 12.12* and *Figure 12.13 to assess the risk levels within STWTW CZ*. *Table 12.18* summarises the maximum *N* numbers derived from these figures. *Table 12.19* and *Table 12.20* present the overall PLL values, together with a breakdown of the PLL by release scenario and affected population. These results are very similar to those presented in the recent SCL QRA study (ERM, 2011a), since only a few population units have changed slightly.

Figure 12.12 FN Curves for STWTW: Construction Phase (PLL for Total Population is 7.4E-5 and PLL for Construction Population is 2.28E-5)

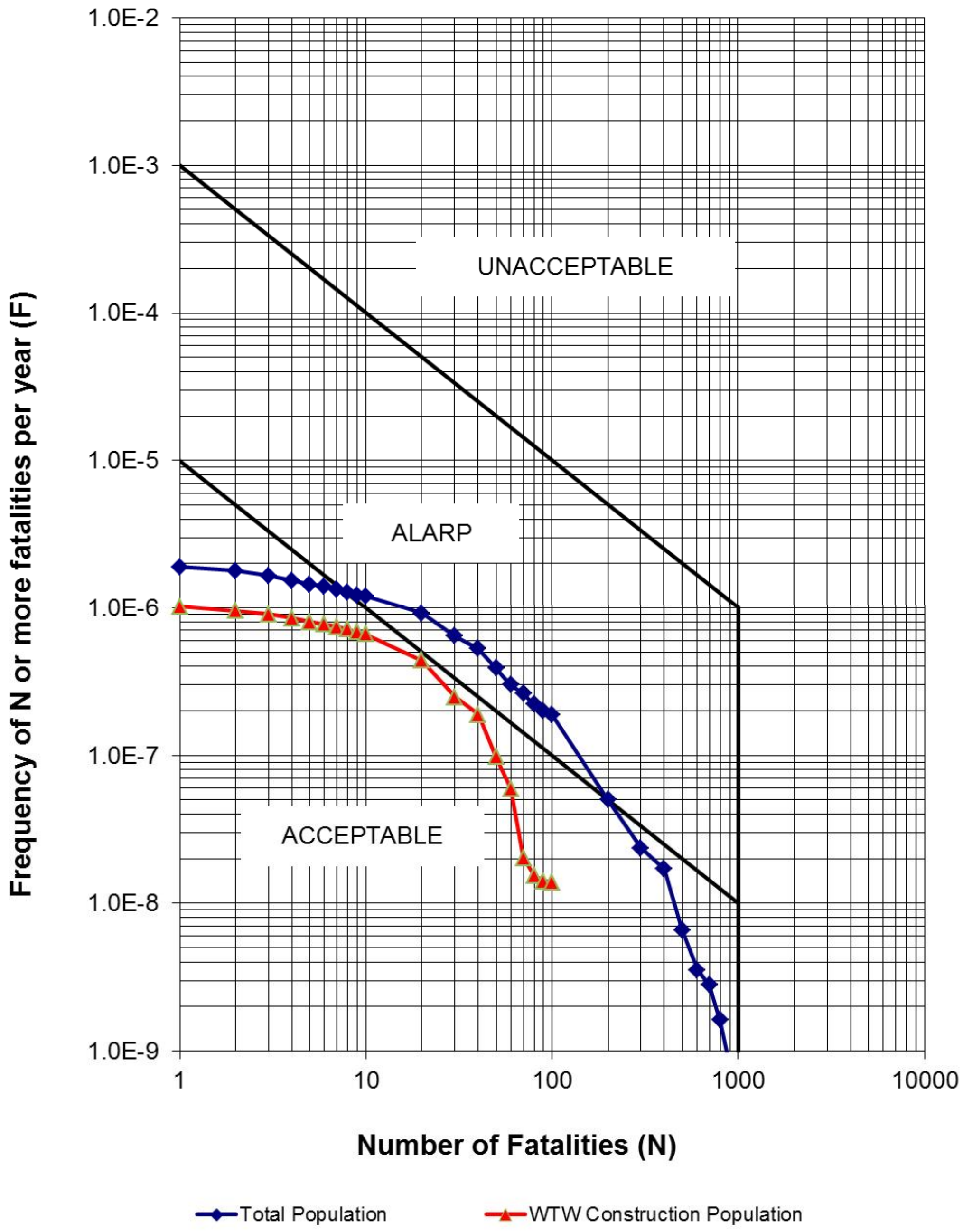
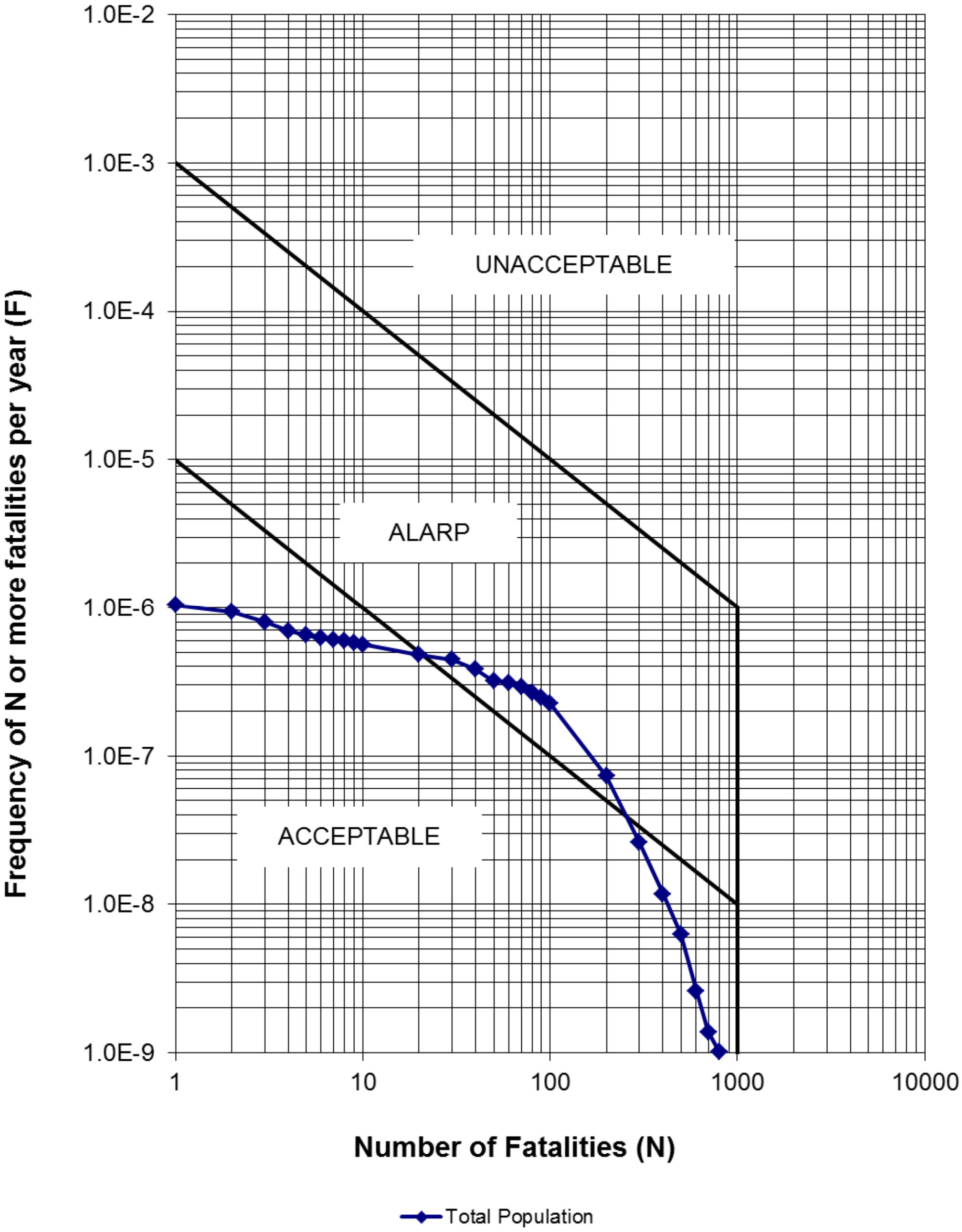


Figure 12.13 FN Curve for STWTW: Operational Phase (PLL for Total Population is 6.0E-5)



Main Risk Contributors

12.12.7 The high number of fatalities shown in *Figure 12.12*, *Figure 12.13* and *Table 12.18* are due to the low frequency/high fatality events such as a multiple drum failure which can result from the Chlorination House roof collapse during a significant (ground acceleration greater than 0.7g) earthquake.

12.12.8 The earthquake frequencies used in this study, 4×10^{-7} (i.e. once in 2.5 million years) and 2.5×10^{-8} for 0.7g and 1g earthquakes, respectively, as well as the probability of a store roof collapse in an earthquake and the numbers of chlorine drums ruptured were derived as part of the *Reassessment of Chlorine Hazard for Eight Existing Water Treatment Works* study commissioned by WSD.

12.12.9 While the earthquake scenarios are dominant for the high *N* values of the FN curve, the chlorine truck accident scenarios that can affect only the populations close to WTW and on their own contribute to about 500 fatalities, have higher frequencies than earthquakes, and contribute about 80% to the total PLL *(Table 12.19).*

Table 12.18 Maximum *N* Value within the FN Chart

Scenario	Max *N* for $F > 1 \times 10^{-9}$
Scenario 1: Construction Phase	880
Scenario 2: Operational Phase	810
2001 QRA (ERM, 2001)	980

Table 12.19 Breakdown of PLL by Release Scenario

Release Scenario	Construction Phase	Operational Phase
RU1TMML	1.8E-5 (24.5%)	2.0E-5 (33.3%)
RU1TSML	2.7E-5 (36.7%)	2.4E-5 (40.2%)
RU1TSRU	1.3E-5 (17.4%)	2.8E-6 (4.7%)
Total: chlorine truck incidents (on-site)	*5.8E-5 (78.6%)*	*4.7E-5 (78.2%)*
AU1TMRU	6.5E-7 (0.9%)	6.5E-7 (1.1%)
EU1TMRU	1.2E-5 (15.9%)	9.9E-6 (16.5%)
EU1TMRU1G	3.4E-6 (4.6%)	2.5E-6 (4.2%)
Total: earthquake and aircraft crash	*1.6E-5 (21.4%)*	*1.3E-5 (21.8%)*
Total (per year)	**7.4E-5 (100%)**	**6.0E-5 (100%)**

12.12.10 The maximum *N* value as shown in *Table 12.18* is a summation of all events causing *N* or more fatalities. Being a summation of multiple events, the contribution of each population group to the total will vary depending on wind direction for example; it is therefore impossible to present a breakdown of max *N* by the different population groups. A more meaningful measure of such contributions is PLL as presented in *Table 12.20.* Nevertheless, while comparing the maximum *N* values for Scenario 1 and Scenario 2 and that for the 2001 QRA, (*Table 12.18*), it may be noted that reduction of chlorine storage results in a reduction of max *N* despite the increase in population.

Table 12.20 Breakdown of PLL by Population

Ref[1]	PLL Scenario 1 Construction Phase	%	PLL Scenario 2 Operational Phase	%
A	8.35E-8	0.1%	8.74E-8	0.1%
A1	4.59E-10	0.0%	6.45E-10	0.0%
B	1.41E-7	0.2%	3.57E-7	0.6%
C	4.21E-8	0.1%	4.80E-8	0.1%
D	0.00E+0	0.0%	0.00E+0	0.0%
E	9.47E-7	1.3%	1.05E-6	1.8%
F	1.91E-8	0.0%	2.31E-8	0.0%
G	6.17E-8	0.1%	6.65E-8	0.1%
H	2.30E-8	0.0%	2.32E-8	0.0%
H1	7.11E-9	0.0%	6.85E-9	0.0%
H2	3.88E-9	0.0%	3.86E-9	0.0%
I	8.44E-7	1.1%	9.82E-7	1.6%
J	2.16E-6	2.9%	2.59E-6	4.3%

Ref[1]	PLL Scenario 1 Construction Phase	%	PLL Scenario 2 Operational Phase	%
K	3.24E-6	4.4%	3.77E-6	6.3%
L	1.55E-8	0.0%	1.59E-8	0.0%
L1	2.67E-8	0.0%	5.46E-9	0.0%
M	2.00E-8	0.0%	2.37E-8	0.0%
N	3.41E-7	0.5%	4.30E-7	0.7%
O	**1.20E-5**	**16.3%**	**1.36E-5**	**22.7%**
P	6.02E-7	0.8%	6.91E-7	1.2%
Q	8.71E-9	0.0%	8.89E-9	0.0%
R1	1.00E-6	1.4%	1.32E-6	2.2%
S1	3.52E-8	0.0%	3.82E-8	0.1%
S2	9.95E-8	0.1%	1.13E-7	0.2%
S3	8.94E-7	1.2%	9.59E-7	1.6%
S3A	7.84E-8	0.1%	8.49E-8	0.1%
T	1.68E-8	0.0%	1.78E-8	0.0%
T1	**8.39E-6**	**11.4%**	0.00E+0	0.0%
T2	**8.64E-6**	**11.7%**	0.00E+0	0.0%
T5	5.75E-6	7.8%	0.00E+0	0.0%
U	2.05E-7	0.3%	2.23E-7	0.4%
V	0.00E+0	0.0%	0.00E+0	0.0%
W	2.35E-7	0.3%	3.00E-7	0.5%
W1	4.11E-8	0.1%	4.83E-8	0.1%
X	8.19E-9	0.0%	1.49E-8	0.0%
Y	7.20E-7	1.0%	7.77E-7	1.3%
Z1	5.64E-6	7.7%	**6.50E-6**	**10.9%**
Z2	9.95E-7	1.4%	1.16E-6	1.9%
Z5	0.00E+0	0.0%	2.42E-8	0.0%
Z6	6.04E-6	8.2%	**1.71E-5**	**28.6%**
Z7	7.47E-6	10.2%	0.00E+0	0.0%
Z8	1.43E-8	0.0%	0.00E+0	0.0%
Z9	3.86E-7	0.5%	0.00E+0	0.0%
Z10	7.15E-7	1.0%	8.23E-7	1.4%
AA1	8.77E-10	0.0%	9.35E-10	0.0%
AA2	2.78E-11	0.0%	8.84E-10	0.0%
AA3	0.00E+0	0.0%	5.02E-11	0.0%
AD	4.08E-9	0.0%	4.25E-9	0.0%
AF	1.29E-9	0.0%	1.34E-9	0.0%
AG	4.40E-9	0.0%	5.17E-9	0.0%
AH	0.00E+0	0.0%	1.64E-11	0.0%
AI	4.12E-9	0.0%	4.12E-9	0.0%
AJ1	1.91E-7	0.3%	2.03E-7	0.3%
AK	8.75E-8	0.1%	8.96E-8	0.1%
AL	2.39E-8	0.0%	2.49E-8	0.0%
AN	3.23E-9	0.0%	3.60E-9	0.0%
AO	4.30E-6	5.8%	4.99E-6	8.3%
AP	3.91E-7	0.5%	4.51E-7	0.8%
others (outside CZ)	6.38E-7	0.9%	7.01E-7	1.2%
Total	7.36E-5	100.0%	5.98E-5	100.0%

Note 1: for description and locations of population units see *Table 12.3* and *Figure 12.8 and Figure 12.9*

Note 2: Highlighted are three top PLL contributors for each scenario

12.12.11 In terms of the Potential Loss of Life *(Table 12.20*), the South Works reprovisioning workers (units T1, T2 and T5) contribute about 31% of the total PLL value for the Construction Phase. This high contribution is due to their proximity to the potential chlorine release locations. The PLL reduces to 5.08×10^{-5} without considering the construction workers, which is less than the total PLL value for Scenario 2 (Operational Phase), which has a higher maximum chlorine storage and usage after the WTW resumes its full throughput after the reprovisioning.

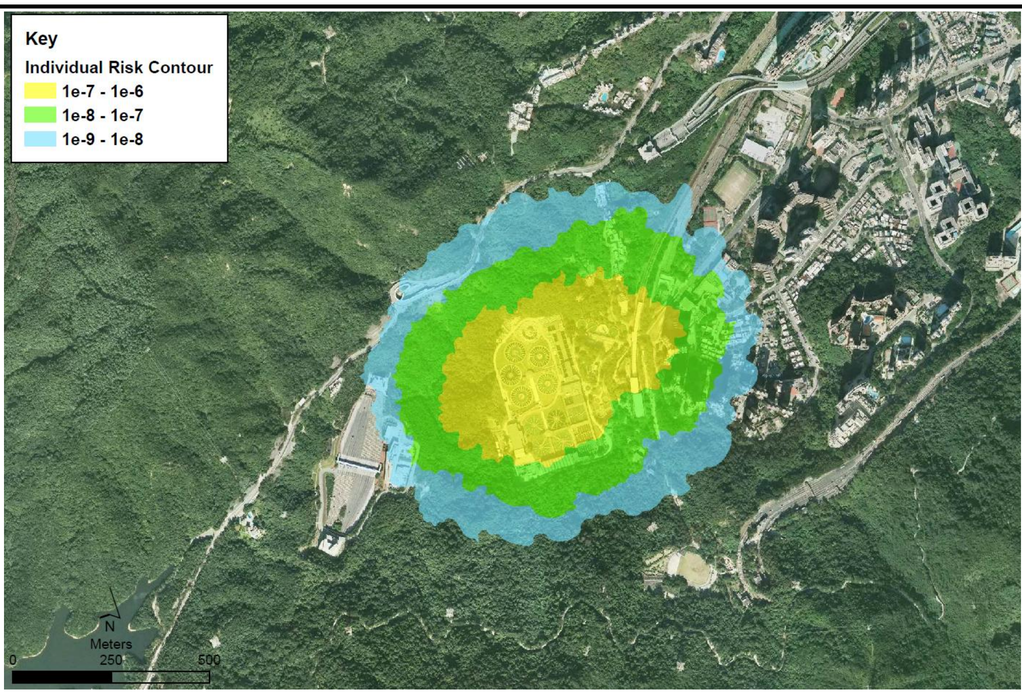
Individual Risk

12.12.12 The individual risk is defined as the probability of a fatality for a hypothetical person spending 100% of their time outdoors in the vicinity of the Sha Tin WTW. As noted in *Section 12.2*, HK Risk Guidelines stipulate that the maximum level of off-site risk should not exceed 1 in 100000 per year, i.e. 1×10^{-5} per year.

12.12.13 Individual risk is independent of the assumed population levels and depends only on the operating parameters of the WTW. Therefore, the estimates of the maximum off-site individual risk levels obtained for the purposes of SCL QRA (ERM, 2011a) remain valid for the present assessment.

12.12.14 Following ERM (2011a), *Figure 12.14* presents the individual risks obtained for the worst case scenario assuming the maximum chlorine storage of 190 tonnes. Risks for actual construction and operational phase scenarios will be slightly lower due to the lower average chlorine storage and usage levels. As can be seen, even for the worst-case scenario the risks are low, and nowhere outside the WTW site boundary does the individual risk exceed 10^{-6} per year. It is therefore concluded that Sha Tin WTW complies with the individual risk criteria.

Figure 12.14 Individual Risk Contours



Result Summary

12.12.15 The societal risk results are found to be very similar to those obtained in the recent SCL QRA study (ERM, 2011a) and lie within the "ALARP" region of the HKRG.

12.12.16 Individual risk levels are in compliance with HKRG.

12.12.17 In terms of the Potential Loss of Life *(Table 12.20*), the South Works reprovisioning workers contribute about 31%, of the total PLL value for the Construction Phase (Scenario 1). Without the presence of the reprovisioning workers on-site, societal risks expressed in terms of PLL for the Construction Phase (Scenario 1) are lower than for the future Operational Phase (Scenario 2). This is due to the increase in chlorine usage once the Sha Tin WTW returns to full capacity after the reprovisioning work is complete.

12.12.18 Nevertheless, it should be stressed that the South Works reprovisioning is an improvement project. The use of new treatment technologies will lead to a permanent reduction in chlorine storage (from 221 tonnes to maximum of 190 tonnes) and usage when compared to today's levels.

12.13 Risk Mitigation

Recommendations from Previous Studies

12.13.1 Since the societal risk levels for both scenarios considered lie in the ALARP zone of the HKRG, mitigation measures are required to reduce the risks to levels As Low As Reasonably Practicable. This section discusses potential mitigation measures and assesses their practicability.

12.13.2 A number of mitigation measures have been considered and assessed in the original QRA for Sha Tin WTW (ERM, 2001). According to the information provided by WSD, those of the 2001 measures considered practicable have been already implemented at the WTW.

12.13.3 A comprehensive set of possible mitigation measures, related to the WTW operations was also considered under the recent SCL QRA (ERM, 2011a) however none of these measures passed the cost-benefit analysis test. That ALARP analysis remains valid for the present QRA as well.

12.13.4 Another measure that would reduce the risks related to the chlorine storage as well as on-site and off-site transport would be the on-site generation of chlorine by electrolysis of brine solution and on-site hypochlorite generation. Such a measure was suggested for consideration in the CCPHI-approved QRA for the expansion of Tai Po WTW. However, according to information provided by WSD, on-site generation of chlorine is not adopted worldwide for drinking water treatment. For on-site generation of hypochlorite, WSD has recently reviewed the latest developments of such technology. After considering the merits and demerits of the technology, worldwide practice, operation and maintenance details, capital and operating costs, regulations on the Disinfection Byproducts (DBPs) and the suitability of its use in Hong Kong, it has been concluded that among the options of chlorine base disinfectants used for potable water treatment, liquid chlorine is still the most suitable and cost-effective disinfectant for water treatment use in Hong Kong situation. WSD has no plan to change the present practice of using liquid chlorine as a disinfectant for the present moment. Nevertheless, WSD will continue to keep under review the latest developments of use of alternative disinfectants in the water supply industry.

Protection of the Reprovisioning Workers

12.13.5 ERM (2011a) conducted a detailed analysis of possible measures for protection of the SCL construction workers and concluded that the only potentially practicable mitigation option was the installation of chlorine gas monitors in the relevant work areas. The same mitigation option is appropriate for WTW reprovisioning workers. Gas detectors and audible alarms should be provided around on-site work areas and these should be connected with emergency response and evacuation plans with adequate training and drills. The emergency response plan also applies to WSD STWTW operation workers and surrounding population during both Construction and Operational Phases in case there is chlorine leak in STWTW.

