LANDFILL GAS HAZARD ASSESSMENT
GUIDANCE NOTE

Environmental Protection Department
The Government of the Hong Kong Special Administrative Region

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CONTENTS:

LIST OF ANNEXES

VERSION	**Remark**
- Original 1997	
- 1st update on October 2022	Annex A: The Figures A14, A15 and A16 on NENT Landfill, SENT Landfill and WENT Landfill respectively being updated.

EXECUTIVE SUMMARY

INTRODUCTION

When an area of land in close proximity to a landfill site is to be developed there is a potential risk that the development may be adversely affected by the lateral migration of landfill gas unless suitable precautionary measures are taken. This document provides guidance on how the evaluation of the risk which landfill gas may pose to such a proposed development should be undertaken and provides an introduction to the different types of protection measure which may be incorporated in the design of developments potentially at risk from landfill gas migration.

This Guidance Note is aimed primarily at Professional Persons responsible for developments and should be read in conjunction with the Professional Persons Environmental Consultative Committee (ProPECC) Practice Note PN 3/96 issued by the Director of Environmental Protection.

The potential hazards posed by landfill gas migration and the need for protection measures for developments close to landfill sites are outlined in Section 6.5 of Chapter 9 of the Hong Kong Planning Standards and Guidelines (HKPSG). It is a requirement that project proponents of relevant developments undertake a landfill gas hazard assessment and submit the findings of this assessment to the Environmental Protection Department (EPD) for vetting. This Guidance Note provides a framework for undertaking these assessments.

In general, an evaluation of the risk posed by landfill gas is required for any development which is proposed within a 250m "Consultation Zone" around any landfill site. To assist developers in identifying whether any particular development falls within this criterion, all the landfills in the Territory and their associated Consultation Zones are delineated on plans held by EPD. These plans are available for inspection and small scale copies are included in the Guidance Note (Annex A).

Certain types of development have a very low sensitivity to the potential impacts of landfill gas and so the requirement for a formal assessment of the hazards due to landfill gas migration may be waived for such developments even though they may fall within a landfill's Consultation Zone. Conversely, in particular and exceptional circumstances, a landfill gas hazard assessment may be required despite a proposed development being outside of any Consultation Zones. The particular circumstances for each of these two exceptions to the general requirements for undertaking landfill gas hazard assessments are discussed in the Guidance Note.

ASSESSMENT OF LANDFILL GAS HAZARDS

Assessing the degree of risk due to landfill gas migration requires special expertise so the hazard assessment for any particular development should be undertaken by an appropriately qualified and experienced professional.

In general, the evaluation of the hazards posed by landfill gas to a proposed development involves a qualitative risk assessment, the framework for which is detailed in this Guidance Note. Such an assessment should include the following steps:

Review of Background Information

Any relevant information should be collected and assessed to determine the likelihood of landfill gas having an impact on the proposed development. Such information will include historical information about how the landfill was engineered and operated, geological and hydrogeological data and results of any environmental monitoring. A more comprehensive list of the type of information which should be obtained, typical sources of the information and the way in which the gathered information should be presented are detailed in Section 2.

Evaluation of Sources

The nature and extent of the source(s) of landfill gas, including the likely concentrations and volumes of hazardous emissions which may have the potential to affect the proposed development need to be assessed. Where direct measurements of gas concentration and flowrate are not available, information about amount, nature and age of the waste will need to be used to assess the rate of gas evolution.

Identification of Pathways

Possible pathways along which gas could travel from the landfill site to the development site, through the ground, underground cavities, utilities and groundwater, should be identified and their nature evaluated.

Identification of Potential Targets

The different elements of the proposed development which will be sensitive to the impacts of landfill gas must be identified. Such potential "targets" will include building basements and ground level rooms, underground car parks, service ducts and manholes, unventilated excavations and other confined spaces at or below ground level.

Assessment of the Risk to Each Target

A methodology for qualitatively assessing the degree of risk which hazardous emissions may pose to each of the identified targets is presented in Section 3. Specific guidance is provided to assign each source, pathway and target to one of three categories and a matrix has been developed to classify the overall risk for each Source-Pathway-Target combination into one of five risk categories.

Any particular, proposed development can then be assigned to an overall risk category depending on the number and level of risks associated with each of the potential impacts identified from the Source-Pathway-Target analyses. The method of categorising developments is detailed in Section 4 and three worked examples of qualitative risk assessments are presented in

Annex C.

The assessment process often comprises two stages. The first stage, or 'Preliminary Qualitative Assessment', is carried out at the planning stage of a development project and its scope is necessarily limited by the level of available detail about the proposed development. It may be used to determine the acceptability in principle of a proposed development and to identify the scope of any further investigations which may be required to complete the assessment.

In many cases, the existing information about the landfill site and potential routes by which gas may migrate to the proposed development will need to be supplemented by a site investigation in order to allow a full assessment of the potential risks. Typical parameters to be monitored in such a site investigation are discussed in Section 5.

The Stage II or 'Detailed Qualitative Risk Assessment' is undertaken at the stage when the project is definitely proceeding and when all the relevant details of its design and results of any site investigations are known. The detailed assessment will review and, where necessary, revise the findings of the initial assessment (Section 6). In many cases, due to project constraints, the two stages of assessment may be combined.

DESIGN OF PROTECTION MEASURES

In undertaking the assessment of the potential risks, it is essential that any protection measures are designed by an appropriately qualified and experienced person. Whereas guidance can be given for the assessment of potential landfill gas hazards, the design of gas protection measures is more site specific and dependent on the particular targets identified as being at risk. However, a number of generic types of measure which may be employed for protecting developments from the affects of landfill gas are discussed in Section 7.

In general, to provide confidence that failure of a single measure will not result in a hazardous situation, it is necessary to adopt a multiple system approach to the provision of gas protection measures. This is particularly the case where active systems, such as those which involve mechanical ventilation, are involved. In most cases, passive systems of control are preferred for the same reason.

In addition to designing an appropriate gas protection scheme it is also essential that it is properly constructed and maintained and that monitoring is undertaken to confirm its ongoing effectiveness.

Sub-surface building services are particularly important in the protection of developments against lateral landfill gas migration because, if not properly designed, they can provide a direct route by which landfill gas can enter a building. General guidance on measures which may be applied to services is included in Section 7 and more specific advice together with typical design drawings are presented in Annex B.

POTENTIAL HAZARDS DURING CONSTRUCTION AND SAFETY MEASURES WHICH SHOULD BE ADOPTED

The potential hazards due to landfill gas which may be encountered during the construction of developments close to landfill sites and the safety procedures which should be implemented to minimise the risks are discussed in Section 8.

The precautions recommended include the appointment of a Safety Officer trained in the use of appropriate gas monitoring equipment, the implementation of specific safety measures, such as controls on methods of working and possible sources of ignition, and the undertaking of gas monitoring. The contractor also needs to develop a 'permit to work' system for any work involving potential sources of ignition within any trenches or confined spaces.

The actions to be taken for different levels of gas which are detected are also discussed and specific advice is provided regarding the drilling of boreholes.

1 INTRODUCTION

Purpose

1.1 It is recognised that development of land adjacent to landfill sites may be affected by problems associated with migrating landfill gas and/or leachate unless specific precautions are taken to control these potential hazards. A Practice Note for Professional Persons (ProPECC PN 3/96) has been issued by the Environmental Protection Department (EPD) to set out the conditions when a landfill gas hazard assessment may be required and to provide general guidelines on how such an assessment should be undertaken. The purpose of this Guidance Note is to describe in more detail the process which should be followed by a Professional Person working in the private sector or public sector in evaluating the risk to development due to landfill gas and designing appropriate protection measures. The Guidance Note is not intended to provide comprehensive guidance on all aspects of risk assessment or design of precautionary/protection measures, but rather to give general guidance on important issues such as the factors to be considered when assessing the level of risk and the procedures which should be followed in undertaking the assessment. This Guidance Note is intended to provide a risk assessment framework to be followed by project proponents when evaluating the risk related to developments described under *Section 6.5, Chapter 9* of the Hong Kong Planning Standards and Guidelines.

1.2 The general location of each of the landfill sites in Hong Kong is shown on Figure 1.1

Hazards Associated with Landfill Gas

1.3 Landfill gas can present a number of potential hazards if it is not adequately controlled. The following properties of landfill gas are of particular note when considering development close to landfill sites.

- *Methane,* one of the major components of landfill gas, is flammable and will burn when mixed with air between approximately 5% by volume and 15% by volume (the Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL) respectively). If a mixture of methane and air with a composition between the LEL and UEL is ignited in a confined space, the resulting combustion may give rise to an explosion. Methane is also an asphyxiant.

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

- *Carbon Dioxide,* the other major component of landfill gas, is asphyxiating and causes adverse health effects at relatively low concentrations. The long-term Occupational Exposure Limit (OEL) is 0.5% by volume. Like methane, in the pure form, it is odourless and colourless and its presence (or absence) can only be confirmed by using appropriately calibrated detectors.

- *Gas Buoyancy.* 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 than air or heavier than air. As a result, landfill gas may collect in the bottoms of trenches or excavations, or may rise up and accumulate beneath structures and foundations.

Definitions

1.4 A number of definitions have been developed, for use in this Guidance Note, to describe the areas under consideration and the processes being used. These are defined below:

1.5 *Development*: Under the Town Planning Ordinance (TPO), development is defined as "carrying out building, engineering, mining or other operations in, on, over or under land, or making a material change in the use of land or buildings."

1.6 *Building*: Under the Town Planning Ordinance, building includes a structure or part of a structure.

1.7 *Consultation*: A process required for all development proposed in the Consultation Zone whereby the project proponent should consider the potential for hazards to affect the development arising from the close proximity of a gassing landfill including liaison with concerned Government departments (such as EPD). A procedure for this process is described in the Guidance Note, outlined in Figure 1.2.

1.8 *Consultation Zone*: The area of land surrounding the landfill boundary as defined by a line running parallel to and 250 m away from the edge of the waste if this can be identified or, if not, the recognised landfill site boundary. Detailed plans delineating the Consultation Zone for each of the landfill sites are kept by EPD and are available for inspection.

1.9 In general, if a proposed development is to be located within the Consultation Zone of a landfill, the project proponent or professional person responsible for the development is required to undertake a landfill gas hazard assessment and submit a report to EPD for vetting. If the proposed development is of a sufficiently low sensitivity to the effects of landfill gas, however, the requirement for the hazard assessment may be waived even though the development falls within a Consultation Zone. The general criteria for determining whether the hazard assessment may be waived are discussed below.

1.10 Conversely, in some particular, exceptional, circumstances a landfill gas hazard assessment may be required even though the proposed development is located outside any Consultation Zones. This would be the case in any situation where the ground between a landfill site and the proposed development site is identified as having distinct geological features, such as fault lines or lineaments, or predominant artificial buried structures, such as utility conduits, which might act as preferential pathways for gas migration. If the need for a landfill gas hazard assessment is in doubt, advice can be sought from EPD.

1.11 *No Build:* A restriction on the construction of any form of development in a "no build zone" which is set aside for monitoring/landfill control works. The land may be landscaped or used for open car parking areas, but should remain accessible for plant and equipment to carry out work to the landfill control measures, if found necessary in the future. Although there may be existing buildings or structures present within the "no build" zone, restrictions may need to be applied at any time such land is redeveloped. The restriction on construction should preferably include services which can act as conduits for gas migration but, where it is essential that such services or roads cross the zone, or there is limited intrusion of other structures, it is important that these do not impact on the accessibility of the zone for monitoring and possible future engineering works.

1.12 *No Build Zone:* The dimensions of the no build zones have been determined individually for each site to allow for the possible need to install additional monitoring facilities or gas controls and taking into account the access requirements and physical constraints specific to each site. For most landfill sites, the allocated area for the restoration contract encompass all of the No Build Zone. For a few particular sites the No Build Zone extends beyond the allocated area.

1.13 Detailed plans have been prepared to indicate the Consultation and No Build Zones for each of the landfills in the territory and are available for inspection at EPD's office. A4 sized plans showing the approximate extent of the Consultation Zone around each of the landfills, together with outline planning information, are presented in Annex A to this Guidance Note.

Phased Approach

1.14 In many cases there will be two stages to undertaking the landfill gas hazard assessment which will each require a different level of detail in terms of background information and accuracy of assessment. Stage I is the planning stage when a development is first proposed, but specific details are not finalised and the suitability of the particular form of development may still be uncertain. For many "low risk" developments, such as public open space, car parking, open storage and any uses which do not involve buildings with ground floor rooms, the Stage I assessment to determine their suitability in principle may require only a very simple and quick assessment of the potential risks. The Stage I assessment (as indicated by the flowchart shown in Figure 1.2) is, nevertheless, important because many such developments have ancillary structures or services associated with them which could be at potential risk from landfill gas migration. In addition, the development may affect the general pattern of gas migration thereby altering the risk to other nearby developments. Certain types of development have a low enough sensitivity that risk assessment can be waived. In general, such developments must fulfill all of the following conditions:

- have no underground services and conduits;
- not significantly reduce the permeability of the surface soils, alter groundwater flows or change the drainage pattern of the land;
- have no fully enclosed spaces; and
- have no sources of ignition (such as electrical or other equipment which may give rise to sparks).

1.15 Stage II, the development stage, assumes that the project is definitely proceeding and investment in site investigation is sanctioned by the project proponent. The output of Stage II includes a review of the preliminary qualitative risk assessment, preparation of a detailed qualitative risk assessment and preparation of detailed design of gas protection measures for submission to EPD. The detailed design submission should include maintenance and monitoring programmes to ensure the continued performance of the proposed control measures.

1.16 In some cases the distinction between the Stage I and Stage II assessments is blurred because the nature of the development and its outline design have already been decided before there is an assessment of the risks due to landfill gas. In these cases a combined Stage I/II assessment will need to be undertaken covering all of the elements indicated on the flowchart shown on Figure 1.2.

Process of Assessment

1.17 A flow chart illustrating the process is given as Figure 1.2. This Guidance Note follows the procedures in the flow chart and expands upon each element to provide for information to assist in the assessment of risk. The tasks envisaged in Figure 1.2 should be conducted such as to be compatible with the requirements under the TPO, and current land exchange processes, managed by the District Planning Offices and District Lands Offices respectively.

2 REVIEW OF EXISTING INFORMATION

Types and Sources of Information

2.1 To understand better the conditions existing at and around a landfill site which may affect a development, the first step should be to collect and collate all available relevant information. A step-by-step procedure for this activity is given in the flow chart on Figure 2.1. This desk-based study should draw upon records held by the project proponent or the landowner and any other third parties who may have relevant data. At this stage it is not the intention to require the project proponent to carry out ground investigations.

2.2 Sources of information are listed in *Table 2.1*, but this list is not exhaustive. As can be seen from the table, the type of data which should be considered for the assessment includes, but may not be limited to, the following:

- topographical information for both current and previous landforms to assess whether land has been built up in level by import of fill;

- historical information about the landfill including how the site was prepared prior to filling, the nature and amount of wastes deposited, the period over which the site was filled and the extent of any gas controls employed at the site;

- environmental data such as the presence of gas both within and beyond the landfill boundary, or the extent of groundwater contamination by leachate;

- geological and hydrogeological information to assess the likely ground conditions, permeability of soil/rock, level of groundwater, etc;

- location of utilities trenches in the ground which may form high permeability pathways; and

- evidence of gas emissions through, for example, the presence of bubbles in standing water on site.

Table 2. 1 List of Sources of Information

Type of Data	Source
1. Large-scale topographic maps	Survey and Mapping Office, Lands Department.
2. Geological maps	Survey and Mapping Office, Lands Department.
3. Aerial photographs	Survey and Mapping Office, Lands Department.
4. Location of utilities (gas, electricity, etc)	Utilities Companies
5. Information from previous ground investigations at development site.	Existing or previous land owners
6. Information from previous ground investigations between development site and landfill.	Hong Kong Government Civil Engineering Department Library.
7. Information regarding landfill including engineering and dates of filling.	Hong Kong Government - Environmental Protection Department and Civil Engineering Department.
8. Gas monitoring data	EPD's computer database
9. Visual data at development site surface	Site visit and walkover
10. Background/ informal information	Site visit, discussion with neighbours to site, contractors working in vicinity.

(Note: See also Sub-Chapter 2.2, Chapter 12 of the Geotechnical Manual for Slopes)

Presentation of Information

2.3 It is expected that the Professional Person or an appointed specialist consultant will obtain all available data of this nature, such that a picture can be built up of the conditions which exist at the landfill, the development site and any intervening ground. It would be appropriate to present the data in its collated form, and usually to include a plan and a simple section.

Plan of Site

2.4 The plan typically should have a scale in the range 1:500 to 1:2000 and should include, but not be limited to, the following:

- the relevant area of the landfill;
- the development site;
- all intervening land;
- positions of monitoring wells (gas and leachate/groundwater);
- position and nature of any landfill gas/leachate control measures;
- nature and location/alignment of utilities;
- any relevant surface features;
- position of proposed development including its various components such as buildings, car parks, manholes (if such details are available);
- major dimensions such as distance from edge of waste to buildings;
- position of surface water courses; and
- location and orientation of any cross-section lines.

Cross-Sections

2.5 Where possible, the section should include, but not be limited to, the following:

- the same area of land shown in the plan;
- depth and edge of waste;

- geology of ground from landfill through to development site;
- groundwater levels;
- position and depth of landfill monitoring wells including the screened sections;
- position and nature of any landfill gas/leachate control measures such as barriers, liners and vent trenches;
- location of utilities; and
- topography along section line.

2.6 More than one section should be shown if there is an extensive linear interface and, for developments which cover a large frontage, cross-sections should be provided at 100m intervals. In such cases a long section through the development site (parallel to the site/landfill interface) should also be provided.

Other Data

2.7 Other data, such as landfill gas/leachate monitoring results should be clearly tabulated for boreholes along the boundary of the landfill relevant to the proposed development.

3 PRELIMINARY QUALITATIVE ASSESSMENT

Assessment Model

3.1 A relatively simple procedure is used to evaluate the degree of risk which landfill gas may create for a particular development. The procedure is based on the "Source - Pathway - Target" model and requires the following information:

3.2 **Source** - the location, nature and likely quantities/concentrations of hazardous materials which have the potential to affect development.

3.3 **Pathway** - the ground and groundwater conditions, through which the hazardous materials must pass if they are to reach the development.

3.3 **Target** - the elements of the development which are sensitive to the effects of the hazardous materials.

3.5 For a particular risk to be identified, there must be a source of hazard which has one or more viable pathways by which it may reach a sensitive target and cause a problem. This Guidance Note is primarily concerned with the potential hazards caused by the migration of landfill gas towards development sites. Thus, the hazardous material of concern is landfill gas. In certain circumstances landfill gas may be transported in solution in leachate or may be generated from the anaerobic degradation of organic compounds in the leachate. Hence, when considering the possible risks due to gas migration it is important to assess leachate controls and groundwater flows. The hazards, other than those related to landfill gas, which may be posed by leachate are beyond the scope of this Guidance Note. The procedure for the preliminary qualitative risk assessment is given in Figure 3.1.

Input Data

3.6 At the planning stage, the assessment will be limited in scope and degree of confidence due to the probable lack of ground investigation data beyond the landfill and at the development site. However, the data can be used as far as practicable to evaluate sources, pathways and targets. Information obtained under Section 2 can be used in the model as follows:

Source

- Location of gas-producing wastes, likely volumes of gas evolution may be estimated from concentrations of methane, carbon dioxide and oxygen and gas pressures or flow rates measured within the landfill and at its boundaries over the preceding six months.

- Where information relating to gas concentrations and pressures/flowrates is not available, the age of the waste (time since deposition) and type of material deposited should be used to assess the likely rate of gas evolution.

- Level and location of leachate, data on concentration of major components of leachate, data on leachate in perimeter monitoring wells, including apparent flow directions of groundwater and perched water tables.

- The nature of the lining of the site (if any) and any gas/leachate controls which are in place.

Pathways

- Location of soils/rocks with a high primary permeability including depth and thickness.
- Location of soils/rocks with a high secondary permeability due to discrete fissures and joints. (Information on joint patterns and bedding planes etc should be included where possible).
- Location and nature of different utilities noting those with permeable backfill.
- Location of any tunnels, shafts, mines etc.
- Groundwater depths and flow patterns.

Targets

Locations of the following elements of the proposed development noting, in each case, the likely presence of any sources of ignition and the general nature of access (frequency and persons involved):

- Building basements or ground floor rooms in contact with the ground.
- Service ducts, cupboards or other confined spaces at basement or ground floor levels.
- External manholes, inspection chambers, ducts or other accessible enclosed spaces in the ground.
- Outbuildings, sheds and temporary structures such as construction site offices.
- Deep unventilated excavations such as pile shafts, trenches for utility installation and basement excavations.

Process of Assessment

3.7 The linkage of source, pathway and target should be set out in a logical manner, and where more than one pathway exists from the source which affects the same or a different target, then this should be easily discernible. The identification of a potential impact (by having a viable source-pathway-target), then requires an assessment of the risk that this impact poses to the target. In qualitative risk assessment, this assessment is a matter for professional judgement based upon experience of the issues and a well rounded knowledge of the technical background to the subject.

Categorisation of Inputs

3.8 Prior to carrying out the preliminary qualitative risk assessment, each of the source, pathway and target elements need to be categorised in order to facilitate the assessment process. At this preliminary stage, the following definitions may apply to the description of categories, although **it must be recognised that there will be exceptions to these guidelines**, as each combination of landfill site and development will have different characteristics.

Source

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

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).

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.

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.

3.10 The 'significance' of migration should be assessed by reference to the concentration, frequency and location at which gas is detected. For guidance, it should be assumed that **any** concentration of methane or carbon dioxide greater than 5% v/v above background levels in **any** monitoring well outside the landfill's boundary indicates significant migration. Lower concentrations may still be 'significant' if they are observed in more than one monitoring well, on several occasions or in monitoring wells located some distance from the site boundary. In general, concentrations of greater than 1% v/v methane or 1.5% v/v carbon dioxide (above background levels in each case) indicate less than adequate control of the gas at source.

3.11 In classifying the source term, account needs to be taken of the likelihood and probable effect of a failure of the gas controls. Thus, if it has been demonstrated that there is no migration of gas and there is little danger of the gas controls failing (eg if these comprise solely of passive measures such as a liner) it can be assumed that the site represents a "Minor" *Source*. Where there is no gas migration but this may be as a result of a single, "vulnerable" control measure (eg. an active extraction system with no warning of failure), the site should be regarded as a "Medium" or even a "Major" *Source* depending on the other factors (eg size of site and age of waste).

3.12 Where the effectiveness of the gas controls has not been proven by off-site monitoring or if there is some doubt as to the adequacy of the monitoring, this should be taken into account when considering the impact of the control measures on the *Source* term. Assessments should always err on the side of caution and, in general, if the effectiveness cannot be demonstrated the assessment should be undertaken on the same basis as if the controls were not in place.

3.13 The reliability of the monitoring, for determining the efficacy of the gas controls, needs to take account of the design, number and location of the monitoring points together with the frequency and duration over which monitoring has been undertaken. Monitoring should have been undertaken under different weather conditions including, in particular, periods of low or falling atmospheric pressure.

Pathway

3.14 The broad classification of the Pathway should be undertaken as follows:

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

3.15 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:

- particular permeability of the soils;
- 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);
- the nature of the strata over the potential pathway;
- the number of different media involved; and
- depth to groundwater table and flow patterns.

3.16 Thus, although there may be permeable soil between the landfill site and a proposed development say 80m from the edge of the site, if the soil layer is very shallow and thin with its upper surface exposed to the atmosphere then it will be appropriate to consider this as a long/indirect pathway. This could of course alter if the land between the landfill site and the development was paved over or altered in some other way which reduced the potential for gas release. Similarly, if the land is flat, the surface may be prone to waterlogging which will also effectively seal it at times of heavy rain. In general, a conservative approach should be adopted and it should be assumed that any such permeable surface soils may become less permeable in the future.

3.17 If it is known that a conduit (man-made or natural feature such as a fault plane) leads directly from the landfill to the development area, it should be regarded as a "direct/short" pathway even if it is longer than 100m.

Target

3.18 Different types of target may be broadly classified as follows:

Highly Sensitive	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 could pose potential problems.

3.19 Again, the above examples of the different categories should be used as a general guide only and particular aspects of a building or development may render it more or less sensitive than indicated. Account should be taken of any particular circumstances when assigning a target to one of the three categories.

Assessment of Risk Category

3.20 Having determined into which categories of source, pathway and target the combination of landfill and development fall, a preliminary assessment of the overall risk may be made by reference to *Table 3.1*.

Table 3.1 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

The classification matrix for an example typical landfill gas qualitative risk assessment is given in *Table 3.2*.

Table 3.2 Example of Qualitative Risk Assessment Matrix

Source	**Pathway**	**Target**	**Assessment of Risk**
Recently deposited domestic and commercial wastes. Landfill gas measured in perimeter monitoring boreholes at landfill with 50% by volume methane (flammable gas) and 20% carbon dioxide. No gas controls at the landfill. (*Major source*)	Via unsaturated fissures and joints (tightly spaced) in granite bedrock. Source-Target distance = 40m (*Very short/direct pathway*)	1. Basement of building development with utilities entering via ducts, (*Highly sensitive*)	Very High
	Via unsaturated fissures and joints in granite bedrock. Building located 200m from the landfill (*Long/indirect pathway*)	2. Ground floor rooms of building with basement. (*Highly sensitive*)	High
	Via unsaturated fissures and joints in granite bedrock. Targets located 150-200m from the landfill (*Long/indirect pathway*)	3. Manholes for drainage pipes. Access by utilities personnel only. (*Medium sensitivity*)	Medium

4 SITE CATEGORISATION

Purpose

4.1 The qualitative risk assessment provides a means of understanding the degree of risk which landfill gas may pose to a particular development, but does not identify the nature of gas protection measures which a development will require. At the preliminary assessment stage it is not practicable to determine detailed protection, but a provisional classification of the site into one of five categories will allow the Professional Person a means of understanding the generic types of protection which would be appropriate. A simple flow chart for this stage of the procedure is given in Figure 4.1.

Method Of Categorisation

4.2 The preliminary risk assessment will have already defined a number of potential impacts, ie links from source via pathway to target, and assigned a risk level based upon professional judgement and the criteria set out above. For the purposes of categorising the site at the planning stage (Stage I), the category will be based upon the highest level of risk nominated for any of the potential impacts identified. For example, a site with three low risks, and one medium risk will fall into Category C, and a site with three low risks, three medium risks and one high risk will fall into Category B (See *Table 4.1*).

4.3 If four or more different impacts arise in a particular risk category, however, then the overall risk classification may be considered to be one category higher. For example, a site with two low risks and five medium risks will fall into Category B.

4.4 *Table 4.1* summarises the general implications for developments which fall into the different overall risk categories.

Table 4.1 Summary of General Categorisations of Risk

Category	Level of Risk	Implication
A	Very high (Undesirable)	The type of development being proposed is very undesirable and a less sensitive form of development should be considered. At the very least, extensive engineering measures, alarm systems and emergency action plans are likely to be required.
B	High	Significant engineering measures will be required to protect the planned development.
C	Medium	Engineering measures will be required to protect the proposed development.
D	Low	Some precautionary measures will be required to ensure that the planned development is safe.
E	Very low (Insignificant)	The risk is so low that no precautionary measures are required.

Generic Protection Measures

4.5 It is expected that five generic forms of protection will be used in mitigating the hazards to developments. Generally, higher risk categories will warrant the use of more active control measures, or more sophisticated combinations of control measures. These generic forms, corresponding to the five risk levels, are set out in *Table 4.2*.

4.6 It must be emphasised that **this classification is intended only as preliminary guidance on the nature of protective works anticipated for the development,** and that more detailed investigation and reassessment at the Development Stage II will allow targeted and more accurate design of protective measures.

Table 4.2 Generic Protection Measures for Planning Stage Categorisation

Category	Generic Protection Measures
A	For the planned development active control of gas, supported by barriers and detection systems. Another, less sensitive form of development should also be considered.
B	Active control of gas, including barriers and detection systems[(1)].
C	Use of 'semi active' or enhanced passive gas controls. Detection systems in some situations.
D	Passive control of gas only.
E	No precautionary measures required.

Note : (1) The gas protection measures required to allow the safe development of a Category A risk development will need to be more extensive than those for a Category B risk development.

Definitions

4.7 The terms used in *Table 4.2* are defined in *Table 4.3* below.

Table 4.3 Definition of Control Terms

Term	**Definition**
Active control	Control of gas by mechanical means eg ventilation of spaces with air to dilute gas, or extraction of gas from the development site using fans or blowers.
'Semi active' control	Use of wind driven cowls and other devices which assist in the ventilation of gas but do not rely on electrically powered fans.
Passive control	Provision of barriers to the movement of gas eg membranes in floors or walls, or in trenches, coupled with high permeability vents such as no-fines gravel in trenches or voids/permeable layers below structures.
Detection systems	Electronic systems based upon, for example, catalytic oxidation or infra-red measurement principles, which can detect low concentrations of gas in the atmosphere and can be linked to alarms and/or telemetry systems.

5 SITE INVESTIGATION

Introduction

5.1 When a decision is taken to proceed with the development, it will be necessary to carry out a site investigation targeted towards understanding the occurrence of gas and leachate at the development site. The output from the investigation should bring the level of knowledge of these parameters up to a level sufficient to allow for the proper assessment of the risk and design of appropriate protection measures. When carrying out the investigation, it must be borne in mind that flammable gas can occur in the soil as a result of other factors besides landfills. Other sources of flammable gas include:

- marine sediments;
- wetlands (marshes, peat bogs etc.);
- sewer gas;
- geological methane;
- groundwater; and
- mains (piped) gas.

5.2 In addition to methane, carbon dioxide is produced by landfills and some of the above sources. Other gases can occur in particular circumstances such as hydrogen sulphide, hydrogen, ammonia and carbon monoxide.

5.3 Where a site investigation reveals the presence of flammable or other gases within the ground which are not related to the migration of landfill gas, the particular source giving rise to the gas(es) and the risk they pose to the development will need to be assessed. Although similar risk categorisation techniques to those presented in this Guidance Note may be applicable, discussion of the hazards posed by such gases is beyond the scope of this document.

Site Investigation Procedure

5.4 A simple, step by step, procedure for procuring and undertaking the specialist gas investigation is given in Figure 5.1. The first step for the Professional Person must be to ensure that the next stage of work is carried out with appropriate specialist support. A specialist consultant should be retained, if expertise is not already held by the Professional Person, to plan and design the investigation, supervise the works and interpret the results with respect to risk assessment and building protection.

5.5 A site investigation for gas and leachate normally follows four stages:

1. Desk Study - a review of existing information
2. Main investigation
3. Supplementary investigation (optional)
4. On-going monitoring

5.6 The desk study has already been described under Section 2 of this Guidance Note. Where all available information sources have been consulted and a thorough review has been undertaken, then it is appropriate to move on to the main investigation. Depending upon the extent of available information, this may need to involve investigation of the landfill site as well as the proposed development site and the ground between the two sites.

5.7 The main investigation may benefit from an initial use of screening techniques which allow the investigator, at low cost, to gain an overview of any surface gas emissions. Such techniques may include:

- Site walkover with a sensitive portable gas detector which can detect low concentrations of gas being emitted from the ground surface.

- Grid of temporary soil probes across the development site using simple hand-driven measuring probes to monitor gas composition and concentrations in the upper one metre of ground.

5.8 Other remote sensing techniques, such as aerial photography (infra-red and visible from a full-scale aircraft, radio controlled model aircraft or tethered balloon) can be used but are not widely available in Hong Kong and may require special clearances.

5.9 The results of these types of investigations can be beneficial in planning the locations of boreholes in the main investigation.

5.10 Methods of investigation are described in great detail in a number of published documents (UK HM Inspectorate of Pollution 1991, Hooker and Bannon 1993, Crowhurst and Manchester 1993) and it is not intended to go into such detail in this Guidance Note. The reader is referred to these documents for information. It is expected that the specialist consultant will be fully familiar with their content. The main gas investigation will draw upon the following techniques in order to install gas monitoring points and allow *in situ* measurement of gas in the ground:

- wells with monitoring/gas sampling device(s);
- trial pits with monitoring/gas sampling device(s); and/or
- permanent driven probes.

5.11 The investigation of the development site should obtain sufficient information in relation to the following relevant aspects to enable the detailed qualitative risk assessment to be completed:

- gas concentrations, particularly methane, carbon dioxide and oxygen;
- gas emission rates;
- *in situ* gas pressure with respect to atmospheric pressure;
- the likely variation in the above as a result of normal meteorological variations with time;
- identification of the source of gas;
- the extent of any lateral migration from the landfill;
- the presence of methane or other gases in the groundwater; and
- the geology/hydrogeology of the site.

Site Specific Factors and General Requirements

5.12 The design of the investigation, in terms of the techniques to be employed, number of boreholes to be drilled and type/layout of the monitoring wells will very much depend upon the location, size and configuration of the development site. However, as general guidance, the following points should be noted:

- at least three monitoring wells should penetrate to a depth where groundwater levels can be measured and water samples taken;

- monitoring wells along the edge of the site nearest to the landfill should penetrate to a depth equivalent to the waste depth or one metre below groundwater level, whichever is shallower;

- a series of shallow probes may be used within the area of the development site; and

- the boreholes and trial pits should all be logged to provide engineering records of strata encountered.

