ENVIRONMENTAL PROTECTION AGENCY

An Ghníomhaireacht um Chaomhnú Comhshaoil

LANDFILL MANUALS

INVESTIGATIONS FOR LANDFILLS

This document contains 50 pages

LANDFILL MANUALS

INVESTIGATIONS FOR LANDFILLS

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The Agency personnel involved in the preparation and production of this manual were Ms. Anne Butler, Mr. Gerry Carty, Dr. Matt Crowe, Mr. Ger Keohane (now Geotechnical and Environmental Services), Mr. Larry Kelly and Ms. Marion Lambert (word processing).

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Environmental Protection Agency
Ardcavan, Wexford, Ireland.
Telephone : +353-53-47120   Fax : +353-53-47119

The Environmental Protection Agency was established in 1993 to license, regulate and control activities for the purposes of environmental protection. In the Environmental Protection Agency Act, 1992, it is stated that "*the Agency shall, as soon as is practicable, specify and publish criteria and procedures for the selection, management, operation and termination of use of landfill sites for the purposes of environmental protection.*" These criteria and procedures are being published in a number of manuals under the general heading of LANDFILL MANUALS.

This manual describes the sequence and extent of investigations required to progress the selection, construction and operation of a landfill site. It also outlines the procedures to be adopted in the investigation of existing landfill sites, such investigations being required to complete a site conditioning, closure or aftercare plan. Other manuals on Site Selection, Monitoring and Operational Practices are also being prepared. This manual should be read in conjunction with the other manuals as they are published. The manual on 'Site Selection' outlines the criteria to be considered in the site selection process. This process involves consideration of all relevant criteria in an integrated, informed and transparent manner. As the investigations described herein are an integral part of the site selection process, progress on the investigations is essential to the decision making process.

Future Irish landfills will be developed, managed and subjected to aftercare procedures within the framework of the EU proposal for a Directive on the Landfilling of Waste and the Waste Bill, when enacted. This manual is being published to assist in meeting the statutory obligations of Section 62 of the Environmental Protection Agency Act, 1992. It is intended to be a nationally adopted guidance manual for use by those involved in landfilling. The extent to which the contents are applied to a particular project will be a matter for the judgement of the Principal Technical Adviser(s) as defined herein.

The current standard of operation of many landfills is unsatisfactory and significant improvements are required if we are to meet the higher standards proposed in national legislation and EU directives. To meet these standards, a thorough, professional and consultative approach to the selection, operation, management and aftercare of our landfills is required. Our determination to deal with waste in a responsible manner should be reflected in our approach to all aspects of the planning and management of existing and proposed landfills.

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OPW	Office of Public Works
GSI	Geological Survey of Ireland
OS	Ordnance Survey
ICE	Institution of Civil Engineers
BOQ	Bill of Quantities
EU	European Union
SMR	Sites and Monuments Record
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
BS	British Standards
IS	Irish Standard
Agency	Environmental Protection Agency
ISO	International Standards Organisation
ICRCL	Interdepartmental Committee on the Redevelopment of Contaminated Land (UK)
SISG	Site Investigation Steering Group

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1.1 GENERAL

The disposal of waste to landfill is a difficult and contentious matter. With continued economic growth we are producing and consuming more goods and materials and we now produce one third more domestic and commercial waste than a decade ago. At present the majority of this waste is landfilled in unlined sites which do not meet the standards now required, and this practice cannot continue indefinitely.

1.2 ROLE OF THE EPA

The Environmental Protection Agency (EPA) was established in July 1993 and its functions include the monitoring of the quality of the environment, the provision of support and advisory services for the purposes of environmental protection, the licensing of major industries and other activities. In carrying out these duties the Agency is required to have regard to the need for a high standard of environmental protection and the need to promote sustainable and environmentally sound developments. Where there are reasonable grounds for believing that the potentially harmful effects of emissions could cause significant environmental pollution, the Agency shall have regard to the need for precautions to be taken.

The Agency is required to specify and publish criteria and procedures for the selection, management, operation and termination of use of landfill sites for the disposal of domestic and other wastes. These criteria may relate to:

- site selection;
- design and bringing into operation of sites;
- impacts on the environment;
- leachate management, treatment and control;
- control and recovery of landfill gas;
- operational guidelines, including classification of wastes and establishment of acceptance criteria for landfill;
- acceptance of different classes of waste at different classes of sites;
- fire, pest and litter control;
- appropriate recovery, reuse and recycling facilities;
- co-disposal of industrial and other wastes;
- monitoring of leachate, other effluents and emissions; and
- termination of use and subsequent monitoring.

