Appendix 13 C

PHI Assessment: Shatin Water Treatment Works

EXECUTIVE SUMMARY

Project Background

ERM-Hong Kong Ltd (ERM) has been commissioned to conduct a Hazard Assessment (HA) for the Shatin Water Treatment Works (STWTW) in relation to the construction and operation of the Shatin to Central Link (SCL).

The STWTW is designated as a Potentially Hazardous Installation (PHI) since it stores and handles chlorine in 1 tonne drums. The proposed SCL railway extension and Hin Keng Station will be located within the 1000m Consultation Zone at a distance of about 450 m from the Chlorine Store.

It is expected that during at least part of the SCL construction period, the WTW will undergo a refurbishment which will result in temporary reduction of the chlorine storage and usage levels. These reduced levels are therefore taken into account in the assessment as well as the ultimate storage case.

Methodology

The Study methodology is based on the approved methodology which was used in the HA for STWTW conducted by ERM in 1997-2001. That previous study was part of the *Reassessment of Chlorine Hazard for Eight Existing Water Treatment Works* study commissioned by WSD and involved the use of wind tunnel and CFD modelling results. The population and WTW operational data have now been updated to reflect the conditions during the SCL construction and operation.

Risk Criteria

As required by the EIA Study Brief No. ESB-191/2008, the individual and societal risks assessed under the study should be compared to the Hong Kong Risk Guidelines (HKRG) as stipulated in Annex 4 of the Technical Memorandum on Environmental Impact Assessment Process (EIAO-TM). The criterion that appears most pertinent to this study is the requirement that any scenario with a frequency of occurrence greater than 1×10^{-9} per year (once in one billion years) should not cause more than 1000 fatalities.

Population Data

The background population data for the study area within the 1000m WTW Consultation Zone (CZ) as well as the population outside the CZ that may be affected by a chlorine release at WTW have been updated based on the latest available information from the Planning Department, publicly available sources and site surveys.

The SCL population data for the construction and operational phases of the project (number and locations of the construction workers, and expected

numbers of passengers using SCL trains and the HIK Station) are based on information provided by MTRC.

Scenarios Considered, Results and Discussion

The scenarios considered for the construction and operational phases of the project are listed in the table below, together with the corresponding WTW storage and usage data (provided by WSD). The results on the maximum number of fatalities are also shown in *Table 1*.

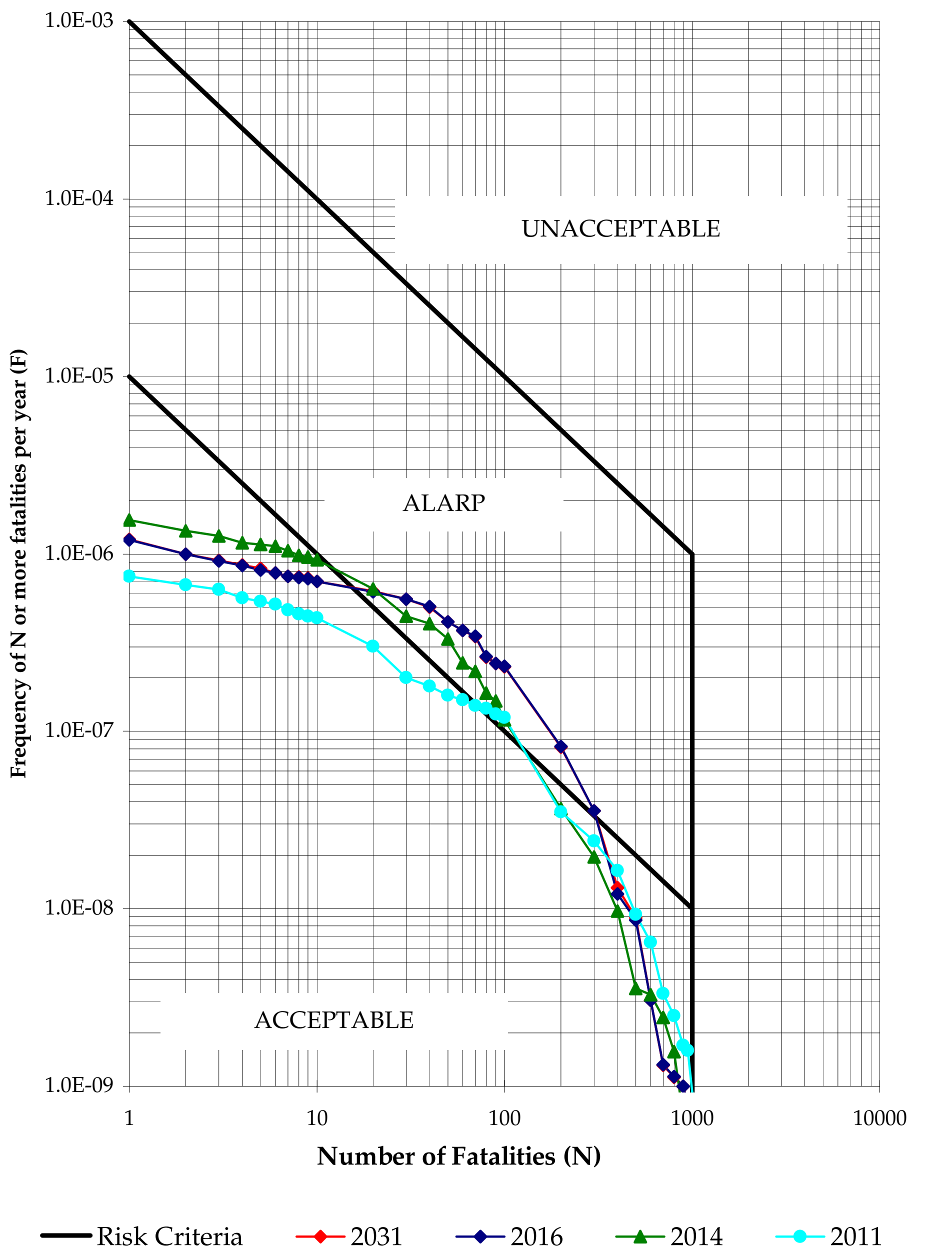
Table 1: Scenarios Considered in QRA

Scenario	Assessment year	Maximum Chlorine Storage at WTW (tonnes)	Weighted Average Chlorine Storage Time Distribution Assumed in the QRA (tonnes, % of time)	Average Chlorine Usage at WTW (tonnes per year)
SCL Construction Period 1 (before WTW refurbishment starts)	2011	221	203 (10%)[1] 183 (80%) 158 (10%)	896
SCL Construction Period 2 (during the WTW refurbishment between 2012 and 2016)	2014	158	158 (100%)	642
SCL Operation Period 1 (after completion of WTW refurbishment)	2016	190	190 (20%) 150 (80%)	761
SCL Operation Period 2 (increase in SCL patronage and surrounding population growth taken into account)	2031	190	190 (20%) 150 (80%)	761

Note (1): if necessary, the period for which WSD will maintain this time distribution will be agreed between MTR and WSD after the details of the SCL construction programme and the SCL construction workforce mobilization plan are known

The Societal Risk results for all scenarios fall in the "ALARP" region of the HKRG. The risks to the SCL population alone (considering HIK Station and the train populations) lie within the "Acceptable" region. The FN curves are illustrated in *Figure 1* below.

Figure 1: FN Curves for the Scenarios Considered



The main contributors to the risks causing large numbers of fatalities are catastrophic events such as earthquakes and plane crashes. These lead to the collapse of the store building and multiple chlorine drum ruptures.

It may be noted that the 2001 STWTW QRA predicted the societal risk within the ALARP region of the HKRG, but very close to the 1000 fatalities criterion. Any increase in population due to natural growth or any new development including transient construction workforce might therefore be expected to result in exceedance of the HKRG criteria (ie N>1000).

Nevertheless, societal risk levels for all scenarios studied have N<1000. This is due to the lower chlorine storage and use anticipated during and after the WTW refurbishment. For the possible SCL construction period before the WTW refurbishment begins, WSD has agreed to maintain the chlorine storage time distribution that will not lead to an exceedance of the N<1000 criterion.

The individual risk levels are low and in compliance with HKRG.

Mitigation

Mitigation measures were considered, however following a formal cost-benefit analysis all were deemed not practicable. Nevertheless it is recommended that adequate emergency response/evacuation plans for the SCL works area and the future Hin Keng Station staff and passengers are established and emergency training/drills for all relevant MTR personnel conducted at regular intervals. Installation of on-site gas monitors is also recommended.

CONTENTS

EXECUTIVE SUMMARY

1 INTRODUCTION

ERM-Hong Kong Ltd (ERM) has been commissioned to conduct a Hazard Assessment (HA) for the Shatin Water Treatment Works (STWTW) in connection with the construction and operation of the Shatin to Central Link (SCL).

The STWTW is designated as a Potentially Hazardous Installation (PHI) owing to its use and storage of chlorine in 1 tonne drums. The proposed SCL railway extension and Hin Keng Station will be located within the 1000m Consultation Zone of the Chlorine Store of the STWTW and therefore a hazard assessment is required. This Report presents the results of the Hazard Assessment.

1.1 PROJECT BACKGROUND

SCL consists of two sections; the Tai Wai to Hung Hom Section and the Cross Harbour Section. The Tai Wai to Hung Hom Section will be an extension of the Ma On Shan Line from Tai Wai Station to Hung Hom Station. The cross harbour section will extend from the existing East Rail Line from Hung Hom to Admiralty with one intermediate station at Exhibition.

The development and operation of the Project will have the following components:

- A railway of approximately 11km long from Tai Wai to Hung Hom;
- Six railway stations at Diamond Hill, Kai Tak, To Kwa Wan, Ma Tau Wai, Ho Man Tin and Hung Hom, with a future station at Hin Keng. Diamond Hill, Ho Man Tin and Hung Hom will become integrated interchange stations with the existing Kwun Tong Line, the proposed Kwun Tong Line Extension and the future Cross Harbour Section of the SCL, respectively;
- A railway depot at the former Tai Hom Village at Diamond Hill; and
- Associated works including storage of explosives, supporting facilities and infrastructures for the construction and operation of the Project.

1.2 PURPOSE OF THE HAZARD ASSESSMENT

Under Section 5(7) of the Environmental Impact Assessment (EIA) Ordinance (Cap. 499) (EIAO), the Director of Environmental Protection (Director) from the Environmental Protection Department (EPD) has issued a Study Brief No. ESB-191/2008 for this project (EIA Study Brief). Section 3.4.5 of the EIA Study Brief specifies Hazard to Life assessments to be conducted for the Project. Part of this requirement addresses risks in relation to Shatin WTW. For completeness, these requirements are repeated in *Table 1.1*.

Table 1.1 EIA Study Brief - Hazard to Life Requirement

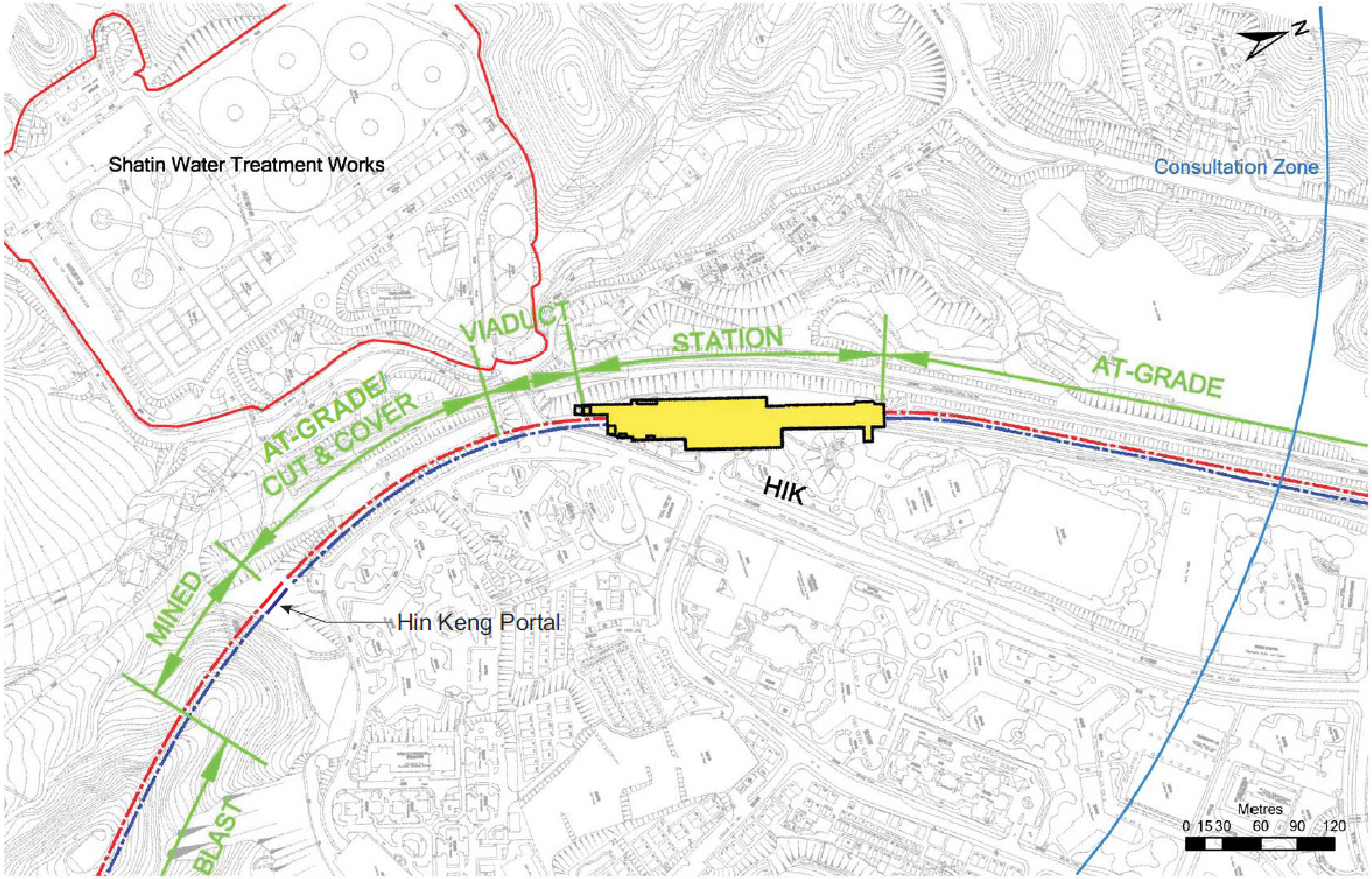
3.4.5	**Hazard to Life**
3.4.5.4	The Applicant shall carry out hazard assessment to evaluate potential hazard to life during construction and operation stages of the Project due to Sha Tin Water Treatment Works. The hazard assessment shall include the following : (i) Identify hazardous scenarios associated with the on-site transport, storage and use of chlorine at Sha Tin Water Treatment Works 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. “Reassessment of Chlorine Hazard for Eight Existing Water Treatment Works” commissioned by Water Supplies Department).

The STWTW is designated as a Potentially Hazardous Installation (PHI) owing to its use and storage of chlorine in 1 tonne drums. A Consultation Zone (CZ), centred at the chlorine store, of 1000 m radius but excluding the areas located at over 150m above sea level is established around the WTW. Part of the railway alignment and the future station at Hin Keng will be located within the CZ (*Figures 1.1, 1.2*).

Societal risks from a PHI depends on surrounding population levels. Consultation Zones are established around PHIs to control developments in the vicinity and prevent population accumulating to the point where societal risks may become unacceptable. Any new development within the Consultation Zone of a PHI that may lead to an increase in population requires a hazard assessment to be conducted to ensure that the societal risks remain acceptable. The purpose of this assessment, therefore, is to assess risks from STWTW to the surrounding population including the construction and operational phases of SCL and Hin Keng Station. The criteria and guidelines for assessing Hazard to Life are stated in Annexes 4 and 22 of the Technical Memorandum (EIAO-TM Criteria).

Figure 1.1 Consultation Zone of STWTW

Figure 1.2 Hin Keng Station and SCL Alignment



1.3 *Previous QRA Study for Shatin WTW*

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;
- Shatin WTW;
- Sheung Shui WTW;
- Tai Po Tau WTW;
- Tsuen Wan WTW;
- Tuen Mun WTW; and
- Yau Kom Tau WTW.

The approved methodology for the above QRA studies is detailed in the 8 WTW Study *Methodology Report* (ERM, 1997). Results for the STWTW (ERM, 2001) showed that:

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

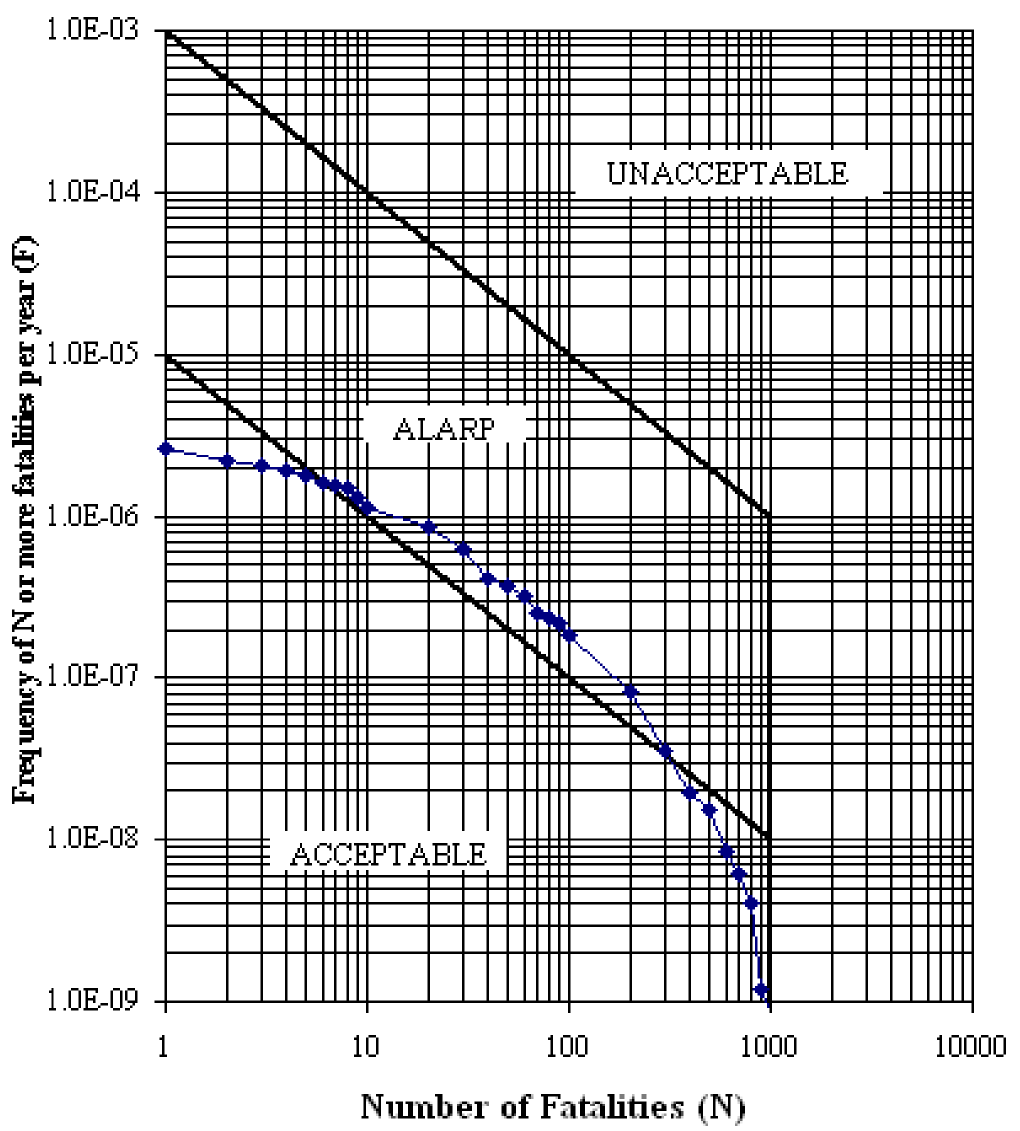
This is illustrated in the FN chart shown in *Figure 1.3*.

The previous QRA study for STWTW (ERM, 2001) was based on the following operational data:

- 223 tonnes of chlorine storage;
- 7.5 mg/l dosing giving a consumption of 3359 tonnes/year; and
- Population based on 1997 data, projected to year 2006.

The ERM (2001) study methodology has been consistently adopted for the current assessment, as specified in the EIA study brief (*Table 1.1*).

Figure 1.3 FN curve from the 2001 STWTW Hazard Assessment (ERM, 2001)



1.4 *Structure of the Report*

The rest of this report is divided into the following sections:

- *Section 2* provides a description of the Shatin WTW, the construction and operation of the SCL project as relevant for this study, and details of the project and surrounding population that may be subject to chlorine hazards from the WTW;
- *Section 3* presents the results of the hazard identification;
- *Section 4* presents the results of the consequence analysis;
- *Section 5* presents the chlorine release scenarios and estimation of scenario frequencies;

- *Section 6* presents the risk results;
- *Section 7* discusses possible risk mitigation measures;
- *Section 8* presents the conclusions and recommendations of the study; and
- *Section 9* provides the list of references used in this study.

2 DESCRIPTION OF SHATIN WTW AND THE SCL CONSTRUCTION AND OPERATION AREAS

2.1 DESCRIPTION OF SHATIN WTW

2.1.1 Location

Shatin WTW is located at the head of a valley on Keng Hau Road, Hin Tin to the south-west of Shatin new town. The site is approximately rectangular in shape and measures 400m north to south by 300m 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 and the site layout plan are shown in *Figures 2.1* and *2.2*.

The site is approached from Keng Hau Road or Che Kung Miu Road. The existing on-site access road to the chlorination house follows the east, south and south west edges of the site (*Figure 2.3*). Chlorine trucks must first drive past the administration building, chemical house, alum tanks and M&E Workshop before reaching the store.

Figure 2.1 Shatin WTW and its Surroundings

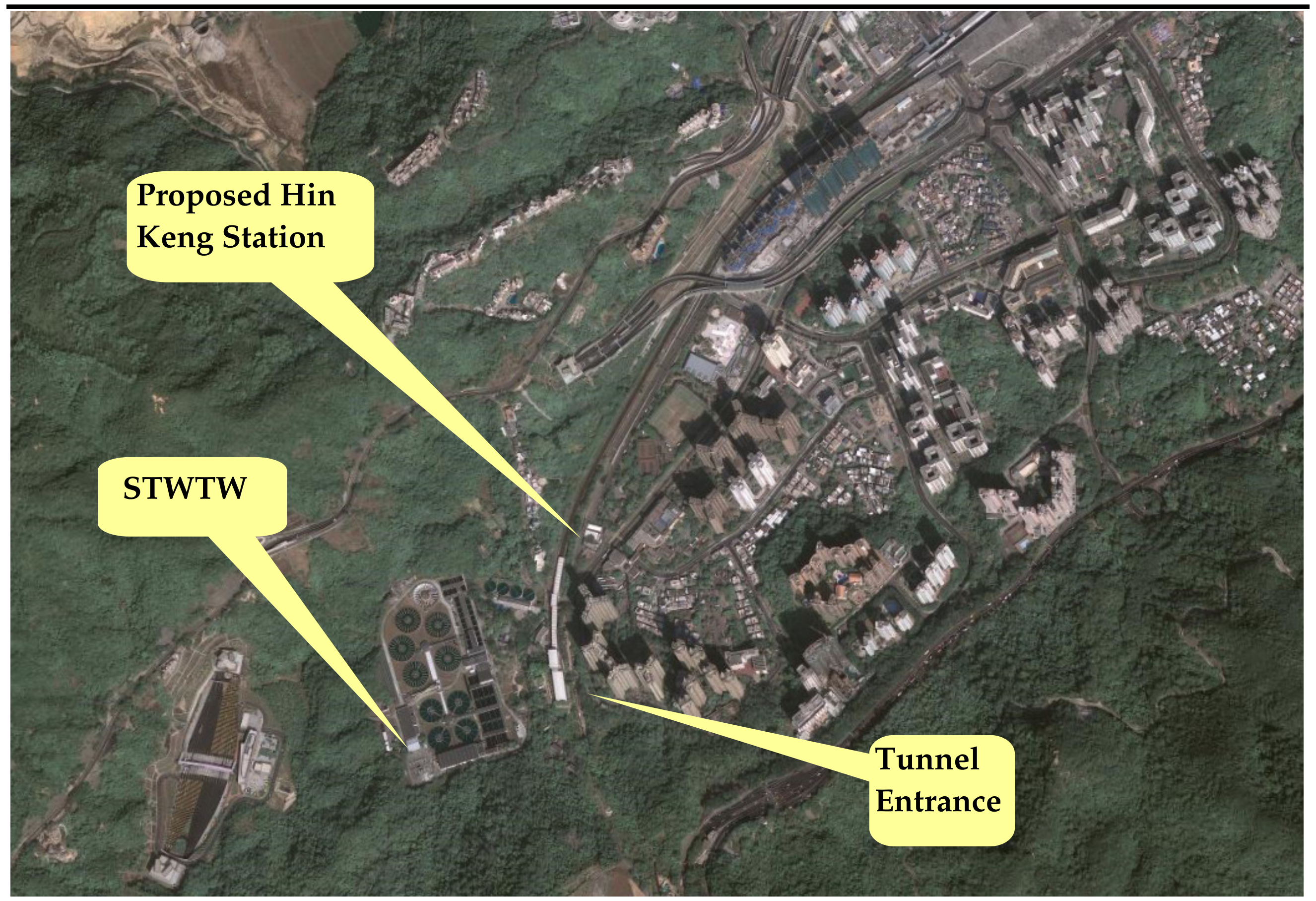
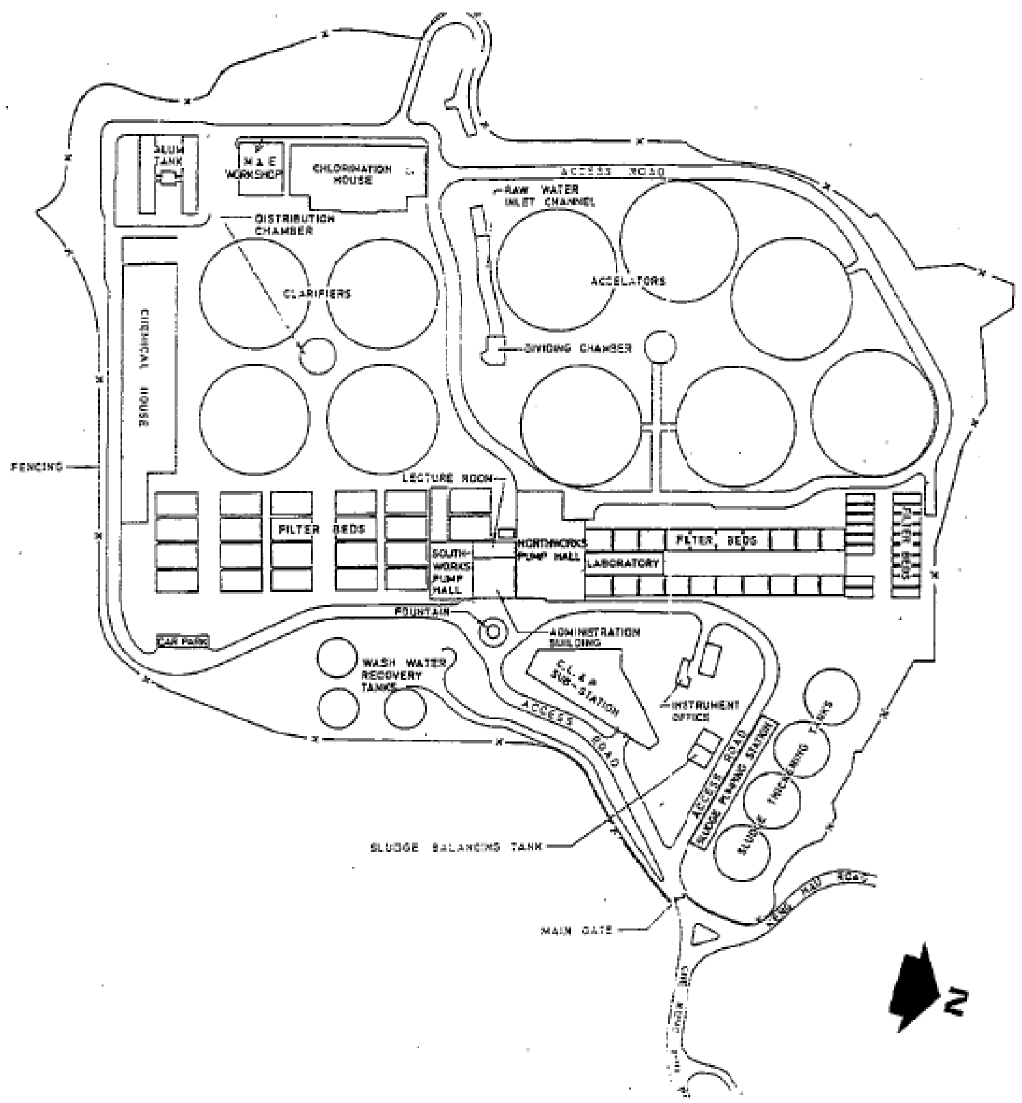


Figure 2.2 *Site Layout of Shatin WTW*



2.1.2 *Operations*

Delivery, Storage and Handling of Chlorine

Chlorine is delivered to Shatin WTW 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 '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.

Chlorination System

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.

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. This reduces the chances of chlorine leaks. Double non return valves are provided within the chlorinator units.

Ventilation System

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

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 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.

The scrubber system is normally set at auto standby mode for discharge of the treated air to atmosphere at roof level (chlorine concentration below 3 ppm). If the chlorine concentration rises above 3 ppm, the discharge to atmosphere will be stopped and air will be recycled back to the drum storage area for further treatment. In case of chlorine concentrations above 15 ppm, the whole scrubbing operation will be stopped (by stopping the scrubber fan) and the plant operator will check the proper functioning of the scrubber system. 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 the 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 preparation 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

According to 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.

WTW Refurbishment

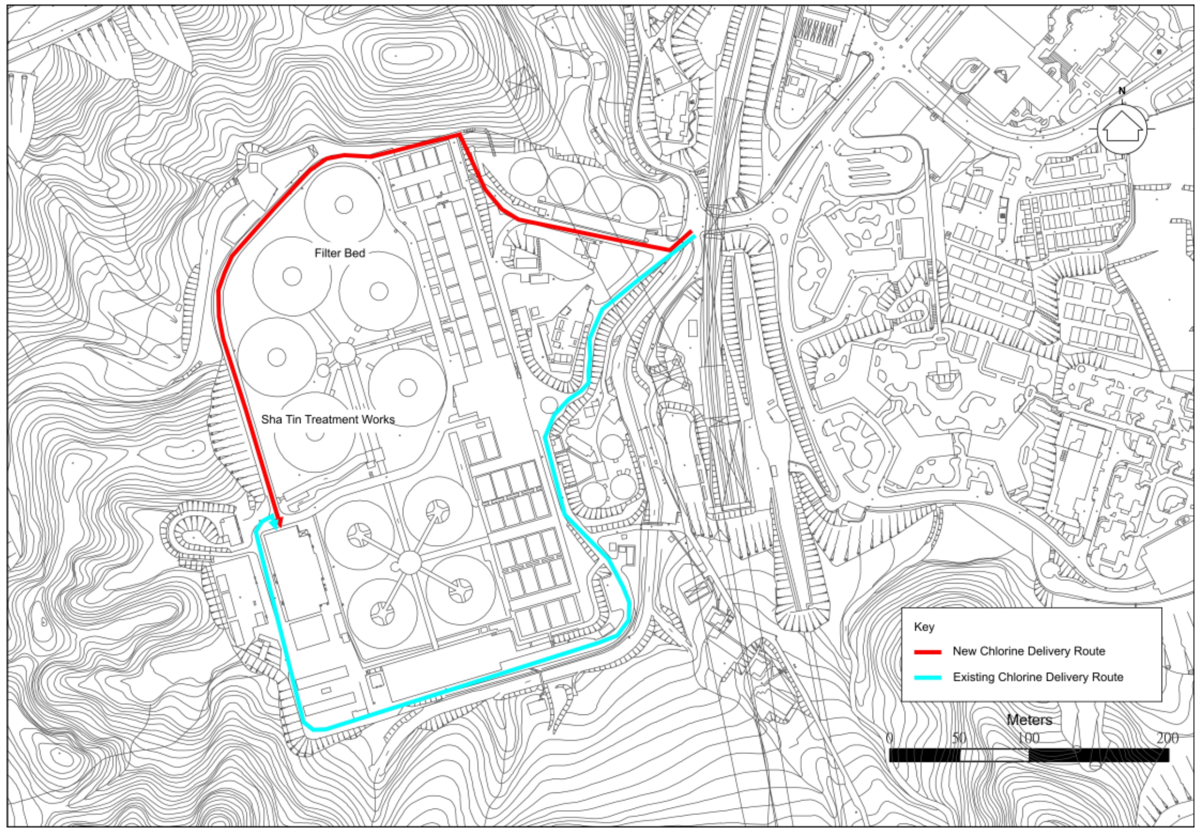
Water Supplies Department is planning a major ST WTW refurbishment programme, which is scheduled to commence in mid-2012 tentatively. During the refurbishment, since parts of the plant will have to be temporarily shut down, the water throughput will decrease and accordingly, chlorine storage and usage levels will be significantly reduced. Following completion of the refurbishment at the end of 2016, water throughput will return to 1,227 Mld.

Chlorine dosage levels were assumed at 7.5 mg/l in ERM (2001) but current dosing levels are below 2 mg/l. This will be further reduced to 1.7 mg/l following the refurbishment, due to the introduction of new treatment technology. This will result in a permanent reduction in chlorine usage once refurbishment is completed in 2016. Details are presented in *Table 2.1*.

Chlorine truck supplies to the chlorine store will be diverted during the refurbishment period from the existing route around the south side of the site to an alternative route. According to the information provided by WSD, the most likely alternative route will take chlorine trucks around the north side of the site (*Figure 2.3*) to avoid the construction activities. Note however, that this alternative chlorine delivery route, which is also expected to be permanently used after the WTW refurbishment is completed, is subject to detailed design and assessment/scrutiny by the prospective D&C consultants and approval from relevant government departments such as FSD.

The exact number of refurbishment construction workers on-site will depend on a number of factors such as the actual scope of works, construction sequence etc, to be scrutinized by the prospective D&C consultants and so it is not known at the moment. Based on the preliminary WSD information the maximum number of construction workers is estimated at 110 persons.