5.13 It is not possible to define absolute depths of boreholes/wells and the criteria set out above should be followed in designing the investigation.

5.14 Gas monitoring and sampling should be undertaken by competent and trained operators who are familiar with the limitations of the equipment being used. Appropriate portable equipment should be used and a proportion of *in situ* monitoring data should be checked by taking samples of gas and carrying out laboratory analysis using gas chromatography.

5.15 Monitoring should be continued for a period of at least 3 months, and preferably for six months, after installation of sampling points. At least six sets of readings should be obtained before the results are interpreted and a report produced.

5.16 At this stage, sufficient information should be available to allow progression to the finalisation of qualitative risk assessment and building protection design. However, if the results of the investigation are contradictory or require further clarification, then it may be appropriate to carry out a supplementary investigation. This should draw on the techniques already described above.

5.17 It is good practice to continue monitoring after completion of the main and supplementary investigations, typically at monthly intervals until the development is completed. Other arrangements for long-term monitoring will be determined as part of the overall building protection design.

6 DETAILED QUALITATIVE RISK ASSESSMENT

6.1 Completion of the site investigation allows a much more detailed and accurate picture of ground conditions and evidence of gas migration to be built up. The information is likely to affect the results of the preliminary qualitative risk assessment, and it is therefore appropriate to review the preliminary assessment and to produce a revised output. The format of the assessment can remain the same, although some new pathways may have come to light, and some presumed pathways may be discounted. The procedure for this review is given in Figure 6.1.

6.2 Whereas the results of the preliminary assessment were used to categorise the site into five risk groups, this is not the purpose of the final assessment. Rather the final assessment should highlight the vulnerable aspects of the development and direct the specialist towards those areas of design which require upgrading or revising to take account of the presence of gas or leachate in the ground.

6.3 In some circumstances where the need to understand the degree of risk is critical, it may be necessary to undertake a quantitative risk assessment (QRA). This may require very detailed information on the source of gas, in particular data on volatile organic compounds (VOCs) both at the landfill and in gas reaching the development site, and on the nature of the activities to be undertaken at the development site. The procedures for carrying out the QRA are complex and beyond the scope of this Guidance Note.

7 DEVELOPMENT PROTECTION DESIGN

Introduction

7.1 In describing the planning stage (Stage 1), in Section 4 of this Guidance Note, a series of generic protection measures were described for each of the five different categories of development site. Whilst these generic groups will be helpful in forming an early indication of the nature of protection required for the development, they should not be seen to be absolute requirements. On the basis of detailed site investigation and revised risk assessment, specific protection measures can then be designed which are directly related to the targets identified as being at risk in the assessment. A flow chart for procedures at this stage is given on Figure 7.1.

Design Objectives

7.2 It is important when designing gas protection measures to establish a set of objectives which must be achieved by the final design. The gas protection measures may be located on the boundary of the development site closest to the landfill (to prevent gas migration into the area of the development), at the buildings or at both locations.

7.3 Control of landfill gas and leachate within landfills is the subject of detailed advice already available in, for example, Waste Management Paper 27 (UK HM Inspectorate of Pollution, 1991) and Guidelines for the Safe Control and Utilisation of Landfill Gas (UK Department of Trade and Industry et al 1993). The reader is referred to these documents for information and may consider the relevance of the guidance to the circumstances at their development.

7.4 A reasonable set of objectives for design of building protection may be:

- In terms of methane and carbon dioxide hazards, to exclude completely landfill gas from all buildings, services, ducts and enclosed spaces.

- To design sufficient gas control methods to facilitate successful operation of the development throughout the remaining gas producing lifetime of the landfill site.

- To use a set of control systems which are simplest and require the least maintenance to achieve the above objectives.

Multiple System Design

7.5 In order to meet the general design objectives and to provide "sufficient gas control methods", it will generally be necessary to have more than one system of control to ensure that landfill gas does not affect the development. This is the basis of the concept of "multiple system" design. The number and type of "systems" provided is related to the perceived degree of risk from landfill gas to the development. The risk will depend on the nature of the development itself and will be different for, for example, buildings, car parks and landscaped areas. The design of the "systems" is carried out on the basis of each being able to stand in its own right as a means of controlling gas.

Site Specific Design Measures

7.6 It is inappropriate for this Guidance Note to be prescriptive regarding the detail of gas protection measures. However, the types of measures which can be adopted are described below in relation to the generic terms set out in Section 4 and *Table 4.2*. Selection of protection measures must be based upon the actual risk identified and should be designed to reduce the risk to a normally acceptable (or background) level.

7.7 Sketches showing the general concepts of the various types of gas protection measures and drawings of typical design details are provided in *Figures 7.2* to *7.9*. Drawings of typical design details for protection of services, are included in Annex B.

General Protection Measures

7.8 One approach to the protection of buildings against landfill gas ingress is to provide measures which prevent gas entering the ground on which the buildings are to be constructed. This approach has the advantage that it is largely independent of the design of the buildings, or their foundations, and also protects services running through the same area of land as the development.

Passive Systems (Gas Barriers and Vents)

7.9 The most common way of preventing gas from entering an area of ground is to set a 'gas barrier' into the ground which is either keyed into low permeability strata or extends at least 1 metre below the lowest groundwater level.

7.10 Any gas barriers used for this purpose should be engineered to be effectively impermeable to gas transport and, as such, for natural material barriers (for example soil bentonite mixes) the permeability (hydraulic conductivity) should be 10^{-9} ms^{-1} or lower and for membrane liners the hydraulic conductivity should be 10^{-12} ms^{-1} or lower. The difference in these values reflects the relative thickness of a soil-bentonite filled trench compared with a membrane lined trench, which is generally three orders of magnitude.

7.11 Barriers using membranes, often called 'Flexible Membrane Liners' (FMLs), may utilise polyethylene (low or medium density), asphaltic composites or other polymeric materials which can be demonstrated to possess a long-term stability which will guarantee a lifetime of at least 30 years.

7.12 The presence of a gas barrier to the movement of gas may lead to a gradual build up of gas on the landfill side of the barrier if the gas migration pathway is covered by low permeability materials. To relieve the potential build up of gas, it may be necessary to install additional measures for venting the gas such as trenches filled with no-fines, granular material, such as gravel, connected to venting pipes which will provide a preferential pathway for the release of gas to atmosphere. An outline of this type of protection measure is shown on Figure 7.2 and a more detailed cross-section of a typical design is presented on Figure 7.3.

7.13 The current level of understanding of gas transport in soils around landfill sites does not allow rigorous analysis and consequently there are no 'design equations' for cut-off barrier specifications. **It is therefore essential to seek expert advice before finalising the design detail of any cut-off barrier.**

Active Systems

7.14 Active systems for preventing gas entering an area of land usually comprise a series of vertical wells arranged in a line across the route of gas migration. By applying suction to the wells gas is drawn out of the ground and gas which is migrating horizontally towards the development site is intercepted. In practice, such systems are generally not employed, unless there are substantial volumes of gas migrating through the ground, because there are a number of potential drawbacks to the method as follows:

- By applying suction to the ground at the development site, gas will tend to be drawn away from the landfill site and encouraged to migrate laterally into the ground outside the landfill. This goes against the general philosophy of landfill gas control which is to contain the gas within the landfill site. (Installation of wells within the waste, however, is a commonly and successfully used technique for controlling the gas at source - see UK HM Inspectorate of Pollution 1991, UK Department of Trade and Industry et al 1993).

- Such systems have to be carefully controlled on an ongoing basis (eg. amount of suction applied to each well). As well as being expensive to install they are therefore expensive to maintain.

- Being mechanical systems they are prone to failure.

7.15 The alternative active control scheme of injecting an inert gas into the ground to create a positive pressure in order to reduce migration and cause dilution of the landfill gas is unproven and generally not used. The technique suffers most of the same problems as active extraction with the added complication, cost and uncertainties of introducing the inert gas into the ground.

7.16 Outlines of these two types of active protection measure are shown on Figure 7.4.

Gas Monitoring

7.17 With either the passive or active systems described above it is usual to install monitoring wells into the ground on the development side of the barrier or extraction wells. These are used to measure the concentrations of methane and carbon dioxide within the ground and hence determine the effectiveness of the measures in preventing landfill gas migration.

Building Protection Design Measures

7.18 Building design measures can be both passive, meaning they rely on natural air movement to prevent gas build-up, or active, meaning they require energy input to mechanically move air to protect against gas build-up.

Passive Systems

7.19 Passive control measures for buildings include the following:

- Gas-resistant polymeric membranes which can be incorporated into floor or wall construction as a continuous sealed layer. Membranes should be able to demonstrate low gas permeability and resistance to possible chemical attack, and may incorporate aluminium wafers to improve performance.

- Other building materials such as dense well-compacted concrete or steel shuttering which provide a measure of resistance to gas permeation.

- Creation of a clear void under the structure which is ventilated by natural air movements such that any emissions of gas from the ground are mixed and diluted by air.

- Synthetic composite geotextiles which provide a free-venting cellular structure and provide preferential pathways for release of gas.

7.20 Passive control measures may be used in low and medium risk situations where gas emissions are expected to be at relatively low rates and concentrations and venting to atmosphere is unlikely to cause a hazard or nuisance due to the low concentration or high dilution which will occur. Passive control measures are generally preferable, if the rates of gas emission are not too high, because they do not require as much maintenance or monitoring as active control systems.

7.21 The general principle of passive sub-floor venting is shown on Figure 7.5*(a)* and typical design details for flexible membrane protection measures are shown on Figure 7.6.

Active Systems

7.22 Active control measures are employed where the rates of gas emission are too high to rely on passive ventilation or in particular circumstances where, for example, there is a sensitive target to protect. Active control measures include the following.

- A void under the structure, as discussed for passive control, but which is continuously ventilated by a fan, such that any emissions of gas from the ground are mixed and diluted in the air flow before discharge to atmosphere. The rate of ventilation is usually expressed in terms of the number of air changes (volume of the void) per hour and is designed to ensure that, based on the estimated rate at which gas will enter the void, the landfill gas will be diluted to safe concentrations. Discharge to atmosphere usually takes place above the eaves level of the building or, in the case of high rise structures, at a minimum height of 10 metres above ground and away from air intakes to the building.

- Construction of a granular layer incorporating perforated collector pipes which is continually ventilated by a fan, such that any emissions of gas from the ground are drawn towards the end of the pipes and diluted in the air flow before discharge to atmosphere above the eaves level of the building, or in the case of high rise structures, at a minimum height of 10 metres above ground and away from air intakes to the building.

- Creation of a positive pressure zone below the building structure by injection of air from a blower into the granular layer.

- Creation of positive air pressure zones within building structures to counteract possible leakage of gas into the building from the ground.

7.23 The general principle of active sub-floor ventilation is shown in Figure 7.5*(b)*.

7.24 Active control measures should always be used in conjunction with passive barriers such as membranes in floors, in order that there is no leakage of air/gas flow through a floor or wall into a structure. Gas detection systems should also be used to monitor gas in extracted air flow, and to monitor internal spaces inside buildings. Active systems are normally required for high risk sites where gas has been measured in the ground at or close to the development site, and buildings are close to the source of gas.

Gas Detection System

7.25 Gas detection systems include the following:

- A series of sensors located in appropriate positions within a structure where gas has the potential to accumulate eg. near to service entries, in unventilated basements, cupboards or ducts. The sensors detect flammable gas by the catalytic oxidation or infra-red principles, and pass data back to a control panel by electrical cabling. The control panel can be set to have two triggers activating alarms, and may also be linked by telemetry to off-site offices. A schematic of a typical gas detection system is presented in Figure 7.7. The sensors can also be used to activate fans, or increase speed of fans, in active gas control schemes.

- A series of sampling tubes which are located in appropriate positions (see above) and run back to a single measurement station operating on infra-red measurement principles. A pump automatically draws samples of air/gas along each tube in a pre-set pattern such that measurements of flammable and/or other gases (such as carbon dioxide) can be taken at regular and frequent intervals. Triggers, alarms and telemetry systems can be incorporated.

- Manual monitoring can be undertaken using a range of portable instruments. Instruments used in areas where flammable gas may be present should be intrinsically safe.

7.26 Gas detection systems should only be proposed where there is an organisation involved in the long-term use of the development which can be relied upon to maintain and calibrate the system on a regular basis. The systems can be used in three ways:

- as a means of monitoring the amount of gas being extracted from below a building and initiating actions such as an increase in ventilation in the event of rising gas concentrations;

- as a final line of defence in detecting gas which has, by whatever means, by-passed other protective measures; and

- as a means of demonstrating the effectiveness of gas protection measures.

7.27 Where a detection system is used as a final defence, it must be ensured that appropriate emergency actions, to be taken in the event of the trigger levels being exceeded, are specified. These should include procedures for evacuation if necessary.

Maintenance of Control Measures

7.28 Fundamental to the success of gas protection measures is the means by which they are monitored, managed and maintained, and thus all designs must be accompanied by a statement or set of procedures showing how the measures proposed can be confidently expected to operate satisfactorily for the duration of the potential gas-producing lifetime of the landfill.

Design Measures for Sub-Surface Building Services

7.29 Whilst the design of the development is the responsibility of the project proponent, there will be an interface with the utility companies, and the Professional Person should liaise with them about the gas protection measures being implemented for the development, particularly with respect to service entries and excavations for cable/pipe laying. The utility company should also ensure that their works, both feeding to the development site and in roads passing by, are protected from landfill gas and that their trench excavations do not form a route for gas migration.

General

7.30 Protection measures applied to service conduits should not be considered in isolation and it is essential that an integrated approach is adopted in which gas protection of the building (or development) is formulated in conjunction with the service conduits. However, there are a number of generic protection measures which may be applied to service conduits. The choice and exact details of any particular measures used for services must be considered in conjunction with the primary building protection strategy as discussed above.

7.31 The Professional Person's attention is drawn to the need to consult with Government and relevant utility companies prior to specification of the gas protection measures; including, but not limited to:

- Electricity supply utilities;
- Hong Kong and China Gas Co;
- Water Supplies Department; and
- Drainage Services Department.

7.32 Attention is also drawn to developments which may be located outside the consultation zone but which have service runs which pass through the zone. Under these conditions, whilst the building development itself falls outside the requirements of the Guidance Note, the service runs and any construction work which involves excavation deeper than 300mm which is located in the Consultation Zone should have some form of protection measures.

7.33 Therefore, the advice which follows applies equally to both service installations for developments within the Consultation Zone and also to service conduits and runs which are located within the Consultation Zone but which feed building developments located outside the Consultation Zone. Additional recommendations, specific to the case of service conduits which pass through the Consultation Zone, are also presented.

7.34 Basically, there are three generic measures which may be employed, as follows:

- barriers;
- vents; and
- location of the service utilities outside the potential gas migration pathway.

7.35 A general discussion on each of these types of protection measure is presented below and more detailed information is provided in Annex B.

Generic Protection Measures

Gas Barriers

7.36 As for barriers used to prevent movement of gas through the ground, use may be made of clay (or clay-rich soils), bentonite or polymeric membranes (such as HDPE). A gas barrier used to prevent movement of gas through services may form part of a more extensive barrier to prevent general migration towards the development (see above). The design detail at the point where the service penetrates the membrane is important and, in the case of HDPE membranes, pre-formed shrouds are often available.

7.37 A schematic of a natural material cutoff barrier, including sealing of a service trench is shown in Figure 7.8 and a schematic for an HDPE flexible membrane cut-off is shown in Figure 7.9.

7.38 In the case of water pipes and sewers which are not always fully filled, water traps, such as U-bends, should be provided to effectively seal off the conduit and prevent gas-phase transport. Further discussion on the measures which may be applied to water pipes and those which may be used to prevent the ingress of gas into a building via the interface between a pipe and the backfilled soil are discussed in Annex B.

Gas Vents

7.39 Vent pipes or gridded manhole covers may be used to avoid build-up of gas in underground utilities manholes. Venting stacks may be built into inspection chambers or connected to collection pipes within high permeability drainage layers adjacent to gas barriers. The various types of venting arrangement are discussed further in Annex B.

7.40 Under all circumstances, due to the possible accumulation of gas, care will be needed in accessing any manhole chambers, especially those which are not fitted with vents and the safety procedures detailed below must be rigidly followed.

Location of Service Entry Points Above Ground

7.41 In some cases it is possible to route service entries into a building above ground level, thereby providing a discontinuity in the gas migration pathway and thus eliminating the risk of gas entry to the building interior. Further details, including means of overcoming potential architectural constraints of this approach, are presented in Annex B.

Service Conduits Which Pass Through the Consultation Zone

7.42 In addition to the general guidance given above, the following recommendations apply to service conduits which pass through the Consultation Zone with connections to developments outside the Zone:

- For all such service runs, the aim should be to provide a protection barrier located at the point (or points) where the trench passes through the perimeter of the Consultation Zone.

- The service runs through the Consultation Zone may remain 'unprotected' since the risks will be minimised by the protection measures installed at the perimeter of the Consultation Zone and because the general public do not have access to such underground features.

- The service run should be designated as a 'special route' and the utility companies should be informed to that effect so that they may implement precautionary measures (see below).

- Any future works such as maintenance or extension should be subject to the recommendations specified in this Guidance Note.

- Any above ground (minor) termination features, such as telecom cabinets, should be considered to be 'buildings' and should be protected by, for example, membrane barriers to minimise the possibility of gas ingress.

7.43 Typical details of the measures required for services which pass through a Consultation Zone are shown in Annex B.

Guidance for Entry Into Manholes and Chambers

7.44 Any chamber, manhole or culvert which is large enough to permit access to personnel should be subject to entry safety procedures. 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.

7.45 The key issues with regards to confined spaces which are at risk of landfill gas build-up are set out below.

- The entry or access point should be clearly marked with a warning notice (in English and Chinese) which states that there is the possibility of flammable and asphyxiating gases accumulating within.

- The warning notice should also give the telephone number of an appropriate competent person who can advise on the safety precautions to be followed before entry and during occupation of the manhole.

- Personnel should be made aware of the dangers of entering confined spaces potentially containing hazardous gases and, where appropriate, should be trained in the use of gas detection equipment.

- Prior to entry, the atmosphere within the chamber should be checked for oxygen, methane and carbon dioxide concentrations. The chamber may then only be entered if oxygen is greater than 18% by volume, methane is less than 10% of the Lower Explosive Limit (LEL), which is equivalent to 0.5% by volume (approximately), and carbon dioxide is less than 0.5% by volume.

- If either carbon dioxide or methane are higher, or oxygen lower, than the values given above, then entry to the chamber should be prohibited and expert advice sought.

- Even if conditions are safe for entry, no worker should be permitted to enter the chamber without having another worker present at the surface. The worker who enters the chamber should wear an appropriate safety/recovery harness and, preferably, should carry a portable methane, carbon dioxide and oxygen meter.

7.46 In general, when work is being undertaken in confined spaces sufficient approved resuscitation equipment, breathing apparatus and safety torches should be available. Persons involved in or supervising such work should be trained and practised in the use of such equipment. A permit-to-work system for entry into confined spaces should be developed by an appropriately qualified person and consistently employed.

8 HAZARDS ARISING DURING CONSTRUCTION

Introduction

8.1 During the construction phase, hazards may arise which are related either to the flammability of landfill gas or to it's potentially asphyxiating properties. In particular cases, it is possible that toxicity effects may be significant. The following sub-sections of the Guidance Note may be used to form the basis of Specification Clauses for incorporation in Contract Documentation for developments within the Consultation Zone.

General Hazards Which May Be Encountered

8.2 The developer should be aware of, and should inform construction contractors accordingly, that methane and carbon dioxide are always likely to be present in the soil voids. In addition the developer should be aware of the potential hazards and other properties of landfill gas as described in Section 1.

Outline of Safety Requirements

8.3 In all construction work adjacent to landfill sites, safety procedures should be implemented to minimise the risks of:

- fires and explosions;
- asphyxiation of workers; and
- toxicity effects.

8.4 Precautions should be clearly laid down and rigidly adhered to with respect to:

- trenching and excavation; and

- creation of confined spaces at, near to or below ground level.

8.5 In addition to normal site safety procedures, gas detection equipment and appropriate breathing apparatus should be available and used when entering confined spaces or trenches deeper than 1 metre.

Additional General Requirements

8.6 During the construction phase, the following additional precautions should be followed.

Appointment of Safety Officer

8.7 For large developments, a Safety Officer, trained in the use of gas detection equipment and landfill gas-related hazards, should be present on site throughout the groundworks phase. The Safety Officer should be provided with an intrinsically safe portable instrument (or instruments), appropriately calibrated and capable of measuring the following gases in the ranges indicated:

methane	0-100% LEL and 0-100 % v/v
carbon dioxide	0-100%; and
oxygen	0-21%

8.8 For smaller developments, if a Safety Officer is not appointed, then expert opinion and advice should be sought on a regular basis.

Safety Measures

8.9 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 excavations. Safety notices should be posted warning of the potential hazards.

8.10 Those staff who work in, or have responsibility for 'at risk' areas, including all excavation workers, supervisors and engineers working within the Consultation Zone, should receive appropriate training on working in areas susceptible to landfill gas, fire and explosion hazards.

8.11 An excavation procedure or code of practice to minimise landfill gas related risk should be devised and carried out by the project proponent.

8.12 No worker should be allowed to work alone at any time in or near to any excavation. At least one other worker should be available to assist with a rescue if needed.

8.13 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 and, if necessary, special areas designated for smoking.

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

8.15 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 (or, in the case of small developments, other appropriately qualified person).

8.16 The permit to work procedure should set down 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 shall be responsible for reviewing the gas measurements as they are made, and who shall 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.

8.17 Ground level construction plant should be fitted with vertical exhausts at least 0.6m above ground level and with spark arrestors.

8.18 Any electrical equipment, such as motors and extension cords, should be intrinsically safe.

8.19 During piping assembly or conduiting construction, all valves/seals should be closed immediately after installation. As construction progresses, all valves/seals should be closed as installed to prevent the migration of gases through the pipeline/conduit. All piping/conduiting should be capped at the end of each working day.

8.20 Mobile offices, equipment stores, mess rooms etc. should be located on an area which has been proven to be gas free (by survey with portable gas detectors) and ongoing monitoring should be carried out to ensure that these areas remain gas free. The use of permanent gas detectors may be appropriate in some circumstances where there is a relatively high risk but for many developments it will be sufficient to have regular monitoring undertaken manually by the safety officer. The particular arrangements to be adopted at a specific site will need to be determined during the risk assessment/design of protection measures.

8.21 Alternatively, such buildings should be raised clear of the ground. If buildings are raised clear of the ground, a minimum, clear separation distance (as measured from the highest point on the ground surface to the underside of the lowest floor joist) should be 500mm.

8.22 During construction, adequate fire extinguishing equipment, fire-resistant clothing and breathing apparatus (BA) sets should be made available on site.

- At larger developments, fire drills should be organised at not less than six monthly intervals.

- The developer should formulate a health and safety policy, standards and instructions for site personnel to follow.

Monitoring

8.23 Periodically during ground-works construction, the works area should be monitored for methane, carbon dioxide and oxygen using appropriately calibrated portable gas detection equipment.

8.24 The monitoring frequency and areas to be monitored should be set down prior to commencement of ground-works either by the Safety Officer or by an appropriately qualified person.

8.25 Routine monitoring should be carried out in all excavations, manholes and chambers and any other confined spaces that may have been created by, for example, the temporary storage of building materials on the site surface.

8.26 All measurements in excavations should be made with the monitoring tube located not more than 10mm from the exposed ground surface.

8.27 Monitoring of excavations should be undertaken as follows:

For excavations deeper than 1m, measurements should be made:

- 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 made:

- directly after the excavation has been completed; and
- periodically whilst the excavation remains open.

For excavations less than 300mm deep, monitoring may be omitted, at the discretion of the Safety Officer or other appropriately qualified person.

Actions in the Event of Gas Being Detected

8.28 Depending on the results of the measurements, actions required will vary and should be set down by the Safety Officer or other appropriately qualified person. As a minimum these should encompass those actions specified in *Table 8.1*.

Table 8.1 Actions in the Event of Gas Being Detected in Excavations

Parameter	Measurement	Action
O_2	< 19%	Ventilate trench/void to restore O_2 to >19%

Parameter	Measurement	Action
	< 18%	Stop works evacuate personnel/prohibit entry increase ventilation to restore O_2 to >19%
CH_4	> 10% LEL	Post 'No Smoking' signs prohibit hot works ventilate to restore CH_4 to <10% LEL
	>20% LEL	Stop works evacuate personnel/prohibit entry increase ventilation to restore CH_4 to <10% LEL
CO_2	>0.5%	ventilate to restore CO_2 to <0.5%
	> 1.5%	Stop works evacuate personnel/prohibit entry increase ventilation to restore CO_2 to <0.5%

Specific Advice Relating to the Drilling of Boreholes

8.29 As part of the site investigation and subsequent ground works for a development within a Consultation Zone, it will often be necessary to drill exploratory boreholes. Such work should be undertaken following the general advice given above. Specific recommendations relating to the drilling of boreholes within the Consultation Zone are presented below.

Supervision and Safety Management of Drilling Operations

8.30 Drilling should only proceed with adequate care and precautions against the potential hazards which may be encountered.

8.31 Before site works begin, the drilling contractor should devise a 'method-of-working' statement covering all normal and emergency procedures and the site supervisor and all operatives must be familiar with this statement.

8.32 The method-of-working statement should cover, *inter alia*:

- number of operatives;
- experience and special skills of operatives;

- normal method of operations;
- emergency procedures, including fire fighting;
- supervisors responsibilities;
- storage and use of safety equipment;
- safety procedures; and
- signs, barriers and guarding.

Safety Equipment and Clothing

8.33 An intrinsically safe, portable methane meter should be available at all times.

Other safety equipment should include:

- no smoking signs, to be placed prominently adjacent to the drilling area;
- portable fire extinguisher;
- high visibility clothing to be worn by all drilling operatives; and
- additional protective clothing should include stout industrial boots (with steel toe cap and insole), plastic hard hats, heavy duty waterproof industrial groves.

Working Procedures

8.34 On arrival at site the drilling rig should be set-up up-wind of the borehole location, 'No smoking' signs set out and the working area should be roped or coned-off.

8.35 When drilling on landfill sites, all spoil obtained from the borehole should be stockpiled alongside the borehole and disposed of (to an appropriately licensed disposal site) at the end of the working day. At the end of the working day all vehicles, the drilling rig and any hand tools should be hosed-down with clean water to remove deposits of excavated spoil. Suitable guards or barriers should be placed around the excavation or borehole to prevent access by unauthorised persons.

Safety Procedures

8.36 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.

8.37 Smoking should be prohibited anywhere on a landfill site and within 15 metres of a boring or excavation at any locations within the Consultation Zone.

8.38 For large diameter boreholes, a working platform should be placed over the hole which will prevent accidental entry into the hole by operatives.

8.39 No worker should be allowed to work alone at any time near the edge of the well under construction. Another worker should always be present, beyond the area considered to be subject to the possible effects of landfill gas or cave-in.

8.40 Periodically during the well construction, the work areas should be monitored for levels of methane.

8.41 If the well construction is not completed by the end of the working day, the hole should be covered with a plate of sufficient overlap to prevent access to the hole and sufficient structural strength to support expected loads. The plate should be weighted down to discourage removal and, on landfill sites, the edges of the plate should be covered with sufficient depth of wet soil to prevent escape of gas.

8.42 All pipes or casings should be capped at the end of each working day.

8.43 Engine-driven rigs should have vertical exhaust stacks discharging not less than 1.5m above ground level and should have overspeed limits to prevent engine run away on ingested gas.

8.44 Diesel engine air-intakes should also be located not less than 1.5m above ground level.

8.45 Any electrical equipment should be intrinsically safe.

8.46 Additional safety advice and guidance may be found in 'Investigation into Establishing an Effective Practical Safe Working Practice When Drilling in Landfill Sites and Adjacent Areas and Contaminated Ground and Adjacent Areas' compiled by the British Drilling Association (1993).

Installation of Vertical Wells

8.47 To prevent uncontrolled gas release and to protect personnel from the risk of falling into the borehole, the open borehole should be covered with a sheet or plate strong enough to support personnel and having an overlap all round the borehole.

8.48 The drilling rig, boring machine or excavator should remain in place over the borehole and could be used as a support to assist placement of the casing.

8.49 The upper end of the well casing should be sealed, preferably with a fused or screwed end cap or alternatively with an inflatable bag type flow stopper, until the permanent headworks/monitoring tap is fitted. Landfill gas must not be allowed to vent freely at the site surface.

9 REFERENCE LIST

1. United Kingdom Her Majority's Inspectorate of Pollution, 1991. The Control of Landfill Gas. Waste Management Paper No. 27. 2nd Edition.

2. United Kingdom Department of Trade and Industry, Department of the Environment, of gas, 1993. Guidelines for the Safe Control and Utilisation of Landfill Gas.

3. Hooker P J and Bannon M P, 1993. Methane: Its Occurrence and Hazards in Construction. CIRIA Report 130.

4. Crowhurst D and Manchester S J, 1993. The Measurement of Methane and Associated Gases from the Ground. CIRIA Report 131.

5. British Drilling Association, 1993. Investigation into Establishing an Effective Practical Safe Working Practice When Drilling in Landfill Sites and Adjacent Areas and Contaminated Ground and Adjacent Areas.