Where criteria and procedures are specified by the Agency (under Section 62, Environmental Protection Agency Act, 1992), the local authority responsible for the management and/or operation of a landfill site shall, where necessary, take steps as soon as is practicable to ensure that the management and operation of the landfill site complies with the specified criteria and procedures. Where landfill sites are operated by other persons or organisations they should also be required to comply with these criteria and procedures.

1.3 NATIONAL POLICY

At present, a comprehensive waste management framework for Ireland is being developed by the Department of the Environment. This framework includes policy, legislation, infra-structural and other management measures. In the Operational Programme for Environment Services, 1994 to 1999, Section 9, Waste Management, it is stated that particular emphasis will be placed on waste management planning, arrangements and services.

Strategic considerations which influence the definition and development of the waste management framework are outlined below in Sections 1.4 to 1.6.

1.4 EU POLICY

The objectives of EU Policy on waste management are:

- to reduce the quantity of non recoverable waste;
- to recycle and re-use waste to the maximum extent for raw materials and energy; and

- to dispose safely of any remaining non-recoverable wastes.

The EU Fifth Environmental Action Programme, 'Towards Sustainability' sets out the means by which these objectives are to be pursued. Particular attention is to given to the prevention of waste, the use of clean technologies, the encouragement of re-use and recycling, the provision of facilities for recycling and the development of infrastructure for safe disposal of waste. In recent years, the EU has adopted a Waste Strategy, a revised Framework Directive on Waste and a Directive on Packaging Wastes. An amended proposal for a Directive on Landfills is under negotiation. The standards and requirements set out in National Regulations implementing these Directives will have a direct bearing on our approach to waste prevention, reduction and disposal.

1.5 WASTE BILL, 1995

The Waste Bill, which was published in May 1995, proposes that the Agency be designated as the sole licensing authority for landfills. Landfill has to date offered the most economical solution to our waste disposal requirements and while there has been a trend towards larger, engineered sites, many existing landfills will require considerable upgrading to meet the higher environmental standards demanded by prospective EU and national legislation and by public opinion generally. Investment in new and/or upgraded facilities must take account of the national policy emphasis on waste prevention, recovery and recycling. Measures will include the provision of recycling and recovery facilities as outlined in the national recycling strategy 'Recycling in Ireland' published in July 1994 and the preparation of waste management strategies at local authority and/or regional level to assess management options.

1.6 ENVIRONMENTAL IMPACTS

Proposals for the development of a landfill must take into account the requirements stated in the Planning Acts and Local Government (Planning and Development) Regulations. The requirements stated in the County Development Plan and any Waste Management Plan or Strategy must also be considered.

Under the European Communities (Environmental Impact Assessment) Regulations, 1989-1994, landfill sites with an annual intake in excess of 25,000 tonnes require the preparation of an environmental impact statement, although an EIS may be requested for any landfill site. These Regulations provide for publication of notices advising that the statement is available, provisions for the receipt of comments and consideration of the statement by the competent authority. The statement provides information on the likely significant impacts of the proposed development.

The Agency published draft guidelines on the information to be contained in Environmental Impact Statements and advice notes on current practice in July 1995. Those preparing an EIS and the competent authority considering it, are required to have regard to the guidelines, which will be introduced in June 1997.

1.7 LANDFILL MANUALS

The selection of a site for a landfill is an interactive process. The developer of the site, the local authorities concerned and members of the public should all play a significant part in the selection process. The Agency is preparing a series of manuals for landfills to comply with the requirements of Section 62 of the Environmental Protection Agency Act, 1992. The manuals being prepared at present include:

- Site Selection;
- Investigations for Landfills;
- Operational Practices; and
- Monitoring.

This manual on investigations is being prepared to assist developers in 'Site Characterisation'. That is, to identify the pertinent characteristics of the areas and sites being considered and establish the information required to discriminate between potential sites in a logical, economical and transparent manner. Information generated in the investigations will be used in site selection, the preparation of preliminary and detailed designs, the monitoring and aftercare plans for the site(s) chosen, the Environmental Impact Statement, submissions to the planning authority and the Department of the Environment. Manuals should not be read or used in isolation from each other, the relevant legislation, the draft directive on landfilling, the County Development Plan, Waste Management Plan or Strategy.

The purpose of an investigation is to determine the most suitable site or sites having regard to the objectives established in the Local Authority Waste Management Strategy or Plan. At the conclusion of an investigation a recommendation in respect of one or more sites for use as a landfill should be made if it is determined that a suitable site(s) exists. If, at the conclusion of investigations at a particular site, it is determined that the site is unsuitable, then other potential sites should be investigated.

