12 LANDFILL GAS HAZARD ASSESSMENT

12.1 Introduction

12.1.1 Procedures and Guidelines

Landfill Gas Hazard Assessment Guidance Note (hereinafter referred to as *Guidance Note*) for the assessment of the hazards which landfill gas may present to developments close to landfills has been published by the EPD of the Government of the Hong Kong SAR. This provides an assessment framework to be followed when evaluating the risks related to developments described under *Section 6.5*, *Chapter 9* of the *Hong Kong Planning Standards and Guidelines*. The *Guidance Note* applies to all developments proposed within 250m of the edge of a landfill site, known as the landfill Consultation Zone. Part of the desalination plant and the indicative area of natural slope mitigation works fall within the SENT Landfill Extension Consultation Zone; and part of the 1,200 mm diameter fresh water mains along Wan Po Road falls within the SENT Landfill and SENT Landfill Extension Consultation Zones, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill Consultation Zones (see ***Figure 12.1***). Thus a Qualitative Landfill Gas Hazard Assessment (QLGHA) must be carried out.

12.1.2 Previous Studies Undertaken at the Site

A number of previous studies have been undertaken at, or involving, the SENT Landfill, SENT Landfill Extension, TKO Stage II/ III Restored Landfill and TKO Stage I Restored Landfill. The documents which have been used as background materials for the preparation of this assessment include the following:

- *Environmental Review for Extension of Fill Bank Operation at TKO Area 137,* ERM-Hong Kong, 2013;
- *SENT Landfill Annual Environmental Audit,* ERM-Hong Kong, 2013;
- *Environmental Review of the Revised Scheme of SENT Landfill Extension,* ERM-Hong Kong, 2011;
- *SENT Landfill Extension EI A,* ERM-Hong Kong, 2008;
- *Qualitative Landfill Gas Hazard Assessment for TVB City,* ERM-Hong Kong, 2004;
- *Environmental Review of Urban Landfills and TKO Landfills – Feasibility Study,* ERM-Hong Kong, 2003;
- *TKO Area 86, Wan Po Road Substation: Qualitative Landfill Gas Hazard Assessment,* ERM-Hong Kong, 2001;
- *MTR TKO Extension Phase II EIA – TKO Stage I Landfill Qualitative Landfill Gas and Leachate Hazard Assessment*, ERM-Hong Kong, 1998;
- *Restoration of TKO Landfills: Detailed EIA,* ERM-Hong Kong, 1997;

- *MTR TKO Extension Phase II EIA,* ERM-Hong Kong, 1997; and
- *Landfill Gas Hazard Assessment Guidance Note,* EPD, 1997.

The EPD has also provided the landfill gas and groundwater monitoring data for the SENT Landfill covering the period from January 2013 to June 2014 and March 2013 to March 2014, respectively; and the TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill covering the period from January 2013 to May 2014 and January 2013 to April 2014, respectively.

12.1.3 Scope of this section

The following tasks have been undertaken as part of this section:

- review of background information and studies related to the SENT Landfill, SENT Landfill Extension, TKO Stage II/ III Restored Landfill and TKO Stage I Restored Landfill;
- identification and investigation of the sources of landfill gas and leachate which have the potential to affect the development from both desktop studies and the previous monitoring conducted at the landfill boundary;
- identification of viable pathway through the ground, underground cavities, utilities or groundwater and the conditions of these pathways through which the landfill gas must pass if they are to reach the development;
- review of the Project design and identification of elements which are sensitive to the effects of landfill gas during construction and subsequent operation;
- qualitative assessment of the degree of risk which landfill gas pose to the development taking account of each source-pathway-target combination; and
- recommendation of protection and precautionary measures (if required) to minimise any risks due to landfill gas and leachate hazards during the construction and operation of the development.

12.1.4 Section Structure

The remaining section is structured as follows:

- *Section 12.2* describes the QLGHA methodology and the framework within which the identified levels of risk may be compared;
- *Section 12.3* describes the SENT Landfill, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill, including its history and the engineering measures taken to control landfill gas and leachate as well as the completed restoration works;

- *Section 12.4* describes the Project design and reviews the sensitivity of key elements of the development to the possible presence of landfill gas and leachate;

- *Section 12.5* reviews the geology and hydrology of the area and evaluates the potential pathways through which landfill gas and leachate may impact the development;

- *Section 12.6* evaluates the qualitative risk of landfill gas and leachate to impact the development; and

- *Section 12.7* provides recommendations for precautionary and protection measures to be adopted during the construction and operation of the development based on the findings of the hazard assessment.

12.2 Landfill Gas Risk Assessment Methodology

12.2.1 Landfill Gas Assessment Criteria and Methodology

a) General

In accordance with the *Guidance Note*, the risk due to landfill gas may be evaluated based upon the following three criteria:

- Source – the rate and concentration of gas generation by the landfill;

- Pathway – the nature of and length of potential pathways through which landfill gas can migrate and leachate flow, such as geological strata, utility services; and

- Target – the level of vulnerability of various elements of the development to landfill gas.

Each of these criteria is further described in the sub-sections below.

b) Source

The classification of the Source (ie the landfill) should be undertaken as follows:

Major

- Recently filled landfill site at which there is little or no control to prevent migration of gas or at which the efficacy of the gas control measures has not been assessed; or

- Any landfill site at which monitoring has demonstrated that there is significant migration of gas beyond the site boundary.

Medium

- Landfill site at which some form of gas control has been installed (eg lined site or one where vents or barriers have been retrospectively installed) but where there are only limited monitoring data to demonstrate its efficacy to prevent migration of gas; or

- Landfill site where comprehensive monitoring has demonstrated that there is no migration of gas beyond the landfill boundary but where the control of gas relies solely on an active gas extraction system or any other single control system which is vulnerable to failure.

Minor

- Landfill sites at which gas controls have been installed and proven to be effective by comprehensive monitoring which has demonstrated that there is no migration of gas beyond the landfill boundary (or any specific control measures) and at which control of gas does not rely solely on an active gas extraction system or any other single control measure which is vulnerable to failure; or

- Old landfill sites where the maximum concentration of methane within the waste, as measured at several locations across the landfill and on at least four occasions over a period of at least 3 months (preferably longer), is less than 5 % by volume (v/v).

c) Pathway

Generally, three types of pathway are considered for the transmission of landfill gas. They are:

- Man-made pathways, e.g. utility connections, stormwater channels, etc.;

- Natural pathways such as rock jointing planes, fissures and other naturally occurring phenomena which may promote or give rise to the transmission of gas over distances; and

- A combination of the previous two categories. An example of the latter may be, for instance, where a specific geological feature promotes gas transmission but which stops short of directly linking the landfill and target. A man-made connection, however, may also co-exist near the edge of the geological feature, which in combination with the former, may act to link the two sites. In this instance, careful assessment of the likelihood of the mechanism acting to link the two pathways needs to be undertaken before assigning an appropriate pathway classification.

The broad classification of a Pathway is as follows:

Very short/ direct	Path length of less than 50 m for unsaturated permeable strata and fissured rock or less than 100m for man-made conduits.
Moderately short/ direct	Path length of 50-100 m for unsaturated permeable soil or fissured rock or 100-250 m for man-made conduits.
Long/ indirect	Path length of 100-250 m for unsaturated permeable soils and fissured rock.

In classifying the pathway, however, adjustment to the above general guidelines will often be required to take account of other factors which will affect the extent of gas migration including the following:

- a broad assessment of the specific permeability of the soil;
- spacing, tightness and direction of the fissures/ joints;
- topography;
- depth and thickness of the medium through which the gas may migrate (which may be affected by groundwater level);
- nature of the strata over the potential pathway;
- number of different media involved; and
- depth to groundwater table and groundwater flow patterns.

d) Target

Different levels of vulnerability or sensitivity of potential Targets for landfill gas have been classified as follows:

High Sensitivity

- Buildings and structures with ground level or below ground rooms/ voids or into which services enter directly from the ground and to which members of the general public have unrestricted access or which contain sources of ignition.
- This would include any developments where there is a possibility of additional structures being erected directly on the ground on an *ad hoc* basis and thereby without due regard to the potential risks.

Medium Sensitivity

- Other buildings, structures or service voids where there is access only by authorised, well trained personnel, such as the staff of utility companies, who have been briefed on the potential hazards relating to landfill gas and the specific safety procedures to be followed.
- Deep excavations.