6. Hong Kong Government, 1994. Geotechnical Manual for Slopes. 2nd Edition.

7. Hong Kong Government, 1996. Factories and Industrial Undertakings (Confined Spaces) Regulations.

Figure 1.1

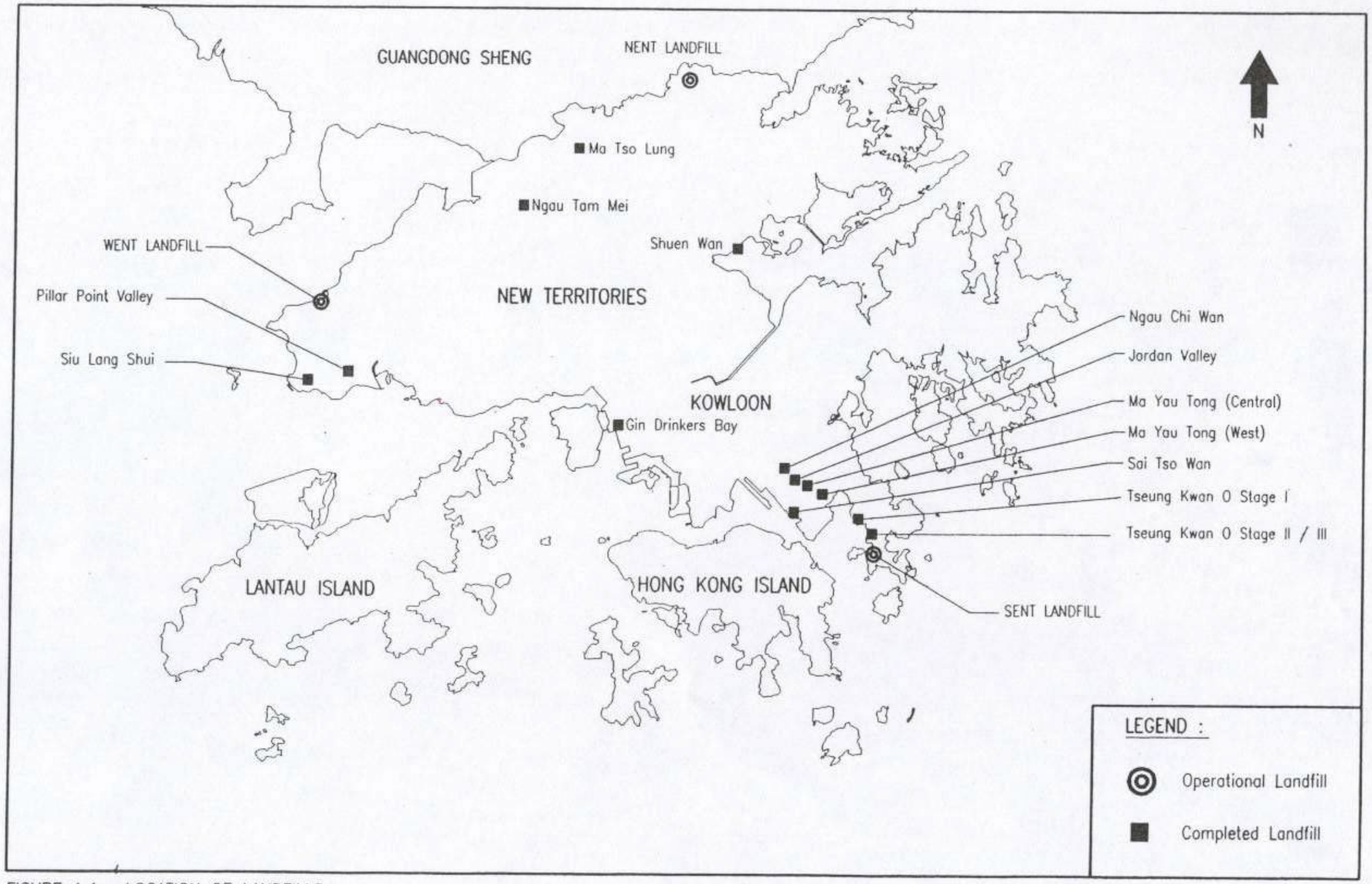


FIGURE 1.1 : LOCATION OF LANDFILLS

Figure 1.2

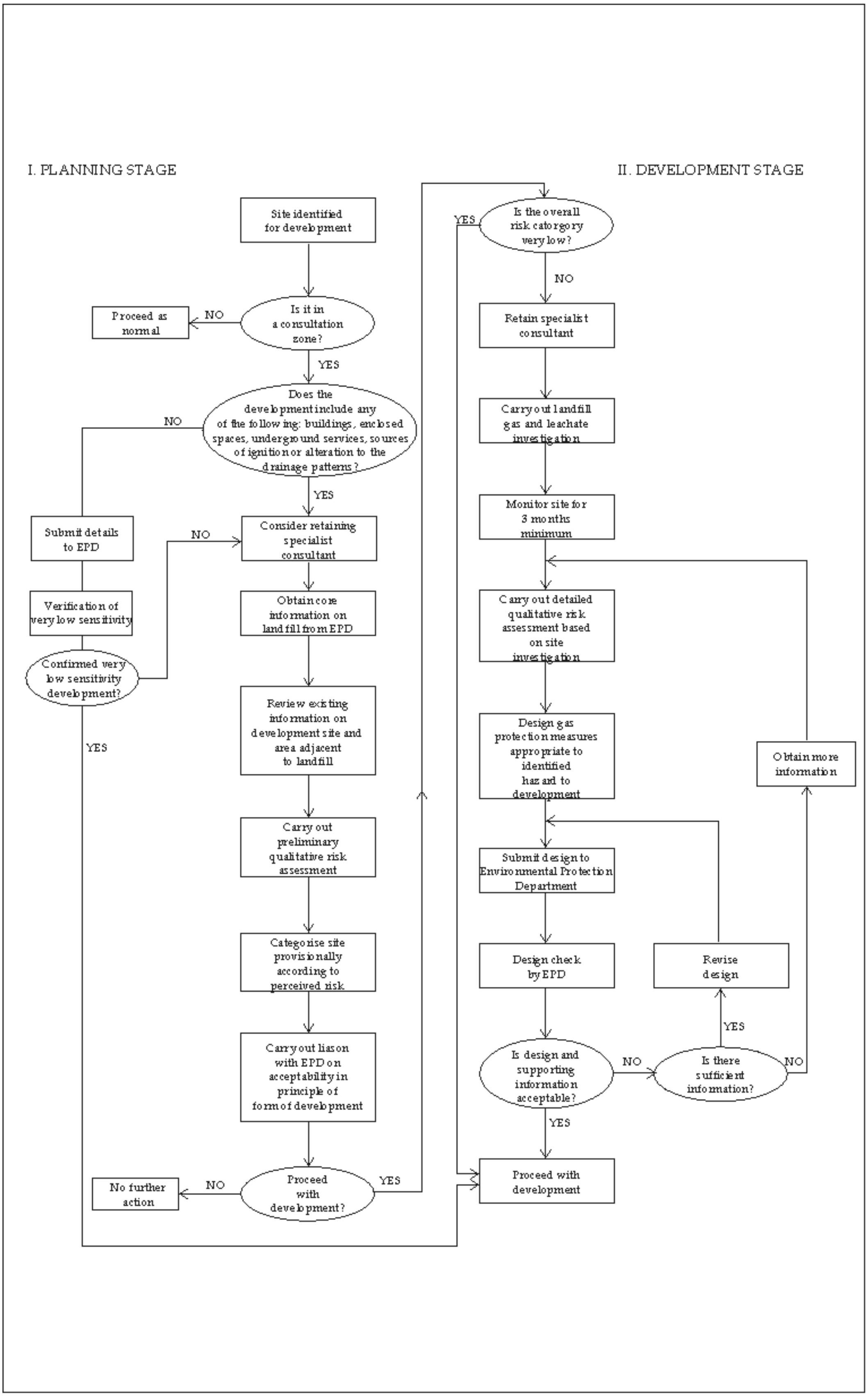


FIGURE 1.2 - FLOW CHART FOR PROFESSIONAL PERSON WHEN DEVELOPING WITHIN LANDFILL CONSULTATION ZONE

Figure 2.1

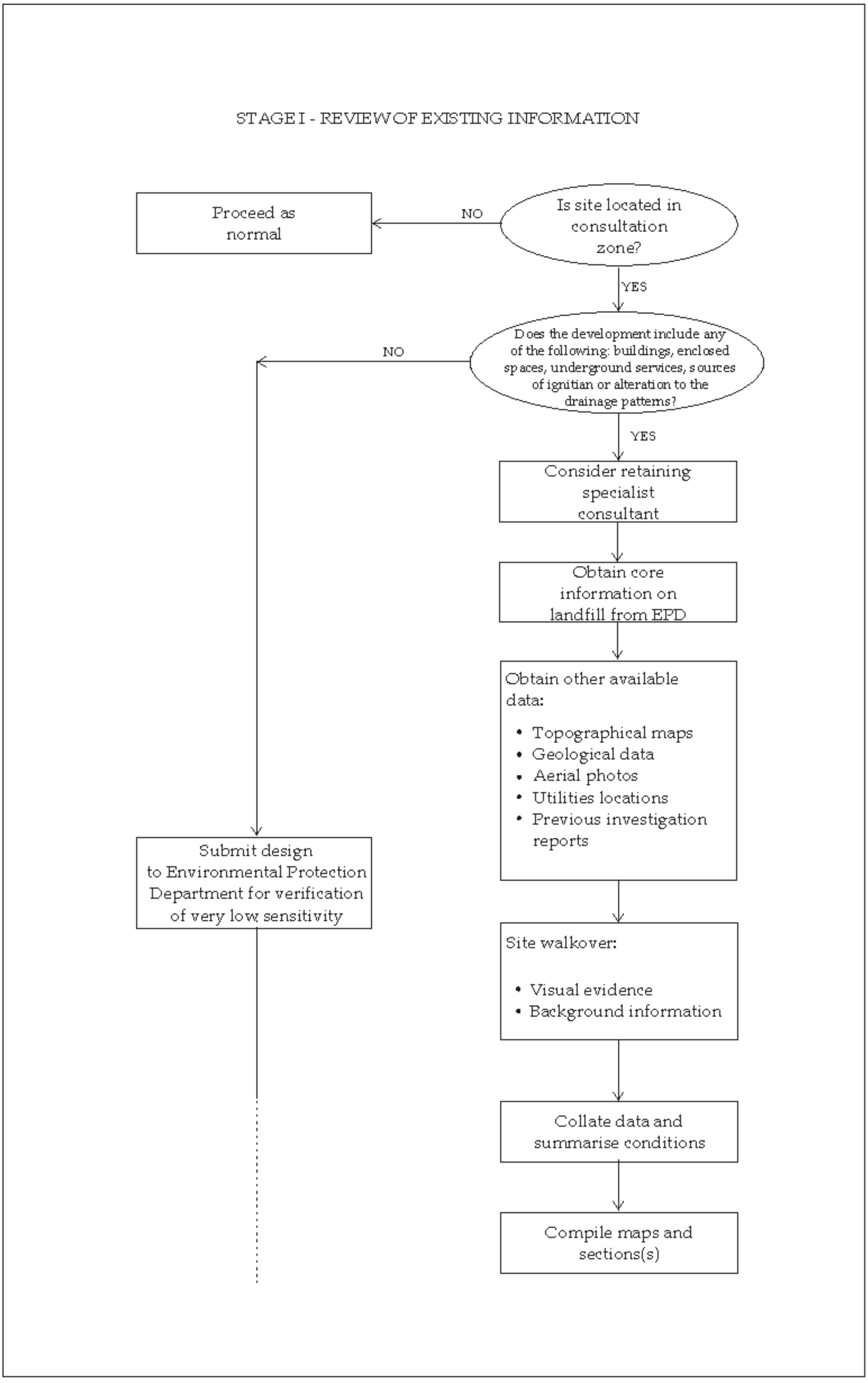


FIGURE 2.1 - FLOW CHART FOR PROFESSIONAL PERSON FOR PROCEDURES IN REVIEW OF EXISTING INFORMATION

Figure 3.1

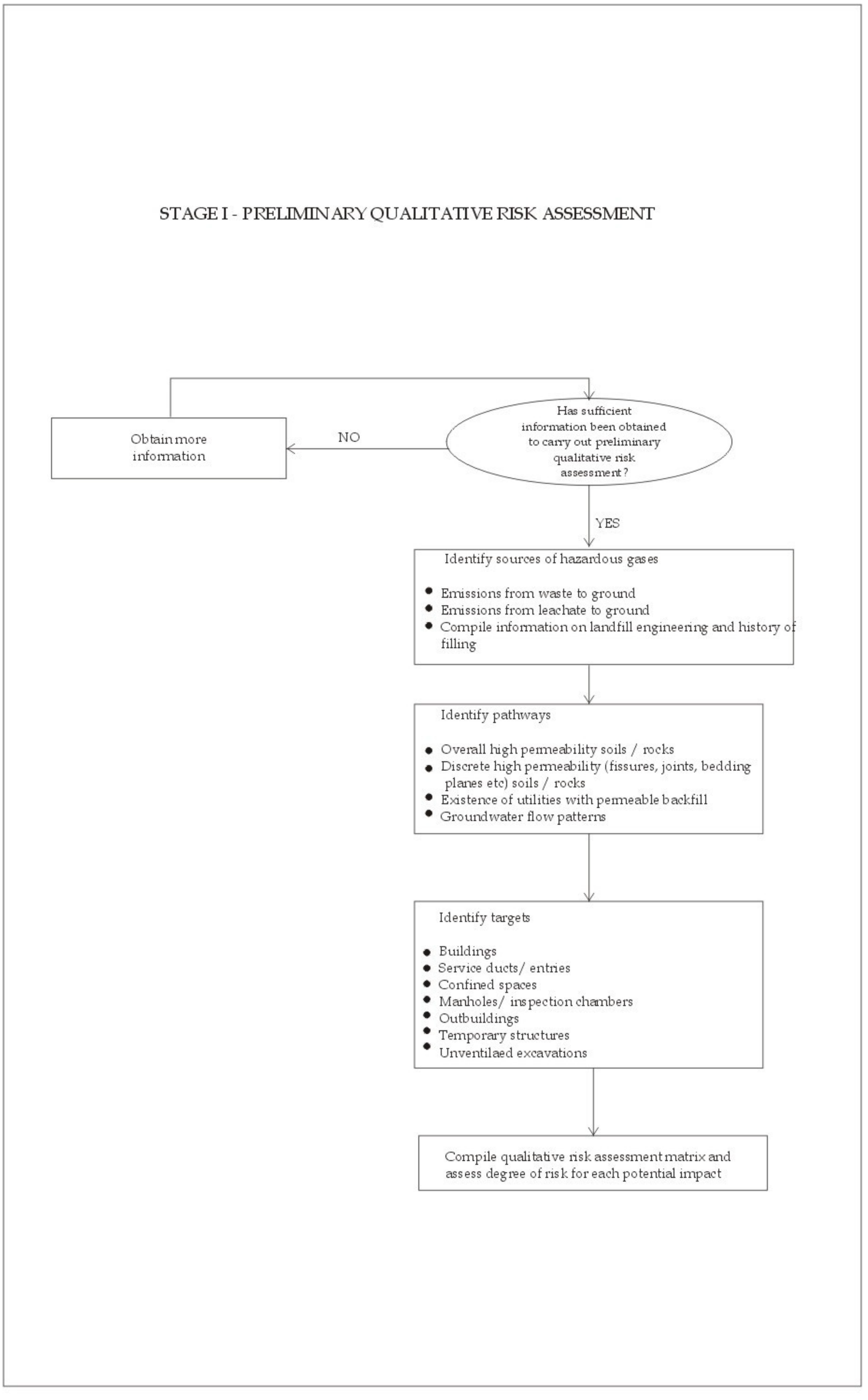


FIGURE 3.1 - FLOW CHART FOR PROFESSIONAL PERSON FOR PROCEDURES IN PRELIMINARY QUALITATIVE RISK ASSESSMENT

Figure 4.1

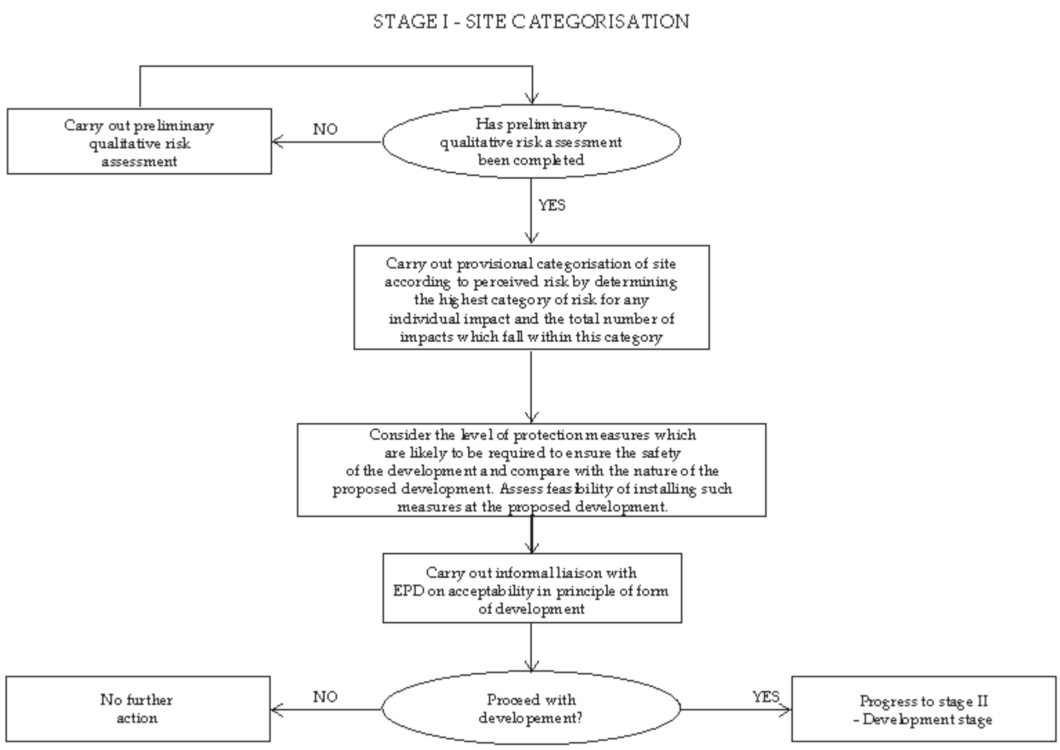


FIGURE 4.1 - FLOW CHART FOR PROFESSIONAL PERSON FOR PROCEDURES IN SITE CATEGORISATION

Figure 5.1

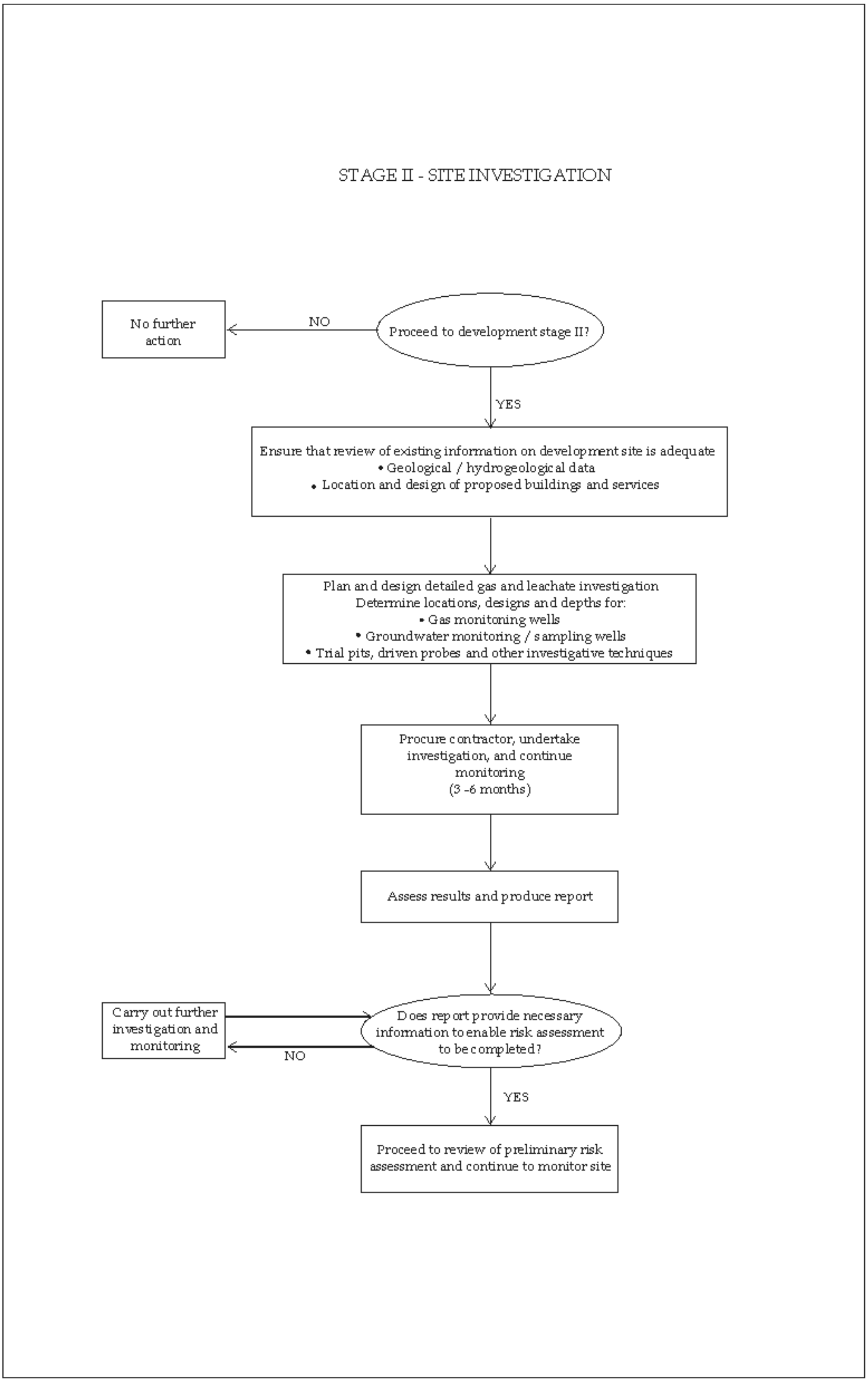


FIGURE 5.1 - FLOW CHART FOR PROFESSIONAL PERSON FOR PROCEDURES IN CARRYING OUT SITE INVESTIGATION

Figure 6.1

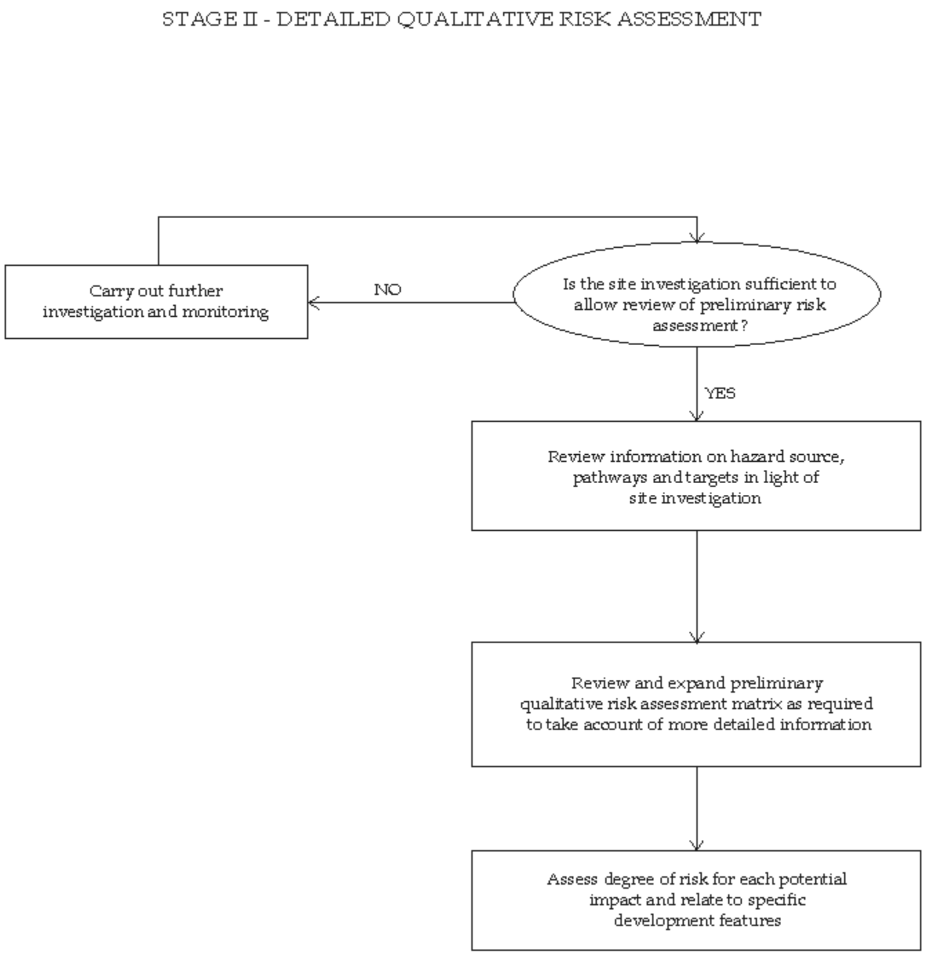


FIGURE 6.1 - FLOW CHART FOR PROFESSIONAL PERSON FOR PROCEDURES IN CARRYING OUT REVIEW OF QUALITATIVE RISK ASSESSMENT

Figure 7.1

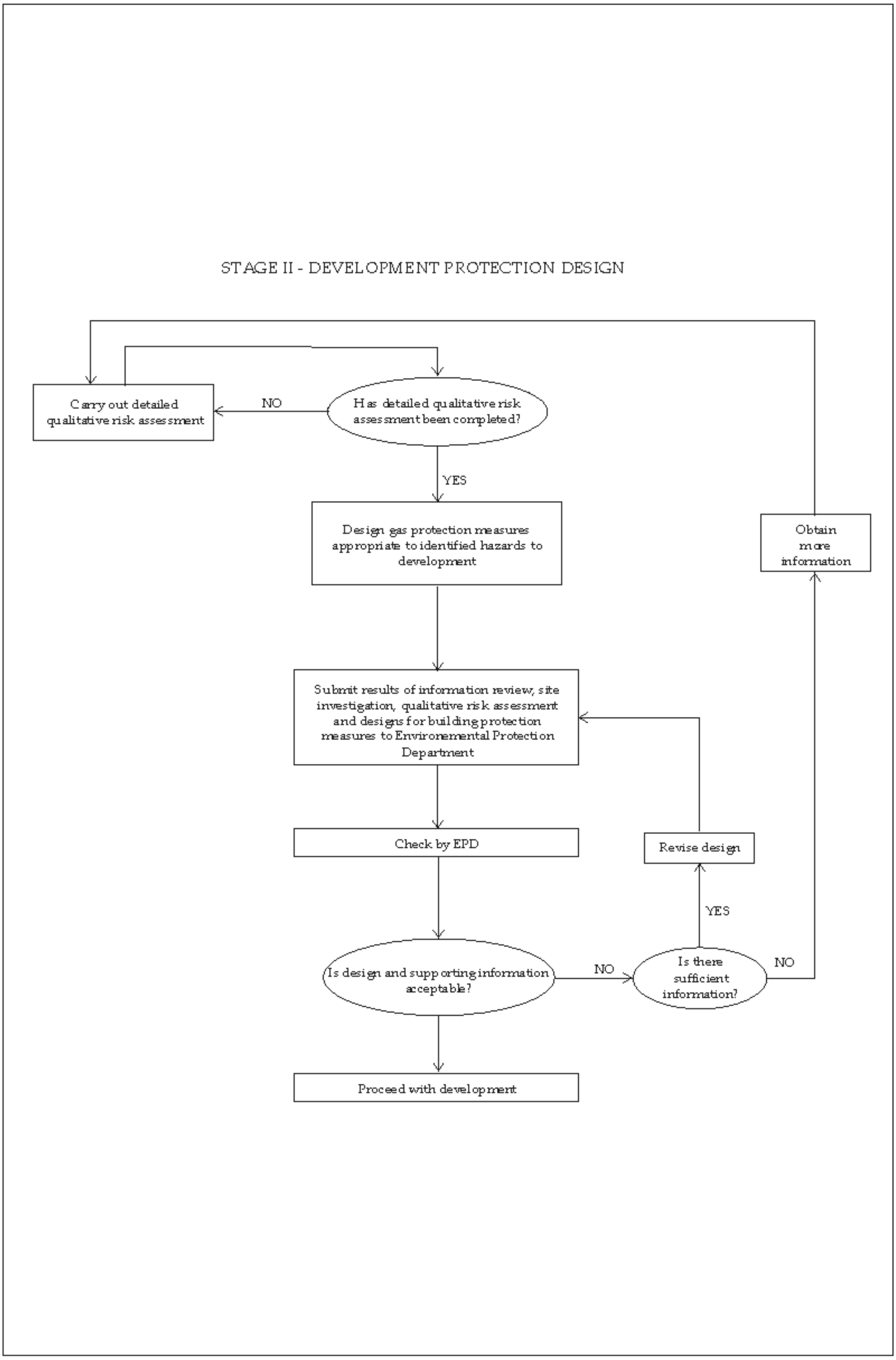


FIGURE 7.1 - FLOW CHART FOR PROFESSIONAL PERSON FOR PROCEDURES FOR DEVELOPMENT OF GAS PROTECTION DESIGN

Figure 7.2

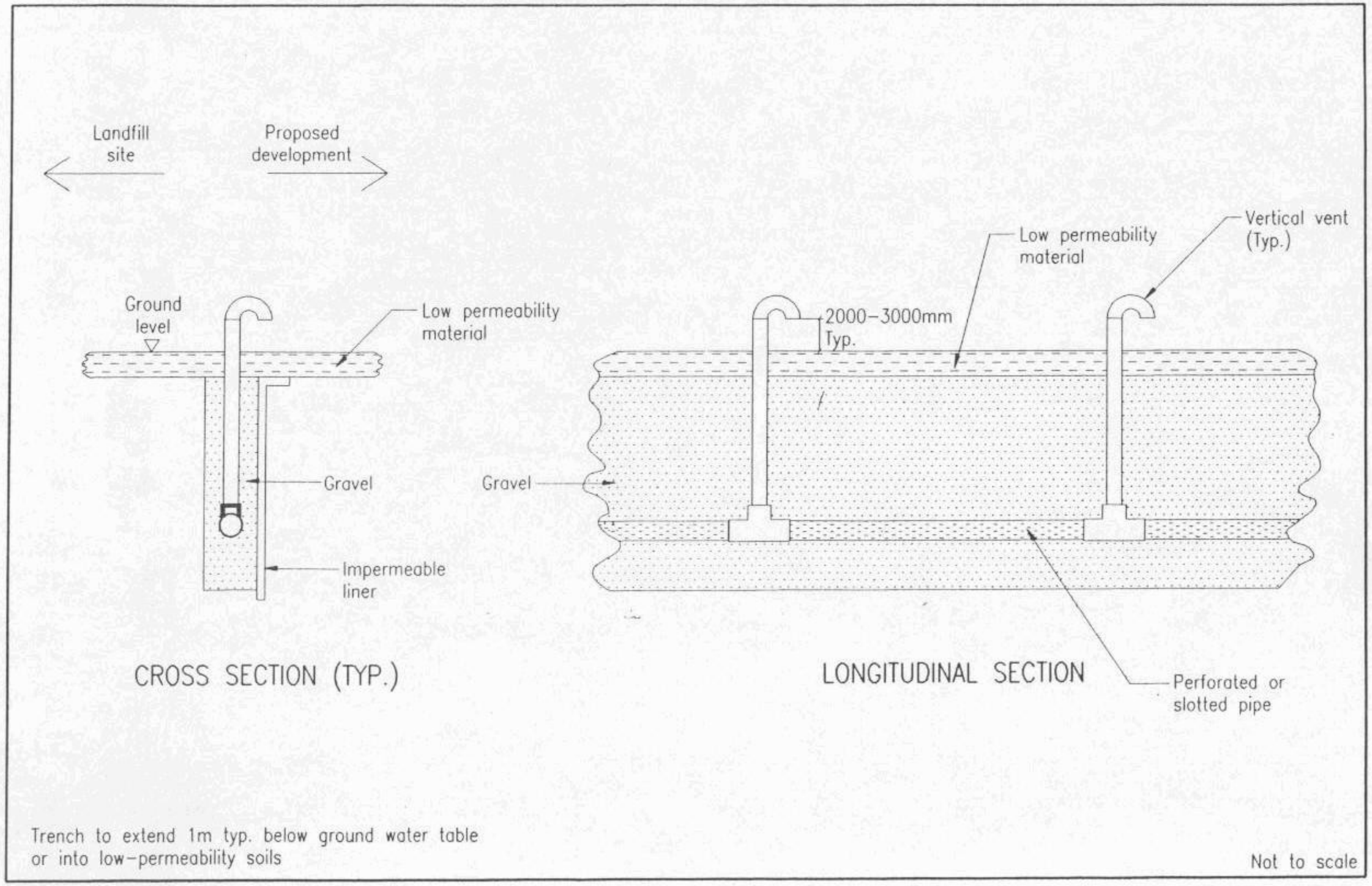


FIGURE 7.2 : PASSIVE TRENCH VENT (OUTLINE)

