9 Hazard to Life

9.1 Introduction

Parts of the proposed NDAs (KTN and FLN) are located within the 1 km Consultation Zone (CZ) of Sheung Shui Water Treatment Works (SSWTW), which is a potentially hazardous installation (PHI) **(Figure 9.1)**. According to Clause 3.4.10 of the EIA Study Brief (ESB-176/2008), a quantitative risk assessment is required.

A previous Hazard to Life Assessment was conducted on SSWTW in 1991 [9-1] and reassessed in 2001 [9-2] due to upgrade on chlorine dosing facilities. This hazard assessment (HA) study follows the same methodology as the previous Reassessment study [9-2].

This chapter aims to present the Hazard to Life Assessment for SSWTW and to demonstrate the risk imposed by SSWTW to the proposed NDAs development complies with the requirement of the Hong Kong Risk Guidelines in Annex 4 of the EIAO-TM [9-3].

9.2 Scope and Objectives

This HA aims to achieve the objectives specified in the Section 2.1 (iv) and (vi) of the EIA Study Brief (No. ESB-176/2008) [9-4]. The Study Brief has required assessment of risks from chlorine and explosives where necessary. Technical requirements in the Study Brief are reproduced below:

3.4.10 Hazard to Life

3.4.10.1 The Applicant shall follow the criteria for evaluating hazard to life as stated in Annexes 4 and 22 of the TM.

3.4.10.2 The Applicant shall carry out hazard assessment to evaluate risks due to transport, storage and use of chlorine associated with the operations at Sheung Shui Water Treatment Works during the implementation of the Project. The hazard assessment shall include the following:

(i) Identify hazardous scenarios associated with the transport, storage and use of chlorine 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 of hazard assessment shall be agreed and approved by the Director.

3.4.10.3 If there is use of explosives for construction activities and storage or blasting location is in close proximity to populated areas and / or Potentially Hazardous Installation site(s) (such as Sheung Shui Water Treatment Works), the

Applicant shall carry out hazard assessment as follows:

(i) Identify hazardous scenarios associated with the transport, storage and use of explosives 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 of hazard assessment shall be agreed and approved by the Director.

According to the latest engineering design, there is no need to use explosives in the construction activities. Hence, this HA will only consider the hazards posed by the storage, use and transport of chlorine at SSWTW.

This study is based on the results of the previous reassessment study of SSWTW [9-2] and therefore similar in scope. The input data for the risk modelling will be updated to reflect the changes since then, especially the projected population in the surrounding area of SSWTW.

The geographical scope is defined as the population areas within the CZ. However, where the hazard range of certain chlorine release events (e.g. collapse of the chlorine store caused by earthquake) reaches areas outside the CZ, those areas will be included. It should be noted that only parts of the NDAs (KTN and FLN) would be affected by the accidental chlorine release, which will be considered in this assessment.

9.3 Study Approach

9.3.1 Overview

The overall approach of the assessment is illustrated in **Figure 9.2**.

As discussed in **Section 9.2**, the Reassessment Study [9-2] conducted in 2001 will be adopted as the basis for the current HA, and its methodology will be closely followed.

Other risk assessment studies of similar nature or facility in Hong Kong will be reviewed [9-5][9-6], so as to maintain consistency with similar studies in Hong Kong.

Hazard scenarios adopted in the Reassessment Study will be confirmed independently using review of historical incidents as instructed by the Court of Final Appeal (CFA) in [9-7]. The Major Hazard Incident Data Services (MHIDAS) accident database will be reviewed in this HA.

With regard to the assessment of impact of chlorine release on the transient population (on road and railways), the approach as documented in the HSE study "The implication of major hazard sites in close proximity to major transport route" [9-8] will be adopted. As for other populations, consideration is given for the possibility of escape from the toxic cloud, protection of the buildings, and higher fatality rate of sensitive groups. This methodology was also adopted in the 2001 Reassessment Study.

The major steps of the HA are:

a) **Hazard Identification**: Identify hazard scenarios associated with the transport, storage and use of chlorine and then determine a set of relevant scenarios to be included in a QRA.

b) **Consequence Analysis**: Assess the consequences and impact to the surrounding population.

c) **Frequency Estimation**: Estimate the likelihood of occurrence of the identified hazard scenarios.

d) **Risk Summation and Assessment**: Evaluate the risk level, in terms of individual risk and societal risk. The risk will be compared with the criteria stipulated in Annex 4 of the TM to determine their acceptability, as described in **Section 9.3.2** below.

e) **Identification of Mitigation Measures**: If the overall risk exceeds the "Acceptable" level and resides in the "ALARP" region, practicable and cost-effective risk mitigation measures will be identified. The risk of mitigated cases will then be reassessed to determine the level of risk reduction.

This assessment makes use of a risk summation model, RISKSUM, to assess the level of risk. The tool is developed by BMT Asia Pacific Ltd. A calibration exercise has been conducted and confirmed outputs from RISKSUM are consistent with previous results generated by GISRisk model used in the 2001 Reassessment Study.

9.3.2 Risk Acceptability Criteria

As stipulated in Annex 4 of the EIAO-TM [9-3], the risk guidelines comprise two criteria shown as follows:

Individual Risk: The maximum level of off-site individual risk should not exceed 1 x 10^{-5} per year, i.e. 1 in 100,000 per year.

Societal Risk: It can be presented graphically as in **Figure 9.3**. The Societal Risk Guideline is expressed in terms of lines plotting the frequency (F) of N or more fatalities in the population from accidents at the facility of concern. In the figure, ALARP means As Low As Reasonably Practicable. Risk in this region should be reduced to As Low As Reasonably Practicable by implementation of practicable and cost-effective risk mitigation measures.