Low Sensitivity

- Buildings/ structures which are less prone to gas ingress by virtue of their design (such as those with a raised floor slab).
- Shallow excavations.
- Developments which involve essentially outdoor activities but where evolution of gas can pose potential problems.

The above examples of different categories within each criterion are to be used as a general guide only and specific aspects of a development may render it more or less sensitive than indicated. Account needs to be taken of any particular circumstances when assigning a target to one of three indicated categories.

e) Assessment of Risk Criteria

Following the determination of the categories of source, pathway and target in which the landfill, pathway and development fall, a qualitative assessment of the overall risk may be made by reference to ***Table 12.1*** which is extracted from the *Guidance Note*. The potential implications associated with the various qualitative risk categories are summarised in

Table 12.2 below. It should be noted that the different levels of risk determine the likely extent of the protection measures required to ensure the safety of a development, but with the possible exception of the very risk category, development is not precluded for any of the assessed levels of risk.

Table 12.1 Classification of Risk Category

Source	Pathway	Target Sensitivity	Risk Category
Major	Very short/direct	High	Very high
		Medium	High
		Low	Medium
	Moderately short/ direct	High	High
		Medium	Medium
		Low	Low
	Long/ indirect	High	High
		Medium	Medium
		Low	Low
Medium	Very short/direct	High	High
		Medium	Medium
		Low	Low
	Moderately short/ direct	High	High
		Medium	Medium
		Low	Low
	Long/ indirect	High	Medium
		Medium	Low
		Low	Very low
Minor	Very short/ direct	High	High
		Medium	Medium
		Low	Low
	Moderately short/ direct	High	Medium
		Medium	Low
		Low	Very low
	Long/ indirect	High	Medium
		Medium	Low
		Low	Very low

Table 12.2 Summary of General Categorisation of Risk

Level of Risk	Implication
Very high	At the very least, extensive engineering measures and alarm systems are likely to be required. An emergency actions plan should also be developed so that appropriate actions may be immediately taken in the event of high gas concentrations being detected within the development.
High	Significant engineering measures will be required to protect the planned development.
Medium	Engineering measures required to protect the development.
Low	Some precautionary measures will be required to ensure that the planned development is safe.
Very low	No protection or precautionary measures are required.

12.3 Nature of the SENT Landfill and TKO Stage II/III and I Restored Landfills

12.3.1 Landfill History

a) SENT Landfill

SENT Landfill is located on the western edge of Clear Water Bay Peninsula in the south-eastern corner of the New Territories (refers to ***Figure 12.1***). The site covers an area of about 100 ha, half of which has been reclaimed from Shek Biu Wan (Junk Bay). To the north and east of the landfill lies Clear Water Bay Country Park; to the west lies reclaimed as industrial estate next to the Wan Po Road (where part of the fresh water mains is located); and to the south reclamation (TKO Area 137 where the desalination plant is located).

The landfill is one of three strategic landfills in operation in Hong Kong and was designed to receive approximately 40 million tonnes of waste over a period initially projected as 15 to 17 years. The landfill commenced operation in 1995 and accepts domestic, commercial and industrial (C&I), construction and demolition, chemical and clinical wastes, dewatered sewage sludge and stablised incineration residues.

b) TKO Stage II/III Restored Landfill

TKO Stage II/III Restored Landfill is located at approximately 0.5 km to the north of the SENT Landfill and 1 km to the south of the TKO Stage I Restored Landfill (refers to ***Figure 12.1***). TKO Stage II/III Restored Landfill received waste from 1988 to 1994. A total of approximately 12.6 million tonnes of domestic, C&I, construction, chemical, clinical and special wastes were landfilled. The landfill was constructed in a reclaimed bay, the boundary being defined by hills on three sides. The maximum waste depth is about 90 m and the landfill covers an area of 42 hectares.

c) TKO Stage I Restored Landfill

TKOL Stage I Restored Landfill is located at the southeast of the TKO New Town. To the east of the landfill is Wan Po Road (refers to ***Figure 12.1***). TKO Stage I Restored Landfill received waste from 1978 to 1990 and from 1992 to 1995. A total of approximately 15.2 million tonnes of domestic, C&I, construction, chemical, clinical and special wastes were landfilled. The landfill was reclaimed from the sea and functioned

as a "disperse-and-attenuate" site, with wastes being deposited above the marine mud. The finished landfill is dome-shaped, covering a base area of 68 hectares with a maximum waste depth of about 70m.

12.3.2 Historical and Existing Landfill Gas Control

a) SENT Landfill

The landfill has been designed to incorporate extensive measures to obtain, collect and treat/ utilise landfill gas. Such measures include the state-of-the-art technologies (including a composite liner systems, active landfill gas extraction and landfill gas treatment and utilisation) in accordance with international best practices for landfill operations. Presently a skid mounted mobile flare unit with an electrically driven blower is utilised to extract and flare gas in a 'candlestick' type flare. It is deployed to extract from a number of temporary gas wells and collectors beneath 'green liner' of the landfill. In addition, the landfill contractor is undertaking routine maintenance and checking of the landfill gas extraction system to ensure it is operating satisfactorily. As the landfill is lined and landfill gas is collected and treated, it effectively controls sub-surface off-site migration of landfill gas. Typical details of the composite liner system (including an impermeable liner) installed at the SENT Landfill are presented in ***Figure 12.2***.

A comprehensive environmental monitoring programme has been implemented to monitor landfill gas generated within the landfill and at the perimeter boreholes around the landfill (refers to ***Figure 12.3***). Under the existing contract, the landfill contractor will be required to continue the control and monitoring of landfill gas following closure of the landfill for a period of 30 years.

b) TKO Stage II/III Landfill and TKO Stage I Landfill

Before restoration, the TKO Stage I Landfill was not lined and no leachate or gas abstraction systems were installed during the landfill construction; and the TKO Stage II/III Landfill was originally not fully lined and no leachate or gas abstraction system was installed during the landfill operation.

12.3.3 Historical and Existing Leachate Control

a) SENT Landfill

A comprehensive environmental monitoring programme has been implemented to monitor the levels of leachate within the landfill, off-site leachate migration/ groundwater contamination and concentration of landfill gas at the perimeter boreholes around the landfill. As the landfill is lined and leachate is extracted for treatment, the leachate head within the landfill is minimised.

a) TKO Stage II/III Landfill and TKO Stage I Landfill

During the development of both TKO Stage II/III Landfill and TKO Stage I Restored Landfill, no measure was implemented to achieve the collection of leachate from beneath the waste.

12.3.4 Extension of the SENT Landfill

a) General

The EIA Report (AEIAR-117/2008) for the SENT Landfill Extension was approved under the *EIA Ordinance (EIAO)* in May 2008 and an Environmental Permit (EP-308/2008) was granted on 15 August 2008. Since then, the administration has decided to reduce the scale of the extension scheme assessed in the approval EIA Report, and the SENT Landfill Extension will only receive construction waste. Thus an Environmental Review was undertaken in 2011 to address the findings of the approved EIA Report as a result of the changes to the SENT Landfill Extension and a Variation of an Environmental Permit (EP-308/2008/A) was granted on 6 January 2012.

The SENT Landfill Extension with a void space of about 6.5 million m^3 will occupy 13 hectares in part of the TKO Area 137 and be located immediately to the south of the existing infrastructure area of the SENT Landfill (refers to ***Figure 12.1***).

The date of commencement is to be confirmed and the construction period of the SENT Landfill Extension is expected to take about 2 years.

b) Landfill Gas

Under the SENT Landfill Extension contract requirements, the contractor will be required to control off-site landfill gas migration such that the methane and carbon dioxide concentrations at the perimeter monitoring wells will not exceed 1% v/v and 1.5% v/v above the background levels, respectively. A landfill gas management system will be installed and operated. As presented in the approval EIA Report (AEIAR-117/2008), the SENT Landfill Extension was classified as a "medium" source taking into account the multiple landfill gas control measures to be installed, the recent landfill gas monitoring data of the SENT Landfill, and stringent contract requirements for controlling off-site landfill gas migration.

It is envisaged that construction waste (with high portion of inert materials) will generate significantly lower quantities of landfill gas than municipal solid waste and sludge. Thus, the quantity of landfill gas generated in the latest extension scheme is expected to be lower than that estimated in the approved EIA Report (AEIAR-117/2008). Nevertheless, landfill gas control measures will still be implemented to ensure that any landfill gas generated can be collected and treated in a controlled and safe manner.