12.13.6 A number of measures, relating to protection of construction workers on-site were also recommended in the EIA for *Integration of Siu Ho Wan and Silver Mine Bay Water Treatment Works* (B&V, 2010). Most of these measures that are relevant to this project (such as installation of audible chlorine release alarm in the chlorine store area, imposing of speed limits for the chlorine truck etc. have already been implemented at Sha Tin WTW. Nevertheless a number of measures proposed in (B&V, 2010) has been considered in this study and recommended as good practice measures (see *Table 12.22).*

Cost-Benefit Analysis

12.13.7 Cost-benefit analysis compares the Implied Cost of Averting a Fatality (ICAF) with "the adjusted value of life" which, following ERM (2001, 2011a) is assumed at HK$ 660M. ICAF is defined as:

ICAF = Cost of mitigation measure / (Reduction in PLL value × Design life of mitigation measure)

12.13.8 ICAF for provision of gas detectors and emergency drills is estimated considering that they can enhance the escape probability of workers and effectively provide a 50%[1] PLL reduction for the reprovisioning workers (i.e. 50% reduction of the 2.28×10^{-5} total for the rows T1, T2 and T5 in *Table 12.20*) over a three years period and that their cost will amount to about HK$ 1M. Thus:

$$ICAF = 1M/(1.14 \times 10^{-5} \times 3) = 2.93 \times 10^{4}M$$

As can be seen, the above ICAF is well above the practicability criterion of 660M. Nevertheless, installation of chlorine gas monitors with audible alarms in the relevant reprovisioning works areas, establishing emergency response and evacuation plans and adequate training and drills are recommended for implementation.

12.13.9 ERM (2011a) considered two measures to mitigate the risks related to a massive chlorine release due to the chlorine store roof collapse during an earthquake. These included the reduction of chlorine storage at the WTW and the enhancement of the seismic performance of the chlorine store. Both these measures were deemed not practicable based on the cost-benefit analysis. Since for the operational phase scenario the PLL values due to the earthquake and aircraft crash (see *Table 12.19*) are close to those obtained in the previous study, the conclusion of ERM (2011a) remains valid. However, due to the presence of construction workers, the cost-benefit analysis needs to be repeated for the construction phase scenario. Details are provided in *Table 12.21.*

Table 12.21 Calculation of ICAF for Candidate Mitigation Measures (Construction Phase Scenario)

Mitigation measure	Cost Estimate (HK$M)	PLL reduction (per year)	Design life (years)	ICAF (HK$M)	Practicable? (ICAF< $660M ?)	Notes
Chlorine gas monitors with audible alarms in reprovisioning works areas, emergency response and evacuation plans	1	1.14×10^{-5}	3	2.93×10^{4}	N	Recommended as a matter of good practice
Reduction of chlorine storage at WTW	10	7.55×10^{-6}	3	4.42×10^{5}	N	Further reduction of storage may not be possible for logistical reasons or would involve significant capital and operational costs (building alternative storage elsewhere), that for the purpose of this analysis are estimated at HK$ 10M. ICAF is estimated based on the 50% reduction in PLL due to the store roof collapse. ERM (2011a) estimated ICAF for the

[1] This value is consistent with those used in the QRA for the SCL Project. See Appendix 13C of ERM (2011a) for details.

Mitigation measure	Cost Estimate (HK$M)	PLL reduction (per year)	Design life (years)	ICAF (HK$M)	Practicable? (ICAF< $660M ?)	Notes
						Operational Phase at HK$ 33,333 M
Enhancement of seismic performance of chlorine store	5	1.51×10^{-5}	3	1.10×10^{5}	N	This measure would eliminate (or significantly reduce) the seismic risk. However it would involve major civil works, hence the estimated cost is HK$ 5M. ICAF is estimated based on the 100% reduction in PLL due to the store roof collapse. ERM (2011a) estimated ICAF for the Operational Phase at HK$ 8,333 M

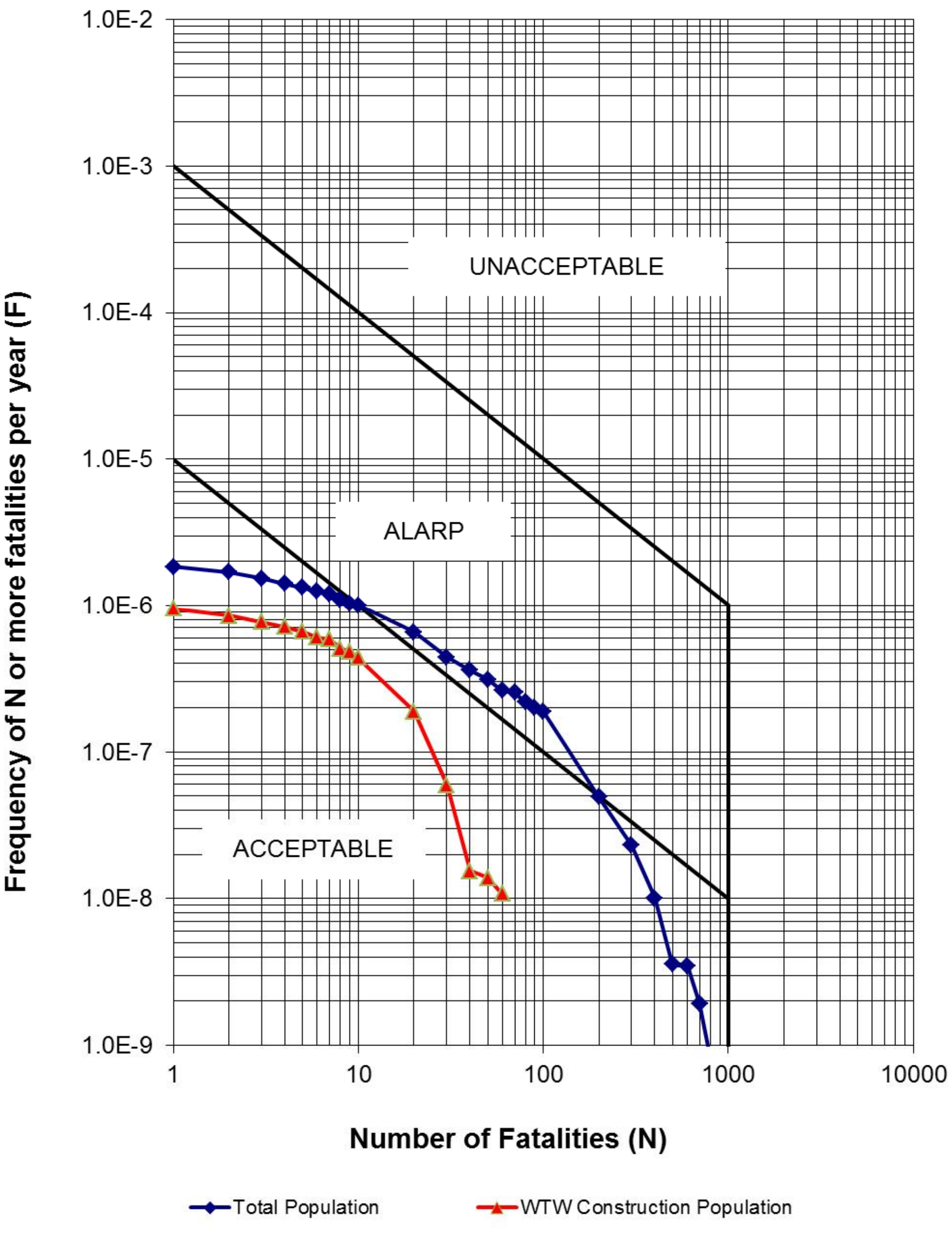
12.13.10 Therefore, based on the cost-benefit analysis, apart from the provision of chlorine gas monitors with audible alarms in reprovisioning works areas and establishing emergency response and evacuation plans, no additional risk mitigation measures during the Construction and Operational Phases of this project are considered practicable.

Mitigated Case: Societal Risk Results

12.13.11 Based on estimation in SCL project, implementation of the chlorine gas monitors with audible alarms in the relevant works areas, establishing emergency response, and evacuation plans and adequate training and drills will result in a 50% decrease in the PLL for the reprovisioning workers, the total PLL for the Construction Phase would be reduced to 6.2×10^{-5} per year.

12.13.12 The FN curve obtained under the assumption that risks to the construction workers are reduced by 50% is shown in *Figure 12.15.*

Figure 12.15 FN Curve for the Mitigated Case of Construction Phase Scenario (PLL for Total Population is 6.2E-5 and PLL for Construction Population is 1.14E-5)



Good Practice Measures

12.13.13 In addition to the above specific mitigation measures, general good practice measures should also be adopted. Chlorine risks related to the construction activities were subject of the HAZID workshop described in *Section 12.9*. The workshop concluded with 22 detailed good practice measures concerning the organisation of the works and workers protection as listed in *Table 12.22*.

12.13.14 In addition to the measures proposed at the HAZID workshop, it is also recommended that an accompanying vehicle is provided for the chlorine truck on the WTW site and that during the chlorine drums delivery construction works are stopped and the construction workers moved away from the Chlorination House.

12.13.15 A liaison between the contractor and HKCG should be established with an emergency response plan to ensure gas safety at the neighbouring Beacon Hill North Offtake Station and adjacent gas pipelines during the reprovisioning works.

12.13.16 In order to avoid potential crane impact on the chlorine truck, chlorine delivery will be temporarily suspended during the short period of construction of the concerned section of elevated walkway and hence mobile crane impact on the chlorine truck can be avoided.

12.13.17 The construction team and chlorine delivery team will be instructed to immediately suspend operation in case of concurrent operation and this clause will be added to the respective contractor's contract.

12.13.18 Most of the above good practice measures are similar or equivalent to those proposed in the approved EIA for the *Integration of Siu Ho Wan and Silver Mine Bay Water Treatment Works* (B&V, 2010). However, a number of additional measures identified in B&V (2010) that are considered relevant to this Project but had not been considered at the HAZID workshop are proposed. They are listed in the bottom rows of *Table 12.22*. As indicated in *Section 12.9,* this study assumes that all these recommendations, including establishing adequate emergency response and communication procedures, staff training etc will be implemented during the construction stage of the Project.

Table 12.22 Summary of Good Practice Measures to Protect Reprovisioning Workers

Category	Recommendation Reference	Proposed Measure	Parties Responsible
Construction Management	HAZID Recommendation #1	Ensure speed limit enforcement is specified in the contractor's Method Statement to limit the speed of construction vehicles on site	Engineer/WSD
Construction Management	HAZID Recommendation #2	Develop an audit procedure to ensure enforcement of speed limits and to ensure adequate site access control	Engineer/WSD
Construction Management	HAZID Recommendation #3	Ensure construction Method Statement is endorsed by the Engineer (AECOM) and WSD	Engineer/WSD
Construction Management	HAZID Recommendation #4	Ensure designated manoeuvring area for the new access road construction is away from the Chlorination House	WSD/Engineer/Contractor
Personnel Management & Training	HAZID Recommendation #5	Provide training for both chlorine delivery vehicle drivers and construction vehicles drivers to ensure the right access route is used at any stage during the reprovisioning activities	WSD/Engineer/Contractor
Personnel Management & Training	HAZID Recommendation #6	Ensure that the emergency response plan and procedures (including drills) cover the reprovisioning activities	WSD/Engineer/Contractor
Personnel Management & Training	HAZID Recommendation #7	Safety training to be provided to construction workers and WSD/Engineer staff regarding evacuation procedures	WSD/Engineer/Contractor
Construction Management	HAZID Recommendation #8	Ensure communication protocol is in place between construction and operation staff with regard to the change of chlorine delivery route and the switchover from the existing to new chlorinated water piping.	WSD/Engineer/Contractor
Construction Management	HAZID Recommendation #9	Ensure temporary suspension of crane operation and construction truck movements during chlorine delivery	WSD/Engineer/Contractor
Construction Management	HAZID Recommendation #10	Provide a crash barrier between the construction site and the north side of the Chlorination House	Engineer/WSD
Monitoring	HAZID Recommendation #11	Conduct vibration monitoring at the Chlorination House during piling activities to ensure vibration levels are acceptable and will not lead to any damage of the Chlorination House	WSD/Engineer/Contractor

Category	Recommendation Reference	Proposed Measure	Parties Responsible
Construction Management	HAZID Recommendation #12	Dedicated person to supervise the crossover between the construction access and operational access routes	WSD/Engineer/Contractor
Investigation	HAZID Recommendation #13	Civil engineering calculation to be performed to confirm differential settlement from excavation work is within acceptable limits for the Chlorination House	Engineer/WSD
Monitoring	HAZID Recommendation #14	Provide settlement monitoring for the Chlorination House to ensure no subsidence occurs from nearby excavation works	WSD/Engineer/Contractor
Monitoring	HAZID Recommendation #15	Confirm the chlorine concentration for the chlorinated water before the switchover from the existing to new piping. This is to avoid the potential for chlorine gas vapours being released if the concentration is too high and there is spillage during switchover.	WSD
Construction Management	HAZID Recommendation #16	Develop an operating procedure for performing the chlorinated water switchover from the existing piping to new piping	WSD/Engineer/Contractor
Construction Management	HAZID Recommendation #17	Ensure the location/height of the tower crane is such there is no impact on Chlorination House/chlorine delivery route in case of falling, swinging or dropped load	WSD/Engineer/Contractor
Construction Management	HAZID Recommendation #18	Ensure the location/height of the lifting equipment is such there is no impact on Chlorination House/chlorine delivery route in case of falling, swinging or dropped load	WSD/Engineer/Contractor
Construction Management	HAZID Recommendation #19	Implement the controlled demolition of the existing E&M workshop to ensure that any steel structural elements can only fall away from the Chlorination House	WSD/Engineer/Contractor
Investigation	HAZID Recommendation #20	Confirm whether slope/boulder stabilisation is required along the chlorine delivery route	Engineer/WSD
Monitoring	HAZID Recommendation #21	Conduct vibration monitoring at the slopes with potential for slope/boulder disturbance located close to chlorine delivery route	WSD/Engineer/Contractor
Construction Management	HAZID Recommendation #22	Stop any construction activities which may lead to vibrations and potential slope/boulder disturbance during the chlorine deliveries	WSD/Engineer/Contractor
Monitoring	S 12.13.5	Installation of chlorine gas monitors with audible alarms in the relevant reprovisioning work areas	WSD/Engineer/Contractor
Construction Management	S 12.13.14	Provision of an accompanying vehicle for the chlorine truck on the WTW site and ensuring that during the chlorine drums delivery construction works are stopped and the construction workers moved away from Chlorination House	WSD/Engineer/Contractor
Construction Management	S 12.13.15	Establish a liaison between the contractor and HKCG and develop a chlorine/town gas emergency plan to ensure gas safety during the Construction Phase.	WSD/Engineer/Contractor/HKCG
Construction Management	S 12.13.16	Temporarily suspend chlorine delivery during the short period of construction of the concerned section of elevated walkway to avoid mobile crane impact on the chlorine truck.	WSD/Engineer/Contractor

Category	Recommendation Reference	Proposed Measure	Parties Responsible
Construction Management	S 12.13.17	Instruct the construction team and chlorine delivery team to suspend operation in case of concurrent operation and this clause will be added to the respective contractor's contract.	WSD/Engineer/Contractor
Construction Management	B&V (2010)	Provide clear road signs for site vehicles	WSD/Engineer/Contractor
Construction Management	B&V (2010)	Large equipment/plant movement should be controlled by "Permit-to-move" system	WSD/Engineer/Contractor
Construction Management	B&V (2010)	Define restricted zone for the equipment (i.e. keep the equipment from the Chlorination Building at a safe distance). The extent of the restricted zone would be determined by the size of the equipment	WSD/Engineer/Contractor
Construction Management	B&V (2010)	Locate the construction site office at or near property boundary away from the chlorine store as far as possible	WSD/Engineer/Contractor
Construction Management	B&V (2010)	The number of workers on-site should be kept to the minimum required to maintain the construction programme. Entry of non-authorised personnel to the construction site to be prohibited.	WSD/Engineer/Contractor

12.14 Risk Conclusions

12.14.1 A Hazard Assessment of the risks associated with the on-site storage and handling of chlorine at Sha Tin Water Treatment Works has been conducted for the Construction and Operational Phases of the Project.

12.14.2 The assessment methodology and assumptions were based on the previous assessments for Sha Tin WTW (ERM 2001, 2011a), however the information on reprovisioning workers locations and numbers was more detailed than that used in ERM (2011a). Minor updates to a few other population units were also made based on latest information. These changes, however, are not significant.

12.14.3 For both Construction and Operational Phases, the Individual Risk complies with the Hong Kong Risk Guidelines.

12.14.4 The societal risk expressed in the form of FN curves, lies in the "ALARP" region of the HKRG.

12.14.5 For the Construction Phase, good practice measures were considered during a HAZID workshop and 22 recommendations were made. Several additional good practice measures are proposed following B&V (2010). It is also recommended that an accompanying vehicle is provided on-site for the chlorine truck and the construction activities are temporarily stopped during chlorine deliveries and that gas monitors with audible alarms are installed in the relevant reprovisioning work areas. Implementation of these measures would reduce the societal risks for the Construction Phase of the Project.

12.14.6 No specific mitigation measures are recommended for the Operational Phase. These were subject of detailed analysis under the SCL QRA (ERM, 2011a), but no risk mitigation measures related to the WTW operation were found to be practicable.

12.14.7 The Sha Tin WTW Reprovisioning Project is an improvement project. Due to the introduction of the new treatment technologies, the reprovisioning works will lead to a permanent reduction in chlorine storage (from 221 tonnes to maximum of 190 tonnes) and usage at the WTW. As a result, the residual impacts from chlorine-related risks for the surrounding population will be reduced in comparison with current levels.

QRA for Off-site Transport of Chlorine

12.15 Introduction

12.15.1 Earlier sections of the report addressed risks associated with on-site use, storage and transport of chlorine. This chapter of the report addresses risks associated with the off-site chlorine transport within the Sha Tin WTW Consultation Zone (CZ).

12.15.2 The objective of the study is to evaluate risks to the general public located near or next to the designated chlorine transport route for the purpose of evaluating the total chlorine risk and cumulative risks within the 1-km CZ. It should be noted that this study only covers the road transport risk within Sha Tin WTW CZ which is in line with the on-site risk assessment. The road transport risk from Sham Shui Kok Dock to the Sha Tin WTW entrance gate was assessed as a reference and the details are provided in *Appendix 12.11*. In addition, this study does not include the upstream transport risk from the Mainland to the chlorine dock nor the risks associated with the loading/unloading operations at the dock.

12.15.3 The indoor, outdoor and transient populations potentially exposed to the chlorine hazards are considered for both the Construction Phase and Operational Phase described in *Table 12.1*. Since transport risks are directly proportional to quantity of chlorine transported, the most relevant data from *Table 12.1* are the annual usage quantities of 642 and 761 tonnes/year for Construction and Operational Phases respectively. This quantity of chlorine must be delivered by trucks to the Sha Tin WTW, requiring 107 trucks per year during Construction Phase, and 127 trucks per year during Operational Phase.

12.15.4 A number of standard provisions will be implemented before the commencement of the Project. These include a GPS fleet management system with driver training to help enforce truck speeds, use of existing clamps with independent checks to prevent load shedding and installation of fire screen and larger fire extinguishers to prevent engine and wheel fires from spreading to the cargo area. As these will be implemented before the onset of the Project, credit is taken for these in the analysis. Also, the analysis is based on the shortest transport route with lowest population density as described in *Section 12.18*.

12.16 Previous Hazard Assessments for Chlorine Transport in Hong Kong

1989 and 1997 DNV Technica Studies

12.16.1 The first comprehensive assessment of the risks associated with the chlorine transport to different Water Treatment Works in Hong Kong was conducted in 1989 (Technica, 1989) on behalf of the Water Supplies Department.

12.16.2 In 1997 DNV Technica conducted another chlorine transport study using a modified methodology and updated data relating to population, transport routes and WTW chlorine usage levels (DNV, 1997). Some of the findings and/or assumptions of the study, e.g. on the frequencies of transport-related chlorine releases were subsequently used for the on-site chlorine transport hazard assessments of ERM's Eight WTWs Study and the later studies based on the same methodology (e.g. ERM 1997, 2001, 2011a).

2006 Atkins Study

12.16.3 The most recent comprehensive risk assessment for the chlorine transport in Hong Kong was conducted for the Water Supplies Department by Atkins (2006). The QRA introduced a number of modifications to the methodology of the previous transport studies and assessed the risks for the years of 2006 and 2016 considering a number of alternative road transport routes, starting at different DG pier locations. It is of note that the Atkins study for the first time included an assessment of chlorine road transport from the Sham Shui Kok pier in North Lantau. This is the pier that will be used by WSD for deliveries to Sha Tin WTW following commencement of the STWTW Reprovisioning Project. Sham Shui Kok pier is used as the starting point of road transport in the current assessment.

12.16.4 Similar to the DNV study, since the purpose was to address risks associated with relocation of the Kowloon bay Dock, Atkins presents only the overall FN curves without any breakdown by transport route to the individual WTWs. However, a breakdown of PLL values is provided, and the Sha Tin WTW is the greatest contributor. This is as expected, since Sha Tin WTW has the largest consumption of chlorine and so the tonne-km of chlorine transport is the highest.

12.16.5 The Atkins (2006) methodology is followed in this study with only a few modifications, as described in the following sections.

12.17 Methodology Overview

12.17.1 The QRA combines information on the consequences of chlorine releases with information on the likelihood of releases to determine the risk.

12.17.2 The assessment involves the following procedures:

- Hazard Identification;
- Data collection;
- Consequence analysis and modelling;
- Frequency analysis;
- Risk integration; and
- Risk mitigation.

12.17.3 The QRA methodology is consistent with previous studies having similar issues and in particular previous studies on chlorine transport in Hong Kong, i.e. DNV (1997) and Atkins (2006).

12.17.4 A transport risk QRA model has been developed to enable assessment of the risks associated with a specific transport route. The detailed analysis of each route section is achieved by overlaying consequence contours from releases modelled along the transport route with population local to each release point. The steps involved in the calculation are summarised below:

- The frequency of each potential release scenario is estimated combining the various probabilities associated with wind direction and the base release frequency;
- The consequences of each release scenario are modelled using the ALOHA model to obtain a fatality footprint. Three contours corresponding to fatality probabilities of 0.9, 0.5 and 0.03 are obtained;
- The hazard footprints are overlaid on a database of population polygons to determine the number of fatalities for each release scenario;
- Combining the number of fatalities with the frequency for all release locations enables the risk for the entire route length to be determined.