Figure 2.3 ***Existing Chlorine Delivery Route at STWTW and the Tentative Alternative Route to be used during and after the Refurbishment***



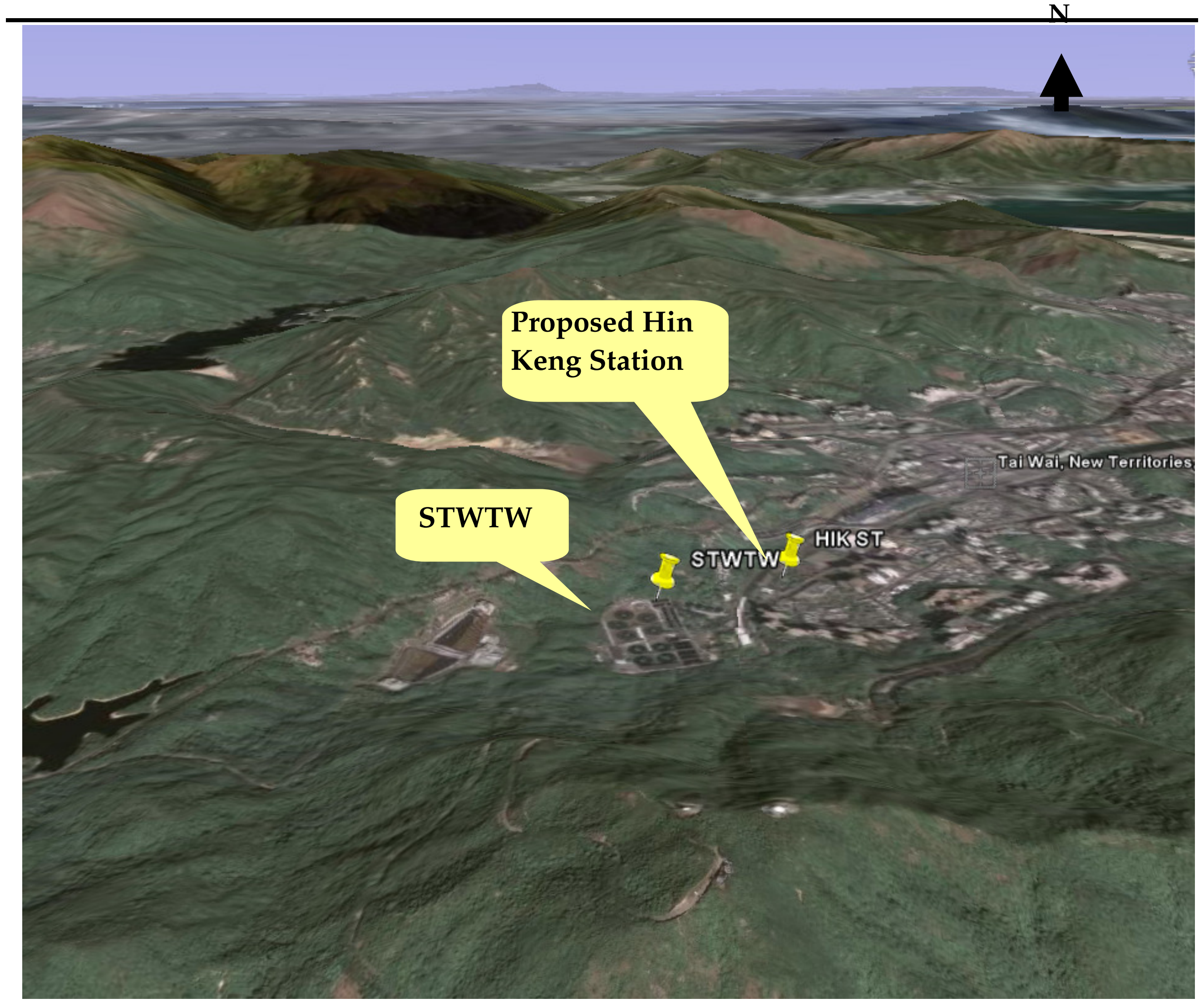
Basic Operating Data for Shatin WTW

The operating data for the WTW at different time periods are listed in *Table 2.1,* based on the information provided by WSD.

2.1.3 *Surrounding Topography*

Shatin WTW is located at 30m above the Principal Datum (PD) and is surrounded on three sides by hills rising to approximately 300m. To the north-east the land slopes gently downwards towards the town of Shatin. The topography is of particular relevance; since chlorine is a dense gas the spread of 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 2.4*.

Figure 2.4 Shatin WTW and Topography (not to scale)



2.2 SHATIN TO CENTRAL LINK (SCL)

The proposed SCL railway will extend the Ma On Shan Line from Tai Wai Station to Hung Hom Station.

Of interest to this QRA is the proposed Hin Keng Station as well as the SCL alignment and construction works areas within the Consultation Zone of STWTW. The proposed location of the Hin Keng Station and the SCL alignment in relation to the STWTW are shown in *Figure 1.2*.

The proposed Hin Keng Station construction site is located approximately 450m to the north-east of Shatin WTW chlorine store, but only some 90 m from the WTW site entrance and its access road which is used by the trucks delivering chlorine to the WTW. Similarly, the SCL tunnel entrance work area is located about 375 m from the chlorine store and 150 m from the WTW access road. The exact location of the construction works office and yard is not known at the moment; for the purpose of this assessment it was assumed that they will be located close to the NW corner of the Hin Keng Station area.

According to the information provided by MTRC, major construction activities in the area under consideration in this QRA will commence by mid-2012 to be completed by the end of 2016. Note that this period mostly coincides with the STWTW refurbishment works, although, depending on the future detailed schedules of WSD and MTRC and the possibility of programme slippages, the SCL construction may begin before or after the start of WTW refurbishment. A worst-case scenario is therefore considered in the assessment, namely that of SCL construction beginning before WTW refurbishment. This gives the worst case as chlorine storage and usage levels are still high at this time and SCL construction will introduce more population (workers) in the vicinity.

2.3 SCENARIOS CONSIDERED IN THE QRA

Based on the SCL construction and WTW refurbishment schedules described above, four scenarios have been considered in the QRA including two possible stages of the construction phase and two periods of the SCL operation. The main assumptions used for each scenario, based on WTW operational data provided by WSD, are listed in *Table 6.1*. The chlorine storage levels and their time distribution for the future scenarios have been agreed with WSD. Details of the population data for each assessment year are provided in *Table 2.3*.

As mentioned earlier, Scenario 1 is included to cover the possibility that SCL construction may begin before WTW refurbishment. Chlorine usage is still high during this scenario.

The second scenario considers the period when both SCL construction and WTW refurbishment are taking place simultaneously. Chlorine usage is lower during this period since the WTW will be operating at reduced capacity, but population levels are higher with both SCL and WTW workers present.

The third and fourth scenarios consider SCL operational phases after completion of WTW refurbishment. The year 2016 is considered for immediately following refurbishment, and a future year 2031 to allow for possible population growth.

Table 2.1 ***Scenarios Considered in QRA***

Scenario	Assessment year	Maximum Chlorine Storage at WTW (tonnes)	Weighted Average Chlorine Storage Time Distribution Assumed in the QRA (tonnes, % of time)	Average Chlorine Usage at WTW (tonnes per year)
Scenario 1: SCL Construction (before WTW refurbishment starts)[1]	2011	221	203 (10%)[1] 183 (80%) 158 (10%)	896
Scenario 2: Simultaneous SCL Construction and WTW refurbishment	2014	158	158 (100%)	642
Scenario 3: SCL Operation Period 1 (after completion of WTW refurbishment)	2016	190	190 (20%) 150 (80%)	761
Scenario4: SCL Operation Period 2 (surrounding population growth taken into account)	2031	190	190 (20%) 150 (80%)	761
Assumed in 2001 QRA	2006	223	223 (100%)	3359

Notes:
(1): If necessary, the period for which WSD will maintain this time distribution will be agreed between MTRC and WSD after the details of the SCL construction programme and the SCL construction workforce mobilization plan are known.

2.4 *METEOROLOGICAL CONDITIONS*

For the sake of consistency, this study uses the same meteorological data set as was used in the previous QRA (ERM, 2001), ie the data recorded at the Shatin weather station in the year 1996 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 2.2*. 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 2.2 *Meteorological Data for Shatin 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

2.5 POPULATION DATA

2.5.1 General Approach

The approach to the population data used in this study for the total risk assessment is as per the 2001 QRA for Shatin WTW (ERM, 2001). The population data from the 2001 study were updated to reflect the current situation (the "base population data") and the current projections to the assessment years for construction and operational phases of the project. Note that this approach (retaining the basic structure of the 2001 QRA data, but updating it based on the latest information is consistent with other recent studies assessing chlorine hazards in vicinity of WTWs, such as the approved EIA on *Tsuen Wan Bypass, widening of Tsuen Wan Road between Tsuen Tsing Interchange and Kwai Tsing Interchange, and associated junction improvement works* (EIA-152/2008).

2.5.2 Sources of Information

MTRC

Railway-specific data such as SCL train and station loadings for 2016 (Scenario 3) and 2031 (Scenario 4) operational phases, population of the Tai Wai MTR Depot, number and locations of the SCL construction workers etc. were provided by MTRC.

WSD

Population data for the STWTW staff quarters as well as the number of STWTW refurbishment workers were provided by WSD.

PlanD

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 PlanD website.

The Territory Population and Employment Data Matrix (TPEDM) 2006-based population projections for different planning areas (PVS) 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.

Centamap

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 of building groups. Where available, population data from the 2006 by-census was used in this study.

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. The number of units was, however, not available for village housing and public housing estates.

The Centamap website was also used to verify the locations and/or further existence of the population units assumed in the 2001 QRA and to check for any new developments that may have been constructed following that assessment.

Leisure and Cultural Services Department

Daily attendance data at Hin Tin Swimming Pool the period of December 2008 to November 2009 and the highest and average daily usage data for the Hin Tin Playground were obtained from LCSD.

Transport Department

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 2007[2].

Since the traffic data for the newly opened Route 8 are not included in the 2007 Traffic Census, the recent monthly data for the Tsing Sha Control Area were obtained from TD[3].

Site Survey

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. Its main objectives were:

1 http://www.centamap.com/gc/home.aspx

2 http://www.td.gov.hk/publications_and_press_releases/publications/free_publications/the_annual_traffic_census_2007/index.htm

3 http://www.td.gov.hk/en/transport_in_hong_kong/transport_figures/monthly_traffic_and_transport_digest/index.html

- Estimation of the numbers of floors and units for the public housing estates for which such information was not available from the Centamap website;

- Verification of some population numbers estimated during the ERM survey of 6 November 1997;

- Identification of any new developments under construction and/or not included in the Centamap information;

- Verification of the locations and/or further existence of some population units assumed in the 2001 QRA;

- Vehicle count on the Che Kung Miu Road and Hin Keng Street.

An additional site survey of areas around the SCL project site was conducted in July 2011.

Education Bureau Data

For most kindergartens, primary and secondary schools and colleges, data from the Education Bureau website[1] was used. This included the number of classrooms and the capacity of each classroom.

Telephone Interviews

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.

2001 STWTW QRA Report

For a few cases where the actual population data could not be verified using any of the above sources of information, the 2006 projections of the 2001 STWTW QRA Report (ERM,2001) were used in this study and further projected to the assessment years considered in this study. Details are provided in *Section 2.5.4* and *Table 2.3*.

The percentages of the maximum population present (occupancy) at different times of the day and the indoor/outdoor fractions for the total unit population were also mainly based on those used in the 2001 STWTW QRA.

[1] http://www.edb.gov.hk/index.aspx?nodeID=163&langno=1

2.5.3 Population Units

All the population units defined in the form of GIS-based polygons, points and lines that were included in the 2001 QRA have been retained for this study; however, the extent of the Hin Tin Playground (polygon B) has been reduced to make way for the planned Hin Keng Station. A number of new units have also been created. The full list of population units considered is provided in *Table 2.3* and their locations shown in *Figure 2.5*. 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.

The new units introduced for the purposes of this study include:

- Polygon units B1 and B2: Hin Tin Playground which in the 2001 assessment was represented by Polygon unit B for the purposes of the present assessment has been split into polygons B1 and B2, representing the main playground and the tennis court and football field areas, respectively;

- Line unit Z5: SCL train (moving, operational phase only);

- Polygon unit Z6: Hin Keng (HIK) Station works area (construction phase); HIK Station and a stationary SCL train at the station (operational phase);

- Polygon unit Z7: Tunnel portal (construction phase only);

- Line unit Z8: SCL track construction (construction phase only);

- Polygon unit Z9: construction yard and offices (construction phase only);

- Polygon unit T1: WTW refurbishment workers (Scenario 2 only);

- Polygon unit 17A: new residential development in the Tai Wai MTR Depot Area;

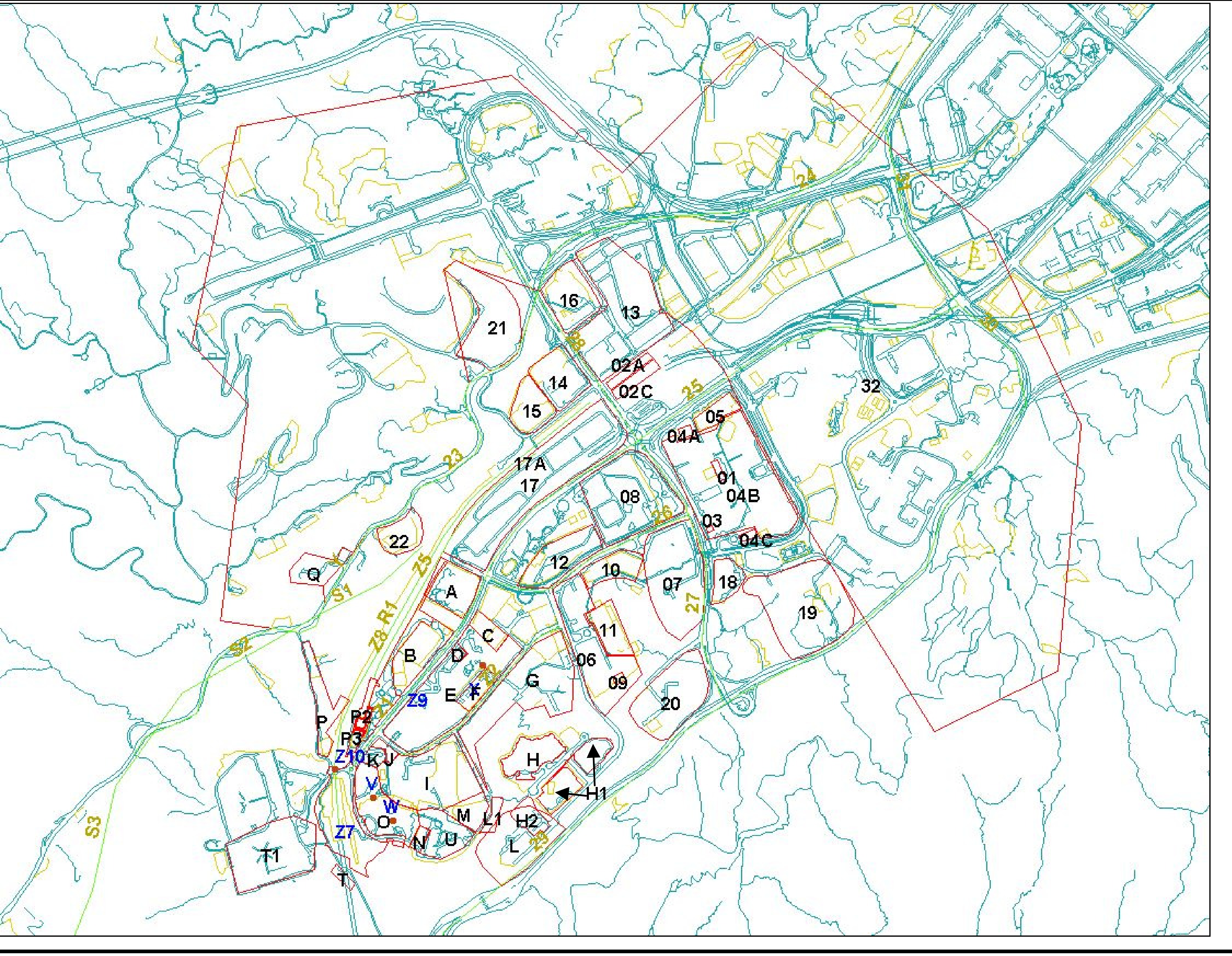
- Polygon unit L1: Proposed residential development at Hin Tin St, to the north-west of the Union Hospital;

- Polygon unit H1 Julimount Garden;

- Polygon unit H2 Hill Paramount; and

- Point Unit Z10: Keng Hau Rd underpass below the SCL alignment.

Figure 2.5 Population Units used in QRA



2.5.4 *Processing Population Data*

This *Section* outlines the procedures used in obtaining the population numbers for the construction and operational phases assessment years from the general data described above.

MTR Trains (items 2B, R1, Z5, Z6)

Peak hour and daily total passenger numbers were provided by MTRC. 28 trains per hour in each direction are expected for the peak period. Percentages for the off-peak periods were determined based on the ERM (2001) QRA study methodology taking into account the difference of the daily and peak values in the recent MTRC data.

For the moving trains (items R1 and Z5), following the ERM (2001) QRA methodology, the train population was evenly distributed along the respective length of the track, additionally introducing a 0.1 protection factor due to the limited exposure duration.

MTR Stations (items 2A, 2C, Z6)

Peak hour and daily total numbers of passengers boarding or alighting from a train at each station were provided by MTRC. It has been assumed that each of these passengers spends 5 minutes at the Tai Wai station.

For the new Hin Keng Station (*Figure 2.6*) situated near the WTW, the average time spent by each passenger in the station has been determined by calculating:

- the time needed to go from the train to the station exit for alighting passengers, assuming 4 km/h walking speed; and
- the time needed to go from the station entrance to the train platform, with an average of 1 minute waiting added for the people boarding the train.

According to the MTR predictions, 7000 passengers are expected to use the Hin Keng Station during peak hours in both 2016 and 2031. It is assumed that on average, 3500 of these passengers will be boarding a train each hour and 3500 alighting. The walking distance to/from the platform is estimated at 180 m resulting in 2.69 min walking time. The peak hour station population walking to/from the train can then be estimated at 7000*2.69/60 = 314, while the number of people waiting at the platform is 3500*1/60 = 58, giving a station total of 314+58 = 372.

The proposed Hin Keng Station will be an open construction, so while following the ERM (2001) approach, the stationary train passengers are considered indoors, the station population is treated as being outdoors in the modelling. On the other hand, it is an elevated structure (platforms at 12 m above the ground) which may collapse in an earthquake leading to fatalities much like any other low rise concrete building. Therefore in the case of an earthquake, the station population (concourse, stairs and platforms) is conservatively treated as outdoor population with regards to exposure to a chlorine cloud but only the earthquake-surviving fraction may be affected. The surviving fraction of the station and stationary train population was computed in the same way as for the population of low-rise reinforced concrete buildings. More details of this approach, which is consistent with ERM (2001) are provided in *Annex G*.

SCL construction areas, MTR Tai Wai Depot, WTW Staff Quarters, WTW refurbishment area (items 17, T, T1, Z6, Z7, Z8, Z9)

Population data for these units were directly adopted from the information provided by MTRC and WSD.

Public Housing Estates and Private Residential Developments

Items 1, 6, 7, 12, 13, 14, 18, 20, E, F, H, H1, O, U

2006 population levels for these units were based on the 2006 by-census data available on the Centamap website.

Item H2

Information on number of units was obtained from the developer website.

Item L1

While exact number of units for this development is not yet known, the probable number of units as well as planned average number of residents per unit was obtained from PlanD.

Items 22, P, Q

2006 population levels estimated for these units were based on the number of units determined from the Centamap website multiplied the 2006 average household size obtained from the TPEDM data for their respective PVSs.

Item 17A

The number of units for the development under construction in the Tai Wai MTR Depot area was not available from Centamap and was roughly estimated during the ERM site survey in April 2009. The future population was estimated based on that number of units and the average household size for the appropriate PVS.

Village Housing (items 8, 19, G, I)

For these villages, the number of units is not available on Centamap and 2006 population levels estimated for these units were therefore based on the number of houses determined from the Centamap website. It was then assumed that the average number of storeys is 3 and that there is 1 unit per storey. The 2006 average household size was obtained from the TPEDM data for their respective PVSs.

Schools, Kindergartens, Hospitals, Homes for the Aged etc (items 3, 4, 5, 9, 10, 11, 15, 16, C, D, L, M, N, V, W, X)

Where available, capacity was taken from the Education Bureau or the Social Welfare Department websites. Populations of units D and W were obtained from telephone interviews. In two cases (units 9 and L), the current information could not be obtained from any of these sources, so data from the 2001 QRA has been used.

All schools considered in this QRA belong to the "whole day" category that has about 190 school days per year. To account for the school closures during the holidays, appropriate time factors have been applied to the F values in all FN pairs involving schools as part of societal risk evaluation.

Item 32

Population of item 32, defined as "Populated area 2-3 km northwest of Shatin WTW" was determined mainly from the by-census and number of unit information available from the Centamap website, supplemented by other data sources outlined above. Following the 2001 QRA, the population was deemed as mostly residential and the average number of floors assumed at 20.

Hin Tin Swimming Pool and Hin Tin Playground (items A, B1, B2)

Population of the Hin Tin Swimming Pool at any given time has been estimated based on the year-long daily attendance figures provided by LCSD and an interview with the pool staff. It has been assumed that each person spends at the pool 1.5 hours on the average and that attendance on weekends is twice as high as on weekdays. Two periods are separately considered in the QRA: summer months (June to September) and the remaining part of the year, with higher attendance and lower proportion of users attributed to the indoor pool during the summer period.

The population of Hin Tin Playground, tennis court and football field was based on the average daily attendance for the whole year. Similar to the swimming pool, it has been assumed that each person spends at the playground 1.5 hours on the average and that attendance on weekends is twice as high as on weekdays.

During the construction of Hin Keng Station and SCL alignment, the Playground (unit B1), with the exception of its tennis court and the football field (unit B2), will be converted to the construction work areas (unit Z9). Therefore, only the tennis court and football field population is taken into account for the Construction Phase scenarios.

Similarly, a part of the Hin Tin Playground will be permanently converted to the future Hin Keng Station site; therefore its existing population has been reduced for the 2016 and 2031 assessment years in proportion to the planned area reduction.

Bus Terminus and Commercial Areas (items J, K)

Population of these units has been estimated based on the population data reported in the ERM (2001) study. These data were verified for the purpose of the present study by a site survey on 29 April 2009. As a result, the population of the commercial area J has been significantly increased, while that of the bus terminus decreased, the indoor fraction of the area J population has also been adjusted.

Road Populations (items 23, 24, 25, 26, 27, 28, 29, 30, 31, Y, Z1, Z2, Z10)

Road populations were estimated according to the AADT values obtained from 2007 Annual Traffic Census.

The peak hour population was then established by multiplying the AADT value by a factor of 0.00943 and the length of the road in km. The factor 0.00943 is equal to 0.1 x 3.3 /35 where 0.1 is the assumed fraction of AADT during the peak hour, 3.3 the average number of people per vehicle and 35 the assumed speed in km/hr.

In some cases (items 23, 24, 29, Y) a traffic jam was assumed in one direction during the jammed peak period; the jammed road population was then obtained assuming that each vehicle with 3.3 people occupies on average 6 m of the road.

No AADT data were available for the Che Kung Miu Street and Hin Keng Street (units Z1, Z2). Since the limited-time traffic count undertaken during the April 2009 site survey yielded results lower than those used in the 2001 QRA, the latter, more conservative data were adopted for this study as well.

As no information on the future traffic trends was available for these roads and the examination of past traffic data shows no significant upward traffic trend over recent years, the population numbers as described above were not further projected to the future years.

Estimate of Z10 population was based on site survey conducted in July 2011.

Route 8 Road Populations (items S1, S2, S3)

Since the Route 8 AADT data are not available from the 2007 Annual Traffic Census, they have been estimated from the monthly traffic data (from November 2008 to October 2009) provided by Transport Department.

The methodology of estimating population for different time periods is similar to that described above. Similar to items 23, 24, 29, and Y, a traffic jam was assumed in one direction during the jammed peak period for Tsing Sha Highway (S1), Shatin Heights Tunnel (S2) and the Toll Plaza (S3).

Population Forecast

It has been assumed that, in the Consultation Zone, there is no space available for further residential development.

Outside the Consultation Zone, the 2006 residential population levels determined as described above have been scaled up or down according to the population trends determined from the area-specific TPEDM PVS-based projections. Details are provided in *Annex F*.

For population types other than residential, no growth has been assumed.

2.5.5 Summary

The population data used in this study are summarised in *Table 2.3* and their locations shown in *Figure 2.5*. The total population levels are greater than those used in the 2001 QRA (ERM, 2001) due to general population growth in the area.

A definition of the time periods included in *Table 2.3* is provided in *Annex F*.

Figure 2.6 *Proposed Hin Keng Station and its Assumed Population Levels*

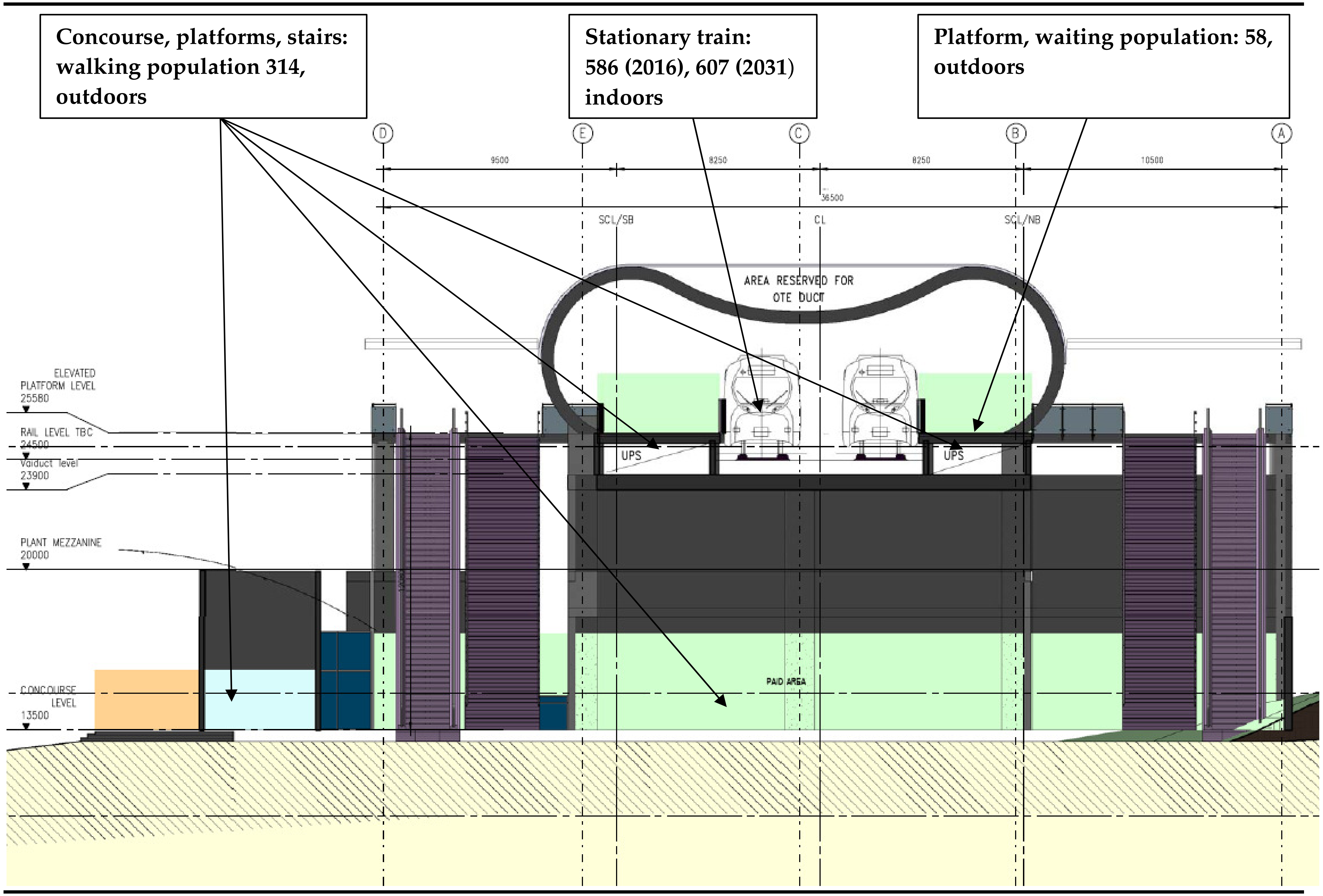


Table 2.3 Population Units

Ref	Name	2006 Projection used in 2001 HA	Base (latest data available)	2011	2014	2016	2031	Occupancy: Night	Occupancy: Jammed Peak	Occupancy: Peak Hour	Occupancy: Weekend Day	Occupancy: Working Day	Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
01	Sun Chui Estate	18800	18717	17471	19414	20828	20633	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (2006 population by-census), scaled according to PVS projection.
02A	East Rail Tai Wai Station	720	2000	2000	2000	2000	2083	20%	100%	100%	50%	50%	0%	1	1	Based on MTRC data
02B	East Rail Train at Tai Wai Station	3600	1304	1304	1304	1304	1464	20%	100%	100%	50%	50%	100%	1	1	Based on MTRC data
02C	SCL Tai Wai Station	1250	500	500	500	500	1250	20%	100%	100%	50%	50%	100%	1	1	Based on MTRC data
03	Home for the Aged ground floor Sun Chui Estate	143	68	68	68	68	68	100%	100%	100%	100%	100%	95%	3.3	1	Value from: http://www.swd.gov.hk/
04A	Cheong Wong Wai Primary School	780	315	315	315	315	315	0%	50%	50%	0%	100%	95%	3.3	5	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling.
04B	Free Methodist Bradbury Chun Lei Primary School	780	1087	1087	1087	1087	1087	0%	50%	50%	0%	100%	95%	3.3	5	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling
04C	KCBC Hay Nien (Yan Ping) Primary School	780	780	780	780	780	780	0%	50%	50%	0%	100%	95%	3.3	5	School capacity: from 2001 QRA. Time factor of 0.67 applied in modelling
05	Ng Yuk Secondary School and Shatin Tsung Tsin Secondary School	2655	2386	2386	2386	2386	2386	0%	50%	50%	0%	100%	95%	1	5	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling
06	Lung Hang Estate	13500	15563	17119	17119	16964	16497	100%	50%	50%	70%	50%	99%	1	12	Value from Centamap (2006 population by-census), scaled according to PVS projection.
07	King Tin Court	4000	4068	4475	4475	4434	5109	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (2006 population by-census), scaled according

Ref	Name	2006 Projection used in 2001 HA	Base (latest data available)	2011	2014	2016	2031	Occupancy: Night	Occupancy: Jammed Peak	Occupancy: Peak Hour	Occupancy: Weekend Day	Occupancy: Working Day	Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
																to PVS projection.
08	Tin Sam Village	1817	1817	1999	1999	1981	2670	100%	50%	50%	70%	50%	99%	1	3	Number of houses extracted from Centamap, scaled according to PVS projection.
09	Home for the Aged ground floor Lung Hang Estate	134	134	134	134	134	134	100%	100%	100%	100%	100%	95%	3.3	1	Value from 2001 QRA
10.1	PLK C. H. Wong Primary School	780	1215	1215	1215	1215	1215	0%	50%	50%	0%	100%	95%	3.3	1	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling
10.2	PLK C W Chu College	1350	1035	1035	1035	1035	1035	0%	50%	50%	0%	100%	95%	1	5	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling/
11	Lok Sin Tong Young Ko Hsiao Lin Secondary School and Pok Oi Hospital Chan Kai Memorial College	2700	2428	2428	2428	2428	2428	0%	50%	50%	0%	100%	95%	1	5	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling
12	Carado Garden	6700	6648	7313	7313	7246	7047	100%	50%	50%	70%	50%	99%	1	20	Value from Centamap (2006 population by-census) scaled according to PVS projection.
13	Misc. residential buildings	2363	8203	7957	7793	7629	7547	100%	50%	50%	70%	50%	99%	1	10	Value from Centamap (2006 population by-census) scaled according to PVS projection.
14	Holford Garden	5100	2470	2396	2347	2297	2272	100%	50%	50%	70%	50%	99%	1	25	Value from Centamap (2006 population by-census) scaled according to PVS projection.

Ref	Name	2006 Projection used in 2001 HA	Base (latest data available)	2011	2014	2016	2031	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
								Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
15	Christian Alliance Cheng Wing Gee College and GCC&ITKD Lau Pak Lok Secondary School	2700	2324	2324	2324	2324	2324	0%	50%	50%	0%	100%	95%	1	5	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling
16	Shatin Public School	160	220	220	220	220	220	0%	50%	50%	0%	100%	95%	1	1	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling
17	Tai Wai MTR Depot	455	47	47	47	47	47	44%	50%	50%	55%	100%	80%	1	1	Based on MTRC data
17A	Highrise residential buildings being constructed in Tai Wai Depot area	0	6107	6107	6718	6657	6473	100%	50%	50%	70%	50%	99%	1	40	Following the April 2009 site visit, population assumed as 8 buildings x 40 floors x 6 units x 3.28 persons per unit. Scaled according to PVS projection.
18	Golden Lion Garden - Phase II	4563	3300	3080	3423	3672	3637	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (2006 population by-census) scaled according to PVS projection.
19	Kak Tin Village	2048*	1067	996	1107	1187	1176	100%	50%	50%	70%	50%	99%	1	1	Number of houses extracted from Centamap, scaled according to PVS projection. Note that in the 2001 Report, unit 21 population was listed together with unit 19.
20	Worldwide Garden	1154	1480	1628	1628	1613	1569	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (2006 population by-census) scaled according to PVS projection.
21	Tai Wai Village	0*	1098	1061	1041	1021	1010	100%	50%	50%	70%	50%	99%	1	3	Number of houses extracted from Centamap, scaled according to PVS

Ref	Name	2006 Projection used in 2001 HA	Base (latest data available)	2011	2014	2016	2031	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
								Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
																projection. Note that in the 2001 Report, unit 21 population was listed together with unit 19.
22	Shatin Heights	432	294	529	517	510	535	100%	50%	50%	70%	50%	99%	1	5	Based on number of units extracted from Centamap and PVS household size (3.46).
23	Tai Po Road (1 km from WTW to Mei Tin Rd)	720	563	563	563	563	563	2%	100%	36%	18%	20%	0%	1	-	Traffic data from 2007 Annual Traffic Census; 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)	1300	1043	1043	1043	1043	1043	2%	100%	53%	25%	27%	0%	1	-	Traffic data from 2007 Annual Traffic Census 1997; 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)	340	264	264	264	264	264	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2007 Annual Traffic Census; length 1.8 km.
26	Tin Sam Street	86	102	102	102	102	102	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2007 Annual Traffic Census; length 0.7 km.
27	Hung Mui Kuk Road	210	175	175	175	175	175	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2007 Annual Traffic Census; length 0.8 km.
28	Mei Tin Road	230	168	168	168	168	168	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2007 Annual Traffic Census; length 0.7 km.
29	Lion Rock Tunnel Road - Shatin Rd to Lion Rock Tunnel	3080	2502	2502	2502	2502	2502	4%	100%	76%	40%	45%	0%	1	-	Traffic data from 2007 Annual Traffic Census. Road length ~2.6km; Assume one direction jammed and the other free-

Ref	Name	2006 Projection used in 2001 HA	Base (latest data available)	2011	2014	2016	2031	Occupancy: Night	Occupancy: Jammed Peak	Occupancy: Peak Hour	Occupancy: Weekend Day	Occupancy: Working Day	Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
																flow at Jammed Peak.
30	Lion Rock Tunnel Road - Che Kung Miu Rd to Shatin Rd	50	42	42	42	42	42	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2007 Annual Traffic Census; length 0.4 km.
31	Lion Rock Tunnel Road - Tai Po Rd to Che Kung Miu Rd	130	102	102	102	102	102	5%	100%	100%	50%	55%	0%	1	-	Traffic data from 2007 Annual Traffic Census; length 0.6 km.
32	Populated area 2-3 km northeast of Shatin WTW	83500	82224	85451	87096	88734	87018	100%	50%	50%	70%	50%	99%	1	20	Based on Centamap and other sources, scaled according to PVS projections
A	Hin Tin Swimming Pool	700†	300*	300*	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.
B1	Hin Tin Playground	300	133	0	0	128	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. scenarios. To be converted to the Project works areas (unit Z9) during the construction phases.