12.3.5 Restoration of TKO Stage II/III Landfill

a) General

The TKO Stage II/III Landfill was subject to restoration works commissioned by the Government in 1997. A restoration works contract was awarded to a restoration contractor who designed and implemented a system of controls to achieve the contractual limits on environmental emissions and is responsible for the management of installed environmental control facilities and environmental impacts arising from the landfill for a period of 30 years following completion of the works.

b) Landfill Gas

The TKO Stage II/III Landfill was originally not fully lined and no leachate or gas abstraction system was installed during the landfill operation. The major restoration works regarding the management of landfill gas and leachate under the contract included:

- placing of a membrane over the waste;
- placing of soil above the membrane and the installation of a comprehensive surface water drainage system;
- installation of a landfill gas collection and abstraction system;
- utilisation of landfill gas abstracted;
- treatment of surplus landfill gas in a landfill gas flare; and,
- collection and storage of leachate and landfill gas condensate for treatment.

There are a total of 50 vertical wells were installed within the landfill to extract landfill gas.

c) Leachate

The leachate collected is pumped to the Leachate Pre-treatment Works (LPTW) at the landfill for treatment prior to be discharged to sewer leading to the TKO Sewage Treatment Works (TKOSTW).

Active groundwater control in the form of groundwater abstraction wells, were installed at TKO Stage II/III Restored Landfill, upstream of the waste boundary. The wells reduce the ingress of groundwater to the wastes and hence minimise leachate generation. Groundwater collected from groundwater extraction wells at TKOL-II/III is used in the LPTW and the excess groundwater is discharged to the stormwater drains.

Sixteen groundwater wells (DG1 to DG7, UG1 to UG9) were monitored quarterly throughout the aftercare period which is 30 years from the landfill restoration works completion date (refers to ***Figure 12.4***).

d) Status of the Restoration Works

The landfill restoration works were completed in February 1999. Monitoring and auditing of potential environmental impacts through landfill gas and leachate measurements around the perimeter of the site are currently ongoing. This monitoring will be continued until the end of the landfill aftercare period.

12.3.6 Restoration of TKO Stage I Landfill

a) General

The restoration works for TKO Stage I Landfill had been undertaken since 1997 under the same restoration works contract for TKO Stage II/III Landfill.

b) Landfill Gas

The major restoration works undertaken by the restoration contractor for TKO Stage I Landfill include those specified for TKO Stage II/III Restored Landfill. There are 49 vertical wells to extract landfill gas from the deeper parts of the site and 10 horizontal collectors to extract landfill gas from the shallower areas of waste and from beneath the afteruse platforms.

There is a landfill gas interception/venting trench, which was installed prior to the restoration contract, running along the southern perimeter of the landfill. Landfill gas intercepted by this trench is vented to atmosphere via passive vents.

A high-density polyethylene barrier and passive vent were also installed at the north-west of the site as part of the development of the former Hong Kong Oxygen site.

c) Leachate

The capping and surface water drainage systems installed at TKO Stage I Landfill have the effect of limiting the leachate generation rate. To reduce the leachate levels within the waste, leachate was also envisaged to be abstracted from on-site wells at the eastern edge of the landfill by pumping and temporarily held in an on-site storage facility. The leachate would then be collected by truck and tankered to the LPTW at the TKO Stage II/III Landfill for treatment.

Ten groundwater monitoring wells (DG1 to DG6, D113, D114, D115 and D120) were monitored quarterly throughout the aftercare period (refers to ***Figure 12.5***).

d) Status of the Restoration Works

The landfill restoration works were completed in February 1999. Monitoring and auditing of potential environmental impacts through landfill gas and leachate measurements around the perimeter of the site are currently ongoing. This monitoring will be continued until the end of the landfill aftercare period.

12.4 Proposed Desalination Plant and Fresh Water Mains

12.4.1 Location of Desalination Plant and Fresh Water Mains

As discussed in *Section 12.3*, the desalination plant is located in TKO Area 137 with a reserved site area of about 10 hectares. TKO Area 137 is located to the south of the SENT Landfill and the TKO Industrial Estate. About 9 km of 1,200 mm diameter fresh water mains will be laid along Wan Po Road, Po Hong Road and Tsui Lam Road. ***Figure 12.1*** indicates that part of the desalination plant and fresh water mains along the Wan Po Road lie within the SENT Landfill Consultation Zone, SENT Landfill

Extension Consultation Zone, TKO Stage I Restored Landfill Consultation Zone and TKO Stage II/III Restored Landfill Consultation Zone, respectively.

12.4.2 Description of Desalination Plant and Fresh Water Mains

a) Desalination Plant

Figure 12.11 (*Drawing No. 178901/B/PDR/40020*) shows the preliminary general layout plan and elevation plan of the desalination plant, respectively. The ground surface level of the desalination plant is at about +5.0 mPD. The desalination plant includes the following buildings:

- Incoming Switchgear Room;
- 132kV Substation;
- Sludge Filter Press Building;
- Sludge Thickener (I);
- Chlorine Store (I) & (II);
- Underground Clear Water Storage Tank (I);
- Chlorine Contact Tank (I);
- Post Treatment (I);
- Chemical Building;
- Maintenance Workshop;
- Reverse Osmosis Building (I) and Secondary Stage Media Filter (I);
- Clarifier - Dissolved Air Flotation (DAF) (I);
- First Stage Media Filters (I);
- Administrative Building and Laboratory;
- Intake Pumping Station;
- Standby Generator and Switchgear Room;
- Treated Water Pump Station and Switchroom (III); and
- Sodium Hypochlorite Storage Tank and Dosing Station.

The buildings located within the SENT Landfill Extension Consultation Zone are the Incoming Switchgear Room, 132 kV Substation, Treated Water Pump Station and Switchroom (III), Chlorine Contact Tank(I) & (II), Treated Water Tank and Standby

Generator and Switchgear Room (see ***Figure 12.10***). A brief description of these buildings is given below. Since parts of the TKO Area 137 are located within the existing SENT Landfill Consultation Zone and the new Landfill Consultation Zone of the Extension, the area that is not covered by the existing consultation zone is defined as Additional Area Covered by Consultation Zone in the figures.

Incoming Switchgear Room

The Incoming Switchgear Room is a single storey building located at the north-west corner of the Project Site. The room will be located on the ground floor with the provision of mechanical ventilation.

132 kV Substation

The 132 kV Substation has two storeys housing the 132 kV transformers. The substation is located at the north-west corner of the Project Site. The substation will be unmanned most of the time and most of the areas are open to the atmosphere.

Treated Water Pump Station and Switchroom (III)

The Treated Water Pump Station and Switchroom (III) is a two-storey building located at the north-east corner of the Project Site. Mechanical ventilation will be provided and the buildings will be unmanned most of the time.

Chlorine Contact Tank (I) & (II)

The Chlorine Contact Tank (I) & (II) are two single storey buildings housing the chlorine contact tanks, ventilation and scrubber systems. Mechanical ventilation will be provided and access to the building will be by authorisation.

Treated Water Tank

The Treated Water Tank is an open-air structure located between the Chlorine Contact Tank (I) & (II) and Treated Water Pump Station and Switchroom (III) along the northern boundary of the Project Site. The working area within the building is open to the atmosphere.

Standby Generator and Switchgear Room

The Standby Generator and Switchgear Room is a single storey building located next to the Incoming Switchgear Room and 132 kV Substation. There will be mechanical ventilation.

Table 12.3 provides a summary of the dimensions of the rooms of the abovementioned buildings and the ventilation design.

Table 12.3 Dimensions of the Rooms/ Buildings within the SENT Landfill Extension Consultation Zone and Ventilation Information

Item	Buildings	Floor Area (m^2)	Height (m)	Room Volume (m^3) (a)	Type of Ventilation	No. of Storey	Design Air Change Per Hour (ACH)
1	Incoming Switchgear Room	400	6	2,400	Mechanical Ventilation	1	5
2	132 kV Substation	486	16	7,776	Mechanical Ventilation	2	4-6
3	Treated Water Pump Station and Switchroom (III)	793	18	14,274	Mechanical Ventilation	2	4-6
4	Chlorine Contact Tank(I)	850	3	2,550	Mechanical Ventilation	1	4-6
5	Chlorine Contact Tank (II)	850	3	2,550	Mechanical Ventilation	1	4-6
6	Treated Water Tank (b)	500	2	N/A	N/A	1	N/A
7	Standby Generator and Switchgear Room	154	5	770	Mechanical Ventilation	1	4-6

Note:
(a) Room volume was calculated by multiplying the preliminary area and height of the structures.
(b) Treated Water Tank is an open-air structure.

b) Water Mains along

The DN1200 fresh water mains will transfer the fresh water output from the desalination plant to the TKOPFWSR. The water mains will be located at about 1.0 m - 1.5 m below ground level whilst part of it will be laid along the Wan Po Road.