12.17.5 Associated with the program is a database containing all the relevant information relating to meteorological data, population data, the likelihood of releases, and the chlorine cloud dimensions. The database contains the routines for the calculation of societal risk.

12.18 Chlorine Transport Route

12.18.1 Chlorine is delivered to Sha Tin WTW in batches of up to 6×1-tonne drums. The transport route from Sham Shui Kok dock on North Lantau is shown in *Figure 12.16*. The route passes along the North Lantau Expressway, around the northern edge of Tsing Yi, through Tsuen Wan and along Tai Po Road (Piper's Hill) to Sha Tin (*Table 12.23).*

12.18.2 The transport route was divided into segments according to similar attributes, such as road type and traffic density. A detailed description is provided in *Table 12.24*. As shown in *Table 12.24* and *Figure 12.17* based on their surroundings, particular route segments are characterised as either 'open' or 'urban'. This has implications in the consequence modelling, as discussed in *Section 12.21*. Essentially, heavily built up areas are assumed to have lower near surface wind speeds and dispersion along streets will be more likely due to channelling effects of the buildings. Areas of Tsing Yi, Tsuen Wan, Kowloon and Sha Tin are designated as 'urban' due to high density of buildings near the transport route. Other sections of the route are designated as 'open'.

12.18.3 Some roads are indicated as 'Urban/Open' as they have some sections with each characteristic. These roads were subdivided into smaller sections for modelling, some specified as 'open', some as 'urban'.

Figure 12.16 Chlorine Transport Route to Sha Tin Water Treatment Works

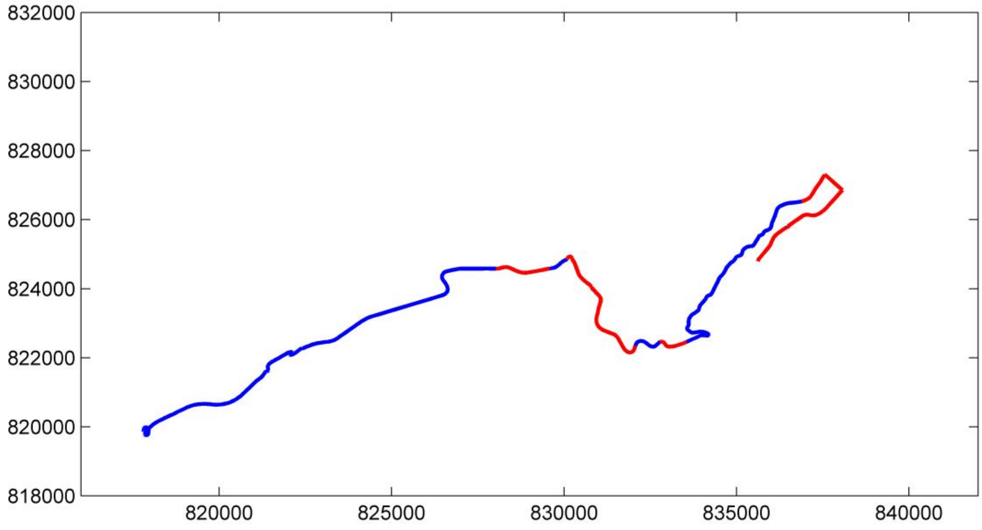
Table 12.23 Chlorine Truck Transport Route

Destination	Route
From SSK Dock to Sha Tin WTW	Sham Shui Kok Dock > Cheung Tung Road > Sunny Bay Road > N Lantau Highway > Lantau Link > NW Tsing Yi Interchange > Tsing Yi North Costal road > Tsing Tsuen Road > Tsuen Wan Road > Kwai Chung Road > Ching Cheung Road > Tai Po Road > Tai Po Road (Piper's Hill) > Tai Po Road (Sha Tin Heights) > Tai Po Road > Tsing Sha Highway (Sha Tin) > Tai Po Rd (Sha Tin) > Sha Tin Rural Committee Rd > Tai Chung Kiu Rd > Che Kung Miu Road > Sha Tin WTW

Table 12.24 Details of Route Sections

Section Name	Length (km)	Characteristic
Sham Shui Kok Dock	0.51	Open
Cheung Tung Road	4.41	Open
Sunny Bay Road	1.35	Open
N Lantau Highway	0.72	Open
Lantau Link	4.13	Open
NW Tsing Yi Interchange	0.34	Open
Tsing Yi North Costal road	2.43	Urban/Open
Tsing Tsuen Road	1.50	Urban
Tsuen Wan Road	1.57	Urban
Kwai Chung Road	2.25	Open
Ching Cheung Road	2.20	Urban/Open
Tai Po Road	0.91	Open
Tai Po Road (Road-Piper's Hill)	1.18	Open
Tai Po Road (Sha Tin Heights)	3.07	Open
Tsing Sha Highway (Sha Tin)	1.00	Urban
Tai Po Road (Sha Tin)	1.03	Urban
Sha Tin Rural Committee Road	0.67	Urban
Tai Chung Kiu Road	1.70	Urban
Che Kung Miu Road	1.70	Urban/Open
Total Route Length	**32.67**	

Figure 12.17 Open (blue) and Urban (red) Sections of the Delivery Route



Axes are coordinates in metres in Hong Kong's 1980 grid system

12.19 Hazard Identification

12.19.1 The hazardous properties of chlorine were discussed in *Section 12.9*. This is also applicable to hazards associated with off-site transport.

12.19.2 Extensive reviews of the past chlorine incidents were conducted in previous studies (Technica, 1989, DNV, 1997, ERM, 1997). In general, only a small number of such incidents involved chlorine releases from drums or cylinders during their road transport. For example, ERM (1997) attributes 14% of the 86 chlorine incidents recorded worldwide over 77 years to the road transport, but about half of these occurred during the loading/unloading operations rather than the transport itself.

12.19.3 The most recent review of past incidents for the period 1995–2004 worldwide was conducted by Atkins (2006). While it was noted that one major incident (involving a 35-tonne road tanker rather than chlorine drums) occurred during that time, the report concluded that no changes in the study methodology, and in particular in the incident frequencies derived from the generic worldwide data was necessary.

12.20 Release Scenarios

12.20.1 Hazard release scenarios for chlorine transport were identified in terms of release inventory, hole size, and phase of release.

12.20.2 *Table 12.25* lists the representative release cases considered in this study, which are based on DNV (1997) and Atkins (2006). The associated release rates are also shown in the table.

Table 12.25 Representative Release Cases Considered

Release type	Event Code	Hole Size	Release Rate (kg/s)
Small leak	SLD	2.5 mm	0.1
Medium leak	MLD	7.5 mm	1
Large leak	LLD	22.5 mm	10
Rupture	RD		instantaneous 1 t
Medium leaks from 3 drums	RDM1	3×7.5mm	3
Medium leaks from 6 drums	RDM2	6×7.5mm	6

12.20.3 The data presented in *Table 12.25* are consistent with Atkins (2006) except for the following three minor differences:

- All chlorine releases from drums is considered to be in the liquid phase, which is an approach consistent with the SCL QRA (ERM, 2011a). This is slightly conservative over the Atkins (2006) approach which distributed failures between vapour and liquid releases;
- For small leaks, two separate cases SLDF and SLDS are considered in Atkins (2006) depending on whether the emergency services succeeded or failed to stop the leak quickly. In the current study, these two events are combined in the one SLD event, conservatively assuming a failure in stopping the leak; and
- For the RDM2 scenario, the current study assumes only new type drums will be used, whereby each drum has only one fusible plug. If all six drums leak in a fire, the total leak rate then becomes 6kg/s. Atkins (2006) assumed older type drums which have 3 fusible plugs on each drum.

12.21 Consequence Analysis

12.21.1 The assessment of the consequences of a chlorine release involves three steps:

- Modelling the initial discharge rate of chlorine;
- Modelling the dispersion of chlorine in the atmosphere; and
- Assessing the toxic impact to people (whether indoors or outdoors).

Initial Discharge Rate

12.21.2 The release rates or 'source terms' are not modelled in this study but extracted from Atkins (2006), which in turn are based on DNV (1997). These are summarised in *Table 12.25*;

Dispersion of Chlorine in the Atmosphere

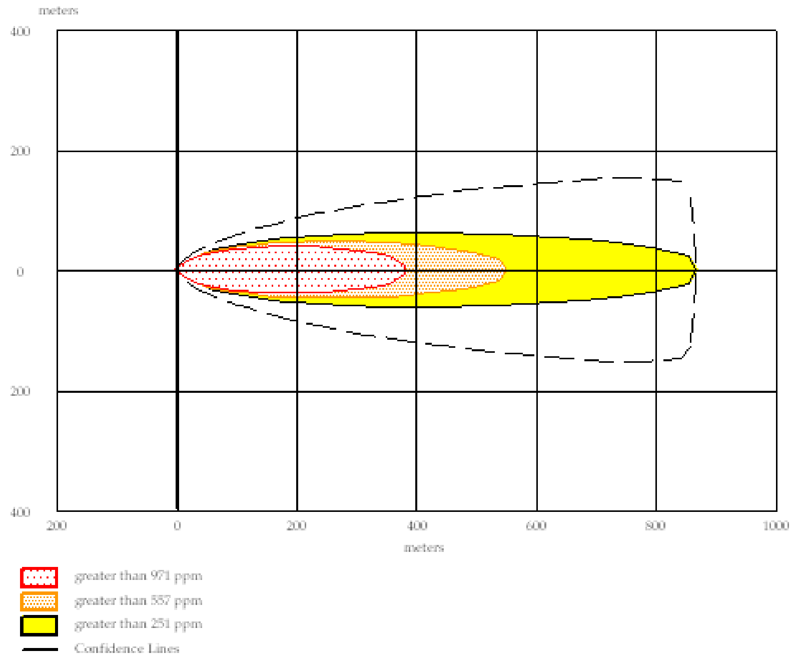
12.21.3 Following Atkins (2006), the US EPA ALOHA model[1] is used for dispersion modelling. A distinction is made between 'open' and 'urban' sections of the transport route due to the effect high rise buildings will have on the dispersion behaviour. Specifically, high rise buildings in urban areas will:

- Increase the surface roughness;
- Create more drag and lower the near surface wind speeds; and
- Create a channelling effect whereby winds along the road are more likely than cross road directions. This is considered in further detail in *Section 12.22*.

12.21.4 To differentiate between urban and open areas, ALOHA modelling was performed twice for each release scenario. Open areas were modelled for the weather class 5D (wind speed of 5 m/s and atmospheric stability class D), while urban areas were modelled with a lower wind speed of 2 m/s (weather class 2D). ALOHA default surface roughnesses for open and urban areas were used. This approach is consistent with Atkins (2006).

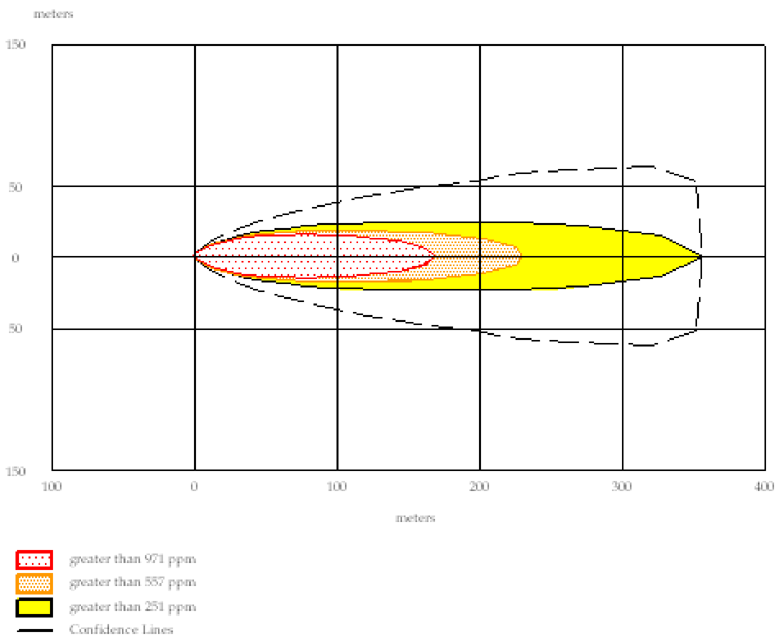
12.21.5 Examples of ALOHA-derived consequence contours for wind speed of 5 m/s in the open areas are shown in *Figure 12.18* and *Figure 12.19*.

Figure 12.18 ALOHA Consequence Contours, RD Case



1 http://www.epa.gov/osweroe1/docs/cameo/ALOHAManual.pdf

Figure 12.19 ALOHA Consequence Contours, RDM1 Case



12.21.6 The current assessment applies 12 wind directions in line with Atkins (2006). There is a difference in spatial resolution however. Atkins (2006) modelled a release every kilometre along the route. This is considered inadequate in the current study due to a higher resolution of population data. Instead, releases are modelled at 796 release points along the delivery route, which amounts to a release every 40 m on average.

12.21.7 Similar to a number of other QRA studies (e.g. ERM, 2009), for the purposes of the risk model used in this study, ALOHA-derived consequence contours are expressed in terms an ellipse using the following four parameters as illustrated in *Figure 12.20*:

- *d*: maximum downwind distance;
- *c*: maximum half-width;
- *s*: offset distance between source and effect zone; and
- *m*: downwind distance at which the maximum width, *c*, occurs.

12.21.8 All consequence data used in this QRA are summarised in *Table 12.26*. The fatality probabilities adopted are discussed in the following sections.

Figure 12.20 Presentation of Consequence Results

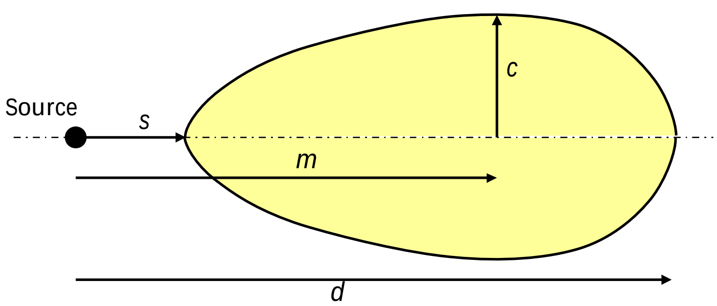


Table 12.26 Consequence Distances (m)

Outcome ID	Release	Nominal fatality prob.	Outdoor fatality prob.	Indoor fatality prob.	Fatality in vehicles	Open areas (5D)				Urban areas (2D)			
						d	*c*	*s*	*m*	*d*	*c*	*s*	*m*
SLD	0.1 kg/s	0.9	0.9	0.09	0.9	36	2.6	0	19.7	32	5.6	0	15.7
		0.5	0.31	0.05	0.31	48	3.5	0	26.2	45	7.9	0	22.1
		0.03	0.007	0.003	0.007	75	5.5	0	41	75	13.2	0	36.8
MLD	1 kg/s	0.9	0.9	0.09	0.9	108	11.4	0	58.6	101	32.1	0	66.7
		0.5	0.31	0.05	0.31	152	14.3	0	70.7	139	36.9	0	84.5
		0.03	0.007	0.003	0.007	240	19.6	0	106.5	221	46.4	0	125
LLD	10 kg/s	0.9	0.9	0.09	0.9	320	44.8	0	182	324	130	-10.9	230
		0.5	0.31	0.05	0.31	453	51.2	0	234	425	150	-10.9	270
		0.03	0.007	0.003	0.007	749	67.5	0	365	608	180	-10.9	380
RD	1 t	0.9	0.9	0.09	0.9	411	59.6	0	237	368	170	-18.9	260
		0.5	0.31	0.05	0.31	573	71.2	0	304	460	190	-18.9	330
		0.03	0.007	0.003	0.007	896	91.2	0	470.6	627	222.2	-18.9	400
RDM1	3 kg/s	0.9	0.9	0.09	0.9	179	22.1	0	84.6	177	62.9	-5.9	114
		0.5	0.31	0.05	0.31	255	26	0	125	244	74.3	-5.9	158
		0.03	0.007	0.003	0.007	425	36.4	0	197	394	91.4	-5.9	233
RDM2	6 kg/s	0.9	0.9	0.09	0.9	250	34.3	0	134	255	93	0	180
		0.5	0.31	0.05	0.31	355	40	0	173	350	110	0	230
		0.03	0.007	0.003	0.007	591	51.4	0	280	558	140	0	330

Chlorine Cloud Height

12.21.9 Information on the height of a chlorine cloud is required for determining the degree of protection for people inside high rise buildings. *Table 12.27* shows the predicted cloud heights derived by Atkins (2006) from the wind tunnel simulations, CFD modelling and DRIFT flat terrain dispersion modelling performed for ERM's Eight Water Treatment Works Study. The same data are adopted for the present assessment and the same cloud heights are applied for urban and open areas.

Table 12.27 Predicted Chlorine Cloud Heights

Release Quantity (tonne)	Cloud Height (m)		
	LD03	LD50	LD90
1	6	3.75	3
3	11.25	7	5.6
10	16	10	8

12.21.10 Following Atkins (2006), the above cloud heights have been further scaled for different release quantities and converted into floor levels based on the assumption of 3 m per storey. The resulting affected floor levels are tabulated in *Table 12.28*.

Table 12.28 Predicted Affected Floor Levels

Release Scenario	Event Code	Floor Levels		
		LD03	LD50	LD90
Small leak	SLD	1	1	1
Medium leak	MLD	1	1	1
Large leak	LLD	3	2	2
Rupture	RD	3	2	2
Medium leaks from 3 drums	RDM1	2	1	1
Medium leaks from 6 drums	RDM2	4	3	2

Toxic Impact Assessment

12.21.11 Similar to the previous QRAs (ERM 2001, 2011a and Atkins, 2006), the following probit equation (TNO, 1992) has been used in this study to estimate the likelihood of fatality due to exposure to chlorine:

$$Pr = -14.3 + \ln C^{2.3}t$$

Where:

Pr = probit value,

C = chlorine concentration (mg/m^3), and

t = exposure time (minutes)

12.21.12 *Table 12.29* shows the relationship between the chlorine concentration and the probability of fatality for the TNO probit obtained assuming a 10 minute exposure duration, which is consistent with ERM (2001, 2011a) and Atkins (2006).

Table 12.29 Chlorine Toxicity

Chlorine Concentration (ppm)	Probit Value for 10 min Exposure (TNO probit)	Nominal Probability of Fatality (LD = lethal dose)
251	3.17	0.03 (LD03)
557	5.00	0.50 (LD50)
971	6.28	0.90 (LD90)

<u>*Modelling of Escape from the Chlorine Cloud*</u>

12.21.13 In risk assessments for toxic gas releases it is common practice to take into account the possibility of escape of exposed persons. This is because at lower concentrations of the gas, people may be able to obtain protection by moving indoors or directly out of the cloud.

12.21.14 The approach adopted for chlorine releases from trucks during transport is the same as that described for releases from on-site facilities (*Sections 12.10.28–12.10.31*). This gives effective outdoor fatality probabilities, i.e. the fatality probability that can be applied to the total outdoor population at any given location taking into account the probability of escape. These were summarised in *Table 12.13* and are shown in the consequence results (*Table 12.26*).

12.21.15 Atkins (2006) uses a slightly different, but roughly equivalent approach, based on estimated escape distance and the basic escape velocity of 2 m/s reduced according to the chlorine concentration level.

<u>*Protection for Persons Indoors*</u>

12.21.16 Following similar previous studies undertaken in Hong Kong and elsewhere, and in particular Atkins (2006), it is assumed that the probability of fatality for a person indoors is 10% of that for a person remaining outdoors, i.e. the nominal outdoor fatality probability.

12.21.17 Protection is also considered for people on the upper floors of high rise buildings. This is based chlorine cloud height obtained from the dispersion modelling. For each release scenario, the corresponding population on affected floor levels has been predicted and included in the risk assessment.

12.21.18 No protection is assumed in this QRA for the people in vehicles; the road population is therefore treated the same way as the outdoors population.

12.22 Frequency Analysis

<u>*Review of Base Failure Rates*</u>

12.22.1 The current study uses scenario frequencies consistent with Atkins (2006). The following paragraphs discuss the basis for these frequencies and make comparisons with other studies where applicable. In some cases, frequencies are refined compared to the Atkins (2006) study based on updated information and to allow for improvements in truck design that have been implemented since the previous study.

Spontaneous Container Failure

12.22.2 Both DNV (1997) and Atkins (2006) applied a frequency of 1.1×10^{-3} per container year. This was estimated based on a limited number (only three reported cases worldwide) of spontaneous chlorine container failure in transport over 20 years and is likely an overestimate. Nevertheless, the Atkins (2006) base frequency has been adopted for this study.

12.22.3 Following Atkins (2006) this base frequency is converted to per truck-km units assuming 6 drums per truck and an average truck speed of 45 km/h. This gives a spontaneous drum failure rate of 1.67×10^{-8} per truck-km.

12.22.4 Conditional probabilities for small, medium, and large leaks and drum rupture are adopted as 0.54, 0.35, 0.065 and 0.045, respectively and are consistent with those of Atkins (2006).

Load shedding

12.22.5 The load shedding frequency of 1.1×10^{-7} per truck-km is consistent with DNV (1997) and Atkins (2006). This estimate is based on historical data of world-wide accidents (1.1×10^{-8} per truck km) but adjusted to Hong Kong conditions by applying a factor of 100 accounting for the steepness of HK roads and a factor of 0.1 to account for special, custom-built lashing arrangements used in HK chlorine drum trucks (*Figure 12.21*).

12.22.6 In addition to the lashings, clamps (*Figure 12.21*) are used at each end to the drums (total 12 clamps for 6 drums) to ensure that drums cannot roll off the truck. Although these clamps have been in use for some years, no credit was taken in the previous Atkins (2006) analysis. Consider the latest chlorine usage of 895 tonne per year and about 20 years of operation since 1990, the total number of trips is given by N = 20 × 895/6 = 2983. Let p be the probability of failure of an individual lashing/ clamp. The probability of no failure in a single trip is given by $(1 - p)^{12}$ considering there are 12 lashing/ clamps used for each trip. It follows that the probability of having any failure in a single trip is$1 - (1 - p)^{12}$. By assuming Poisson Distribution with a 50% [1] level of confidence, we have $\ln(2)/2983 = 1 - (1 - p)^{12}$ which gives $p = 1.94 \times 10^{-5}$.