9.4 Cases to Be Assessed

Population in the vicinity of SSWTW is expected to increase with the NDAs development. Based on the NDAs implementation plan (**Figure 9.4**), site formation and construction at KTN and FLN areas will commence at Year 2016, and the first population intake is scheduled at Year 2023. Site development will complete at Year 2030 (early finish) for KTN and FLN areas near SSWTW, which may be delayed to Year 2031 (late finish) considering potential project uncertainties. This assessment conservatively considers late finish of the project implementation. Therefore, it is anticipated that KTN/FLN areas and related roads near SSWTW will be fully occupied at Year 2032 after completion of the new development. It is therefore proposed to adopt Year 2032 as the assessment year for the ultimate NDA development.

As shown in **Figure 9.5**, major construction work within 1 km CZ of SSWTW includes (1) Sewage Treatment Works Extension (Lot FLN-A2-

3), which is scheduled to start construction at March 2021 and complete at February 2023 (early finish); (2) facilities for Hong Kong Police Force (HKPF, Lot FLN-A1-8 and FLN-A1-11), which is planned to start construction at July 2018 and complete at December 2022 (early finish). Due to their close proximity to SSWTW, these sites are exposed to much higher potential risk than other sites outside the CZ. More population (construction workers) could be present during the construction stage than the working staff during the operation stage at the sewage treatment works extension site. Thus consideration is given to the construction stage at Year 2023, when the highest number of construction workers near SSWTW is anticipated. It is noted that Year 2023, instead of Year 2022, is adopted considering there may be potential delay of the construction work at the aforementioned facilities, e.g. late finish of the site construction.

A total of six cases are considered in this HA to demonstrate the changes in risk level caused by the NDAs development:

9.4.1 Construction Stage (3 Cases)

- Case 1 (2023 no NDA): Surrounding population projected at 2023 (no NDAs development). It aims to obtain the background risk level without NDAs development. Population in the vicinity of SSWTW will be updated and projected to the future year.
- Case 2 (2023 NDA only): Forecast population at NDAs at 2023 only. The purpose is to investigate the additional risk caused by the NDAs development.
- Case 3 (2023 NDA + Surrounding): Surrounding population projected at 2023 + forecast population at NDAs at 2023. This case considers the overall risk level in the future with the NDAs development.

9.4.2 Operation Stage (3 Cases)

- Case 4 (2032 no NDA): Surrounding population projected at 2032 (no NDAs development). It aims to obtain the background risk level without NDAs development. Population in the vicinity of SSWTW will be updated and projected to the future year.
- Case 5 (2032 NDA only): Forecast population at NDAs at 2032 only. The purpose is to investigate the additional risk caused by the NDAs development.
- Case 6 (2032 NDA + Surrounding): Surrounding population projected at 2032 + forecast population at NDAs at 2032. This case considers the overall risk level in the future with the NDAs development.

9.5 Description of Sheung Shui Water Treatment Works

9.5.1 Location

SSWTW is located at 10 mPD and 700m to the north-west of the town of Sheung Shui, near to the MTR East Rail. Access to SSWTW site is via Fu Tei Au Road. The area within the CZ of SSWTW is relatively sparsely populated and the terrain surrounding SSWTW is mostly flat. The site

location and the site layout are shown in **Figure 9.1** and **Figure 9.6**, respectively.

9.5.2 Operations

9.5.2.1 Delivery, Storage and Handling of Chlorine

Chlorine is delivered to SSWTW in batches of up to 6 x 1 tonne drums. Unloading takes place inside the chlorine store with the doors closed in a designated truck unloading bay. The movement of drums within the storage area and unloading bay is carried out using an electrically-operated overhead travelling crane with purpose-built lifting beam. Prior to usage, the drums are stored on cradles within the chlorine storage area. **Table 9.1** provides the basic plant operating data for SSWTW.

Table 9.1 - Plant Operating Data for SSWTW

Items	Units	Quantity	
Type of container in use	-	1 tonne	
Situation in		2011	1996
Design capacity of plant	Mld	200	200
Plant throughput (average)	Mld	134	115
Chlorine usage (average)	tonnes per year	108	514
Chlorine stock level (average)	tonnes	41	35
Chlorine storage capacity (including duty and standby containers)	tonnes	56	56
Number of draw-off units	-	2	2
Ultimate Loading of Chlorine Plant			
Chlorine dosage (average)	mg/l	2.2	15
Estimated chlorine usage	tonnes per year	161	1095
Chlorine storage capacity (including duty and standby containers)	tonnes	112	112
Number of draw-off units	-	2	2
General			
Chlorine container lifting device	-	EOTC[(1)]	EOTC[(1)]
Scrubber capacity	tonnes chlorine	1	1
Distance travelled by chlorine truck along site access road	km	0.2	0.2

Notes:

(1) EOTC – Electrical Overhead Travelling Crane.

9.5.2.2 Chlorination System

The draw-off units comprise 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.

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 a chlorinated water solution for feeding into the bulk water stream during the treatment process.

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

9.5.2.3 Ventilation System

The chlorine drum storage/evaporator area and chlorinator rooms are normally ventilated via a supply of fresh air at high level and extracted at low level. On detection of chlorine levels above 3 ppm there are visual and audible alarms and the ventilation extract fans stop.

9.5.2.4 Chlorine Scrubbing System

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.