12.4.3 Sensitive Receivers for Landfill Gas

The majority of areas in the 132 kV Substation and Treated Water Tank will be insensitive to the potential effects of landfill gas as they will be open to atmosphere; however, the Incoming Switchgear Room, Treated Water Pump Station and Switchroom (III), Standby Generator and Switchgear Room and Chlorine Contact Tank (I) & (II), which are enclosed, will have the potential to accumulate landfill gas. Nevertheless, these rooms/ buildings will be provided with mechanical ventilation to prevent the accumulation of landfill gas. The potential for landfill gas to reach the upper floors will be low.

Any utility pits and manholes along the underground fresh water mains within the landfill gas consultation zones are of high potential for ingress of landfill gas. However, the access to these areas will be rare and by authorised and well trained personnel only.

12.5 Potential for the Development to Intercept Landfill Gas

12.5.1 Geology and Hydrogeology

The desalination plant is located at the TKO Area 137, which was formed by public fill generated from construction projects in Hong Kong as it has been operating as a fill bank since 2002. The future final level of the desalination plant is at approximately +5.0 mPD. Based on records of the ground investigation undertaken as part of the *SENT Landfill Extension EIA*, the level of groundwater table is approximately at +2.8mPD, leaving an unsaturated layer of 2.2m. It is considered that this permeable layer between the SENT Landfill, the SENT Landfill Extension and the desalination plant must be conservatively considered as conducive to landfill gas migration.

Figure 12.1 and ***Figure 12.6*** *(Drawing No. 178901/B/EIA/64029(TEMP)),* ***Figure 12.7*** *(Drawing No. 178901/B/EIA/64028(TEMP)),* ***Figure 12.8*** *(Drawing No. Drawing No. 178901/B/EIA/64027(TEMP))* and ***Figure 12.9*** (Drawing *No. 178901/B/EIA/64026(TEMP))* show the cross-sections through the SENT Landfill Extension, SENT Landfill, TKO Stage II/ III Restored Landfill and TKO Stage I Restored Landfill, respectively, as well as the types and profiles of soils and groundwater tables. The lowest level of groundwater is approximately at + 1.5mPD at the Project Site and along Wan Po Road.

12.5.2 Overview of Results from Recent Monitoring

The EPD has provided the monitoring data for:

- the SENT Landfill monitoring wells covering the period from January 2013 to June 2014 and from March 2013 to March 2014 for landfill gas and groundwater, respectively;
- the TKO Stage II/III Restored Landfill monitoring wells covering the period from January 2013 to May 2014 and from January 2013 to April 2014 for landfill gas and groundwater, respectively; and
- the TKO Stage I Restored Landfill monitoring wells covering the period from January 2013 to May 2014 and from January 2013 to April 2014 for landfill gas and groundwater, respectively.

a) Landfill Gas

A number of landfill gas monitoring wells were installed and used to monitor off-site landfill gas migration for the SENT Landfill, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill. Recent landfill gas monitoring results of these wells are summarised in ***Table 12.4***, ***Table 12.5*** and ***Table 12.6***. Details of the monitoring results are presented in *Annex 12A*.

Table 12.4 Summary of Landfill Gas Monitoring Results of the SENT Landfill (From January 2013 to June 2014)

Location	Methane (% v/v)		Carbon Dioxide (% v/v)		Oxygen (% v/v)	
	Range	Average	Range	Average	Range	Average
Monitoring Wells along the Southern Boundary of the SENT Landfill						
P1	0.0 - 0.0	0.0	0.0 – 13.9	5.7	0.2 – 20.7	11.6
P2	0.0 - 0.0	0.0	0.0 - 9.9	6.0	1.1 - 20.7	10.5
P3	0.0 - 0.0	0.0	0.0 – 11.5	5.6	0.1 – 20.7	11.0
P4	0.0 - 0.0	0.0	0.1 – 20.4	12.3	0.0 – 20.5	3.8
P5	0.0 - 0.0	0.0	0.0 – 15.1	3.1	4.1 – 20.7	17.1
P6	0.0 - 0.0	0.0	0.2 – 1.5	0.8	19.3 – 20.6	19.9
GP9	0.0 - 0.0	0.0	0.3 – 9.0	4.5	1.5 – 20.4	14.0
GP10	0.0 - 0.0	0.0	3.9 – 11.7	8.7	0.1 – 19.0	11.8
GP11	0.0 - 0.0	0.0	0.1 – 16.8	6.3	4.9 - 20.7	15.0
GP12			Filled with Water			
Monitoring Wells along Wan Po Road						
P7	0.0 - 0.0	0.0	0.0 - 0.0	0.0	20.7	20.7
P8	0.0 - 0.0	0.0	0.0 - 0.1	0.0	20.5 – 20.7	20.7
P9	0.0 - 0.0	0.0	0.0 - 0.1	0.0	20.6 – 20.7	20.7
P10	0.0 - 0.0	0.0	0.0 - 0.3	0.0	20.3 – 20.7	20.6
P11	0.0 - 0.0	0.0	0.0 - 0.7	0.1	20.2 – 20.7	20.6
P12	0.0 - 0.0	0.0	0.0 – 2.7	1.2	14.7 – 20.7	18.1
P13	0.0 - 0.0	0.0	0.0 - 0.6	0.2	19.8 – 20.7	20.5
P14	0.0 - 0.0	0.0	0.4 – 6.2	3.6	15.0 – 20.4	17.5
P15	0.0 - 0.0	0.0	0.0 – 0.9	0.2	19.8 – 20.7	20.5
P16	0.0 - 0.0	0.0	0.0 – 0.6	0.1	20.0 – 20.7	20.6
P17	0.0 - 0.0	0.0	0.0 – 0.7	0.2	19.5 – 20.7	20.5
P18	0.0 - 0.0	0.0	0.0 – 0.8	0.2	20.1 – 20.7	20.6
P19	0.0 - 0.0	0.0	0.0 – 7.9	0.9	13.1 - 20.8	19.8
P20	0.0 - 0.0	0.0	0.0 – 21.9	9.7	1.1 – 20.8	11.7
P21	0.0 – 0.0	0.0	0.0 – 16.8	5.2	2.9 – 20.8	15.4
P22	0.0 - 0.0	0.0	0.0 - 10.8	0.8	5.9 – 20.7	19.6
P23	0.0 - 0.4	0.0	2.9 – 22.4	11.4	0.4 – 18.0	9.7
P24	0.0 - 0.0	0.0	0.0 – 13.3	4.7	7.1 – 20.8	16.1
GP15	0.0 - 0.0	0.0	0.0 – 0.2	0.0	20.5 – 20.7	20.7
GP16	0.0 - 0.0	0.0	0.0 – 1.1	0.4	18.8 – 20.7	20.2
GP17	0.0 - 0.0	0.0	0.0 – 3.5	0.6	4.9 – 20.7	17.7
GP18	0.0 - 0.0	0.0	0.0 – 11.4	6.0	1.1 – 20.7	14.9
GP19	0.0 - 0.0	0.0	0.0 - 0.5	0.1	20.2 – 20.7	20.6
GP20	0.0 - 0.0	0.0	0.1 – 16.3	6.6	4.4 – 20.6	16.0
GP21	0.0 - 0.0	0.0	0.0 - 18.0	1.6	3.5 – 20.7	19.1
GP22	0.0 - 0.0	0.0	0.0 – 8.3	0.7	14.0 – 20.8	20.1

Table 12.5 Summary of Landfill Gas Monitoring Results of the TKO Stage II/III Restored Landfill (From January 2013 to May 2014)

Location	Methane (% v/v)		Carbon Dioxide (% v/v)		Oxygen (% v/v)	
	Range	Average	Range	Average	Range	Average
DG1	0.0 - 0.0	0.0	0.0 – 3.7	0.6	16.1 – 20.5	19.6
DG2	0.0 - 0.0	0.0	0.0 – 4.8	1.6	16.5 – 20.7	18.8
DG3	0.0 - 0.0	0.0	0.2 – 6.5	1.7	9.4 – 20.4	18.0
DG4	0.0 - 0.0	0.0	0.1 – 7.3	3.1	12.1 – 20.1	17.2
DG5	0.0 - 0.0	0.0	0.0 – 0.3	0.1	19.9 – 20.7	20.3

Location	Methane (% v/v)		Carbon Dioxide (% v/v)		Oxygen (% v/v)	
	Range	Average	Range	Average	Range	Average
DG6	0.0 - 0.0	0.0	0.2 – 1.1	0.7	18.2 – 20.4	19.5
DG7	0.0 - 0.0	0.0	0.0 – 2.7	0.8	15.7 – 20.6	19.2

Note:
DG6 is the monitoring well nearest to Wan Po Road. Referring to *Figure 12.4,* monitoring wells UG1, UG2 and UG3 are close to Wan Po Road. However, no monitoring data of these wells is available on request.