12.22.7 The weight of a fully-loaded chlorine drum is approximately 1.7 tonne and the existing clamps can already stand the required dynamic load during chlorine transport. The effectiveness of these clamps has been reviewed as part of the current study and improvements have been recommended in the design which will be implemented before the start of the Project. The modification aims to decrease the gaps between clamps and chlorine drums. The clamps will be designed, tested, and independently verified by a certified engineer to stand the required load, with the consideration of stress during transport. The failure rate of the clamps is further assessed by human error analysis and it is shown that failure should be dominated by human error in tightening the clamps during loading. It is therefore recommended that independent checks are performed during loading i.e. operator who attaches the lashings should cross check that the clamps are correctly tightened. Based on a human error analysis (*Appendix 12.10*), a factor of 0.03 on the load shedding frequency is applied in the current study. This gives a load shedding frequency of 3.49×10^{-9} per truck-km.

12.22.8 The conditional probability of a leak is taken to be 0.25 per accident following DNV (1997) and Atkins (2006). Of this, 25% are assumed to be medium leaks and 75% are small leaks. This gives a conditional probability of medium leak of 0.0625 and small leak of 0.1875.

12.22.9 Since the previous study, however, emergency repair kits have been provided and are carried on all chlorine trucks. These provide a means of sealing off small leaks from either the valve area or the drum surface by clamping patches over the leaking area. A reduction factor of 0.10 has been derived from human error analysis (*Appendix 12.10*). This is applied only to small leaks as the emergency kit is considered ineffective for larger leaks. This gives a revised conditional probability of 0.019 for small leaks while the conditional probability for medium leaks is maintained at 0.0625. Errors related to other failure modes such as mechanical failure can be estimated using similar approach as in *Section 12.22.6* but with N = 6 × 895/6 = 895 (6 years of operation) and consider each chlorine truck is equipped with one emergency kit. Therefore $p = \ln(2)/895 = 7.74 \times 10^{-4}$.

12.22.10 It may be noted that no credit was taken for the emergency repair kit for small leaks resulting from rollover or spontaneous drum failure scenarios. For truck rollover, the driver and driver's mate are considered to be incapacitated and unable to carry out remedial measures while small leaks from spontaneous failures are likely to go unnoticed during transit.

[1] This value is consistent with those used in the QRA for the XRL Project. See Appendix 13 of ERM (2009) for details.

Figure 12.21 Drum Lashing and Clamp Arrangements

Rollover

12.22.11 DNV (1997) and Atkins (2006) adopted a rollover frequency of 1.9×10^{-7} per truck-km. This value was based on the 1993 medium and heavy vehicles accident involvement rate in Hong Kong of 5.9×10^{-7} per truck km, and 32% rollover rate for dangerous goods trucks involved in accidents from a 1985 Belgium study (Technica, 1989). A detailed review of Hong Kong accident data was carried out for the MTRC XRL project (ERM, 2009). This study suggests that a lower involvement rate of 2.25×10^{-7} per vehicle-km is justified for MGV/HGV.

12.22.12 Prior to commencement of the reprovisioning project, a GPS fleet management system will be implemented on all chlorine delivery trucks. This will provide local alarm to warn the driver in case of speeding as well as provide centralised monitoring with radio communication. Regular defensive driving training will also be provided to drivers. Considering these new measures, the truck involvement rate was adjusted by a factor of 0.12 (see *Appendix 12.10*).

12.22.13 Adopting the same 32% probability of rollover gives the base frequency used in this study of 8.64×10^{-9} per truck-km.

12.22.14 The conditional probabilities of different leaks categories due to a drum impact in a rollover (0.243, 0.154 and 0.0104 for the small, medium and multiple medium leaks, respectively) adopted in this study are consistent with those of Atkins (2006) and ERM (2011a).

12.22.15 Technica (1989) and Atkins (2006) also considered the possibility of rollover leading to fire. The conditional probability per rollover accident leading to fire for medium leak from a single drum was specified as 9×10^{-4}, conditional probability for medium leaks from 3 drums as 6.66×10^{-4} and conditional probability for medium leaks from 6 drums as 2.79×10^{-4}. These include the probability of fire resulting from a rollover.

Vehicle Impact

12.22.16 The crash frequency (excluding rollover) of 4.0×10^{-7} per truck-km was used by DNV (1997) and Atkins (2006). This value has been estimated in DNV (1997) in the same way as the rollover frequency discussed above.

12.22.17 A detailed review of Hong Kong accident data was carried out for the MTRC XRL project (ERM, 2009). This study suggests that a lower frequency of 2.25×10^{-7} per vehicle-km (with a breakdown of 1.59×10^{-8}, 1.43×10^{-7}, and 6.61×10^{-8} with respect to high, medium, and low truck impacts) is justified for accidents having the potential to cause significant mechanical (impact) energy on the cargo. Excluding the rollover events gives the base frequency of 1.53×10^{-7} per truck-km.

12.22.18 This is further adjusted by a factor of 0.12 to take credit for the GPS fleet management system as discussed for the rollover scenarios. This gives a base frequency of 1.84×10^{-8} per truck-km used in the current study.

12.22.19 The 0.017 conditional probability of a drum rupture conservatively includes all smaller releases and is consistent with the two previous transport studies.

12.22.20 Technica (1989) and Atkins (2006) also considered the possibility of collision leading to fire. The conditional probability per accident leading to fire for medium leak from single drum was specified as 9×10^{-4}, conditional probability for medium leaks from 3 drums as 6.66×10^{-4} and conditional probability for medium leaks from 6 drums as 2.79×10^{-4}. These include the probability of fire resulting from an impact.

Truck Fire

12.22.21 DNV (1997), Atkins (2006) and ERM (2011a) used a frequency of 4.0×10^{-9} per km for truck fires affecting the load.

12.22.22 The incident rate of truck fires was reviewed in detail in the XRL study (ERM, 2009). Based on fire call data for all goods vehicles, an overall vehicle fire probability of 2.186×10^{-8} per km was derived, of which less than 20% spread to affect the cargo (DNV, 1997 and Moreton, 1993). This gives a frequency of fire affecting the chlorine drums of 4.37×10^{-9} per km which is very similar to the value used in Atkins (2006) and DNV (1997).

12.22.23 Truck modifications since the last assessment, however, include a fire screen, fire resistant material over wheel arches, reduction of combustible materials and provision of larger fire extinguishers. These will be implemented before the start of the Project and are calculated to give an adjustment factor of 0.1 on fire frequency affecting the chlorine drums (ERM, 2009).

12.22.24 Truck fires are considered to cause medium leaks, with 25% causing a medium leak in a single drum, 25% causing a medium leak in 3 drums and 50% causing a medium leak in all 6 drums. This approach is consistent with Atkins (2006).

Summary of Base Frequencies

12.22.25 Based on the above considerations the following base frequencies (*Table 12.30*) have been selected for the modelling in this QRA. Combining the base frequencies with the conditional probabilities for different outcomes gives the event frequencies as summarised in *Table 12.31*.

Table 12.30 Summary of Release Frequencies

Scenario	Frequency (per truck-km)	Conditional Probabilities for Different Leak Sizes					
		Small (SLD)	Medium (MLD)	Large (LLD)	Rupture (RD)	Medium Leaks from 3 Drums (RDM1)	Medium Leaks from 6 Drums (RDM2)
Spontaneous failure	1.67E-8	0.54	0.35	0.065	0.045	-	-
Load shedding	3.49E-9	0.019	0.0625	-	-	-	-
Rollover	8.64E-9	0.243	0.155	-	-	0.01106	2.79E-4
Collision	1.84E-8	-	9E-4	-	0.017	6.66E-4	2.79E-4
Truck fire	4.37E-10	-	0.25	-	-	0.25	0.50

Table 12.31 Event Outcome Frequencies

Release Scenario	Event Code	Frequency (per truck-km)
Small leak	SLD	1.12E-8
Medium leak	MLD	7.54E-9
Large leak	LLD	1.09E-9
Rupture	RD	1.07E-9
Medium leaks from 3 drums	RDM1	2.17E-10
Medium leaks from 6 drums	RDM2	2.26E-10

12.23 Population Data

Road Traffic and Population

12.23.1 The road traffic data were based on Annual Average Daily Traffic (AADT) and travel speed.

12.23.2 Traffic data for the year 2031 were updated with consideration of the impact of the future Hong Kong – Zhuhai – Macao Bridge (HKZMB) and the proposed Lantau Logistics Park (LLP) development. The latest estimations on the AADT figures resulting from the bridge were obtained from the Highways Department of HKSAR. The vehicle composition and the proportion of traffic on North Lantau Highway that will pass through Tsing Yi North Coastal Road in 2031 were also obtained and incorporated into the traffic model.

12.23.3 It is assumed that in case of a road incident leading to chlorine release, the road traffic will come to a stop and form a traffic jam. Estimation of the traffic population follows the Atkins (2006) approach and is based on the following assumptions:

- At least 20 minutes is required to clear the road traffic;
- Average vehicle interval (vehicle length and spacing) of 10 m;
- Average occupancy of vehicle of 3.3 persons;
- An escaping factor of 0.5 to account for half of the affected length of the road is free of vehicles i.e. vehicle in front of the point of accident will continue to move away, while vehicles behind the accident point will start to accumulate into a traffic jam.

12.23.4 The traffic population is calculated as follows:

$$TP_{\max} = \frac{AL}{VI} \times NL \times AO \times EF \qquad (1)$$

$$TP_{AADT} = \frac{AADT}{DM} \times ST \times AO \times EF \qquad (2)$$

$$TP = \min\left(TP_{AADT}, TP_{\max}\right)$$

where:

TP_{max} - maximum traffic population (derived from the road geometry)

TP_{AADT} - population based on the traffic flow data

TP - traffic population (number of people on the affected length of road) used in modelling

AL - affected length of road (taken as 1000 m)

VI - vehicle interval (10 m)

NL - number of lanes

AO - average occupancy (3.3)

EF - escaping factor (0.5)

AADT - Annual Average Daily Traffic (from Annual Traffic Census data)

DM - Number of minutes in a day (1440)

ST - Stopping time (20 min)

12.23.5 The above model compares the road population under full traffic jam conditions (equation 1) with the population that flows along the road within a 20 minute period (equation 2). For roads with heavy traffic, a traffic jam will form quickly and the affected population will be given by equation 1. For roads with light traffic, there may be insufficient vehicles to lead to a long tail back and the affected population will be limited to that derived from equation 2. The model therefore takes the minimum of the two predictions.

12.23.6 The affected length of road (AL) under full traffic jam conditions is taken to be the whole length of the transport route. The population affected is then determined by overlaying the consequence contours with the transport route. In other words, the maximum length of road affected is equal to the maximum consequence distance obtained from dispersion modelling. This is a slight refinement of the Atkins (2006) approach wherein roads were considered in 1 km sections with a release at the midpoint. This effectively limited the length of road affected to 500 m in Atkins (2006).

General Population

12.23.7 The population densities of different land uses were estimated based on the data collected from the Territorial Population and Employment Data Matrix (TPEDM) and site specific surveys. The TPEDM data covers the whole territory, and the predicted residential and employment population for years 2016 and 2031 were applied in the chlorine transport QRA. The population data from TPEDM is classified by Planning Data Zone (PDZ) zones. The chlorine transport route and PDZ Zones in Hong Kong are shown in *Figure 12.22*. Outline Zoning Plans (OZPs) within each PDZ are used as individual units to allocate the population. A map of OZPs in Ma Wan, within 1 km distance from the transport route is shown in *Figure 12.23* for illustration. A 2km wide corridor (1km either side of the transport route) of population is considered along the full length of the route since the worst case consequence distances are close to 1 km. A figure showing all population polygons is provided in *Figure 12.24*.

Figure 12.22 Chlorine Transport Route and PDZ Zones

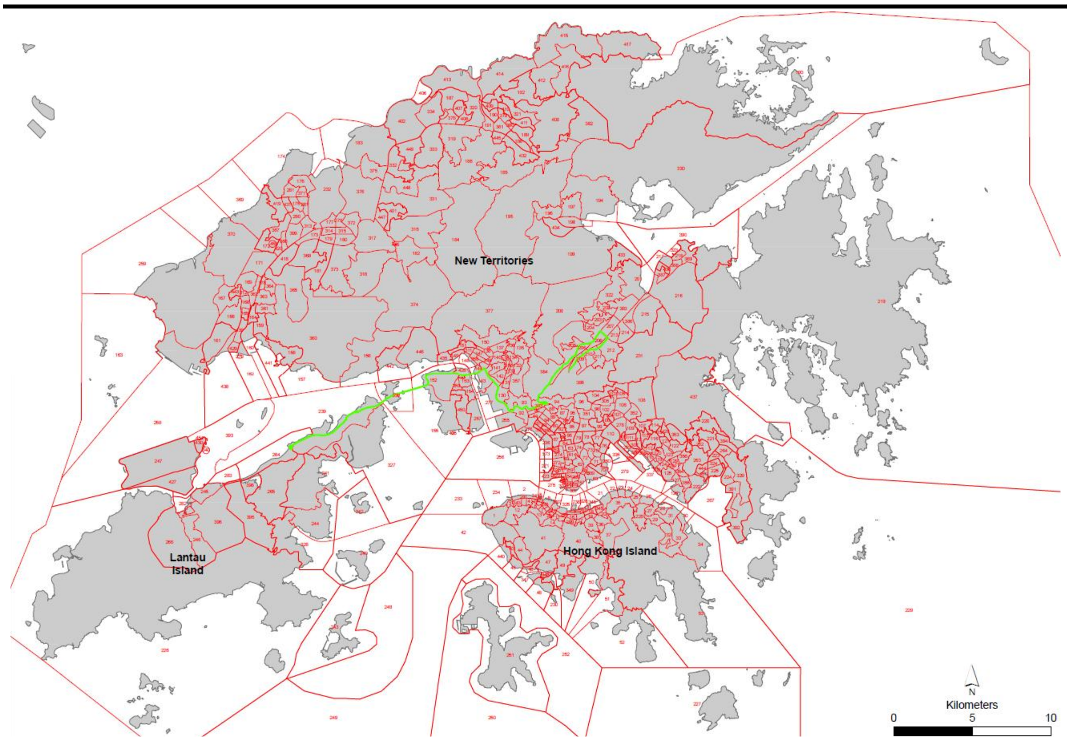
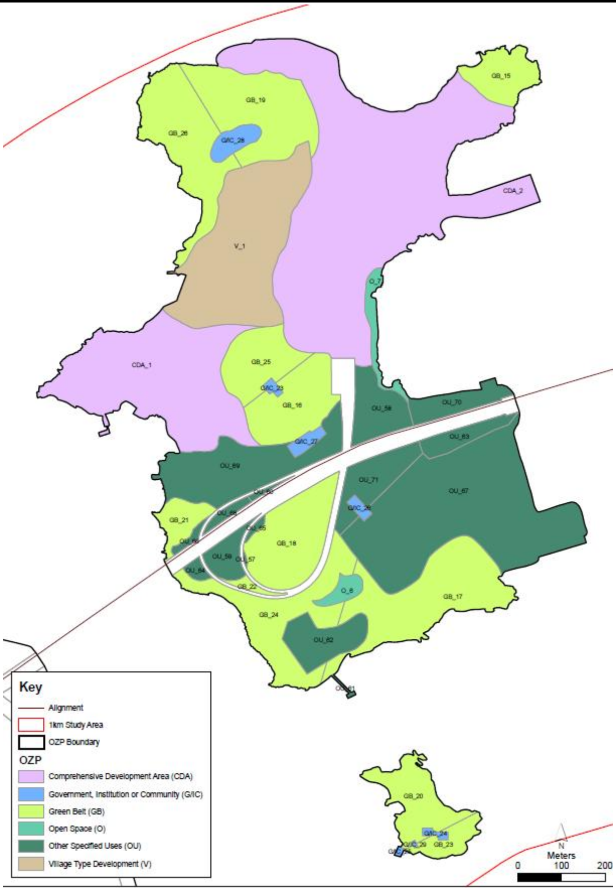


Figure 12.23 A Map of OZPs in Ma Wan



12.23.8 Following the methodology of Atkins (2006), the Domestic Plot Ratio (*DPR*) and Non-Domestic Plot Ratio (*NDPR*) data is used to estimate the height of buildings in different OZPs.

Table 12.32 summarises the *DPR* and *NDPR* data used in this study. For each OZP zone, the total population is the sum of predicted residential population (RP_z) and employment population (EP_z). The RP_z and EP_z are given by:

$$RP_Z = \frac{Area_z \times DPR_z}{\sum_i^n Area_{z,i} \times DPR_{z,i}} \times RP_{PDZ} \text{ and}$$

$$EP_Z = \frac{Area_z \times NDPR_z}{\sum_i^n Area_{z,i} \times NDPR_{z,i}} \times EP_{PDZ},$$

where

- RP_z is the residential population of an OZP zone within a PDZ zone;
- EP_z is the employment population of an OZP zone within a PDZ zone;
- $Area_z$ = is the area of the OZP zone within the PDZ zone;
- DRP_z is the Domestic Plot Ratio of the OZP zone within the PDZ zone;
- $NDRP_z$ is the Non-Domestic Plot Ratio of the OZP zone within the PDZ zone;
- n is the number of OZP zones in the PDZ zone;
- $Area_{z,i}$ is the area of the i^{th} OZP zone with the PDZ zone;
- $DPR_{z,i}$ is the Domestic Plot Ratio of the i^{th} OZP zone within the PDZ zone;

- $NDPR_{z,i}$ is the Non-Domestic Plot Ratio of the ith OZP zone within the PDZ zone;
- RP_{PDZ} is the residential population of the PDZ zone; and
- EP_{PDZ} is the employment population of the PDZ zone.

12.23.9 The residential population and employment population are further split into outdoor population and indoor population. For each OZP zone, the proportion of indoor and outdoor from the previous chlorine transport QRA (Atkins, 2006) is used. The data is shown in *Table 12.32*. For the residential population and employment population,

$$IRP_z = RP_z \times f_{\mathrm{in}},$$

$$ORP_z = RP_z \times f_{\mathrm{out}},$$

$$IEP_z = EP_z \times f_{\mathrm{in}}, \text{ and}$$

$$OEP_z = EP_z \times f_{\mathrm{out}},$$

where

- IRP_z is the indoor residential population of the OZP zone;
- ORP_z is the outdoor residential population of the OZP zone;
- IEP_z is the indoor employment population of the OZP zone;
- OEP_z is the outdoor employment population of the OZP zone;
- f_{in} is the ratio of indoor population to the total population of the OZP zone; and
- f_{out} is the ratio of outdoor population to the total population of the OZP zone.

12.23.10 For each release scenario, the affected indoor residential population (AIRP) and affected indoor employment population (AIEP) are given by:

$$AIRP = \sum_i^N \frac{IRP_i}{DPR_i/0.3} \times F_i \times \frac{Area_{i,exposed}}{Area_i} \text{ and}$$

$$AIEP = \sum_i^N \frac{IEP_i}{NDPR_i/0.3} \times F_i \times \frac{Area_{i,exposed}}{Area_i},$$

where

- IRP_i and IEP_i are indoor residential population and indoor employment population of the i^{th} affected OZP zone;
- N is the total number of affected OZP zones;
- DPR_i and $NDPR_i$ are domestic plot ratio non-domestic plot ratio of the i^{th} affected OZP zone;
- $DPR_i/0.3$ and $NDPR_i/0.3$ are the maximum number of floors for residential and employment population. This assumption follows the Hong Kong Planning Standard Guideline, Chapter 2, Section 3.6;
- F_i is the number of floors of the i^{th} affected OZP zone, if F_i > maximum number of floors of the OZP zone, then F_i = maximum number of floors of the zone;
- $Area_{i,exposed}$ is the exposed plan area of the i^{th} affected OZP zone; and
- $Area_i$ is the total plan area of the i^{th} affected zone.

12.23.11 The affected outdoor residential population (AORP) and affected outdoor employment population (AOEP) are given by:

$$AORP = \sum_i^N ORP_i \times \frac{\text{Area}_{i,exposed}}{\text{Area}_i}$$ and

$$AOEP = \sum_i^N OEP_i \times \frac{\text{Area}_{i,exposed}}{\text{Area}_i},$$

where

- ORP_i and OEP_i are outdoor residential population and outdoor employment population of the i^{th} affected OZP zone.

12.23.12 A day time population factor has been applied to calculate the population during the day time. A factor of 0.25 has been used for residential population and 0.8 has been used for employment population.