On detection of a chlorine concentration of 3 ppm or above in the chlorine handling or storage areas, the scrubbing system will be activated 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.

The scrubber system is normally set at auto control mode to recycle air back to the drum storage area. However, the treated air may be discharged to atmosphere at roof level when the chlorine concentration is below 3 ppm. The control for recycling or discharging air to atmosphere is effected by means of a pair of electrically operated change-over dampers which can also be manually controlled from the local control panel. A continuous chlorine monitor is installed at a point downstream of the packed tower and upstream of the vent/recycle changeover dampers. It has a high level alarm which sounds at both the local control panel and in the main control room when the chlorine concentration exceeds a pre-set level.

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 recirculated 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.

The scrubber is provided with the following additional features: a sampling point, a top entry mixer (for in-situ 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.

9.5.2.5 Emergency Repair/Stoppage Kit for Chlorine Spillage/Leakage

According to Fire Services Department's fire safety requirements, a set of 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.

9.5.3 Surrounding Topography

The topography around the SSWTW is shown in **Figure 9.7**. To the immediate south and east of SSWTW, there are small hills rising to between 35 and 70m above PD. About 1km to the north west of the site are larger hills rising to nearly 200m. The remaining areas surrounding the WTW are flat. It is noted the chlorine dispersion modelling undertaken for SSWTW in the 2001 Reassessment Study takes account of these topographic features, as well as the on-site buildings.

9.6 Meteorological Conditions

The meteorological data used in this study is the data recorded at the Ta Kwu Ling weather station in Year 2006 - 2011 by the Hong Kong Observatory. 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 9.2**. 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 moderately stable conditions which typically arise on clear nights with little wind. Turbulent mixing, which will affect the dispersion of a chlorine cloud, increases through the stability class range from F to A. Distribution of wind directions in 2006 - 2011, as plotted as a wind rose in **Figure 9.1**, shows the prevalent wind direction is from the east.

Table 9.2 - Meteorological Data (2006 - 2011)

		Probability							
		Day				Night			
Wind Speed (m/s)		2.5	2	4.5	1	1.5	4.5	4.5	
Atmospheric Stability		B	D	D	F	D	D	F	Total
Direction	N	0.0366	0.0226	0.0287	0.0187	0.0104	0.0258	0.0451	0.1880
	NE	0.0099	0.0061	0.0043	0.0061	0.0017	0.0059	0.0187	0.0527
	E	0.0865	0.0469	0.0341	0.0221	0.0350	0.0316	0.0934	0.3496
	SE	0.0190	0.0171	0.0101	0.0130	0.0163	0.0142	0.0831	0.1729
	S	0.0150	0.0084	0.0019	0.0091	0.0018	0.0011	0.0569	0.0943
	SW	0.0246	0.0090	0.0022	0.0045	0.0023	0.0007	0.0248	0.0681
	W	0.0153	0.0034	0.0002	0.0039	0.0003	0.0001	0.0141	0.0373
	NW	0.0108	0.0036	0.0004	0.0056	0.0009	0.0004	0.0153	0.0370
Total		0.2176	0.1172	0.0820	0.0832	0.0686	0.0799	0.3515	1

9.7 Population Considered in the Assessment

9.7.1 SSWTW Surrounding Population

Population data to be considered include the existing population around SSWTW and future NDAs population, which may be affected by an accidental release of chlorine from SSWTW. Details of population distribution and population data are presented in **Appendix 9.1**.

Population considered in this assessment includes all population within the 1km CZ, as well as population outside the CZ which might be affected by the toxic releases in case of catastrophic events such as collapse of the chlorine building in an earthquake.

With the proposed NDAs development, projected population at 2032 inside the Consultation Zone (CZ) of SSWTW is expected to increase from 4,720 to 5,460 (by about 16%), most of which is planned far away to the east and south-east of SSWTW, avoiding the impact of accidental chlorine release from the prevalent wind direction (East, nearly one third of the time in a year). Furthermore, these locations are shielded by small hills at immediate east and south boundary of SSWTW.

Estimation of future population is based on the following sources:

1) Planning parameters for the areas in the NDAs. The data include:

a. G/IC Provision Assessment tables for NDAs;

b. Development Schedules; and

c. Data from other departments such as Correctional Services Department and Hong Kong Police Force.

2) For other areas surrounding SSWTW, the figures are based on the 2006 Population Census from the Census and Statistics Department and other available information sources. An average annual growth rate of 1.1%, as estimated by the Planning Department [9-9], was adopted to project the future population at surrounding areas of SSWTW with potential further residential development such as villages. For well-established areas with no further residential development such as Tsui Lai Garden (Estate), it is conservatively assumed population will remain the same for the future years, considering the decreasing trend of average domestic household size in North District (3.2 in 2001, 3.1 in 2006 and 3.0 in 2011) according to the Census and Statistics Department [9-10]. For areas with approved future residential development such as public housing development site at Choi Yuen Road, population will be considered in the assessment for projected future years.

3) Population in Riverside Promenade areas (where cycle tracks and pedestrian linkages will be provided) is estimated from a site survey at Sha Tin, where similar facilities are provided in riverside/seafront areas. Details are described in **Appendix 9.2**. For amenity areas where recreation facilities will be provided, a population density of 0.01 person per m^2 will be adopted, as reference to other approved EIA study [9-11].

4) For schools, kindergartens and elderly homes, information will be collected from the Education Department, Social Welfare Department and corresponding websites.

5) Surveys undertaken by the consultants.