Ref	Name	2006 Projection used in 2001 HA	Base (latest data available)	2011	2014	2016	2031	Occupancy: Night	Occupancy: Jammed Peak	Occupancy: Peak Hour	Occupancy: Weekend Day	Occupancy: Working Day	Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
B2	Hin Tin tennis court and Football field	n/a	87	87	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. Note that in ERM (2001) items B1 and B2 were treated as one unit B.
C	Carmel Alison Lam Primary School	823	1042	1042	1042	1042	1042	0%	50%	50%	0%	100%	95%	3.3	6	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling
D	Wong Wah San Hostel for the Elderly	150	140	140	140	140	140	100%	100%	100%	100%	100%	95%	3.3	1	Telephone interview, June 2009
E	Hin Keng Estate North	9800	10763	10763	10763	10763	10763	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (2006 population by-census)
F	Ka Keng Court	2300	1140	1140	1140	1140	1140	100%	50%	50%	70%	50%	99%	1	41	Value from Centamap (2006 population by-census)
G	Sheung/Ha Keng Hau Village	2121	2155	2155	2155	2155	2155	100%	50%	50%	70%	50%	99%	1	3	Based on the number of houses from Centamap.
H	Parc Royale	1792	2470	2470	2470	2470	2470	100%	50%	50%	70%	50%	99%	1	20	Based on Centamap (2006 population by-census)
H1	Julimount Garden	n/a	810	810	810	810	810	100%	50%	50%	70%	50%	99%	1	22	Based on Centamap (2006 population by-census)
H2	Hill Paramount	n/a	518	518	518	518	518	100%	50%	50%	70%	50%	99%	1	27	Based on the number of units
I	Hin Tin Village Housing	960	1350	1350	1350	1350	1350	100%	50%	50%	70%	50%	99%	1	3	Based on the number of houses from Centamap.
J	Market Place/Bazaar/Restaurant	300	400	400	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

Ref	Name	2006 Projection used in 2001 HA	Base (latest data available)	2011	2014	2016	2031	Occupancy Night	Occupancy Jammed Peak	Occupancy Peak Hour	Occupancy Weekend Day	Occupancy Working Day	Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
																sports centre across the street taken into account.
K	Bus Station	100	50	50	50	50	50	10%	100%	100%	50%	50%	0%	1	1	Value from 2001 QRA reduced following the 2009 survey.
L	Union Hospital and Staff Quarters	473	473	473	473	473	473	100%	100%	100%	100%	100%	99%	3.3	13	Value from 2001 QRA
L1	Proposed residential development at Hin Tin St	n/a	0	0	765	765	765	100%	50%	50%	70%	50%	99%	1	40	Estimates based on information from PlanD
M	Helen Liang Memorial School	1200	1040	1040	1040	1040	1040	0%	50%	50%	0%	100%	95%	1	6	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling
N	CUHK FAA Thomas Cheung Primary School	500	1116	1116	1116	1116	1116	0%	50%	50%	0%	100%	95%	3.3	6	School capacity from: http://www.edb.gov.hk/. Time factor of 0.67 applied in modelling
O	Hin Keng Estate South	9800	9454	9454	9454	9454	9454	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (2006 population by-census)
P	Residential Area (Keng Hau Road)	186	129	129	129	129	129	100%	50%	50%	70%	50%	99%	1	3	Based on number of units and PVS household size (3.3).
Q	Low Rise Residential Buildings	183	180	180	180	180	180	100%	50%	50%	70%	50%	99%	1	1	Based on number of units and PVS household size (3.46).
R1	East Rail Train near Shatin WTW	1912	718	718	718	718	806	16%	100%	100%	41%	41%	100%	1	1	Based on MTRC data
S1	Tsing Sha Hwy (formerly Route 16: Northern Section)	345	362	362	362	362	362	1%	100%	18%	9%	10%	0%	1	-	Based on the traffic data provided by TD. Traffic assumed stationary in one direction during Jammed Peak.

Ref	Name	2006 Projection used in 2001 HA	Base (latest data available)	2011	2014	2016	2031	Occupancy Night	Occupancy Jammed Peak	Occupancy Peak Hour	Occupancy Weekend Day	Occupancy Working Day	Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
S2	Shatin Heights Tunnel (formerly Route 16: Shatin Tunnel)	1035	1275	1275	1275	1275	1275	1%	100%	18%	9%	10%	100%	1	-	Based on the traffic data provided by TD. Traffic assumed stationary in one direction during Jammed Peak.
S3	Route 8 (formerly Route 16): Toll Plaza	867	708	708	708	708	708	1%	100%	43%	10%	16%	0%	1	-	Based on the traffic data provided by TD. Traffic assumed stationary in one direction during Jammed Peak.
T	Staff Quarters of Shatin WTW	114	10	10	10	10	8	100%	50%	50%	70%	50%	99%	1	1	Based on WSD data
T1	WTW refurbishment workers	0	0	0	110	0	0	0%	50%	50%	0%	100%	10%	1	1	Based on WSD data. Exact locations not known at the time. Workers assumed to be spread throughout the South Works area
U	Ka Tin Court	4700	4956	4956	4956	4956	4956	100%	50%	50%	70%	50%	99%	1	35	Value from Centamap (2006 population by-census)
V	Kindergarten G/F of Hing Kwai Lau	150	90	90	90	90	90	0%	50%	50%	0%	100%	95%	3.3	1	Value from: http://www.edb.gov.hk/
W	Baby Care Centre G/F of Hing Fu Lau	50	0	0	0	0	0	0%	50%	50%	0%	100%	95%	3.3	1	Based on the 2009 site survey and telephone interviews the centre is closed.
X	Kindergarten G/F of Hing Tak Lau	150	240	240	240	240	240	0%	50%	50%	0%	100%	95%	3.3	1	Value from: http://www.edb.gov.hk/
Y	Tai Po Road	1030	1057	1057	1057	1057	1057	2%	100%	43%	21%	24%	0%	1	-	Traffic data from the 2007 annual traffic census. Length 1.5 km. Assume one direction jammed and the other free-flow at Jammed Peak.
Z1	Che Kung Miu Road	300	300	300	300	300	300	5%	100%	100%	50%	55%	0%	1	-	Value from 2001 QRA, partially verified during 2009 ERM survey

Ref	Name	2006 Projection used in 2001 HA	Base (latest data available)	2011	2014	2016	2031	Occupancy					Fraction Indoors	Vulner-ability Factor	No. of Floors	Remarks
								Night	Jammed Peak	Peak Hour	Weekend Day	Working Day				
Z2	Hin Keng Street	270	270	270	270	270	270	5%	100%	100%	50%	55%	0%	1	-	Value from 2001 QRA, partially verified during 2009 ERM survey
Z5	SCL train (moving)	0	0	0	0	486	501	16%	100%	100%	41%	41%	100%	1	-	Based on MTRC data
Z6	Hin Keng Station	0	0	0	0	372	372	16%	100%	100%	41%	41%	0%	1	4	Based on MTRC data.
	Stationary train at HIK Station	0	0	0	0	586	607	16%	100%	100%	41%	41%	100%	1	4	
	HIK Station construction workers	0	0	140	140	0	0	0%	50%	50%	10%	100%	0%	1	-	
Z7	Tunnel portal	0	0	120	120	0	0	0%	50%	50%	10%	100%	0%	1	-	Based on MTRC data
Z8	Alignment Construction	0	0	20	20	0	0	0%	50%	50%	10%	100%	0%	1	-	Based on MTRC data
Z9	Construction Offices/yard	0	0	80	80	0	0	0%	50%	50%	10%	100%	50%	1	1	Based on MTRC data
Z10	Keng Hau Rd underpass below the SCL alignment	n/a	6	7	7	6	6	5%	100%	100%	50%	55%	0%	1	-	Based on ERM 2011 site survey
	CZ total	42611	43742	43970	44845	45946	46068									
	Total (inside & outside CZ)	211721	217602	222356	227639	231523	231058									

* Note: For the 2001 HA population assumptions of Refs 19 & 21 please see the comment in the Remarks column

3 HAZARD IDENTIFICATION

3.1 HAZARDOUS CHARACTERISTICS OF CHLORINE

The following paragraphs 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 500ppm) many times higher than the danger level (see *Table 3.1* 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 3.1*.

Table 3.1 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.

3.2 REVIEW OF PAST INCIDENTS

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.

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, and is continuously updated);
- 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).

3.3 HAZARD AND OPERABILITY STUDY

3.3.1 *Overview*

A Hazard and Operability (HAZOP) study was conducted for Shatin WTW as part of the *Eight WTWs Study* 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.

The primary focus of the HAZOP was on the hazards posed to people off-site. 'Internal' as well as' external' hazards were considered, ie 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 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 store;
- containers in storage;
- connection and disconnection of containers;
- chlorination system (including the liquid chlorine pipework, evaporators, chlorinators and ejectors); and
- Contain and Absorb system.

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.

3.3.2 *Results of the HAZOP Study*

Table 3.2 shows the hazards which were identified for Shatin WTW.

In summary, the primary hazard arises from a loss of containment of chlorine with subsequent acute exposure of people off-site leading to injuries or fatalities. Releases may range in size from a small leak (eg via a valve gland), through to dislodgement of a fusible plug (¾" diameter) or catastrophic failure of the container itself. The releases may be isolatable (ie via closure of the changeover valves or drum valve) or non-isolatable (ie a leak from the shell of the container).

The physical state of the release may be gas, liquid or two-phase depending on the precise location, eg 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, eg in the case of a severe external event such as an earthquake.

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, as identified at the HAZOP, are summarised in *Table 3.3*.

Table 3.4 cross-references chlorine leak incidents which have occurred in Hong Kong against the hazards identified in *Table 3.2*.

Table 3.2 Hazards Identified in HAZOP Study for Shatin WTW

Hazard	
1.	*ACCESS ROAD*
1.1	Fire on the truck leading to melting of the fusible plugs on one or more containers
1.2	Fire on the roadside leading to melting of the fusible plugs on one or more containers
1.3	Impact with object during truck manoeuvring
1.4	Lorry over-turns
1.5	Collision with another vehicle
1.6	Loadshedding
1.7	Spontaneous drum failure
2.	*CONTAINER HANDLING*
2.1	Dropped container
2.2	Collision of container with another object
2.3	Accidental impact of drum on pigtail during setdown at standby position
2.4	Overextension during use of truck crane (not normally used)
2.5	Section of monorail track incorrectly aligned leading to a dropped drum
3.	*CONTAINERS IN STORAGE*
3.1	Leaking chlorine containers
3.2	Overfilled containers leading to overpressurisation on thermal expansion
3.3	Impurities in chlorine containers, in particular nitrogen trichloride (leading to explosion) or moisture (causing accelerated corrosion)
3.4	Object falls onto chlorine containers
3.5	Fire (external or internal)
3.6	External explosion
3.7	Lightning strike
3.8	Extreme wind
3.9	Flooding
3.10	Construction activities
3.11	Subsidence
3.12	Earthquake
3.13	Aircraft crash
3.14	Sabotage
3.15	Vehicle crash
3.16	Electromagnetic interference
4.	*CONNECTION AND DISCONNECTION OF CHLORINE CONTAINERS*
4.1	Human error or equipment failure during connection/disconnection of containers
5.	*CHLORINATION SYSTEM*
5.1	Trapping of liquid chlorine between closed valves and subsequent thermal expansion leading to overpressurisation of pipework
5.2	Pigtail failure
5.3	Failure of fixed chlorine pipework
5.4	Open end on pipework due to operator or maintenance error
5.5	Corroded pipework
5.6	Presence of nitrogen trichloride in evaporator leading to explosion
5.7	Presence of moisture in evaporator leading to accelerated corrosion

Table 3.3 Failure Modes of Contain and Absorb System Identified in HAZOP Study

Hazard
1. *LEAK DETECTION SYSTEM*
Chlorine leak detector 'cell' malfunction
2. *CONTAIN SYSTEM*
Door left open
Air inlet louvres fail to close on demand
Normal ventilation left in manual mode, therefore does not shutdown on detection of chlorine leak
Failure of chlorine absorption system (see below) with dampers set to 'exhaust to atmosphere' position and failure to detect chlorine breakthrough
Failure of door seals
Outage due to maintenance
System disabled by operator
3. *CHLORINE ABSORPTION SYSTEM*
Caustic pump failure
Blockage in caustic pipework
Overloading of scrubber
Caustic valve inadvertently closed
No caustic in tank
Caustic pipe leakage
Scrubber nozzles blocked
Initial make-up of caustic incorrect
Leakage of water into tank causing dilution of caustic and reduced efficiency
Degradation of caustic over a period of time
Wrong chemical in tank
Failure due to power failure
Outage due to maintenance
System disabled by operator

Table 3.4 Chlorine Leak Incidents in Hong Kong

Location	**Date**	**Description**	**Cross ref to *Table 3.2***
Eastern WTW	1962	Valve gland leak.	Item 3.1
Cheung Sha Wan SW Pumping Station	1982	Connection failure	Item 5.2
Tai Po Tau WTW	8.6.83	A chlorine leak from a one tonne drum occurred on 8.6.83 at Tai Po Tau WTW. Following changeover between drums, the copper coil connection failed.	Item 5.2
Hong Kong	25.7.90	Brass pipe attached to chlorine cylinder fractured causing gas leak at water park	Not relevant to WTWs
Tai Lam Chung Pre-chlorination House	28.9.90	11.2 kg of chlorine leak from a one tonne drum in the chlorine store at Tai Lam Chung Prechlorination House in the New Territories on 28.9.90. The leak was repaired on site by the chlorine supplier with the presence of Fire Services personnel by tightening the gland of the drum isolating valve.	Item 3.1

Location	**Date**	**Description**	**Cross ref to *Table 3.2***
Sek Kong	19.10.90	On 19.10.90, two men were injured when a lorry carrying six chlorine containers over-turned. One container fell from the vehicle, but did not leak. The cause of the accident is believed to be brake failure of the lorry.	Item 1.4
Shatin Treatment Works	8.9.92	The incident occurred inside the chlorine transfer room of the Shatin Water Treatment Works on 8.9.92. Workers were charging liquefied chlorine from 1 tonne drums to bulk chlorine vessels each with a maximum holding capacity of 125 tonnes. 150 kg of chlorine was leaked from the liquid chlorine charging line.	Not relevant (Bulk chlorine vessels since replaced)
Pak Yue Kong Swimming Pool	18.5.92	Liquid chlorine was found leaking from the valve spindle of a 1-tonne chlorine drum inside the chlorine store of the Pak Yue Kong Public Swimming Pool, on 18.5.92.	Item 3.1
Sheung Shui WTW	25.1.93	2 kg of chlorine leaked form the connection between the feeding pipe and chlorine drum at the Sheung Shui Water Treatment Works on 25.1.93.	Item 5.2
Tai Lam Chung Pre-chlorination House	March 94	In March 1994 leakage occurred at isolating valve of full chlorine drum at Tai Lam Chung Prechlorination House.	Item 3.1
Tai Po Tau WTW	8.3.96	Gaseous chlorine was leaking from the pressure gauge of No. evaporator. Chlorine dosing was suspended for 3.5 hours.	Item 5.3
Yau Kom Tau WTW	6.1.99	A chlorine leak occurred inside the chlorine plant room at about 3:00pm. The leakage was due to the rupturing of the chlorine pressure gauge at the No. 1 evaporator which was on standby position.	Item 5.3

3.4 *CHARACTERISATION OF CHLORINE RELEASE SCENARIOS*

Having identified various possible mechanisms for a chlorine release (*Table 3.2*), the next step in the Hazard Assessment is to characterise these release scenarios in terms of the releasing inventory, hole size and phase of release (*Table 3.5*). This follows the approach outlined in the Consultants' Methodology Report for the *Eight WTWs Study* (ERM, 1997). *Table 3.5* also screens out scenarios considered to present negligible off-site risk.

Table 3.5 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	3x6mm	liquid
1.2 Fire on the roadside	Considered to present negligible off-site 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 (eg valve gland failure)	1	3mm	liquid
1.4 Rollover	Single drum - small leak(eg valve gland failure)	1	3mm	liquid
	Single drum - medium leak(eg guillotine failure of drum valve)	1	8mm	liquid
	Three drums - medium leak (eg guillotine failure of drum valves on three drums)	3	3x8mm	liquid
	Fire (outcomes as item 1.1 above)			
1.5 Collision	Single drum - rupture	1	-	liquid
	Fire (outcomes as item 1.1 above)			
1.6 Load-Shedding	Single drum - small leak	1	3mm	liquid
	Single drum - medium leak	1	8mm	liquid
1.7 Spontaneous drum failure	Single drum - medium leak	1	8mm	liquid
	Single drum - large leak (eg. dislodgement of a fusible plug)	1	20mm	liquid
	Single drum – rupture	1 (inst)	-	liquid
2. DRUM HANDLING				
2.1 Dropped drum	Single drum - medium leak	1	8mm	liquid
	Single drum - large leak (eg dislodgement of fusible plugs)	1	20mm	liquid
	Single drum - rupture	1 (inst)	-	liquid
2.2 Collision of drum with another object	Single drum - medium leak	1	8mm	liquid
2.3 Accidental impact of drum on pigtail during setdown at standby position	Pigtail - guillotine failure	1	4.5mm	two-phase
2.4 Dropped drum due to overextension of truck crane	Single drum - medium leak	1	8mm	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	8mm	liquid
	Single drum - large leak	1	20mm	liquid
	Single drum - rupture	1 (inst)	-	liquid
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 off-site 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 off-site risk as chlorine stores are 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	8mm	liquid
3.7 Lightning strike	Considered to present negligible off-site risk as the chlorine store is lightning protected and a lightning, while it can result in electrical damage, is unlikely to cause a chlorine release	-	-	-

Chlorine release scenario	Outcome	Releasing inventory (tonnes)	Hole size (diameter)	Phase
3.8 Extreme wind	Considered to present negligible off-site risk as chlorine store 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 chlorine store 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	1 (inst)	-	liquid
	Roof collapse: Multiple drum-rupture	42 (inst) [5]		
3.13 Aircraft crash	Roof collapse: Multiple drum-rupture (similar to earthquake)	42 (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.)	1	8mm	liquid
3.15 Vehicle crash	Single drum - medium leak	1	8mm	liquid
3.16 Electromagnetic interference	Considered to present negligible off-site risk 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	4.5mm	two-phase
5. CHLORINATION SYSTEM				
5.1 - 5.5 Failures associated with the chlorination system pipework	Liquid chlorine pipework - guillotine failure	1.05[3]	4.5mm[4]	two-phase

Chlorine release scenario	Outcome	Releasing inventory (tonnes)	Hole size (diameter)	Phase
5.6 - 5.7 Failure of evaporator	Evaporator - leak or rupture	1.05	4.5mm	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 chlorine store see Annex G
(3) Inventory of drum (1 tonne) and evaporator (50kg)
(4) Diameter of liquid chlorine pipework is 20mm but limiting orifice size is that of pigtail, ie 4.5mm.
(5) The values listed are for 221 tonnes storage. For reduced storage scenarios they are reduced in proportion to the storage levels (see discussion in *Annex G*).

3.5 *HAZARDS RELATED TO THE WTW REFURBISHMENT WORKS*

During the WTW refurbishment period (Scenario 2 of this QRA), some additional chlorine release events may be caused by interference of the simultaneous WTW operations and refurbishment work. Since no details of the refurbishment works are yet available, reference was made to the recently approved EIA-186/2010 for Integration of Siu Ho Wan and Silvermine Bay Water Treatment Works (Black & Veatch 2010) which assessed similar issues concerning construction related hazards. This gives some insight into the potential hazards, although not all of the following may be applicable to STWTW:

- Structural damage to Chlorine Store, piping and other facilities caused by disorderly movement of mechanical equipment, construction vehicles (bulldozers, mobile cranes, trucks etc.) and insufficient supervision of the work;
- Structural damage to Chlorine Store, piping and other facilities caused by nearby excavation works;
- Structural damage to Chlorine Store, piping and other facilities caused by collapse of tower cranes / rollover of mobile cranes;
- Accidents involving Chlorine Delivery Trucks on the access road due to movements of construction vehicles and equipment, and obstructions along the route; and
- Fire / explosion hazards to Chlorine Store, piping and other facilities from storage of construction related chemicals and fuels.

Measures will be implemented to mitigate or eliminate these risks. In particular, construction related activities will be separated from the operating chlorine facilities. Separate transport routes will be used for chlorine delivery trucks and construction related movements. Specifically, chlorine delivery trucks will utilize a route around the north side of the site, while construction activities will utilize a route around the south side. The following general recommendations should also be considered as good practice:

- Adequate monitoring, inspection, training and management of construction related activities;
- Adequate traffic management; although separate transport routes will be used for chlorine deliveries and construction vehicles, they share a common entrance gate; and
- Establishment of proper WTW/contractor communication channels.

For the STWTW refurbishment works, additional chlorine release hazards will be identified and adequate mitigation measures recommended during the detailed design stage. WSD as the proponent of the refurbishment works has confirmed that "*a Hazard and Operability (HAZOP) study will be carried out during detailed design stage to select appropriate safety measures to ensure that likelihood of chlorine release will not be increased*."

This assessment has therefore assumed that refurbishment works will be adequately managed and any additional hazardous scenarios from these activities will be adequately mitigated and will not result in additional hazardous impact to the construction and operation of the SCL Project.

3.6 *HAZARDS ASSOCIATED WITH LIQUID OXYGEN*

The WTW refurbishment will introduce new technology (ozonation) to reduce chlorine consumption. According to WSD, liquid oxygen (LOX) is proposed to be used in the process. Storage of LOX may be required as a backup to the online generation although this is not yet confirmed and design details are not available at this time.

The storage of LOX, if implemented, may present new hazards relevant to the operational phases of the current analysis (Scenarios 3 and 4) after completion of the refurbishment works.

Oxygen is present normally in air at a concentration of 21%. Short term exposure to elevated concentrations of oxygen is not harmful. Oxygen is not flammable by itself, but its main hazards are associated with its role in supporting combustion. In an oxygen enriched atmosphere, combustible materials ignite at a lower temperature, burn at a higher flame temperature, and burn more rapidly. Fires are therefore more likely in an oxygen enriched atmosphere. The effects are slight at 25% oxygen, significant at 40% oxygen and near to their maximum at about 50% oxygen (EIGA 2004). Normal

combustible materials such as workmen's clothing, wood, plastics, hydrocarbons, etc. may burn fiercely in an oxygen enriched environment.

Apart from the fire hazards discussed above, LOX also presents cryogenic hazards from its storage at -183°C. Spills can lead to embrittlement of materials and cold burns. These effects will be very localised and will not contribute to offsite risks.

The main concern associated with LOX is therefore the increased possibility of fires which may escalate to surrounding facilities. The chlorine store would not be significantly affected by accidental releases of LOX since it is built from non-combustible materials and all piping is underground. Nevertheless, it is recommended to segregate the LOX tank from the chlorine store as far as practicable.

The hazards associated with LOX are well understood and WSD has experience with a similar system at their Ngau Tam Mei works. Any LOX installation at Sha Tin WTW will adopt standard engineering safeguards including:

- Overpressure protection for the storage tank by means of pressure relief valves and rupture discs;
- LOX tanks design, construction and testing to appropriate standard such as ASME Boiler and Pressure Vessel Code, Section VIII or equivalent;
- Dual tank arrangement with inner vessel and outer jacket to reduce the chance of tank failure;
- Special paving of non-combustible and non-sparking material;
- Non-combustible tank supports;
- Elimination of nearby ignition sources;
- No oil or grease used in the system;
- Segregation from flammable and combustible materials; and
- Fire-fighting facilities, etc.

In addition to the above engineered controls, implementation of good practice and management is expected to mitigate any risks from the LOX. WSD as the proponent of the refurbishment works has confirmed that a Hazard and Operability (HAZOP) study will be carried out during detailed design stage to select appropriate safety measures to ensure that likelihood of chlorine release will not be increased and hence there will be no additional hazardous impact on the construction and operation of the SCL Project.

4 CONSEQUENCE ANALYSIS

4.1 METHODOLOGY

4.1.1 *Overview*

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).

In this study, the methodology for the consequence analysis follows that of the *Eight WTWs Study* as detailed in the *Methodology Report* (ERM, 1997) and summarised below.

4.1.2 *Initial Release of Chlorine*

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.

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 (1996). 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. 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.

4.1.3 *Dispersion of Chlorine in the Atmosphere*

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.

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 (Shatin 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.

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.

4.1.4 *Toxic Impact Assessment*

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 (TNO, 1992) and incorporates the findings of recent investigation into chlorine toxicity. It supersedes the 'Hong Kong' probit, which was widely used in chlorine Hazard Assessments undertaken in the past.

Table 4.1 shows the relationship between the chlorine concentration and the probability of fatality for the TNO probit (assuming a 10 minute exposure duration).

Table 4.1 *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)

Modelling of Escape from the Chlorine Cloud

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.

Annex F1 of ERM (2001) provides details of the modelling of escape from a chlorine cloud. The methodology followed is similar to that developed by the UK Health and Safety Executive (Lees and Ang, 1989). 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' 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.

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 4.2*.

Table 4.2 *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%
3%	80%	0.7%

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 outdoors, 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 (*Section 4.2.3*).

Sensitive Populations

Certain groups of people, ie the young, the elderly and the infirm will be more sensitive to the effects of chlorine than others (see *Methodology Report* for further details). 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 2.3*).

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.

4.2 CONSEQUENCE ANALYSIS RESULTS

4.2.1 *Initial Release of Chlorine*

The results of the 'source term' modelling of chlorine releases is summarised in *Table 4.3* below.

Table 4.3 ***Summary of Source Term Modelling Results for Shatin 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
Multiple medium leaks	6 (x6)	Liquid	-	4.8 kg/s	3.5 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 chlorine store - 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, eg 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 chlorine store - release via weak points' will be more dominant in the QRA.

From *Table 4.3* it is apparent that releases from a drum due to melting of the fusible plugs (4.8 kg/s) or dislodgement of the plugs (8.8 kg/s) occur sufficiently rapidly to cause emptying of the drum in a short period of time (within a few minutes). Therefore these release cases are treated as effectively instantaneous releases.

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 (eg 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. 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).

4.2.2 *Chlorine Dispersion Modelling Results*

Wind Tunnel Modelling Results

The results of wind tunnel testing for Shatin WTW are summarised in *Table 4.4* and *Figures B1* to *B14* in *Annex B*.

Table 4.4 ***Summary of Wind Tunnel Tests Results for Shatin WTW***

Release case	Release location	Description	Weather class	Wind directions (Note 1)	Maximum extent of LD03 contour (m) (Note 2)
0.2 kg/s (aerosol) Continuous	Access Road	Small leak (3mm) from chlorine drum	D2	SW, W	No LD03 contour off-site
0.5 kg/s (vapour) continuous	Chlorine store	Chlorine vapour release from store due to large leak (20mm) 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 (8mm) from chlorine drum	D2	S, SW, W NW, SE, NNE	No LD03 contour off-site

Release case	Release location	Description	Weather class	Wind directions (Note 1)	Maximum extent of LD03 contour (m) (Note 2)
			D5	W, SE	No LD03 contour off-site
1 tonne (aerosol) instantaneous	Chlorine store	Catastrophic failure of a chlorine drum	D2	SSW, WSW, SE, NNE, WNW	350 650 250 285 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, ie not taking into account escape and assuming 10 min exposure duration or cloud passage time (whichever is the shorter)

From the results in *Table 4.4* above, *Annex B* 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 Shatin 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 (eg 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 Shatin valley (ie following the path of least resistance).

CFD Modelling Results

The results of the CFD modelling for Shatin WTW and Tai Po Tau WTW are summarised in *Table 4.5* below. Full details can by found in HSL (1998) and HSL (1999).

Table 4.5 Summary of CFD Modelling Results

Release case	Weather Class	Maximum extent of LD contour (m)		
		LD90	LD50	LD03
Shatin WTW				
1.4 kg/s continuous	D2	110	140	205
	F2	145	155	225
1 tonne instantaneous	D	170	200	255
	F2	220	255	275
Tai Po Tau WTW				
1.4 kg/s continuous	D2	135	165	265
	F2	130	180	330
1 tonne instantaneous	D2	200	215	255
	F2	180	255	355
	B2	75	95	105

From *Table 4.5*, 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 (ie 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 (ie 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 (ie 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.

Flat Terrain Dispersion Modelling Results

The results of the flat terrain dispersion modelling using DRIFT are presented in *Annex A* and summarised in *Table 4.6* below.

Table 4.6 ***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 tonne instantaneous	D2	586	735	1044
10 tonne instantaneous	D2	1004	1286	1790

From the results in *Table 4.6* 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.

Comparison of Results of Wind Tunnel Testing, CFD Modelling and DRIFT Modelling

Table 4.7 compares the key results from the wind tunnel testing, CFD modelling, and DRIFT flat terrain dispersion modelling.

Table 4.7 ***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)

From *Table 4.7* 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

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 *Annex D*.

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.

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 Shatin WTW and Tai Po Tau WTW, are used in the QRA in preference to those from the wind tunnel.

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 (eg 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).

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 Shatin 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.

Comparison of Dispersion Model Results with Data from Actual Incidents

There have been two significant chlorine release incidents at WTWs in Hong Kong;

- Shatin WTW, Sep 1992: 150 kg release of chlorine from a 1/4 inch hole in a liquid charging line, which escaped to atmosphere via folding doors, which were open; and
- Tai Po Tau WTW, June 1983: 725 kg release of chlorine from an adapter on a chlorine drum valve (1/4 inch hole) which escaped to atmosphere via the exhaust fan, doors and door louvres.

Data from the first incident provides some indication of the extent of the off-site effects of the chlorine release as it is known that four tenants at the staff

quarters (200m from the chlorine store) suffered respiratory discomfort during a period of exposure of 30 seconds. This would indicate chlorine concentrations of around 10-30 ppm (*Table 3.1*).

A release from a 1/4 inch hole in a liquid chlorine line would produce a release rate of around 0.26 kg/s, taking into account two-phase flow due to flashing in the line. The incident description indicates that the building may have had little or no mitigating effect on the release. However considering the two extremes of (i) a release direct to atmosphere via the open doors and (ii) a release which is initially held up and diluted in the building air, then the respective predictions of the wind tunnel testing for Shatin WTW and the DRIFT modelling for this scenario are shown in *Table 4.8* below.

Table 4.8 ***Predictions of Wind Tunnel Testing, CFD and DRIFT Modelling for release from 1/4 inch hole in liquid chlorine line in Shatin WTW (incident Sept 1992)***

Model	**Chlorine Concentration (ppm) at 200m distance (Note 1)**		**Actual Concentration (ppm) at 200m distance**
	Case (i)	**Case (ii)**	**(inferred from incident data)**
Wind Tunnel Testing	14	0.50	
CFD	35	- (Note 2)	10-30
DRIFT	20	80	

Note 1: Case (i): a release direct to atmosphere via the open doors (chlorine aerosol release)

Case (ii): a release which is initially held up and diluted within the building (chlorine vapour release)

Note 2: No data from CFD modelling for chlorine vapour releases.

It should be emphasised that these comparisons are approximate only as the precise circumstances of the 1992 release are not known. However they indicate (as noted above) that the wind tunnel tests for small, continuous releases may be optimistic, whilst the DRIFT predictions are certainly conservative. The CFD predictions are reasonably consistent with the incident data, although a comparison cannot be made for Case (ii).

4.2.3 *Chlorine Cloud Height*

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.

The data in *Annex E* have been rationalised for use in the QRA as shown in *Table 4.9* below.

Table 4.9 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 tonne 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 3m per storey.

5 RATIONALISATION OF CHLORINE RELEASE SCENARIOS AND ESTIMATION OF SCENARIO FREQUENCIES

5.1 RATIONALISATION OF CHLORINE RELEASE SCENARIOS

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 4.4* and *Table 4.5*). 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 *Section 3* (*Table 3.5*) can be eliminated from further consideration in the QRA. *Table 5.1* 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 5.2* then summarises the results of the analysis in *Table 5.1* by grouping the release scenarios into 'events' having identical release characteristics (ie the same release rate, duration and phase of release). *Table 5.3* shows the events grouped according to the leak quantity.

Table 5.1 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.	3x6mm	Liquid	2.4	3	2.4 kg/s	Y	RU1TMML
1.3 Manoeuvring accident	Single drum - small leak	3mm	liquid	0.2	1	0.2 kg/s	N	-
1.4 Rollover	Single drum - small leak	3mm	liquid	0.2	1	0.2 kg/s	N	-
	Single drum - medium leak	8mm	liquid	1.4		1.4 kg/s	Y	RU1TSML
	Three drums - medium leak	3 x 8mm	liquid	4.2	3	4.2 kg/s	Y	RU1TMML
	Fire (outcomes as item 1.1 above)							
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	3mm	liquid	0.2	1	0.2 kg/s	N	-
	Single drum - medium leak	8mm	liquid	1.4	1	1.4 kg/s	Y	RU1TSML
1.7 Spontaneous container failure	Single drum - medium leak	8mm	liquid	1.4	1	1.4 kg/s	Y	RU1TSML
	Single drum - large leak	20mm	liquid	8.8	1	8.8 kg/s(3)	Y	RU1TSRU
	Single drum - rupture	-	liquid	-	1(inst)	1 tonne	Y	RU1TSRU
2. *DRUM HANDLING*								
2.1 Dropped drum	Single drum - medium leak	8mm	liquid	1.4	1	0.30 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)
	Single drum - large leak	20mm	liquid	8.8	1	0.55 kg/s	N	-
	Single drum - rupture	-	liquid	-	1 (inst)	16 kg	N	-
2.2 Collision of drum with another object	Single drum - medium leak	8mm	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	4.5mm	two-phase	0.12	1	0.027 kg/s	N	-
2.4 Dropped drum due to overextension of truck crane	Single drum - medium leak	8mm	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	8mm	liquid	1.4	1	0.30 kg/s	N	-
	Single drum - large leak	20mm	liquid	8.8	1	0.55 kg/s	N	-
	Single drum - rupture	-	liquid	-	1 (inst)	16 kg	N	-
3.2 Overfilled drums leading to overpressurisation on thermal expansion	As item 3.1 above							
3.3 Impurities in	As item 3.1 above							

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]
chlorine drum leading to explosion or leak								
3.6 External explosion	Single drum - medium leak	8mm	liquid	1.4	1	0.30 kg/s	N	-
3.12 Earthquake	Overhead crane dislodged from rails: single drum-rupture	-	liquid	-	1 (inst)	16 kg	N	-
	Roof collapse: multiple drum-rupture	-	liquid	-	42[4] (inst)	26.8 tonnes[1,4]	Y	EU1TMRU EU1TMRU1G
3.13 Aircraft crash	Roof collapse: multiple drum rupture (similar to earthquake)	-	liquid	-	42[4] (inst)	26.8 tonnes[1,4]	Y	AU1TMRU
3.15 Vehicle crash	Single drum - medium leak	8mm	liquid	1.4	1	0.30 kg/s	N	-
4. CONNECTION AND DISCONNECTION OF CHLORINE CONTAINERS								
4.1 Human error or equipment failure during connection/disconnection of drums	Pigtail - guillotine failure	4.5mm	two-phase	0.12	1	0.027 kg/s	N	-
5. CHLORINATION SYSTEM								
5.1 - 5.5 Failures associated with the chlorination system pipework	Liquid chlorine pipework - guillotine failure	4.5mm	two-phase	0.12	1.05	0.027 kg/s	N	-
5.6 - 5.7 Failure of	Evaporator - leak or rupture	4.5mm	two-	0.12	1.05	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]
Evaporator			phase					

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 x 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 221 tonnes storage. For reduced storage scenarios they are reduced in proportion to the storage levels (see discussion in *Annex G*)

Table 5.2 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 Truck fire Spontaneous failure	1 tonne	Instantaneous	Access road
EU1TMRU	Earthquake: roof collapse, ground acceleration 0.7g	26.8(1) tonnes	Instantaneous	Chlorine store
EU1TMRU1G	Earthquake: roof collapse, ground acceleration 1g	26.8(1) tonnes	Instantaneous	Chlorine store
AU1TMRU	Aircraft crash	26.8(1) tonnes	Instantaneous	Chlorine store

Note (1): the values listed are for 221 tonnes storage. For reduced storage scenarios they are reduced in proportion to the storage levels

Table 5.3 Release Scenarios Categorised by Leak Quantity

Leak Quantity (kg)	Event Ref
100-1000	RU1TSML, RU1TMML, RU1TSRU
>1000	EU1TMRU, EU1TMRU1G, AU1TMRU

5.2 *FREQUENCY ESTIMATION*

Having identified the chlorine release scenarios of interest (*Section 5.1*), the next step in the Hazard Assessment is to determine their frequency of occurrence. This is based on the approach outlined in the Consultants' *Methodology Report* (ERM, 1997).