Figure 7.3

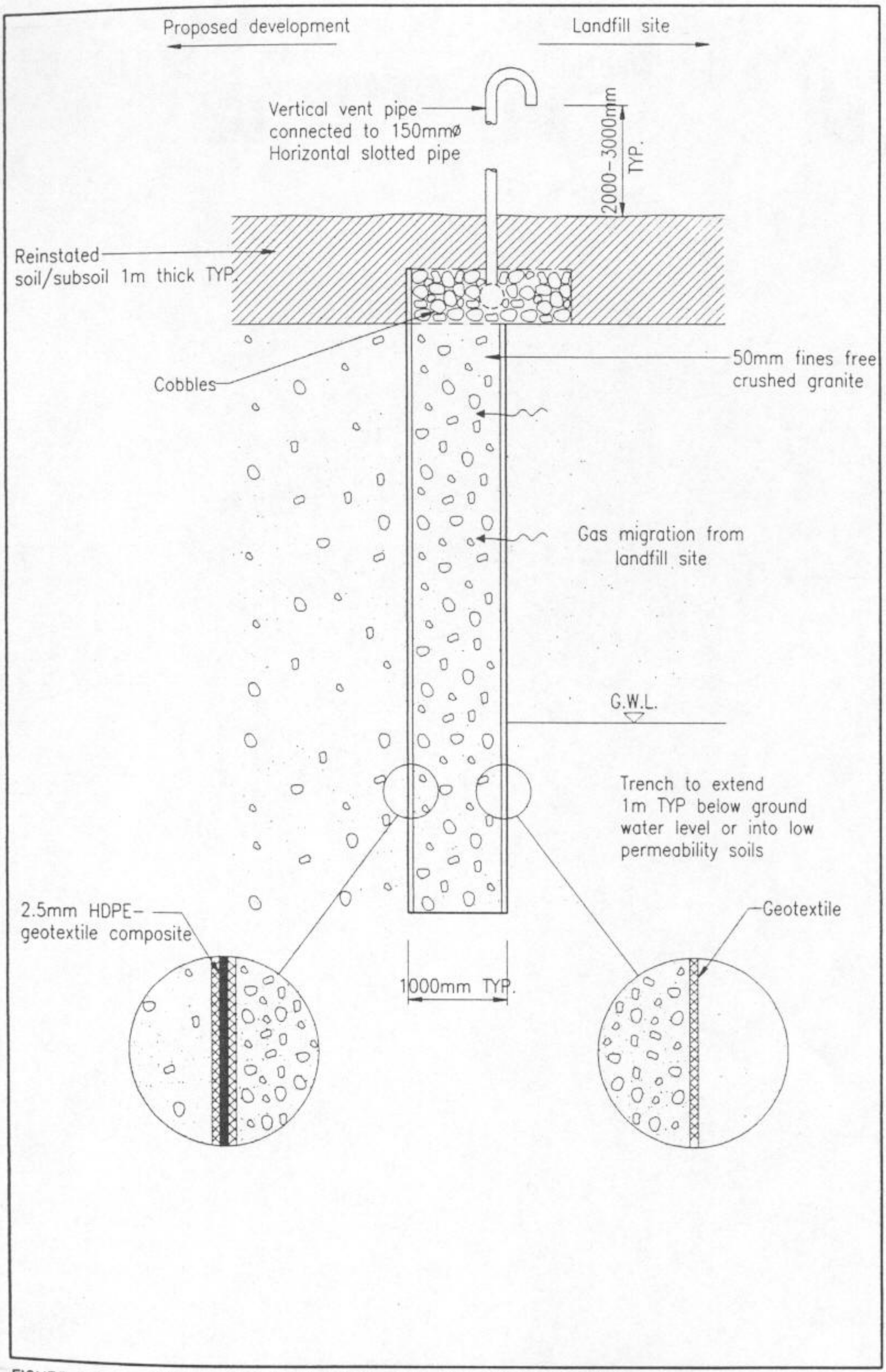


FIGURE 7.3 : TYPICAL DESIGN OF REMOTE CUT-OFF TRENCH BARRIER

Figure 7.4

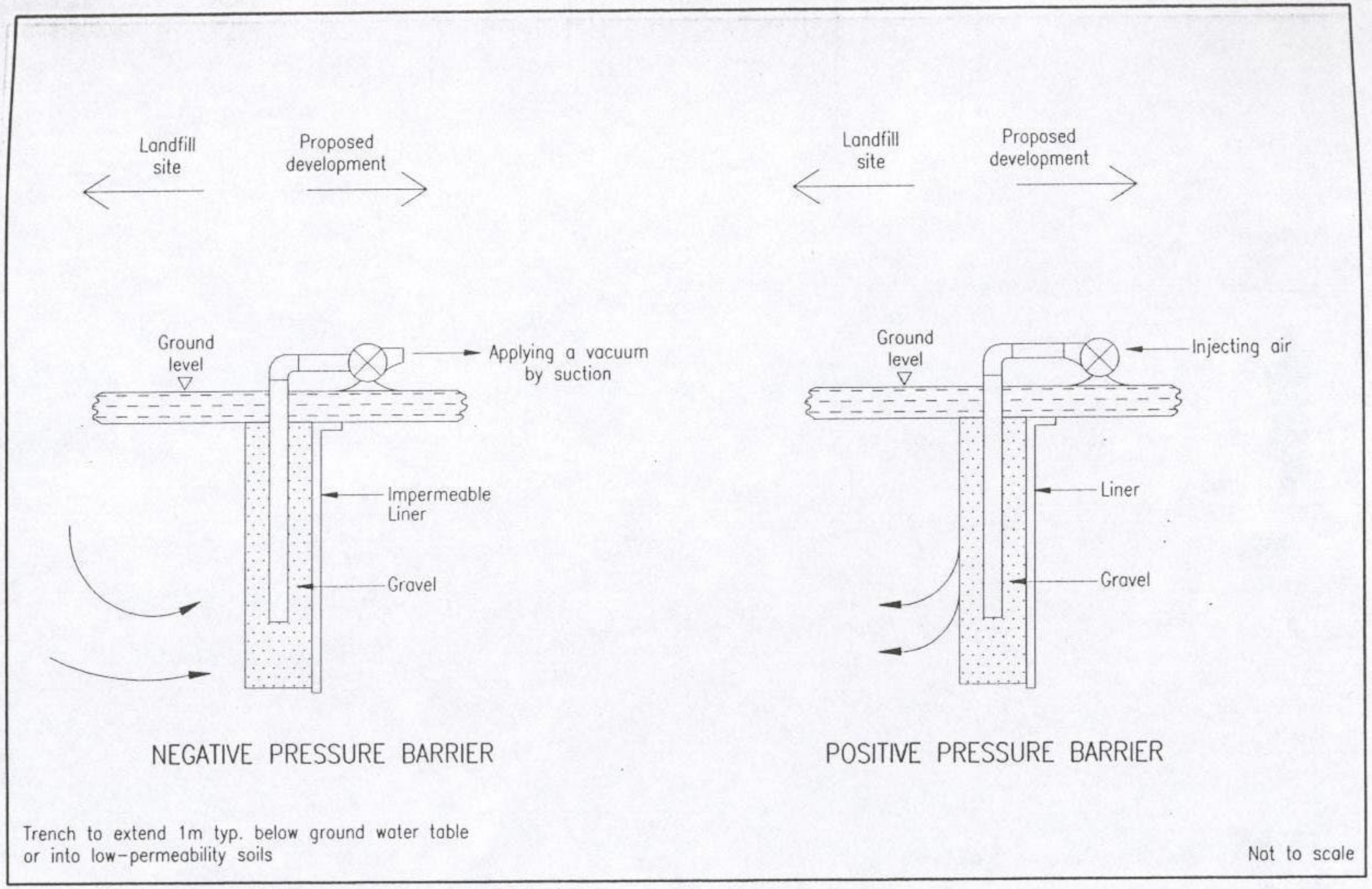


FIGURE 7.4 : ACTIVE TRENCH VENT (OUTLINE)

Figure 7.5

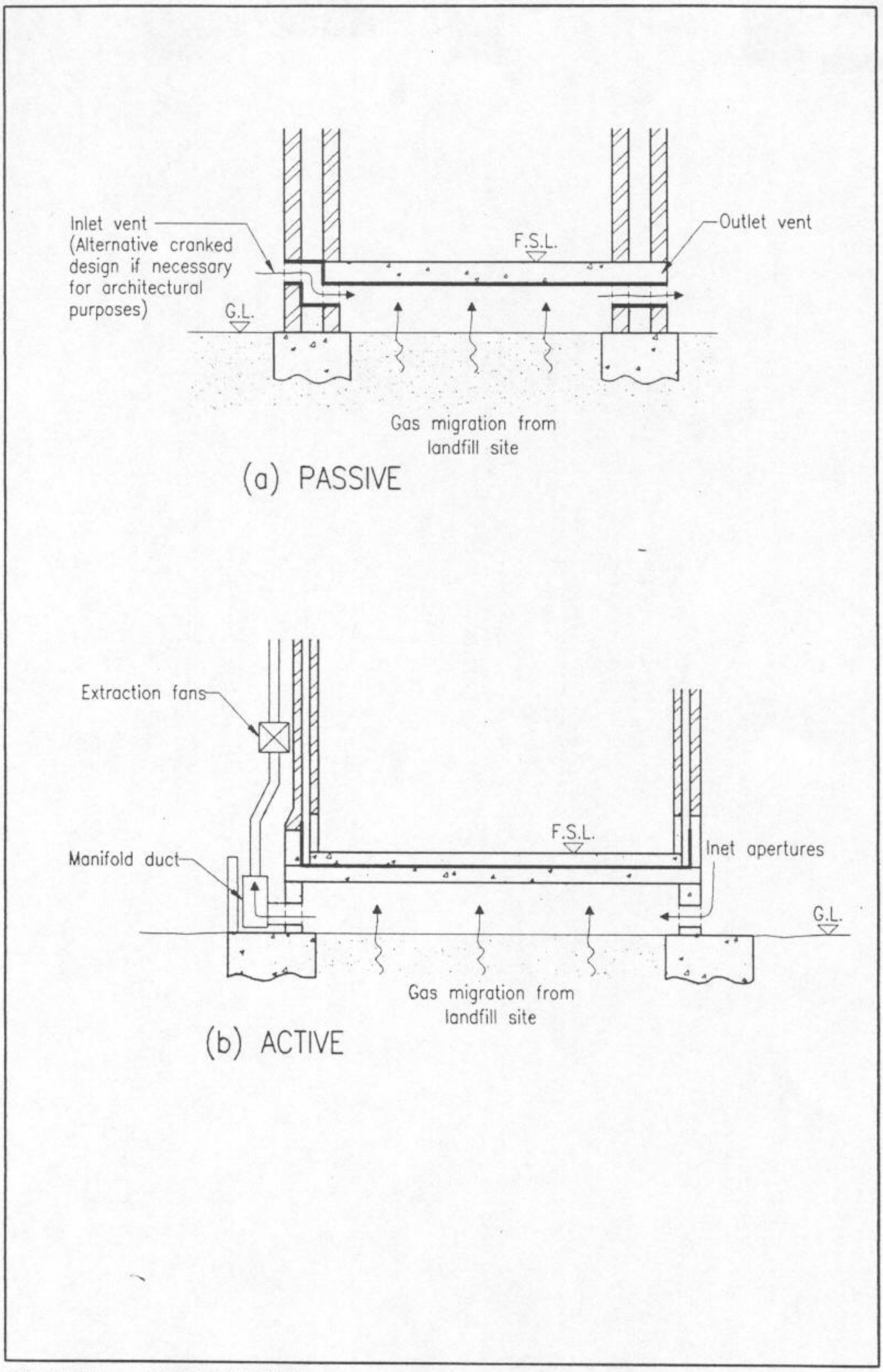


FIGURE 7.5 : SUBFLOOR VENTING

Figure 7.6

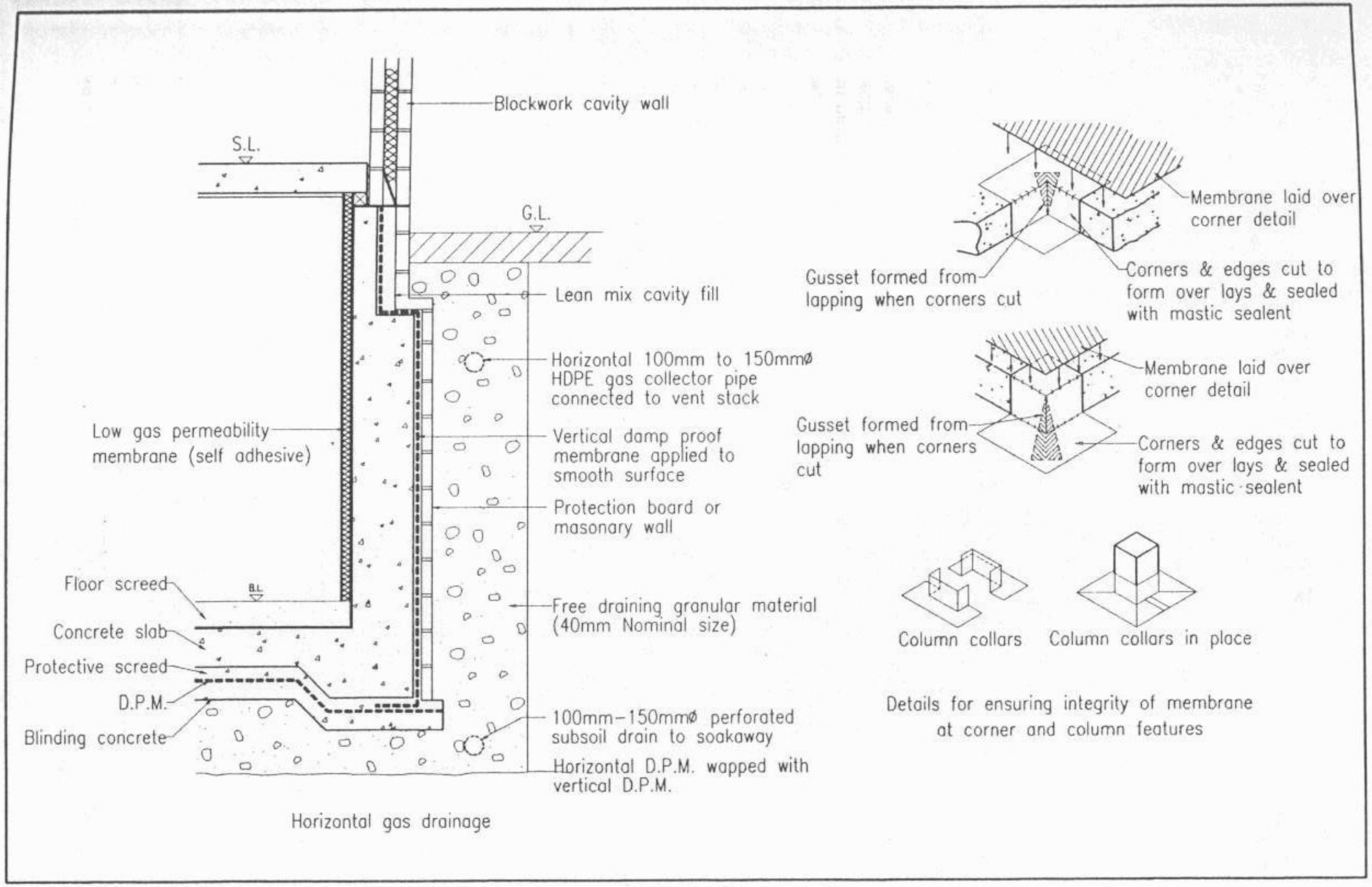


FIGURE 7.6 : TYPICAL DETAILS OF FLEXIBLE MEMBRANE PROTECTION FOR BUILDINGS

Figure 7.7

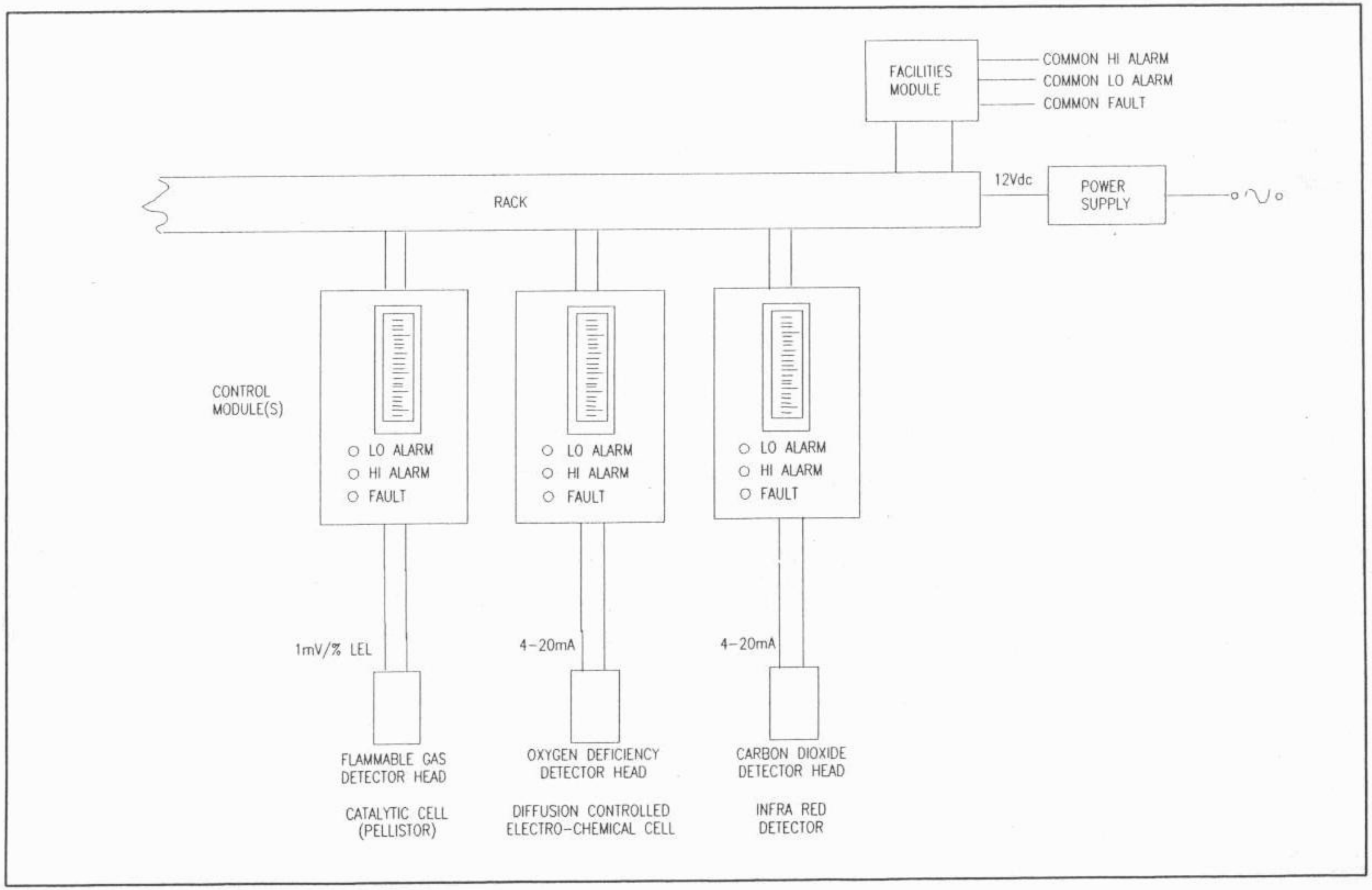


FIGURE 7.7 : SCHEMATIC OF AUTOMATIC GAS DETECTION SYSTEM

Figure 7.8

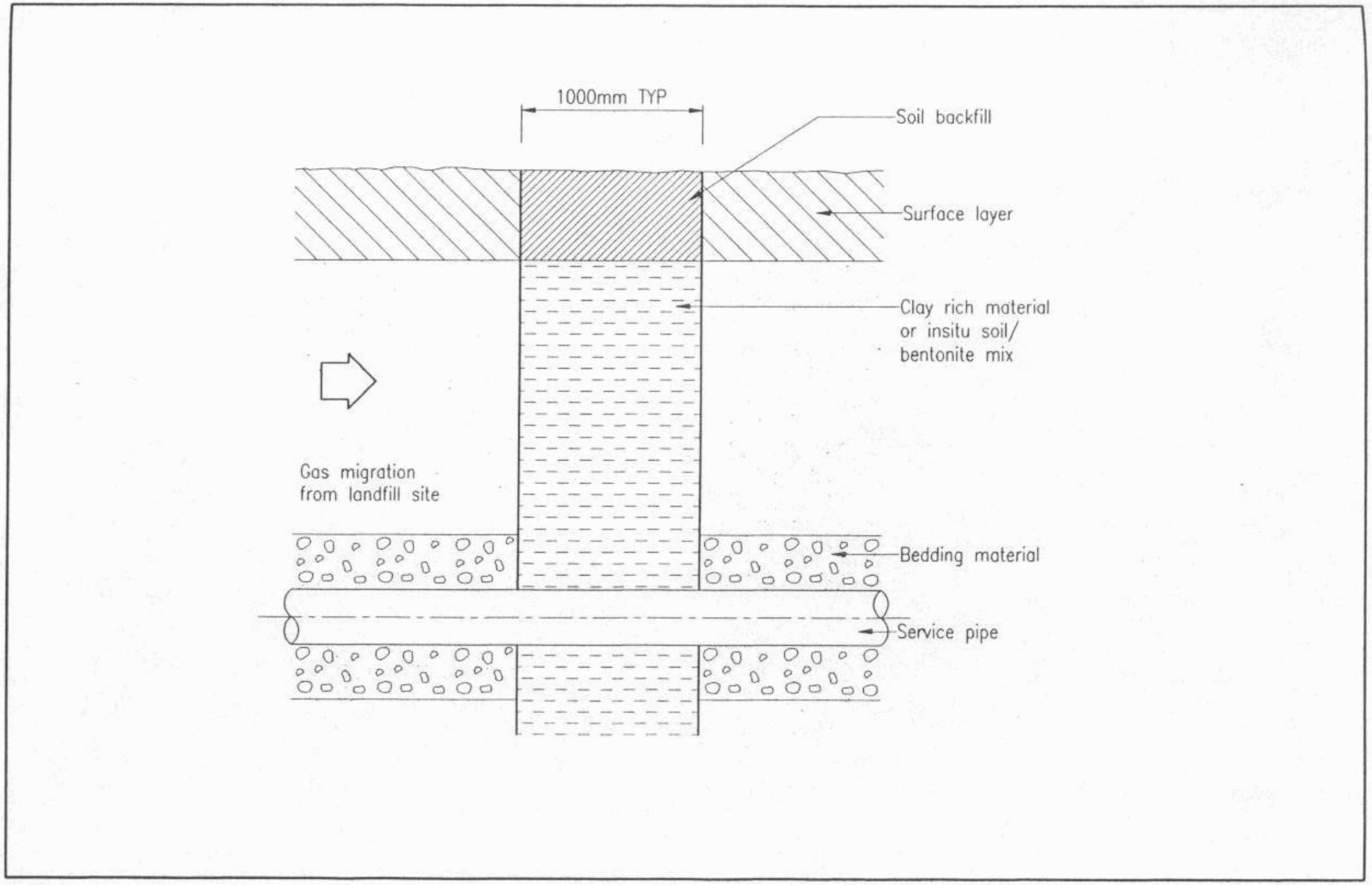


FIGURE 7.8 : NATURAL MATERIAL CUT-OFF BARRIER

Figure 7.9

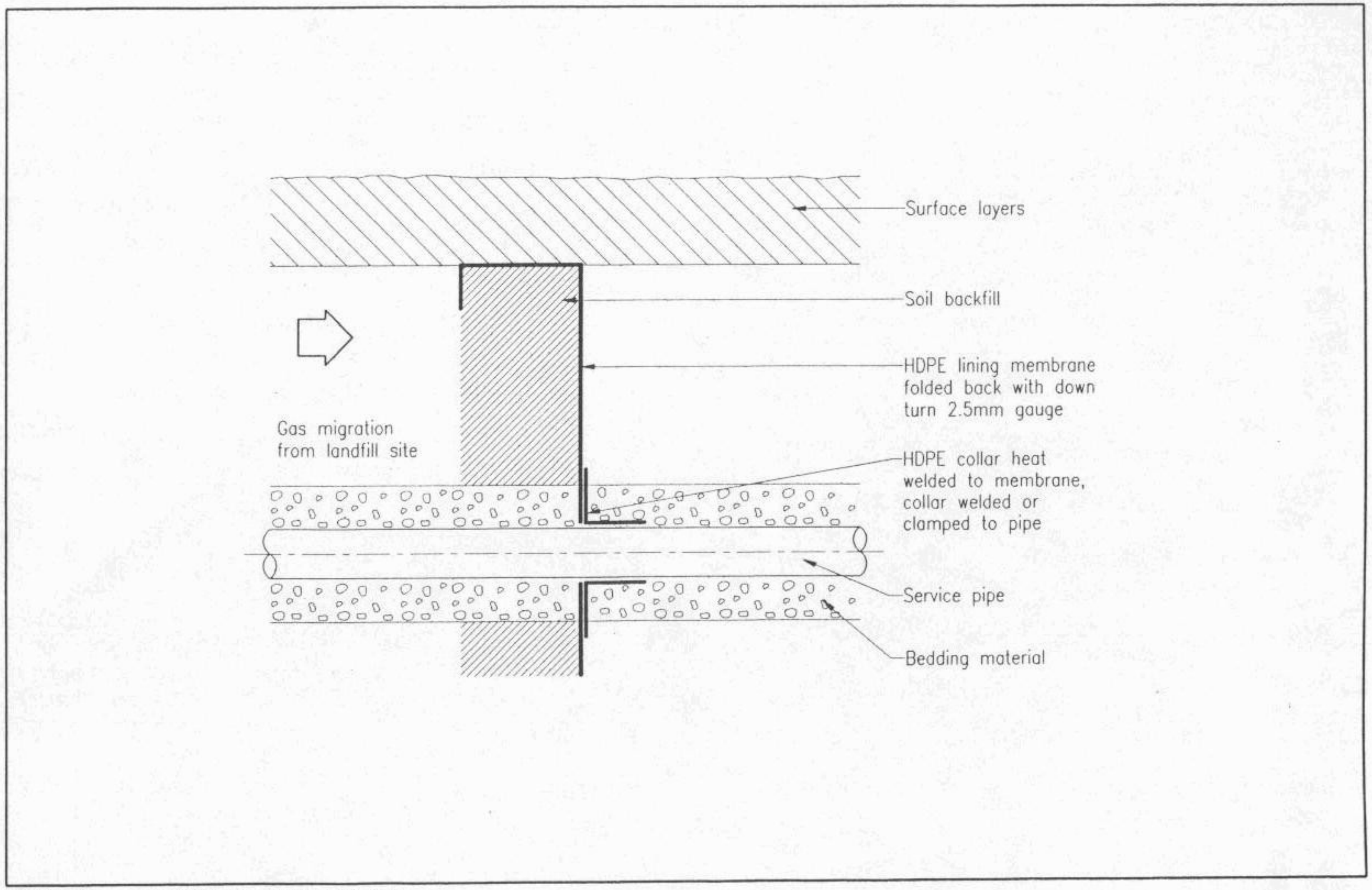


FIGURE 7.9 : FLEXIBLE MEMBRANE CUT-OFF

Annex A

Plans of the Landfill Sites Showing Extent of Consultation Zones

Figure A1 Gin Drinkers Bay Landfill

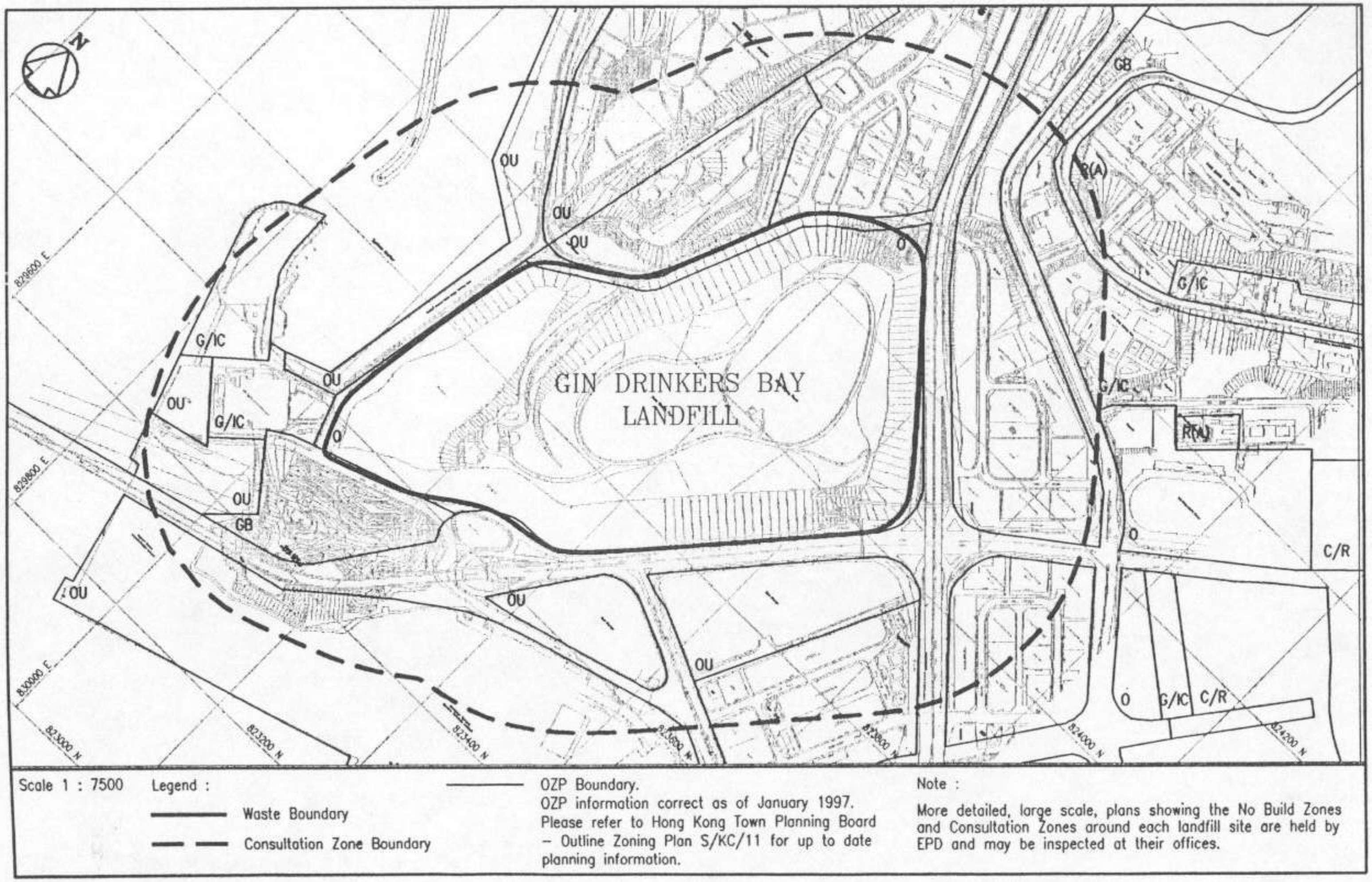


FIGURE A1 : GIN DRINKERS BAY LANDFILL

Figure A2 Jordon Valley Landfill

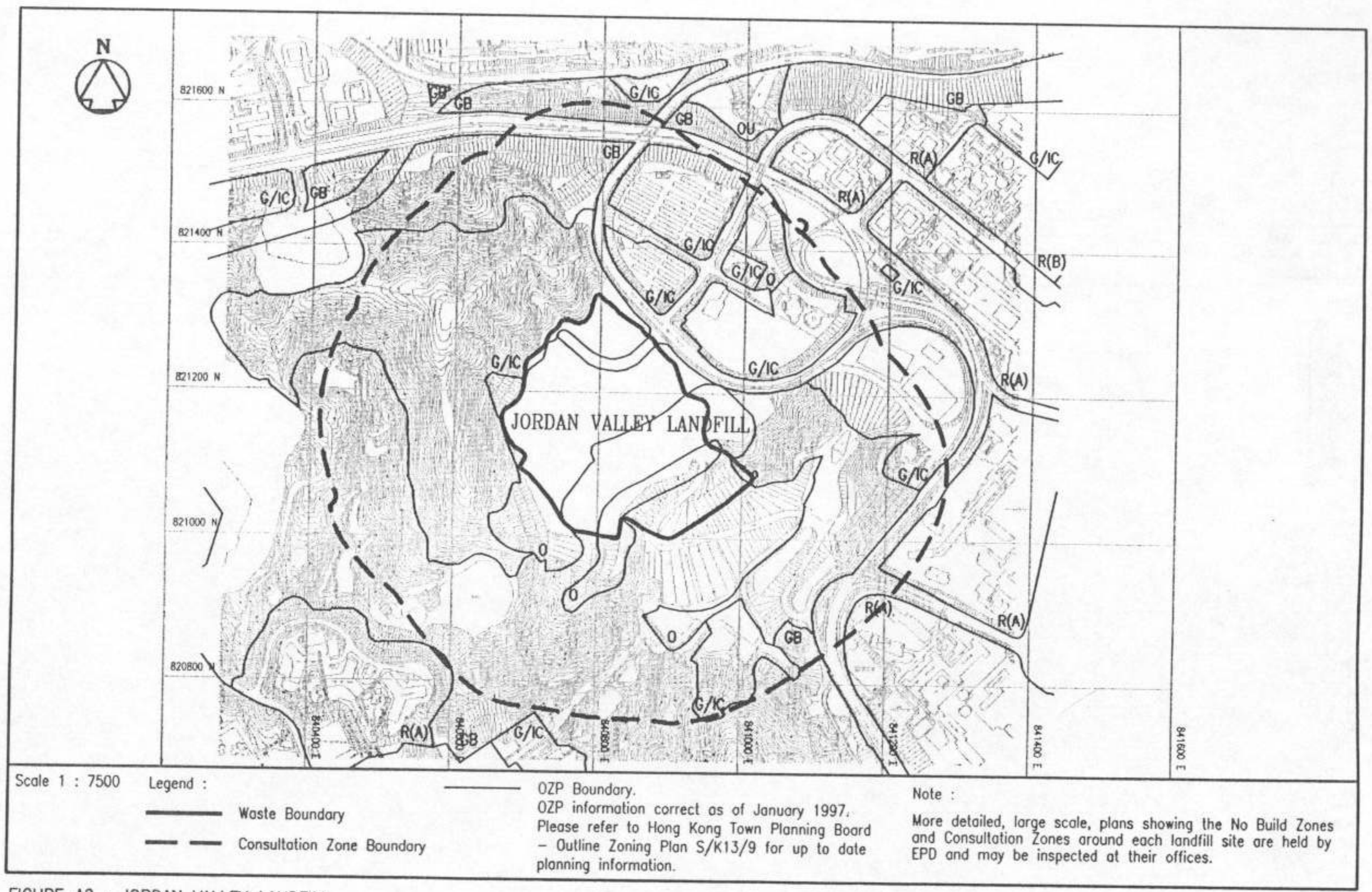
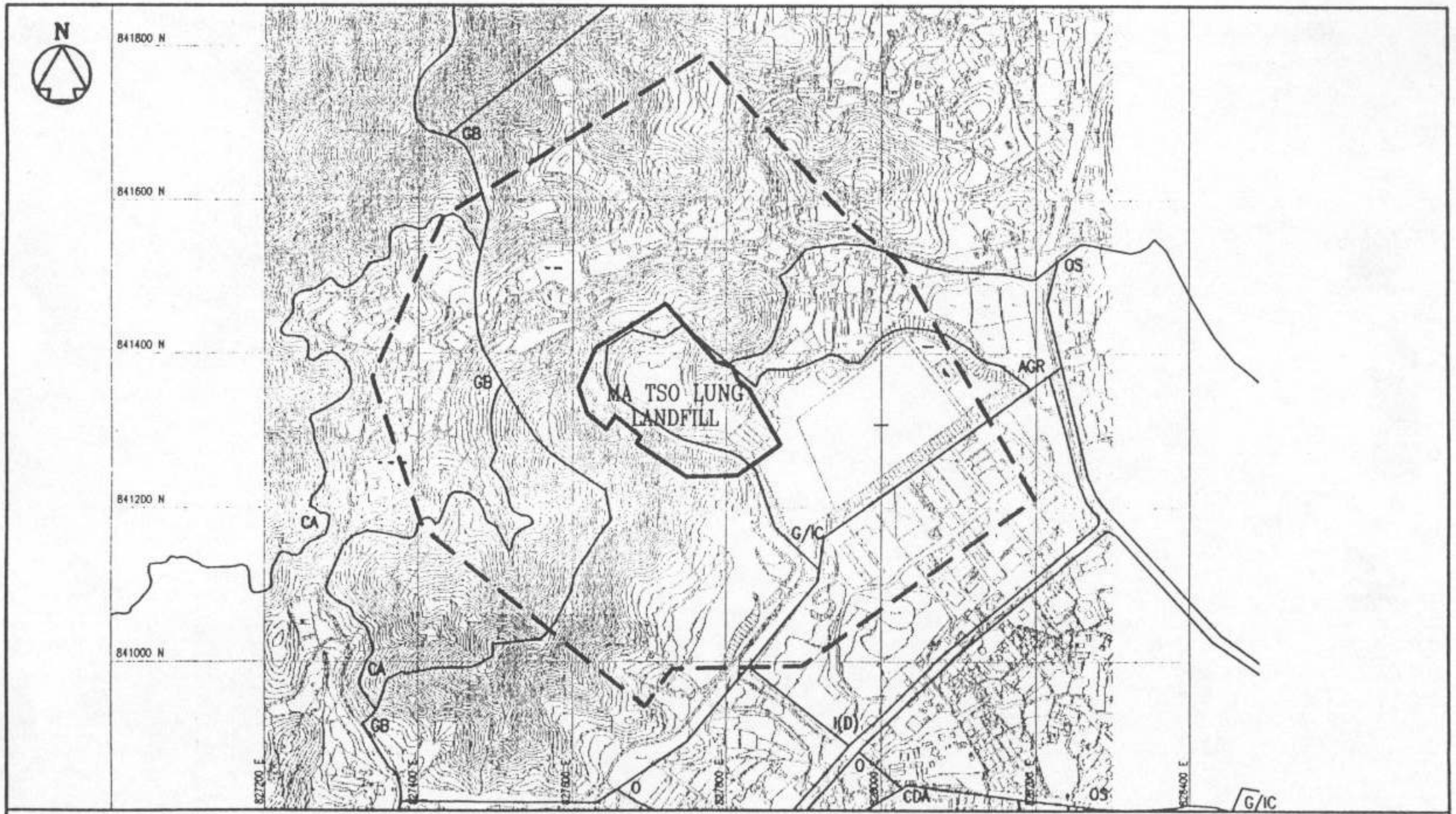


FIGURE A2 : JORDAN VALLEY LANDFILL

Figure A3 Ma Tso Lung Landfill



Scale 1 : 7500

Legend :

Waste Boundary

Consultation Zone Boundary

OZP Boundary.
OZP information correct as of January 1997.
Please refer to Hong Kong Town Planning Board – Outline Zoning Plan S/NE-KTN/1 & S/YL-ST/1 for up to date planning information.