Table 12.32 Plot Ratio Data and Indoor/ Outdoor Population Ratio

Gzone	Description	*DPR*	*NDPR*	Indoor (f_{in})	Outdoor (f_{out})
AGR	Agriculture	0.00	0.01	0.00	1.00
C	Commercial	0.00	12.00	0.98	0.02
C/R	Commercial/Residential	5.00	2.50	0.95	0.05
CA	Conservation Area	0.00	0.01	0.00	1.00
CDA	Comprehensive Development Area	3.00	1.50	0.98	0.02
G/IC	Government/Institution/Community	0.00	12.00	0.98	0.02
GB	Green Belt	0.00	0.01	0.00	1.00
I	Industrial	0.00	12.00	0.98	0.02
LDC	Land Development Corp Area	0.00	0.01	0.98	0.02
MRDJ	Major Road Junction	0.00	0.01	0.00	1.00
NPPS	Pedestrian Precinct	0.00	0.00	0.00	1.00
O	Open Space	0.00	0.01	0.00	1.00
OS	Open Storage	0.00	0.01	0.98	0.02
OU	Other Specified Uses	0.00	12.00	0.98	0.02
R(A)	Residential (Group A)	8.00	1.00	0.90	0.10
R(B)	Residential (Group B)	5.00	1.00	0.98	0.02
R(C)	Residential (Group C)	3.00	0.50	0.90	0.10
R(D)	Residential (Group D)	0.20	0.50	0.98	0.02
R(E)	Residential (Group E)	1.00	0.50	0.98	0.02
RAIL	Railway (MTR/KCR/LRT)	0.00	0.01	0.00	1.00
REC	Recreation	0.00	0.01	0.00	1.00
RPA	Reaction Priority Area	0.00	0.01	0.00	1.00
SSSI	Site of Special Scientific Interest	0.00	0.01	0.00	1.00
U	Undetermined	0.00	0.01	0.98	0.02
V	Village Type Development	3.00	0.01	0.90	0.10

12.23.13 Site Surveys have been undertaken to collect data to estimate road-side population densities along the chlorine transport route. As the transport route mainly consists of highways and rural roads, the road-side population in these road sections is low. Only the following route sections have noticeable road-side population:

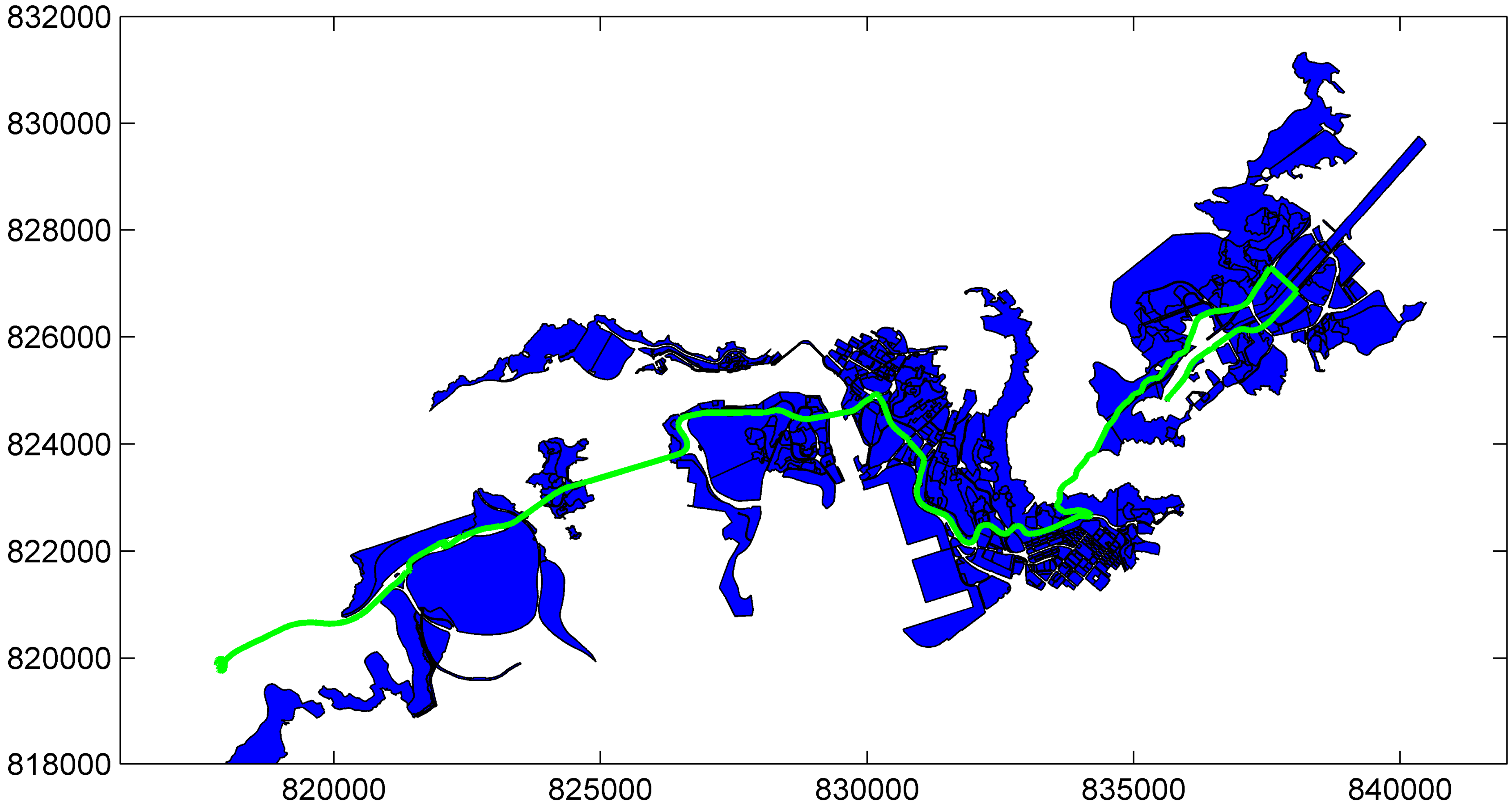
- Ching Cheng Road;
- Tai Po Road;
- Tai Po Road-Sha Tin Heights;
- Tai Po Road-Tai Wai;

- Mei Tin Road; and
- Che Kung Miu Road.

12.23.14 For areas close to the Sha Tin WTW, the population data and population units used for the on-site chlorine assessment (see *Section 12.8*, *Figure 12.8, Figure 12.9* and *Table 12.3*) are used for the off-site transport assessment. This data provides a more detailed population breakdown in the surroundings of the Sha Tin WTW.

12.23.15 Population polygons considered in this study are shown in *Figure 12.24*.

Figure 12.24 Population Polygons



Axes are coordinates in metres in Hong Kong's 1980 grid system

12.24 Meteorological Data

12.24.1 Following Atkins (2006), twelve wind directions are used in the modelling (*Table 12.33*) directions are modelled. Following Atkins (2006), it has been assumed that in the open areas, all wind directions are of equal probability, while for the urban areas, based on the CFD modelling reported in Technica (1989), the wind directions along the route are given a higher probability than those at an angle to the route directions.

Table 12.33 Wind Direction Probabilities

	Open Areas	Urban Areas
Along route	8.33%	21.42%
30° to route	8.33%	8.33%
60° to route	8.33%	4.17%
90° to route	8.33%	3.58%
120° to route	8.33%	4.17%
150° to route	8.33%	8.33%
Backwards (180° to route)	8.33%	21.42%
210° to route	8.33%	8.33%
240° to route	8.33%	4.17%
270° to route	8.33%	3.58%
300° to route	8.33%	4.17%
330° to route	8.33%	8.33%

12.24.2 Following Atkins (2006), stability class of D (i.e. neutral stability) has been assumed in the QRA. A wind speed of 5 m/s is adopted in open areas and 2 m/s in urban areas.

12.25 Off-site Transport Risk Results

12.25.1 The QRA combines information on the consequences of chlorine releases with information on the likelihood to generate individual risk contours and FN curves. Individual risk is the chance of death per year to a specified individual at a specific location. Societal risk (FN curves) is the risk to the population as a whole.

Societal Risk

12.25.2 FN Curves for the Construction and Operational Phases of the reprovisioning project within the 1-km Consultation Zone are shown in *Figure 12.25.*

12.25.3 Risks during the Operational Phase are slightly higher than the Construction Phase due to higher chlorine delivery quantities (127 trucks per year during Operational Phase compared to 107 trucks per year during construction).

12.25.4 As can be seen, the societal risks are in the lower ALARP region. N_{max} (the number of fatalities at frequency of 10^{-9} per year) is below 500 for both Construction and Operational Phases.

12.25.5 A breakdown of risks by scenario is shown in *Figure 12.26* for the operational case. Collisions, truck rollover and spontaneous failures are the major contributors to the risk. This can also be seen in the potential loss of life (PLL) data (*Table 12.34*).

Figure 12.25 FN Curves for Off-site Chlorine Transport

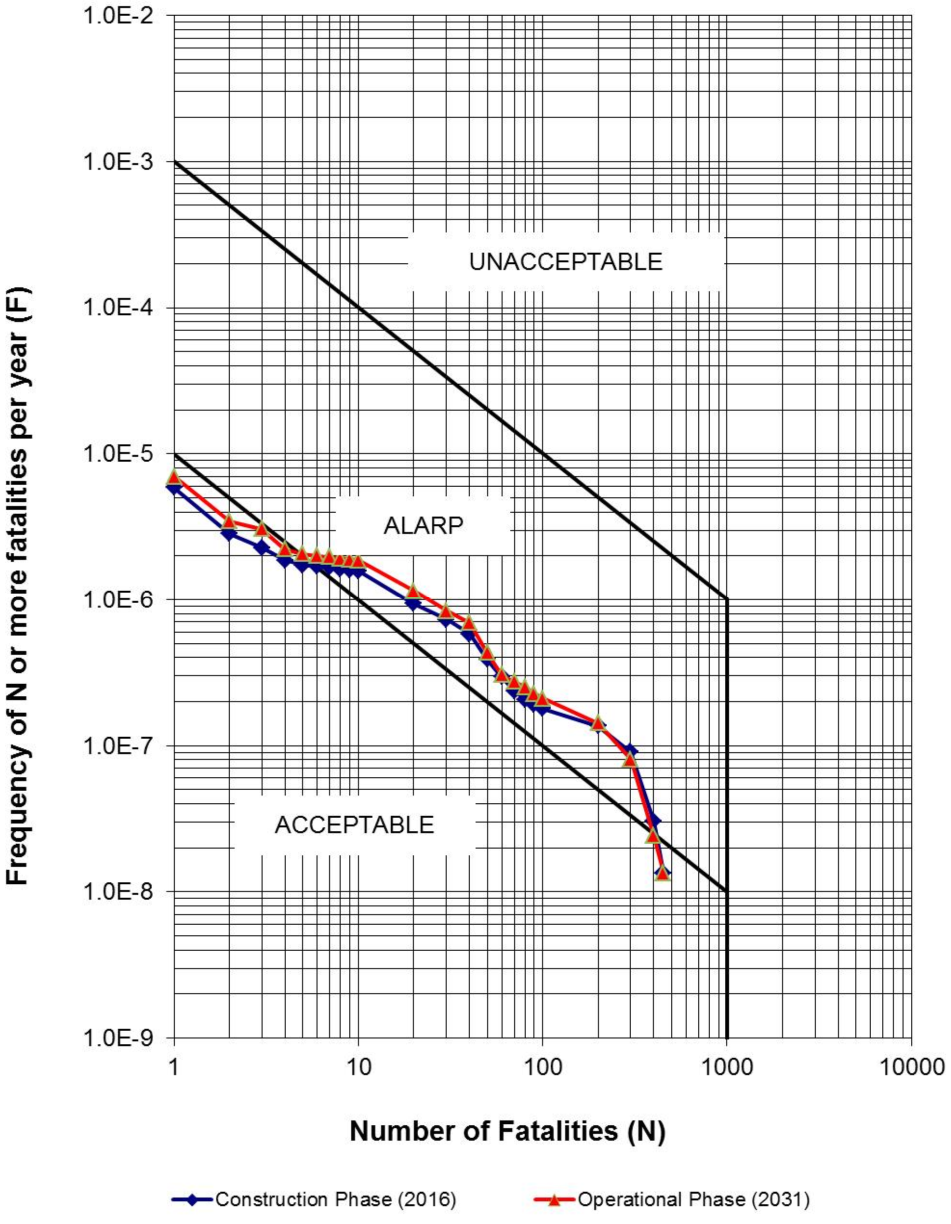


Figure 12.26 FN Curves for Off-site Chlorine Transport Breakdown by Scenario

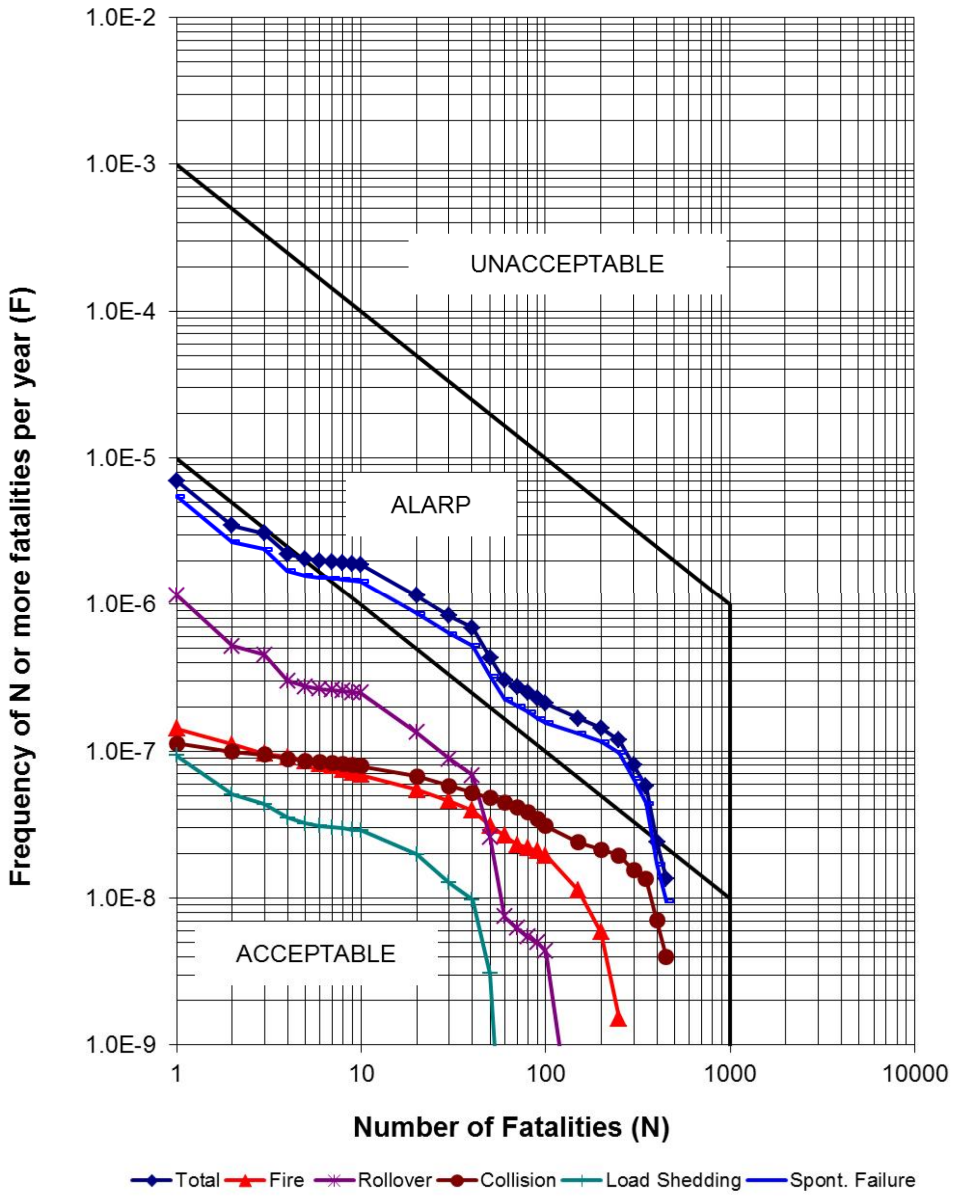


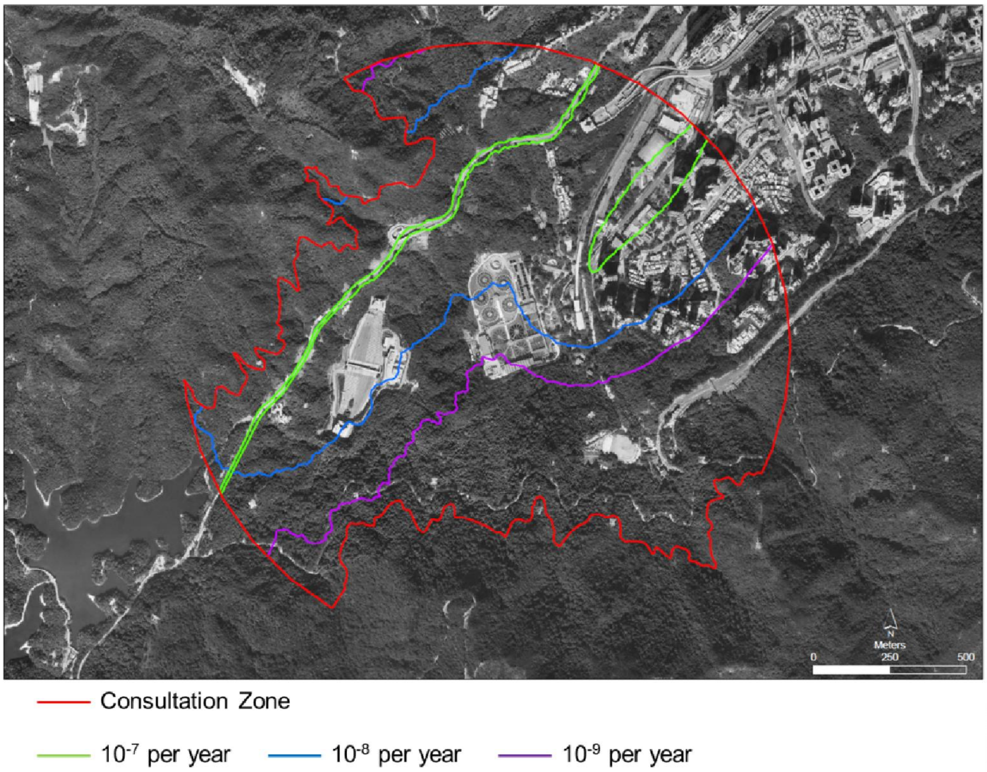
Table 12.34 PLL for Off-site Chlorine Transport

Release Scenario	PLL per year (Construction Phase)	PLL per year (Operational Phase)
Spontaneous failures	7.73E-5	8.75E-5
Fire	4.82E-6	5.44E-6
Collision	1.02E-5	1.12E-5
Rollover	7.34E-6	8.63E-6
Load shedding	8.63E-7	1.01E-6
Total	**1.01E-4**	**1.14E-4**

Individual Risk

12.25.6 The individual risk (IR) for off-site chlorine transport is shown in *Figure 12.27*. For brevity, only the Operational Phase is shown since this is the worst case (chlorine transport quantities are slightly higher during Operational Phase). For the Construction Phase, risks are slightly lower. As can be seen, the individual risk levels are well below the Hong Kong Risk Guidelines criterion of 10^{-5} per year. This is typical of transport-related risks where the risk is spread along an extended route.

Figure 12.27 Individual Risk for Off-site Chlorine Transport, Operational Phase



12.25.7 IR tends to be higher along the urban sections of road, compared to open sections. This is due to the lower wind speeds (2 m/s) assumed in the modelling for urban sections. Lower wind speeds are detrimental to dispersion and hence larger toxic clouds are predicted. Also, the channelling effect of building is reflected in the modelling of urban areas by prescribing a higher probability of dispersion along the road direction. These effects combined lead to higher IR in urban sections.

12.26 Risk Mitigation and ALARP Assessment

12.26.1 Since the societal risk levels lie in the ALARP region of the HKRG, mitigation measures are required to reduce the risks to levels As Low As Reasonably Practicable. This section discusses potential mitigation measures and assesses their practicability.

12.26.2 The assessment focussed on the following categories of mitigation options:

- Improved design of the Water Treatment Works which could result in reduced transport risk;
- Improved truck design;
- Improved chlorine drum design;

- Improved procedural controls; and
- Any other identified mitigation measures not belonging to the above categories.

12.26.3 A number of mitigation measures have been considered and assessed in the previous Chlorine Transport QRA (Atkins, 2006) and, according to the information provided by WSD, those considered practicable have been already implemented at the WTW. Nevertheless, some of the mitigation measures at the WTW that were previously deemed not practicable, are re-examined here based on the updated PLL results.

12.26.4 In addition, a series of workshops were undertaken to further identify mitigation options and assess their practicality.

12.26.5 Practical mitigation measures are further considered in the Cost Benefit Analysis to ensure compliance with the ALARP process.

Identification of Potential Risk Mitigation Measures

12.26.6 Potential risk mitigation measures were identified using the following steps:

- An initial list of risk mitigation measures was identified, making reference, as far as possible, to existing and relevant Hong Kong reports and other international references. The list was further supplemented following two risk mitigation workshops held on 23 November 2011 and 18 January 2012;
- The identified mitigation measures were discussed with relevant specialists and screened for their practicability as part of the two workshops and subsequent discussions with WSD;
- A site visit was conducted on 26 April 2012 to directly observe loading operations of chlorine trucks and the transport to Sha Tin WTW; and
- The potential mitigation measures assessed to be practical (shortlist) are retained for the Cost Benefit Analysis.

Risk Mitigation Workshop & Screening

12.26.7 The latest and most relevant report which addressed chlorine transport risk mitigation is the Atkins (2006) study. The study identified several risk mitigation measures related to chlorine transport as summarised in *Table 12.35*.

Table 12.35 Risk Mitigation Measures from Atkins (2006) Study

Item	Risk Reduction Measures
R1	Restrict the delivery of chlorine by truck to night time deliveries only.
R2	Road improvements – barriers, signs, etc.
R3	Road improvements – new roads
R4	Optimise the transport routes to minimise risks
R5	Optimise the transport routes to minimise risks with import by truck direct from mainland China
R6	Improvements to drum designs to minimise the risk of a leak in an impact situation (e.g. truck crash, load shed, and boat collision)
R7	Internal excess flow valve or restriction orifice in the valve pipe inside the drums which limits the maximum flow in the event of a valve failure or valve damage
R8	Use of smaller drums
R9	Bulk transport of chlorine

Item	Risk Reduction Measures
R10	Improvements to truck's design and operation to reduce the chance of accidents: - Crashes - Load shedding - Other potentially dangerous situations (e.g. driving off the side of a road, brake failure causing loss of control on a steep road)
R11	Improvements to truck's design and operation to reduce the chance of a chlorine release once the initial accident has happened.
R12	Improvements to truck's design and operation to reduce the consequences of a chlorine release once a drum is leaking
R13	Improvements to truck's design and operation to improve emergency response in the event of a chlorine incident
R14	Improvements to emergency response in the event of a road truck chlorine incident
A1/ A2	Change the water treatment process or use on-site generation at the WTWs so that chlorine drums are not used, hence there is no longer any need to transport them
A3	Pre-treatment of water in China so that the water reaching the WTWs in Hong Kong is of a significantly higher standard

12.26.8 The first Risk Mitigation Workshop, attended by representatives of MTRCL, WSD and ERM, was held on 23 November 2011 and discussed a preliminary list of possible risk mitigation measures. The mitigation measures identified during the first workshop were systematically presented and discussed. Some were accepted and recommended, others deemed impractical.

12.26.9 Following the first workshop, a short list of mitigation measures was selected for further evaluation and discussion on their practicality.

12.26.10 The objective of the second Risk Mitigation Workshop was to review the shortlisted mitigation measures and further assess their practicability. Some additional potential mitigation measures were also identified through the discussions.

12.26.11 Following the identification process described above, the full list of potential risk mitigation measures is provided in *Table 12.36* together with an assessment of their implementation practicality.