Table 12.6 Summary of Landfill Gas Monitoring Results of the TKO Stage I Restored Landfill (From January 2013 to May 2014)

Location	Methane (% v/v)		Carbon Dioxide (% v/v)		Oxygen (% v/v)	
	Range	Average	Range	Average	Range	Average
D113	0.0 - 0.0	0.0	0.2 – 6.4	2.1	6 - 21	17.8
D114	0.0 - 0.0	0.0	0.0 – 0.7	0.2	19.5 – 21.1	20.1
D115	0.0 - 0.0	0.0	0.1 – 6.1	1.2	13.2 – 21.0	19.0
D118	0.0 - 0.0	0.0	0.0 – 0.7	0.3	19.0 – 20.7	20.1
D120A	0.0 - 0.0	0.0	0.0 – 0.6	0.1	18.1 – 20.8	19.9
D157	0.0 - 0.0	0.0	0.0 - 0.0	0.0	19.8 – 20.8	20.3
D126	0.0 - 0.0	0.0	0.0 – 1.4	0.4	18.5 – 20.7	19.8
D130R	0.0 - 0.0	0.0	0.0 – 0.9	0.3	18.9 – 20.6	20.0

According to the above monitoring data, zero concentration of methane has been observed in all the monitoring wells of the SENT Landfill along its southern boundary, and the TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill along Wan Po Road near the fresh water mains. Low concentrations of methane have been observed in monitoring well P23 in the SENT Landfill along Wan Po Road where maximum concentration is less than 1% (v/v). This suggests that the off-site landfill gas migration in these areas is under effective control.

Positive carbon dioxide readings are not in themselves indicative of a landfill gas presence, however, it is acknowledged that under some circumstances, the methane component of landfill gas may be oxidised leaving reduced concentration of oxygen and relatively high concentrations of carbon dioxide and reduced oxygen concentrations are assumed to be associated with a potential landfill gas presence. Carbon dioxide concentrations in monitoring wells are generally expected to be of the order of 1% (v/v), however, under some circumstances, according to geological and hydrogeological conditions, concentrations of 3% or more may reasonably be expected. Oxygen concentrations in monitoring wells are typically 20% (v/v).

The average carbon dioxide concentration detected in the selected monitoring wells of the SENT Landfill, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill ranged from 0.0% to 11.4% (v/v), 0.1% to 3.1% (v/v) and 0.0% to 2.1 % (v/v), respectively. Low concentrations (below 5% (v/v) on average) of carbon dioxide concentrations have been observed in the monitoring wells for the TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill. The monitoring wells for the SENT Landfill where significant carbon dioxide concentrations have been detected are P1 to P4 and GP9 to GP11 along the southern boundary of the landfill, as well as P20 and P23 along Wan Po Road. The maximum gas concentrations ranged from 6.2% to

22.4% (v/v) indicating an elevated concentration compared to the normal background level.

Low levels of oxygen concentrations were detected in monitoring wells P1 to P4 and GP9 to GP11 along the SENT Landfill southern boundary, which further support the occurrence of landfill gas migration.

In summary, zero concentration of methane and low concentrations of carbon dioxide was detected in the monitoring wells for the TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill along Wan Po Road near the fresh water mains. This suggests that off-site landfill gas migration in these areas is under effective control. For the monitoring wells along the southern boundary of the SENT Landfill, although methane was not measured, elevated carbon dioxide and reduced oxygen levels have been detected. In addition, low concentrations of methane have been measured in the SENT Landfill monitoring well P23 along Wan Po Road. These observations suggest that there is still a potential for off-site migration of landfill gas in these areas near the water mains. However, it is likely the migration, if any, is limited and the area of influence is close to the landfill boundary. In general, any excavation work or work involving the construction of trenches will use the open cut method. Any migration of landfill gas will easily be dispersed and diluted upon contact with the atmosphere. Thus migration of landfill gas presents less of risk to the excavation area of the water mains located at about 1.0 m - 1.5 m below ground level.

b) Groundwater Quality

The results of recent groundwater monitoring in the SENT Landfill, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill are presented in *Annex 12B*. Levels of pH are likely to be of interest to designers to assess the likely durability requirements for below grade structures, whilst ammoniacal nitrogen, total organic carbon (TOC) and chemical oxygen demand (COD) parameters are of interest when assessing pollution potential due to organic material within the groundwater.

The pH levels measured at the monitoring wells for the SENT Landfill, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill ranged from 2.84 to 8.35, 6.62 to 7.21 and 5.46 to 7.36, respectively. The monitoring wells where low pH levels have been continuously detected are MW1-2, MW1-3 and MW1-5 in the SENT Landfill and D113 in the TKO Stage I Restored Landfill. A low pH may result from carbon dioxide dissolving into groundwater, although also an ambient feature of the groundwater itself.

Considering ammoniacal nitrogen, TOC and COD, the concentrations measured across the monitoring wells for the SENT Landfill, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill were generally low. The risk of generation of landfill gas from groundwater is therefore considered to be low.

c) Groundwater Level

The ground water level recorded in the groundwater monitoring wells for the SENT Landfill along Wan Po Road ranged from 1.89 m to 11.55 m below ground (refers to

Annex 12B). Although there is a very small potential for landfill gas dissolved in groundwater to be released at remote locations; the groundwater table is generally regarded as an effective barrier to landfill gas movement, noting that the level of groundwater may vary with time.

Information about groundwater level at the monitoring wells for the TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill as well as the Project Site is unknown. However, with reference to *SENT Landfill Extension EIA*, the level of groundwater table of TKO Area 137 is approximately at +2.8 mPD. The formation level of the desalination plant is around +5.0 mPD and hence leaving an unsaturated layer of about 2.2 m. It is considered that this permeable layer between the SENT Landfill, the SENT Landfill Extension and the desalination plant will be conducive to landfill gas migration.

12.5.3 Utilities

With the consultations with utility service providers (including Drainage Services Department, CLP, Towngas, Towngas Telecommunications, Hong Kong Broadband Network (HKBN), Hutchison Communications (HGC) and WSD), it is known that utilities run parallel to Wan Po Road (which is located within the Consultation Zones of the SENT Landfill, SENT Landfill Extension, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill) (***Figures 12.12 – 12.14***). The detailed records of underground utilities in the vicinity of the Project Site and within the Consultation Zones are presented in *Annex 12C*, and the locations of the underground utilities along Wan Po Road are highlighted in yellow in the related drawings. There is no underground service channel, tunnel or culvert connecting the SENT Landfill, SENT Landfill Extension, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill to the areas adjacent to the fresh water mains along the Wan Po Road. In addition, there is currently no man-made underground utility in TKO Area 137, except a box culvert connecting the existing SENT Landfill and the berthing area in TKO Area 137. However, it is envisaged that the utilities along Wan Po Road will be extended to TKO Area 137 (including the Project Site) for the developments in the future.

12.6 Qualitative Assessment of Risks due to Landfill Gas

12.6.1 Introduction

This section reviews the information presented in the preceding sections and evaluates the data presented with reference to the assessment definitions given in the *Guidance Note*. The qualitative assessment of the hazard from landfill gas to the desalination plant and water mains are then concluded.

12.6.2 Source

a) SENT Landfill

SENT Landfill is a large operating landfill, thus the facility must be acknowledged as a significant potential source of landfill gas. SENT Landfill was designed and constructed to incorporate international best practices to contain, manage and control waste,

leachate and landfill gas. It is operated by an experienced international waste management contractor.