Table 5.4 summarises the base data which has been used in the frequency calculations. Following the methodology described in ERM (2001), 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 (see *Table 2.1*) or, in the case of the aircraft crash event, the STWTW location in relation to the flight path, number of flights into CLK airport etc. The resulting total event frequencies are presented in *Table 5.5*.

Table 5.4 Base Failure Rate Data

Data item	Value	Units	Source
1. Chlorine container			
1.1 (i) Spontaneous container failure frequency	1.5E-4	per year	*Methodology Report* (based on review of worldwide failure data for chlorine containers and generic pressure vessel failure data)
(ii) Conditional probability of catastrophic failure	0.027	-	
(iii) Conditional probability of medium leak	0.22	-	
(iv) Conditional probability of large leak	0.081	-	
1.2 (i) Probability of dropped container	7.7E-6	per lift	*Methodology Report* (based on Hong Kong data for number of lifts which have occurred without incident)
(ii) Conditional probability of catastrophic failure	1.0E-4	-	
2. Chlorine delivery vehicle			
2.1 (i) Frequency of loadshedding	1.1E-7	per truck-km	Chlorine Transport Risk Study, DNV (1997)
(ii) Conditional probability of a medium leak	6.3E-2	-	
2.2 (i) Frequency of rollover	1.9E-7	per truck-km	Chlorine Transport Risk Study, DNV (1997)
(ii) Conditional probability of a medium leak of a single drum	1.5E-1	-	
(iii) Conditional probability of medium leak of multiple drums	1.1E-2	-	
2.3 (i) Frequency of vehicle impact	4.0E-7	per truck-km	Chlorine Transport Risk Study, DNV (1997)
(ii) Conditional probability of drum rupture	1.7E-2	-	
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	4.0E-7	per year	Cook et al (1993)
(ii) Probability of roof collapse in an earthquake of 0.7g ground acceleration	0.1	-	*Water Treatment Works Seismic Hazard Assessment*, Ove Arup (2001)
3.2 (i) Frequency of earthquake of 1.0g ground acceleration	2.5E-8	per year	Cook et al (1993)
(ii) Probability of roof collapse in an earthquake of 1.0g ground acceleration	0.5	-	*Water Treatment Works Seismic Hazard Assessment*, Ove Arup (2001)

Data item	Value	Units	Source
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*)

Table 5.5 *Event Frequencies*

Event Ref	Component scenarios	Frequencies (per year)	Time periods during which event could occur
RU1TSML[1]	Rollover	3.21E-6	All except Night
	Loadshedding	7.79E-7	All except Night
	Spontaneous leak	2.54E-7	All except Night
	Total	*4.24E-6*	
RU1TMML[1]	Rollover	2.35E-7	All except Night
	Truck fire	4.52E-7	All except Night
	Total	*6.87E-7*	
RU1TSRU[1]	Truck impact	7.66E-7	All except Night
	Spontaneous drum failure	1.25E-7	All except Night
	Total	*8.91E-7*	
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 maximum WTW chlorine usage of 896 tonnes (150 trucks) per year and the existing truck access route. Frequencies for other scenarios were reduced according to the annual number of trucks and the length of the alternative truck access route.

6 QUANTITATIVE RISK ASSESSMENT

6.1 RISK ASSESSMENT METHODOLOGY

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.

The QRA has been undertaken using a GIS-based software GIS*Risk*, developed for the 8WTW 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.

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.

The main outputs from the software are as follows:

- *Individual risk* in the form 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:

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

6.2 RISK CRITERIA

The Hong Kong Planning Standards and Guidelines (HKPSG), Chapter 12 require that development proposals within the Consultation Zone of a Potentially Hazardous Installation (PHI) are assessed against Hong Kong Risk Guidelines (HKRG) to ensure that risks to the public are confined to within acceptable limits. The same criteria are stipulated in Annex 4 of the Technical Memorandum on the Environmental Impact Assessment Process (EIAO-TM).

Acceptable risk levels are defined as follows:

- *Individual Risk*: The maximum involuntary individual risk of death associated with accidents arising at PHIs should not exceed 1 chance in 100,000 per year (10^{-5}/yr); and
- *Societal Risk*: The societal risk associated with a PHI should comply with the FN diagram (Fig 3 in HKPSG, Ch 12). Three areas of risk are shown:
  - *Acceptable* where risks are so low that no action is necessary;
  - *Unacceptable* where risks are so high that they should usually be reduced regardless of the cost or else the hazardous activity should not proceed; and
  - *ALARP (As Low As Reasonably Practicable)* where the risks associated with each probable hazardous event at the PHI should be reduced to a level >as low as reasonably practicable, usually measured as a trade off between the risk reduction afforded and the cost of that reduction. Risk mitigation measures may take the form of either engineered measures at the PHI or development (ie population) controls in the vicinity of the PHI. In the case of a new development within the Consultation Zone of an existing PHI the onus is on the developer to implement such measures as are necessary to ensure that risk levels at the development site are ALARP.

6.3 *QRA RESULTS*

The following sub-sections present the QRA results for the four scenarios considered in the QRA. For the scenario description, see *Section 2.3* and *Table 2.1*.

6.3.1 *Societal Risk Results*

The FN curves for each scenario listed in *Table 2.1* are presented in *Figures 6.1* to *6.4*. *Table 6.1* summarises the maximum N numbers derived from these figures. *Tables 6.2* and *6.3* present the overall PLL values, together with a breakdown of the PLL by release scenario and population area.

Scenario 1 (SCL Construction before WTW refurbishment)

FN curve for the Scenario 1 is shown in *Figure 6.1*. The risks are in the ALARP zone of HKRG. The risk to SCL construction population, when considered on its own, falls within the "Acceptable" region.

The main contributors to PLL (Potential Loss of Life) are the EU1TMRU event – multiple chlorine drum ruptures following a store roof collapse during an earthquake of 0.7g magnitude and RU1TSRU - a single drum rupture incident due to the chlorine truck fire, truck impact or spontaneous failure.

Scenario 2 (Simultaneous SCL Construction Phase and WTW Refurbishment)

For Scenario 2 (*Figure 6.2*), during the WTW refurbishment period, the FN curve is in the "ALARP" region, even though the additional population of the refurbishment workers is taken into account. This is because the reduced chlorine storage during this period significantly lowers the risks.

The risk to SCL construction population, when considered on its own, falls within the "Acceptable" region.

The main contributor to PLL is the RU1TSML event – a continuous chlorine release from one drum, due to rollover, loadshedding or spontaneous leak.

Operational Phases

The Societal Risk results for both Operational Phase scenarios fall in the "ALARP" region of the HKRG (*Figures 6.3* and *6.4*). The risks to the SCL population alone (considering HIK Station and the train populations) lie within the "Acceptable" region.

The main contributors to PLL are the chlorine truck events RU1TSML and RU1TMML.

Figure 6.1 *FN Curves: Scenario 1 (SCL Construction before WTW Refurbishment)*

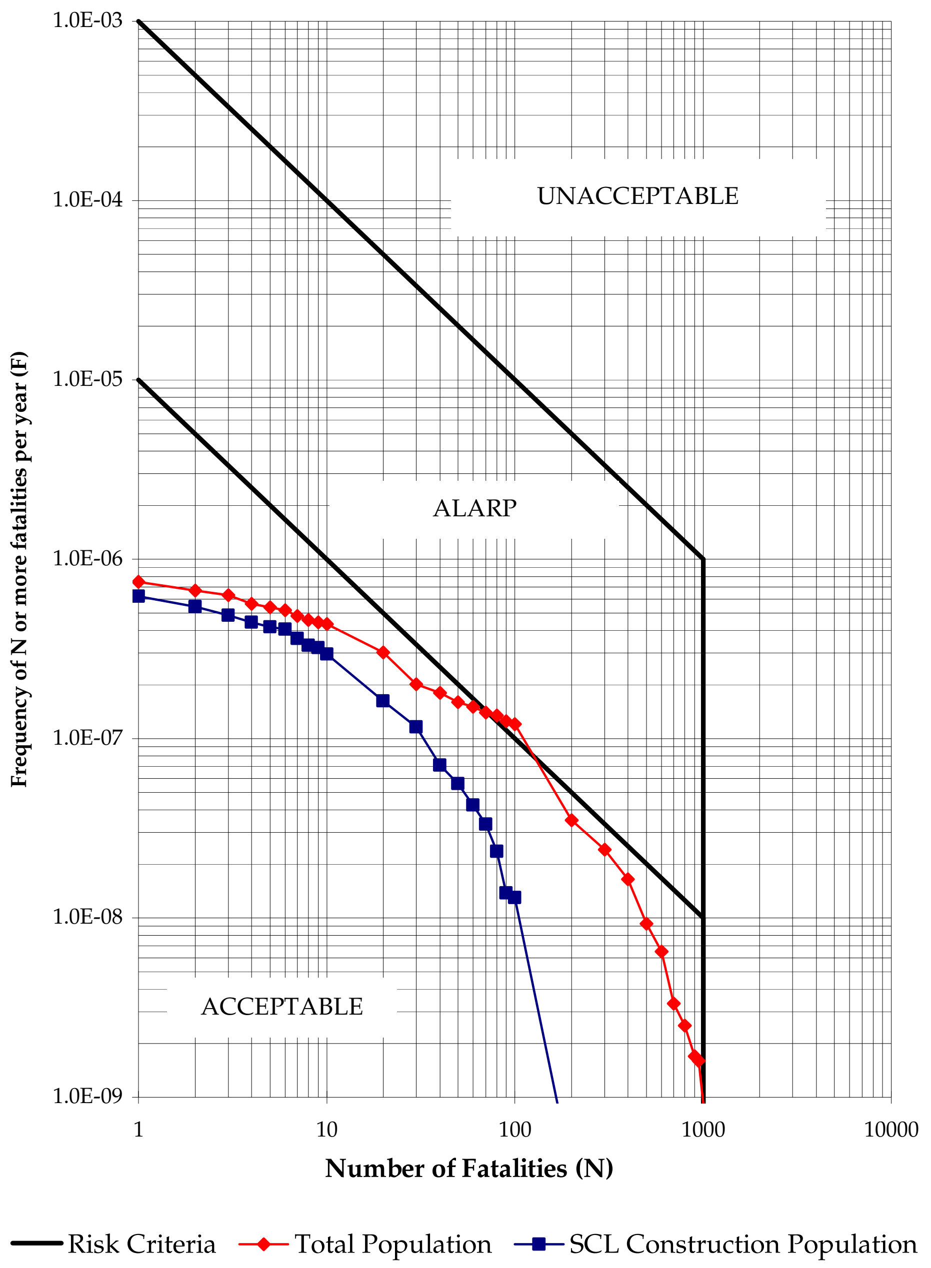


Figure 6.2 *FN Curves: Scenario 2 (Simultaneous SCL Construction and WTW Refurbishment)*

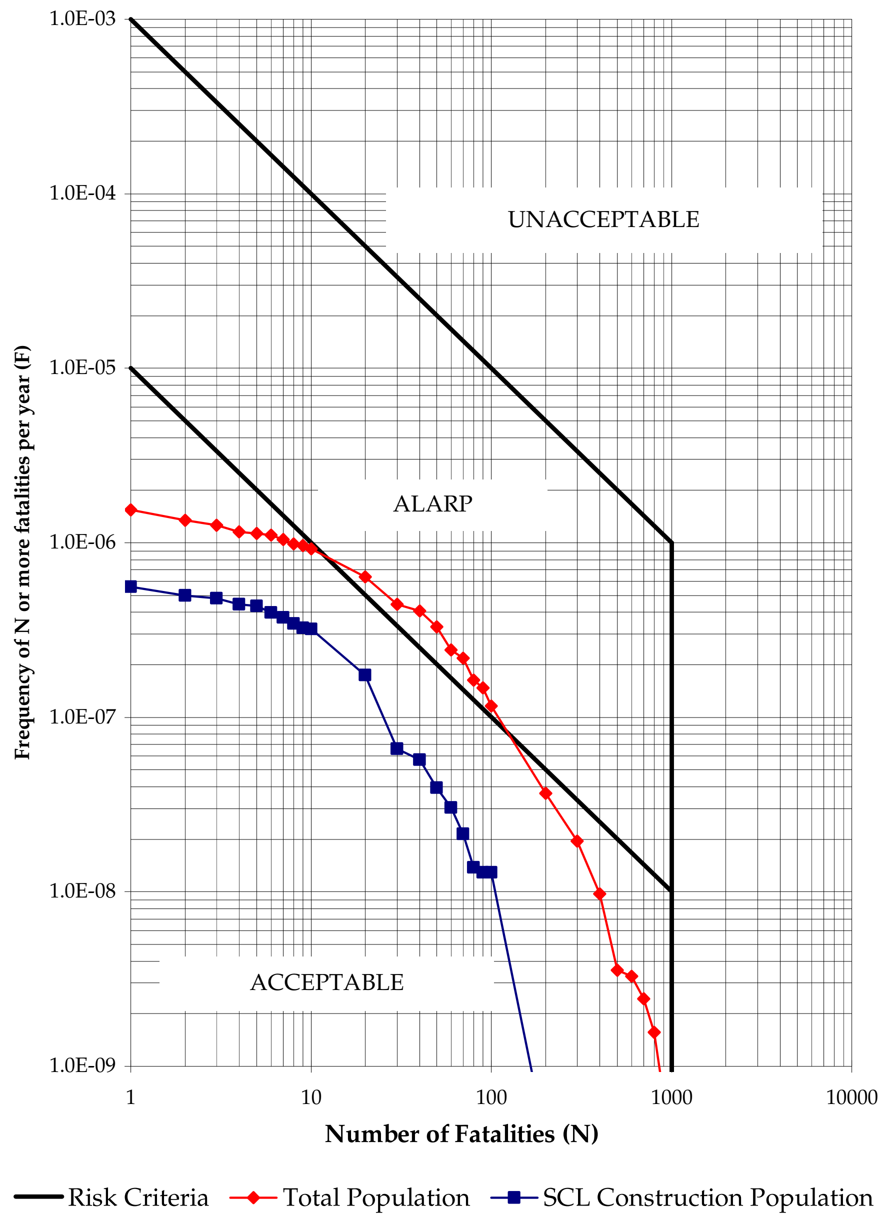


Figure 6.3 FN Curves: Scenario 3 (Operational Phase 2016)

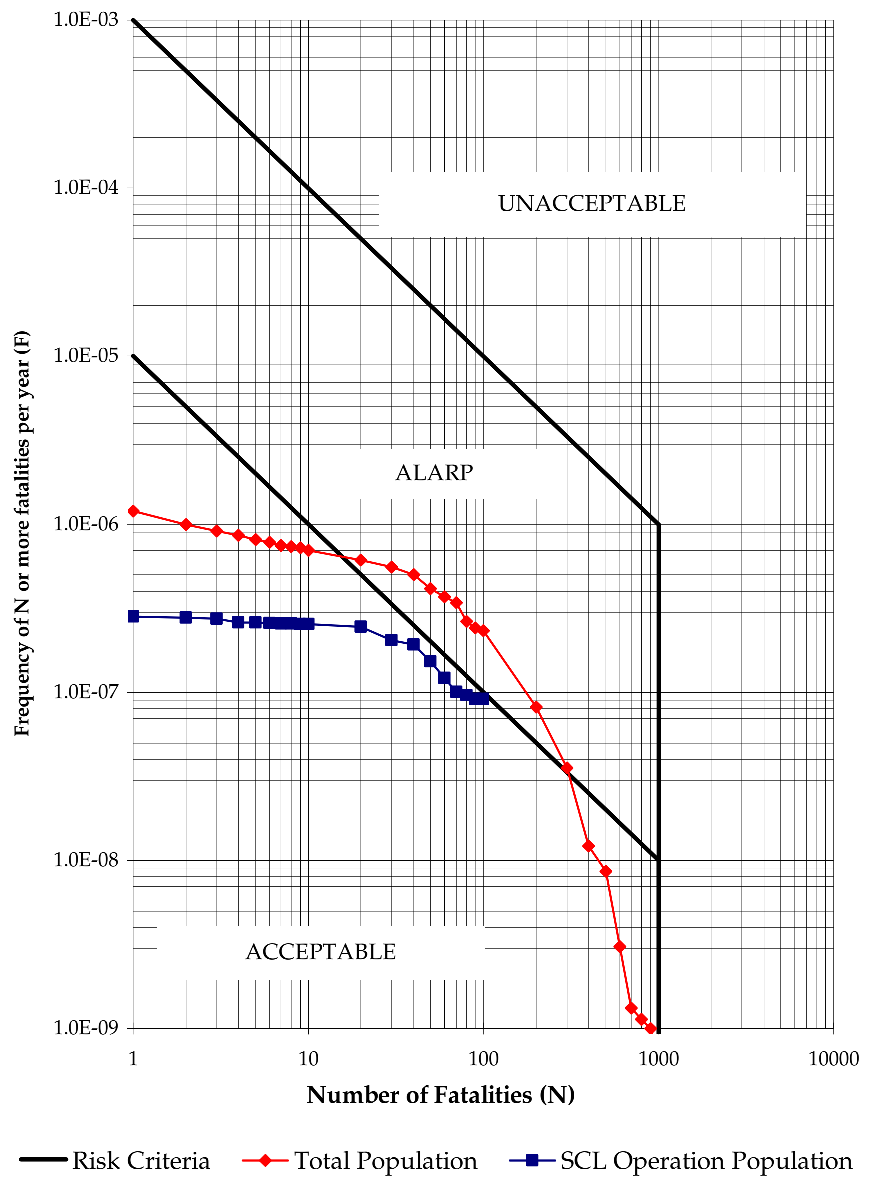
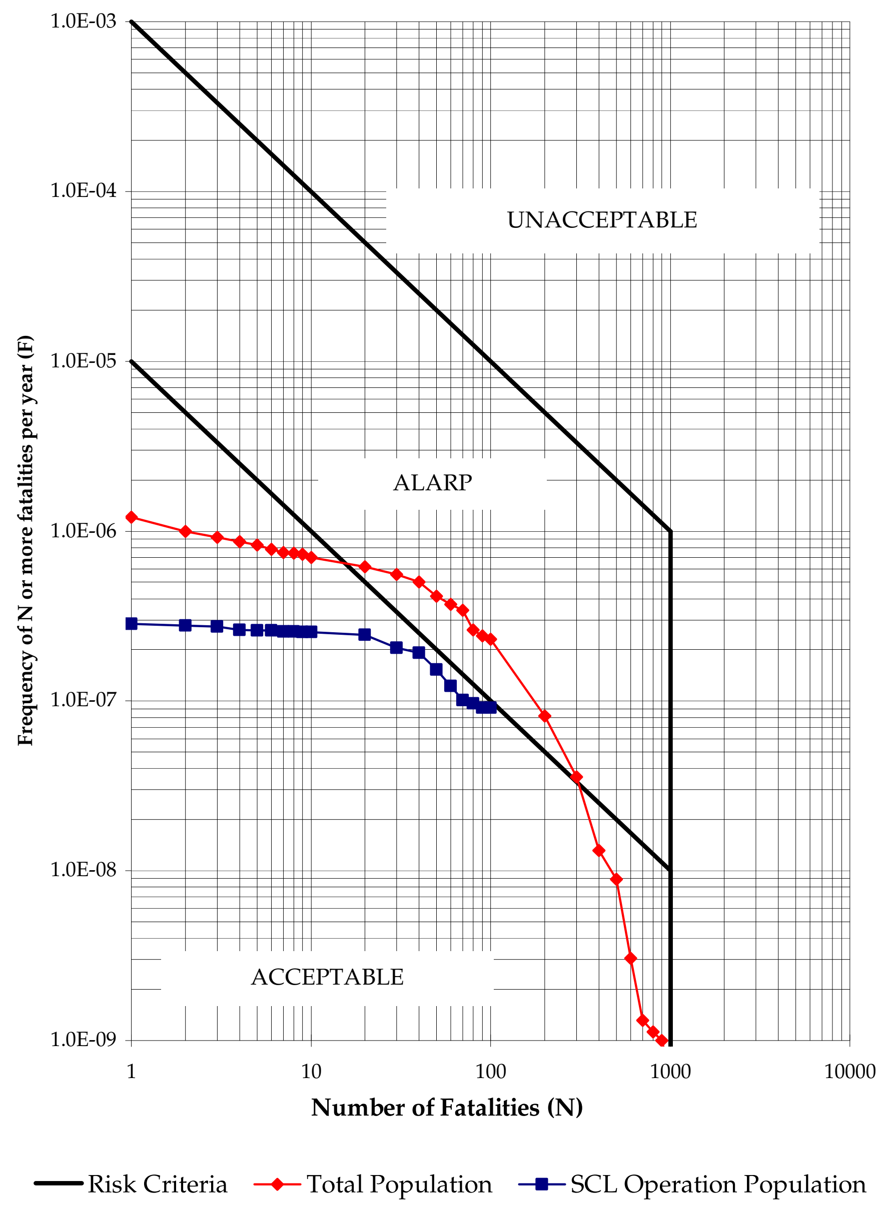


Figure 6.4 FN Curves: Scenario 4 (Operational Phase 2031)



6.3.2 *Societal Risk Result Analysis and Discussion*

Main Risk Contributors (overall population)

The high number of fatalities shown in *Figures 6.1-6.4* and *Table 6.1* are due to the low frequency/high fatality events such as a multiple drum failures which can result from the chlorine store roof collapse during a significant (ground acceleration greater than 0.7g) earthquake.

This can be illustrated by estimating hypothetical Max N values separately for different events. For the 2031 operational case with all events included, Max N is 900 (see *Table 6.1*) while it would be equal to 500 for road accidents alone, 206 for aircraft crash, 764 for both earthquake events combined, and 900 for both earthquake events and aircraft crash combined. Earthquake events considered separately would result in Max N of 690 and 398 for EU1TMRU and EU1TMRU1G, respectively.

The earthquake frequencies used in this study, 4×10^{-7} (i.e. once in 2.5 million years) and 2.5×10^{-8} for 0.7 g 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.

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 50% to 80% to the total PLL *(Table 6.2).*

Table 6.1 Maximum N Value within the FN Chart for the Scenarios considered in QRA

Scenario	Max N for $F > 1 \times 10^{-9}$
Scenario 1: SCL Construction before WTW refurbishment	990
Scenario 2: Simultaneous SCL Construction and WTW refurbishment	864
Scenario 3: SCL Operation Period 1 (after completion of WTW refurbishment)	900
Scenario4: SCL Operation Period 2 (surrounding population growth taken into account)	900
2001 QRA (ERM, 2001)	980

Table 6.2 Breakdown of PLL by Release Scenario

Release Scenario[1]	Construction Phase		Operational Phase	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
RU1TMML	3.8E-06 (10.7%)	1.6E-05 (28.7%)	2.9E-05 (40.0%)	2.9E-05 (40.0%)
RU1TSML	3.9E-06 (11.0%)	2.0E-05 (36.1%)	2.8E-05 (38.4%)	2.8E-05 (38.5%)
RU1TSRU	1.1E-05 (30.3%)	6.0E-06 (10.8%)	3.7E-06 (5.1%)	3.8E-06 (5.2%)
Total: chlorine truck incidents	1.8E-5 (52.0%)	4.2E-05 (75.6%)	6.1E-05 (83.5%)	6.2E-05 (83.6%)
AU1TMRU	7.3E-07 (2.1%)	5.7E-07 (1.0%)	6.0E-07 (0.8%)	6.0E-07 (0.8%)
EU1TMRU	1.3E-05 (35.7%)	1.0E-05 (18.2%)	9.1E-06 (12.5%)	9.1E-06 (12.4%)
EU1TMRU1G	3.7E-06 (10.3%)	2.9E-06 (5.3%)	2.3E-06 (3.2%)	2.3E-06 (3.2%)
Total: earthquake and aircraft crash	1.7E-05 (48.0%)	1.4E-05 (24.4%)	1.2E-05 (16.5%)	1.2E-05 (16.4%)
Total (per year)	3.6-05	5.5E-05	7.3E-05	7.4E-05

Note 1: for definitions of release scenarios see *Table 5.2*

The maximum N value as shown in *Table 6.1* 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 6.3*. Nevertheless, while comparing the maximum N values for Scenario 1 and scenarios 2, 3 and 4

(*Table 6.1*), it may be noted that reduction of chlorine storage results in a reduction of max N despite the increase in population, especially addition of the SCL and HIK Station passenger population (Scenarios 3 and 4). Therefore, the results show that with the reduced chlorine storage, combined with low presence factors of the new population and low frequency of events causing large number of fatalities, the max N remains within the 1000 criterion.

Table 6.3 Breakdown of PLL by Population

Ref[1]	PLL Scenario 1	%	PLL Scenario 2	%	PLL Scenario 3	%	PLL Scenario 4	%
29	7.4E-08	0.2%	1.8E-08	0.0%	2.9E-08	0.0%	2.9E-08	0.0%
32	1.3E-07	0.4%	8.2E-08	0.1%	9.0E-08	0.1%	8.9E-08	0.1%
A	6.1E-08	0.2%	4.4E-08	0.1%	4.6E-08	0.1%	4.6E-08	0.1%
B1	0.0E+00	0.0%	0.0E+00	0.0%	1.4E-06	2.0%	1.4E-06	2.0%
B2	2.4E-07	0.7%	1.4E-07	0.3%	1.5E-07	0.2%	1.5E-07	0.2%
C	8.6E-08	0.3%	5.7E-08	0.1%	6.5E-08	0.1%	6.5E-08	0.1%
D	1.9E-07	0.5%	1.5E-07	0.3%	1.3E-07	0.2%	1.3E-07	0.2%
E	7.0E-07	2.0%	9.9E-07	1.8%	1.3E-06	1.8%	1.3E-06	1.8%
F	5.4E-08	0.2%	2.0E-08	0.0%	2.4E-08	0.0%	2.4E-08	0.0%
G	1.0E-07	0.3%	6.5E-08	0.1%	7.0E-08	0.1%	7.0E-08	0.1%
H	2.3E-08	0.1%	2.2E-08	0.0%	2.2E-08	0.0%	2.2E-08	0.0%
H1	6.8E-09	0.0%	6.4E-09	0.0%	1.7E-08	0.0%	1.7E-08	0.0%
H2	4.0E-09	0.0%	3.5E-09	0.0%	1.1E-08	0.0%	1.1E-08	0.0%
I	4.5E-07	1.3%	9.6E-07	1.7%	1.4E-06	2.0%	1.4E-06	1.9%
J	7.0E-07	2.0%	2.1E-06	3.9%	3.4E-06	4.6%	3.4E-06	4.6%
K	1.3E-06	3.5%	3.2E-06	5.8%	4.7E-06	6.5%	4.7E-06	6.4%
L	2.0E-08	0.1%	1.5E-08	0.0%	1.5E-08	0.0%	1.5E-08	0.0%
L1	0.0E+00	0.0%	1.9E-08	0.0%	1.9E-08	0.0%	1.9E-08	0.0%
M	4.4E-08	0.1%	1.9E-08	0.0%	2.3E-08	0.0%	2.3E-08	0.0%
N	8.2E-07	2.3%	6.3E-07	1.1%	9.5E-07	1.3%	9.5E-07	1.3%
O	5.7E-06	16.2%	1.2E-05	22.4%	1.7E-05	23.9%	1.7E-05	23.6%
P	3.1E-07	0.9%	6.0E-07	1.1%	8.5E-07	1.2%	8.5E-07	1.2%
Q	1.2E-08	0.0%	8.8E-09	0.0%	9.0E-09	0.0%	9.0E-09	0.0%
R1	1.6E-06	4.6%	1.4E-06	2.5%	2.1E-06	2.9%	2.4E-06	3.2%
S1	6.4E-08	0.2%	4.4E-08	0.1%	4.6E-08	0.1%	4.6E-08	0.1%
S2	1.9E-08	0.1%	5.6E-08	0.1%	8.3E-08	0.1%	8.3E-08	0.1%
S3	9.3E-07	2.6%	4.1E-07	0.7%	5.6E-07	0.8%	5.6E-07	0.8%
T	3.5E-08	0.1%	1.7E-08	0.0%	2.0E-08	0.0%	1.6E-08	0.0%
T1	0.0E+00	0.0%	1.2E-05	21.1%	0.0E+00	0.0%	0.0E+00	0.0%
U	3.2E-07	0.9%	2.1E-07	0.4%	2.4E-07	0.3%	2.4E-07	0.3%
V	4.7E-07	1.3%	1.3E-06	2.4%	2.0E-06	2.7%	2.0E-06	2.7%
W	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
X	4.5E-08	0.1%	1.1E-08	0.0%	1.9E-08	0.0%	1.9E-08	0.0%
Y	8.7E-07	2.4%	1.1E-06	2.0%	1.4E-06	1.9%	1.4E-06	1.9%
Z1	3.3E-06	9.4%	5.6E-06	10.1%	8.1E-06	11.0%	8.1E-06	10.9%
Z2	3.0E-07	0.8%	4.9E-07	0.9%	6.8E-07	0.9%	6.8E-07	0.9%
Z5	0.0E+00	0.0%	0.0E+00	0.0%	2.7E-08	0.0%	2.8E-08	0.0%
Z6	5.2E-06	14.5%	2.6E-06	4.7%	2.4E-05	33.0%	2.5E-05	33.4%
Z7	9.3E-06	26.2%	7.2E-06	13.0%	0.0E+00	0.0%	0.0E+00	0.0%
Z8	3.2E-08	0.1%	1.4E-08	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Z9	4.5E-07	1.3%	3.8E-07	0.7%	0.0E+00	0.0%	0.0E+00	0.0%
Z10	8.8E-07	2.5%	8.1E-07	1.5%	1.0E-06	1.4%	1.0E-06	1.4%
others	6.7E-07	1.9%	4.2E-07	0.8%	4.5E-07	0.6%	4.6E-07	0.6%
Total	3.6E-05	100.0%	5.5E-05	100.0%	7.3E-05	100.0%	7.4E-05	100.0%

Note 1: for description and locations of population units see *Table 2.3* and *Figure 2.5*

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

Contribution of SCL Construction and Operation to Overall Risk Results

In terms of the Potential Loss of Life (*Table 6.3*), the SCL construction (units Z6 to Z9) contributes about 42%, and 19% of the total PLL value for Scenarios 1 and 2, respectively. For the SCL construction workers the PLL drop for the Scenario 2 is due to the reduction of chlorine usage and storage and the adoption of the alternative transport route (*Figure 2.3*) located at a greater distance from some main SCL construction areas during the WTW refurbishment (note that while this route relocation benefits some areas, it also increases the PLL for other population units). The main contributor to the increase in total PLL value in Scenario 2 is the introduction of the WTW refurbishment workforce (unit T1) which is much lower than the number of SCL construction workers, but is located very close to the potential chlorine release points.

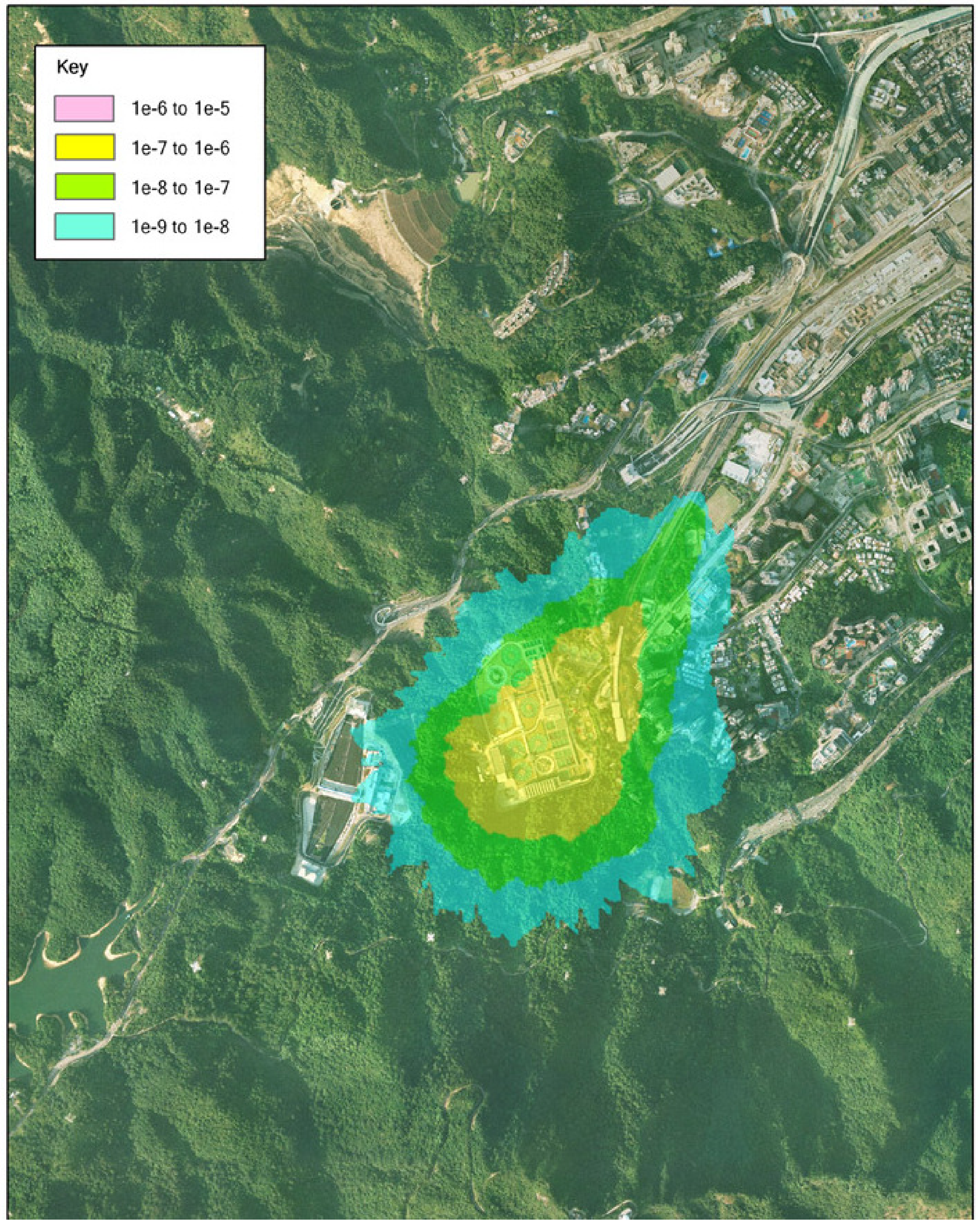
For both operational phase scenarios the PLL for the SCL passengers and HIK Station population (units Z5 and Z6) is about 2.5×10^{-5}, i.e. 33% of the total PLL. This high contribution is due to the large number of SCL passengers and proximity of the HIK Station and SCL alignment to the STWTW.

6.3.3 Individual Risk

The individual risk levels are calculated for a hypothetical person spending 100% of their time outdoors in the vicinity of the Shatin WTW. Individual risk is independent of the surrounding population levels.

Figure 6.5 presents the individual risks obtained for the Scenario 1, but assuming the maximum chlorine storage of 221 tonnes. Risks for other scenarios will be slightly lower due to the lower average chlorine storage and dosage levels (*Table 2.1*). As can be seen, the risks are low and nowhere outside the WTW site boundary does the individual risk exceed 10^{-5} per year. It is therefore concluded that Shatin WTW complies with the individual risk criteria.

Figure 6.5 Individual Risk Contours



6.3.4 Result Summary

The 2001 STWTW QRA (ERM, 2001) predicted the societal risk within the "ALARP" region of the HKRG, but very close to the 1000 fatality criterion (*Figure 1.3*). Any increase in population due to natural growth or any new development including transient construction workforce might therefore be expected to result in exceedance of the HKRG criteria (i.e. N>1000).