The population data are presented in five time periods including night, working day, weekend day, peak hour and "jammed peak", as adopted from the Reassessment Study. A "jammed peak" period is considered for major roads representing the probability of standstill, "bumper-to-bumper" conditions in one traffic direction. The description of the time periods is provided in Annex I of the Reassessment Study. A summary is given in **Table 9.3**.

Sensitive populations such as homes for the elderly, kindergartens and hospitals (vulnerable population factor 3.3) are separately identified from other populations (vulnerable population factor 1). The definition of the vulnerable population factor and its use in the assessment are explained in **Section 9.9.3.4**.

Table 9.3 - Different Time Periods and Distributions

Time Period	Mon. ~ Fri.	Sat.	Sun.	% Distribution
Peak	18.75 hr	3.75 hr	0 hr	13.39%
Jammed Peak	1.25 hr	0.25 hr	0 hr	0.89%
Working Day	40 hr	4 hr	0 hr	26.19%
Weekend Day	0 hr	4 hr	12 hr	9.52%
Night	60 hr	12 hr	12 hr	50.00%

9.7.2 Transient Population

Modelling of the impact of chlorine releases on road and rail populations follows the HSE approach [9-8], as described in Annex F2 of the Reassessment Study. Traffic population considered in this study includes population on those from the roads in the vicinity of SSWTW, and railways to the west of SSWTW. The locations of these roads and railway are indicated in **Figure 9.8**.

9.7.2.1 Road Traffic

Population associated with the road vehicles will be modelled as 100% outdoor, which is consistent with the Reassessment Study.

Current average daily traffic is estimated from Annual Traffic Census 2011 [9-12]. Traffic forecast from the NDA plan are adopted to estimate the peak hour traffic flow in the future projected years for cases with and without NDAs development. Traffic during daytime non-peak hours and night are taken as 87% (=5.65/6.53) and 37% (=2.44/6.53) of peak hour traffic, as estimated from ATC 2011. Traffic variation is estimated from several major traffic stations in New Territories (**Table 9.4**).

Table 9.4 - Traffic Variation during Different Time Periods at Major Traffic Stations (ATC 2011)

Station	Average Hourly Traffic / Daily Traffic(1), %		
	Peak	Day	Night
S5001 Tuen Mun Rd	6.33	5.56	2.55
S5003 Fanling Highway	6.63	5.73	2.35
S5006 Ting Kok Rd	7.05	5.60	2.18
S5008 Yuen Long Tai Yuk Rd & Kau Yuk Rd	6.05	5.39	2.69
S5009 Kwong Fuk Rd	6.10	5.43	2.75
S5011 Wang Chau Rd	6.80	5.91	2.29
S5019 Castle Peak Rd – Yuen Long	6.70	5.92	2.28
S5025 Yuen Long Highway	6.53	5.64	2.44
Average	6.53	5.65	2.44

Note: (1) Estimated from the Figures "Traffic flow variation and growth" of corresponding traffic stations.

Average vehicle occupancy is 1.7 persons per vehicle at Core Station S5003 (a section of Fanling Highway near Sheung Shui Railway Station) as estimated from Annual Traffic Census 2011 [9-12]. In this assessment, average vehicle occupancy of 2 persons per vehicle is adopted for roads near SSWTW, which is deemed as a conservative estimation. The average traffic population is calculated from the following formula:

$$Traffic\ \ Population = \frac{\frac{No.\ of\ \ ppl}{vehicle} \times \frac{No.\ of\ \ vehicle}{hr} \times Road\ \ length\ \ (km)}{Traffic\ \ speed\ \ (km/hr)}$$

It is assumed vehicle speeds under normal traffic conditions are 50 km/hr and 70 km/hr for non-expressways and expressways respectively, according to the HK Road Traffic Ordinance. Vehicle speed during peak hours will be reduced due to traffic congestion, and assumed to be 35 km/hr [9-5]. In the jammed peak cases, it is considered that roads are occupied by slow moving vehicles in one direction. Average vehicle speed in the jammed direction is assumed to be 5 km/hr, which is consistent with the observation from the traffic survey in the Reassessment Study (Population during jammed peak hours is 3.5 ~ 4 times of that during peak hours for Jockey Club Road and Man Kam To Road).

9.7.2.2 Railway - East Rail and Lok Ma Chau Spur Line

MTR East Rail network traverses the 1 km CZ of SSWTW. The minimum distance between the rail line and the WTW is about 90 m, to the west of SSWTW. From the Reassessment Study, the maximum exposure duration is estimated to be 1 minute based on time for train to pass through chlorine cloud and time for chlorine to disperse from train afterwards. Transient population of the East Rail is considered as a source of traffic population.

The Lok Ma Chau spur line is located outside of the CZ, at a distance of more than 1100 m and contained in an underground tunnel. Fatality due to exposure to the toxic cloud is not expected for the passengers on the spur line.

The approach employed in the Reassessment Study will be adopted in this assessment to estimate the affected population on trains by chlorine releases. The trains are much alike to the road vehicles, except that they are unlikely to come to a halt within a chlorine cloud. This means that the

exposure of rail passengers to the released chlorine is limited to the duration for which the train is within the cloud plus the time for the chlorine to disperse from the carriages subsequently. Population is based on crush-loaded train but divided by factors to account for limited exposure duration and length of train, and multiplied by length of track within zone of interest.