Table 12.36 Potential Risk Mitigation Measures

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
Improvement of Sha Tin WTW					
1.1	Reduction of chlorine transport by on-site chlorine generation	1st HAZID Workshop	Not implemented.	On-site generation of chlorine is not adopted anywhere worldwide for drinking water treatment. For on-site generation of hypochlorite, WSD has recently considered the latest development of such technology. After considering the merits and demerits of the technology, worldwide practice, operation and maintenance details, capital and operating costs, regulations on the Disinfection Byproducts (DBPs) and the suitability of its use in Hong Kong, it has been concluded that among the options of chlorine based disinfectants used for potable water treatment, liquid chlorine is still the most practical disinfectant for water treatment used in Hong Kong situation. WSD has no plan to change the present practice of using liquid chlorine as a disinfectant for the present moment. Nevertheless, WSD will continue to keep under review the latest development of use of alternative disinfectants in water supply industry.	Keep in view.
1.2	Reduction of chlorine usage at WTW – ozonation and UV	1st HAZID Workshop Atkins (2006)	Will be implemented as part of reprovisioning project to reduce chlorine to 761 tonnes/ year.	761 tonnes/ year is still required for post-dosing. No further reduction is possible.	No further considerations required.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
		(ref. A1, A2)	This is the basis for the hazard to life assessment.		
1.3	Reduction of chlorine transport by pre-treatment in China	1st HAZID Workshop Atkins (2006) (ref. A3)	Already implemented. This is the basis for the hazard to life assessment.	761 tonnes/ year is still required for post-dosing. No further reduction is possible.	No further considerations required.
1.4	Other water treatment technologies	1st HAZID Workshop	Not implemented.	No other practical established technologies available.	Refer to 1.1.
Improvement of Truck Design					
2.1	Provision of fire screen between wheels and cargo and between cab and cargo and provision of fire retardant materials for the wheel arches	1st HAZID Workshop 2nd HAZID Workshop	Fire shield already partially provided between cab and cargo area as per truck specification. The truck flat bed is metallic and also provides some fire protection. In addition, before the start of the reprovisioning works, the truck is planned to be improved to include a fire screen between the cab and cargo area and around the wheel arches. This should be constructed, installed and operated to international standards with a minimum 3mm thick fire screen,	This will be provided as a standard provision before the start of the reprovisioning works.	No further considerations required.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
			extending 150mm on all sides, and 100mm behind the cab of the vehicle. This is the basis for the hazard to life assessment.		
2.2	Provision of sufficient capacity fire extinguishers (minimum 2 × 9kg or AFFF-type), combined with driver training	1st HAZID Workshop	2 × 2kg fire extinguishers are currently provided and the truck will be provided with 2 × 9L fire extinguishers with dedicated driver training before the start of the reprovisioning works. This is the basis for the hazard to life assessment together with the firescreen measure (Item 2.1).	2 × 2kg fire extinguishers have been provided as a standard provision. Improved (2 × 9L) fire extinguishers) will be provided at the start of reprovisioning works.	No further considerations required.
2.3	Reduction of combustible such as provision of fire resistant materials, cables, and limit on fuel tank capacity	1st HAZID Workshop	The truck design already considers minimum amount of combustibles.	The truck design could be reviewed for possible further practical reduction of combustible materials and possible use of fire retardant materials in the cab to minimise truck fire load.	This potential risk mitigation measure is further evaluated in the Cost Benefit Analysis.
2.4	Securing load by improving brackets/clamp design	1st HAZID Workshop 2nd HAZID Workshop Atkins (2006)	The current assessment takes credit to the existing clamp which is a standard provision of mitigation. This is the basis for the hazard to life assessment. To improve reliability of the	This (existing clamp) is already provided as a standard provision.	No further considerations required

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
		(ref. R10)	clamp, the drum clamping arrangements has been reviewed and an improved design will be implemented before the start of the reprovisioning works. It should be noted that the current QRA does not take credit to the proposed new design of clamp.		
2.5	Provision of side/ front/ rear crash guards with high energy absorption	1st HAZID Workshop	Crash bars implemented but with limited energy absorption capacity.	This option is considered practical subject to agreement with the relevant authorities.	This potential risk mitigation measure is further evaluated in the Cost Benefit Analysis.
2.6	Provision of side/ front/ rear panels to contain leak	1st HAZID Workshop 2nd HAZID Workshop	Not implemented.	Solid and higher side panels on the truck may help contain chlorine gas from minor leaks however the volume of gas from a single drum after expansion is much greater than the possible volume that can be contained within the truck. Specifically, each drum contains 1 tonne of chlorine, which occupies 343 m^3 as a gas at ambient conditions. Assuming 1m high side panels, the volume that could be contained within the truck is approximately $2.5 \times 10 \times 1 = 25m^3$. As such it is not considered effective to contain chlorine leaks.	No further considerations required.
2.7	Provision of leak detectors and alarm with appropriate training to handle leaked	1st HAZID Workshop	Already implemented. This is the basis for the	Measure already implemented.	No further considerations required.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
	drums		hazard to life assessment.		
2.8	Improved tyres design and checks	1st HAZID Workshop	Annual vehicle check performed but no specific measures implemented for tyres.	It is consider practical to implement measures to ban the use of retreaded tyres and to perform visual checks on truck condition on a more frequent basis than on annual basis.	This potential risk mitigation measure is further evaluated in the Cost Benefit Analysis.
2.9	Cargo frame	1st HAZID Workshop 2nd HAZID Workshop	Not implemented.	Provision of a sturdy steel frame similar to that being used for delivery of 50kg chlorine cylinders was considered practical for providing additional protection of drums from impacts (collisions, rollover) subject to acceptance by relevant authorities. There are also concerns that such a frame would interfere with drum loading/unloading since there is little spare space on the chlorine trucks.	This potential risk mitigation measure is further evaluated in the Cost Benefit Analysis.
2.10	Securing load by improving latching arrangements with additional ropes	Atkins (2006) (ref. R10) Further reviewed following 2nd HAZID Workshop	Not implemented.	Two lashing (one per cradle) are already provided. Additional lashings would not provide any further benefit and instead may pose some additional safety concerns. Additional lashings will require the drums to be supported by more than two cradles which may lead to possible loss to contact with the cradle supports and subsequent unstable and unsafe conditions. The option of tying drums together with a steel cable to mitigate load shedding was considered but would	No further considerations required

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
				lead to new hazards. The metal on metal contact with the drums could generate sparks and lead to fire risk and also there could be new hazards arising during lifting operations if these tie cables are not removed. Also under fire condition, it will take more time to remove the drums from the fire source. Additional lashings/ropes therefore not considered practical. It has also been proposed to increase the tensile strength of the lashing. According to the guidelines given by the Chlorine Institute, the aggregate working load limit of the tie-down assemblies used to secure an article in any direction must be at least one half the weight of the article, for instance, the gross weight of a full drum would be about 1,700 kg, then the minimum SWL of each fabric strap (using two straps for one drum) should be 1700 / 2 × 0.5 = 425 kg. The existing arrangement using fabric strap of 1,000kg SWL is therefore safe and adequate for the purpose.	

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
Improvement of Drum Design					
3.1	Improvements to drum design to minimise the risk of a leak in an impact situation (e.g. truck crash, rollover, load shedding)	1st HAZID Workshop Atkins (2006) (ref. R6)	WSD indicated that, impact test has been performed in City University to assess the impact ability of drums. This resulted in recommendations that have led to drum design improvements: valve cap has been strengthened and bolts changed to stainless steel to avoid corrosion. The chlorine container replacement programme is retained at 12 years. In addition there is a procedure to scrap drum in case of visual damage. Already implemented. This is the basis for the hazard to life assessment.	Already implemented.	No further considerations required.
3.2	Higher integrity drums (increased thickness)	1st HAZID Workshop	Not implemented.	Not practical as drums need to comply with Chinese standards GB5100. A drum with thickness higher than 12mm is not available on the market. GB5100 specifies the minimum wall thickness of drums, which is about 4.1 mm for a 1-tonne drum of 800 mm diameter. The current thickness (12 mm)	No further considerations required.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
				is about 3 times the thickness required.	
3.3	Use of smaller drums	1st HAZID Workshop	Not implemented.	Smaller drums are not available on the market. This would also require redesign of the Chlorination House since a larger number of drums would be required if the drums are smaller, to maintain same storage capacity. However, the store is not large enough for increased number of drums. This option is therefore not considered practical.	No further considerations required.
3.4	Use of 50kg cylinders instead of 1-tonne drums	1st HAZID Workshop Atkins (2006) (ref. R8)	Not implemented.	This would require redesign of the Chlorination House as chlorine usage in Sha Tin WTW is very high and store would not be large enough for number of cylinders required. This option is therefore not considered practical.	No further considerations required.
3.5	Bulk transport of chlorine	1st HAZID Workshop Atkins (2006) (ref. R9)	Not implemented.	The Chlorination House is designed for handling one tonne drums (lifting equipment, cradles, process equipment, etc. are designed for handling 1-tonne drums). This will require substantial Chlorine House redesign and modifications. Also, concerns from district council expected given the potential higher consequences than 1-tonne drums. This option is not considered practical.	No further considerations required.
3.6	Internal excess flow valve or restriction orifice in the valve pipe inside the drums	1st HAZID Workshop	Not implemented.	Not available on the market from the 1-tonne drums supplier. This option is not	No further considerations required.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
	which limits the maximum flow in the event of a valve failure or valve damage	Atkins (2006) (ref. R7)		considered practical.	
3.7	Provision of special protective cap and guard for the drum valves	1st HAZID Workshop	Implemented and improved following CityU study. This is the basis for the hazard to life assessment.	Already implemented.	No further considerations required.
3.8	Higher frequency of integrity checks (radiography or ultrasonic test inspection)	1st HAZID Workshop	Hydraulic testing up to 33 bar every 4 years. 100% radiography conducted at time of manufacture. The chlorine container replacement programme is retained at 12 years. In addition there is a procedure to scrap drum in case of visual damage.	Annual periodic radiography or ultrasonic test inspections in addition to full checking at time of manufacture could be conducted. Although, there is a high volume of drums to be checked, this option may be considered practical.	This potential risk mitigation measure is further evaluated in the Cost Benefit Analysis.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
Procedural Control Improvement					
4.1	Emergency kit compliant with Chlorine Institute specifications	1st HAZID Workshop 2nd HAZID Workshop Atkins (2006) (ref. R13)	Already implemented, Kit A and Kit B as per Institute requirements. This is the basis for the hazard to life assessment.	Already implemented.	No further considerations required.
4.2	Improvements to emergency response in the event of a road truck chlorine incident	1st HAZID Workshop	FSD have internal guidelines and training on emergency response to chlorine truck accident. WSD are now developing some simulators and training for using the emergency repair kits for truck drivers. WSD informed that drivers receive training and receive an annual certificate. Communications and PA system available on trucks. This is the basis for the hazard to life assessment.	Already implemented.	No further considerations required.
4.3	Safe/defensive driving training to driver combined with GPS speed control and monitoring system to ensure safe driving	1st HAZID Workshop 2nd HAZID Workshop	A GPS fleet management system is planned to be implemented before the start of the reprovisioning works. This will be used to monitor and enforce operating	This will be provided as a standard provision before the start of the reprovisioning works.	No further considerations required.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
	behaviour from driver		speeds of chlorine trucks. This will also be used to monitor speed profiles and lower speed limits for specific section of the route (high population areas or high transport risk). This is the basis for the hazard to life assessment.		
4.4	Vehicle accompanying chlorine truck along critical road sections in Sha Tin area	1st HAZID Workshop 2nd HAZID Workshop	Not implemented.	The use of an accompanying vehicle was considered feasible if limited to WSD contract vehicles. Escort by FSD or police vehicles was considered not feasible. An accompanying vehicle may help mitigate frequency of collision by providing greater separation distance to other road users but the effectiveness would be limited. An accompanying vehicle may also provide rapid response to an incident (collision, fire, etc.) but any action would be limited to containing a small leak.	This is considered as a “good practice” measure. The vehicle should be equipped with emergency kit, fire extinguisher, radio set for communication.
4.5	Escort vehicle with fire fighting provisions	1st HAZID Workshop	Not implemented.	In addition to considerations for Item 4.4, fire fighting services would require to be of similar design as FSD vehicles and operated by non-FSD personnel. As such vehicle standard is not available for non-FSD operation, agreement from FSD and HKPF is unlikely and such an option is not considered practical.	Refer to Item 4.4.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
4.6	Emergency response coordination between drivers, accompanying vehicles if any and FSD	1st HAZID Workshop Atkins (2006) (ref. R14)	The emergency response plan has already implemented. This is the basis for the hazard to life assessment. Communication system is provided with procedures for contacting FSD and HKPF. FSD have internal guidelines and training on emergency response to chlorine truck accidents. WSD now provide emergency repair kits and training for truck drivers to enable them to respond to small leaks. Truck drivers receive training and an annual certificate.	Already implemented.	No further considerations required.
4.7	Chlorine contain and scrubber system in trucks	1st HAZID Workshop Atkins (2006) (ref. R11, R12)	Not implemented.	The “Scrub and Contain System” prepared by US Scrubber System Supplier in 2003 was purely a proposal which was proven to be not practical in design. Improved version of such “Scrub and Contain System” is not available in the current market. WSD agreed to keep in view latest technology for possible new method to reduce the risks further.	Keep in view.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
4.8	Night time or early morning delivery	1st HAZID Workshop Atkins (2006) (ref. R1)	Not implemented.	From an operational point of view, this measure is not considered practicable because of the noise issue and low manning levels for handling drums at night-time. Also, this poses some control, monitoring and safety concern as small leakages would not be visible and serious traffic accidents tend to occur at night or early morning (driver over speeding under low traffic condition). Therefore, nigh time delivery is not considered practical.	No further considerations required.
4.9	Traffic control during chlorine truck passage	1st HAZID Workshop	Not implemented.	Chlorine delivery is relatively frequent and stopping adjacent traffic during a delivery would affect a large number of road users and cause public concern. This measure would also require approval by the relevant authorities. This measure is not considered practical in Hong Kong given the high traffic volumes.	No further considerations required.
4.10	Half-fill drums	1st HAZID Workshop	Not implemented.	Half fill drums would pose operational constraints with different drums going to different WTWs. In addition, the chlorine storage at Sha Tin WTW not big enough to double the number of drums that would be required if each drum is only half full. This will require substantial Chlorination House redesign and modifications. This is therefore not considered practical.	No further considerations required.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
Other improvements					
5.1	Road improvements – barriers, signs, etc.	1st HAZID Workshop Atkins (2006) (ref. R2)	Not implemented.	All new public roads are designed and constructed to the transport Planning & Design Manual issued by the Transport Department. No further risk mitigation measures considered practical.	No further considerations required.
5.2	Road improvements – new roads	1st HAZID Workshop Atkins (2006) (ref. R3)	Not implemented.	The Transport Department is the responsible authority for any road improvement works related to road safety and should maintain the roads in safe condition. Further improvement is not considered practical.	No further considerations required.
5.3	Alternative transport route	1st HAZID Workshop 2nd HAZID Workshop Atkins (2006) (ref. R4)	The transport route has been reviewed, and the shortest route with the lowest population density has been adopted. This is as the basis for the hazard to life assessment.	Alternative routes through Tai Wai were considered. Widening of Keng Hau Road may be considered for more direct route from Tai Po Road to Sha Tin WTW. This will bypass heavily populated area in Tai Wai. However, this road is steep, has a 5 tonne weight limit and passes close to village houses. This alternative route is not considered practical. Other routes are longer and with higher population density. Therefore the most practical route has already been considered.	No further considerations required.
5.4	Dedicated access tunnel from Tai Po Road	1st Workshop (ref.5.1.4)	Not implemented.	Not practical in short term.	This potential risk mitigation measure is further evaluated in the Cost Benefit Analysis.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
5.5	Optimise the transport routes to minimise risks with import by truck direct from China	1st Workshop (ref.5.1.5) Atkins (2006) (ref. R5)	Not implemented.	This recommendation is applicable only to WTWs near the boundary and would transfer some of the risks to the Shenzhen areas. This would be a sensitive issue and would be difficult to get approval from the Chinese Authorities as the chlorine trucks would be required to route through the heavily trafficked ports at the border. This measure is therefore not considered practical.	No further considerations required.
5.6	Alternative dock	2nd HAZID Workshop	Not implemented.	An alternate chlorine receiving dock in the Sha Tin/Tai Po area would significantly shorten road transport distances with corresponding reduction in risk. This was suggested in the 2006 Atkins study and should be pursued as a long term objective. The Tseung Kwan O dock could be considered as an alternative choice however it requires chlorine transportation in dense population areas. Therefore, to date, no practicable site has been identified for an alternate dock. This option is therefore not considered practical. The option of extending the use of the Kai Tak chlorine dock has also been considered. However, this option is not feasible due to the Kai Tak development	Keep in view.

Ref.	Potential Risk Mitigation Measure	Source	Implementation Status	Evaluation of Risk Mitigation Practicality	Further Consideration
				project.	

Cost Benefit Analysis

12.26.12 The preceding sections identified a number of mitigation measures to take forward into a cost-benefit analysis (CBA). CBA is widely used in QRA studies to evaluate the cost-effectiveness of alternative measures and provide a demonstration that all reasonably practicable measures have been taken to reduce risks.

12.26.13 In this study, the CBA follows the methodology adopted for the on-site Sha Tin WTW QRA and has been applied by calculating the implied cost of averting a fatality (ICAF) for the various mitigation measures identified in the preceding sections. The ICAF value is calculated as follows:

ICAF = Cost of mitigation measure / (Reduction in PLL value × Design life of mitigation measure).

12.26.14 ICAF is a measure of the cost per life saved over the lifetime of a project due to implementation of a particular mitigation measure. It may be compared with the value of life to determine whether a mitigation measure is reasonably practicable to implement, i.e. if ICAF is less than the value of preventing a fatality, then the mitigation measure should be implemented. In this study the value of life is taken as HK$ 33M, which is the same figure as used in previous QRA (ERM, 2001).

12.26.15 Depending on the level of risk, the value of life figure may be adjusted to reflect people's aversion to high risk. Following ERM (2001) the aversion factor is taken as 20, as the FN curve runs close to the 1000 fatalities cut-off line. The adjusted value of preventing a fatality using the aversion factor of 20 becomes HK$ 660M. This also implies the maximum justifiable spend (MJS) for a particular mitigation measure, which is given by

MJS = HK$ 660M × Reduction in PLL value × Design life of mitigation measure.

A mitigation measure is considered cost effective if its cost is less than its MJS.

12.26.16 *Table 12.37* summarises the Cost Benefit Analysis using the ICAF method and MJS method for the various practical risk mitigation measures identified above.

Table 12.37 Cost Benefit Analysis

Ref.	Potential Risk Mitigation Measure	Note	Cost Estimate (HK$M)	PLL reduction (per year)	Design life (years)	MJS (HK$M)	ICAF (HK$M)	(ICAF < $660M?)	Recommendation
1. Improvement of Sha Tin WTW									
Not applicable									
2. Improvement of Truck Design									
2.3	Reduction of combustible such as provision of fire resistant materials, cables, and limit on fuel tank capacity	The cab design should be reviewed for further reduction in combustible. The fuel tank quantity should also be kept to the minimum required for the trip. This measure will have some but no significant reduction in the PLL due to fire scenario (Fire Scenario PLL = 5.44E-6 per year). For the purpose of this assessment a conservative risk reduction of 50% has been considered for all fire events. The cost of implementation is based on modification work assumed to be around HK$ 150,000 in total with a truck service life of 10 years. As this risk mitigation measure may require research and approval by	0.15	2.72E-6	10	0.02	5,517	N	Considering the relative low cost of this measure, it is recommended to further review the practicality of reducing combustible materials or use of fire retardant materials in the cab. This should include procedures to limit contents in fuel tanks. This should be considered as a long term measure.

Ref.	Potential Risk Mitigation Measure	Note	Cost Estimate (HK$M)	PLL reduction (per year)	Design life (years)	MJS (HK$M)	ICAF (HK$M)	(ICAF < $660M?)	Recommendation
		the relevant authorities, this option is not considered practical in the short term.							
2.5	Provision of side/ front/ rear crash guards with high energy absorption	This option will require design and testing in accordance with the relevant authorities' requirements. This may require significant investment. For the purpose of this assessment a relatively low capital expenditure (HK$ 0.5M per truck × 3 trucks) has been considered. This measure will be effective for reducing the likelihood of chlorine release events due to small impact (100% reduction) and medium impact (50% reduction). This gives a base frequency of 7.13E-9 per truck-km for accidents having potential to cause significant mechanical impact on the chlorine drums. As a result, PLL due to collision (see *Table 12.34*) is reduced from 1.12E-5 per year to 4.36E-6	1.5	6.86E-6	10	0.05	21,851	N	It is recommended to implement side, front and rear crash guards with high energy absorption in coordination and accordance with the relevant authorities. Redesign of truck is required and this item will be further reviewed for implementation if a practical design can be agreed by relevant authorities.

Ref.	Potential Risk Mitigation Measure	Note	Cost Estimate (HK$M)	PLL reduction (per year)	Design life (years)	MJS (HK$M)	ICAF (HK$M)	(ICAF < $660M?)	Recommendation
		per year. As this risk mitigation measure may require research, design, testing, and approval by the relevant authorities, this option is not considered practical in the short term.							
2.8	Improved tyres design and checks	It is assumed that banning the use of retreaded tyres and improved visual checks on the tyres will reduce the overall PLL for fire (5.44E-6), collision (1.12E-5) and rollover (8.63E-6) events by 1% overall. This gives a PLL reduction of (5.44E-6 + 1.12E-5 + 8.63E-6) × 0.01 = 2.53E-7.	0.05	2.53E-7	5	8.34E-4	39,550	N	Considering the relative low cost of this measure, it is recommended to ban the use of retreaded tyres and perform regular visual checks on the tyres. This measure should be implemented before the start of the reprovisioning project.
2.9	Cargo frame	Provision of a sturdy steel frame similar to that being used for delivery of 50kg chlorine cylinders would require design and testing in accordance with the relevant authority requirements. This may require significant investment. For the purpose of this assessment a	1.5	7.76E-6	10	0.05	19,323	N	It is recommended to implement a sturdy steel frame to minimise the potential for chlorine release due to truck rollover. Redesign of truck is required and this item will be further reviewed for implementation if a practical design can be agreed by relevant authorities.