Nevertheless, societal risk levels for all scenarios studied are within the ALARP region (N<1000). This is due to the lower chlorine storage and use anticipated during and after the WTW refurbishment. For the possible SCL construction period before the WTW refurbishment begins, WSD has agreed to maintain the chlorine storage time distribution (see the first row of *Table 2.1*) that will not lead to an exceedance of the N<1000 criterion.

In terms of the Potential Loss of Life (*Table 6.3*), the SCL construction contributes about 42%, and 19% of the total PLL value for the Scenarios, 1 and 2, respectively, while for both operational phase scenarios the PLL for the SCL passengers and HIK Station population amounts to about 33% of the total PLL. Of the background population units, the highest contribution to PLL results from Hin Keng Estate (unit O) and Che Kung Miu Road (unit Z1), and, during the WTW refurbishment, from the refurbishment workforce (unit T1)

The individual risk levels are low and in compliance with HKRG.

7 SELECTION OF EFFECTIVE RISK MITIGATION

7.1 INTRODUCTION

Since the societal risk levels for all 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.

A number of mitigation measures have been considered and assessed in the original QRA for STWTW (ERM, 2001) and, according to the information provided by WSD, those considered practicable have been already implemented at the WTW. Therefore, the measures discussed below focus on the SCL construction and WTW refurbishment workforce, the future SCL passengers and not on the WTW operation themselves. 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.

7.2 IDENTIFICATION OF MITIGATING OPTIONS

Possible effective mitigation measures would be to reduce the number of drums that can rupture following a chlorine store roof collapse scenario and protecting the SCL population.

Other options have been identified but already addressed in previous QRAs as reported in the ERM (2001) study.

Based on the findings from *Sections 6* and ERM (2001), no other mitigation measures appear possible.

The options considered are:

- Option 1: Reducing the maximum/average number of chlorine drums;
- Option 2: Improvements to the chlorine store;
- Option 3: Protecting the Railway construction workers; and
- Option 4: Protecting SCL passengers and staff.

These options are discussed in the following sections; the cost-benefit analysis of all options considered is presented in *Section 7.7*.

7.3 *OPTION 1: REDUCING THE NUMBER OF CHLORINE DRUMS IN STORAGE*

A reliable way of reducing the number of fatalities for scenarios with fatalities approximating 1000 is to reduce the number of chlorine drums ruptured during a store roof collapse and the extent of the resulting chlorine cloud. This can be accomplished by reducing the amount of chlorine stored at the WTW. However, the number of chlorine drums to be stored at WTW during the SCL construction and operation has already been reduced from its current level (*Table 2.1*) and the N<1000 criterion is met for all scenarios considered. It is understood that further chlorine storage reduction at the WTW is not possible due to WSD operational requirements.

7.4 *OPTION 2: IMPROVEMENTS TO CHLORINE STORE*

Another way of reducing the number of drums ruptured during a roof collapse would be introducing improvements to the chlorine store construction. Following the recommendation of Ove Arup (2001) three possible improvements to the chlorine store have been considered in the previous, CCPHI-approved QRA (ERM, 2001, Sections 7.1 & 7.2). It is understood that, similar to Option 1, due to time constrains these options could be implemented for the SCL Operational phase only.

They are discussed in the following paragraphs.

7.4.1 *Option 2a: Strengthening of Columns of Chlorine Store*

This measure involves wrapping the columns with a carbon fibre material. It would significantly improve the seismic resistance of the chlorine store by increasing the ductile capacity of the columns and allowing them to deform without the roof collapsing. This treatment is a common method of retrofitting structures in highly seismic areas, but would entail removing the infill walls to allow access to the columns.

7.4.2 *Option 2b: Replacement of the Roof with a Light-weight Structure*

The current roof is a 2 hour fire rated reinforced concrete slab. If it could be replaced by a light-weight structure then this would eliminate the chance of damage to the chlorine containers in the event of a severe earthquake

7.4.3 *Option 2c: Building Additional Structure to Protect the Drums*

This would involve building re-enforced concrete dividing walls inside the chlorine store extending to height 0.5m above the height of the drums. These walls would be capable of supporting the collapsing roof. It is noted that this option would reduce the chlorine storage capacity.

7.5 *OPTION 3: PROTECTING THE RAILWAY CONSTRUCTION WORKERS*

Adequate measures should be in place and coordinated between WSD and MTRC/Contractors, to ensure that in the event of Chlorine release detection, MTRC/Contractors should take the most appropriate actions and the risks to construction workers are minimised. Based on the measures considered for other similar projects, such as Route 16 (now Route 8)[1], the following options are considered. Note that other measures proposed in the Route 16 EIA, such as modifications or reduction of chlorine stock at WTW etc are not included here, since they either are discussed in other parts of this report or are not relevant to this study. For example, provision of a water spray curtain around the WTW was considered in the Route 16 EIA but dismissed on technical grounds as being ineffective. Specifically, NFPA advises that water should not be used on chlorine leaks, as it will increase vaporisation rates and produce hydrochloric acid. Hence this option is not considered further in this assessment.

7.5.1 *Option 3a: Gas Monitors and Emergency Procedures*

This option would include:

- Installation of on-site gas monitors in all relevant SCL construction areas;
- Establishment of emergency response and evacuation plans (co-operation of various parties/departments required); and
- Safety/emergency response/evacuation training and drills for all personnel.

7.5.2 *Option 3b: Suspension of Construction Work during Chlorine Deliveries*

There will be up to 107 chlorine deliveries per year during SCL construction and the chlorine truck accidents account to about 25% of the total PLL for the SCL construction workers. These risks would be significantly lowered if construction workers are evacuated to safe (indoors) location during the chlorine deliveries.

7.5.3 *Option 3c: Limitation of Working Hours and Number of Workers in the area near WTW*

This option may cause significant problems to the SCL construction programme, but is still retained for further consideration

7.5.4 *Option 3d: Reduction of Drum Stock during the Construction Period*

As discussed in other parts of the report, the chlorine storage level is a crucial parameter affecting the risks to the population in the case of an earthquake or aircraft crash and its reduction would significantly reduce the risks to both the SCL construction workers and other populations. This could be achieved by

[1] http://www.epd.gov.hk/eia/register/report/eiareport/eia_02099/index.htm

implementing a "just in time" chlorine delivery at the WTW. Storage levels are determined by the requirement to have 90 days of storage to guard against supply disruptions. WSD has already committed to some reductions in storage quantities and these values have been used in this assessment. This option is therefore not further considered.

7.5.5 *Option 3e: Erecting Physical Barriers between WTW and the Main SCL Work Areas*

This option is similar to Option 4b discussed below, but while the costs would be significantly lower, it also could be only partially effective.

7.5.6 *Option 3f: Erecting Toxic Refuges at all SCL Construction Sites*

This option, implemented together with Option 3a, would provide additional protection for construction workers in the case of chlorine release.

7.6 OPTION 4: PROTECTING SCL STAFF AND PASSENGERS

7.6.1 *Option 4a: Emergency Response Planning*

An emergency plan should be in place and coordinated between WSD and MTRC, to ensure that in the event of Chlorine release detection, Passengers and MTRC staff are appropriately evacuated. Similar to Option 3 discussed above, the particular measures may include installation of on-site gas monitors and adequate training and drills for MTR personnel. The emergency plan should also include adequate procedures for controlling the tunnel ventilation system and stopping of the SCL train traffic in order to prevent the trains moving into the affected areas.

These measures should be implemented as a matter of good practice.

7.6.2 *Option 4b: Physical Barriers*

It may be possible to provide physical barriers (e.g. fully enclosed station) between the possible chlorine clouds and the SCL passengers and staff. The cost for such feature has been estimated at about HKD 500M. This physical barrier, if implemented, would not be able to reliably withstand an earthquake scenario; it will be however be effective for other scenarios.

7.7 COST BENEFIT ANALYSIS

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.

In this study CBA 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 x Design life of mitigation measure)

ICAF is a measure of the cost per life saved over the lifetime of the 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 life, 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).

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, although in the lower ALARP region of the Risk Guidelines, runs close to the 1000 fatalities cut-off line. The adjusted value of life using the aversion factor of 20 is HK$660M.

The ICAF values for the various mitigation measures identified above are presented in *Table 7.1*. They are based on the Operational Phase Scenario 4, characterized by highest PLL (*Table 6.3*). For the measures applicable to the Construction Phases only, the PLL values from Scenario 2 are used.

Table 7.1 Calculation of ICAF for Candidate Mitigation Measures

Mitigation measure	Cost Estimate (HK$M)	PLL reduction (per year)	Design life (years)	ICAF (HK$M)	Practicable? (ICAF< $660M ?)	Notes
Option 1 reduction of chlorine storage at WTW	10	6.0E-6	50	33,333	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
Options 2a-2c Enhancement of seismic performance of chlorine store	5	1.2E-05	50	8,333	N	Each of these measures would eliminate (or significantly reduce) the seismic risk. However they would each involve major civil works, hence the estimated cost of each measure is HK$5M. ICAF is estimated based on the 100% reduction in PLL due to the store roof collapse

Mitigation measure	Cost Estimate (HK$M)	PLL reduction (per year)	Design life (years)	ICAF (HK$M)	Practicable? (ICAF< $660M ?)	Notes
Option 3a Gas Monitors and Emergency Procedures	1	5.1.E-06	5	39,239	N	ICAF is estimated assuming that a 50% PLL reduction for the SCL workforce can be achieved by introducing the measures discussed in *Section 7.5.1*
Option 3b Suspension of Construction Work During Chlorine Deliveries	3	7.7E-06	5	77,922	N	ICAF is estimated assuming a 100% reduction of SCL workers PLL due to chlorine truck accidents
Option 3c Limitation of Working Hours and Number of Workers in the area near WTW	10	2.0E-6	5	980,969	N	Cost of the disruption of SCL construction programme conservatively estimated at only 10M. ICAF is estimated assuming a 20% reduction of SCL workers PLL
Option 3e Erecting Physical Barriers between WTW and the Main SCL Work Areas	5	5.1E-06	5	196,194	N	ICAF is estimated assuming that a 50% PLL reduction for the SCL construction workforce can be achieved by introducing the measures
Option 3f Erecting Toxic Refuge Shelters in addition to implementing of Option 3a	2	3.3E-06	5	121,200	N	ICAF is estimated optimistically assuming that this option together with Option 3a would provide a full protection to the construction workers. Thus an additional 3.3E-06 reduction was assumed.
Option 4a: Protecting SCL Staff and Passengers: Emergency plans and drills; on-site gas monitors	2	8.1E-06	50	4,938	N	ICAF is estimated assuming that a 33% PLL reduction for the SCL staff and passengers can be achieved by introducing the measure.
Option 4b: Protecting SCL Staff and Passengers: Fully enclosed station	500	1.2E-05	50	833,333	N	ICAF is estimated assuming that a 50% PLL reduction for the SCL staff and passengers can be achieved by introducing the measure.

7.8 DISCUSSION

As can be seen in *Table 7.1* none of the mitigation measures discussed above meets the practicability criterion of ICAF being less than "adjusted value of life". Nevertheless, since the costs for options 3a and 4a are relatively lower, these options are recommended for implementation as a matter of good practice. Note that while due to the limited time of its applicability, ICAF for Option 3a is significantly higher than for Option 4a, the equipment acquired and experience gained during the SCL construction phase can be beneficial during operational phase as well, so both the Option 3a and Option 4a should be implemented.

On the other hand, implementation of one of the Options 2a-2c is not recommended even that the ICAF value is similar to that of Option 4a. This is because the store roof collapse scenarios are high fatality/low frequency events for which the FN curves already lie in the Acceptable region of HKRG for all scenarios (*Figures 6.1-6.4*). Their effects on the FN curves in the range of 10 < N < 300, i.e. in the area where they extend into the ALARP zone, would be minimal.

8 *CONCLUSIONS AND RECOMMENDATIONS*

A Hazard Assessment of the risks associated with the storage and handling of chlorine at Shatin Water Treatment Works has been conducted for the Construction and Operational Phases of the SCL Project.

For all cases studied, the Individual Risk complies with the Hong Kong Risk Guidelines.

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

Mitigation measures were considered. However, following a formal cost-benefit analysis all were deemed not practicable. Nevertheless it is recommended that adequate emergency response/evacuation plans for the SCL works area and the future Hin Keng Station staff and passengers are established and emergency training/drills for all relevant MTR personnel conducted at regular intervals. Installation of on-site gas monitors is also recommended.

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Annex A

DRIFT Flat Terrain Dispersion Modelling

DRIFT FLAT TERRAIN DISPERSION MODELLING RESULTS

Table A1 presents the results of the flat terrain dispersion modelling using the DRIFT and EJECT software codes. DRIFT is a 'state-of-the-art' integral dense gas dispersion model and is able to simulate the dispersion of aerosols. The DRIFT model provides a smooth transition from the near field buoyancy-dominated dispersion phase to the far field passive dispersion phase.

EJECT is a 'state-of the art' model for the prediction of the near-field dispersion of jet releases. Like DRIFT, EJECT can also simulate dense, aerosol releases and provides a seamless interface with DRIFT at the end of the momentum-driven dispersion phase. The EJECT model has been used to assess the significance of the initial momentum-dominated dispersion phase of chlorine releases from 1 tonne containers.

Based on the results in *Table A1*, *Figures A1 and A2* show the relationship between the chlorine hazard range and release rate/quantity of chlorine.

Table A1 ***DRIFT Flat Terrain Dispersion Modelling Results***

Release case	**Weather class**	**Downwind distance to LD90 (metres)**	**Downwind distance to LD50 (metres)**	**Downwind distance to LD03 (metres)**
DRIFT Results				
0.2 kg/s continuous	B2	70	89	128
	D2	86	119	182
	D5	48	65	105
	F2	135	190	320
1.4 kg/s continuous	B2	184	234	323
	D2	268	362	550
	D5	150	200	310
	F2	460	650	1120
1 tonne instantaneous	B2	293	350	470
	D2	325	425	600
	D5	300	400	600
	F2	400	550	800
3 tonne instantaneous	D2	586	735	1044
	D5	498	661	968
10 tonne instantaneous	D2	1004	1286	1790
	D5	855	1136	1658
DRIFT + EJECT Results				
1.4 kg/s continuous	D5	181	236	360
	F2	491	770	1380

Figure A1 Downwind distance to 3% fatality vs continuous release rate (aerosol releases)

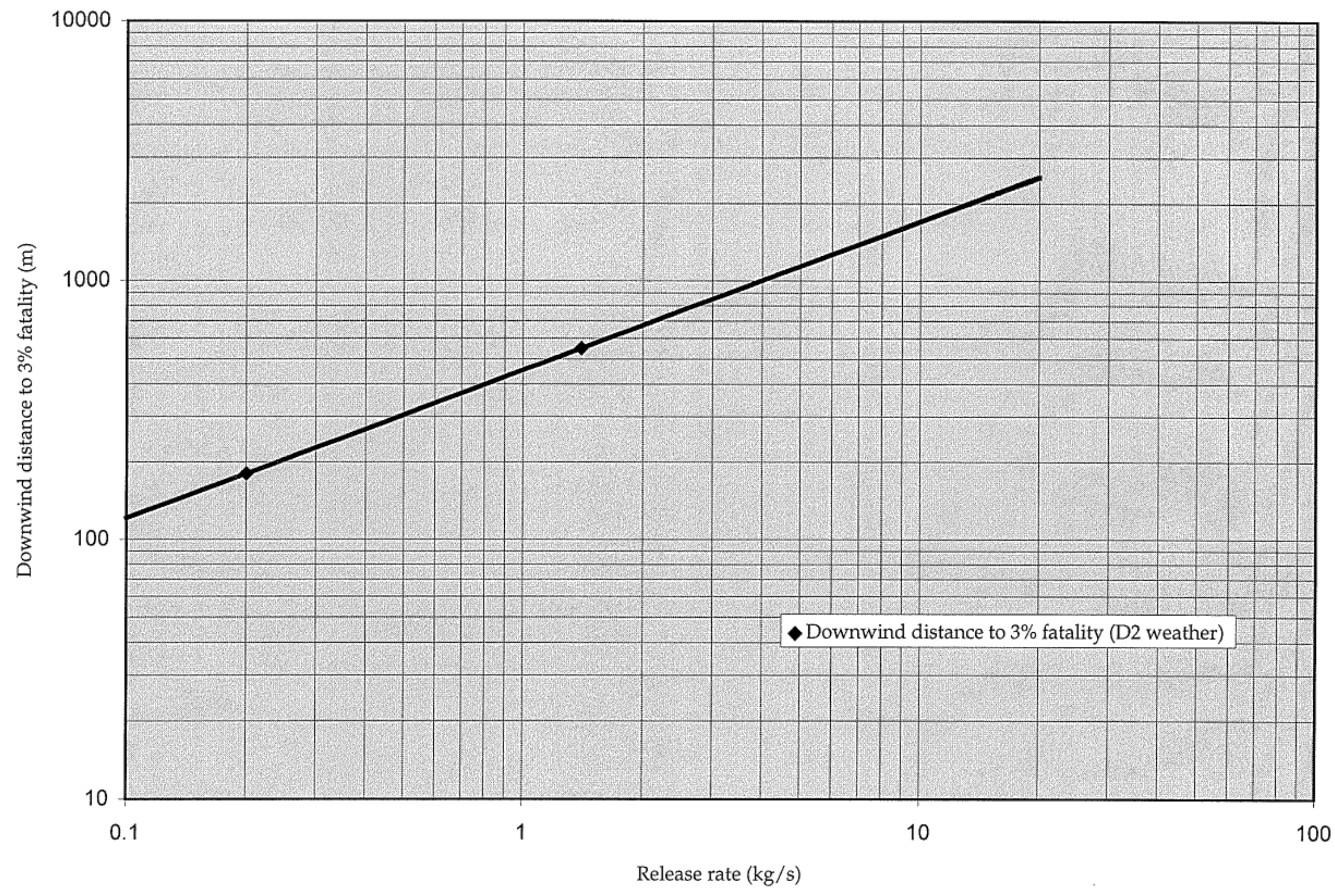
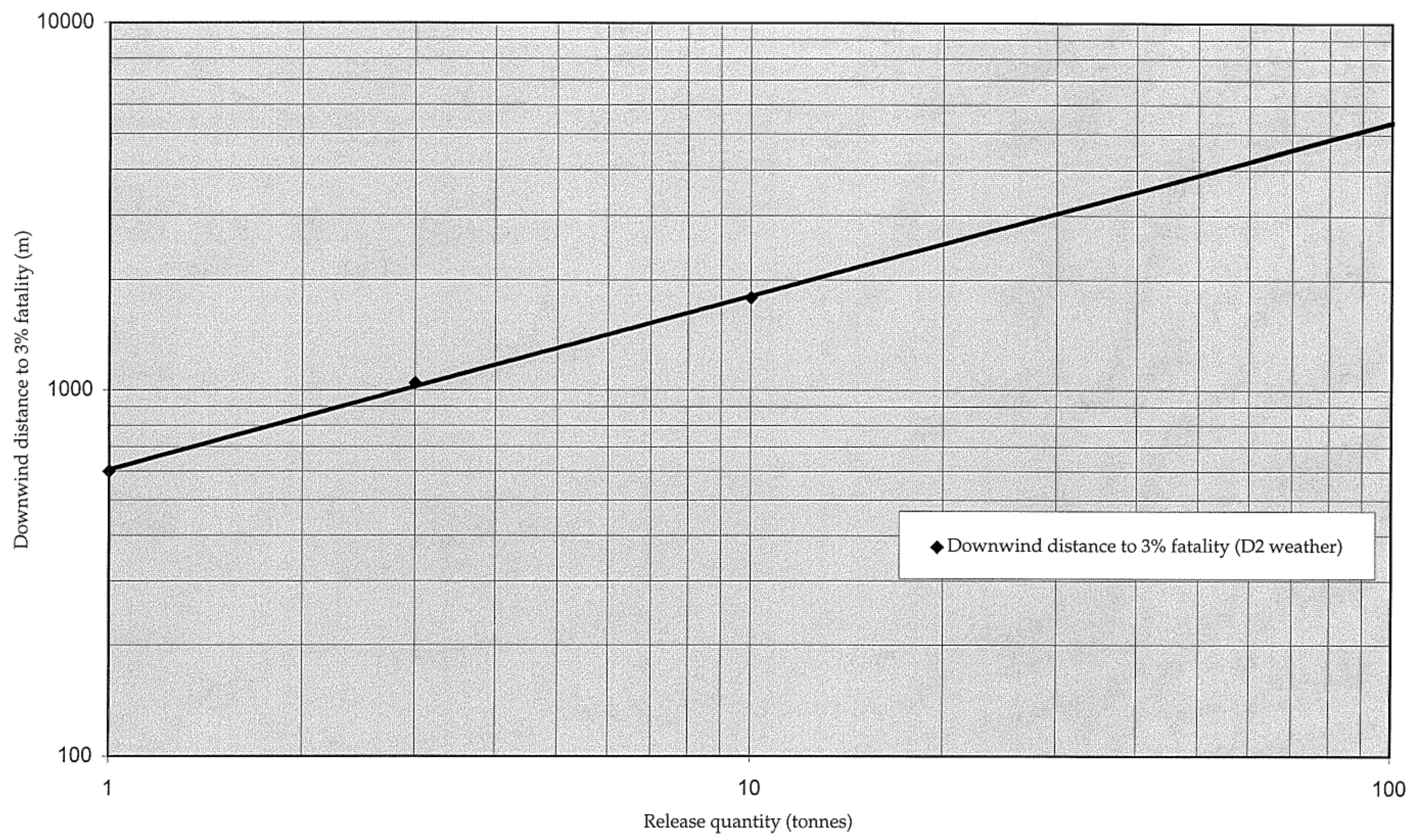


Figure A2 Downwind distance to 3% fatality vs instantaneous release quantity



Annex B

Wind Tunnel Test Results for Sha Tin WTW

Table B1 - Specification for Wind Tunnel Simulations for Sha Tin WTW

Test No.	Release location	Release type	Phase of release	Release rate (kg/s) or quantity (kg)	Wind speed (m/s)	Wind directions	Figure no.s
1 - 3	NE corner of chlorine store	Continuous	Chlorine vapour at ambient temperature	0.5	2	SE, SW, W	
4 - 8	NE corner of chlorine store	Instantaneous	Aerosol	1000.0	2	NNE, SE, SSW, WSW, WNW	B1-B4
9 - 10	NE corner of chlorine store	Continuous	Chlorine vapour at ambient temperature	0.5	5	SE, SW	
11 - 12	NE corner of chlorine store	Instantaneous	Aerosol	1000.0	5	SE, WSW	B5, B6
13 - 18	Access Road (outside Admin Building)	Continuous	Aerosol	1.4	2	NNE, SE, S, SW, W, NW	
19 - 24	Access Road (outside Admin Building)	Instantaneous	Aerosol	1000.0	2	NNE, SE, S, SW, W, NW	B7-B12
25 - 26	Access Road (outside Admin Building)	Continuous	Aerosol	0.2	2	SW, W	
27 - 28	Access Road (outside Admin Building)	Continuous	Aerosol	1.4	5	SE, W	
29 - 30	Access Road (outside Admin Building)	Instantaneous	Aerosol	1000.0	5	SE, W	B13-B14

Note: a small circle on the figures represents invalid contours which do not appear in wind tunnel test results since the contours do not extend off-site.

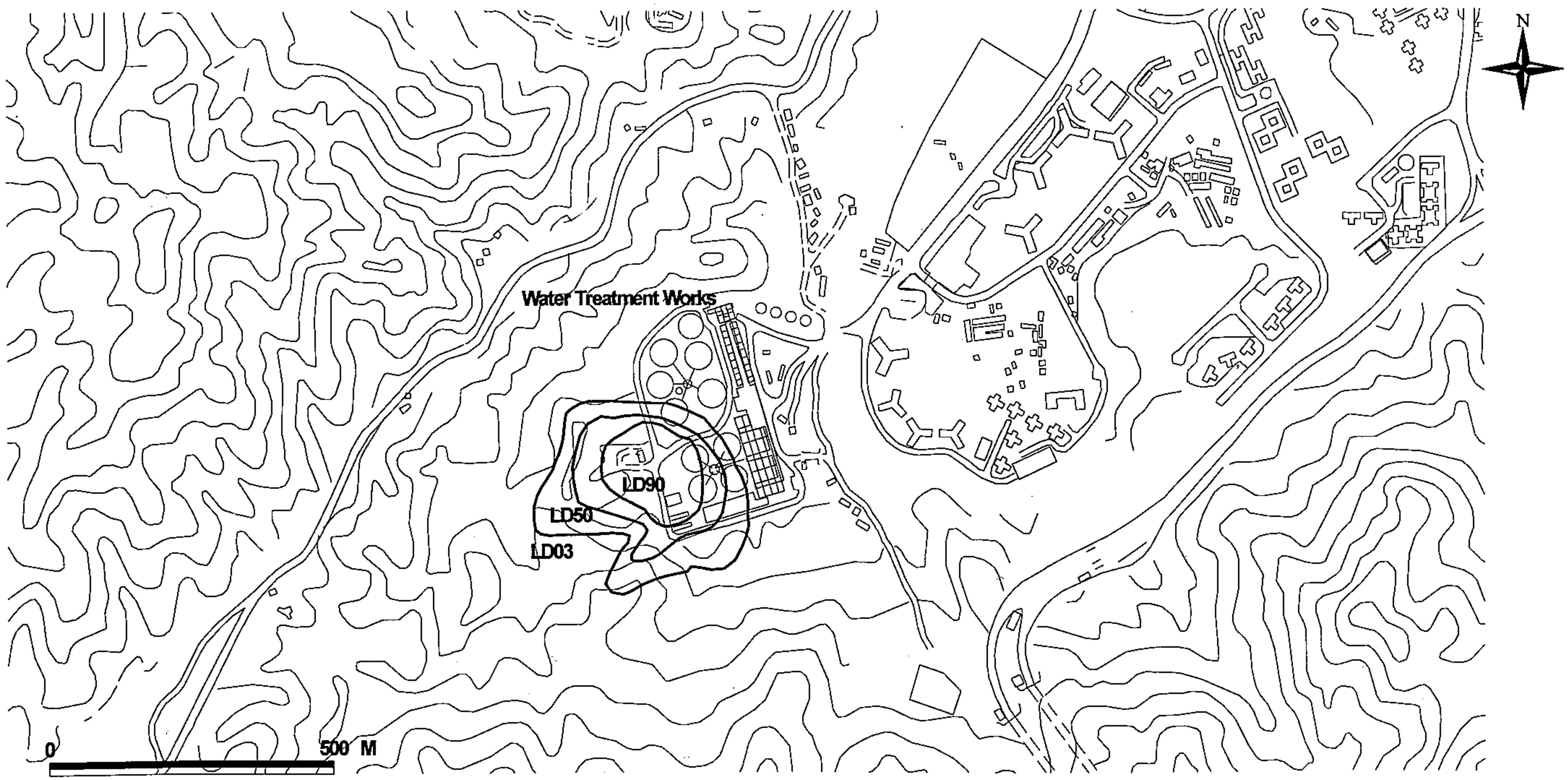


Figure B.1 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Chlorine Store
Wind Direction : NNE
Weather Class: D2

ERM

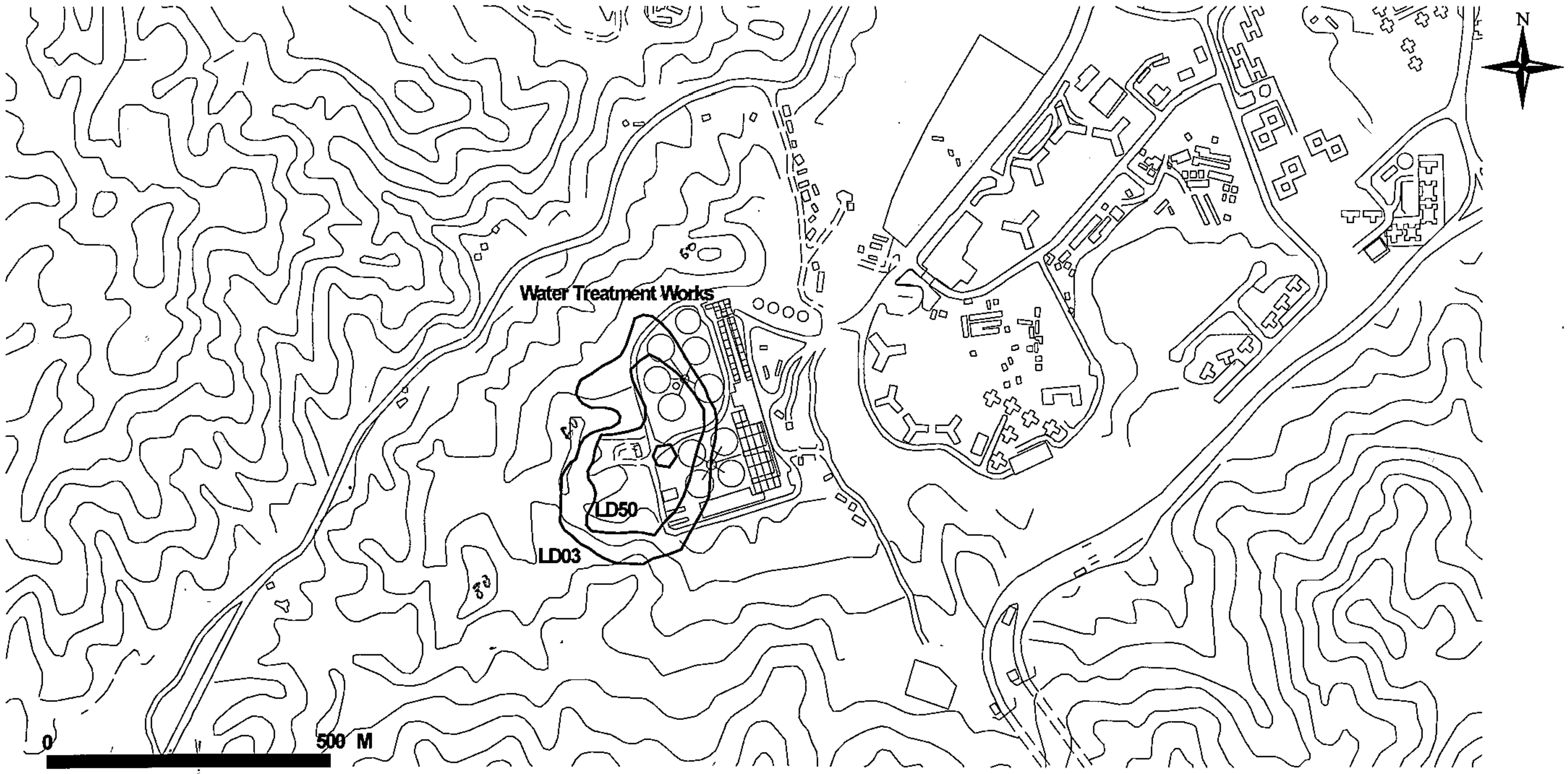


Figure B.2 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Chlorine Store
Wind Direction : SE
Weather Class: D2

ERM

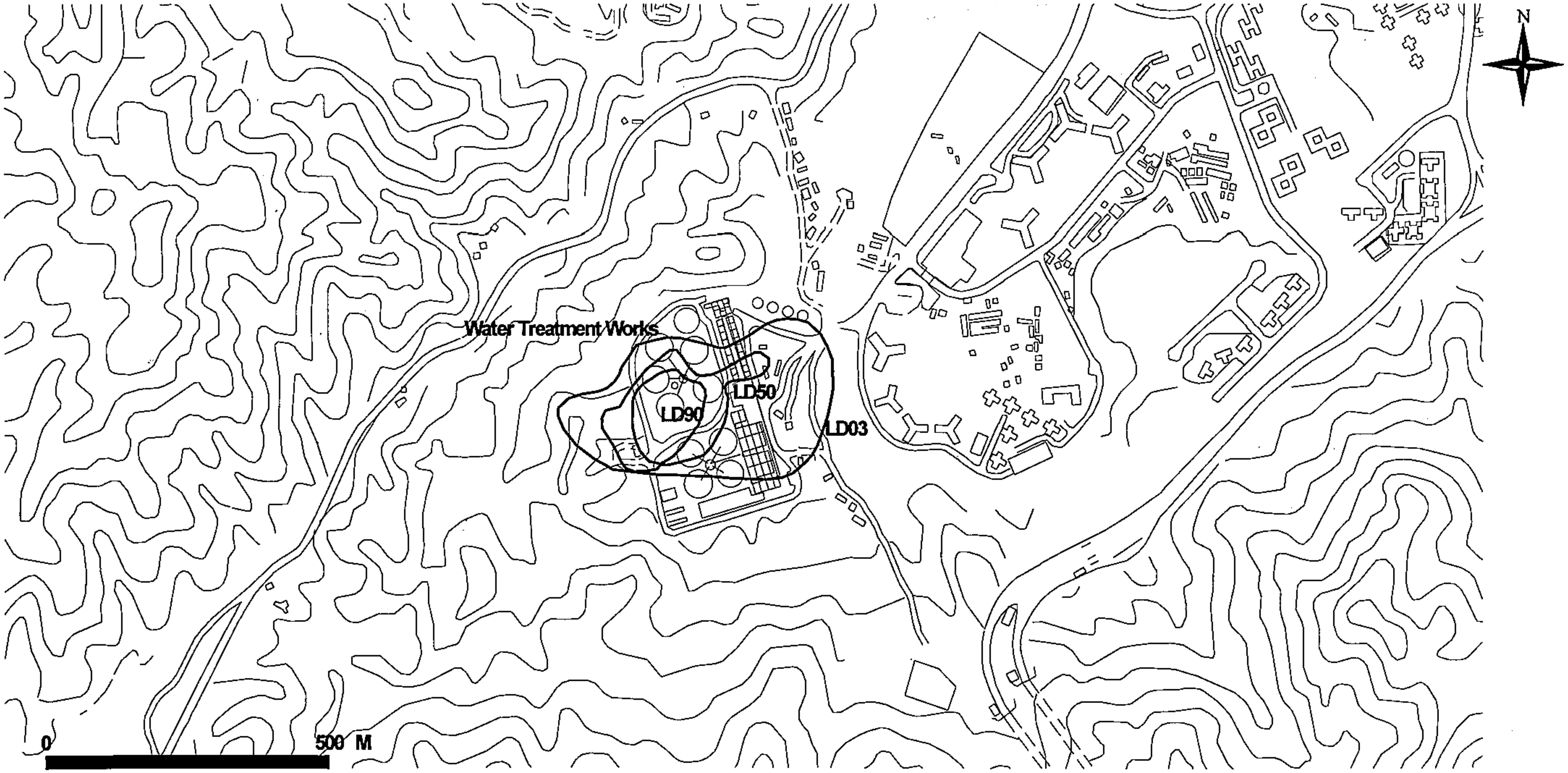


Figure B.3 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Chlorine Store
Wind Direction : SSW
Weather Class: D2