The potential off-site migration of landfill gas should be assessed taking into account the comprehensive and highly effective collection and management system installed and operated. As discussed in *Section 12.5.2* above, the recent landfill gas monitoring results indicate that an insignificant amount of methane was recorded at the monitoring wells along Wan Po Road. However, according to the *Guidance Note*, a carbon dioxide concentration greater than 5% v/v above background levels in any monitoring well indicates significant migration. Thus the potential of off-site migration of landfill gas cannot be eliminated.

With reference to the *SENT Landfill Extension EIA* and the recent landfill gas monitoring data at the SENT Landfill, it is classified as a "medium" source.

b) SENT Landfill Extension

With reference to the *Environmental Review of the Revised Scheme of SENT Landfill Extension*, the SENT Landfill Extension will occupy 13 ha in the TKO Area 137 located immediately south of the existing infrastructure area of the SENT Landfill. The two landfills will be separated by the cap of the SENT Landfill and the liner of the SENT Landfill Extension. The SENT Landfill Extension is designed to receive approximately 6.5 Mm^3 of void space over a period of approximately 6 years.

Although the SENT Landfill Extension is not as large as the SENT Landfill, it should still be acknowledged as a potential source of landfill gas. Similar to the SENT Landfill, the SENT Landfill Extension will be designed and constructed to incorporate international best practices to contain, manage and control waste, leachate and landfill gas. An experienced waste management contractor will be appointed for the operation of the SENT Landfill Extension.

Under the SENT Landfill Extension contract requirement, the Extension contractor will be required to control off-site landfill gas migration such that the methane and carbon dioxide concentration at the perimeter wells will not exceed 1% v/v and 1.5% v/v above background level, respectively. The potential off-site migration of landfill gas should be assessed taking into account the comprehensive and highly effective collection and management system to be installed and operated.

Taking into account the multiple landfill gas control measures to be installed, the recent landfill gas monitoring data of the SENT Landfill, and stringent contract requirements for controlling off-site landfill gas migration, it would be reasonably conservative to classify the SENT Landfill Extension as a "medium" source.

c) TKO Stage II/III Restored Landfill

With reference to the *Environmental Review of Urban Landfills and Tseung Kwan O Landfills – Feasibility* Study, the Restoration Contractor of the landfill has designed and implemented a gas management system for the TKO Stage II/III Restored Landfill. The system included placement of a membrane over the waste to contain the landfill gas,

installation of a gas collection and abstraction system, utilisation of the landfill gas as a fuel to generate electricity and for leachate treatment, and combustion of the surplus gas in enclosed flares. There are a total of 50 vertical wells to extract landfill gas.

In consideration of the recent landfill gas monitoring data as discussed in *Section 12.5.2* (concentration of methane is continuously at 0.0% (v/v)) and the landfill gas management system installed at the landfill, the TKO Stage II/III Landfill is therefore classified as a "medium" source.

d) TKO Stage I Restored Landfill

The TKO Stage I Restored Landfill is a landfill site of over 60 ha in area and estimated to contain between 10.6 and 16.2 million m^3 of waste which was deposited in two phases, the last of which was completed in 1995.

The landfill has been restored since1999. The landfill gas control measures included the provision of a passive gas venting trench along the southern boundary of the landfill and an active gas extraction system for control of gas. The recent landfill gas monitoring data as discussed in *Section 12.5.2* above demonstrates the no methane was detected in the perimeter monitoring wells at the site boundary.

Taking the landfill gas control system installed at the landfill and the recent landfill gas monitoring data (concentration of methane is continuously at 0.0% (v/v)) into account, the TKO Stage I Restored Landfill has been considered to constitute a "medium" source in this assessment.

12.6.3 Pathway

The Incoming Switchgear Room, 132 kV Substation and Chlorine Store (I) and (II) of the proposed desalination plant are about 250 m from the southern boundary of the SENT Landfill Extension. The potential pathways for sub-surface migration of landfill gas from the SENT Landfill Extension to these buildings within the Project Site are considered to comprise only natural features and reclamation fill. Taking account of the distance between the SENT Landfill Extension and these buildings, and the presence of possible anthropogenic migration pathways (such as an extension of the existing utilities along Wan Po Road to the Project Site), it is considered that the hazard category of migration pathway to be moderately short/ direct.

The distances between the fresh water mains and the western boundary of the SENT Landfill (including the extension), TKO Stage II/III Restored Landfill and TKO Stage I Landfill are about 50 m, 200 m and 20 m, respectively. The ground is reclaimed fill and presumed to be moderately high gas permeable. ***Table 12.7*** below classifies the landfill gas pathways for various parts of the fresh water mains.

Table 12.7 Classification of Landfill Gas Migration Pathway

Pathway	Pathway Description	Classification
1. Fresh Water Mains within the SENT Landfill Extension Consultation Zone	Path length of less than 50 m for unsaturated permeable strata and fissured rock or less than 100m for man-made conduits.	Very short/ direct

Pathway		Pathway Description	Classification
2.	Fresh Water Mains within the SENT Landfill Consultation Zone	Path length of less than 50 m for unsaturated permeable strata and fissured rock or less than 100m for man-made conduits.	Very short/ direct
3.	Fresh Water Mains within the TKO Stage II/III Restored Landfill Consultation Zone	Path length of 100-250 m for unsaturated permeable soils and fissured rock.	Long/ indirect
4.	Fresh Water Mains within the TKO Stage I Restored Landfill Consultation Zone	Path length of less than 50 m for unsaturated permeable strata and fissured rock or less than 100m for man-made conduits.	Very short/ direct

12.6.4 Targets

In accordance with the *Guidance Note*, the desalination plant and fresh water mains can be categorised into the following targets:

Target 1 – Construction of the Fresh Water Mains

The fresh water mains fall within the SENT Landfill, SENT Landfill Extension, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill Consultation Zones. The work will involve the excavation to around 2.5 m below ground to construct a trench for the installation of the fresh water mains. In general, open cut method will be used and hence any migration of landfill gas will easily be dispersed and diluted upon contact with the atmosphere. In the case that open cut method is not practical, trenchless method such as pipe jacking by micro-tunnelling will be adopted. ***Figure 12.1*** shows the proposed locations of pipe jacking. Three of the proposed locations will be located within the TKO Stage II/III Restored Landfill and SENT Landfill Consultation Zones, respectively. This target is catergoised as "medium sensitivity" using either open cut or trenchless method.

Target 2 – Construction of the Desalination Plant

The Incoming Switchgear Room, 132 kV Substation, Treated Water Pump Station and Switchroom (III), Chlorine Contact Tank(I) & (II), Treated Water Tank and Standby Generator and Switchgear Room of the desalination plant are located within the SENT Landfill Extension Landfill Consultation Zone. The construction works will include open excavation to around 1 m below ground to construct these buildings. Works (including welding and concreting) will thus be undertaken below ground level. Since the area of excavation is large, and it is open above, the below ground area can be adequately ventilated. Landfill gas, if any, migrated to the Project Site can easily be diluted in the atmosphere. This target is thus classified as "low sensitivity".

Target 3 – Operation of the Desalination Plant

The Incoming Switchgear Room, 132 kV Substation, Treated Water Pump Station and Switchroom (III), Chlorine Contact Tank(I) & (II), Treated Water Tank and Standby Generator and Switchgear Room of the desalination plant will be located within the

250 m Consultation Zone of the SENT Landfill Extension. All these buildings are on the ground level and access to these buildings is restricted to the authourised contractors, CLP or WSD staffs who will be briefed on the potential hazards related to landfill gas and the specific safety procedures to be followed. Thus this target is considered as "medium sensitivity".

Target 4 – Operation of the Fresh Water Mains

The fresh water mains will be located at around 1 m to 1.5 m below ground. Underground confined spaces (such as utility pits and manholes) along the fresh water mains are places where landfill gas can potentially accumulate. Restricted access to the manhole and utility pits by authorised and well trained personnel is expected. This target is therefore considered as "medium sensitivity".

12.6.5 Assessment of Hazard

A qualitative assessment of the hazard to the abovementioned targets based on the catergorisation of the Source, Pathway and Target terms and the EPD assessment framework is presented in ***Table 12.8***.