Note :
More detailed, large scale, plans showing the No Build Zones and Consultation Zones around each landfill site are held by EPD and may be inspected at their offices.

FIGURE A3 : MA TSO LUNG LANDFILL

Figure A4 Ma Yau Tong Central Landfill

Scale 1 : 7500

Legend :

Waste Boundary

Consultation Zone Boundary

OZP Boundary.

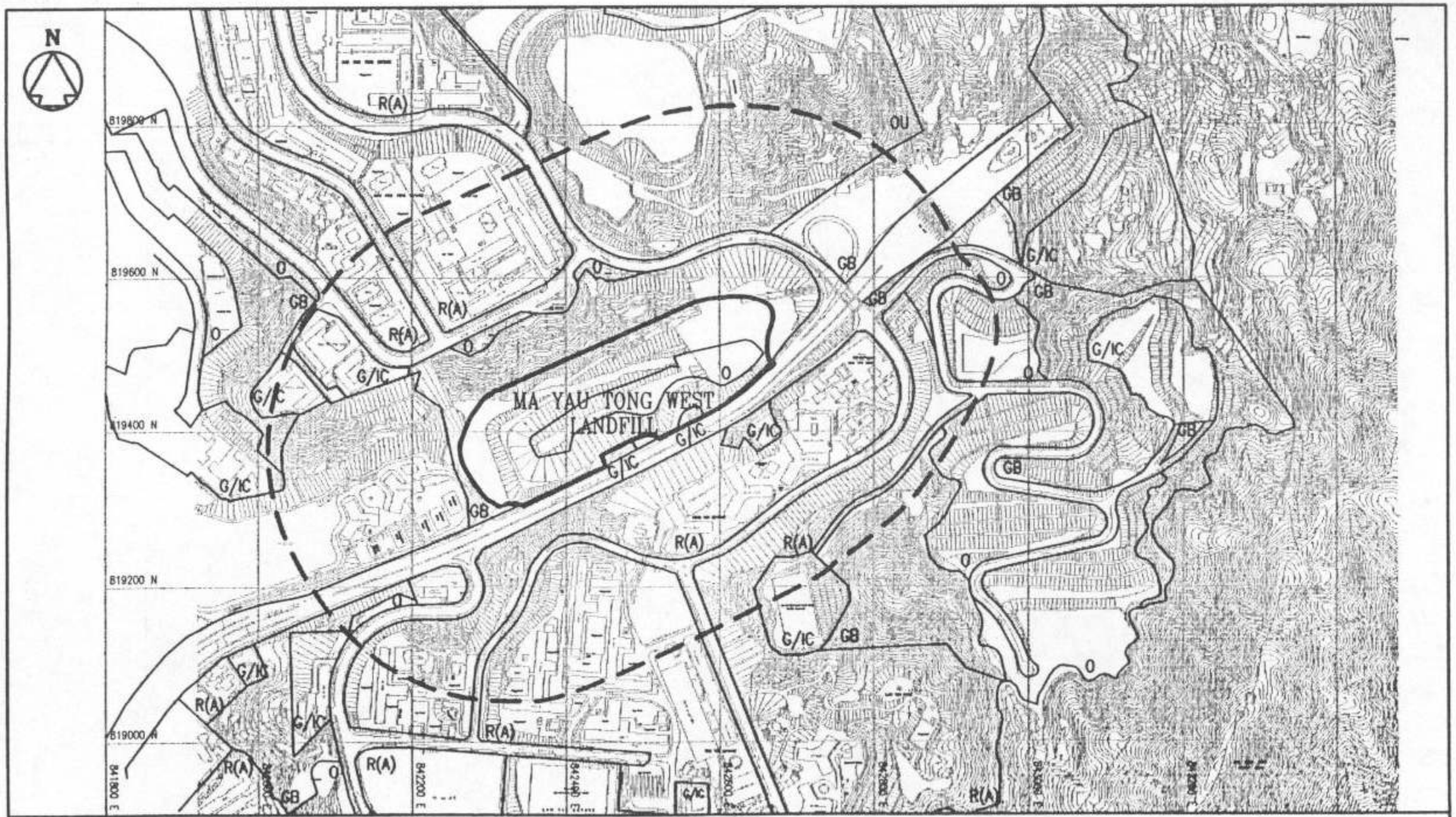
OZP information correct as of January 1997.
Please refer to Hong Kong Town Planning Board – Outline Zoning Plan S/K14S/3, S/K14N/2 & S/SK-TLS/2 for up to date planning information.

Note :

More detailed, large scale, plans showing the No Build Zones and Consultation Zones around each landfill site are held by EPD and may be inspected at their offices.

FIGURE A4 – MA YAU TONG CENTRAL LANDFILL

Figure A5 Ma Yau Tong West Landfill



Scale 1 : 7500

Legend :

Waste Boundary

Consultation Zone Boundary

OZP Boundary.

OZP information correct as of January 1997. Please refer to Hong Kong Town Planning Board – Outline Zoning Plan S/K14S/3, S/K14N/2 & S/SK-TLS/2 for up to date planning information.

Note :

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FIGURE A5 : MA YAU TONG WEST LANDFILL

Figure A6 Ngau Chi Wan Landfill

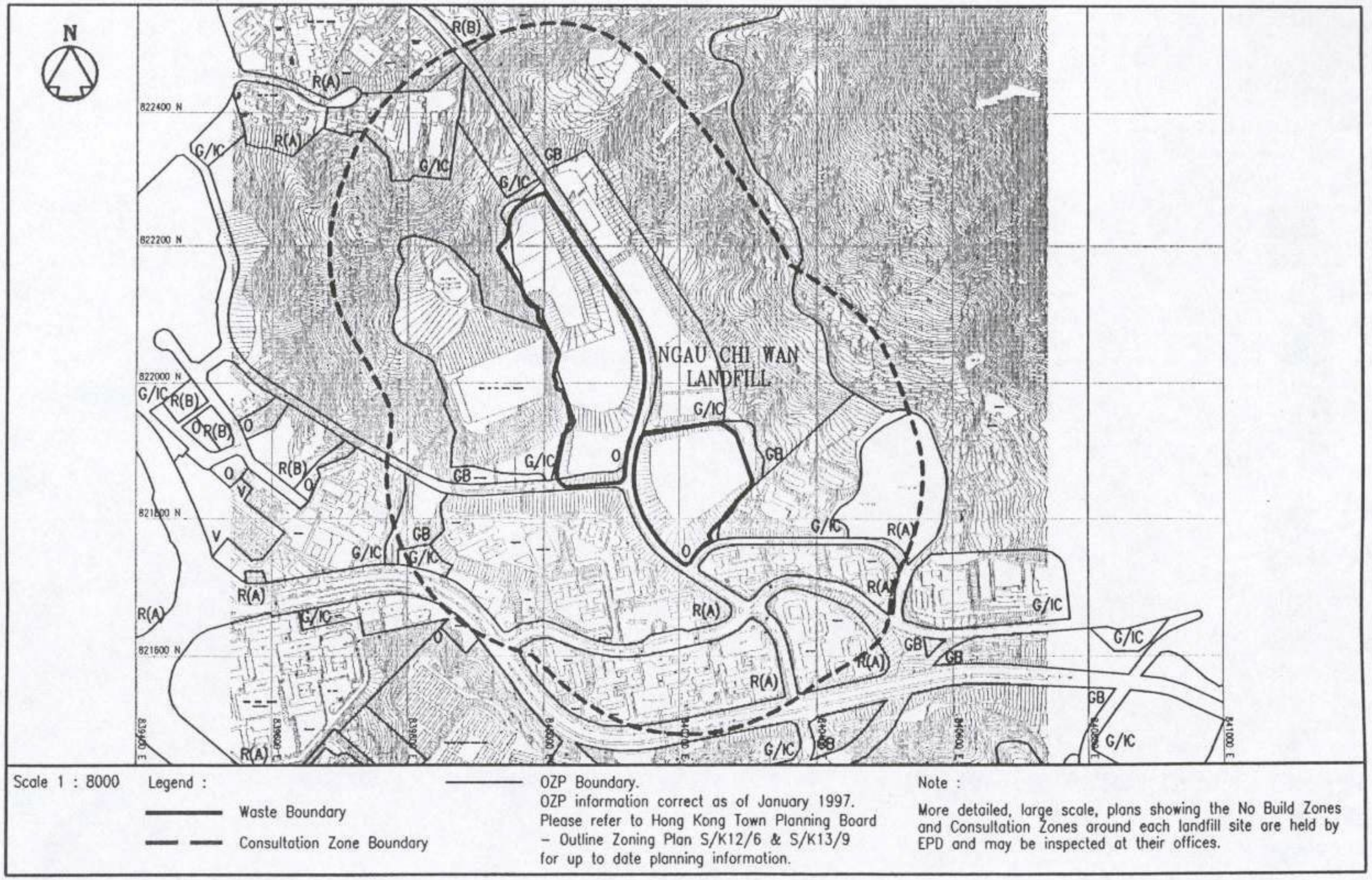
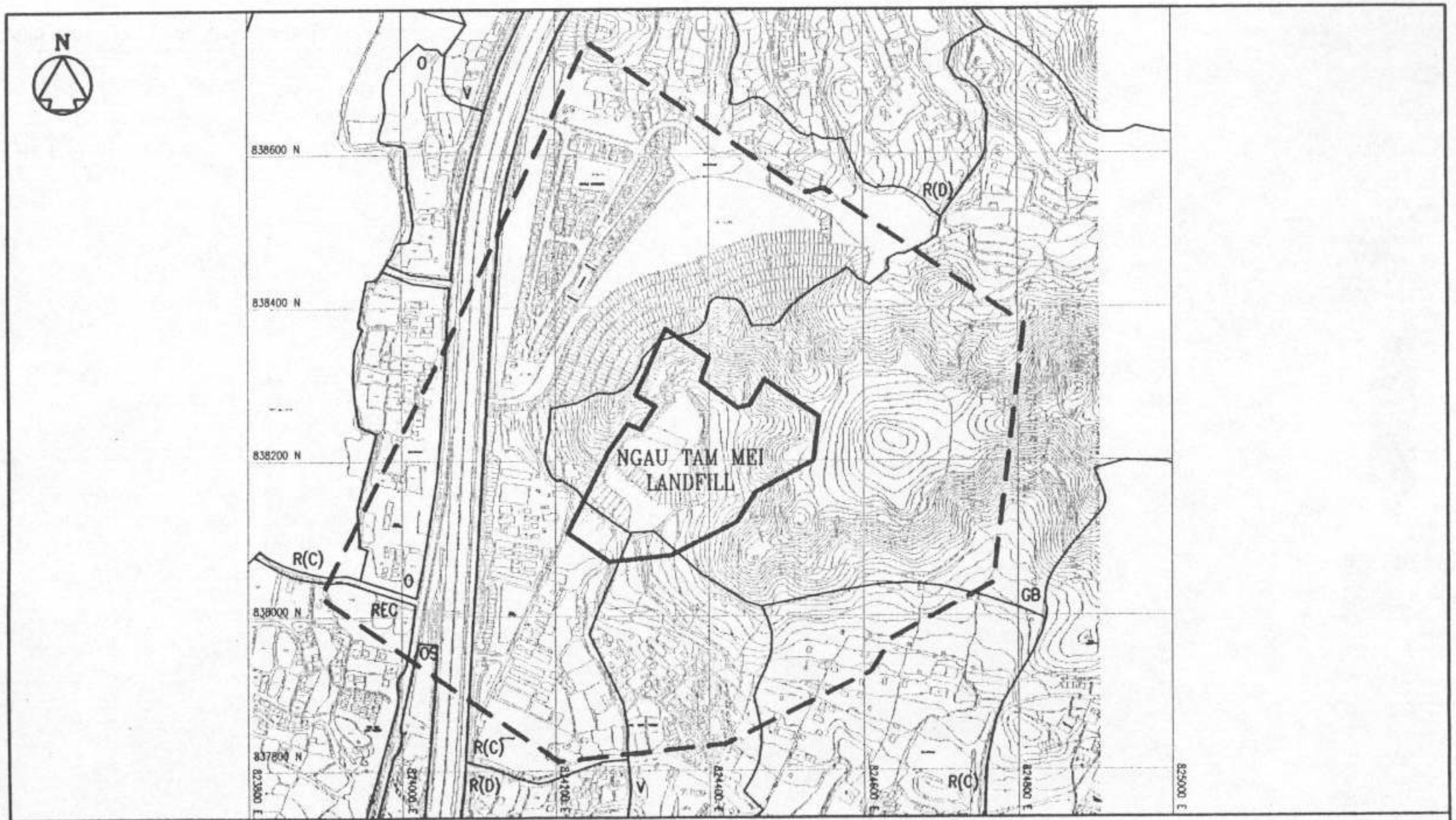


FIGURE A6 : NGAU CHI WAN LANDFILL

Figure A7 Ngau Tam Mei Landfill



Scale 1 : 7500

Legend :

Waste Boundary

Consultation Zone Boundary

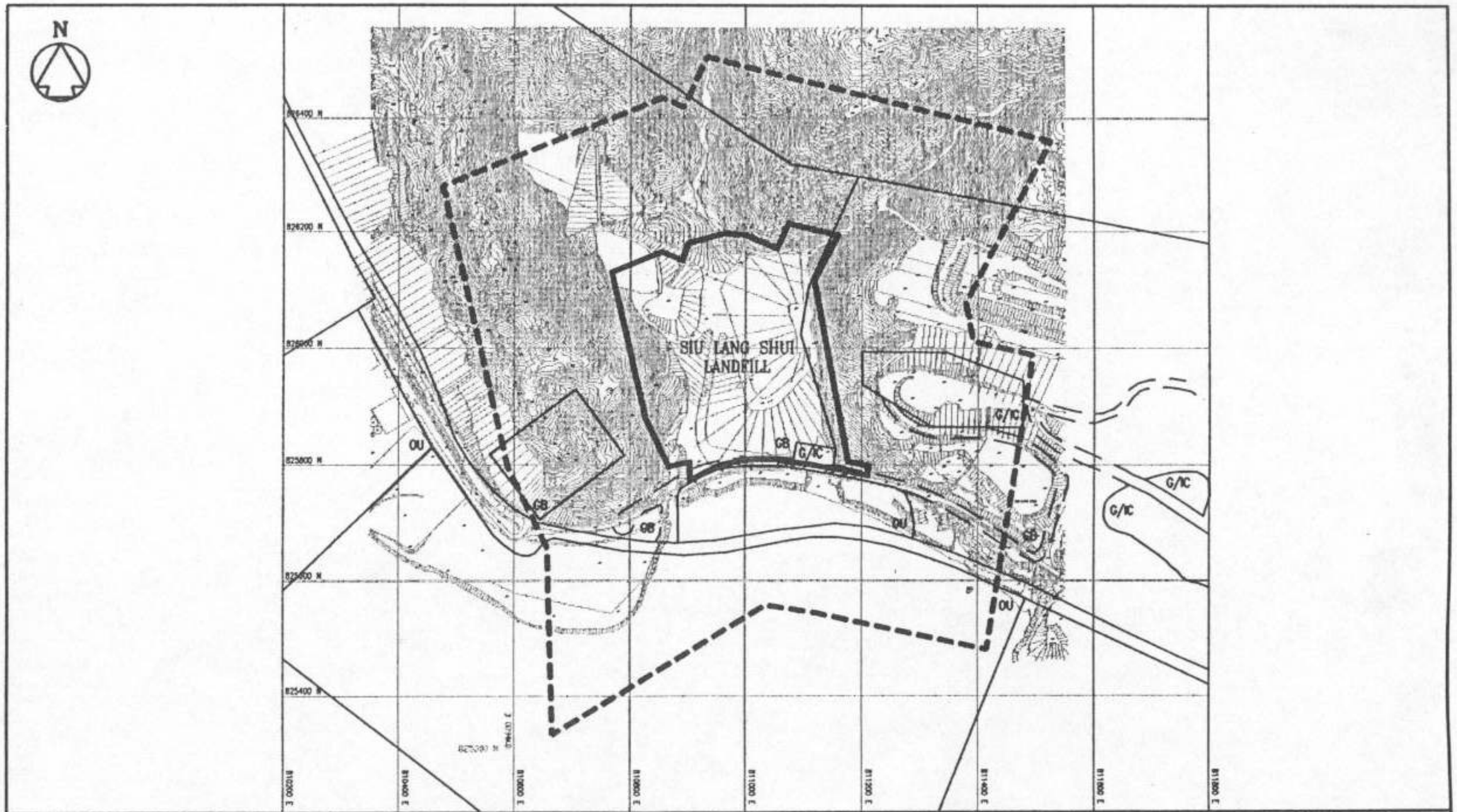
OZP Boundary.
OZP information correct as of January 1997.
Please refer to Hong Kong Town Planning Board
– Outline Zoning Plan S/YL-NTM/1 & S/YL-MP/1
for up to date planning information.

Note :

More detailed, large scale, plans showing the No Build Zones and Consultation Zones around each landfill site are held by EPD and may be inspected at their offices.

FIGURE A7 : NGAU TAM MEI LANDFILL

Figure A8 Siu Lang Shui Landfill



Scale 1 : 10000 Legend :

Waste Boundary

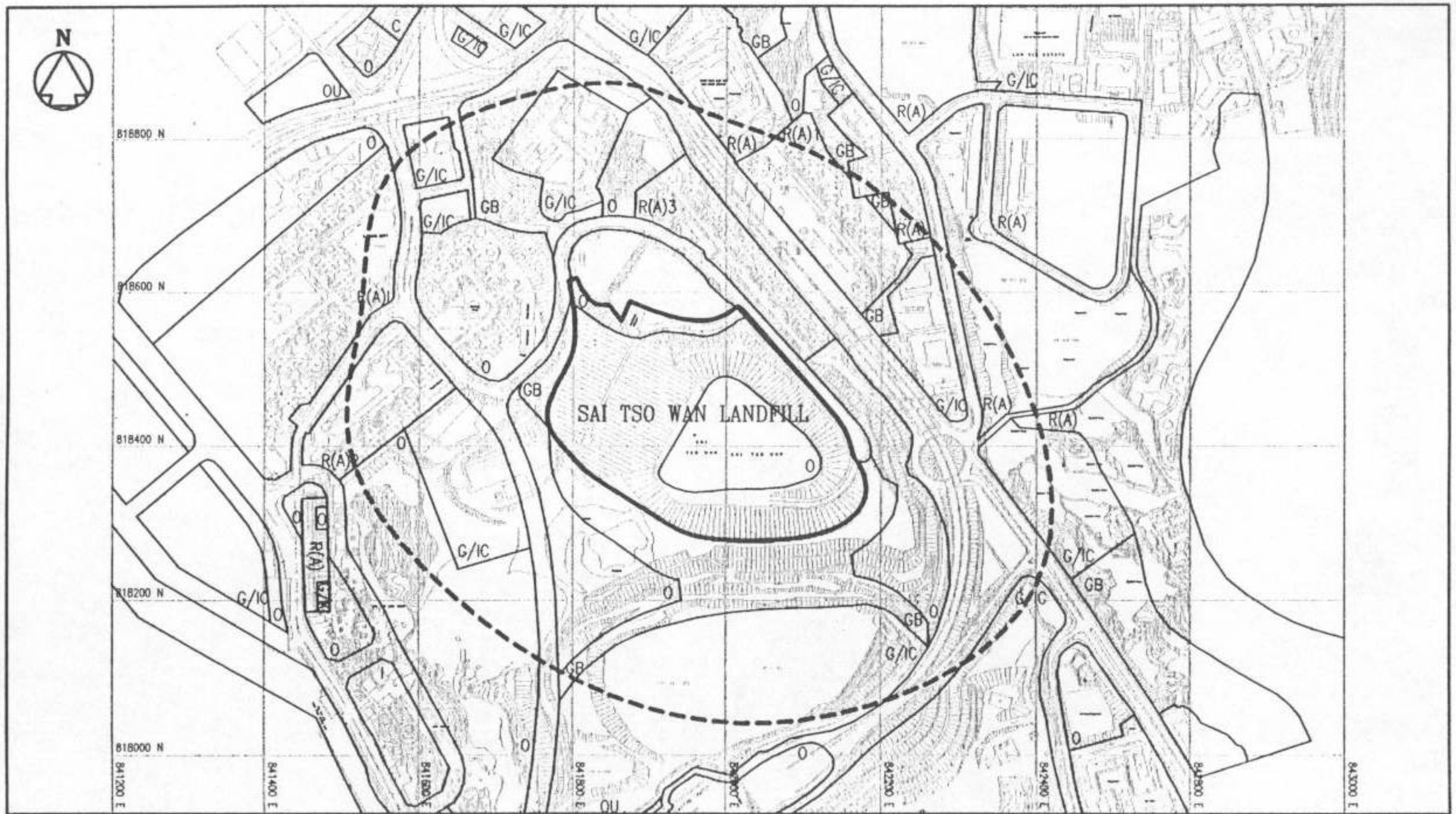
Consultation Zone Boundary

OZP Boundary.
OZP information correct as of January 1997.
Please refer to Hong Kong Town Planning Board – Outline Zoning Plan S/TM/8 for up to date planning information.

Note :
More detailed, large scale, plans showing the No Build Zones and Consultation Zones around each landfill site are held by EPD and may be inspected at their offices.

FIGURE A8 : SIU LANG SHUI LANDFILL

Figure A9 Sai Tso Wan Landfill



Scale 1 : 7500

Legend :

Waste Boundary

Consultation Zone Boundary

OZP Boundary.

OZP information correct as of January 1997. Please refer to Hong Kong Town Planning Board – Outline Zoning Plan S/K15/7 & S/K14S/3 for up to date planning information.

Note : More detailed, large scale, plans showing the No Build Zones and Consultation Zones around each landfill site are held by EPD and may be inspected at their offices.