ERM

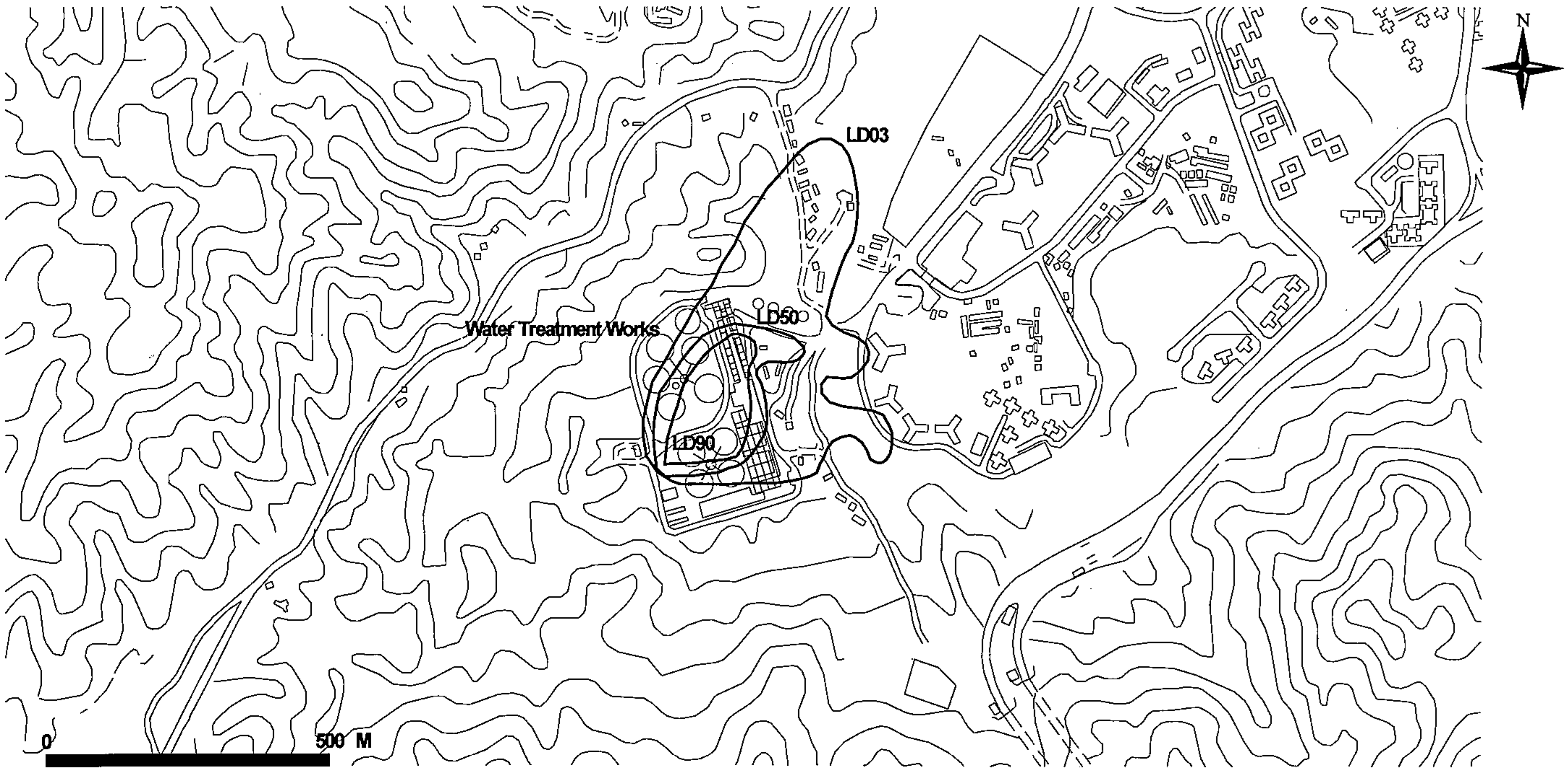


Figure B.4 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Chlorine Store
Wind Direction : WSW
Weather Class: D2

ERM

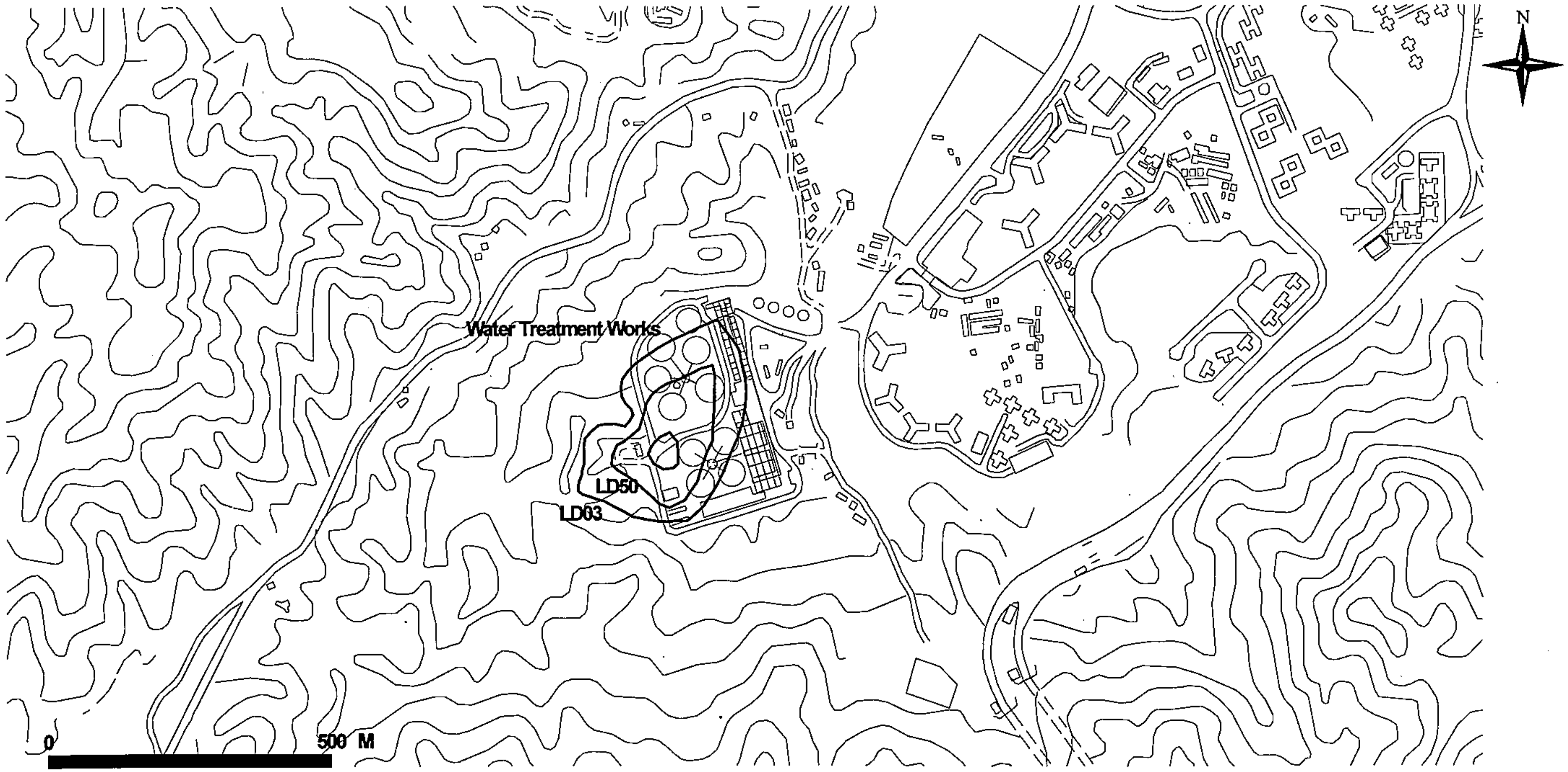


Figure B.5 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Chlorine Store
Wind Direction : SE
Weather Class: D5

ERM

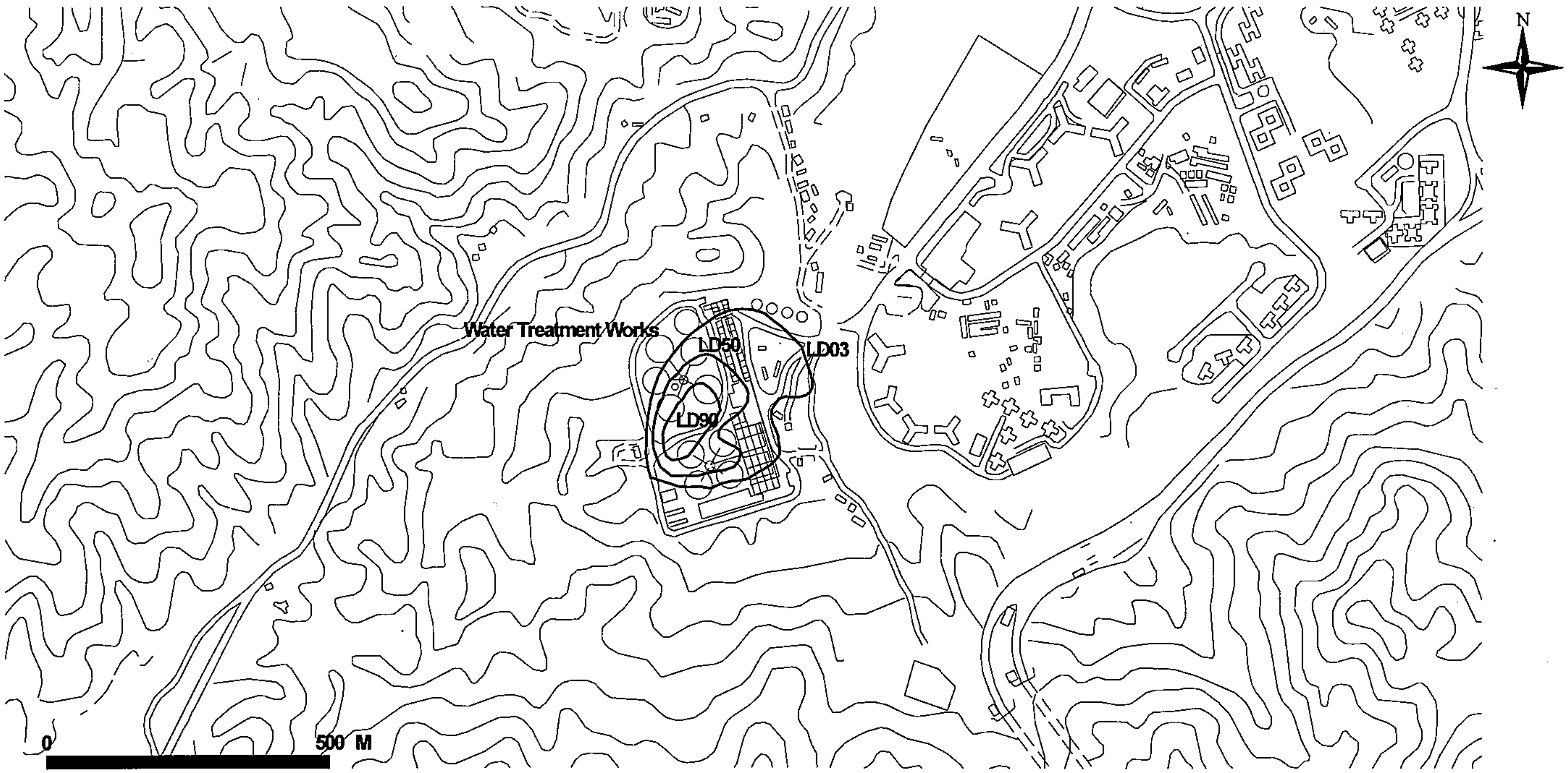


Figure B.6 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Chlorine Store
Wind Direction : WSW
Weather Class: D5

ERM

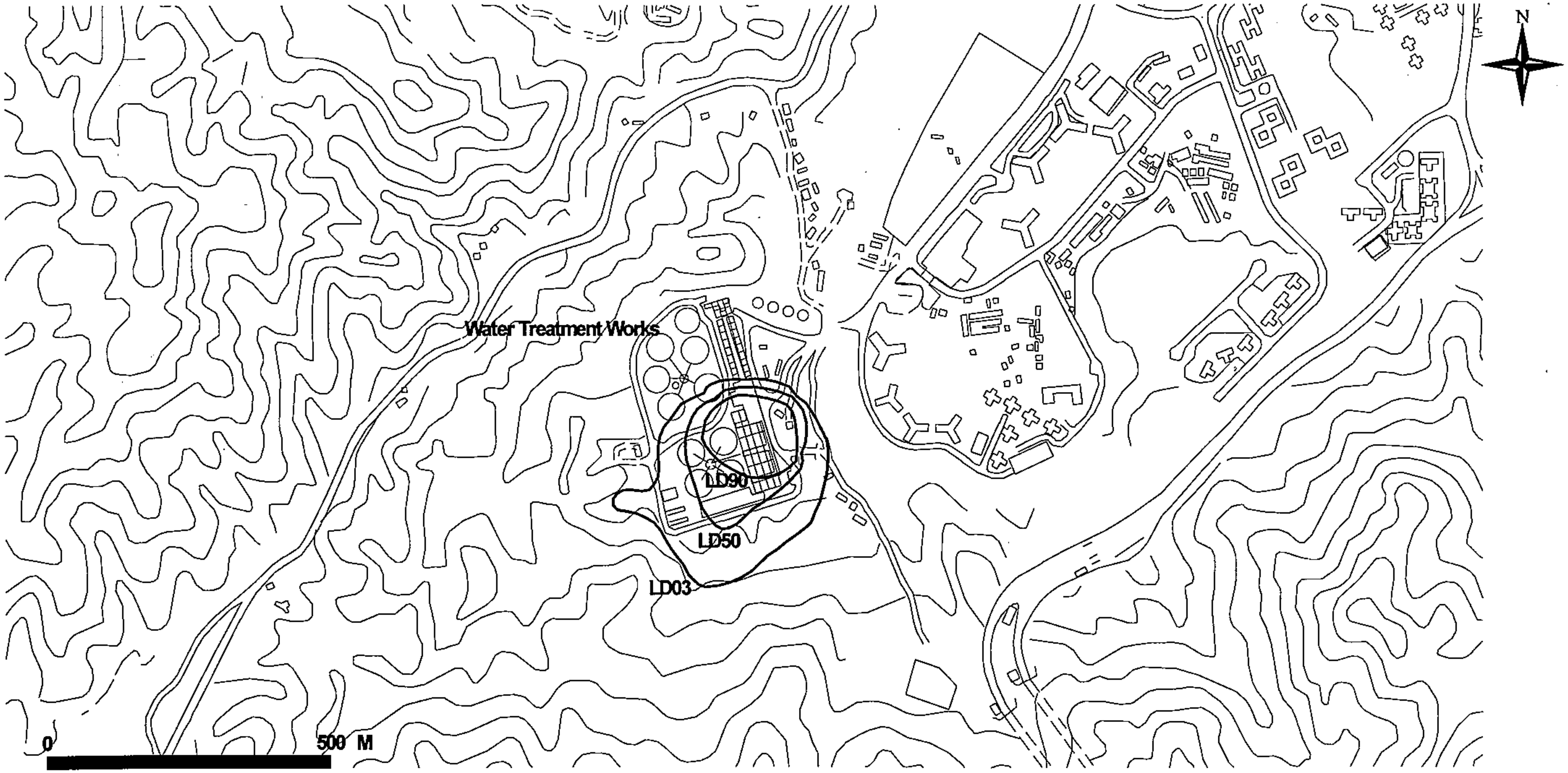


Figure B.7 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Access Road
Wind Direction : NNE
Weather Class: D2

ERM

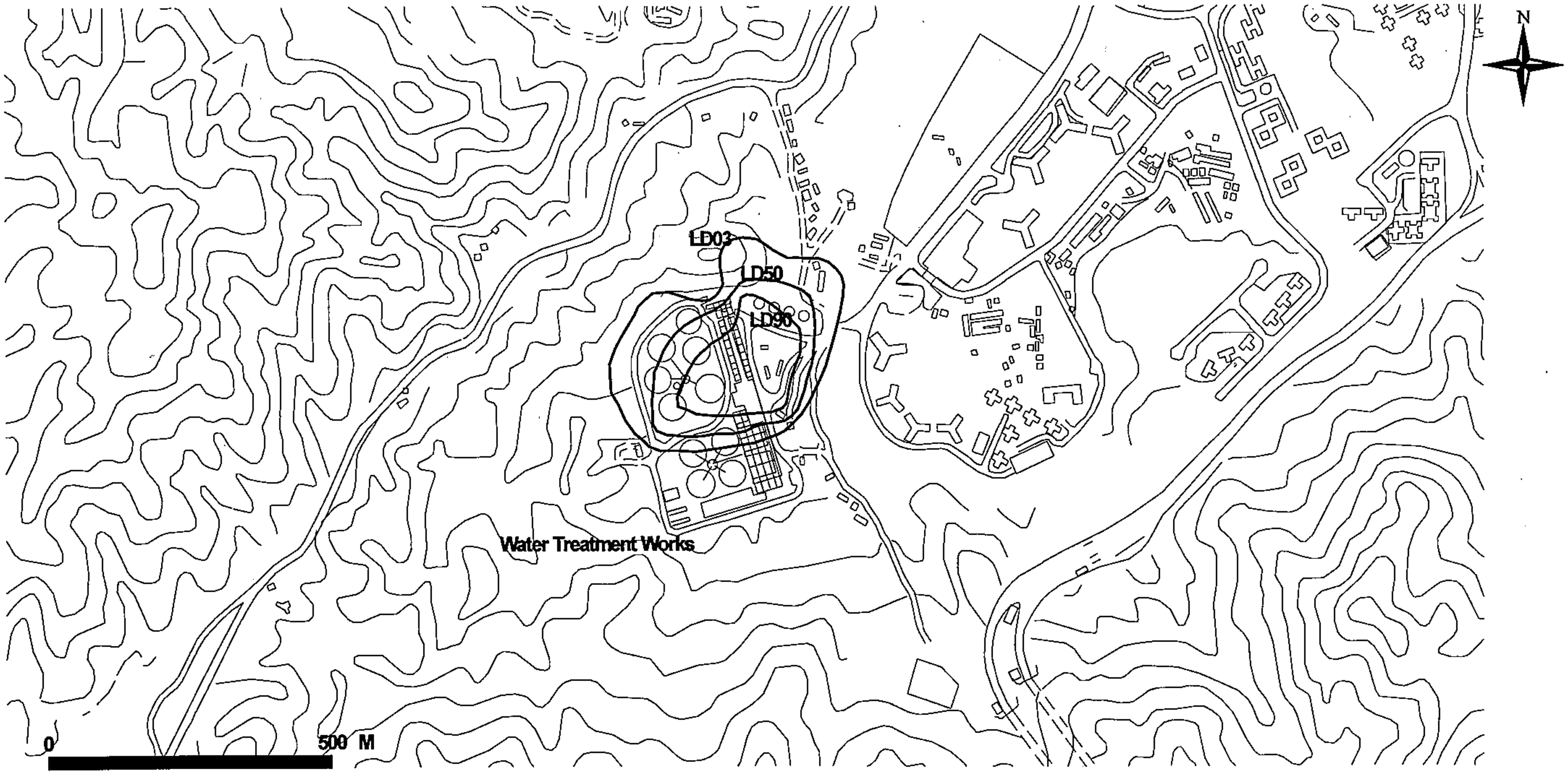


Figure B.8 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Access Road
Wind Direction : SE
Weather Class: D2

ERM

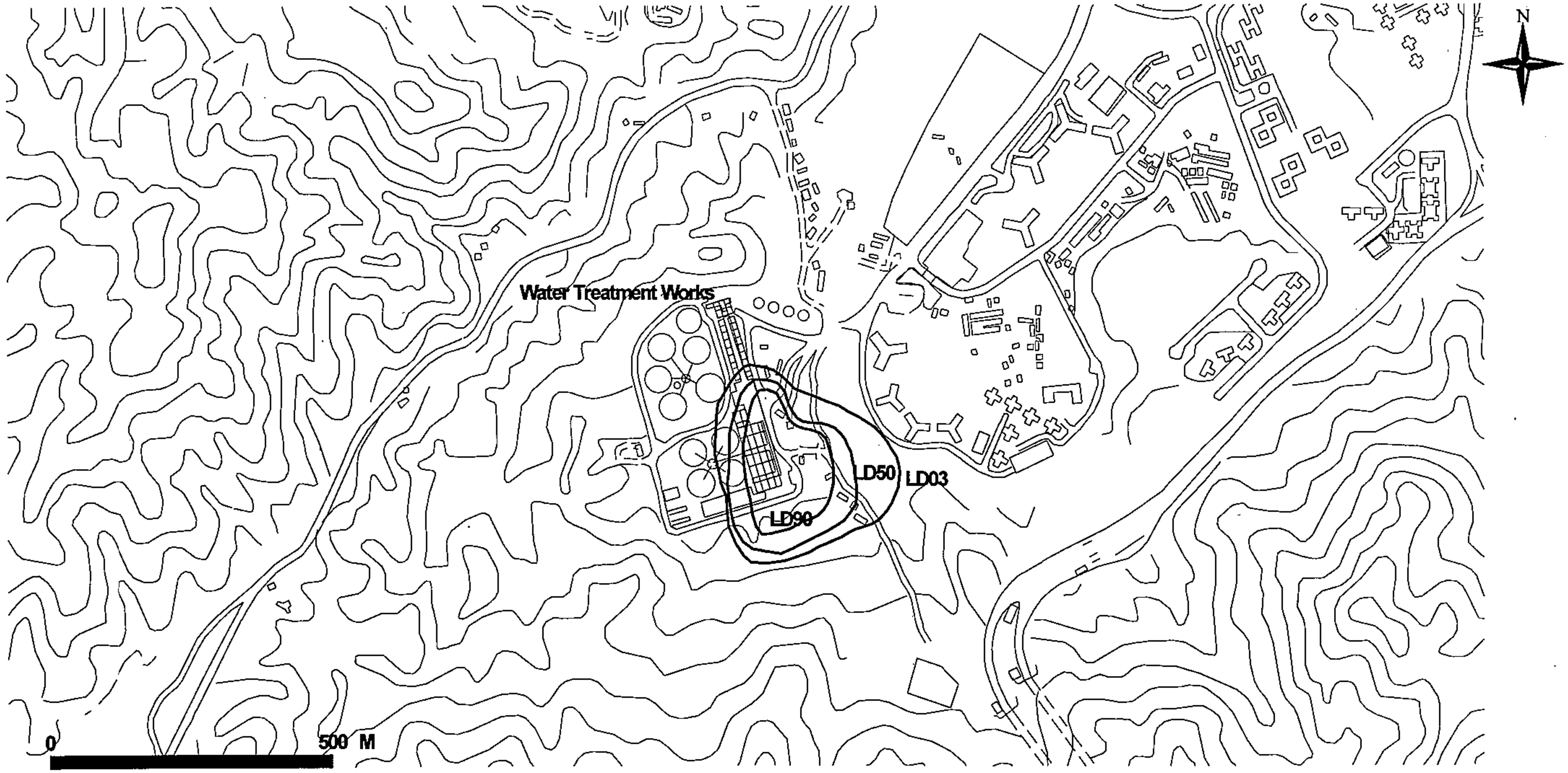


Figure B.9 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Access Road
Wind Direction : S
Weather Class: D2

ERM

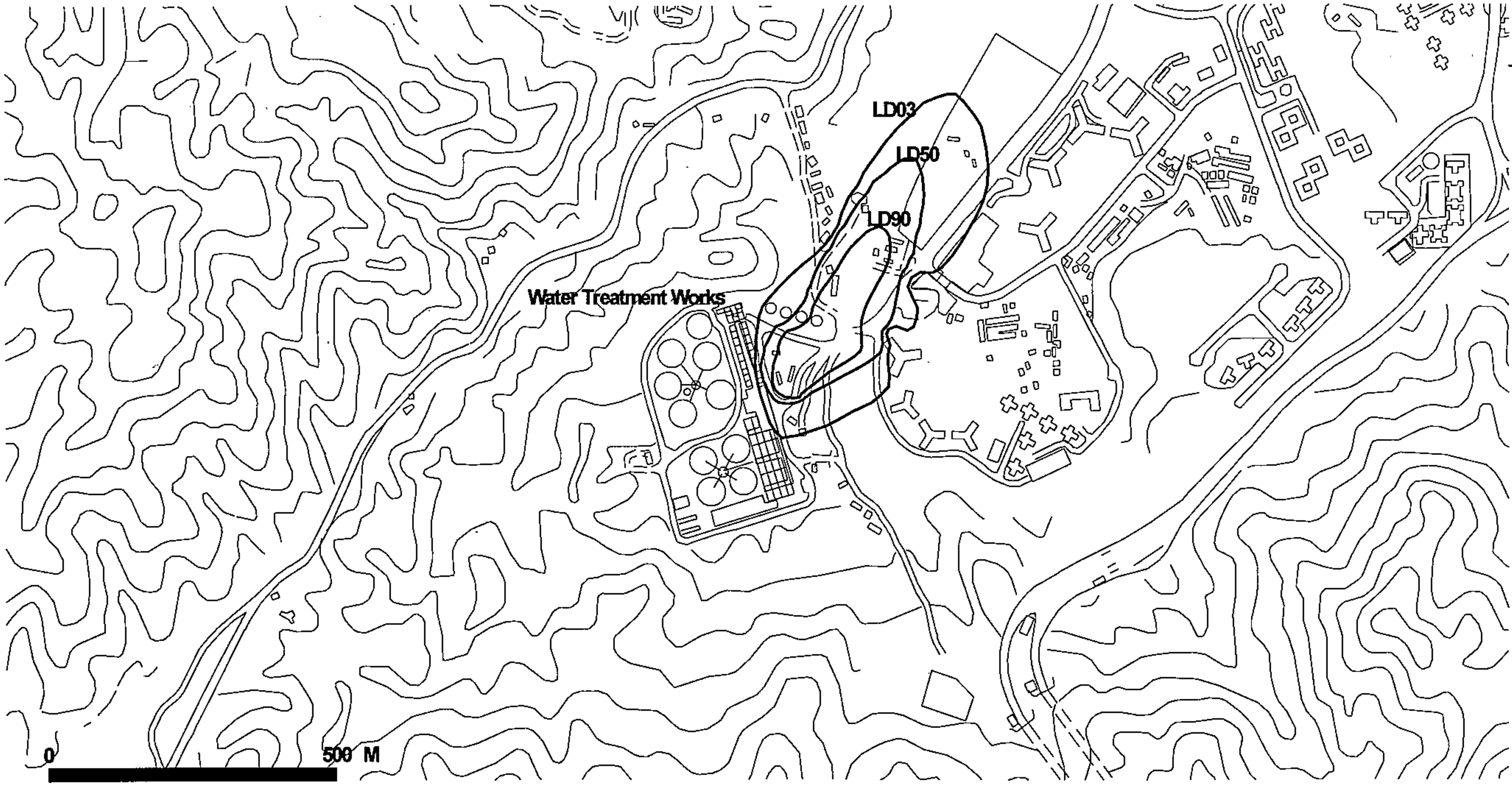


Figure B.10 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Access Road
Wind Direction : SW
Weather Class: D2

ERM

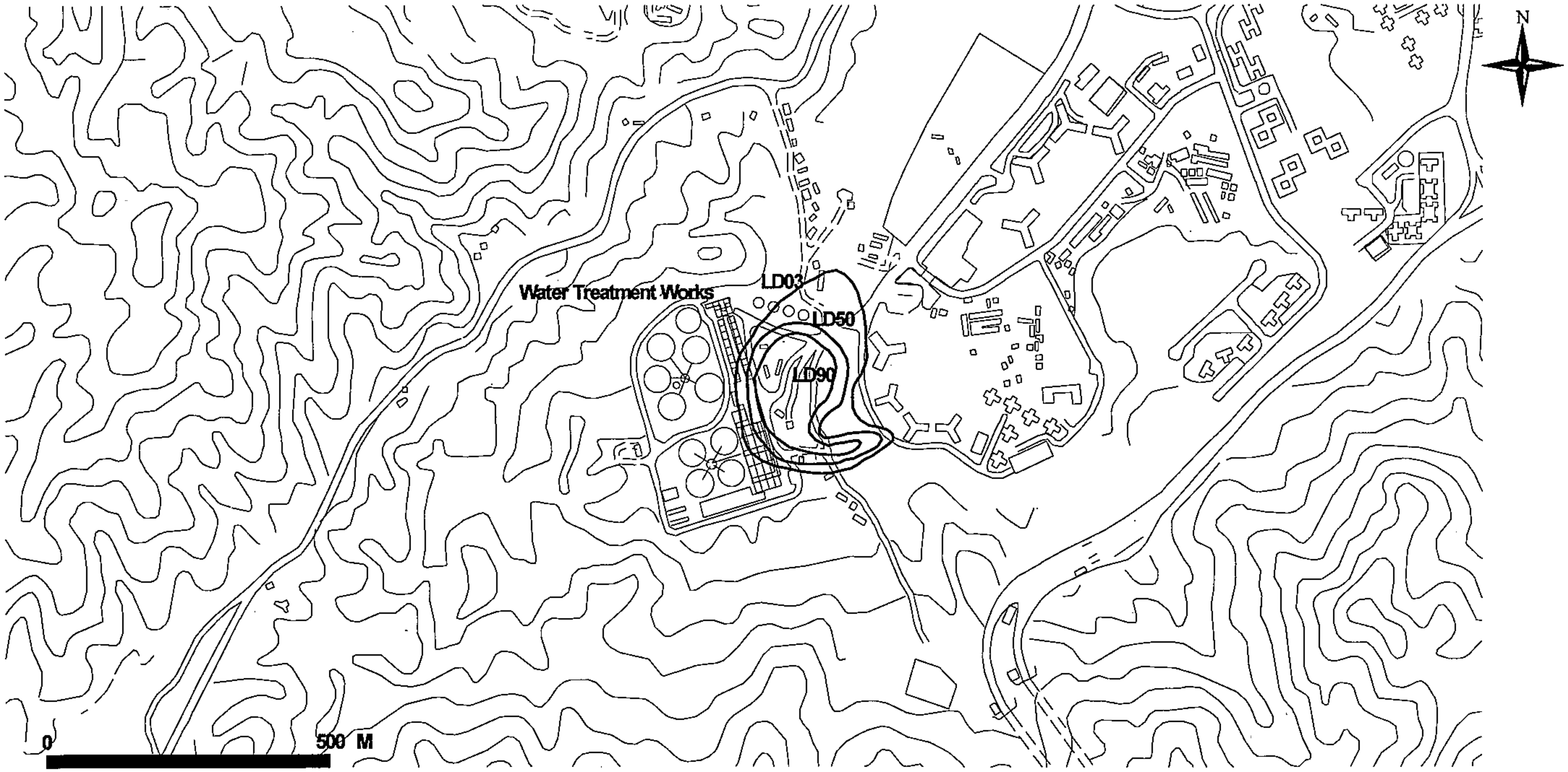


Figure B.11 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Access Road
Wind Direction : W
Weather Class: D2

ERM

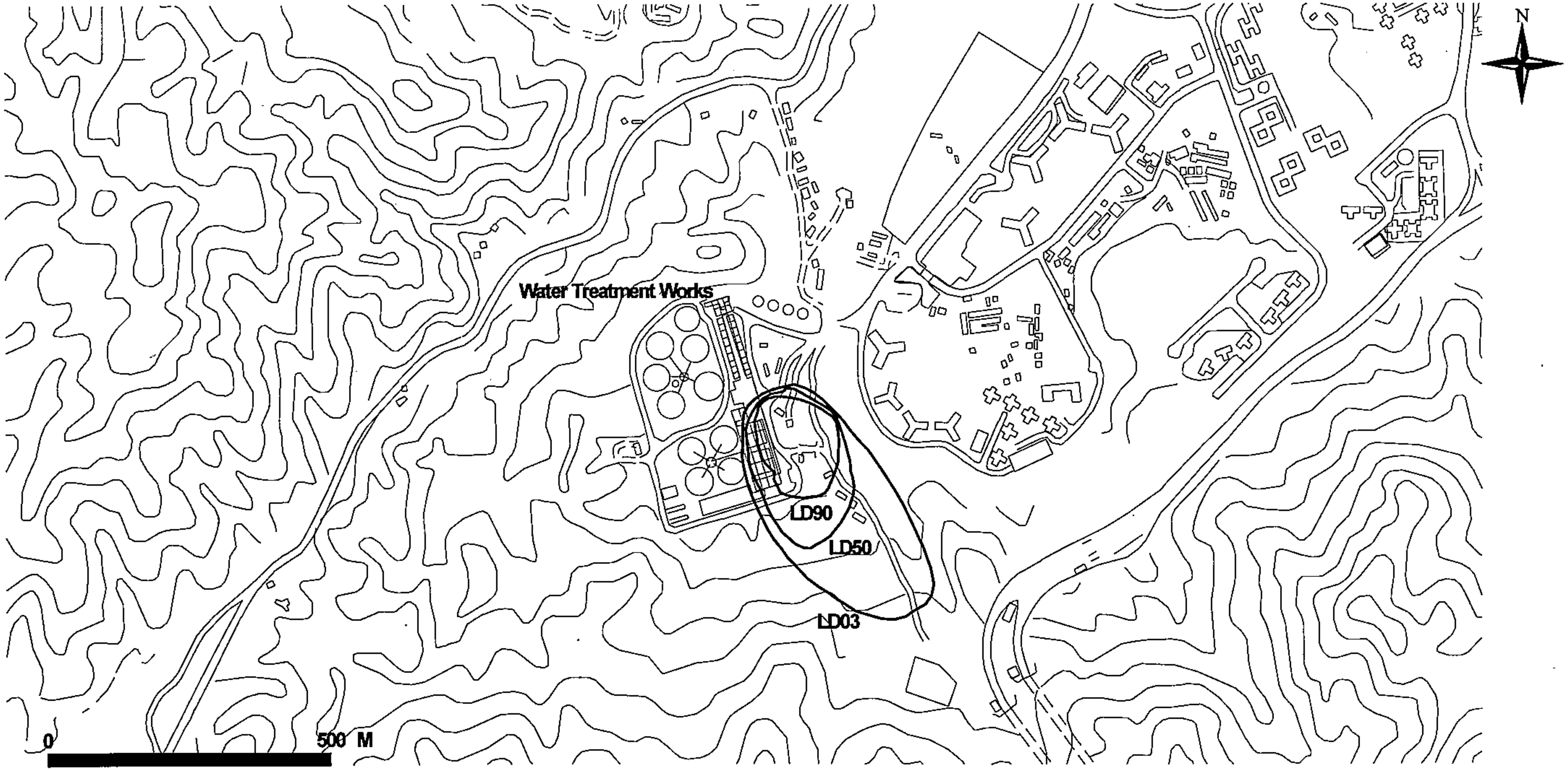


Figure B.12 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Access Road
Wind Direction : NW
Weather Class: D2