Table 12.8 Qualitative Assessment of Landfill Gas Hazard

Source	**Pathway**	**Target**	**Assessment of Hazard**
SENT Landfill. Potential for gas generation over time, but comprehensive and proven mitigation installed. Monitoring data has shown effective control on off-site landfill gas migration. (medium source)	Surface soil, reclamation fill materials and no direct man-made conduit. Part of the fresh water mains located at 50 m from the landfill. (very short/ direct)	Target 1 - Construction of the fresh water mains. (medium sensitivity)	Medium
	Ditto.	Target 4 – Operation of the fresh water mains. (medium sensitivity)	Medium

Source	Pathway	Target	Assessment of Hazard
SENT Landfill Extension. Potential for gas generation over time. Comprehensive and proven mitigation to be installed. (medium source)	Surface soil, reclamation fill materials, and potential direct man-made conduits. The Incoming Switchgear Room, 132 kV Substation, Treated Water Pump Station and Switchroom (III), Chlorine Contact Tank(I) & (II), Treated Water Tank and Standby Generator and Switchgear Room of the proposed desalination plant located at about 250 m from the southern boundary of the SENT Landfill Extension. (moderately short/ direct)	Target 2 - Construction of the desalination plant. (low sensitivity)	Low
	Ditto.	Target 3 – Operation of the desalination plant. (medium sensitivity)	Medium
	Surface soil, reclamation fill materials, and no direct man-made conduit. Part of the fresh water mains located within the SENT Landfill 250 m Consultation Zone. (Very short/ direct)	Target 4 – Operation of the fresh water mains. (medium sensitivity)	Medium
TKO Stage II/III Restored Landfill. Actively producing landfill gas with gas extraction system as gas control measures. Monitoring data has shown effective control of landfill gas is being achieved. (medium source)	Permeable reclamation fill materials. Part of the freshwater mains located at about 200 m from the landfill. (Long/ indirect)	Target 1 - Construction of the fresh water mains. (medium sensitivity)	Low
	Ditto.	Target 4 – Operation of the fresh water mains. (medium sensitivity)	Low
TKO Stage I Restored Landfill. Actively producing landfill gas, retrospective gas control measures installed (including active gas extraction system and a passive gas venting trench	Permeable reclamation fill materials. Part of the fresh water mains located at about 20 m from the landfill. (very short/ direct)	Target 1 - Construction of the fresh water mains. (medium sensitivity)	Medium

Source	Pathway	Target	Assessment of Hazard
along the southern boundary. Monitoring data has shown effective control of landfill gas is being achieved. (medium source)	Ditto.	Target 4 – Operation of the fresh water mains. (medium sensitivity)	Medium

The qualitative hazard to the proposed desalination plant and fresh water mains from landfill gas has assessed as being from low to medium for various targets.

12.7 Recommended Precautionary and Protection Measures for the Construction and Operation of the Desalination Plant and Fresh Water Mains

12.7.1 Introduction

The qualitative hazard assessment undertaken in *Section 12.6* has concluded that the potential for landfill gas to affect the desalination plant and fresh water mains during the operational phase is low to medium. During the construction period, similar hazards may also arise related to the flammability or the potential asphyxiating properties of landfill gas and/ or the potentially toxic nature of leachate. Given the results of the qualitative risk assessment, it should be assumed that the risks due to the landfill gas or leachate during the construction are low to medium.

This section provides advice and recommendations for the avoidance of environmental impacts related to landfill gas and leachate during the construction and operational phases.

In general, the restoration and aftercare of the TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill, and the control of landfill gas and leachate of the SENT Landfill and SENT Landfill Extension should not be relied upon to ensure the safety of adjoining developments; however, it must also be acknowledged that the restoration works and landfill gas control measures undertaken will have the effect of lowering the potential for an incident to occur off-site. Allowance for this has been made in the qualitative assessment undertaken.

12.7.2 General Hazards Related to Landfill Gas and Leachate

a) Landfill Gas

All contractors, CLP or WSD staffs participating in the construction and operation of the desalination plant and fresh water mains should be aware that potential of methane and carbon dioxide present in the soil and all works should be undertaken on the basis of an “assumed presence of landfill gas”. In addition the following properties of landfill gas should be noted.

- *Methane* is odourless and colourless, although in landfill gas it is typically associated with numerous highly odoriferous compounds which give some warning of its presence. However, the absence of odour should not be taken to mean that there is no methane. Methane levels can only be reliably confirmed by using appropriately calibrated portable methane detector;

- *Methane* is flammable gas and will burn when mixed with air between 5% and 15% (v/v). If a mixture of methane and air with a composition between these two values is ignited in a confined space, the resulting combustion may give rise to an explosion. Methane is an asphyxiant;

- *Carbon dioxide*, the other major component of landfill gas, is an asphyxiating gas and causes adverse health impacts at relatively low concentrations. The long-term Occupational Exposure Limit (OEL) is 0.5% (v/v). Like methane, it is odourless and colourless and its presence (or absence) can only be confirmed by using appropriately calibrated portable detectors;

- *Gas density*. Methane is lighter than air whereas carbon dioxide is heavier than air. Typical mixtures of landfill gas are likely to have a density close to or equal to that of air. However, site conditions may result in a ratio of methane to carbon dioxide which may make the gas mixture lighter or heavier than air. As a result, landfill gas may accumulate in either the base or top of any voids or confined spaces.

b) Leachate

The main problem associated with leachate is its potential for corrosion of steel and concrete structures and pollution of receiving waters. Leachate also presents a potential health risk to anyone who comes into contact with it. In particular, it may cause severe irritation if there is contact with skin or eyes. Many of the compounds likely to be present in the leachate are toxic, if present at sufficiently high concentration.

12.7.3 General Recommended Precautionary and Protection Measures

Notwithstanding the development of other safety and protection measures and procedures which will be required through the construction contracts or according to the site conditions, the following recommendations should also be adopted, including:

- All staff working in the Consultation Zones should receive appropriate training on working in areas susceptible to landfill gas, fire and explosion hazards;

- No worker should be allowed to work alone at any time in or near to any excavation areas within the Consultation Zones. At least one other worker should be available to assist with a rescue if needed. An excavation procedure to minimize landfill gas related risk should be devised and carried out;

- Ground level construction plant used in Consultation Zones (such as micro-tunnelling machine) should be fitted with vertical exhausts at least 0.6m above

ground level and with spark arrestors. Any electrical equipment (such as motors and extension cords) should be intrinsically safe;

- During piping assembly within Consultation Zones, all valves should be closed immediately after installation. As construction progress, all valves should be closed as installed to prevent the migration of gases through the pipeline. All piping should be capped at the end of each working day;

- During construction, adequate fire extinguishing equipment, fire resistant clothing and breathing apparatus sets should be made available on site;

- During all works, safety procedures should be implemented to minimise the risks of fires and explosions, asphyxiation of workers and toxicity effects resulting from contact with contaminated soil and groundwater;

- During trenching and excavation as well as creation of confined spaces near to or below ground level, precautions should be clearly laid down and adhered to rigidly. Gas detection equipment and appropriate breathing apparatus should be available and used when entering confined spaces or trenches deeper than 1 metre;

- The Contractor should make the workers aware of potential hazards of working in confined spaces (any chamber, manhole or culvert which is large enough to permit access by personnel). Such work in confined spaces is controlled by the *Factories and Industrial Undertakings (Confined Spaces) Regulations of the Factories and Industrial Undertakings Ordinance*. Following the *Safety Guide to Working in Confined Spaces* ensures compliance with the above regulations;

- Safety officers, specifically trained with regard to landfill gas and leachate related hazards and the appropriate actions to take in adverse circumstances, should be present on the site throughout the works, in particular, when works are undertaken below grade;

- All personnel who work on site and all visitors to the site should be made aware of the possibility of ignition of gas in the vicinity of the works, the possible presence of contaminated water and the need to avoid physical contact with it;

- Monitoring for landfill gas should be undertaken in all excavations, manholes, chambers (particularly during pipe jacking) and any confined spaces through the use of an intrinsically safe portable instrument, appropriately calibrated and capable of measuring the following concentrations:

  - methane 0-100% (Lower Explosive Limit (LEL)) and 0-100% (v/v)
  - carbon dioxide 0-100% (v/v); and
  - oxygen 0-21% (v/v).

All measurements should be made prior to the entry with the use of monitoring tube located not more than 10 mm from the exposed ground surface. Entry should only be allowed if oxygen is greater than 18% by volume, methane is less than 10% of the LEL, which is equivalent to 0.5% by volume (approximately), and carbon dioxide is less than 0.5% by volume;

- Monitoring frequency and areas to be monitored should be specified prior to commencement of groundwork, either by the Safety Officer, or by an appropriately qualified person. All measurements should be recorded and documented;

- For excavations deeper than 1m, measurements should be carried out:

  - at the ground surface before excavation commences;

  - immediately before any worker enters the excavation;

  - at the beginning of each working day for the entire period the excavation remains open; and

  - periodically through the working day whilst workers are in the excavation.