FIGURE A9 : SAI TSO WAN LANDFILL

Figure A10 Shuen Wan Landfill

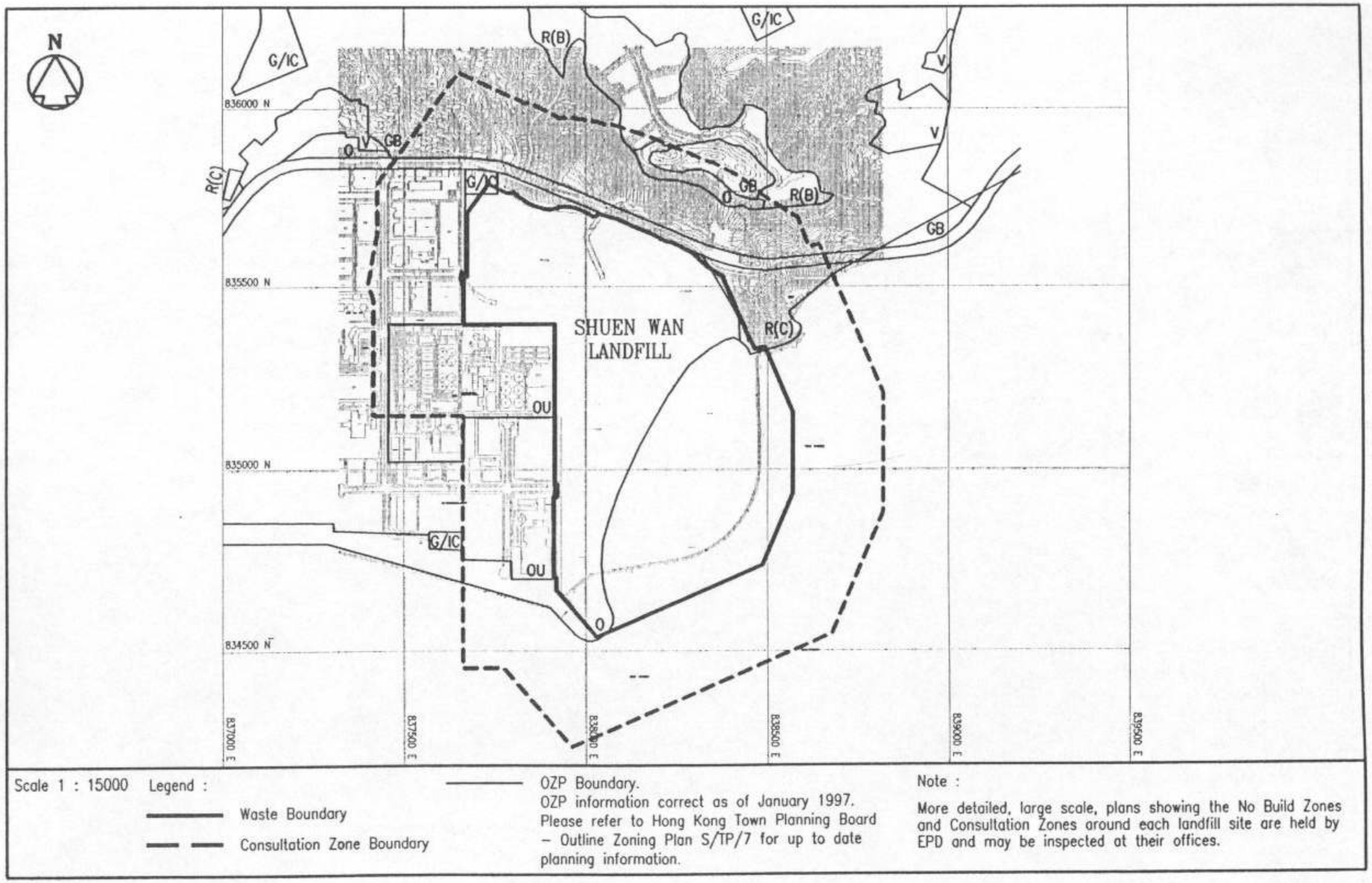


FIGURE A10 : SHUEN WAN LANDFILL

Figure A11 Tseung Kwan O Stage I Landfill

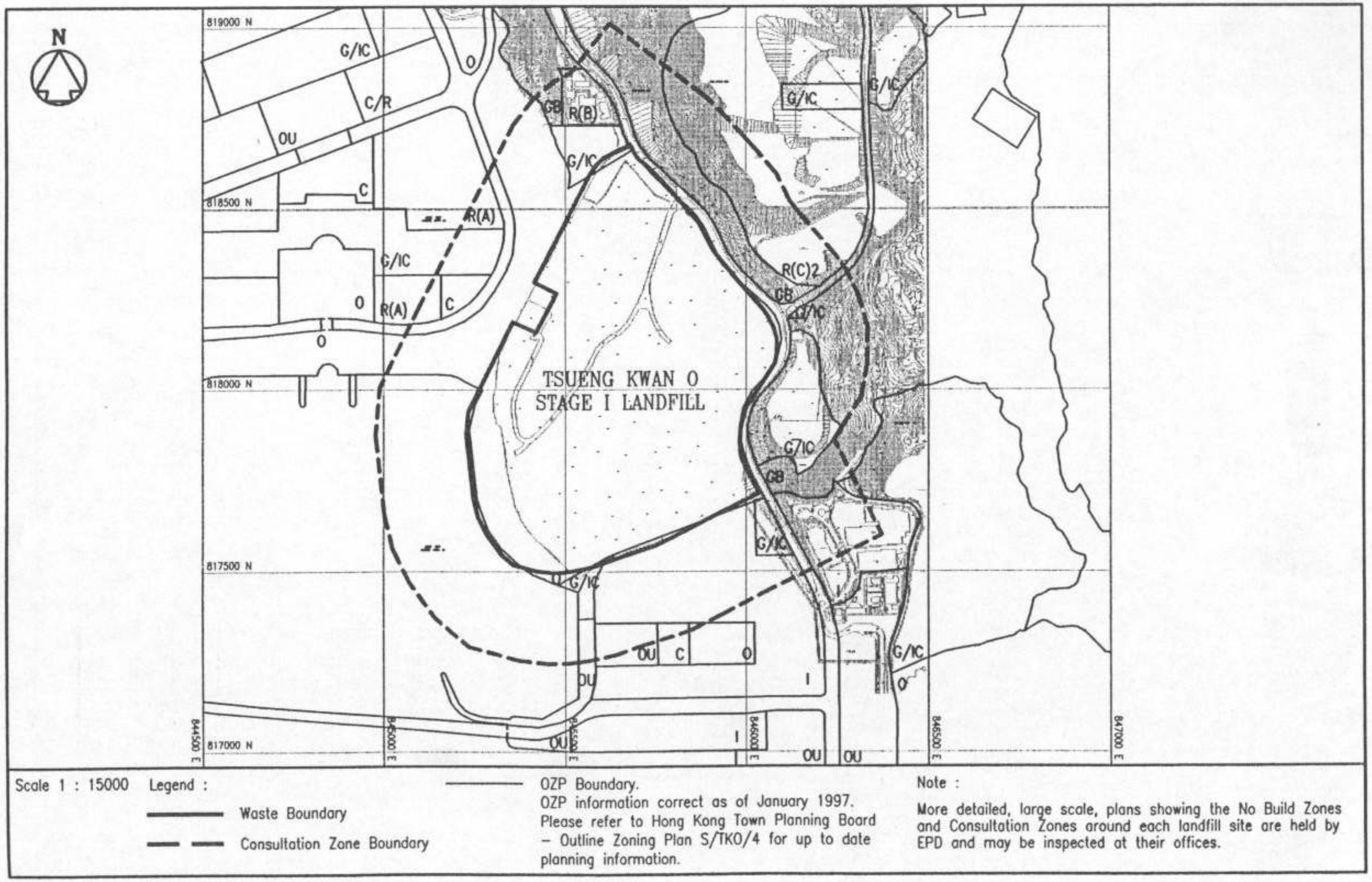


FIGURE A11 : TSEUNG KWAN O STAGE 1 LANDFILL

Figure A12 Tseung Kwan O Stage II/III Landfill

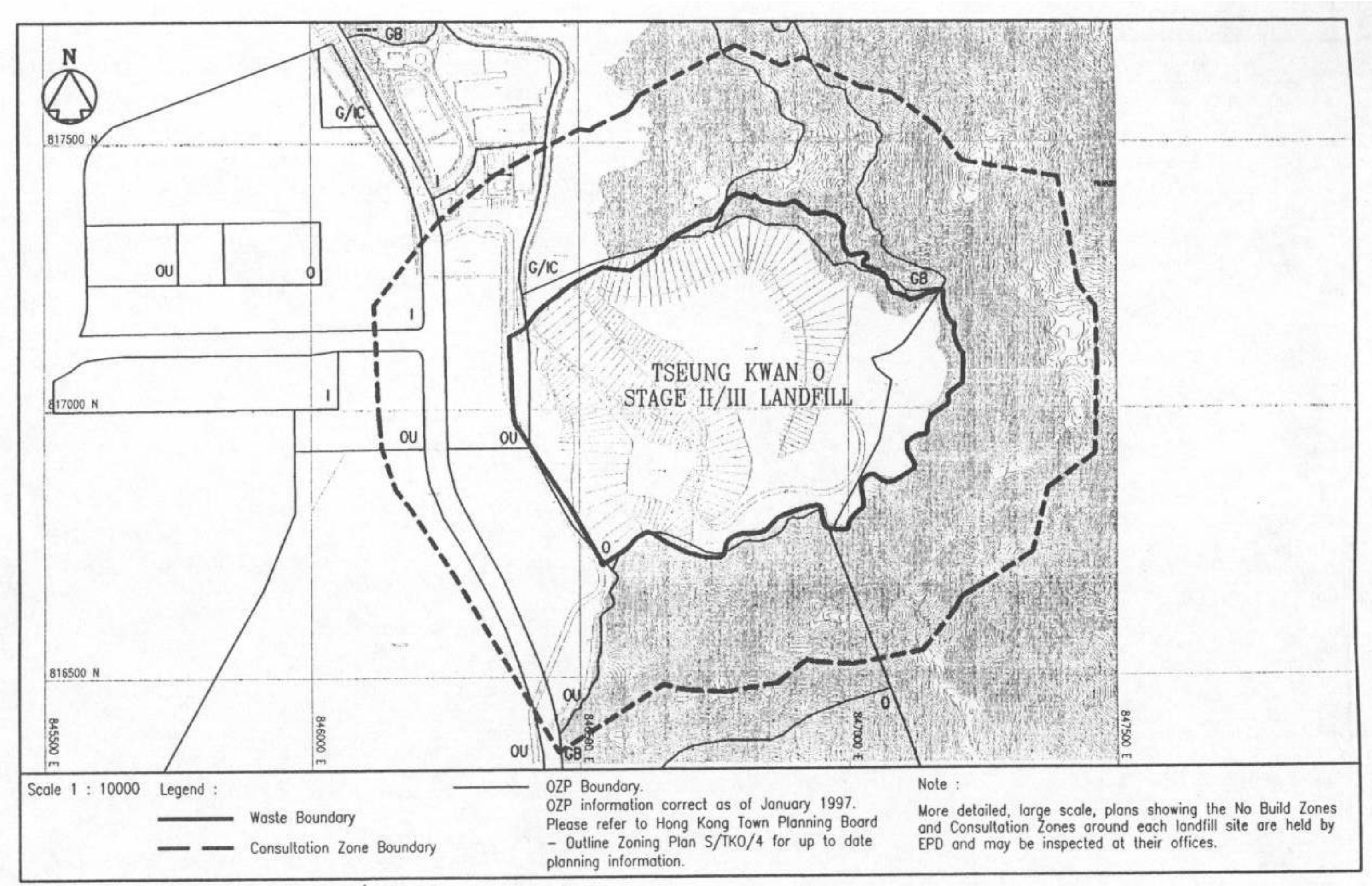
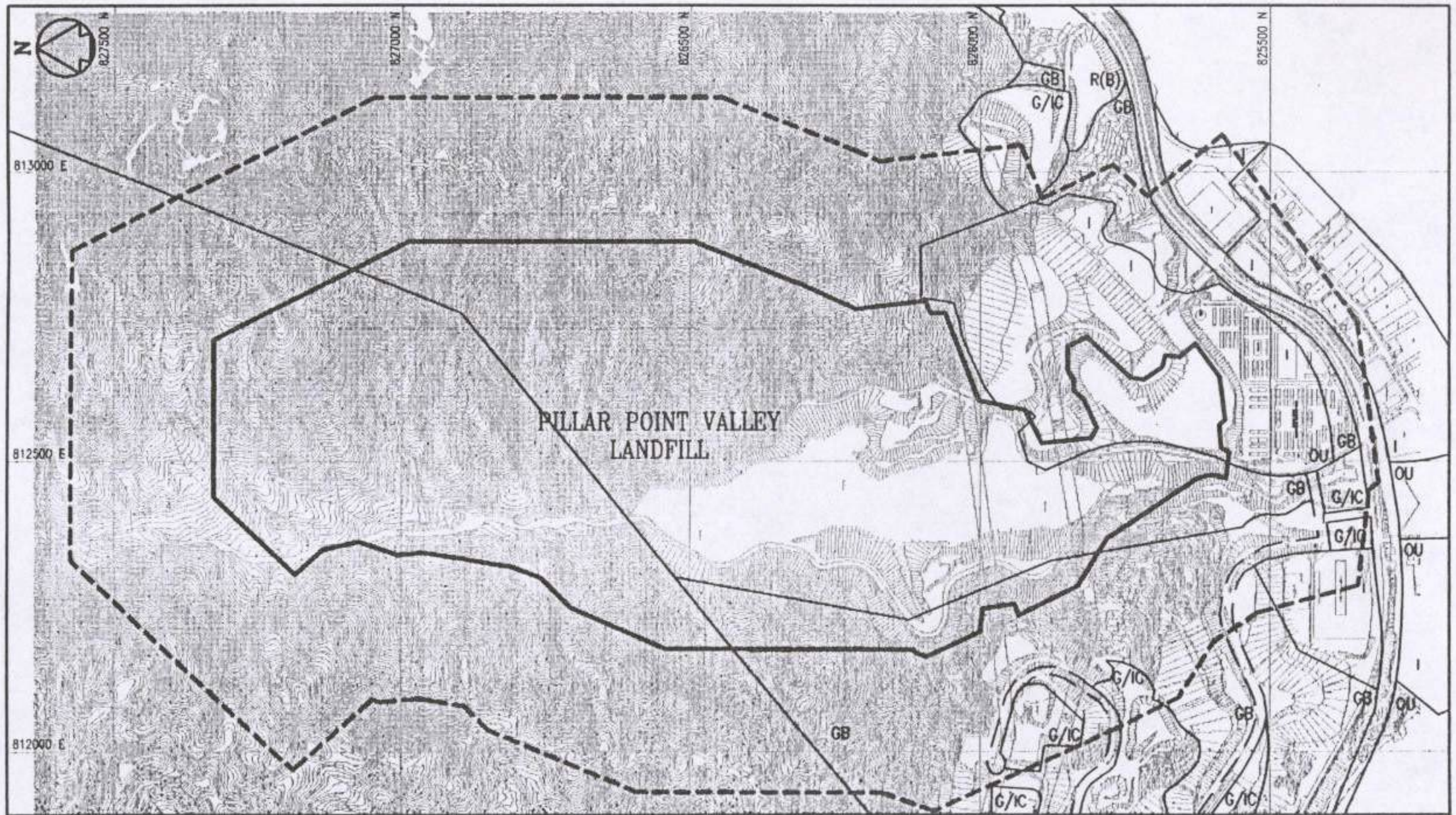


FIGURE A12 : TSUENG KWAN O STAGE II/III LANDFILL

Figure A13 Pillar Point Valley Landfill



Scale 1 : 10000 Legend :

Waste Boundary

Consultation Zone Boundary

OZP Boundary.

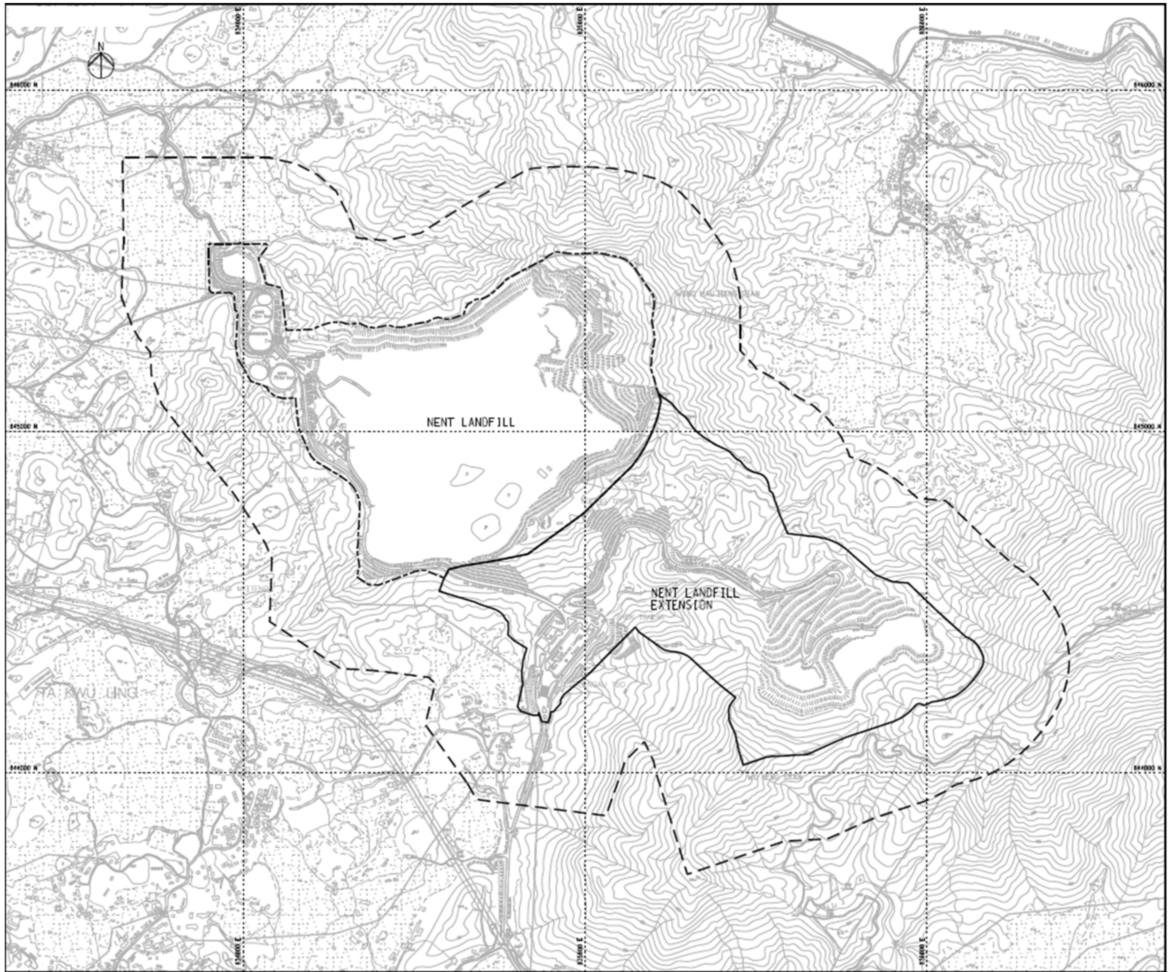
OZP information correct as of January 1997. Please refer to Hong Kong Town Planning Board – Outline Zoning Plan S/TM/8 for up to date planning information.

Note :

More detailed, large scale, plans showing the No Build Zones and Consultation Zones around each landfill site are held by EPD and may be inspected at their offices.

FIGURE A13 : PILLAR POINT VALLEY LANDFILL

Figure A14 NENT Landfill



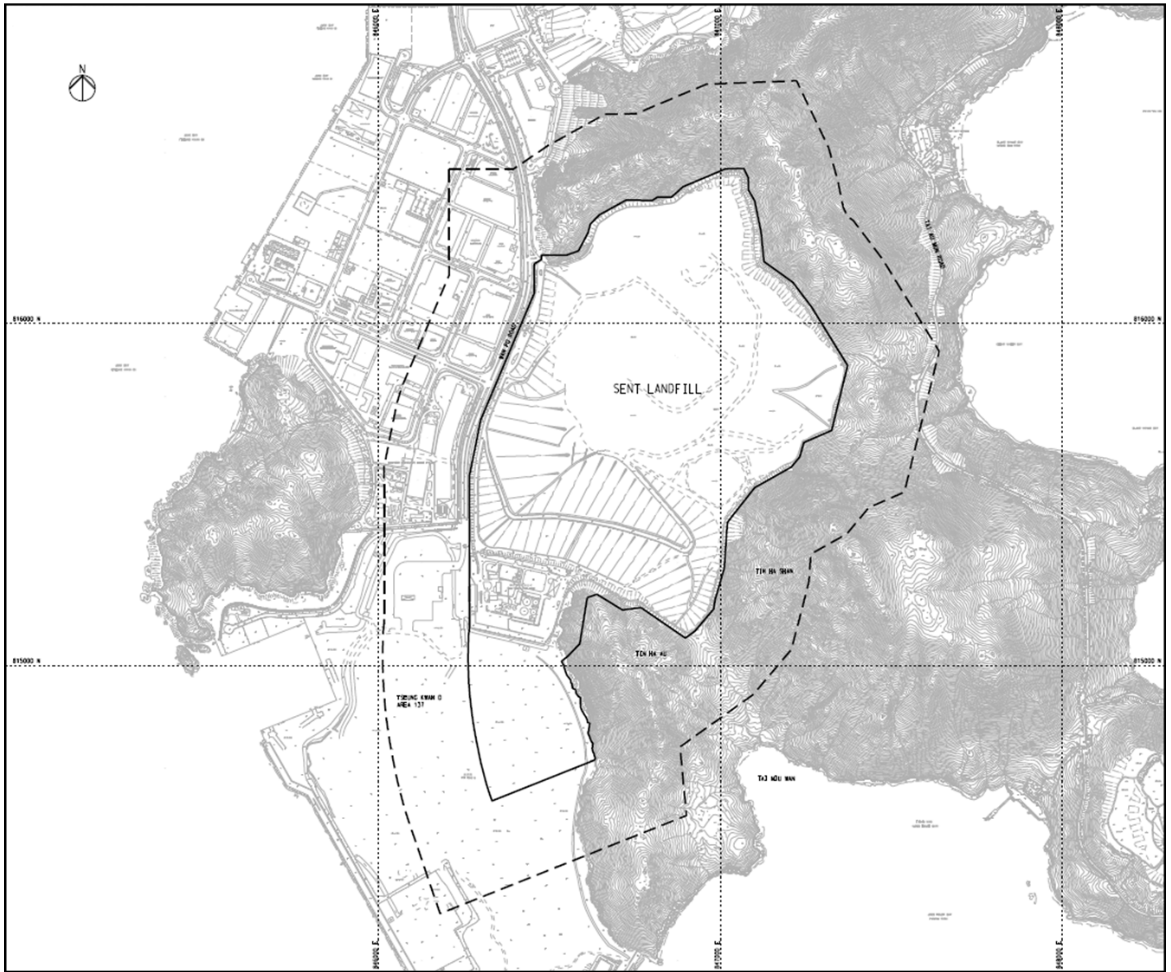
Scale 1:5000

Legend:

- NENT Landfill Boundary (dash-dot line)
- NENT Landfill Extension Boundary (solid line)
- Consultation Zone Boundary (dashed line)

Note:
More detailed, large scale, plans showing the No Build Zones and Consultation Zones around each landfill site are held by EPD and may be inspected at their offices

Figure A15 SENT Landfill



Scale 1:5000

Legend:

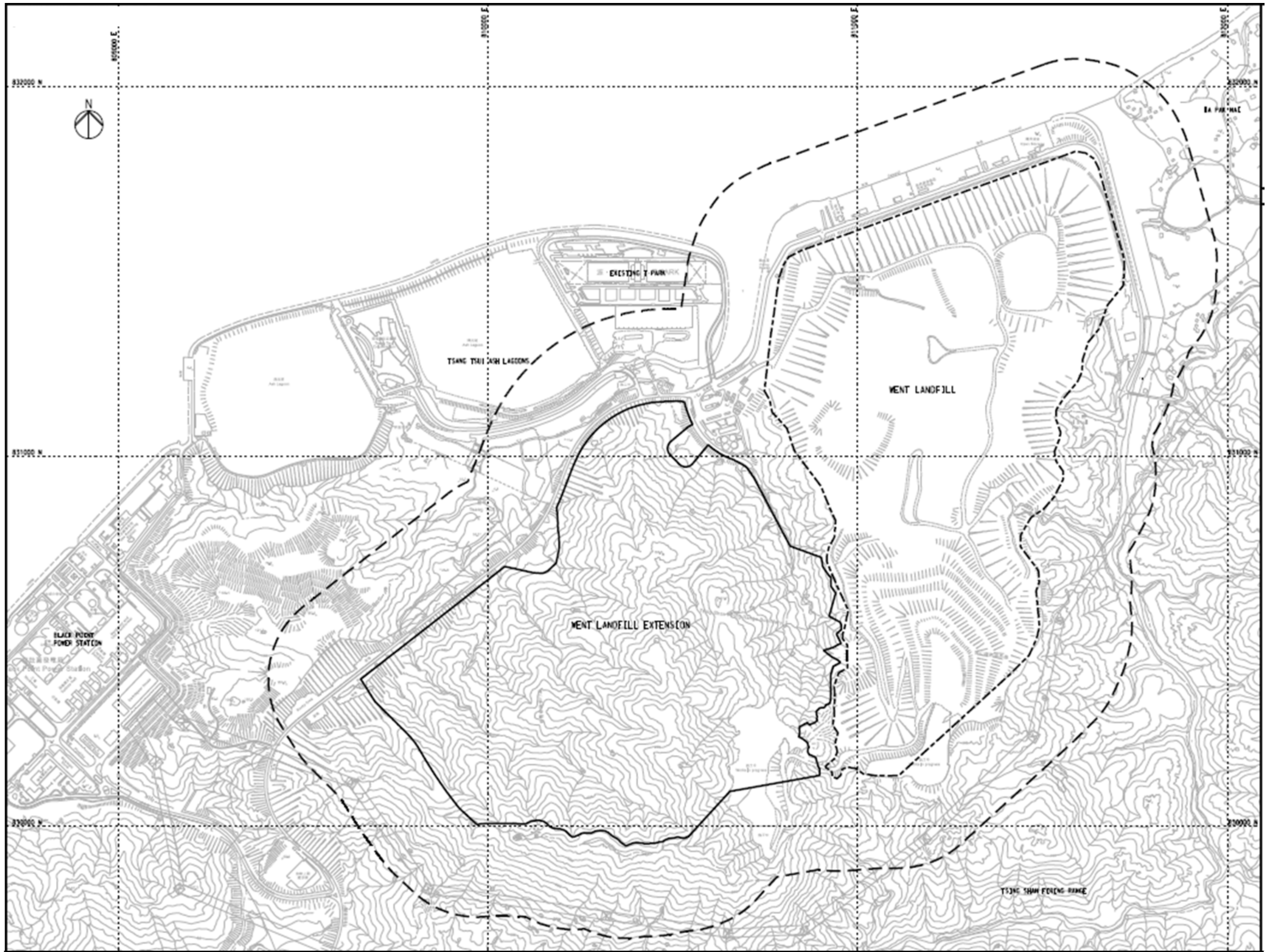
SENT Landfill (including the extension)

Consultation Zone Boundary

Note:

More detailed, large scale, plans showing the No Build Zones and Consultation Zones around each landfill site are held by EPD and may be inspected at their offices

Figure A16 WENT Landfill



Scale 1:5000

Legend:

- WENT Landfill Boundary (dash-dot line)
- WENT Landfill Extension Boundary (solid line)
- Consultation Zone Boundary (dashed line)

Note:
More detailed, large scale, plans showing the No Build Zones and Consultation Zones around each landfill site are held by EPD and may be inspected at their offices

Annex B GENERIC DESIGN MEASURES FOR SUB-SURFACE BUILDING SERVICES

The types of gas protection measures which may be applied to building services were discussed in general terms in the main part of the document (Section 7). This Annex provides further, more specific, information on the protection of services and drawings of typical design measures which may be employed.

B1 TYPES OF SERVICES

B1.1 All buildings and related developments invariably have services which are typically located below ground level. As such they can, if not carefully designed and installed, act as preferential conduits through which landfill gas may be lead into the building interior. In broad terms, these services may be divided into two generic categories:

- open-void conduits; and
- in-filled service runs.

B1.2 In terms of potential gas transport, each category behaves in a different manner and therefore requires a different approach to risk minimisation. The main types of service in common use in each of the two generic categories are summarised in *Tables B1.1* and *B1.2.*

Table B1.1 Building Service Types - Open Void Conduits

Service type	**Typical Construction**	**Typical Sizes**	**Comments**
Foul-water/soil pipes	Concrete, glazed earthen ware, ABS/PVC pipework	100mm NB	Water traps may prevent gas entry
Surface water drains/ Culverts	Concrete pipework, Cast *in situ* channel	300mm and greater	Large conduits may require external gas barrier protection.
Cable trunking	ABS/PVC or PE	50-100mm NB	Consider external gas membranes
Ventilation ducting	Concrete, galvanised steel	300mm+	As culvert
Inspection chambers and manholes	Re-inforced concrete	1000mm diameter	As culvert, plus passive vent stacks
Soakaways and drains	ABS/PVC or PE	50-100mm	Depending on location, may not require protection.
Air conditioning cooling water supply	PE, Stainless steel	150-450mm NB	Consider barrier for service trench
Service tunnels	Re-inforced concrete	2000mm+	As Surface water drains/ Culverts
Land drainage pipes	PE/PP ABS/PVC	50mm NB	As soakaways
Box-outs and substructure cavities	Concrete		Consider external barrier plus venting

Note: NB = Nominal bore

Table B1.2 Building Service Types - Infilled

Service Type	**Typical Construction**	**Typical Sizes**	**Comments**
Electricity supply cables	Armoured/wrapped cables	25 - 50mm diameter	Protect service trench or bring entry above the floor slab
Gas supply pipes	Yellow HDPE; black ductile iron; or white or green steel	50mm NB	No protection required (if vented meter-box outside building)
Fresh water supply mains	Blue MDPE; PVC; or ductile iron	25 - 100mm NB	As electricity supply cables
Salt water flushing mains	Black ductile iron Grey UPVC	300 - 600mm NB < 300mm NB	As electricity supply cables
TV cables	Light cable in steel or plastic conduit/duct	5 - 10mm diameter	Consider gas-tight and vented box
Computer/ communications system cables	As TV cable	5 - 10mm diameter	As TV cables
Process pipework	PE or Steel	25-250mm NB	Protect service trench
Hydrants/fire systems	Steel	100mm NB	As process pipework
Landscape irrigation pipework	PE or ABS/PVC	25-50mm NB	Depending on location, may not require protection
Street lighting cables	Armoured/wrapped cables	10-15mm diameter	Protect service trench, consider sealing of standard
Lightning protection/earth rods	Bare copper conducting rods/bars	15-30mm diameter	Seal earthing cable service trench

B2 GAS PROTECTION MEASURES

B2.1 As stated previously, protection measures applied to service conduits should not be considered in isolation. Gas protection measures for a development should integrate protection of the building with the controls to be applied to the service conduits. It should also be noted that, even if a building development itself falls outside the requirements of the *Guidance Note*, any construction work which involves excavation deeper than 300mm and any service runs which are located within the Consultation Zone will require precautionary measures to be taken during construction (see Section 8) and may require some form of protection measures to be incorporated in their design.

B2.2 The advice which follows applies equally to both service installations for developments within the Consultation Zone and also to service conduits and runs which are located within the Consultation Zone but which feed building developments located outside the Consultation Zone.

B2.3 The developers' attention is drawn to the need to consult with Government and relevant utility companies as indicated in the main part of the report (Section 7).

B2.4 The three generic measures which may be employed to protect services against landfill gas are discussed below.

Gas Barriers

B2.5 Gas barriers are most readily applied to service trenches at a point between the source of the gas and building (or development) itself; preferably as close as is practical to the building although it may form part of a more extensive barrier to prevent general migration towards the development (see Section 7). A barrier to gas movement may be achieved using either clay (or clay rich soil) or soil-bentonite mixtures. A schematic of a natural material cutoff barrier, including sealing of a service trench is shown in *Figure 7.8* (main part of document).

B2.6 As for general cut off barriers, use may also be made of polymeric membranes such as HDPE. For these barriers, the design detail at the point where the service penetrates the membrane is important and use should be made of pre-formed shrouds (or cloaks), skirts and fillets. A schematic for an HDPE flexible membrane cut-off is shown in *Figure 7.9*. In addition, the relative positions and separation of the gas source, the building (or development) and the service trench barrier should also be assessed to identify appropriate dimensions of the cut-off barrier.

B2.7 In some situations, for example where a development is planned very close to an actively gassing landfill, it may be more appropriate to consider routing all services through a sealed culvert or duct which is either completely lined in naturally gas-resistant material (eg clay) or which is lined with an HDPE membrane.

B2.8 Water pipes and sewers which in the normal course of operation are not fully filled with water can provide an additional conduit through which gas could enter a building and, in situations where these are not located in a protected service trench, in-line protection should be provided by incorporating water traps. These may comprise U-bends, drop-legs or chambers with discharge control weirs. An example of a U-bend water seal is shown in Figure B1. The aim of all these features is to provide 'water traps' which will effectively seal off the conduit and prevent gas-phase transport.

B2.9 Even in the absence of permeable backfill to a service pipe, landfill gas tends to migrate along the interface between the pipe and the backfilled soil. Therefore, in order to prevent the ingress of gas into a building via this route, it is important that the annulus around any service entry points is effectively blocked by means of sealant, collars or puddle flanges as appropriate (see Figure B2).

B2.10 In particular circumstances it is possible for methane to become dissolved in water which is at a high pressure and to then be released from solution as the water pressure drops. For water mains which operate at high pressure, therefore, consideration should be given to installing a flash de-pressurisation tank fitted with an appropriately sited atmospheric vent. The aim of a depressurisation tank should be to reduce the water pressure to ambient in an appropriately sized holding tank, in which any dissolved gases will come out of solution and may be safely vented to atmosphere. The original supply pressure may then be re-instated by means of a discharge pumping system.

Gas Vents

B1.11 Vent pipes or gridded manhole covers may be used to avoid build-up of gas in underground utilities manholes.

B1.12 These may be used to serve two purposes:

- to provide additional protection to open conduits such as sewers; or
- to reduce accumulation of gas on the landfill side of a cut-off barrier.

B2.13 In the former case, a simple stack built into an inspection chamber venting to atmosphere at 2-3m above ground level would be adequate. A typical vented manhole arrangement is shown in Figure B3. In the latter case, typical practice would be to lay a high permeability gas drainage layer adjacent to the cut-off barrier and vent any gas to atmosphere through stacks. Care should be taken in the design and construction of such vents to prevent blockages and it is preferable to use washed or single-size aggregate, surrounded by an appropriate geotextile and sealed in to the site surface (see Figure B6).

B2.14 A further type of venting arrangement, which may be appropriate to multiple service entries, comprises a vented gas interceptor cavity through which service pipes pass, as shown in Figure B4. The aim of this protection measure is to locate the barrier component within the building sub-structure in a sealed entry box which is fitted with a vent stack.

B2.15 In some specific cases it will be inconvenient to vent manhole chambers due to their location. Above ground vents to manholes located along highways, for example, would cause obstructions to traffic unless they could be located off the road. Under all circumstances, due to the possible accumulation of gas, care will be needed in accessing any manhole chambers, especially those which are not fitted with vents, and the safety procedures detailed in Section 7 must be rigidly followed.

Location of Service Entries Above Ground

B2.16 In some cases it is possible to route service entries into a building above ground level, thereby effectively providing an 'atmospheric break-leg' and eliminating the risk of gas entry to the building interior. This practice is routinely adopted for Town gas entry pipes and may be extended to cover electricity supply and other types of cable.

B2.17 To overcome architectural constraints, the entry points may be located in ventilated enclosures which may be designed to blend in with the building itself and thereby minimise the visual impact of the service entries. A typical enclosure with above ground service entries is shown in Figure B5.

Service Conduits Passing Through The Consultation Zone

B2.18 Recommendations for the measures which should be applied to service conduits which pass through a Consultation Zone with connections to buildings outside the Zone were presented in Section 7. Typical design details of the measures required for services which pass through a Consultation Zone are shown on Figure B6 and Figure B7.

Figure B1

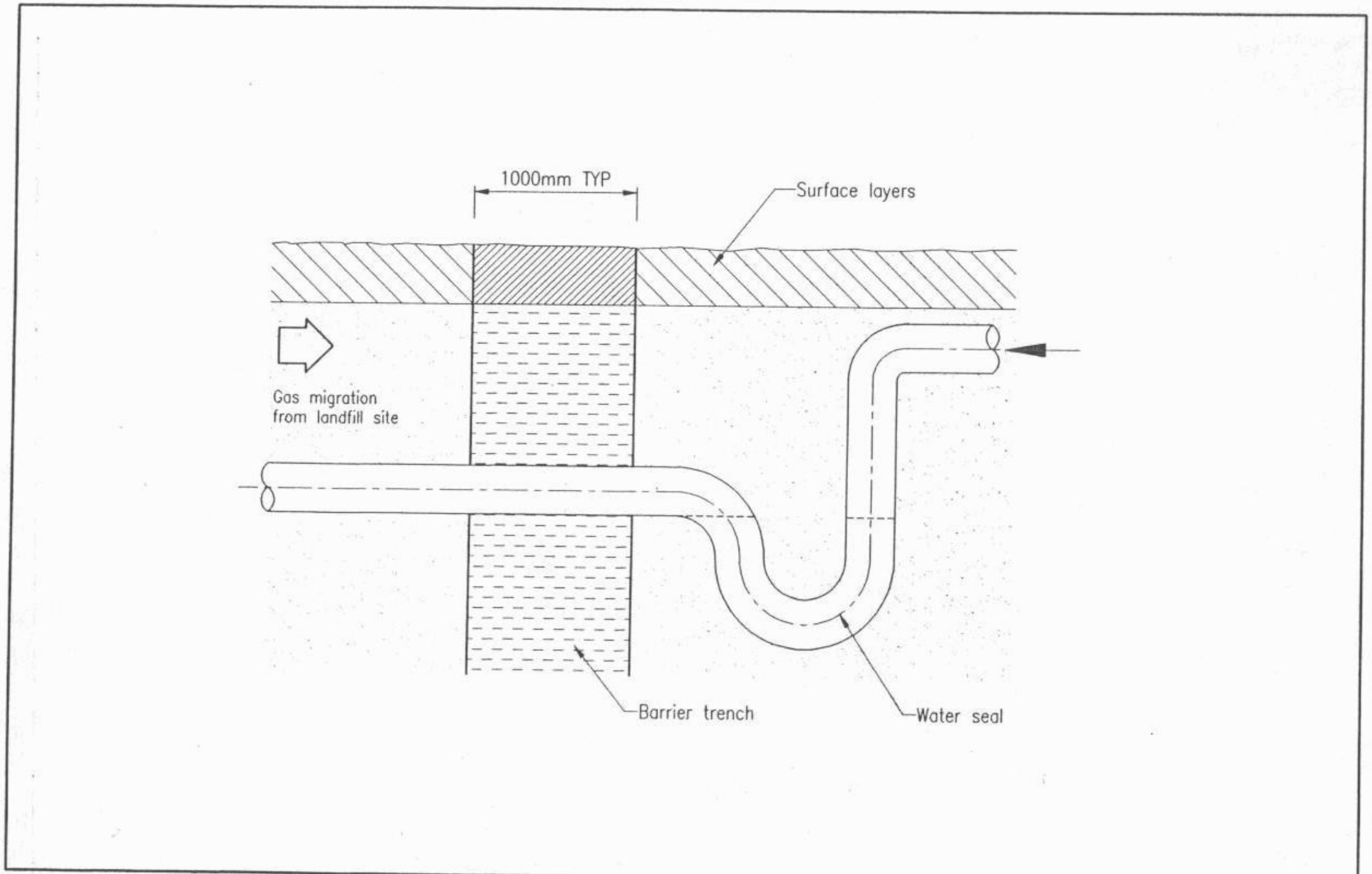


FIGURE B1 : OPEN CONDUIT PROTECTION BY WATER SEAL (LONGITUDINAL SECTION)

Figure B2

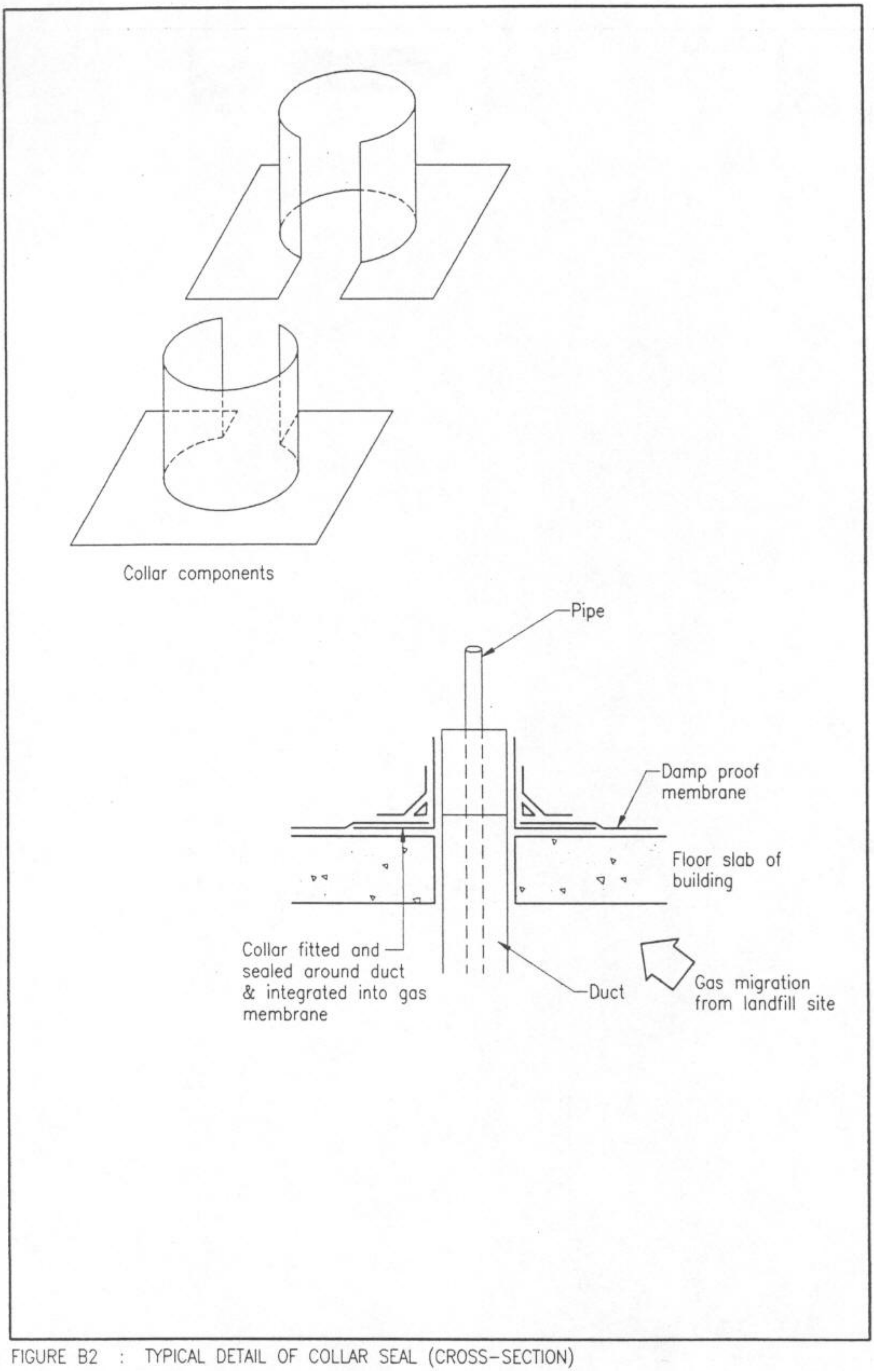


FIGURE B2 : TYPICAL DETAIL OF COLLAR SEAL (CROSS-SECTION)