9.8 Hazard Identification

Potential hazards associated with the storage, use and transport of chlorine in SSWTW were identified in the Reassessment Study. A total of 36 hazards were identified during the HAZOP study for SSWTW, which will be described in details below. A site visit confirms operation of SSWTW has not been changed since the Reassessment Study. These identified hazards were further examined by reviewing historical incident database, the Major Hazard Incidents Data Service (MHIDAS), which confirms the hazard scenarios identified in the Reassessment Study are acceptable for the current assessment.

9.8.1 Hazardous Characteristics of Chlorine

The following paragraphs summarise some of the key hazardous characteristics of chlorine (ICI Chlorine Handbook [9-13]):

- 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 concentrations (above approximately 500ppm) many times higher than the danger level (see **Table 9.5** below).
- 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.

The physiological effects of chlorine are summarised in **Table 9.5**.

Table 9.5 - 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 of 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.

9.8.2 HAZard and OPerability (HAZOP) Study and Characterisation of Chlorine Release Scenarios

In the Reassessment Study, a Hazard and Operability (HAZOP) study was conducted for SSWTW to provide a full and systematic identification of the hazards associated with the delivery, storage and handling of chlorine in the previous Reassessment Study. The HAZOP technique provides a means of examining deviations from the design intent, their causes, consequences and safeguards, in a structured manner.

The primary focus of the HAZOP was on the hazards posed to people off-site. “Internal” as well as “external” hazards were considered, i.e. those within the control of the operating staff, such as the hazards arising during drum connection/disconnection, as well as those outside their control such as an external fire. The information provided for the HAZOP included the site layout plan, Process and Instrumentation Diagram (P&ID), chlorine store layout plan, as well as the Operations and Maintenance Manual.

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.

Chlorine hazards from the following operations were identified during the HAZOP Study for SSWTW:

- 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 store;
- Containers in storage;
- Connection and disconnection of chlorine containers;
- Chlorination system (including the liquid chlorine pipework, evaporators, chlorinators and ejectors);

For releases occurring within the chlorine store a Contain and Absorb system is provided to minimise the likelihood of the release escaping to atmosphere. The principal failure modes of the Contain and Absorb system were identified at the HAZOP:

- Failure of leak detection system
- Failure of contain system
- Failure of chlorine absorption system

Local chlorine leak incidents, which have occurred in Hong Kong, were reviewed against the identified hazardous scenarios during the HAZOP.

The potential hazardous chlorine release scenarios identified by HAZOP were characterized in terms of the release inventory (1 tonne to 14 tonnes), release rate or quantity to atmosphere (57 kg to 10 tonnes for an instantaneous release, 0.027 kg/s to 14.4 kg/s for a continuous release), hole size (3 mm to 18x6 mm) and phase of release (liquid / two-phase), following the approach outlined in the methodology report of the Reassessment Study. Scenarios of insignificant release, which poses negligible off-site risk, were screened out for further risk assessment.

9.8.3 Review of MHIDAS Incident Database

A review on Major Hazard Incident Data Service (MHIDAS) database of the relevant historical incidents of the same genus to SSWTW has been conducted to confirm whether the hazardous scenarios identified in the Reassessment Study are applicable.

16 records from the MHIDAS were identified as the same genus of Water Treatment Plant of this assessment. **Table 9.6** summarises these 16 incidents. Details of each incident are given in **Appendix 9.3**.

From the incidents records, causes of incidents can be classified into three categories. These categories are pipework failure, tank/drum failure and cylinder failure. The first 2 categories of hazard scenarios have been identified and assessed in the Reassessment Study, while the third category is not applicable to the current assessment as no cylinder of chlorine will be used or stored at SSWTW. With respect to transportation hazard, no relevant incident has been found.

Table 9.6 - Summary of Chlorine Incidents of Water Treatment Plant from MHIDAS

Hazardous Scenario	No. of Cases	Country	Related to SSWTW
Pipework Failure	7	France, Hong Kong, UK & USA	Yes
Tank/Drum	6	Puerto Rico, UK, USA	Yes
Cylinder Failure	3	France, UK & USA	No (No cylinder installed in SSWTW)

Upon completion of the incident review, no new hazard has been identified. For other hazards identified in the Reassessment Study, such as earthquake, truck fire, etc, no historical incidents related to these hazards has been found from the MHIDAS search.

The historical incidents search indicates that the Reassessment Study had identified some hazard scenarios that historically had not happened. However, to ensure that potential hazard scenarios have been considered, all hazards identified in Reassessment Study will be adopted for this assessment.

9.8.4 Review of Existing Chlorine Facilities

Information regarding the latest chlorine facilities installed in SSWTW has been gathered during site visit to the water treatment works in July 2009. During the visit, an interview has been conducted with operation staff to confirm the latest operation and safety practice in place in the water treatment works.

As advised by the water treatment works operators, the treatment throughput and storage of chlorine drums have not been changed since the Reassessment Study.

The mechanical ventilation system and the chlorine scrubbing system installed provide controlled air circulation and treatment of air in case of chlorine release. These systems are designed to prevent chlorine gas escape from the storage area in case of leakage.

Regarding the safety provision, emergency repair and stoppage kit manufactured to the specification of the Chlorine Institute is provided according to Fire Services Department's safety requirement.

In the previous Reassessment Study, two mitigation measures were identified to effectively reduce the risk from ALARP to the acceptable level: (1) Provision of a containment barrier at northwest corner of SSWTW, (2) Improvements to access road (markings and signage) to SSWTW. WSD has committed to implement these two mitigation measures scheduled for completion in 2015 prior to the implementation of the NDAs development. Therefore, these mitigation measures will be taken into account in this hazard assessment to examine the risk impacts from SSWTW.