  For excavations between 300mm and 1m deep, measurements should be carried out:

  - directly after the excavation has been completed; and

  - periodically whilst the excavation remains open.

- Smoking, naked flames and all other sources of ignition should be prohibited within 15m of any excavation or ground-level confined space. 'No smoking' and 'No naked flame' notices should be posted prominently on the construction site;

- Welding, flame-cutting or other hot works should be confined to open areas at least 15m from any trench or excavation;

- Welding, flame-cutting or other hot works may only be carried out in trenches or confined spaces when controlled by a 'permit to work' procedure, properly authorised by the Safety Officer. The 'permit to work' procedure will set out clearly the requirements for continuous monitoring for methane, carbon dioxide and oxygen throughout the period during which the hot works are in progress. The procedure should also require the presence of an appropriately qualified person, in attendance outside the 'confined area', who should be responsible for reviewing the gas measurements as they are made, and who should have executive responsibility for suspending the work in the event of unacceptable or hazardous conditions. Only those workers who are appropriately trained and fully aware of the potentially hazardous conditions which may arise should be permitted to carry out hot works in confined areas;

- Enhanced personal hygiene practices including washing thoroughly after working and eating only in "clean" areas should be adopted where contact may have been made with any groundwater which is thought to be contaminated with leachate.

In the case that drilling operations are required to be carried out within any of the landfill consultation zones, the following additional recommendations should also be adopted, including:

- Proceed drilling with adequate care and precautions against the potential hazards which may be encountered;

- Prior to the commencement of the site works, the drilling contractor should devise a 'method-of-working' statement covering all normal and emergency procedures (including but not limited to number of operatives, experience and special skills of operatives, normal method of operations, emergency procedures, supervisors responsibilities, storage and use of safety equipment, safety procedures and signs, barriers and guarding). The site supervisor and all operatives must be familiar with this statement;

- The drilling rig should be set-up up-wind of the borehole location. 'No smoking' signs should be placed prominently adjacent to the drilling area and the working area should be cordoned off;

- One person should be present at all times during drilling operations with the sole responsibility of assuring the observance of all safety procedures. This person should be trained in the use of all recommended safety equipment.

12.7.4 Contractual Obligations of the Successful Tenderer

The construction of the desalination plant and fresh water mains will be undertaken in accordance with the construction contract which specifies the relevant statutory and other recommended environmental, health and safety guidelines to be followed. In addition, and specifically, the tenderers will be made aware of hazards associated with landfill gas and other issues relevant to construction in the vicinity of a landfill through the Materials and Workmanship Specification and further, will be provided with copies of this report in order to inform them of the likely significances of these issues and any additional recommended safety and precautionary measures that may need to be implemented during the construction phase.

Prior to the commencement of works, the employer under the construction contract should ensure through review and verification of the Contractor's Safety Plan that adequate consideration has been given by the contractor to the occurrence and management of emergency situations and that emergency plans have been developed to cover contingencies relating to landfill gas and leachate.

The construction contract also calls for contractor to submit method statement or statements of working procedures to the engineer prior to the commencement of

specific activities on site. The method-of working statement should cover the following aspects, *inter alia*:

- number of operatives;
- experience and special skills of operatives;
- normal method of operations;
- proposed monitoring;
- emergency procedures, including firefighting;
- supervisors responsibilities;
- storage and usage of safety equipment;
- safety procedures; and
- signs, barriers and guarding for safety control.

It is recommended that the employer under the construction contract provides a review of all method statements, where there is a potential for landfill gas and leachate impacts to occur, to ensure that adequate measures are incorporated in the procedures to contour any possible adverse effects. The contractor should not be allowed to commence work prior to the review by these persons and where recommendations are made, until appropriate adjustments to the work procedure as required by these persons have been incorporated and agreed.

Monitoring for methane, carbon dioxide and oxygen should be undertaken during the construction phase where works involve deep excavation (eg mainlaying, piling and foundation works etc.) or entry into confined spaces. The frequency and areas to be monitored should be documented in the Contractor's Safety Plan prior to commencement of the works.

All monitoring shall be carried out by trained technicians and equipment calibrated according to the manufacturers' instructions. A standard record form, detailing the location, time of monitoring and equipment used, together with the gas concentrations measured, should be used to ensure all relevant data are recorded for future reference.

Depending on the results of gas monitoring and the environment under which is conducted (ie confined space or atmospheric works), appropriate actions will vary and should be stated in the Contractor's Safety Plan.

In emergencies, the following bodies should be contacted:

- Fire Services Department;
- Green Valley Landfill Limited (the contractor of the SENT Landfill);

- SITA Waste Services Limited (the contractor of the Restoration of TKO Stage I Restored Landfill and Stage II/III Restored Landfill); and

- EPD.

12.7.5 Protection Measures for the Construction and Operation of the Desalination Plant and Fresh Water Mains

a) General

The qualitative assessment has determined that there is a low to medium potential hazard of landfill gas affecting the identified targets based on the data and assumptions contained in this section. However, the following potential measures are recommended for active consideration by the Project team in the ongoing design, construction and operational processes in order to minimise the potential hazards.

Notwithstanding these recommendations, it should be acknowledged that other methods conceived by the design team may ultimately have a similar effect to those prescribed.

b) Design of Ground Serve Entries

Where below ground service entries are necessary to the Incoming Switchgear Room, 132 kV Substation, Treated Water Pump Station and Switchroom (III), Chlorine Contact Tank(I) & (II), Treated Water Tank and Standby Generator and Switchgear Room, the entry point should be sealed to prevent gas entry. In addition, any below grade cable trenches entering the Incoming Switchgear Room and 132 kV Substation can become the pathway for landfill gas and hence grilled metal covers should be used.

c) Landfill Gas Monitoring

Landfill gas mainly consists of methane and carbon dioxide. Explosion will be resulted when methane mix with air within the 5%, LEL and 15%, Upper Explosive Level (UEL) in confined spaces and given a source of ignition. It is recommended regular landfill gas monitoring should be carried out at the Incoming Switchgear Room, 132 kV Substation, Treated Water Pump Station and Switchroom (III), Chlorine Contact Tank(I) & (II), Treated Water Tank and Standby Generator and Switchgear Room. The monitoring frequency will be monthly for the first year of operation. If the monitoring results show no sign of landfill gas migration, reduce the monitoring frequency to once every six months.

The manholes and utility pits within the Project Site and along the fresh water mains. Each manhole/ utility pit should be monitored with two measurements (at mid depth and base). Each measurement should be monitored for a minimum of 10 minutes. A steady reading and peak reading should be recorded at each manhole/ utility pit and for each measurement. The need for venting the manhole/ utility pit and further monitoring will be reviewed after the initial monitoring.

d) Alert and Training

All construction, operation and maintenance personnel working on-site as well as visitors should be made aware of the hazards of landfill gas and its possible presence on-site. This should be achieved through a combination of posting warning signs in prominent places and also by access to detailed information on landfill gas hazards and the designs and procedural means by which these hazards are being minimised on-site.

The contractor under the construction contract and the WSD should also make arrangement with the landfill and landfill restoration contractors so that they are advised of all situations which may potentially threaten the safety of the visitors and workers on-site resulting from any accidents or failures at the landfill sites.

To ensure that all the aforesaid protection and precautionary measures and issues pertaining to landfill gas are properly and consistently addressed, it is recommended that a comprehensive landfill gas hazard management system be developed. The system shall describe responsibilities for implementing the landfill gas precautionary measures and contingency plan in case of landfill gas being detected.

12.8 Conclusions

This section has provided a qualitative assessment on potential landfill gas hazards posed by the SENT Landfill, SENT Landfill Extension, TKO Stage II/III Restored Landfill and TKO Stage I Restored Landfill to the Project. The source-pathway-target analysis shows that landfill gas hazard posed to the Project Site by the aforementioned landfills range from low to medium for various identified targets during both construction and operation phases of the Project.

Provided that all the recommended precautionary and protection measures are implemented properly, the safety of all personnel presence at the Project Site during the construction and operation phases would be safeguarded. Thus there would be no adverse impact anticipated on the feasibility of the Project.