The EU proposal for a directive on landfilling of waste sets out the general requirements for landfills. These include containment, monitoring, management and aftercare of each landfill. The waste acceptance procedures and types of waste which may be landfilled are also listed together with the minimum permit (licence) requirements. The permit contents and conditions must include particulars of the site, methods of pollution prevention and details of wastes being deposited. The management of the site must be in the hands of a technically competent person and a financial security to ensure that the obligations set out in the permit are met must be provided. Existing landfill sites, may continue in operation on the basis of an approved site conditioning plan subject to the work required being completed within ten years.

The information generated in the investigations outlined in the manual will assist developers and operators to meet the requirements stated in the proposal for a landfill directive. As the Agency is proposed as the sole licensing authority under the Waste Bill, the information requirements outlined herein will be taken into account by the Agency in licensing landfills. The conditions to be attached to licences issued in accordance with national legislation and the Directive (when adopted) will be similar for public and private sector operations as with all other activities licensed by the Agency.

1.8 LANDFILL SITES

Waste disposal sites must be designed and managed in a way that ensures that harmful substances do not reach the environment in unacceptable quantities.

The design concept for a landfill site also depends on the ground conditions, the geology and hydrogeology of the site, the environmental impacts and the location of the landfill.

The planning, development and management of landfill sites must take account of the ecological, geological and hydrogeological conditions. For proposed sites, extension of existing sites and rehabilitation of existing landfills an investigation is therefore essential.

The investigation process includes a step by step evaluation of existing information, the acquisition of additional information and examination of all information obtained prior to reaching a conclusion or decision on the relative merits of the areas and site(s) under investigation as outlined in Figure 1.