ERM

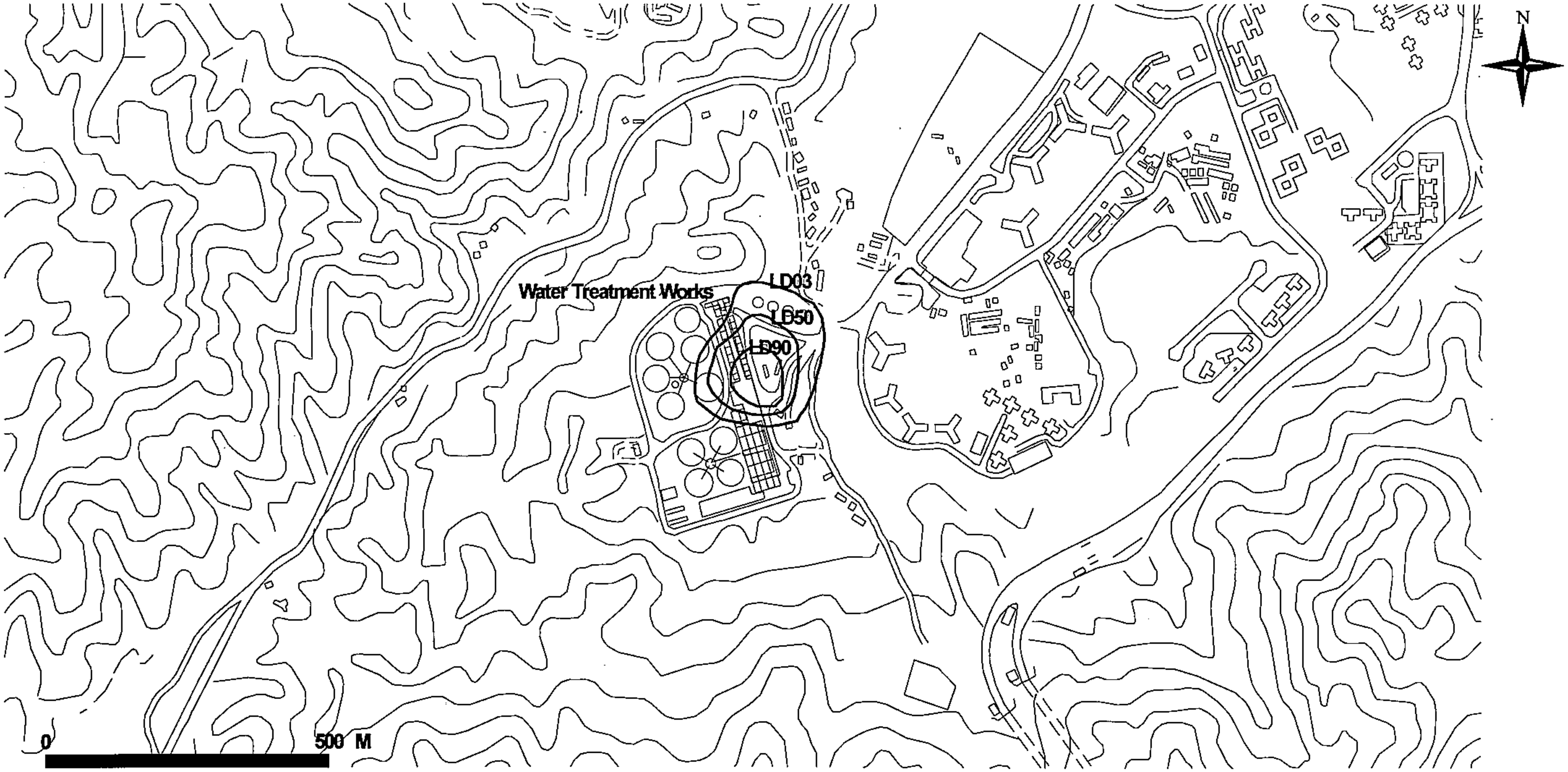


Figure B.13 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Access Road
Wind Direction : SE
Weather Class: D5

ERM

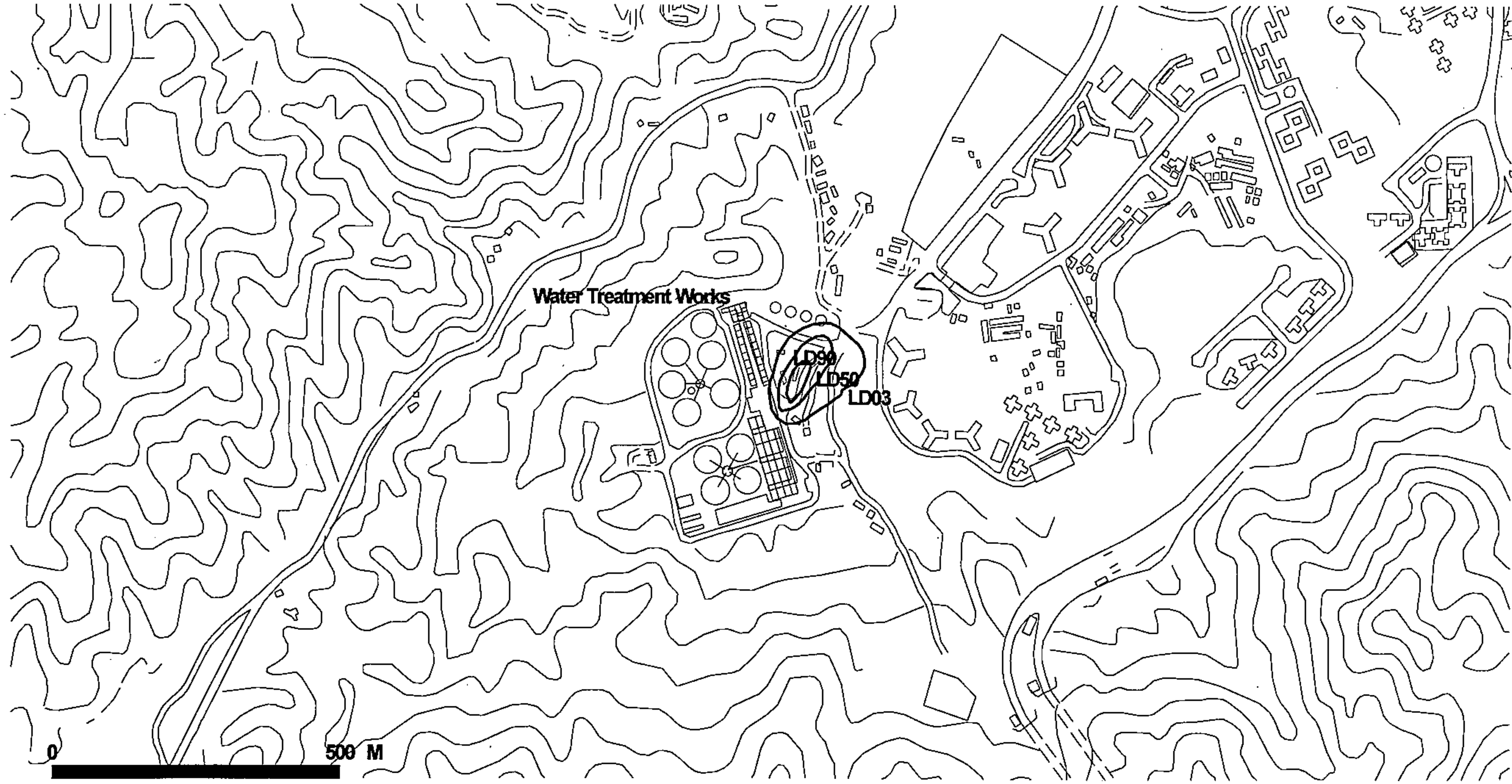


Figure B.14 Wind Tunnel Test LD Contours

Scale : 1:10,000

Date : 29 July 1999 Reference : C:\WTW\SITE.APR

Release Case: External 1 Tonne (Instantaneous)
Release Location: Access Road
Wind Direction : W
Weather Class: D5

ERM

Annex C

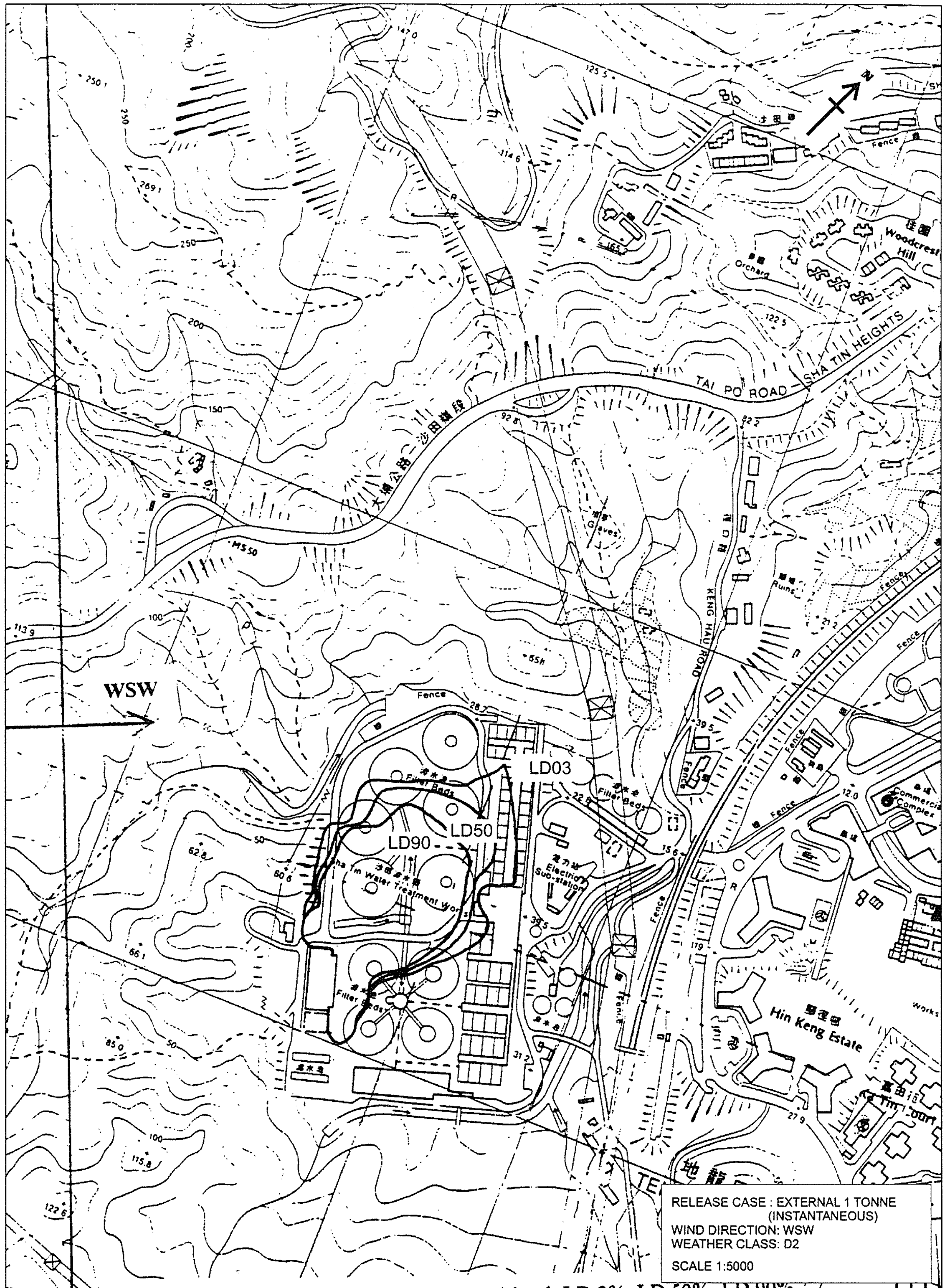
CFD Modelling Results for Sha Tin WTW and Tai Po Tau WTW

Table C1 - Specification for CFD Modelling for Sha Tin Water Treatment Works

Run No.	Release Location	Release type	Release rate (kg/s) or quantity (kg)	Wind Speed (m/s)	Pasquill stability class	Wind direction	Figure no.s
1	NE corner of chlorine store	Instantaneous	1000	2	D	WSW	C1
2	NE corner of chlorine store	Instantaneous	1000	2	F	WSW	C2
4	Access Road (outside Admin Building)	Continuous	1.4	2	D	WSW	C3
5	Access Road (outside Admin Building)	Continuous	1.4	2	F	WSW	C4

Table C2 - Specification for CFD Modelling for Tai Po Tau Water Treatment Works

Run No.	Release Location	Release type	Release rate (kg/s) or quantity (kg)	Wind Speed (m/s)	Pasquill stability class	Wind direction	Figure no.s
1	Access Road	Instantaneous	1000	2	D	SW	C5
2	Access Road	Instantaneous	1000	2	F	SW	C6
3	Access Road	Instantaneous	1000	2	B	SW	C7
4	Access Road	Continuous	1.4	2	D	SW	C8
5	Access Road	Continuous	1.4	2	F	SW	C9



RELEASE CASE : EXTERNAL 1 TONNE (INSTANTANEOUS)
WIND DIRECTION: WSW
WEATHER CLASS: D2
SCALE 1:5000

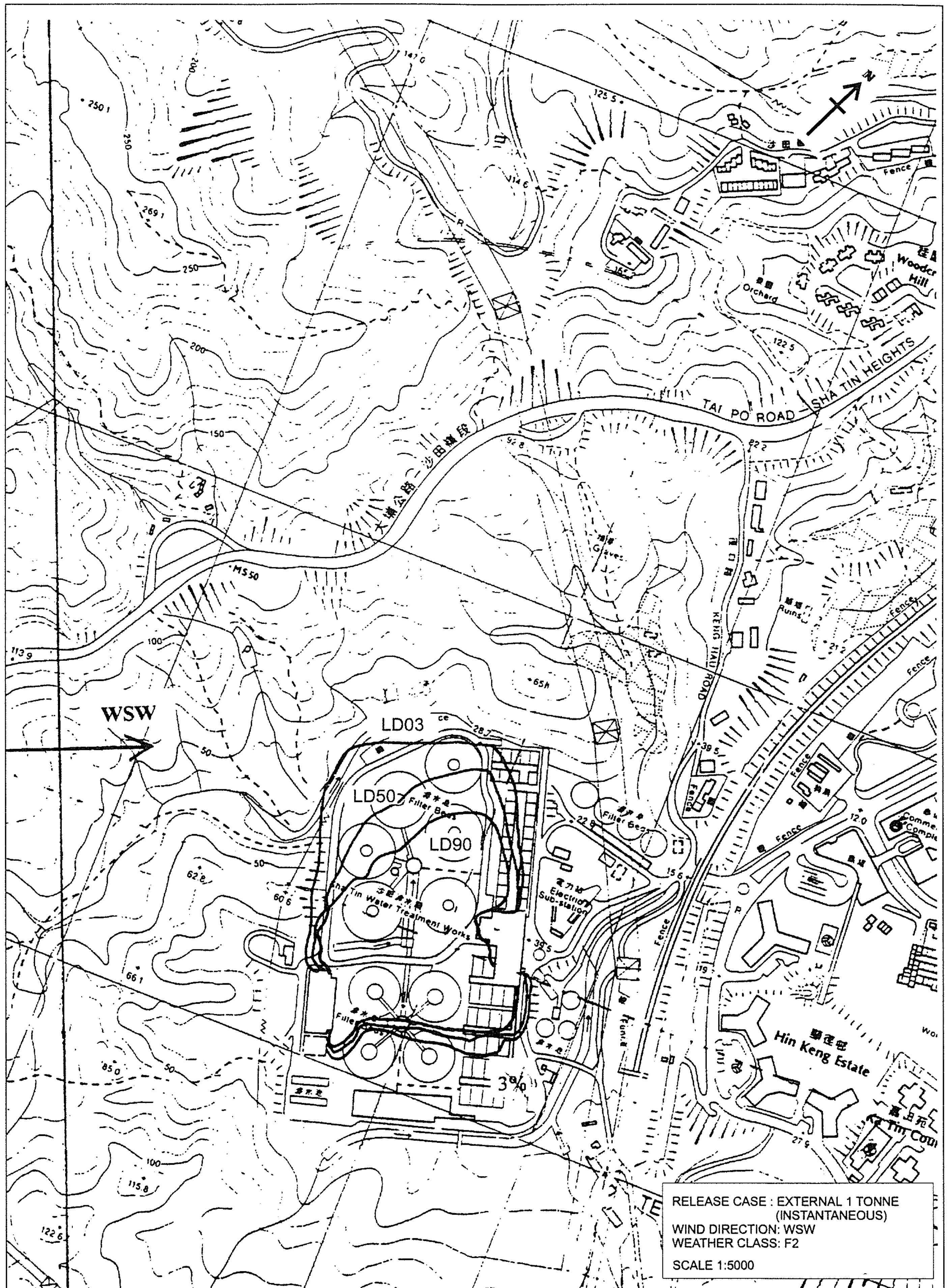
FIGURE C.1

CFD MODELLING RESULTS FOR SHA TIN WTW - LETHAL DOSE CONTOURS LD03, LD50, LD90

Environmental Resources Management

ERM

FILE: C1630u6
DATE: 21/07/99



RELEASE CASE : EXTERNAL 1 TONNE (INSTANTANEOUS)
WIND DIRECTION: WSW
WEATHER CLASS: F2
SCALE 1:5000

FIGURE C.2

CFD MODELLING RESULTS FOR SHA TIN WTW - LETHAL DOSE CONTOURS LD03, LD50, LD90

Environmental Resources Management

ERM

FILE: C1630u8
DATE: 21/07/99

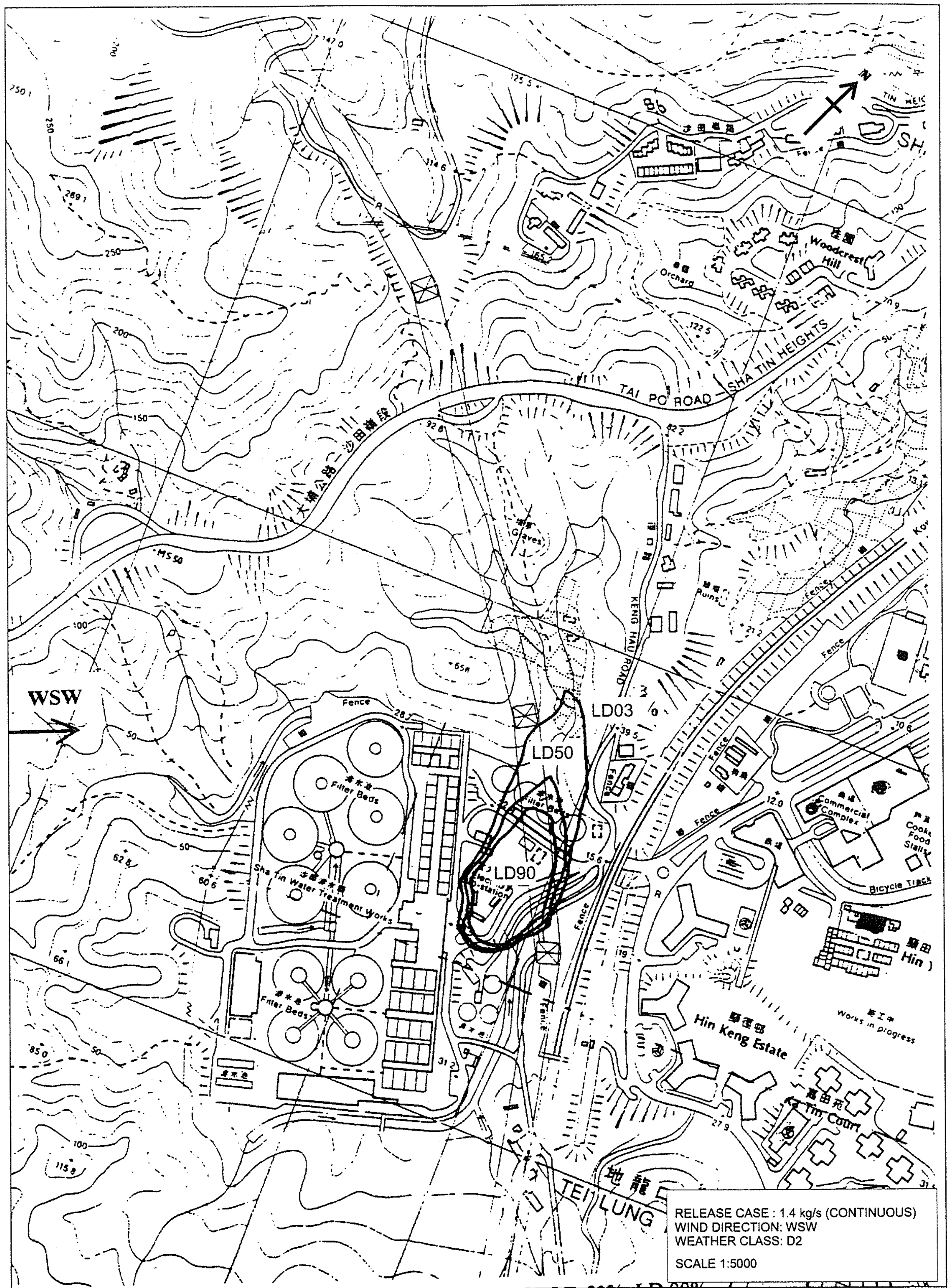


FIGURE C.3 CFD MODELLING RESULTS FOR SHA TIN WTW - LETHAL DOSE CONTOURS LD03, LD50, LD90

Environmental Resources Management

ERM

FILE: C1630u5
DATE: 21/07/99

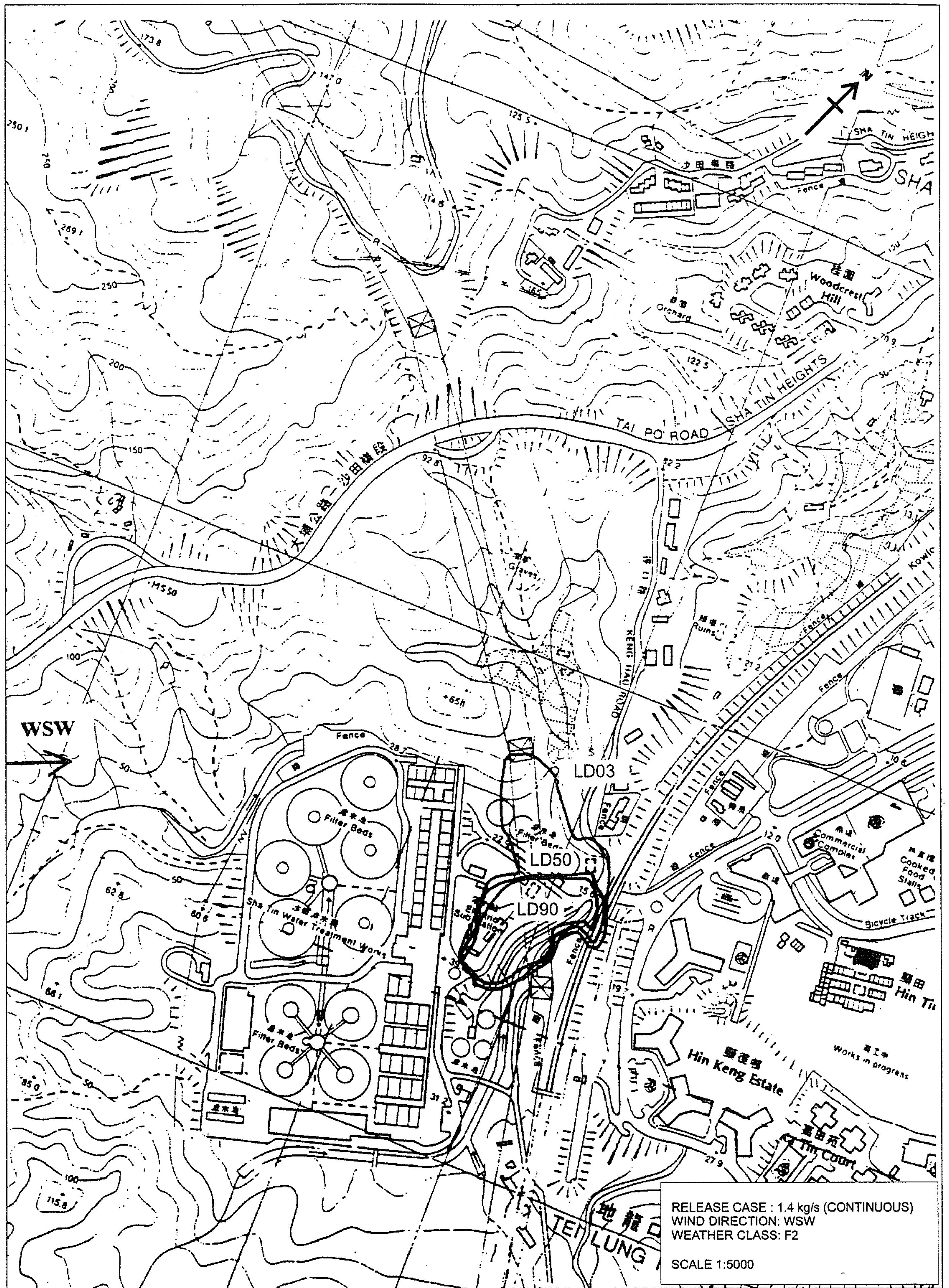
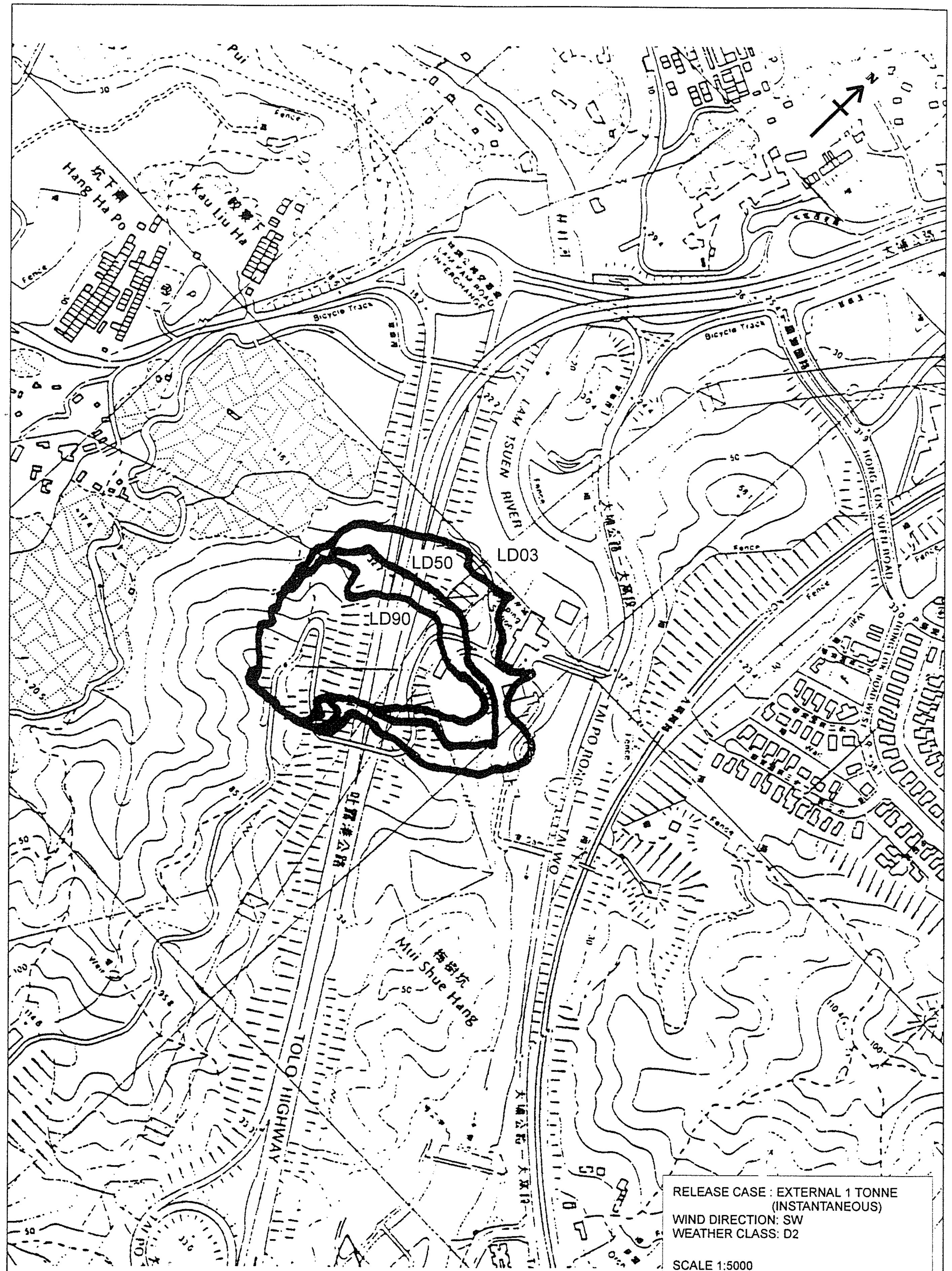


FIGURE C.4 CFD MODELLING RESULTS FOR SHA TIN WTW - LETHAL DOSE CONTOURS LD03, LD50, LD90

Environmental Resources Management

ERM

FILE: C1630u7
DATE: 21/07/99



RELEASE CASE :	EXTERNAL 1 TONNE (INSTANTANEOUS)
WIND DIRECTION:	SW
WEATHER CLASS:	D2
SCALE 1:5000	

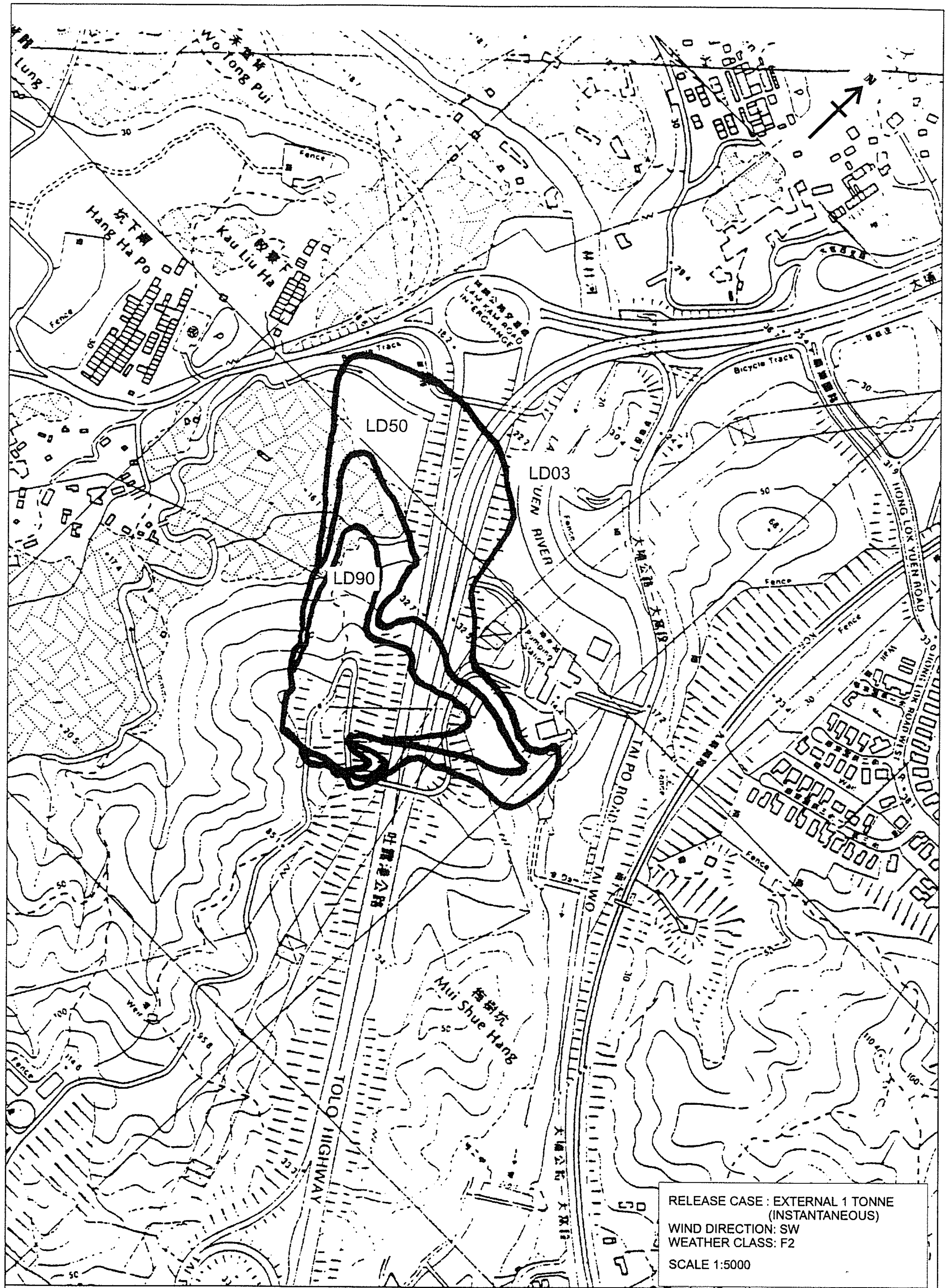
FIGURE C.5

CFD MODELLING RESULTS FOR TAI PO TAU WTW - LETHAL DOSE CONTOURS LD03, LD50, LD90

FILE: C1630u
DATE: 21/07/99

Environmental Resources Management

ERM



RELEASE CASE :	EXTERNAL 1 TONNE (INSTANTANEOUS)
WIND DIRECTION:	SW
WEATHER CLASS:	F2
SCALE 1:5000	

FIGURE C.6

CFD MODELLING RESULTS FOR TAI PO TAU WTW - LETHAL DOSE CONTOURS LD03, LD50, LD90

FILE: C1630u3
DATE: 21/07/99

Environmental Resources Management

ERM

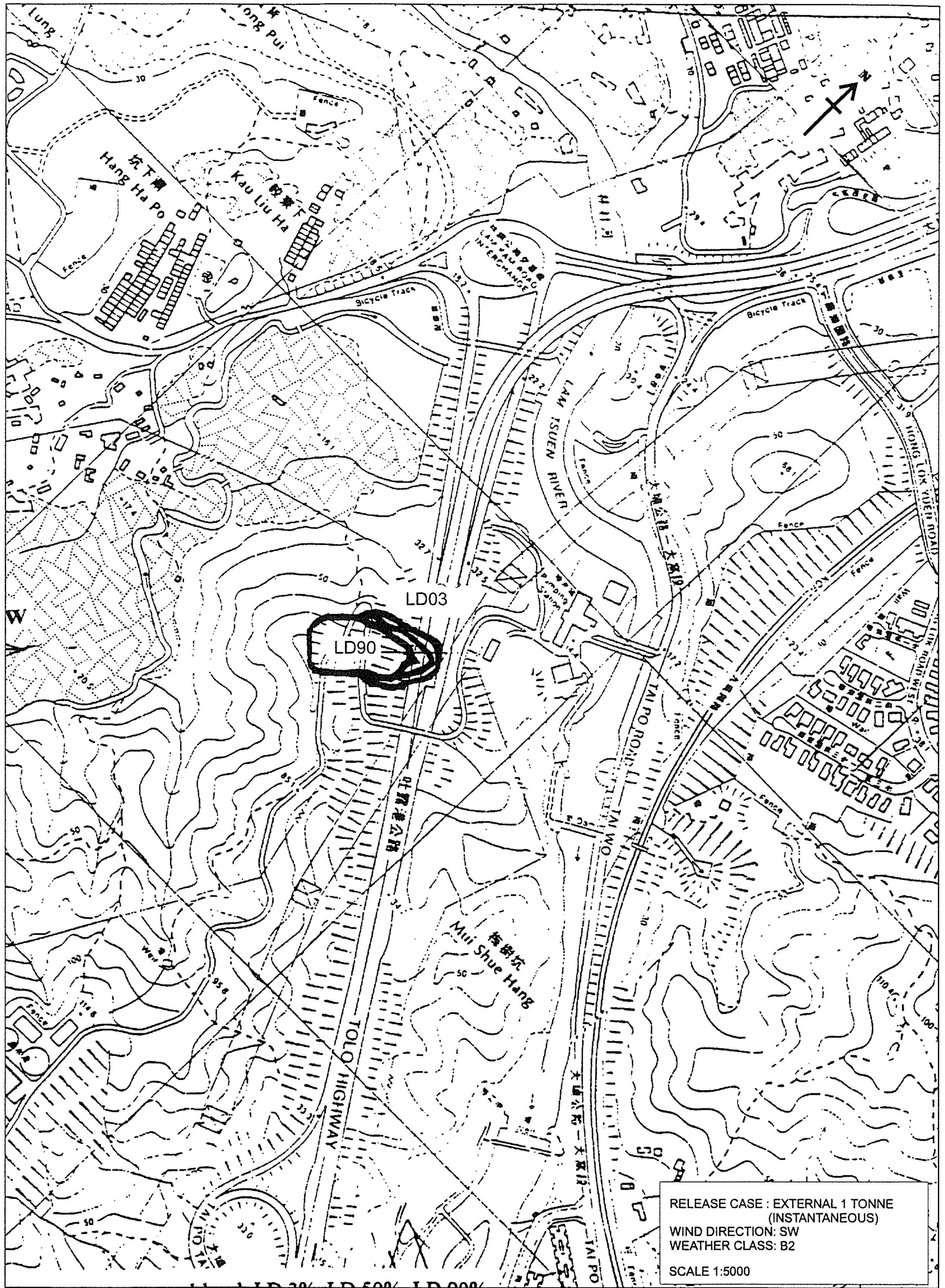


FIGURE C.7

CFD MODELLING RESULTS FOR TAI PO TAU WTW - LETHAL DOSE CONTOURS LD03, LD50, LD90

Environmental Resources Management

ERM

FILE: C1630u4
DATE: 21/07/99

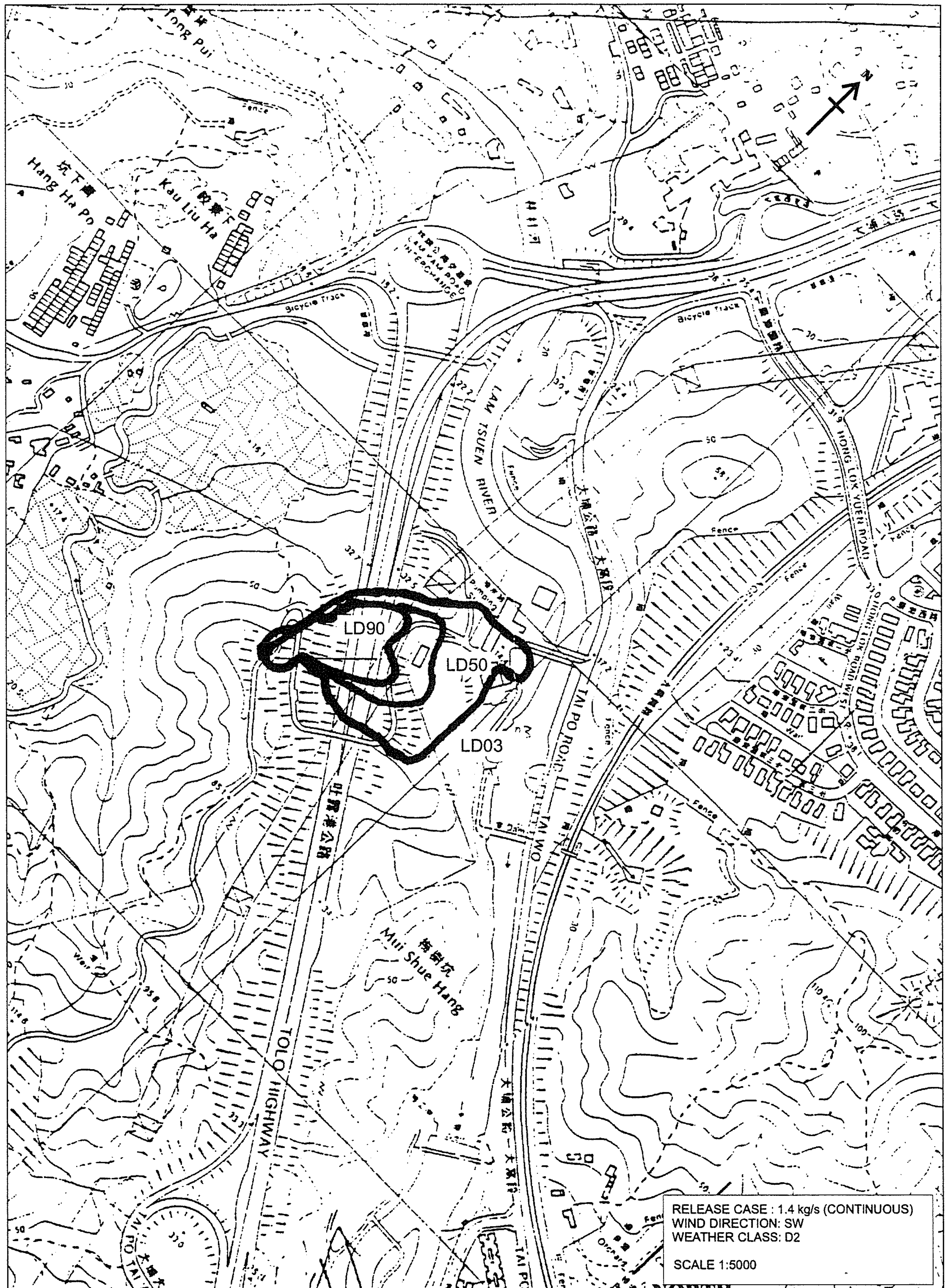


FIGURE C.8

CFD MODELLING RESULTS FOR TAI PO TAU WTW - LETHAL DOSE CONTOURS LD03, LD50, LD90

Environmental Resources Management

ERM

FILE: C1630u1
DATE: 21/07/99

Annex D

Application of Chlorine Dispersion Modelling Results in QRA

APPLICATION OF CHLORINE DISPERSION MODELLING RESULTS IN QRA

This annex presents the details of how the chlorine dispersion modelling results from the wind tunnel testing, CFD modelling and DRIFT flat terrain dispersion modelling have been applied in the QRA. It complements the discussion in *Section 4.2* of the main text of this report.