9.8.5 Hazard Associated with Construction Works

The NDAs development involves construction activities near SSWTW site such as sewage treatment works extension and police driving and traffic training complex, which are at a minimum distance of 290 m and 280 m respectively. These two facilities are separated from SSWTW by a small hill covered with heavy vegetation, which forms a natural protective barrier for SSWTW. It is considered that activities at these sites would not pose any impacts to SSWTW.

Therefore, no adverse impact associated with construction activities to the chlorine storage and dosing system of SSWTW is anticipated.

9.9 Consequence Analysis

A comprehensive consequence analysis (wind tunnel test, CFD modeling and DRIFT modeling) was conducted in the Reassessment Study to assess chlorine gas dispersion from SSWTW. For the NDAs development, medium-rise and high-rise residential/commercial buildings are planned at distances of more than 1.5km and 1km away from SSWTW for KTN and FLN areas, respectively. The wind pattern near SSWTW will not be affected at such distances [9-14]. Therefore, chlorine dispersion results in the Reassessment Study are suitable to be adopted in this assessment.

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 off-site (whether indoors or outdoors).

The methodology for the consequence analysis in this assessment follows the Reassessment Study. A summary of the methodology is given below.

9.9.1 Initial Release of Chlorine

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

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 the chlorine on contact with the ground is assumed to result in entrainment of twice the initial flash fraction as aerosol, following Lees [9-15]. The remainder of the liquid chlorine is modelled as a spreading, evaporating pool.

For releases of chlorine within the chlorine building, a simple 'perfect mixing' model is used to account for the initial dilution of chlorine, based on Brighton [9-16][9-17] and Porter [9-18]. 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.

9.9.2 Dispersion of Chlorine in the Atmosphere

Advanced techniques had been used for prediction of the dispersion of chlorine in the atmosphere. The effects of buildings and variable ground terrain on the dispersion of chlorine were modelled. The modelling involved three elements:

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

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 test has been used in this study to investigate a range of release scenarios, 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.

The role of the flat terrain dispersion modelling had been to provide the 'source term' for both the wind tunnel and CFD studies. The model used in the study was DRIFT [9-19], 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. DRIFT runs were used to simulate the full range of chlorine release rates and weather conditions. In conjunction with the wind tunnel and CFD, this provided all the data needed for input to the QRA.

9.9.3 Toxic Impact Assessment

9.9.3.1 Chlorine Probit Equation

The following probit equation has been used 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)

This probit equation is recommended for use in QRA studies by the Dutch Government [9-20] and incorporates the findings of most recent investigations into chlorine toxicity.

Table 9.7 shows the relationship between the chlorine concentration and the probability of fatality for the TNO probit, assuming 10 minute exposure duration.

Table 9.7 - Chlorine Toxicity Relationship

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

9.9.3.2 Modelling of Escape from the Chlorine Cloud

In risk assessments for toxic gas releases it is a 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.

Modelling of escape from the chlorine cloud is adopted from the Reassessment Study. The methodology followed is similar to that developed by the UK Health and Safety Executive [9-21]. It assumes that a person out of doors 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.

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

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 9.8** below.

However, escape from the chlorine cloud is not assumed for the outdoor population in Lo Wu Correctional Institution (LWCI) due to the physical boundary barriers. Therefore, in this assessment the ‘nominal’ probability of fatality is considered for the outdoor population in LWCI.

Table 9.8 - Effective Outdoors Probability of Fatality

Nominal Outdoor Fatality Probability (for a Person Remaining Outdoors)(1)	% of Population Attempting Escape	Effective Outdoor Fatality Probability (Taking into Account the Probability of Escape)(2)
90%	0%	90%
50%	80%	31%
3%	80%	0.7%

Notes:

(1) Fatality applicable to outdoor population in LWCI.

(2) Fatality applicable to outdoor population other than LWCI.

9.9.3.3 Protection for Persons Indoors

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 out of doors, i.e. nominal outdoor fatality probability.

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.

9.9.3.4 Sensitive Populations

Certain groups of people, i.e. the young, the elderly and the infirm will be more sensitive to the effects of chlorine than others. 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.

In line with data published by Withers and Lees [9-22] 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.

9.9.3.5 Transient Population

The approach to modelling the effect of chlorine releases on transient populations, in particular road vehicles and trains, essentially follows that developed under research work undertaken on behalf of the UK HSE [9-8], as described in Annex F2 of the Reassessment Study. The same approach is adopted in this assessment.

9.10 Rationalization of Chlorine Release Scenarios and Estimation of Scenario Frequencies

9.10.1 Rationalization of Chlorine Release Scenarios

In the Reassessment Study, the consequence analysis from wind tunnel test and CFD modelling shows that only certain, severe types of chlorine release which could produce fatal off-site concentrations of chlorine. 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 whether external or internal.

These results mean that many of the chlorine release scenarios identified in the HAZOP study can be eliminated from further consideration in the QRA. Based on the results of the consequence analysis, scenarios posing an off-site hazard were further considered in the QRA. To simplify

the assessment, these scenarios were further grouped into 'events' having identical release characteristics (i.e. the same release rate, duration and phase of release), as shown in **Table 9.9** and **Table 9.10**.

Base failure rates and event frequencies of occurrence are adopted from the Reassessment Study. **Table 9.11** summarises the results of the frequency calculations of the release scenarios included in QRA.