Ref.	Potential Risk Mitigation Measure	Note	Cost Estimate (HK$M)	PLL reduction (per year)	Design life (years)	MJS (HK$M)	ICAF (HK$M)	(ICAF < $660M?)	Recommendation
		relatively low capital expenditure (HK$ 0.5M per truck × 3 trucks) has been considered. Such cargo frame could reduce the likelihood of chlorine release events due to rollover events by 90%. This gives a PLL reduction of 8.63E-6 × 0.9 = 7.76E-6. As this risk mitigation measure may require research, design, testing, and approval by the relevant authorities, this option is not considered practical in the short term.							
3. Improvement of Drum Design									
3.8	Higher frequency of integrity checks (radiography or ultrasonic test inspection)	Annual periodic radiography or ultrasonic test inspections of the chlorine drums in addition to full checking at time of manufacture and replacement of drums every 10 years will reduce the risk associated with spontaneous failures (PLL = 8.75E-5 per year) by 90% if the radiography of the drum	5	4.38E-5	10	0.29	11,427	N	Annual periodic radiography or ultrasonic test inspections of the chlorine drums should be considered for implementation as soon as feasible. This should be considered as a long term measure.

Ref.	Potential Risk Mitigation Measure	Note	Cost Estimate (HK$M)	PLL reduction (per year)	Design life (years)	MJS (HK$M)	ICAF (HK$M)	(ICAF < $660M?)	Recommendation
		is complete. A conservative 50% reduction in PLL is assumed for calculation purposes. This gives a PLL reduction of 8.75E-5 × 0.5 = 4.38E-5. This risk mitigation measure will require procurement of new materials, additional resources and training. It may not be practical as a short term mitigation measure.							
4. Procedural Control Improvement									
4.4	Vehicle accompanying chlorine truck along critical road sections in Sha Tin area	This is considered as a “good practice” measure.	-	-	-		-	-	-
5. Others improvements									
5.4	Dedicated access tunnel from Tai Po Road	The total PLL is 1.14E-4 (base case during operation phase). Assuming a dedicated tunnel at Tai Po Road for chlorine transport can completely reduce fatality afterwards, this gives	500	1.14E-4	50	3.76	87,868	N	-

Ref.	Potential Risk Mitigation Measure	Note	Cost Estimate (HK$M)	PLL reduction (per year)	Design life (years)	MJS (HK$M)	ICAF (HK$M)	(ICAF < $660M?)	Recommendation
		a PLL reduction of 1.14E-4. Although this measure has significant risk reduction, this requires significant capital expenditure of around HK$ 500 M or more.							

Discussion

12.26.17 It can be concluded from the Cost Benefit Analysis that the following risk mitigation measures should be implemented. It should be noted that some of these mitigation measures require further investigation, detailed design, testing or approval by relevant authorities and are hence considered as long term mitigation measures. The mitigation measures to be implemented together with the implementation schedule are presented in *Table 12.38* below. Item 2.5 (crash guards) and Item 2.9 (cargo frame) of *Table 12.36* require redesign of the truck and either of these will be implemented if a practical design can be agreed by relevant authorities. No credit had been taken in the analysis.

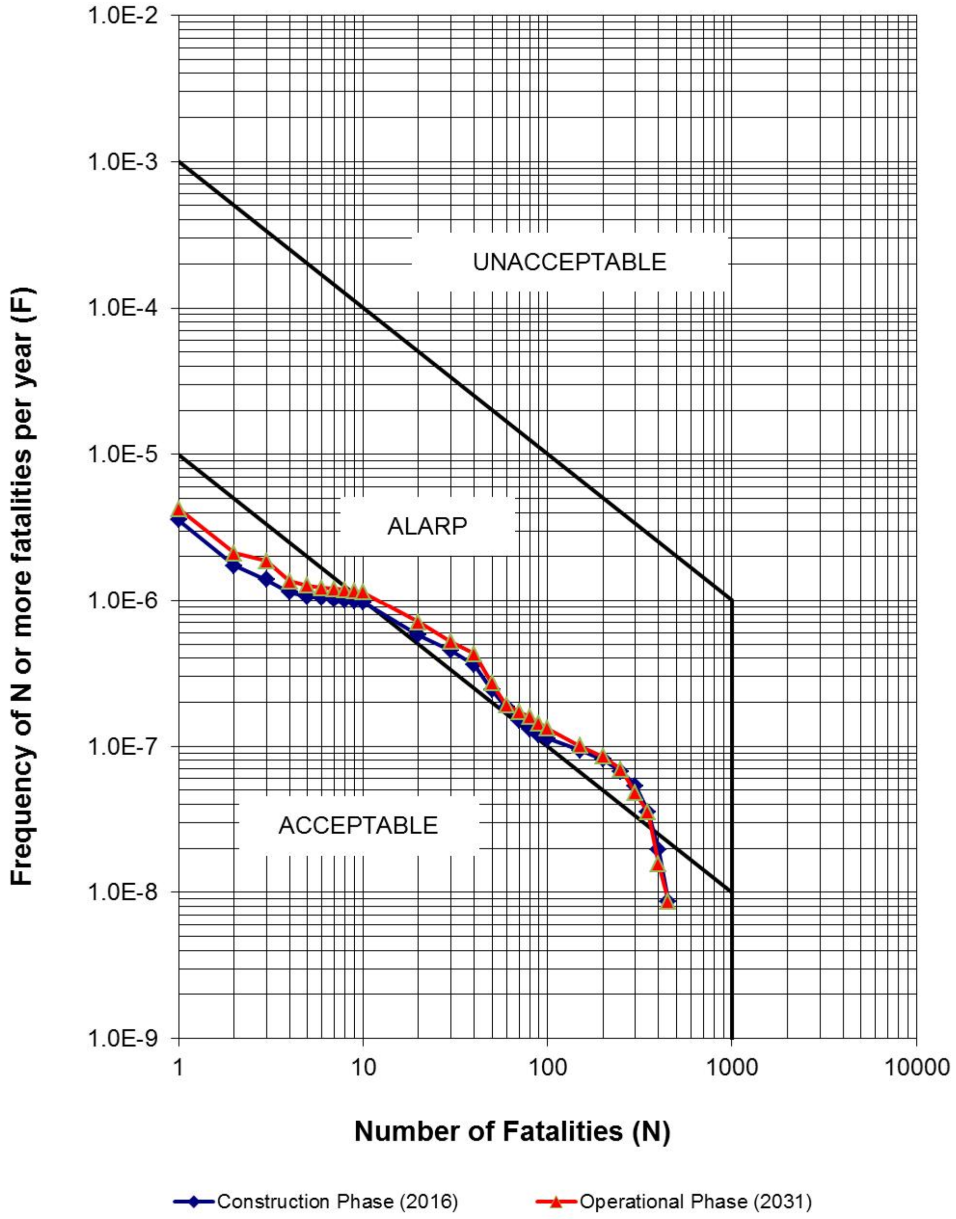
12.26.18 The FN curves after implementing these recommendations are shown in *Figure 12.28*.

Table 12.38 Selected Risk Mitigation Measures and Implementation Schedule

Ref.	Potential Risk Mitigation Measure	Implementation Schedule
2.3	Reduction of combustible such as provision of fire resistant materials, cables, and limit on fuel tank capacity*	Long term measure
2.8	Improved tyre design and checks	To be implemented at the beginning of project
3.8	Higher frequency of integrity checks (radiography or ultrasonic test inspection)	Long term measure
4.4	Vehicle accompanying chlorine truck along critical road sections in Sha Tin area*	Good practice measure

*Credit not taken in the mitigated case.

Figure 12.28 Mitigated FN Curves for STWTW



12.27 Conclusions and Recommendations

12.27.1 The risks related to the chlorine transport to Sha Tin Water Treatment Works have been assessed. The base case assessment considers the transport route within the Sha Tin WTW Consultation Zone. IR results are well below the 10^{-5} per year for all section of the route. This is typical of transport risks where the risks are distributed along the length of the route.

12.27.2 The societal risk expressed in the form of FN curves, lies in the "ALARP" region of the HKRG with N_{max} is below 500 for both Construction and Operational Phases.

12.27.3 A number of mitigation measures have been considered and a number of short term and long term risk mitigation measures have been recommended following a formal Cost Benefit Analysis to ensure the risk is ALARP.

12.27.4 The following are recommendations from the formal Cost Benefit Analysis:

Short term measures

- It is recommended to ban the use of retreaded tyres and perform regular visual checks on the tyres. This measure should be implemented before the start of the reprovisioning project (Item 2.8); and
- Vehicle accompanying chlorine truck along critical road sections in Sha Tin area is recommended as a "good practice" measure. The function of the vehicle is to: (i) monitoring the operation of the chlorine truck; and (ii) providing all necessary assistance in case of any emergency happened to the chlorine truck at the concerned road section. It is recommended that vehicle should be equipped with emergency kit, fire extinguisher, radio set for communication (Item 4.4). The accompanying vehicle will be ahead of the chlorine truck after the vehicles entering the water treatment works site.

  - An accompanying vehicle may provide rapid response to an incident (collision, fire, etc.) but any action would be limited to containing a small leak.

Long term measures

- It is recommended to limit fuel tanks capacity at the beginning of the Project (Item 2.3 – advance measure);
- It is recommended to further review the practicality of reducing combustible materials or use of fire retardant materials in the cab. (Item 2.3 – further measure); and
- Annual periodic radiography or ultrasonic test inspections of the chlorine drums should be considered for implementation as soon as feasible (Item 3.8).

  - The implementation programme for the two long term measures is proposed to split into 2 stages, investigation stage and implementation stage. The investigation stage is to be completed by Q1 of 2016 so that practical RMMs could be incorporated into the next chlorine supply contract. The time frame for the implementation stage, for those RMMs found practical in the investigation stage would be formulated.

  - The investigation stage is further split into 2 phases, the review phase and the preliminary design phase. Despite the fact that time frame for the two phases may vary from one RMM to another RMM, as a general approach and on the assumption that Environmental Permit for the South Works Reprovisioning Project could be obtained in Q2 of 2015, the review phase is proposed to be completed by Q3 of 2015, leaving about 6 months for the preliminary design phase.

  A detailed implementation plan for selected risk mitigation measures is given in *Table 12.39*.

Table 12.39 Detailed Implementation Plan for Selected Risk Mitigation Measures

Risk Mitigation Measures	Date of implementation	Implementation Agent(s)	Relevant Authorities
Improved tyre design and checks (Item 2.8)	To be implemented at the beginning of project	WSD/Chlorine Supply Contractor	EMSD
Limit on fuel tank capacity (Item 2.3 – advance measure)	To be implemented at the beginning of project	WSD/Chlorine Supply Contractor	EMSD
Provision of fire resistant materials, cables (Item 2.3 – future measure)	Q3 of 2015	WSD/Chlorine Supply Contractor	EMSD/FSD
Higher frequency of integrity checks (radiography or ultrasonic test inspection) (Item 3.8)	Q3 of 2015	WSD	-
Vehicle accompanying chlorine truck along critical road sections in Sha Tin area (Item 4.4)	To be implemented at the beginning of project	WSD	FSD

Items to be further reviewed

- It is recommended to implement side, front and rear crash guards with high energy absorption in coordination and accordance with the relevant authorities;
- It is recommended to implement a sturdy steel frame to minimise the potential for chlorine release due to truck rollover; and
- Items 2.5 (crash guards) and 2.9 (cargo frame) require further review and either of these will be implemented in Q1 of 2016 after a practical design is agreed by relevant authorities during the investigation phase. These items will be kept in view if the design cannot be finalised by Q1 of 2016.

12.27.5 The following additional recommendations relating to the transport of Chlorine from SSK dock to Sha Tin WTW have been made to ensure the risk remains in the ALARP region:

- WSD will continue to keep under review the latest development of use of alternative disinfectants in water supply industry to aim at minimizing on-site chlorine storage;
- Training should be provided for the use of the GPS fleet management and improved safe driving;
- It should be ensured that independent checks are performed to ensure proper chlorine drum latching and clamping;
- Chlorine truck drivers or driver attendants should be further trained to check and detect potential chlorine leaks during transport. This should include the timely application of the emergency kit;

- Training should be provided to driver and driver attendant for the emergency use of the new 2 × 9L AFFF extinguishers;

- Induction training for new drivers and driver attendant should include familiarisation with the route, familiarisation with chlorine risks, defensive driving, application of emergency kits, use of fire extinguishers and emergency response;

- Provision of a fire screen between the cab and cargo as well as fire retardant materials for the wheel arches on the chlorine truck should be planned and provided; and

- To keep under review alternate chlorine receiving dock in Sha Tin/Tai Po area for chlorine delivery to STWTW.

Total Chlorine Risk

12.28 Societal Risk

12.28.1 Risks from the on-site Sha Tin WTW chlorine facilities were combined with the off-site chlorine transport risks within the 1-km STWTW CZ to obtain the total chlorine risks. These are presented as FN curves in *Figure 12.29*. Both the Construction Phase (2016) and the Operational Phase (2031) results lie in the ALARP region. RMMs listed in *Table 12.38* are not considered. PLL values are presented in *Table 12.40*.

Figure 12.29 FN Curves for Total Chlorine Risk of STWTW

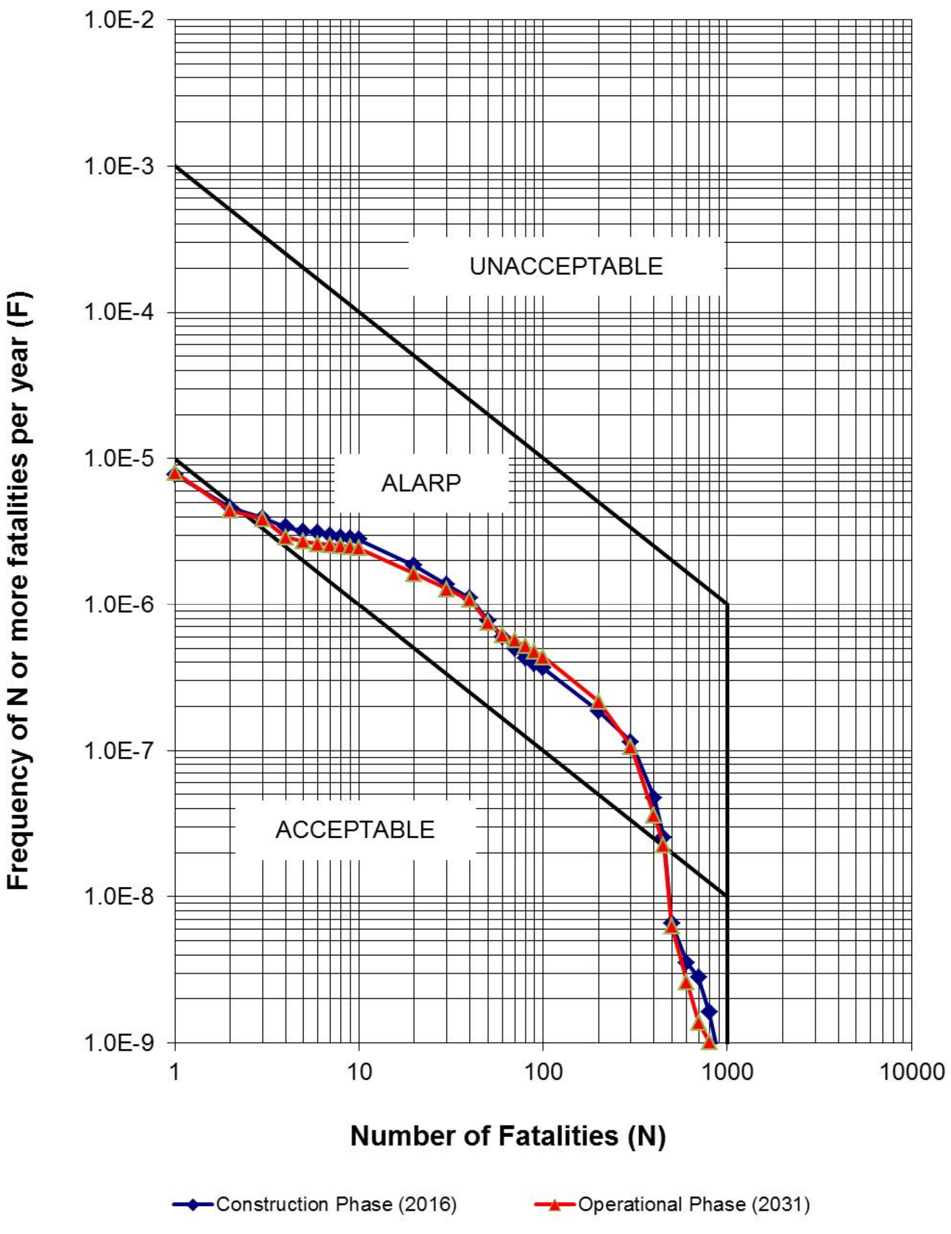


Table 12.40 PLL for On-site Chlorine and Off-site Chlorine Transport

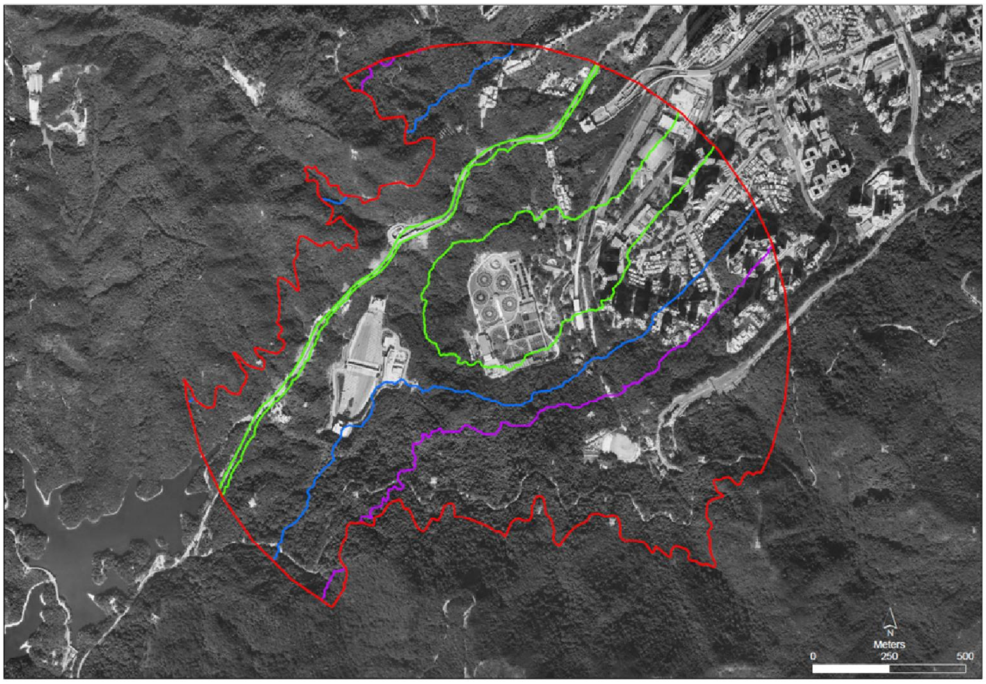
	PLL per year (Construction Phase)	PLL per year (Operational Phase)
Sha Tin WTW on-site	7.36E-5	5.98E-5
Off-site transport	1.01E-4	1.14E-4
Total	**1.74E-4**	**1.74E-4**

12.29 Individual Risk

12.29.1 Combined individual risk contours for the on-site Sha Tin WTW and off-site transport of chlorine are shown in *Figure 12.30*. Only the Operational Phase (2031) results are shown since these have the higher risks owing to higher chlorine usage.

12.29.2 Individual risks are low, reaching a maximum of about 10^{-7} per year.

Figure 12.30 Chlorine Total Individual Risk, Operational Phase



Cumulative Risk within the Consultation Zone

12.30 Cumulative Risk Assessment

12.30.1 This section addresses requirements of Section 3.2.2 (xi) of the Study Brief related to cumulative impacts of the Project. These are presented as combined Individual Risk contours following the same approach as the approved EIA for the Kai Tak Development project. RMMs listed in *Table 12.38* are not considered.

12.30.2 The cumulative risks within the consultation zone of Sha Tin WTW from hazardous installations was calculated by summing the risks from Sha Tin WTW on-site facilities, off-site chlorine transport (section of route within consultation zone), the Beacon Hill North Offtake Station, the 750mm and 500mm gas pipelines that run through the Old Beacon Hill Tunnel, explosives transport through the consultation zone arising from the construction of the SCL project and use of explosive at the Hin Keng portal of SCL.

12.30.3 Assessment of risks from the transport of explosives for SCL was obtained using the same transport model as described in the SCL EIA (ERM, 2011b). The model was rerun for only the section of route that intersects the Sha Tin WTW Consultation Zone. All other parameters are identical to those described in ERM (2011b). These risks, however, contribute only to the construction phase scenario when concurrent Sha Tin WTW reprovisioning and SCL construction will take place. This risk associated with SCL explosives transport are of the order of 2×10^{-8} per year and are included in the IR contour plots.

12.30.4 Risks associated with the use of explosives were also extracted from the SCL EIA (ERM, 2011b). The main hazards are related to ground vibrations leading to building collapse or vibrations leading to falling objects. All buildings within the Sha Tin WTW Consultation Zone are out of range of vibration effects from blasting activities at the Hin Keng portal. The risk associated with initiation of explosives during transit from the Hin Keng portal construction site entrance to the blast face were calculated in the SCL EIA (ERM, 2011b) as 8.62×10^{-8} per year, and included in the IR contour plot.

12.30.5 Risks from the Beacon Hill North Offtake Station and the 750mm and 500mm pipelines were established by conducting a QRA.

12.30.6 The FN curves for the Construction Phase and Operation Phase are shown in *Figure 12.31* and the resulting individual risk contours are shown in *Figure 12.32* and *Figure 12.33* respectively. Cumulative risks are low, below 10^{-6} per year everywhere except for only a very small area around the Beacon Hill North Offtake Station which has been fenced off to prevent the public from getting near this Towngas installation.