In the wind tunnel testing (*Annex B*) 36 separate simulations of chlorine releases were undertaken. However in the QRA it is necessary to consider a much large number of possible release scenarios corresponding to various combinations of chlorine release rate/quantity, release location, wind speed, wind direction and atmospheric stability. This annex describes how the results of the wind tunnel testing, in combination with those from the CFD modelling and DRIFT modelling have been used to generate all the cloud shapes required for the QRA.

The aspects covered are as follows:

- scaling of the wind tunnel results for different chlorine release rates/quantities;
- scaling of the wind tunnel results for different wind speeds;
- simulation of releases at different locations along the site access road;
- interpolation of the wind tunnel results for different wind directions (ie the method of 'wind smoothing'); and
- the influence of atmospheric stability on the chlorine hazard range.

Table D1 below lists each of the key parameters of interest and details how the results of the various strands of the dispersion modelling work have been applied in the QRA.

Table D1 Application of Chlorine Dispersion Modelling Results in QRA

Parameter	Details of Application of Dispersion Modelling Results
1. Chlorine release rate/quantity	The wind tunnel testing considered only a limited range of chlorine release rates/quantities, ie typically one instantaneous release case and one or two continuous release cases per site. However in the DRIFT flat terrain modelling a much greater range of chlorine release rates/quantities was considered (*Annex A*). From the DRIFT results it is possible to derive a relationship between the chlorine release rate/quantity and the hazard range. These relationships are used to scale the LD contours generated by the wind tunnel according to the release rate/quantity of interest. A method of uniform scaling is used, which is undertaken mathematically within the GIS*Risk* software. This method of scaling is sufficiently accurate provided that the range of extrapolation is not too great and that the topography surrounding the WTW is reasonably flat. For Sha Tin WTW the topography surrounding the WTW is not flat and this introduces potential errors when scaling the wind tunnel results for 1 tonne instantaneous releases up to the largest releases of interest (ie 27 tonnes). The method of uniform scaling has therefore been adapted to take into account the effects of the topography. This has been achieved by constraining the cloud to follow the topographic contours (ie the LD90 contour is constrained to 50m PD, based on observed behaviour in the wind tunnel), whilst preserving the cloud area. This method of scaling provides a conservative assessment of the number of fatalities arising from the large release cases, as it results in the cloud penetrating into the populated areas around the Hin Keng Estate. For the LD03 and LD50 contours the scaling is achieved by applying the scale factors (in the normal way). Unlike the LD90 contour, the LD03 and LD50 contours are allowed to expand without regard to the local topography. An adjustment is then made to ensure that the contours still fit with the (modified) LD90 contour, ie to avoid any discontinuities. The scale factors used in the QRA for Sha Tin WTW are as follows: 1. Continuous releases ('Base case' continuous release: 1.4 kg/s) Event RU1TMML (4.2 kg/s continuous release) Scale factor = 1.8 (from *Figure A1*) 2. Instantaneous Releases ('Base case' instantaneous release: 1 tonne) Event RU1TMRU (3 tonne instantaneous release) Scale factor = 1.7 (from *Figure A2*) Event EU1TMRU (instantaneous release) Scale factor = 4.6 for a storage of 203 tons (from *Figure A2*) Scale factor = 4.5 for a storage of 190 tons (from *Figure A2*) Scale factor = 4.4 for a storage of 183 tons (from *Figure A2*) Scale factor = 4.1 for a storage of 158 tons (from *Figure A2*) Scale factor = 4.0 for a storage of 150 tons (from *Figure A2*)

Parameter	Details of Application of Dispersion Modelling Results
2. Wind speed	In the wind tunnel testing for each WTW, most simulations were undertaken at a 2m/s wind speed, which is typical of the weather conditions in Hong Kong. However a small number of tests were undertaken at the higher wind speed of 5 m/s, usually for critical wind directions such as towards the nearest population. The results of the 2 m/s and 5 m/s wind tunnel tests have been compared for all sites to determine a simple scaling factor. This scaling factor is then applied to all the 2 m/s LD contours to generate the corresponding 5 m/s contours. The calculated scaling factor is 0.7.
3. Release locations	Accidents associated with the transport of chlorine along the site access road may occur at any location along the access road and it is important to take this into account in the QRA. In the wind tunnel testing for each WTW, releases were typically modelled at two locations - the store and one location on the access road. In the QRA however releases are considered to occur at several points along the access road (typically one release location every 50m). The cloud contours for each location are generated by simply translating the clouds generated from the nearer of the two locations modelled in the wind tunnel. For Sha Tin WTW the number of release locations considered for both the existing and alternative access roads is nine (for continuous releases) and four (for instantaneous releases). It is not necessary to consider as many release locations for the instantaneous releases, because the clouds are large and the spatial resolution need not be as great.
4. Wind direction	In the wind tunnel testing for each WTW, up to eight wind directions were simulated for the most important release scenarios (eg a 1 tonne instantaneous release). However in the QRA it is necessary to consider a much larger number of possible wind directions, in order to avoid any numerical error in the risk results. The means interpolating between modelled wind directions is called 'wind smoothing'. For the case of flat terrain, wind smoothing can be achieved with sufficient accuracy by the simple method of cloud 'rotation', ie rotating adjacent clouds to fill the directional 'gaps' left by the wind tunnel testing (see *8 WTW Project Technical Note 1, ERM, 1998*). The cloud rotation is achieved mathematically within the GIS*Risk* software. For the case of complex terrain, however, it is necessary to ensure that, within the raw wind tunnel data, the effects of nearby topography (including any high rise buildings) are adequately represented, such that further wind smoothing is either not necessary or can be achieved easily using the method of cloud rotation. For Sha Tin WTW it was demonstrated in *Technical Note 1 (see 8 WTW Project Technical Note 1, ERM, 1998)* that sufficient directions had been considered in the original wind tunnel testing, such that further wind smoothing was not necessary. The above discussion applies to the instantaneous chlorine releases at Sha Tin WTW. For the continuous releases on the access road the results from the CFD modelling (1.4 kg/s continuous release case) have been used in the QRA in preference to the wind tunnel results, as explained in *Section 4.*2 of the main text of the report. For this release case wind smoothing has been achieved by simple rotation of the cloud shape from the CFD study for a total of 16 wind directions at each release location on the access road.

Parameter	Details of Application of Dispersion Modelling Results
5. Atmospheric stability	The CFD modelling for Sha Tin WTW and Tai Po Tau WTW shows that atmospheric stability is not a significant factor influencing the chlorine hazard range, when comparing D (neutral) and F (stable) atmospheric conditions, which are the most important in Hong Kong. Therefore atmospheric stability is not a parameter which is considered in the QRA and the probability of unstable (B) or stable (F) conditions is simply combined with that for D (neutral) conditions.

Annex E

Chlorine Cloud Height Predictions

CHLORINE CLOUD HEIGHT PREDICTIONS

This annex presents information on the height of a chlorine cloud which has been obtained from the wind tunnel testing, CFD modelling and DRIFT flat terrain dispersion modelling. This is important for determining the impact on populations within high rise buildings.

Wind tunnel testing 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. 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.

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 this study was DRIFT (Webber et al, 1992). 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.

Table E1 below summarises the data obtained from the wind tunnel testing, CFD and DRIFT modelling on the chlorine cloud height.

Table E1 Chlorine Cloud Height Predictions

Release case	**Chlorine cloud height (m) at LD03 distance(1)**					
	Wind tunnel(2)		CFD(3)		DRIFT	
1.4 kg/s continuous	30(4)	(D2)	60/60	(D2)	7	(D2)
	-	(D5)	-	(D5)	5.5	(D5)
	-	(F2)	20/30	(F2)	-	(F2)
1 tonne instantaneous	4(5)	(D2)	20/30	(D2)	6.5	(D2)
	4(6)	(D5)	-	(D5)	8.5	(D5)
	-	(F2)	10/20	(F2)	4	(F2)
3 tonnes instantaneous	-		-		10(7)	(D2)
					12.5(8)	(D5)
					-	(F2)
10 tonnes instantaneous	-		-		12(9)	(D2)
					20(10)	(D5)
					-	(F2)

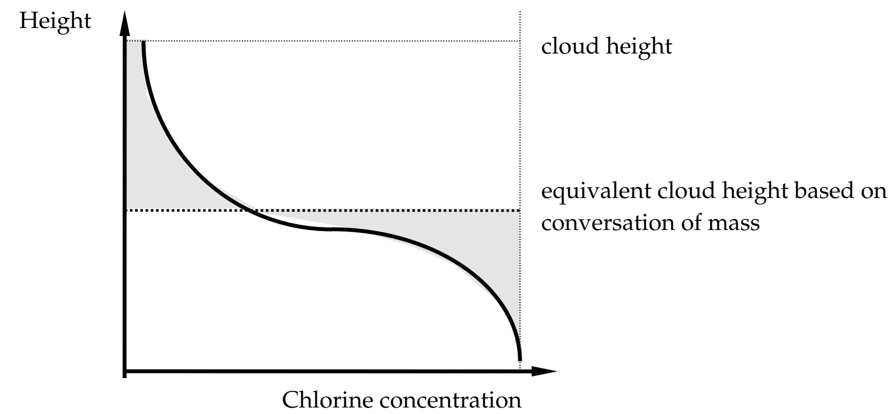
(1) The data given relates to the chlorine cloud height at the maximum horizontal distance to the LD03 (Lethal Dose - 3% fatality) concentration. 'Height' refers to the height at which the chlorine concentration falls to negligible levels, ie <5% of the ground level concentration (unless otherwise stated).
(2) Results are for Sha Tin WTW, measured at nearest block of Hin Keng Estate
(3) Results are for Sha Tin WTW/Tai Po Tau WTW

(4) Estimate by RWDI for cloud height at LD03 distance based on conservation of mass
(5) Height at which concentration drops to 1/2 of ground level concentration
(6) Height at which concentration drops to 1/6th of ground level concentration
(7) Cloud height is 10 metres at LD03 distance and 6 metres at LD50 distance (D2)
(8) Cloud height is 12.5 metres at LD03 distance and 8 metres at LD50 distance (D5)
(9) Cloud height is 12 metres at LD03 distance and 9 metres at LD50 distance (D2)
(10) Cloud height is 20 metres at LD03 distance and 11 metres at LD50 distance (D5)

Continuous Releases

As detailed in *Section 4.2.2* of the main report, the CFD modelling has been used to set the downwind extent of the chlorine hazard range for the 1.4 kg/s continuous release case. Therefore the corresponding value of the chlorine cloud height from the CFD modelling has also been used in the QRA. From *Table E1* it can be seen that the predicted cloud height is 60m, which is the height at which the chlorine concentration drops to negligible levels. However for the purposes of the QRA, the parameter required is the equivalent height of the chlorine cloud based on conservation of mass (to ensure a realistic assessment of fatalities in high rise buildings). The relationship between these two values is illustrated in *Figure E1* below. The equivalent chlorine cloud height is estimated conservatively as 30m, assuming that the chlorine concentration is inversely proportional to cloud height . (In reality the chlorine concentration drops off more rapidly with height and therefore the equivalent cloud height would be less than 30m).

Figure E1 Estimation of Equivalent Chlorine Cloud Height



Instantaneous Releases

For instantaneous releases the wind tunnel LD contours are used in the QRA. However only a limited number of measurements of chlorine cloud height are available from the wind tunnel simulations, indicating a cloud height of around 4m for a 1 tonne instantaneous release (*Table E1*). Consideration has therefore also been given to the cloud height predictions from the DRIFT simulations. These indicate a cloud height of 4 - 8.5m for a 1 tonne instantaneous release. Based on this data, a cloud height of 6m will be assumed for a 1 tonne instantaneous release.

For a 10 tonne instantaneous release a cloud height of 9m will be assumed based on the cloud height predicted by DRIFT at the LD50 distance for D2 weather conditions - see Note (9) to *Table E1*. This is considered to be more representative of the average height of the cloud over the range of chlorine concentrations of interest (LD03 - LD90) than taking the cloud height at LD03.

For instantaneous chlorine releases between 3 and 10 tonnes (or in excess of 10 tonnes), linear interpolation (or extrapolation) of the chlorine cloud height has been performed, but rounding the value thus obtained up to the nearest number of equivalent building storeys. The calculations assume 3m per storey.

Annex F

Definition of Time Periods and Population Scaling Factors

F1 DEFINITION OF TIME PERIODS

The population data is presented in five time periods within a week: night, jammed peak, peak, weekend day and working day. The classification of the time periods is shown in *Table F1*. The frequency of events occurring at a certain time period is calculated by multiplying the time period percentage shown in *Table F1* and the event frequencies (listed in *Table 5.5* of the *Main Report*). For events related to transport of chlorine, which does not take place at night, the frequency at any other time periods is calculated by doubling the corresponding time period percentages.

Table F1 ***Definition of Time Periods***

From	To	Mon-Fri	Sat	Sun	
00:00	01:00	Night	Night	Night	
01:00	02:00	Night	Night	Night	
02:00	03:00	Night	Night	Night	
03:00	04:00	Night	Night	Night	
04:00	05:00	Night	Night	Night	
05:00	06:00	Night	Night	Night	
06:00	07:00	Night	Night	Night	
07:00	08:00	Peak	Peak	Weekend day	
08:00	08:15	Jammed Peak	Jammed Peak	Weekend day	
08:15	09:00	Peak	Peak	Weekend day	
09:00	10:00	Working day	Working day	Weekend day	
10:00	11:00	Working day	Working day	Weekend day	
11:00	12:00	Working day	Working day	Weekend day	
12:00	13:00	Working day	Working day	Weekend day	
13:00	15:00	Working day	Peak	Weekend day	
15:00	16:00	Working day	Weekend day	Weekend day	
16:00	17:00	Working day	Weekend day	Weekend day	
17:00	19:00	Peak	Weekend day	Weekend day	
19:00	20:00	Night	Night	Night	
20:00	21:00	Night	Night	Night	
21:00	22:00	Night	Night	Night	
22:00	23:00	Night	Night	Night	
23:00	00:00	Night	Night	Night	
Days		5	1	1	
Peak	(hours)	18.75	3.75	0	13.39%
Jammed Peak		1.25	0.25	0	0.89%
Working day		40	4	0	26.19%
Weekend day		0	4	12	9.52%
Night		60	12	12	50.00%

F2 POPULATION FORECAST – DEFINITION OF SCALING FACTORS

It has been assumed that in the Consultation Zone there is no space available for further residential development, the residential populations are therefore assumed at their 2006 levels.

Outside the Consultation Zone, the 2006 residential population levels have been scaled up or down according to the population trends determined from the area-specific TPEDM PVS-based projections.

For population types other than residential, no growth has been assumed. TPEDM data included average household size for the years 2006, 2011, 2016 and 2031.

Table F2 provides the scaling factors for different PVSs.

Table F2 ***Population Data from TPEDM by PVS***

PVS	2006	2011	2016	Scaling factor 2014/2006	Scaling factor 2016/2006	2031	Scaling factor 2031/2006
205	35175	36 607	39 632	1.08	1.13	38 531	1.10
206	12233	11 819	11 370	0.95	0.93	11 271	0.92
208	17527	16 459	15 462	0.91	0.88	15 715	0.90
209(*)	30711	33 827	33 571	1.10	1.09	32 462	1.06
210	30338	28 318	33 760	1.02	1.11	33 443	1.10
211	25372	25 493	25 986	1.01	1.02	25 042	0.99
212	49103	47 661	65 088	1.15	1.33	62 454	1.27
384	6491	11 676	11 249	1.77	1.73	11 817	1.82
385	33928	35 139	35 151	1.04	1.04	33 783	1.00

Note: since the future population of Unit 17A (the new development in the Tai Wai MTR Depot area) which is estimated at 6107, is specifically included in the QRA, for the purposes of population scaling, its population has been subtracted from the 2014, 2016 and 2031 totals of the PVS 209.

For the year 2014, values from TPEDM were not available. The scaling factors were therefore interpolated using the values available for 2011 and 2016.

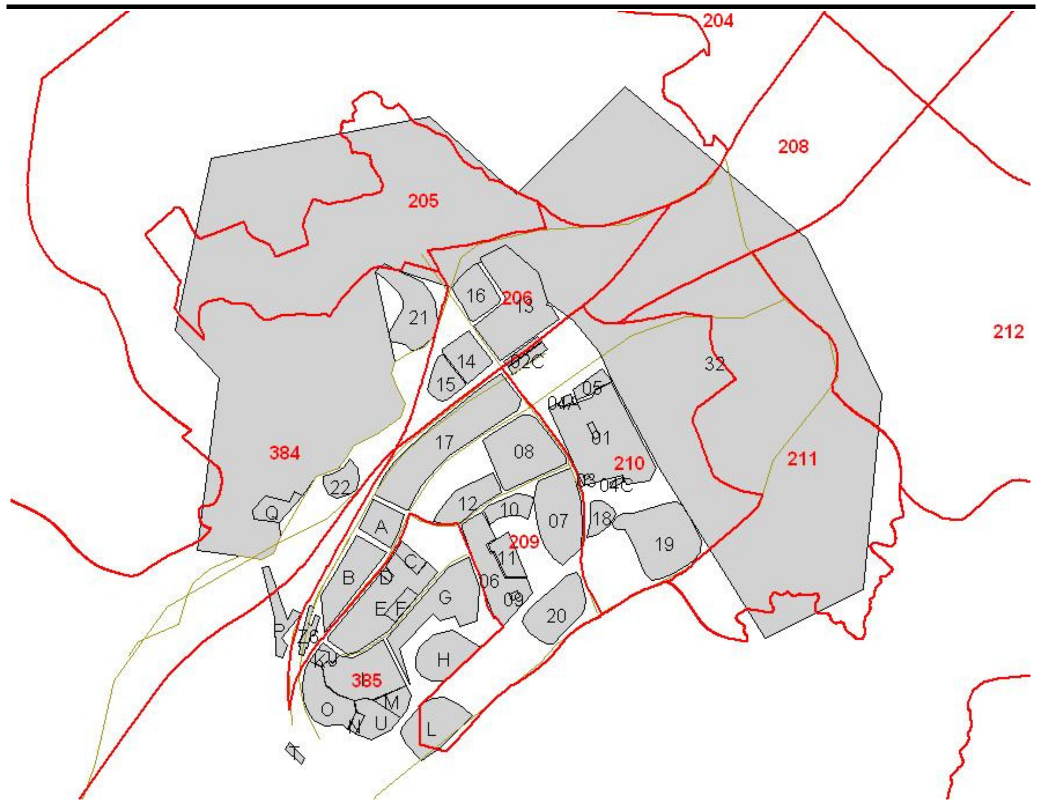
Each population was then scaled according to the PVS where it is located. The locations of relevant PVS areas are shown *Figure F1. Table F3* shows the residential population units outside the STWTW Consultation Zone that are associated with each PVS. For the exact locations of the population units see *Figure 2.5* of the *Main Report*.

As can be seen, only the population unit 32 spreads across several PVSs. In this case the scaling factor has been evaluated considering the different areas that the population unit 32 overlaps.

Table F3 ***PVS Scaling Factors Used for Residential Population Units***

Residential population unit	PVS scaling factor used
1	210
6	209
7	209
8	209
12	209
13	206
14	206
17A	209
18	210
19	210
20	209
21	384
22	384
32	Average of 205, 206, 208, 210, 211, 212, 384

Figure F1 ***Locations of PVS areas***



Note: the grey polygons represent the population units considered in the QRA. For their full description see *Table 2.3* and *Figure 2.5* of the *Main Report*.

Annex G

Seismic Hazard Assessment

SEISMIC HAZARD ASSESSMENT

Introduction

This annex presents a summary of the Seismic Hazard Assessment for the eight WTWs which was undertaken by Ove Arup (2001). The following paragraphs summarise the work which has been undertaken and the application of the results of the Seismic Hazard Assessment in the QRA.

Scope of Work

The work undertaken by Ove Arup investigated the seismic vulnerability of the chlorine stores at the eight WTWs and advised on the magnitude of earthquake necessary to cause varying levels of damage, from relatively minor, 'internal' damage to gross collapse of the store. The focus of the work was on the consequences of earthquakes in terms of the potential release of chlorine, whereas the likelihood of an earthquake of a given magnitude was derived from the *Daya Bay Risk Assessment* study (Cook et al, 1993), which has been used in past Hazard Assessment studies of WTWs in Hong Kong. Apart from advising on the likely damage to the chlorine stores at the eight WTWs, part of Ove Arup's scope of work was also to advise on the likely levels of damage to the general building stock in Hong Kong. This assists in determining the marginal impact of an earthquake on the surrounding population.

Methodology

The methodology for the Seismic Hazard Assessment involved:

- qualitative evaluation of the seismic vulnerability of the chlorine stores against the Federal Emergency Management Agency (FEMA 273) 'checklist';
- review of damage surveys from earthquakes around the world (including assessment of their relevance to structures in Hong Kong); and
- modelling of the dynamics of objects impacting chlorine containers.

Key Findings of Seismic Hazard Assessment

The key findings of the Seismic Hazard Assessment are as follows:

- the outcome of a earthquake of a given magnitude is probabilistic in nature rather than deterministic and graphs have been provided by Ove Arup (derived from historical data) which can be used to determine the probability of a given level of damage for an earthquake of a given magnitude (*Figure G1*);

- the chlorine stores at the eight WTWs may be divided into three groups, according to their vulnerability to seismic loading:

  - *Group 1* (Sha Tin, Pak Kong, Au Tau) being the least vulnerable and ranking amongst the best buildings in Hong Kong;

  - *Group 2* (Sheung Shui and Yau Kom Tau) being of average vulnerability but above average when compared to the general building stock (equivalent to high rise buildings of more than 20 storeys); and

  - *Group 3* (Tuen Mun, Tsuen Wan and Tai Po Tau) being the most vulnerable, equivalent to the average vulnerability of the general building stock in Hong Kong (ie low rise buildings up to 10 storeys in height).

- there is no 'partial' failure mode of the chlorine buildings, ie due to their nature of construction (reinforced concrete) they will either fail catastrophically or not at all;

- the magnitude of earthquake required to cause gross collapse of the chlorine stores is large, eg for a probability of collapse of 50%, the required magnitudes of earthquake (peak ground acceleration) are 1.0g/MMXII (*Group 1* WTWs), 0.80g/MMXI-XII (*Group 2* WTWs) and 0.60g/MMX-XI (*Group 3* WTWs);

- the potential consequences of a roof collapse are severe due to the heavy construction of the roofs at the eight WTWs (roof slabs are typically 200mm thick and roof support beams typically 300mmx500mm in cross section). The predicted number of drums which would fail catastrophically is typically 10-100, depending on the WTW under consideration.

Modelling of Seismic Hazards in the QRA

The assessment of seismic hazards in the QRA for Sha Tin WTW focuses on earthquakes which could cause roof collapse leading to multiple catastrophic failure of chlorine drums. Two magnitudes of earthquake are considered: 0.7g/MMXI (10% chance of roof collapse) and 1.0g/MMXII (50% chance of roof collapse) as shown in *Figure G1* (Ove Arup, 2001). The lower level of earthquake (0.4g/MMIX) which could cause the crane to come off its rails and split a drum is not considered significant because the release would be contained within the chlorine building (the infill walls at Sha Tin are of reinforced concrete construction).

Within the QRA two key aspects are modelled:

- *the impact of the earthquake on the chlorine store*, in terms of the probability of roof collapse, probability of damage to chlorine containers and number of containers failing; and
- *the impact of the earthquake on the buildings surrounding each WTW*, in terms of the % of buildings of different types which would be expected to fail (this information is used to estimate the number of direct fatalities due to the earthquake, hence the surviving fraction which could be exposed to the

chlorine release). Note that the earthquake-surviving fraction of the population of the elevated Hin Keng Station (population unit Z6) which, due to the open character of the station is considered in this QRA as basically outdoors, is estimated in the same way as indoor population of other buildings.

Figure G2 summarises the modelling of seismic hazards in the QRA for Sha Tin WTW in the form of an event tree showing the various outcomes of earthquakes of magnitude 0.7g (MMXI) and 1.0g (MMXII).

In *Figure G2* the 'surviving fraction of the indoor population' calculated in the last column is used to modify the population data (*Table 2.3* of the main text of the report), so that only the *additional* fatalities due to the chlorine release are assessed. For outdoor populations within high-rise, urban areas a fraction (50%) of the outdoor population is also assumed to suffer direct fatality due the earthquake, ie through falling masonry.

A summary of the drum impact assessment for Shatin WTW is shown in *Table G1* below:

Table G1 ***Evaluation of the Damage to the Chlorine Containers for Collapse of Building Structures***

Site Name	**Sha Tin**	
Minimum number of drums ruptured	35	(25)
Intermediate number of drums ruptured	40	(25)
Maximum number of drums ruptured	47	(50)
Weighted average	42	

Note 1: Likelihood (%) of effect

The number of drums ruptured in scenarios where the storage is reduced from 223 tonnes to a lower level is obtained by reducing 42 (number of drums ruptured for the case of 223 tonnes storage) in proportion to the reduced storage level. This is because the according to Ove Arup (2001) the roof beams do not necessarily fall on the drums in predicted ways, but may impact drums located anywhere within several m (the storey height, ie 5.5 m) from the original location of the beam. Since in case of the STWTW chlorine store the distance between the drum racks and the drums themselves is lower than the storey height and the maximum roof beam displacement distance, it can be concluded that in a case of reduced storage no particular layout of the chlorine drums with regard to the roof beam location could reduce the probability of drum failure. Thus, the drum failure pattern is basically random, and the number of drum failures is proportional to the total number of drums in store seems reasonable. Note that results of a recent detailed seismic analysis for two storage levels in a CCPHI-approved Hazard Assessment for Tai Po WTW[1] have also shown that the number of drum failures in a roof collapse scenario is proportional to the assumed storage level.

[1]Expansion of Tai Po Water Treatment Works Investigation Study: Hazard Assessment, ERM Report to Black&Veatch, February 2009

Figure G1 Building Seismic Vulnerability (Figure8.1 of Ove Arup, 2001)

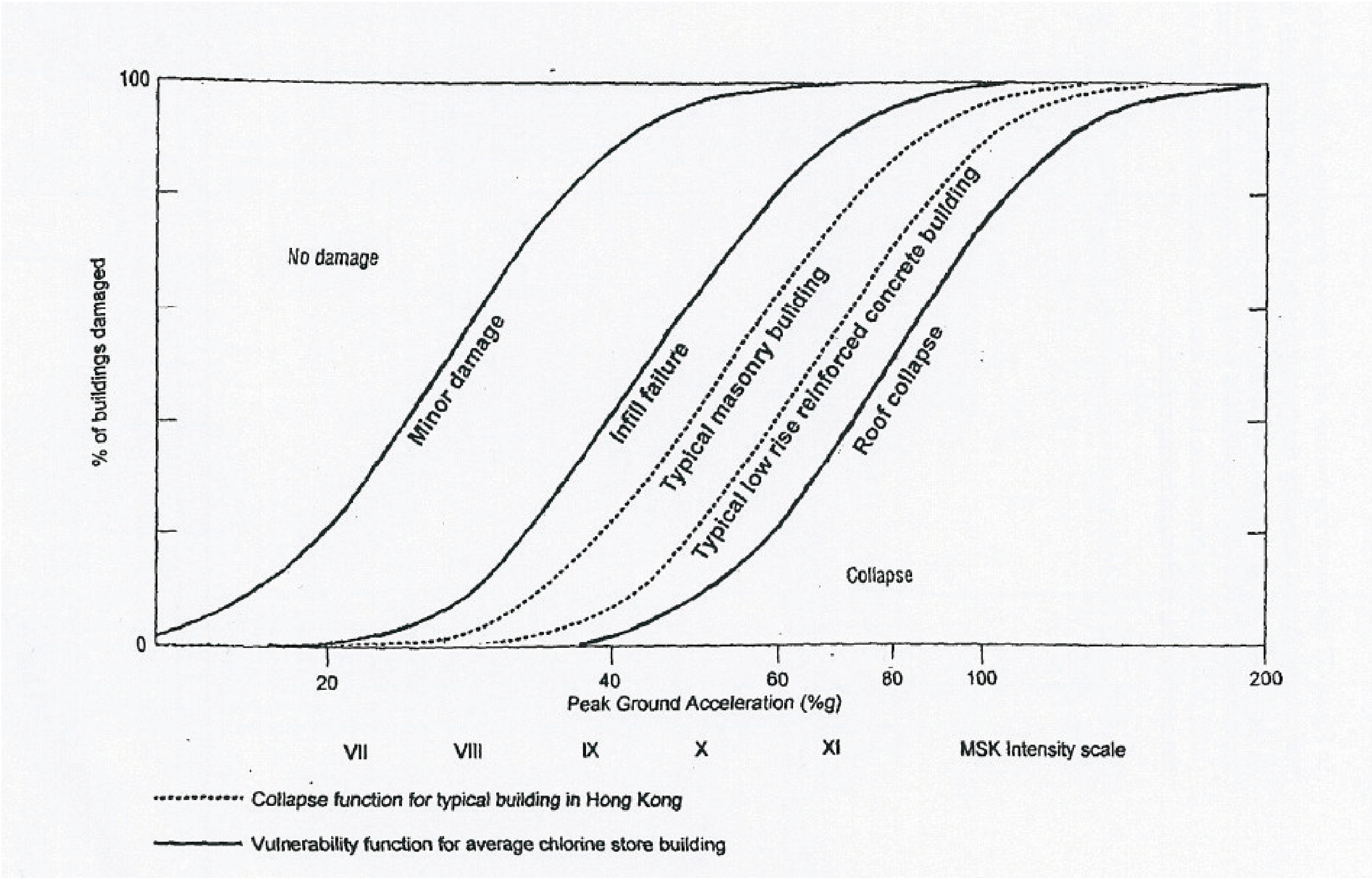


Figure G2: Event Tree for Assessment of Seismic Hazards (Sha Tin WTW)

			Outcome (Chlorine store)			**Outcome (Buildings near Sha Tin WTW)**		
Magnitude of earthquake	Frequency (per year) (Note 1)	Roof collapse ? (Note 2)	Number of containers failing (Note 3)	Probability (Note 3)	Frequency (per year)	Percentage of buildings damaged and associated level of damage (from *Figure 8.1* in Ove Arup, 2001) (Note 4)	Probability of fatality (Note 5)	Surviving percentage of population (Note 6)
0.7g	4.0E-07	Y (p = 0.1)	42	1.0	4.0E-08	60 % (collapse)	0.95	23%
						40 % (partial damage)	0.5	
		N	Not significant					
1.0g	2.5E-08	Y (p = 0.5)	42	1.0	1.3E-08	90 % (collapse)	0.95	10%
						10 % (partial damage)	0.5	
		N	Not significant					

Note 1: from *Daya Bay Risk Assessment* (Cook, et al, 1993)
Note 2: probabilities of roof collapse from Ove Arup (2001)
Note 3: number of drums failing and associated probability from Ove Arup (2001) but simplified to a single outcome with 42 drums failing
Note 4: reference curve in *Figure 8.1*of Ove Arup (2001) is that for typical low rise reinforced concrete buildings (ie up to 10 storeys), which is considered to represent average of buildings around Sha Tin WTW
Note 5: probability of fatality for total collapse of a building estimated to be 95% and for partial damage 50%
Note 6: % surviving population = 1 - [% of buildings collapsing x p(fatality due to collapse) + % of buildings partially damaged x p(fatality due to partial damage)]