Table 9.9 - Release Scenarios Included in QRA

Event Ref	Component Scenarios	Release Rate (or Quantity) to Atmosphere	Type of Release	Release Location
IU1TSRU	Spontaneous failure Dropped drum	57 kg	Instantaneous	Chlorine store
RU1TSML	Rollover Loadshedding Spontaneous failure	1.4 kg/s	Continuous	Access road
RU1TMML	Rollover Truck fire	4.2 kg/s	Continuous	Access road
RU1TSRU	Truck impact Truck fire Spontaneous failure	1 tonne	Instantaneous	Access road
RU1TMRU	Truck fire	3 tonnes	Instantaneous	Access road
EU1TMRU	Earthquake: roof collapse, ground acceleration 0.5g	10 tonnes	Instantaneous	Chlorine store
EU1TMRU1G	Earthquake: roof collapse, ground acceleration 0.8g	10 tonnes	Instantaneous	Chlorine store

Table 9.10 - Release Scenarios Categorised by Leak Quantity

Leak Quantity (kg)	Event Ref
0-10	None
10-100	IU1TSRU
100-1000	RU1TSML, RU1TMML, RU1TSRU
>1000	RU1TMRU, EU1TMRU, EU1TMRU1G

Table 9.11 - Event Frequencies

Event Ref	Component Scenarios	Frequencies (per year)	Time Periods during which Event could Occur
IU1TSRU	Dropped drum Spontaneous drum failure	1.69E-6 4.54E-4	All except Night All
	Total	4.56E-4	
RU1TSML	Rollover Loadshedding Spontaneous leak	1.04E-6 2.54E-7 1.03E-7	All except Night All except Night All except Night
	Total	1.40E-6	
RU1TMML	Rollover Truck fire	7.65E-8 8.99E-8	All except Night All except Night
	Total	1.66E-7	
RU1TSRU	Truck impact Truck fire Spontaneous drum failure Total	2.49E-7 4.76E-8 5.08E-8 3.47E-7	All except Night All except Night All except Night
RU1TMRU	Truck fire	8.89E-9	All except Night
EU1TMRU	Earthquake	3.30E-7	All
EU1TMRUH	Earthquake	7.00E-8	All

9.10.2 Event Frequencies with Implementation of Previous Identified Risk Mitigation Measures

In the previous Reassessment Study, two mitigation measures were identified: (1) Provision of a containment barrier at northwest corner of SSWTW, which could eliminate the risk due to the event IU1TSRU. (2) Improvements to access road (markings and signage) to SSWTW, which could result in a reduction of 50% in frequency of truck-related accidents. Since WSD has committed to implement these two mitigation measures scheduled for completion in 2015 prior to the implementation of the NDAs development, these two mitigation measures will be taken into account in this hazard assessment and the event frequencies are listed in **Table 9.12**.

Table 9.12 - Event Frequencies with Implementation of Previous Identified Risk Mitigation Measures

Event Ref	Component Scenarios	Frequencies (per year)	Time Periods during which Event could Occur
RU1TSML	Rollover Loadshedding Spontaneous leak	5.20E-7 1.27E-7 1.03E-7	All except Night All except Night All except Night
	Total	7.50E-7	
RU1TMML	Rollover Truck fire	3.83E-8 4.50E-8	All except Night All except Night
	Total	8.33E-8	
RU1TSRU	Truck impact Truck fire Spontaneous drum failure Total	1.25E-7 2.38E-8 5.08E-8 2.00E-7	All except Night All except Night All except Night
RU1TMRU	Truck fire	4.45E-9	All except Night
EU1TMRU	Earthquake	3.30E-7	All
EU1TMRUH	Earthquake	7.00E-8	All

9.11 Quantitative Risk Assessment

9.11.1 Risk Assessment Methodology

Risk summation was conducted using RISKSUM, which is developed specifically for the chlorine dispersion risk assessment. It combines input information on the frequencies of hazardous chlorine release scenarios, consequences of chlorine dispersion, population information to generate risk results in terms of individual risk and societal risk.

RISKSUM is a risk assessment tool based on standard, commercial softwares, i.e. Microsoft Excel and Access Database. Microsoft Excel stores all the input information, performs the risk calculation and demonstrates the risk results. It is associated with the Access Database, which saves the intermediate results for data processing. The calibration exercise demonstrates results generated by RISKSUM are consistent with the tool used in the previous Reassessment Study.

The main outputs from RISKSUM are:

- Individual risk in the form iso-risk contours;
- Societal risk in the form of an FN curves and Potential Loss of Life (PLL)

9.11.2 Risk Results for Base Case

9.11.2.1 Societal Risk Results

The societal risk results for SSWTW are shown in **Figure 9.9** and **Figure 9.10** in the form of FN curves. **Table 9.13** and **Table 9.14** present the overall PLL values, with a breakdown by release scenario and population area.

As can be seen from **Figure 9.9** and **Figure 9.10**, FN curves for SSWTW lie in the acceptable region for both cases with and without NDAs development. With NDAs development, the overall potential loss of life (PLL) is anticipated to increase by 18% for Year 2023 (2.36×10^{-5} per year

to 2.78×10^{-5} per year) and 16% for Year 2032 (2.37×10^{-5} per year to 2.76×10^{-5} per year).

From **Table 9.13**, it is clear that the dominant risk contributor is chlorine release due to earthquake, which accounts for about 90% of PLL for the existing population near SSWTW and the additional population within NDAs development, respectively. As shown in **Figure 9.11** (breakdown of FN curves by Accident Type), occurrence of a large number of fatalities (more than 10) is largely caused by high-intensity earthquake, which could lead to rupture of multiple chlorine drums in the chlorine store and impact to a much larger distance than the chlorine release due to accident on the access road. Most of the population within NDAs development is located far away from the SSWTW, outside the 1-km CZ, which accounts for the higher PLL contribution from earthquake. However, it is noted that in Hong Kong the probability of highly intensive earthquake is very low (3.3×10^{-6} and 1.4×10^{-7} per year for ground acceleration of 0.5 g and 0.8 g, respectively).