Figure 12.31 FN Curves of cumulative risks within STWTW Consultation Zone

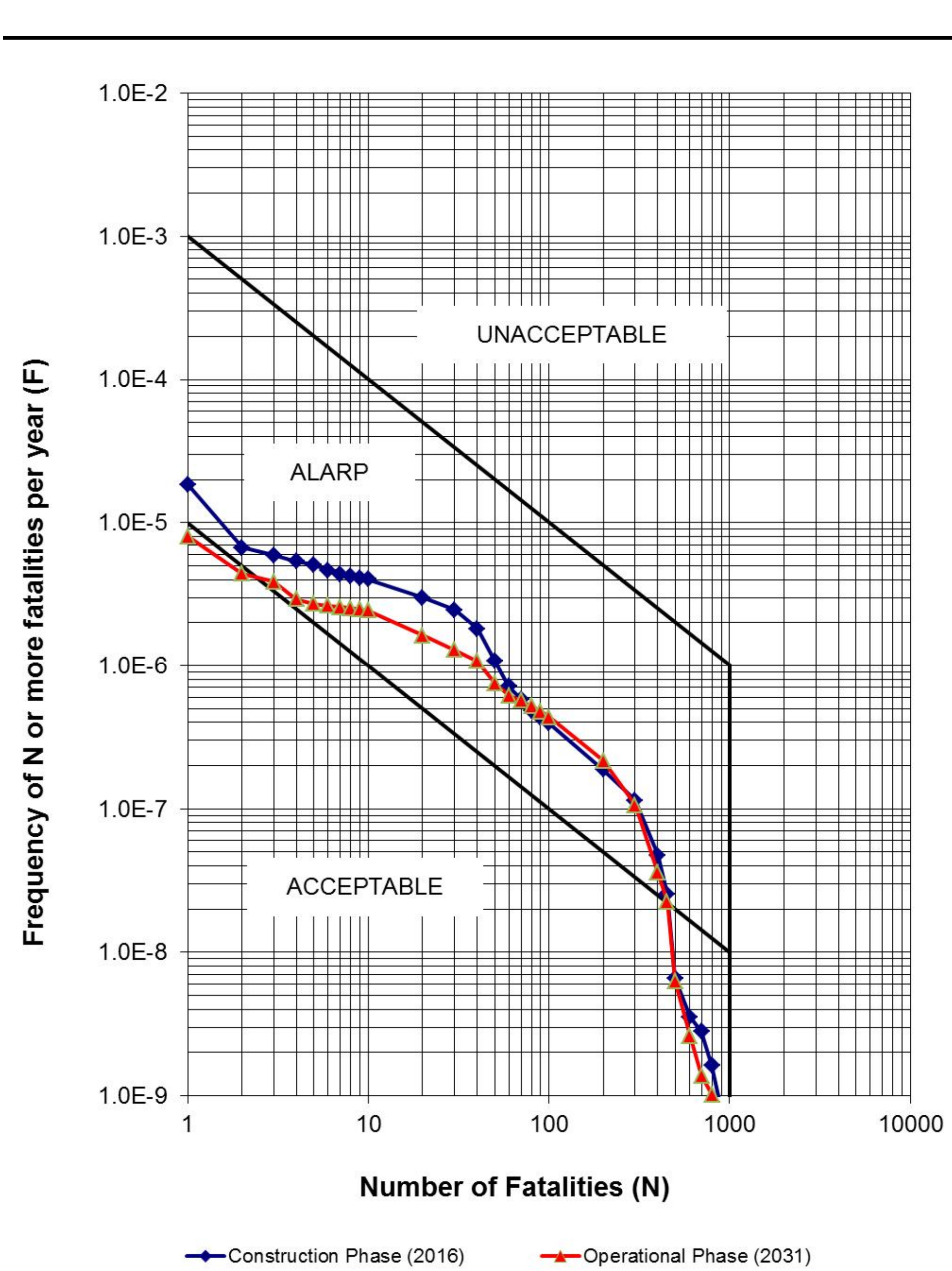


Figure 12.32 Cumulative Individual Risk - Construction Phase

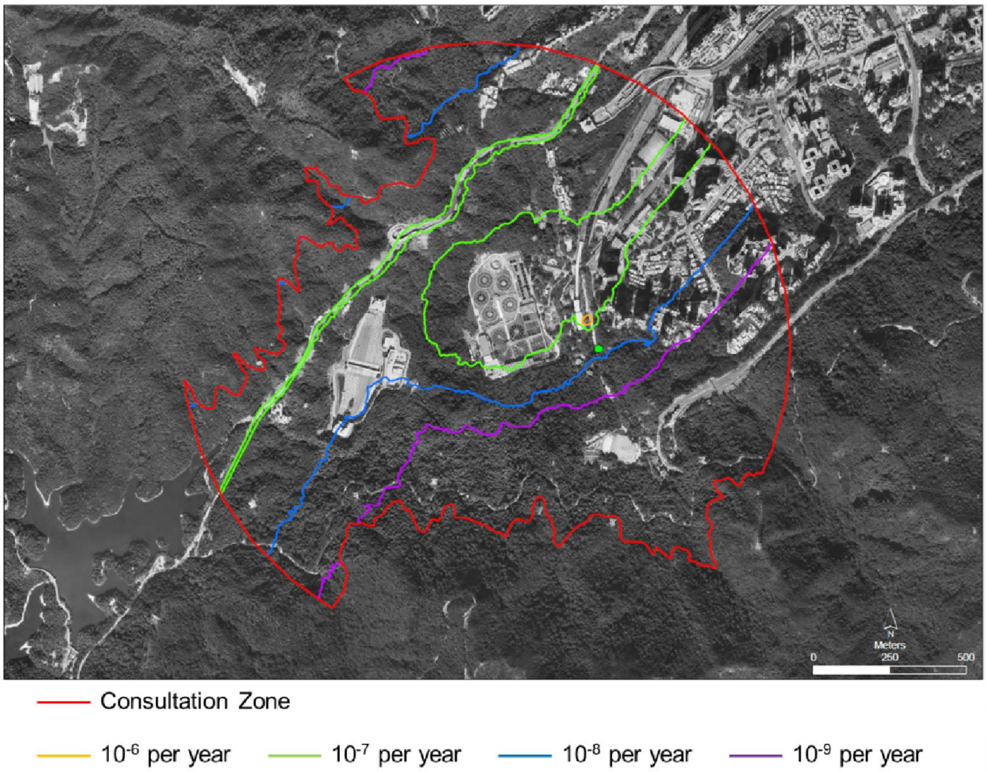
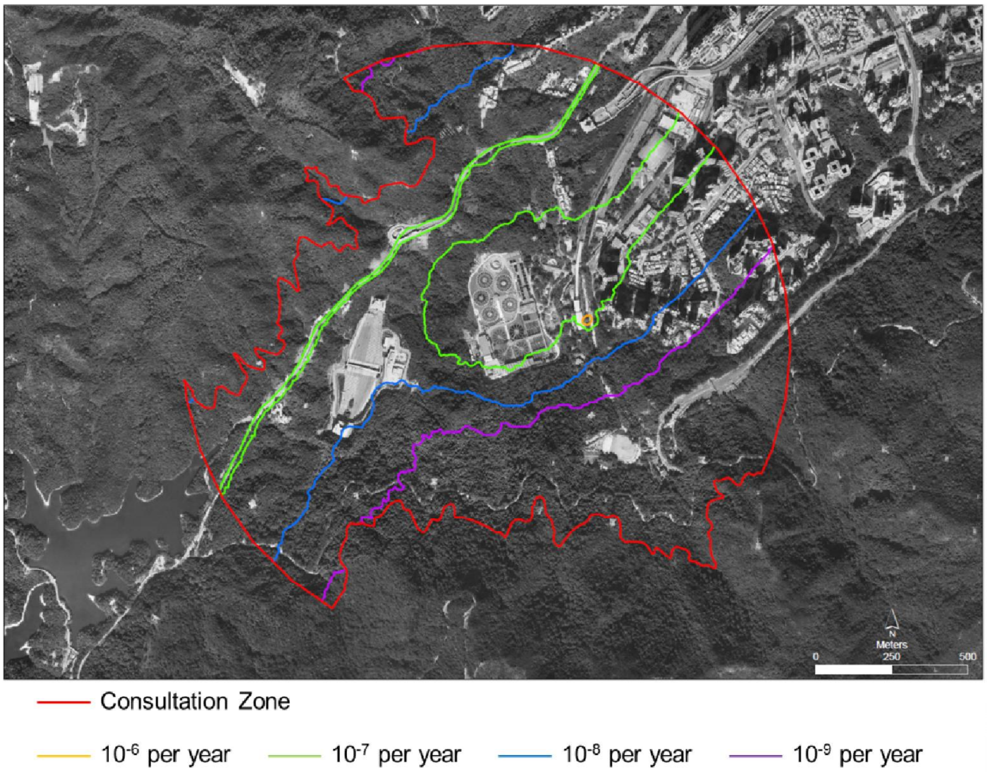


Figure 12.33 Cumulative Individual Risk – Operational Phase



Uncertainty Analysis

12.31 STWTW Chlorine

12.31.1 This section assesses the level of uncertainty in the estimates of individual and societal risk by carrying out sensitivity studies on the key parameters and modelling assumptions, in association with the Sha Tin WTW operation and its reprovisioning works, BHN Offtake Station and gas pipelines within the Old Beacon Hill Tunnel (this analysis shall be read together with the main report figure assessing the 1-km STWTW CZ with the cumulative risk within the CZ (*Figure 12.31*). The purpose of this is to gauge the level of confidence in the risk results.

12.31.2 The overall approach to this study has been to move away from the pessimistic assumptions of past studies to provide a more realistic assessment of the risks posed by the delivery, storage and handling of chlorine at the STWTW. This has involved extensive reviews of all aspects of the assessment methodology. The overall approach which has been adopted may be described as 'cautious best estimate'.

12.31.3 *Annex K* of ERM (2001) lists the key parameters and assumptions in the QRA, then identifies the level of uncertainty in the parameter (or assumption) and, finally, assesses the overall level of uncertainty in the risk results. The focus of this analysis is on key parameters (or assumptions) which may either significantly underestimate or overestimate the risk. The results of the uncertainty analysis are summarised in *Table 12.41* below.

Table 12.41 Summary of Uncertainty Analysis

Parameter	Uncertainty in risk results	
	Magnitude	**Affects frequency (F) or number of fatalities (N) ?**
1. Influence of atmospheric stability on direction of travel of chlorine cloud in complex terrain	± a factor of 2	F or N
2. Extent of isopleths predicted by wind tunnel/ALOHA model	± a factor of 2	N
3. Chlorine toxicity relationship	overprediction by a factor of 5 - 15	N
4. Base event frequency data	± a factor of 10	F
5. Conditional probabilities	± a factor of 3	F

12.31.4 From *Table 12.41*, it is apparent that there are significant sources of uncertainty in the QRA. These are associated, in particular, with:

- the chlorine toxicity relationship, which may overpredict the number of fatalities (or, for an individual, the probability of fatality) by a factor of 5-15 when compared to actual fatalities in past incidents of major chlorine releases in urban environments; and
- estimation of the frequency of chlorine releases, for which the range of uncertainty is ± one order of magnitude (typical of the uncertainty in this aspect of QRA studies).

12.31.5 Considering the uncertainty magnitude shown in *Table 12.41*, an uncertainty band of factor of ±30 could be conservatively applied on the frequency (F) scale to account for the uncertainties in parameters 4 and 5 above. For consequence scale (N), if the N would be reduced by a factor of 10 (parameter 3 has an overestimation of 5-15) then the FN curve will be shifted to the left, with an uncertainty band of factor of ±8 (= 2 × 2 × 10/5 for parameters 1, 2 and 3). From the uncertainty analysis summarized in *Table 12.41*, it can be noted that the net effect of the uncertainties is a shift in the FN curve further towards the left of the FN diagram, with the above range of the FN curves lying in the ALARP region. Thus, the overall approach which has been adopted may be described as 'cautious best estimate'.

12.31.6 In addition, a far more conservative approach has been adopted in this study, including using maximum inventory and omitting credits for risk reduction by "good practice" mitigation measures. They are detailed below.

12.31.7 The maximum chlorine drum storage in the chlorination house will be limited to 190 tonne, noting that there are 221 storage castors, 31 excess storage castors will be carefully selected and to be removed from the chlorination house, priority will be given to those situated immediately under the roof beams so as to further minimize the potential chlorine release quantity upon roof beams collapse during earthquake. Hence, chlorine drums of 190 tonnes at the Sha Tin WTW representing the maximum storage capacity is considered as the reasonably worst case for modeling in the QRA.

12.31.8 The mitigation measures to be implemented together with the implementation schedule are presented in *Table 12.38*. However, it shall be noted that the selected mitigation measure "Vehicle accompanying chlorine truck along critical road sections in Sha Tin area" is considered as a good practice measure without taking credits in the QRA model.

12.31.9 In addition, for the potential mitigation measures discussed in *Table 12.37*, Item 2.5 (crash guards) and Item 2.9 (cargo frame) require redesign of the truck and either of these will be implemented if a practical design can be agreed by relevant authorities, hence, credits had not been taken in the analysis at this stage.

12.31.10 Therefore, the overall approach which has been adopted may be described as 'cautious best estimate', and it shall be noted that the risk analysis are on conservative side, with the off-set of uncertainties by using maximum inventory and omitting credits for risk reduction by "good practice" mitigation measures.

12.31.11 Similar considerations apply to the calculated individual risk levels. Individual risk is proportional to the frequency and number of fatalities summed for all incidents. In this case the combination of uncertainty in the parameters listed in *Table 12.41*, above may mean that the individual risk is underestimated by a factor of 2 × 2 × (1/5) × 10 × 3 ≈ 24. A better estimate of the uncertainty in the individual risk may be obtained by considering the specific events which contribute to individual risk. Close to the site, the dominant contributors to individual risk are the events RU1TSRU (a 1-tonne instantaneous release due to a truck impact or fire) and RUITSML (a medium leak arising due to loadshedding or rollover). The uncertainty in the consequence assessment for these events is as represented in *Table 12.41*. However with regard to the frequency assessment, it is unlikely that the current assessment, which is based on the frequency of truck accidents of public roads (involving increased speeds and traffic compared to the WTW access road) could be a significant underestimate. Therefore assuming that the uncertainty in the base event frequency (parameter 4 in *Table 12.41*) for these events is plus or minus a factor of 3, then the possible underestimate in the overall individual risk is 2 × 2 × (1/5) × 3 × 3 ≈ 7.

12.31.12 This is not considered to be a significant factor, as when occupancy is taken into account, risks to actual individuals will still be below the criteria in the Hong Kong Risk Guidelines. Taking maximum cumulative risk of chlorine, towngas and explosives as example, IR of 10^{-6}/year was found located in the vicinity of towngas pipeline, worker exposure related to worker occupancy in the vicinity (i.e. gas pipeline and SCL) is evaluated by assuming the individual risk could be up to 10^{-5} per year (after taking into account the uncertainties) then the risk to the most exposed individual (a worker spending 100% of his time outdoors) is as follows:

IR (most exposed individual of Towngas workers)

= 10^{-5} × fraction of (outdoor) working hours each year

= 10^{-5} × 2920/8760 = 3.33×10^{-6} per year.

IR (most exposed individual of SCL workers)

= 10^{-5} × fraction of (outdoor) working hours each year

= 10^{-5} × 3003/8760 = 3.43 × 10^{-6} per year.

Note: Workers is assumed 100% of his time outdoors on conservative approach only, in fact the workers will not stay 100% of his time outdoors.

12.31.13 Example for estimating fraction of outdoor working hours each year is shown in *Table 12.42.*

Table 12.42 Fraction of Outdoor Working Hours

Time Period (%)	50.00%	0.89%	13.39%	9.52%	26.19%		
Population Ref.	Night	Jammed Peak	Peak Hour	Weekend Day	Working Day	Total	Hours in a year
Towngas worker (W1)	0%	50%	50%	0%	100%		
	0.00%	0.45%	6.70%	0.00%	26.19%	33.33%	2920
SCL workers (Z6, Z7, Z8)	0%	50%	50%	10%	100%		
	0.00%	0.45%	6.70%	0.95%	26.19%	34.29%	3003
SCL Construction Offices/yard (Z9)	0%	50%	50%	10%	100%		
	0.00%	0.45%	6.70%	0.95%	26.19%	34.29%	3003

12.32 BHN Offtake Station and Pipelines in the Old Beacon Hill Tunnel

12.32.1 Uncertainty factors in assessing BHN Offtake Station and Old Beacon Hill Pipelines risk have also been estimated. Town gas contains hydrogen, methane and carbon monoxide which are flammable. The effects of buoyancy are modelled in the plume rise model and the presence of lighter gas (i.e., hydrogen) has considerable contribution to the overall buoyancy. Methane is conservatively chosen as the representative material for town gas in this assessment study to effectively reduce the buoyancy effect and increase flammable cloud size near ground level. The results given for hazard distances for flash fires and toxic effects are therefore conservative.

12.32.2 Fireball events are found to dominate the PLL and also the high fatality region of the FN curve. However, there are a number of pessimism's in the estimation of fireball effects. For instances, effects at or near ground level may not be significant due to the initial plume rise due to momentum effects prior to ignition; there are limited immediate ignition sources for underground pipe sections and pipelines within tunnel leading to fireball events.

12.32.3 The ignition probabilities adopted for this study are significantly higher than historical data for US and European pipeline failures. The overall ignition probability as given by EGIG data (EGIG, 2007) is 0.1. Despite the urban environment of Hong Kong, the ignition probabilities assumed in this study are probably on the conservative side.

12.32.4 In conclusion, after taking into account the uncertainty in the hazard assessment by adopting conservative assumptions/ parameters and worst case scenario, this gives confidence that the risk level in the assessment will not exceed the Hong Kong Risk Guidelines.

Conclusion

12.33 Summary

12.33.1 A Hazard Assessment of the risks associated with the storage, handling and transport of chlorine at Sha Tin Water Treatment Works has been conducted for the Construction and Operational Phases of the reprovisioning project.

12.33.2 The assessment methodology and assumptions were based on previous assessments having similar issues, namely the SCL EIA (ERM 2011a) for on-site risks and Atkins (2006) for the off-site transport risks.

12.33.3 In all cases, the Individual Risk complies with the Hong Kong Risk Guidelines.

12.33.4 The societal risk expressed in the form of FN curves, lies in the lower "ALARP" region of the HKRG for the on-site facilities and in the lower "ALARP" region for the off-site transport. Risk mitigation and cost-benefit analysis has therefore been conducted. The combined on-site and off-site transport chlorine risk also lies in the mid-ALARP region.

12.33.5 Cumulative risks within the consultation zone were also presented by combining risks from the on-site facilities, off-site chlorine transport (route section lying within consultation zone only), the Beacon Hill North Offtake Station, the 750mm and 500mm gas pipelines that run through the old Beacon Hill Tunnel, explosive transport and use for SCL construction.

12.33.6 The Sha Tin WTW Reprovisioning Project is an improvement project. Due to the introduction of the new treatment technologies, the reprovisioning works will lead to a permanent reduction in chlorine storage and usage at the WTW. As a result, the residual impacts from chlorine-related risks for the surrounding population will be reduced in comparison with current levels.

12.34 Recommendations

<u>*On-site Chlorine*</u>

12.34.1 For the Construction Phase, good practice measures were considered during a HAZID workshop and 22 recommendations were made. Several additional good practice measures are also proposed following B&V (2010). It is also recommended that an accompanying vehicle is provided on-site for the chlorine truck and the construction activities are temporarily stopped during chlorine deliveries and that gas monitors with audible alarms are installed in the relevant reprovisioning work areas. Implementation of these measures would reduce the societal risks for the Construction Phase of the Project.

12.34.2 No specific mitigation measures are recommended for the Operational Phase. These were subject of detailed analysis under the SCL QRA (ERM, 2011a), but no risk mitigation measures related to the WTW operation were found to be practicable.

<u>*Off-site Chlorine Transport*</u>

12.34.3 A number of mitigation measures have been considered and a number of short term and long term risk mitigation measures have been recommended following a formal Cost-Benefit Analysis to ensure the risk is ALARP.

Short term measures

- It is recommended to ban the use of retreaded tyres and perform regular visual checks on the tyres. This measure should be implemented before the start of the reprovisioning project (Item 2.8); and
- It is recommended to have a vehicle accompanying chlorine truck along critical road sections in Sha Tin. The vehicle should be equipped with emergency kit, fire extinguisher, radio set for

communication (Item 4.4). The accompanying vehicle will be ahead of the chlorine truck after the vehicles entering the water treatment works site.

- An accompanying vehicle may provide rapid response to an incident (collision, fire, etc.) but any action would be limited to containing a small leak.

Long term measures

- It is recommended to limit fuel tanks capacity at the beginning of the Project (Item 2.3 – advance measure);
- It is recommended to further review the practicality of reducing combustible materials or use of fire retardant materials in the cab. (Item 2.3 – further measure); and
- Annual periodic radiography or ultrasonic test inspections of the chlorine drums should be considered for implementation as soon as feasible (Item 3.8).

Items to be further reviewed

- It is recommended to implement side, front and rear crash guards with high energy absorption in coordination and accordance with the relevant authorities; and
- It is recommended to implement a sturdy steel frame to minimise the potential for chlorine release due to truck rollover.
- The above two items require further review and either of these will be implemented in Q1 of 2016 after a practical design is agreed by relevant authorities during the investigation phase. These items will be kept in view if the design cannot be finalised by Q1 of 2016.

12.34.4 The following additional recommendations relating to the transport of Chlorine from SSK dock to Sha Tin WTW have been made to ensure the risk remains in the ALARP region:

- WSD will continue to keep under review the latest development of use of alternative disinfectants in water supply industry to aim at minimising on-site chlorine storage;
- Training should be provided for the use of the GPS fleet management and improved safe driving;
- It should be ensured that independent checks are performed to ensure proper chlorine drum latching and clamping;
- Chlorine truck drivers or driver attendants should be further trained to check and detect potential chlorine leaks during transport. This should include the timely application of the emergency kit;
- Training should be provided to driver and driver attendant for the emergency use of the new 2 × 9L AFFF extinguishers;
- Induction training for new drivers and driver attendant should include familiarisation with the route, familiarisation with chlorine risks, defensive driving, application of emergency kits, use of fire extinguishers and emergency response;
- Provision of a fire screen between the cab and cargo as well as fire retardant materials for the wheel arches on the chlorine truck should be planned and provided; and
- To keep under review alternate chlorine receiving dock in Sha Tin/Tai Po area for chlorine delivery to STWTW.

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