Figure B3

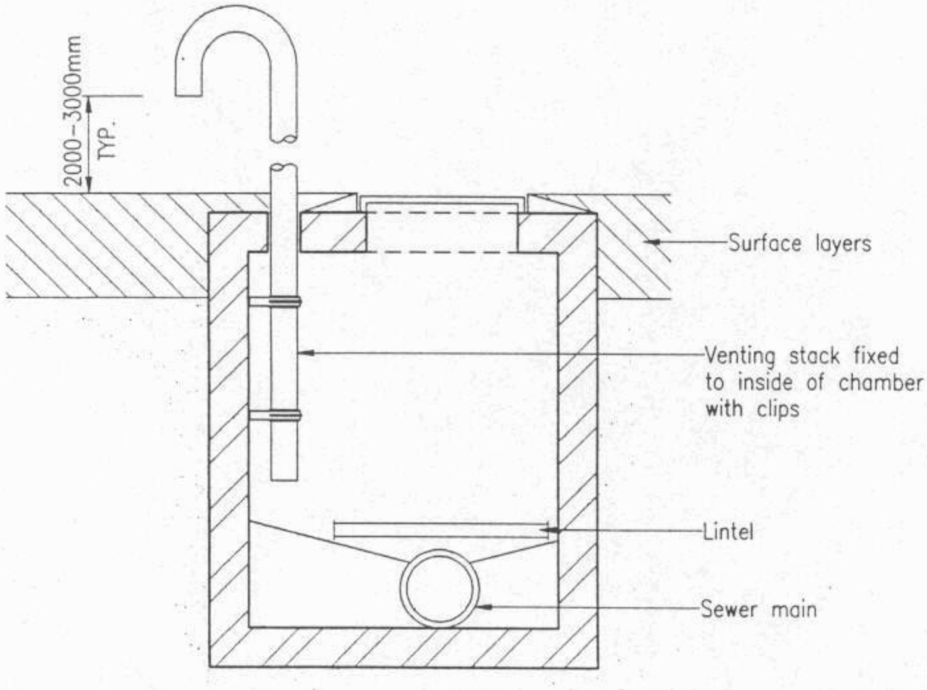


FIGURE B3 : VENTED MANHOLE (CROSS-SECTION)

Figure B4

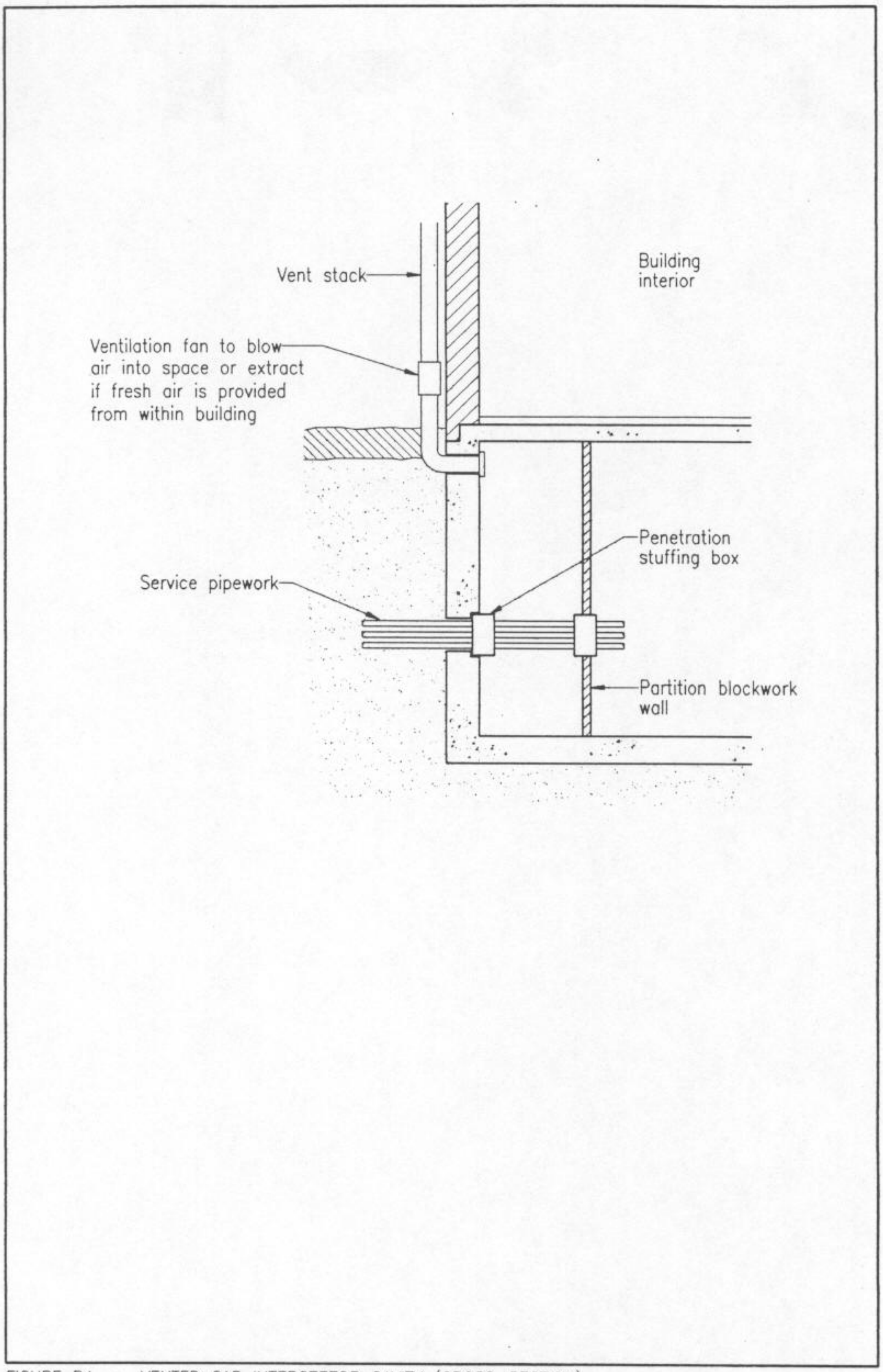


FIGURE B4 : VENTED GAS INTERCEPTOR CAVITY (CROSS-SECTION)

Figure B5

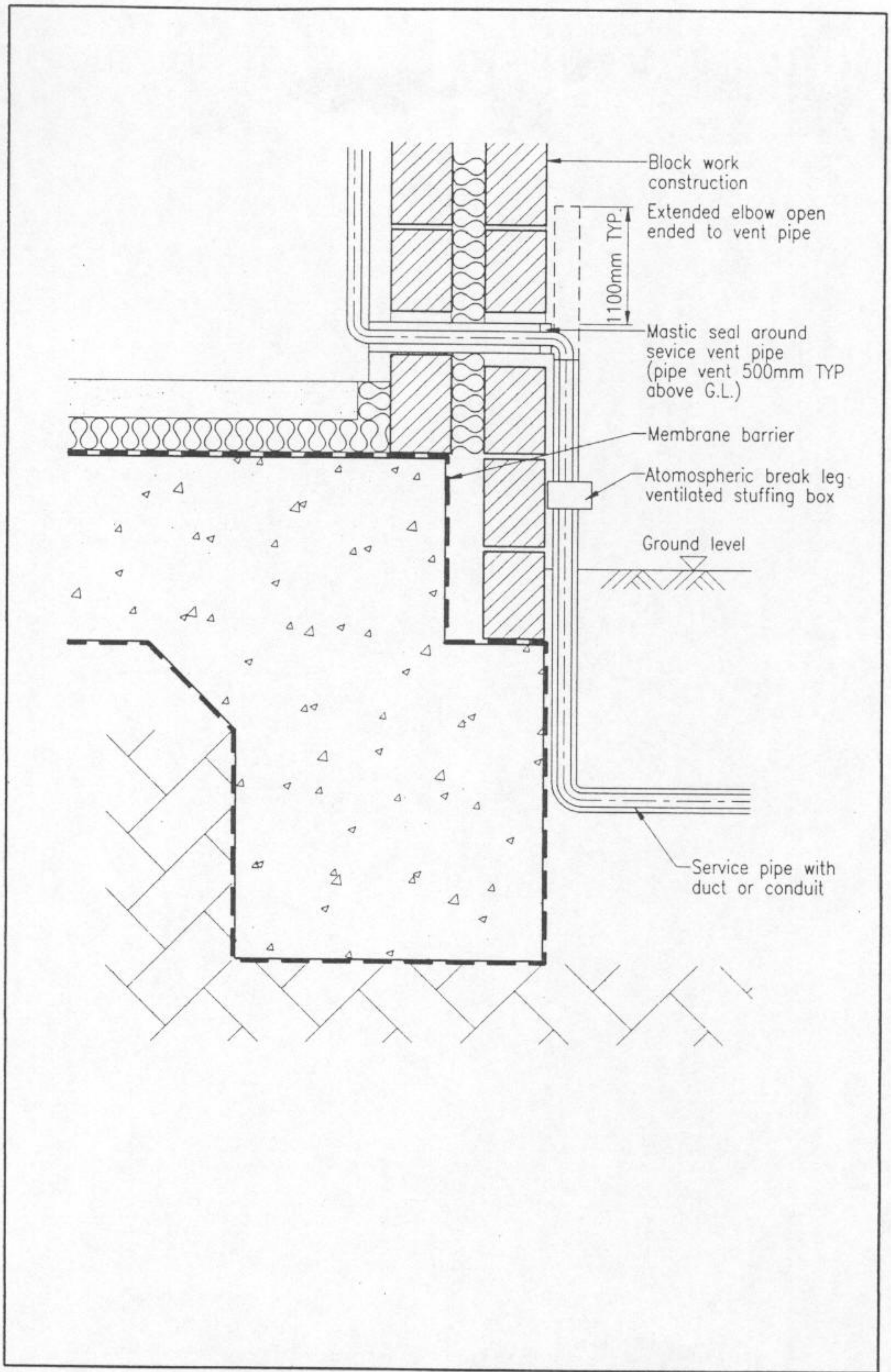


FIGURE B5 : ABOVE GROUND SERVICE ENTRY

Figure B6

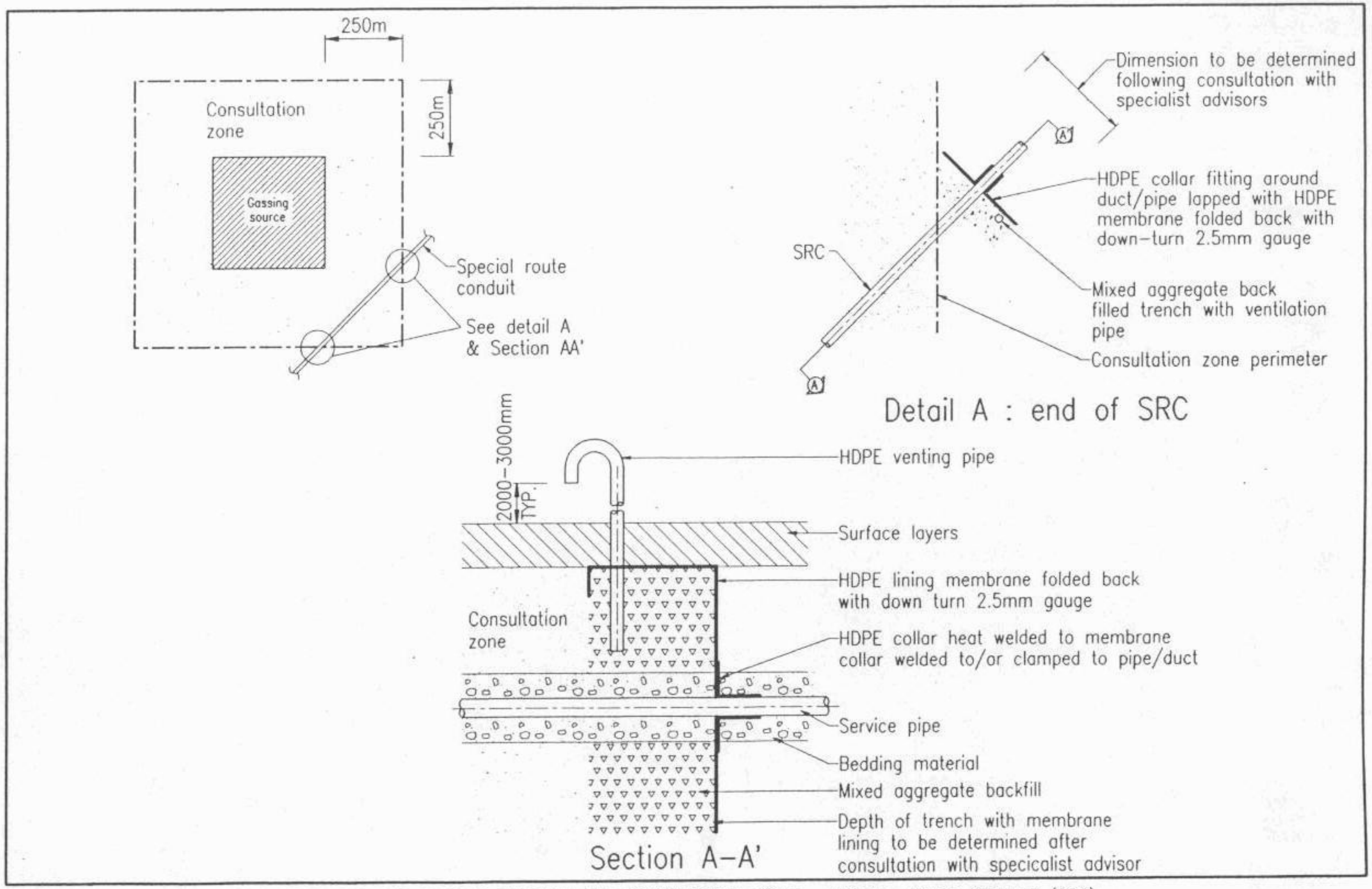


FIGURE B6 : TYPICAL DESIGN FOR SERVICES PASSING THROUGH THE CONSULTATION ZONE – SPECIAL ROUTE CONDUIT (SRC)

Figure B7

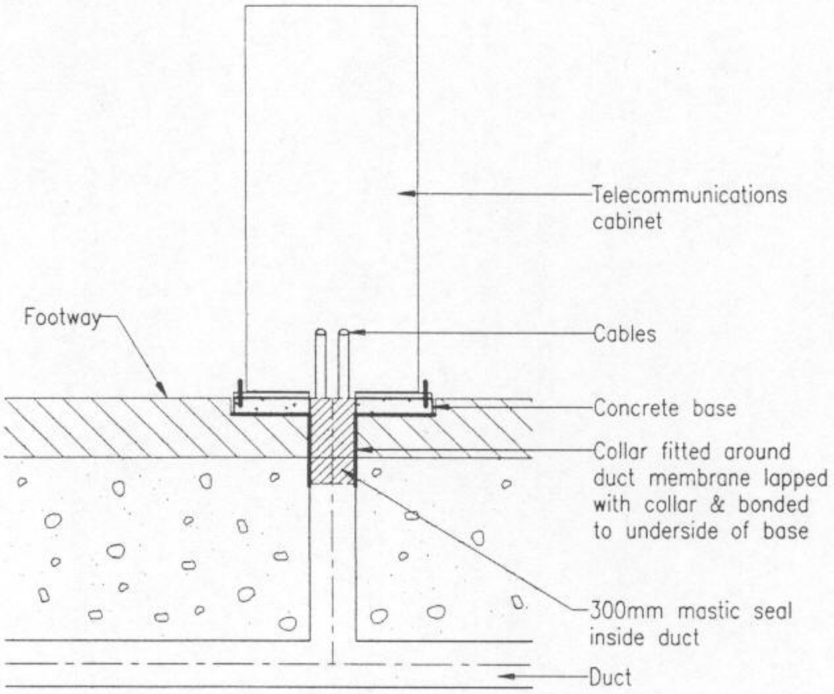


FIGURE B7 : TYPICAL SURFACE DETAIL FOR ABOVE GROUND TERMINATION OF SERVICES WITHIN THE CONSULTATION ZONE (CROSS-SECTION)

Annex C QUALITATIVE RISK ASSESSMENT - WORKED EXAMPLES

Three worked examples of qualitative risk assessment are presented below for illustration. It should be noted that the examples do not include the full content of a normal assessment report. A lot of information, such as detailed project profile and site investigation and monitoring data, has not been presented. Similarly, site plans and cross-sections are included for illustrative purposes only. The general requirements for presentation in a qualitative risk assessment are detailed in Section 2 of this *Guidance Note*.

C1 EXAMPLE 1: SALT WATER PUMPING STATION

Introduction

C1.1 A salt water pumping station is to be constructed near to one of the landfill sites. A plan showing the relative locations of the landfill site and the proposed development is shown on Figure C1.1, a section through the landfill and development site is shown on Figure C1.2, and a detailed source-pathway-target analysis presented on Table C1.1.

C1.2 It can be seen that whilst the risk is generally found to be low, there are some circumstances where a medium risk has been identified. Nine issues are considered arising from this, and recommendations given to address each issue. These are set out in full below, and relate to the pumping station, external areas, the pipeline and temporary works during construction.

The Source

C1.3 The landfill is a marine reclamation landfill. Landfilling started in 1979 with wastes deposited behind bunds constructed over marine muds. A seawall at the southern margin of the landfill comprises a rockfill core with a nominal 17.5 m wide soil margin between the core and the deposited wastes. Imported wastes included domestic, commercial/industrial, construction and special categories, eg asbestos. Overall the site has the potential to produce substantial volumes of landfill gas and leachate.

Targets

C1.4 **External Areas, including service ducts, valve or washout chambers.** A number of trenches and chambers exist in the immediate vicinity of the pumping station which contain pipes, valves and other equipment. The current design proposes to cover these with removable reinforced concrete slabs. These spaces are not designed to resist gas penetration and may create a potential zone of gas build-up which could be ignited on removal of a slab by introduction of an ignition source (cigarette, steel tools etc). *See Recommendation 1.*

C1.5 **The Pumping Station Building Interior.** The pumping station has been designed as a waterproof structure by use of dense well-compacted reinforced concrete and fitting of water bars, sealants and fillers to all joints. This greatly enhances the resistance of the structure to gas penetration although it should be remembered that gas has a permeability of 3 to 4 orders of magnitude greater than water. Furthermore, whilst the waterproofing is detailed to come to future ground level, there may be a danger that detailing will be less careful above nominal groundwater level in the zone where gas is most likely to occur. Particularly sensitive situations which will occur in the unsaturated zone relate to utilities entry into the structure, for example, an opening 1000 x 500 mm is required for power cables at an elevation of 4.15 to 4.65 mPD. The sealing of this aperture around the power cables will be critical for the gas-resistance of the structure. *See Recommendation 2.*

C1.6 Whilst concrete is permeable to gas, the rate of movement of gas through the concrete is slow and any build-up of gas could only occur over a long period of time. Ventilated areas within the pumping station should not be at risk from gas permeating through concrete as the majority of the pumping station open area is ventilated at a rate of 4-6 air changes per hour (as currently proposed for the basement). See *Recommendation 3*.

C1.7 **The pipeline, and the delivery end of the pipeline.** Whilst it is considered very unlikely that flammable gas should enter the pipeline either via the seawater intake in solution, or via a crack in the steel wall of the pipe, it would be prudent to ensure that any air/gas which occurs in the headspace in the pipe can be harmlessly dispersed. See *Recommendation 4*.

C1.8 Note: Methane has low solubility when subject to atmospheric pressure. A degassing facility is incorporated into the station to take off hydrogen from water arising from hypochlorite dosing.

C1.9 If gas enters the backfill around the pipeline, then it may migrate preferentially along the line of the backfill. See *Recommendation 5*.

C1.10 At present, there are no monitoring wells outside the line of the venting trench, and thus there is no means of determining whether the trench is successful in controlling gas migration. See *Recommendation 6*.

C1.11 The vent trench has been constructed with sloping sides, which slope towards the south. The pipeline runs parallel to the vent trench for the majority of the length of the southern landfill boundary. See *Recommendation 7*.

C1.12 **Temporary Works During Construction**. The Works are to be constructed in an area of land which may contain landfill gas. See *Recommendation 8.*

Table C1.1 Source - Pathway - Target Analysis for Worked Example No.1

A. Source	B. Pathway	C. Target	Assessment of Risk
Landfill gas measured at edge of landfill up to 64% by volume methane (flammable gas). Vent trench installed near landfill, to below nominal ground water level, may intercept majority of gas (efficacy not proven). *(major source)*	Soil (unsaturated reclaimed granular) to vicinity of pump station, distance approx. 120 m. May enter station via cracks or construction joints in basement walls and floors. *(long/indirect pathway)*	**External areas of pumping station.** Service ducts, valve or washout chambers on pipeline. *(Medium sensitivity target)*	Medium
		Internal areas of pumping station. Particularly those areas with no ventilation. Basement is designed to be waterproof. *(Low sensitivity)*	Low
		Temporary works during construction *(Low sensitivity target)*	Low
	Pipe trench. Via backfill around pipeline as it runs parallel to vent trench. May enter station via defects in seal as pipeline passes through basement wall. *(Moderately short/direct pathway)*	**External areas of pumping station.** Valve or washout chambers on pipeline. Developments further along pipeline outside the scope of this study. *(Medium sensitivity target)*	Medium
		Internal areas of pumping station. Particularly those with no ventilation. Basement is designed to be waterproof. *(Low sensitivity target)*	Low
		Temporary works during construction *(Low sensitivity target)*	Low
	Pipe. Gas may enter into pipeline from pipe trench via crack in weld or pipe. However, pipe nearly always under positive pressure, and wrapped in bituminous sheeting. *(Long/indirect pathway)*	Delivery end of pipe (consumer/reservoir) *(Low sensitivity target)*	Low

A. Source	B. Pathway	C. Target	Assessment of Risk
Leachate from landfill (contaminated water which has the potential to give off flammable gas). *(Minor source)*	Flow beyond vent trench, then outgassing to produce methane in unsaturated soil zone. Leachate should outgas partially, at or before vent trench. *(Long/indirect pathway)*	**External areas of pumping station** such as ducts or valve/washout chambers. *(Medium sensitivity target)*	Low
		Internal areas of pumping station. *(Low sensitivity target)*	Very Low
		Temporary works during construction *(Medium sensitivity target)*	Low
Seawater coming from landfill. Methane may dissolve into salt water intruding into wastes, particularly if under pressure. *(Minor source)*	Such water entering sea intake of pumping station may outgas methane within the pumping station if there is a pressure decrease, as methane has low solubility when subject to atmospheric pressure. However, a degassing facility is incorporated into station to take off hydrogen from water which has been dosed with hypochlorite. *(Long/indirect pathway)*	**External areas of pumping station** *(Medium sensitivity target)*	Low
		Internal areas of pumping station. Particularly internal spaces of pumps. *(Low sensitivity target)*	Very Low
		Temporary works during construction *(Medium sensitivity target)*	Low

Source-Pathway-Target Analysis

C1.13 On the basis of the information available, a source-pathway-target analysis has been undertaken for the different combinations of source and target, as discussed above, and is presented on Table C1.1. In general, although the landfill represents a major source, the combination of long/indirect pathways and relatively low sensitivity targets results in the overall risks being assessed as low. The exceptions to this are the service ducts etc. installed within the ground outside the pumping station which are assessed as being of medium sensitivity resulting in an overall medium risk. Leachate and seawater are both deemed to be only minor sources of landfill gas at this site resulting in low or very low risks to the various features of the development.

Recommendations

C1.14 *Recommendation 1:* Utility companies should be advised of the possible presence of flammable gas in the ground and should take this into account in designing, constructing and maintaining their works. All ducts and chambers, whether specific to the pumping station equipment or to utility services such as electricity, water, telephone etc., should be either sealed off from the ground to prevent gas entry, or provided with vented covers to allow any gas which does enter to dissipate harmlessly to the atmosphere. Procedures should be established for monitoring any such confined spaces before entry.

C1.15 *Recommendation 2:* Waterproofing details on below ground structures should be maintained to ground level if not already done so. As soon as reclamation has been completed up to the sheet piled excavation for the new pumping station, groundwater should be sampled for contaminants to check their compatibility with waterproofing materials.

C1.16 *Recommendation 3:* Ventilation should be provided to all areas of the pumping station with walls or floors in contact with the ground. The ventilation should operate 24 hours a day with an automatic alert facility in the event that the fans breakdown. If this is not practicable, then flammable gas detectors should be installed. These should detect gas by catalytic oxidation or infra-red techniques and be capable of measuring concentrations of gas in the range 0-100% of the Lower Explosive Limit. Two trigger values which sound different alarm signals should be set at 10% LEL (early warning of a problem) and 20% LEL (evacuation of building until problem is resolved). The location of the detectors should be determined on the basis of areas or rooms where little or no ventilation is available, and where there are floors or walls in contact with the soil, or where ducts run from the basement to above ground floor levels. A procedure should be developed as part of the station operation to respond to gas detector alarms. The detection system should be maintained and calibrated regularly in accordance with the manufacturer's recommendations. In the event of a power failure, the detectors should have an 8 hour battery back-up system, and the procedures should indicate for manual monitoring in the station in the event of prolonged power failure (of longer than 8 hours).

C1.17 *Recommendation 4:* All valve and washout chambers along the pipeline should be adequately vented by provision of appropriate covers or other means such that gas cannot build up in the chamber. Venting of air from within the pipeline should take place to the open atmosphere. At the reservoir, the pipeline should discharge its water through an open ventilated space, or the headspace above the water in the reservoir should be adequately ventilated.

C1.18 *Recommendation 5:* Where the pipeline leaves the zone of gas influence it should be provided with suitable barriers (collars) to movement of gas along the line of the pipe trench and backfill, together with adequate venting of the backfill at the position of the barrier. The venting could consist of a short length of trench backfilled entirely with no fines 20 - 40 mm gravel or stone, left free to vent at the ground surface. If it is necessary to cover over the trench, then two vent pipes should be placed in the gravel, one on either side of the salt water pipe, perforated throughout their buried depth and terminated typically 2 metres above ground level with a cowl. The gravel vent should be placed on the landfill side of the barrier or collar.

C1.19 *Recommendation 6:* A series of monitoring wells should be constructed immediately south of the vent trench to the depth of groundwater. The boreholes should have a record of ground conditions encountered and be fitted with gas monitoring standpipes. The standpipes should be regularly monitored.

C1.20 *Recommendation 7:* The alignment of the pipeline should be checked to ensure that it does not compromise the buried membrane on the southern sloping face to the vent trench. When constructing the excavation for the pipeline (typical depth 2.5m) the stability of the excavation sides should be assessed with respect to the presence of a buried sloping membrane nearby.

C1.21 *Recommendation 8:* All temporary works and construction activities should be carried out with an awareness of the potential presence of landfill gas in the ground, and appropriate precautions taken to guard against any hazard arising. This should not only apply to the initial construction, but during any subsequent excavations that are carried out in future years for maintenance or upgrading of the pipeline.

C1.22 Whilst the measures recommended above are relatively simple to implement, their effectiveness will be diminished in the future if they are not properly managed and maintained. For example, the venting provided to manholes might be inadvertently blocked off without an appreciation of the possible consequences. See *Recommendation 9*.

C1.23 *Recommendation 9:* A set of management procedures should be drawn up which ensure that, as part of the routine maintenance of the pumping station and pipeline, the gas protection measures are regularly checked to ensure their continued effectiveness. An annual report should be prepared documenting the procedure.

C2 *EXAMPLE 2: RESIDENTIAL SCHOOL*

Introduction

C2.1 The development for a residential school is on a cut platform within 15 m of a completed landfill site. The site is bordered to the east by the steep hills and to the west by a street which previously was the landfill access road. A plan showing the relative locations of the landfill site and the proposed school is shown on Figures C2.1. A section through the landfill and the proposed school site is shown on Figure C2.2.

The Source

C2.2 The landfill was filled during the late 1970s, holds a total of approximately 750,000 tonnes of domestic and commercial waste and comprises a series of platforms. The depth of waste varies between 10m and 30m. Much of the waste was deposited above the level of the surrounding land although there is up to 14m below the level of the adjacent street. There was some basal engineering prior to landfilling, as follows:

- 750 mm CDG oversite
- 225 mm diameter groundwater drain
- 0.8 mm PVC liner
- 225 mm diameter leachate drain.

C2.3 The platform areas were capped with at least 3 m of silty sand, partly covered by asphalt. There is no information available regarding side slope capping. A total of 32 passive gas vents were installed upon completion of filling although, as of 1994, most were no longer in existence. Thus, minimal measures exist to prevent gas migration. At the time of the assessment, no restoration works had been carried out for the landfill.

C2.4 Gas yield forecast was estimated at 210 m^3hr^{-1} of methane and 172 m^3hr^{-1} carbon dioxide, during site investigation work in 1994. Existence of landfill gas in the ground alongside the street was typically at 1.5 % LEL, with one area at 5.2% v/v. Some service voids nearby had periodically high gas concentrations (up to 10.3% CH_4).

Pathways

C2.5 The main pathways for potential gas migration to the development are:

- soil;
- fractured bedrock;
- a proposed surface water culvert; and
- below ground electrical cables entering a transformer room.

C2.6 Leachate is unlikely to affect the residential school site because the hydraulic gradient is from the development site towards the landfill.

C2.7 Migration of gas from the landfill site is estimated to be low, with 98% of the forecast landfill gas yield escaping directly to atmosphere, most likely through uncapped sides. While the distance between the landfill and the development is short, there is a relatively high groundwater table which restricts the cross-sectional area of unsaturated soil through which the gas can migrate.

Targets

C2.8 The residential school will comprise a three/four storey complex grouped into the following three targets.

C2.9 **Dormitory blocks and offices,** which by virtue of their small rooms and limited ventilation, are at risk of gas build-up on the ground floors.

C2.10 **Teaching areas and indoor open areas,** which due to their large room size and good ventilation, are at lower risk of gas build-up than the dormitory and office areas.

C2.11 **A transformer room,** constructed below ground, with incoming cables, placing it at high risk in terms of gas ingress and accumulation.

C2.12 Total landtake is approximately 1.5 ha. All the buildings will have strip footing foundations, approximately 2 m deep, without any pilings. A stormwater culvert passes under part of the site but this will be redirected around the site during the works.

Source-Pathway-Target Analysis

C2.13 On the basis of the source, pathways and targets identified above, a source-pathway-target analysis has been undertaken and is presented in Table C2.1. The combination of a medium source term and a moderately short distance between the landfill site and the development site results in a range of overall risks depending on the sensitivity of the particular targets. Below ground rooms with cable entry points and potential sources of ignition are highly sensitive resulting in a high risk whereas the large, well ventilated rooms are of low sensitivity and only at a low risk.