As shown in **Table 9.14**, for existing populated areas, the major risk receptors are population located to the west of SSWTW. The most significant population affected is associated with existing MTR East Rail and Lo Wu Correctional Institution, which account for about 50% of the overall PLL, and are situated at a distance of 90 m and 500 m from SSWTW, respectively. These two risk receptors are situated downwind of the SSWTW from the prevalent wind direction (East, nearly one third of the time in a year). The dominant risk receptors within the NDAs development are areas in close proximity of the SSWTW, such as Sewage Treatment Works Extension (construction site) and Riverside Promenade areas near SSWTW. It is noted that the densely populated residential / commercial areas planned at FLN and KTN are far away from SSWTW (about 1 km and 1.5 km respectively), and outside the impact zone of the prevalent wind direction (East).

9.11.2.2 Individual Risk Results

The individual risk results are shown in **Figure 9.12**. The maximum individual risk level is in the range of 1×10^{-6} per year and 1×10^{-7} per year, which is lower than 1×10^{-5} per year thus meets the individual risk criteria.

It should be noted that individual risk refers to the risk to a hypothetical person spending 100% of his/her time outdoors in the vicinity of the SSWTW, thus the upper-bound estimate of the risk to an actual individual. Individual risk reflects the risk of a person at a specific location, and is not affected by population around the hazardous sources, i.e. not affected by the NDAs development.

Table 9.13 - Breakdown of PLL by Release Scenario

Release Scenario	Case 1 (2023 no NDA)		Case 2 (2023 NDA only)		Case 3 (2023 NDA + Surrounding)		Case 4 (2032 no NDA)		Case 5 (2032 NDA only)		Case 6 (2032 NDA + Surrounding)	
	PLL	%	PLL	%	PLL	%	PLL	%	PLL	%	PLL	%
Spontaneous container failure	3.68E-07	1.6	6.49E-08	1.5	4.23E-07	1.5	3.68E-07	1.6	5.32E-08	1.3	4.12E-07	1.5
Earthquake	2.14E-05	90.6	4.01E-06	91.4	2.53E-05	91.0	2.15E-05	90.8	3.74E-06	92.4	2.51E-05	91.1
Dropped drum	0	0	0	0	0	0	0	0	0	0	0	0
Truck – impact	8.14E-07	3.4	1.50E-07	3.4	9.50E-07	3.4	8.15E-07	3.4	1.21E-07	3.0	9.23E-07	3.3
Truck – fire	5.56E-07	2.4	9.98E-08	2.3	6.47E-07	2.3	5.56E-07	2.3	8.12E-08	2.0	6.28E-07	2.3
Truck – rollover	4.15E-07	1.8	5.71E-08	1.3	4.49E-07	1.6	4.15E-07	1.7	5.05E-08	1.2	4.43E-07	1.6
Truck - loadshedding	4.35E-08	0.2	4.82E-09	0.1	4.40E-08	0.2	4.35E-08	0.2	4.63E-09	0.1	4.38E-08	0.2
Total	2.36E-05	100	4.39E-06	100	2.78E-05	100	2.37E-05	100	4.05E-06	100	2.76E-05	100

Table 9.14 - Breakdown of PLL by Population Area

Top Risk Receptors	Case 1 (2023 no NDA)		Case 2 (2023 NDA only)		Case 3 (2023 NDA + Surrounding)		Case 4 (2032 no NDA)		Case 5 (2032 NDA only)		Case 6 (2032 NDA + Surrounding)	
	PLL	%	PLL	%	PLL	%	PLL	%	PLL	%	PLL	%
SS-R (MTR East Rail)	7.57E-06	32.0			7.57E-06	27.2	7.57E-06	31.9			7.57E-06	27.4
SS-42 / KTN-G1-8 (Lo Wu Correctional Institution)	5.62E-06	23.8			5.62E-06	20.2	5.62E-06	23.7			5.62E-06	20.4
SS-22 (Lo_Wu_Station)	1.41E-06	6.0			1.41E-06	5.1	1.41E-06	5.9			1.41E-06	5.1
FLN-A2-3 (Sewage Treatment Works Extension, Construction Stage)			9.91E-07	22.6								
KTN-C2-1 (Open Space, Riverside Promenade Area)			8.01E-07	18.3					8.01E-07	19.8		
FLN-A1-5 (Amenity, Riverside Promenade Area)			7.86E-07	17.9					7.86E-07	19.4		
FLN-A2-2 (Amenity, Riverside Promenade Area)									6.10E-07	15.1		
Others	9.04E-06	38.2	1.81E-06	41.2	1.32E-05	47.5	9.11E-06	38.5	1.85E-06	45.7	1.30E-05	47.1
Total	2.36E-05	100	4.38E-06	100	2.78E-05	100	2.37E-05	100	4.05E-06	100	2.76E-05	100

9.12 Conclusions and Recommendations

The hazard to life assessment concludes individual risk and societal risk of SSWTW are acceptable for the proposed NDAs development (both construction stage and operation stage), The overall PLL is increased by about 18% by implementation of NDAs development. Nevertheless, the overall risk (in terms of individual risk and societal risk) lies within the acceptable level.

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