Table C2.1 - Source - Pathway - Target Analysis for Worked Example No. 2 (Residential School)

A. Source	B. Pathway	C. Target	Assessment of Risk
Monitoring results indicate that migration of landfill gas alongside the street typically at 1.5 % LEL, with one area at 5.2 % v/v. Gas yield forecast estimated 210 m^{3}hr^{-1} of methane and 172 m^{3}hr^{-1} carbon dioxide. Migration offsite is estimated to be low, with 98 % of the forecast landfill gas yield escaping directly to atmosphere, most likely through uncapped sides. Hydraulic conductivity of 10^{-5} to 10^{-6} ms^{-1} give migration rates of 3 to 7 m^{3}m^{-2}year^{-1} for methane and 1 to 3 m^{3}m^{-2}year^{-1} for carbon dioxide. *(medium source)* There is potential for increased migration of landfill gas offsite if the restoration of the landfill does not include gas venting or collection measures.	**Soil** beneath Fung Shing Street, 1 to 40 m thick, 10 to 17 m directly below development site. Groundwater typically 6 mbgl. Distance 30 to 50 m, but very shallow unsaturated zone. *(moderately short/direct pathway)*	Ground level dormitory/office buildings *(medium sensitivity target)*	Medium
		Teaching areas and indoor open areas (large rooms) *(low sensitivity target)*	Low
		Transformer room *(high sensitivity target)*	High
	Discontinuities in bedrock. Moderately strong to medium grained granite with both closely and widely spaced discontinuities. Two major subvertical joint sets, continuous over 30 m with spacing ranging from 3200 to 1500 mm, some infilled, some showing evidence of water seepages. *(moderately short/direct pathway)*	Dormitory/office buildings *(medium sensitivity target)*	Medium
		Teaching areas and indoor open areas *(Low sensitivity target)*	Low
		Transformer room *(high sensitivity target)*	High
	Surface water culvert. 1000 mm dia concrete culvert will traverse the development site and run under the adjoining street. No direct connection to buildings of the development. *(moderately short/direct pathway)*	Dormitory/office buildings *(medium sensitivity target)*	Medium
		Teaching areas and indoor open areas *(low sensitivity target)*	Low
		Transformer room *(high sensitivity target)*	High
	Electrical cables to below ground level transformer room. *(moderately short/direct pathway)*	Transformer room *(high sensitivity target)*	High

Recommendations

C2.14 Although there is not a significant threat to the residential school from methane or carbon dioxide, in view of the close proximity of the landfill as well as the possibility that the migration and gas dispersion patterns could alter over time, it is advisable to provide for future gas control and monitoring.

C2.15 *Recommendation 1:* During site formation works, portable gas detectors should be available for routine monitoring of deep excavations for methane, carbon dioxide and oxygen. The main area of concern in this context is the transformer room where excavation below the level of the street will take place.

C2.16 *Recommendation 2:* Piezometers installed during the landfill risk assessment study should be periodically monitored for methane and carbon dioxide, to provide an ongoing assessment of potential migration of landfill gas towards the residential school development.

C2.17 *Recommendation 3:* The building designs should incorporate a means of passively venting gas and isolating the interiors from the potentially gassing ground strata. Measures should be taken to protect, in particular, the below ground level transformer room, the buildings directly adjacent to the street separating the development from the landfill, and those buildings close to the surface water culvert. These measures should include either the installation of a gas barrier along the side of the development closest to the landfill or the incorporation of gas resistant membranes in the floor slabs of the buildings together with underfloor (passive) ventilation. Mechanical ventilation and/or installation of gas detectors is recommended for the transformer room.

C2.18 *Recommendation 4*: Services for buildings in the highest risk level should be brought into the buildings above ground floor level. If this is not possible, the service conduits should be sealed into the gas protection membrane and the void around any cables etc. within the conduit filled with gas-resistant mastic.

C2.19 *Recommendation 5:* The installation of sub-floor monitoring points, which should be periodically checked, should be considered during the building design development.

C3 EXAMPLE 3: STATION AND OTHER DEVELOPMENTS

Introduction

C3.1 A station development and a number of other developments are planned near a completed landfill site. A plan of the landfill site and the development area is shown on Figure C3.1, a section through the landfill and development site is shown on Figure C3.2, and a source-pathway-target analysis is presented on Table C3.1.

C3.2 The station development is part of a major infrastructure improvement involving extension of the railway system. A new station complex has been built including high rise commercial and residential premises. In addition to the station development, a special school, a high rise residential development and recreation areas are near the landfill.

C3.3 Prior to placement of waste, the landfill site was used in part as a stone quarry. The site retained a significant proportion of the pre-existing natural topography; namely, a steep-sided valley confined between granite ridges.

Source

C3.4 The landfill is relatively large, covering about 14 ha. Basal preparations preceding placement of waste included a PVC liner, bituminous Chunam applied to valley sides, and separate leachate and groundwater drainage pipes. Waste was reported to have been placed in 2 m lifts with up to 250 mm of soil cover between lifts. The depth of waste is up to a maximum of 70 m. The landfill was operational between 1978 and 1981.

C3.5 The site has undergone restoration in the form of capping with thick layers (up to 7 m) of CDG soils and (at the time of the risk assessment, 1987-88) a passive gas extraction system. Prior to the completion of the station development, an active landfill gas extraction system will be installed.

Pathways

C3.6 **CGD capping soil** on landfill, up to 7 m deep, provides a possible migration route off the landfill site.

C3.7 **Discontinuities in bedrock**. A granite ridge lies between the landfill and the station development. The ridge comprises fine to medium grained granite with at least three major and three minor joint sets, which in places are open, providing a route for gas migration. In addition, there is a high likelihood of additional fractures caused by the earlier quarrying activities. The site is also underlain by a geological fault although the direction of this is not towards the developments.

C3.8 **A leachate drain** passes under the high rise residential development to foul sewer. Leachate from the site has relatively low organic strength. There does not appear to be a head of leachate over the basal liner, suggesting rapid dispersal of leachate, although perched leachate does exist in some areas.

Targets

C3.9 The **railway tunnels and stations** involve extensive excavations, which are at risk of ingress and build-up of gas, being located 200 m from the waste boundary. These risks could occur during both construction and operation of the tunnels and stations.

C3.10 The **residential/commercial development** will be directly above the new station, being 32 storeys tall. The foundation works for the development will create the risk of gas ingress and build-up. Risks will arise during construction and occupation of the buildings.

C3.11 A **Special School,** lies on the granite ridge north of the landfill site.

C3.12 **High rise residential properties** are to be built to the west of the landfill, over a former stream bed which has been filled by up to 9 m of clayey sands and gravels. Deep caisson foundations will be constructed with the associated risk of gas ingress and build-up during their construction.

C3.13 **Recreation areas** will be sited on top of the landfill crest platform and on a lower level platform, and will include a booking office, changing rooms/toilets, and pump rooms.

Source-Pathway-Target Analysis

C3.14 The Source-pathway-target analysis for the various combinations of source, pathway and target discussed above is presented on Table C3.1. The medium source, a range of short/direct to long/indirect and either high or medium sensitivity targets results in overall risks ranging from low to high. The highest risk is to those features, such as a pump room, to be located on the actual landfill site. Most targets fall into the medium risk category because they are of medium sensitivity and close to the landfill or of high sensitivity and located further away from the landfill.

Recommendations

C3.15 *Recommendation 1:* Those developments which have medium or higher risk of landfill gas build-up should be monitored to determine the actual degree of landfill gas migration and build-up. Those with significant levels of landfill gas should have monitoring and/or mitigating measures installed as appropriate. These should include gas sensors, barriers and passive or active ventilation.

C3.16 *Recommendation 2:* During site formation and construction works, portable gas detectors should be used to regularly check the gas levels in depressions, trenches, and other excavations. If monitoring indicates the necessity, ventilation of such excavations should take place, and sources of ignition should be kept away from areas where build-up of gas is possible unless these have been demonstrated to be free of gas.

C3.17 *Recommendation 3:* As the station and tunnels are substantially below ground, a high level of ventilation should be employed during their operation.

C3.18 *Recommendation 4:* The high rise residential property will require caisson foundations which should also be carefully monitored and ventilated as necessary during construction works.

C3.19 *Recommendation 5:* The leachate drain passing under the high rise residential property should be monitored for the presence of landfill gas to ensure there is no ingress from the surrounding soil and rock. If necessary, venting should be installed along the drain.

C3.20 *Recommendation 6:* The recreation area structures on the landfill platforms should incorporate design features to prevent gas ingress, such as raised floor slabs with passive or active ventilation, and gas barriers in the floors and around the foundations, pump rooms and other below ground structures. Gas monitoring should be undertaken and consideration should be given to the installation of permanent gas detection systems.

C3.21 *Recommendation 7:* Utility companies should be advised of the possible presence of flammable gas in the ground and should take this into account in designing, constructing and maintaining their works. All ducts and chambers should be either sealed off from the ground to prevent gas entry, or provided with vented covers to allow any gas which does enter to dissipate harmlessly to the atmosphere. Procedures should be established for monitoring any such confined spaces before entry.

Table C3.1 *Source - Pathway - Target Analysis for Worked Example No. 3 (Station and other developments)*

A. Source	B. Pathway	C. Target	Assessment of Risk
Gas yield forecast is high, estimated at 2000 to 4000 m^3hr^{-1} with a steady methane concentration of 47% v/v. However, a passive gas extraction system comprised of 50 vertical gas vent stacks is installed, limiting migration offsite. Migration of landfill gas was identified in a risk assessment, however, rates of migration are relatively low. *(medium source)*	**CDG Capping Soil** on landfill of up to 7 m and 3 m on the sides. Capping permeability measured at 10^{-6} to 10^{-7} ms^{-1}. *(short/direct pathway)* for the recreation areas which are sited on the landfill. This pathway is not relevant to the other targets which are not in contact or close proximity to the capping soils.	**Recreation areas** including buildings and pump rooms. *(high sensitivity target)*	High
	Discontinuities in bedrock. Fine to medium grained Hong Kong granite, slightly weathered, with a SE-NW trending fault defining the valley containing the landfill. Orthogonal joint patterns associated with this fault occur in the granite ridge to the NE of the landfill. These joint patterns are made up of three major and three minor joint sets, including one sub-horizontal major joint set. Most of these joints are open, though some have been filled by kaolin in the SW portion of the site, as a result of local kaolinisation in this area as a result of a syenite dyke trending SW-NE across the site. *(moderately short/direct)* for the special school because it is sited on the fractured granite ridge. *(long/indirect pathway)* for the two station developments and the high rise residential property. [Not applicable to the recreation areas on top of the landfill]	**Railway tunnels and station** *(high sensitivity target)*	Medium
		Station residential/commercial development *(medium sensitivity target)*	Low
		High rise residential properties *(medium sensitivity target)*	Low
		Special School *(medium sensitivity target)*	Medium
	Leachate drain passing under the residential development site to foul sewer. *(very short/direct)* for high rise residential property [Not applicable for the other developments]	**High rise residential properties** *(medium sensitivity target)*	Medium

Figure C1.1

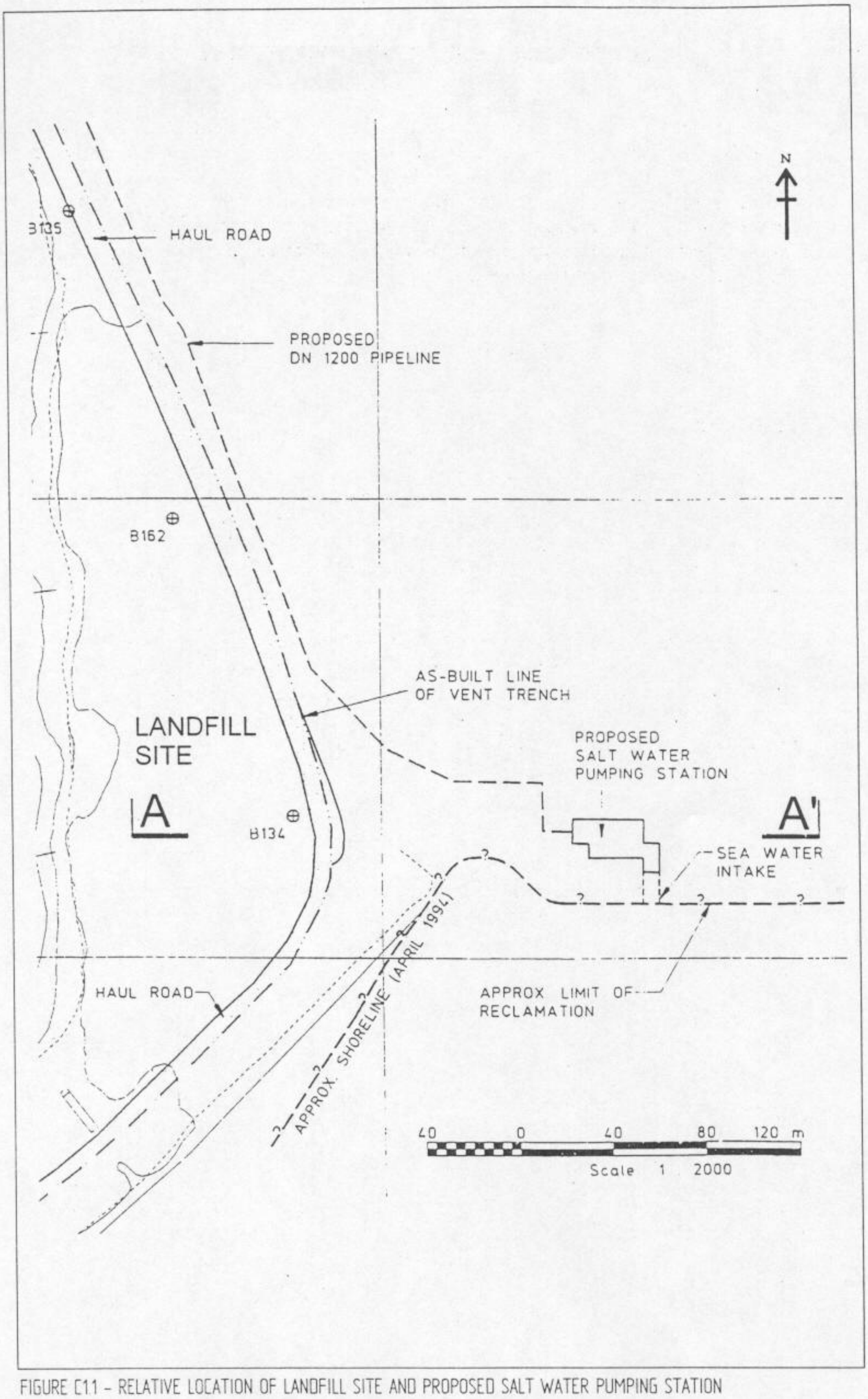


FIGURE C1.1 - RELATIVE LOCATION OF LANDFILL SITE AND PROPOSED SALT WATER PUMPING STATION

Figure C1.2

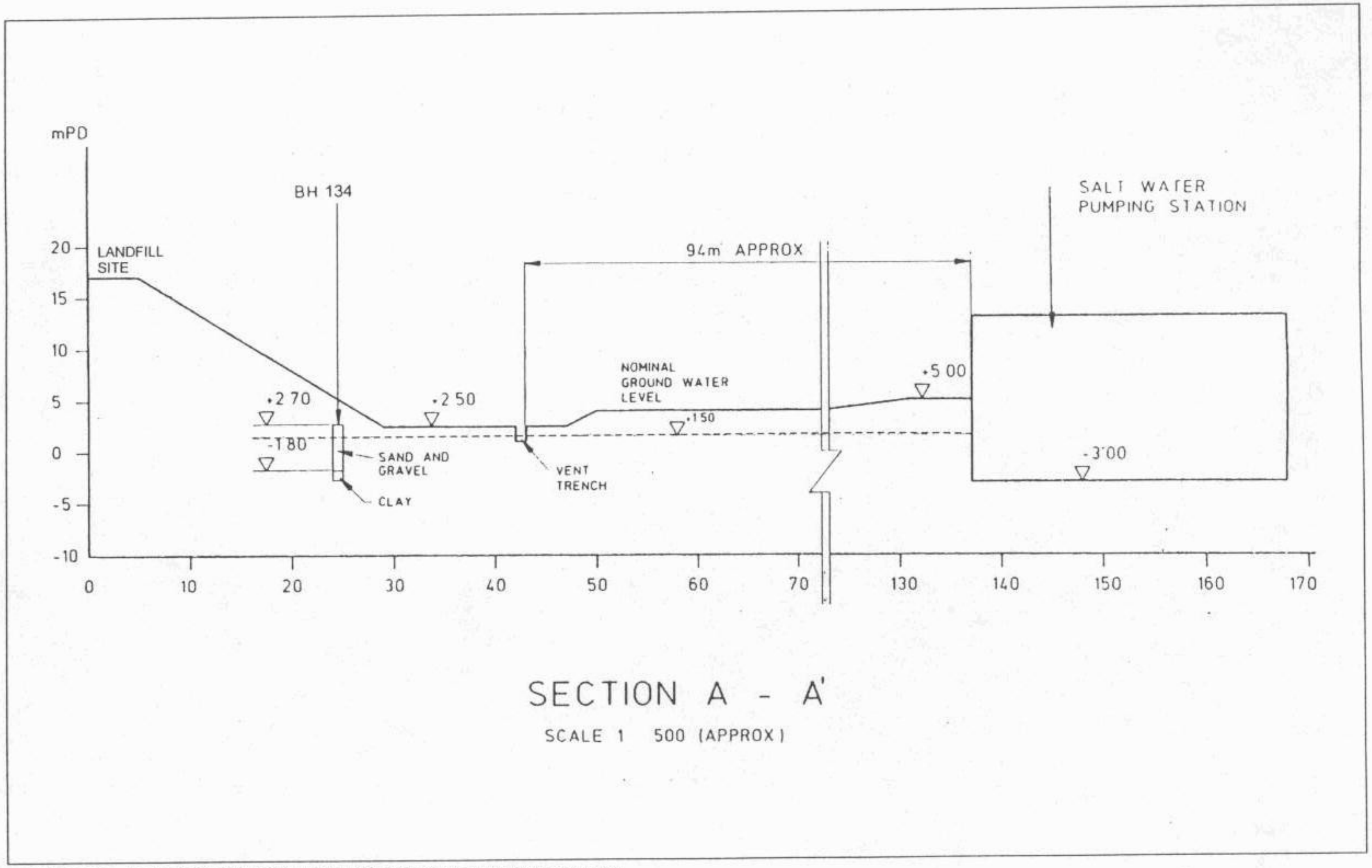


FIGURE C1.2 - CROSS SECTION THROUGH SALTWATER PUMPING STATION AND LANDFILL

Figure C2.1

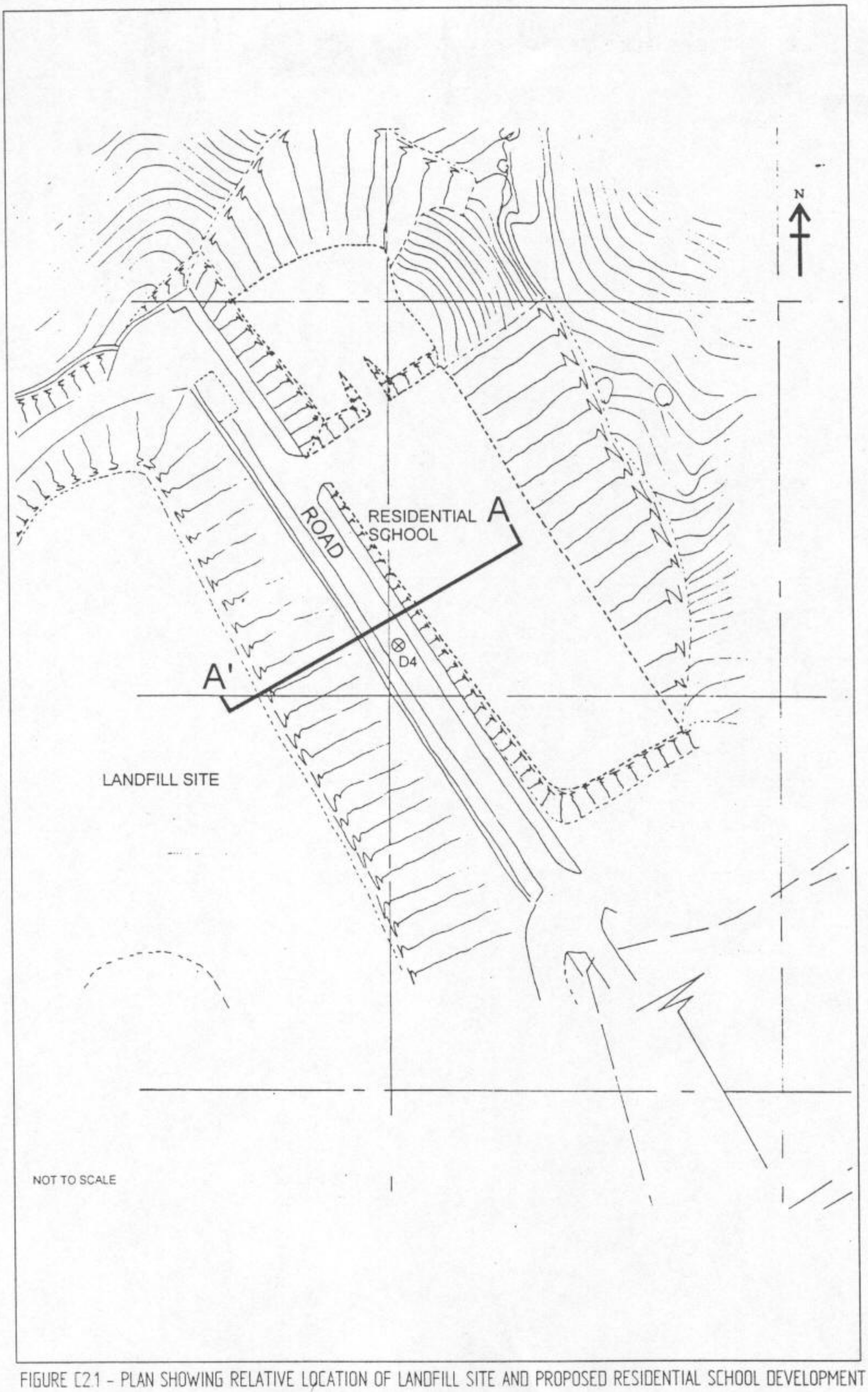


FIGURE C2.1 - PLAN SHOWING RELATIVE LOCATION OF LANDFILL SITE AND PROPOSED RESIDENTIAL SCHOOL DEVELOPMENT

Figure C2.2

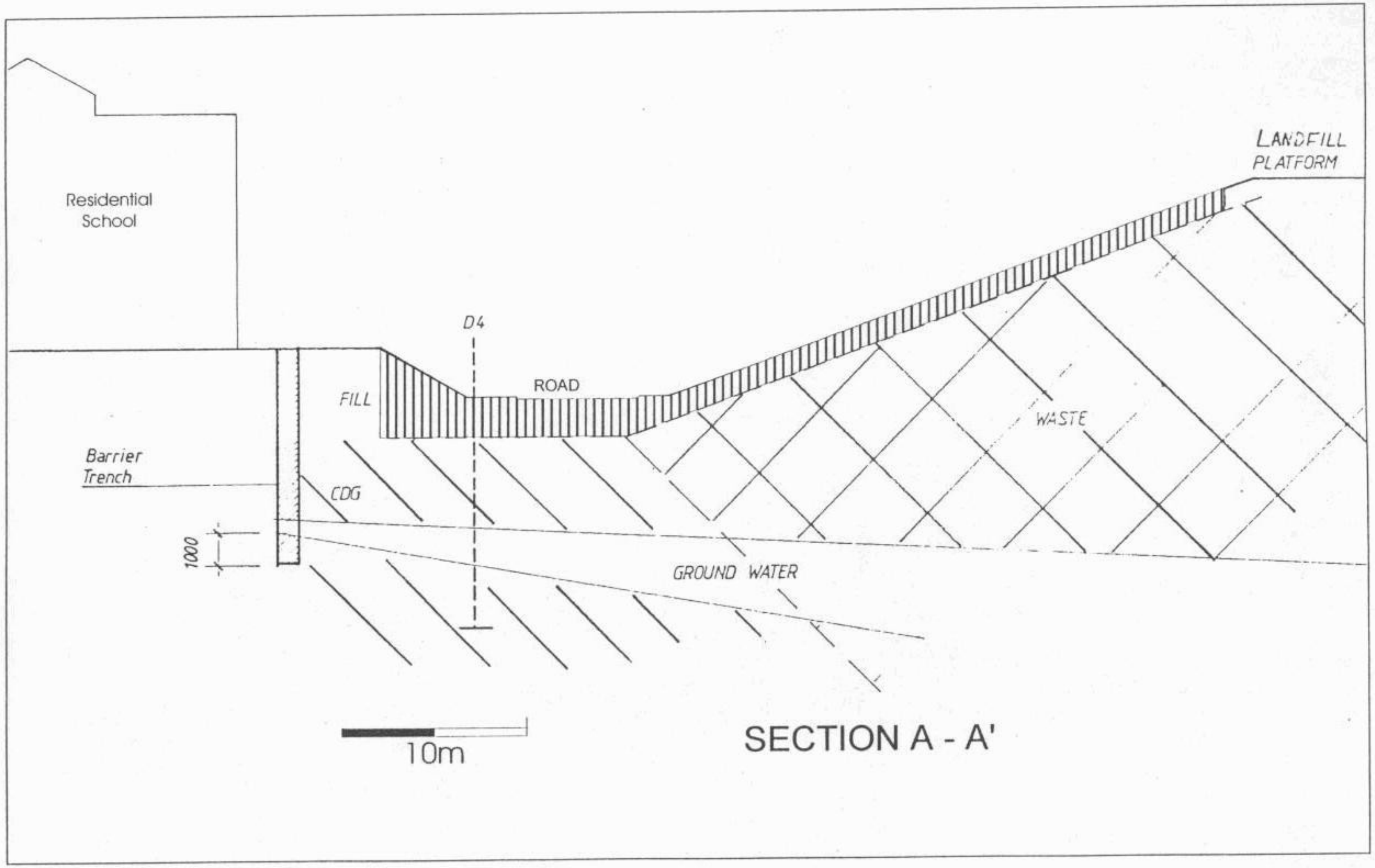


FIGURE C2.2 - CROSS SECTION OF RESIDENTIAL SCHOOL AND LANDFILL

Figure C3.1

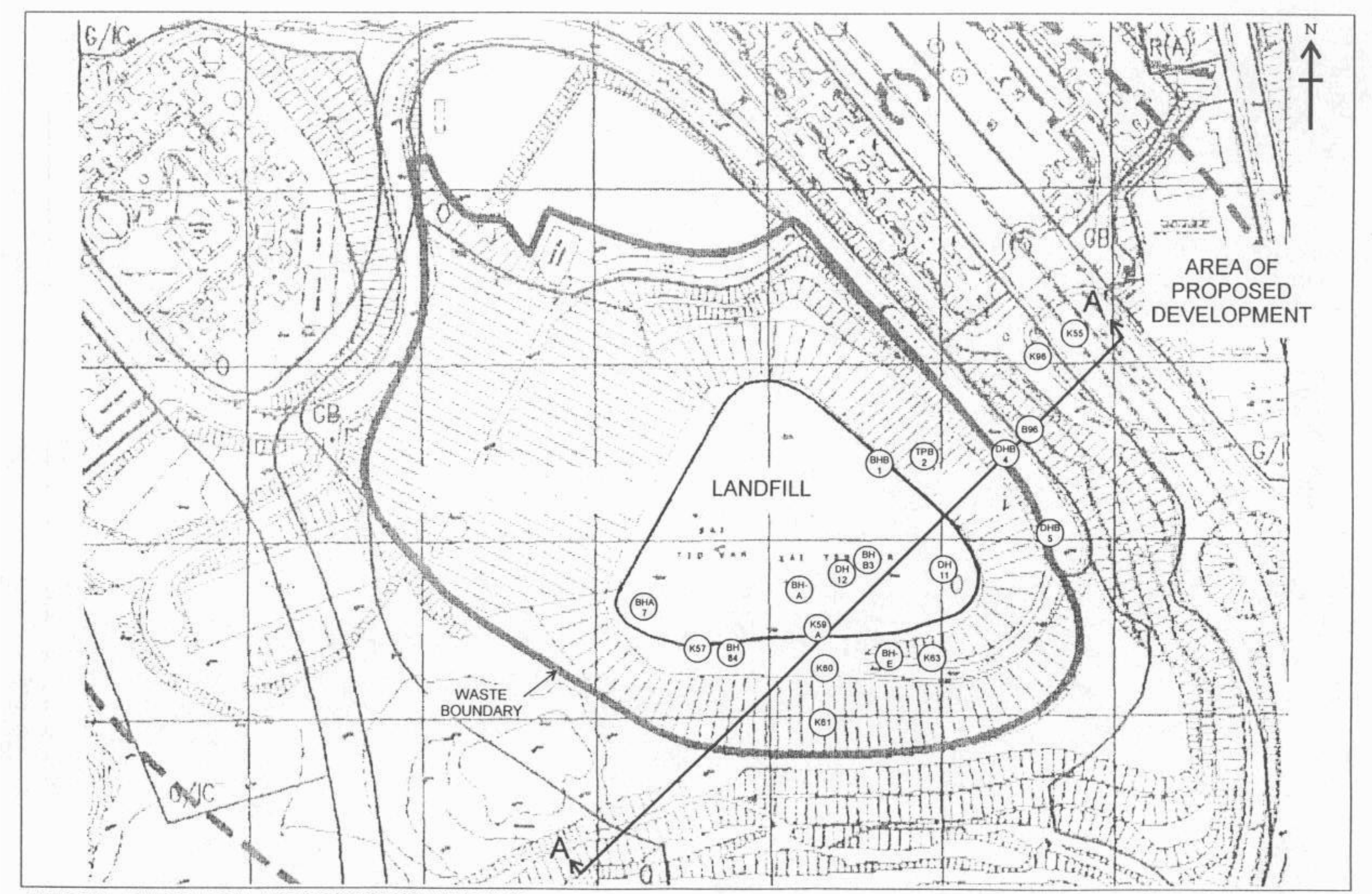


FIGURE C3.1 – PLAN OF LANDFILL AND PROPOSED STATION DEVELOPMENT

Figure C3.2

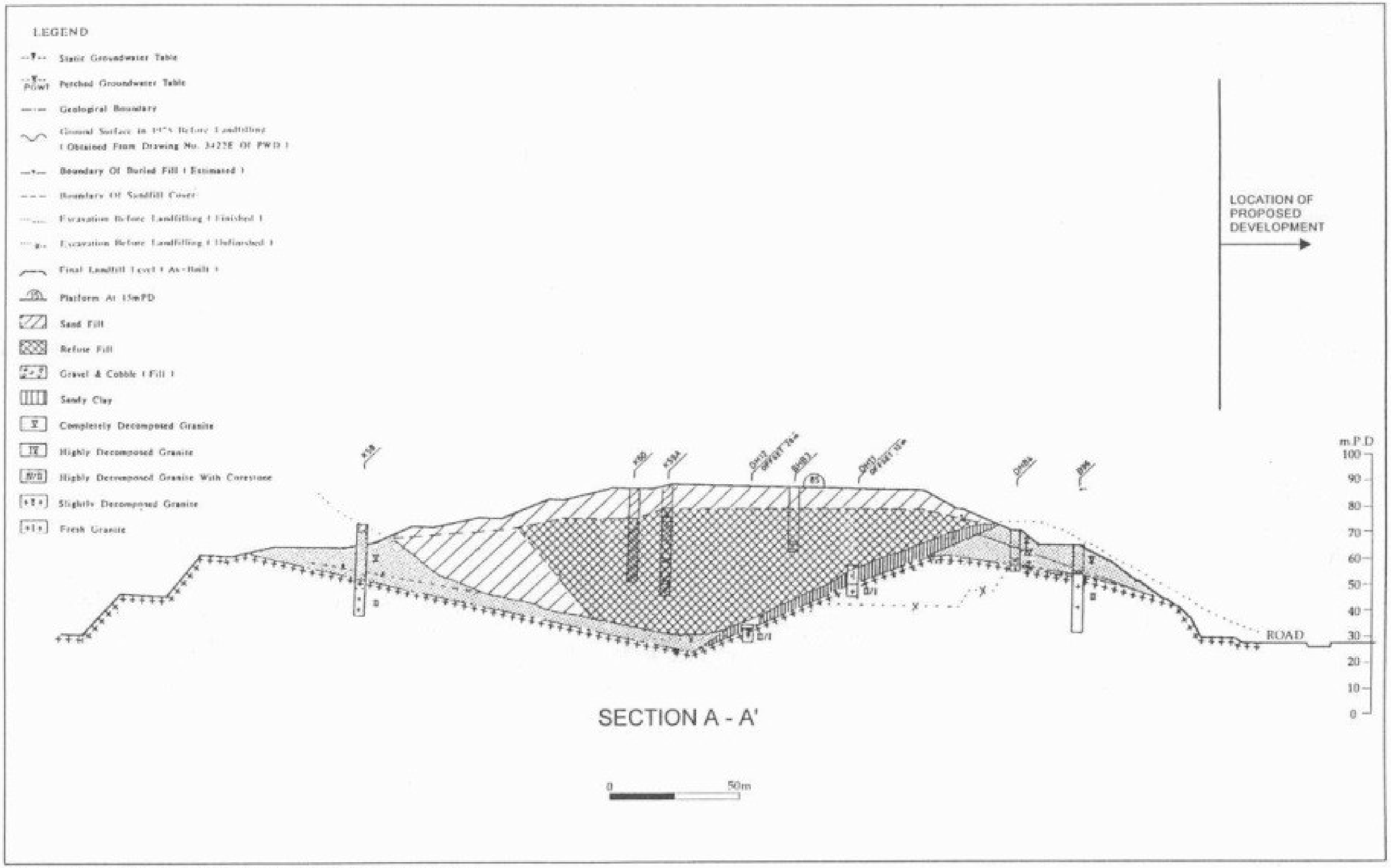


FIGURE C3.2 – CROSS SECTION OF LANDFILL AND ADJOINING LAND