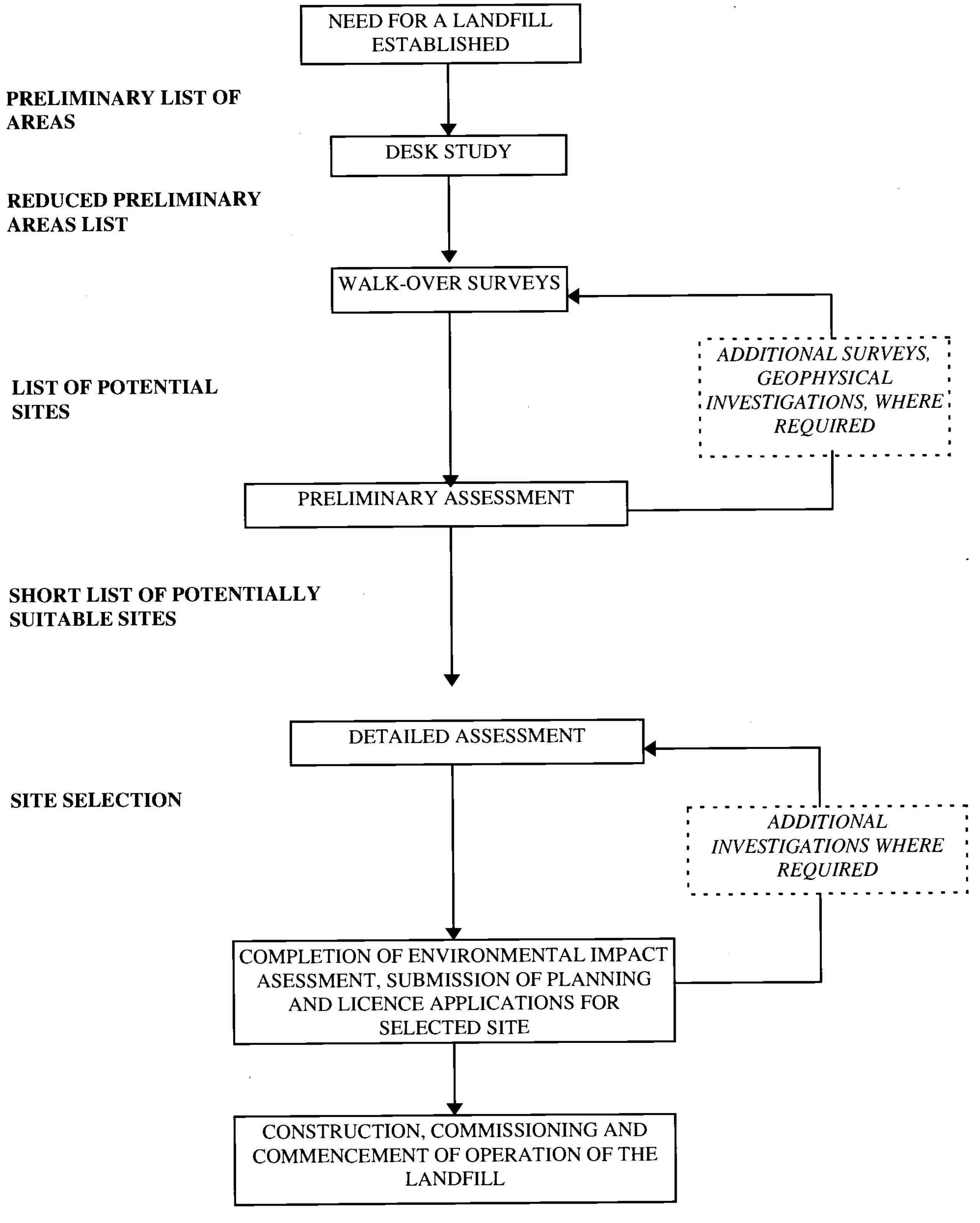

FIGURE 1: INVESTIGATIONS FOR A LANDFILL AND LINK TO SITE SELECTION

2. OBJECTIVES OF AN INVESTIGATION

2.1 GENERAL

An investigation aims at determining the nature and behaviour of all aspects of a site and its environs that could significantly influence or be influenced by the landfill. The work involved in investigation includes noting the proximity of human habitation, researching the history, prior uses, potential uses, hydrology, hydrogeology, ecology, archaeology, geology, geotechnology, means of access to and environmental aspects of the site.

The investigation is used to determine the fluxes of gas/water which influence the design, operation and aftercare of a landfill. The origin of potential impacts and the identification of measures to mitigate potential impacts should be considered as part of the investigation.

2.2 OBJECTIVES

The main objective of an investigation is to ensure an economical and safe development by reducing to an acceptable level the uncertainties and risks that the ground (geology) poses to the project or that the project poses to the environment and public health.

In selecting a landfill site it is essential to:

- ensure that the risk to the environment is low;
- the site is suitable for the disposal of waste;
- the financial cost to the community is minimised; and
- the site selection process is transparent.

Investigation of potential sites for a landfill is an essential part of the site selection process will be outlined in the 'Site Selection ' manual.

The objectives of an investigation may vary from project to project but can be summarised as the provision of data for:

- site suitability considerations;
- site design considerations; and
- environmental impact assessment.

2.2.1 SITE SUITABILITY CONSIDERATIONS

Site Selection

Local authorities are required to prepare Waste and Hazardous Waste Management Plans and update these plans on a regular basis.

The selection of a landfill site commences at regional level with the identification of areas (using key parameters, such as geology, hydrogeology, rainfall, etc.) where a landfill might be located.

The areas selected are reduced, based on criteria identified, and a list of sites are considered for preliminary assessment and subsequently detailed assessment of one or more sites as outlined in Figure 1.

In the initial stages of the implementation of a waste management plan it may be necessary to select at least one landfill site from a number of possibilities. Such siting should have regard to the transportation economics of the disposal location bearing in mind the waste source(s). A preliminary assessment at each listed site provides data that will allow comparisons to be made between sites and assist in the choice of one site over another. Detailed assessment at one or more sites will be required before a final selection can be made.

Reference should be made to the manual on 'Site Selection' for details of how site selection should be approached and how it relates to the investigations proposed in this manual.

Identification of potential environmental effects

The construction of a landfill site will impact on the environment as a whole. It may lead to changes in the surface water and groundwater regime, or pose the threat of the release of gas or harmful substances into the environment. This may occur due to the geology or hydrogeology of the area where the site is located, the nature of the subsoils and the bedrock. The investigations provide information to identify and assess these effects and quantify the risks.

The data obtained will also be used in the preparation of an Environmental Impact Statement, the Operating Plan for the selected site and ultimately the Closure Plan for the site. Data obtained should be representative of the full annual cycle.

Safety assessments

The public needs to be reassured that the landfill will be operated safely and remain safe after it ceases to be used for the deposit of waste. An investigation will provide data that can be used in the preparation of an adequate operational safety plan, covering aspects such as the stability of the waste mass and leachate and gas control measures.

Aftercare

Investigation data are used to provide information for the preparation of a comprehensive aftercare plan which should include post closure monitoring, remedial measures to prepare the site for the proposed end use and to ensure that no further detrimental impact on the environment occurs.

2.2.2 SITE DESIGN

Information is required on the particle distribution, permeability, strength, compressibility and pore water conditions of the underlying ground to assess the deformation behaviour and sealing potential of the subsoil and the stability of the bedrock.

The potential for working the material to provide the required permability (lining of the site) needs to be assessed. Subsoil parameter values may be required for embankment design, building design and other earthworks at the site. Design parameters for surface water and groundwater control measures will also be required.

The location of suitable cover material on site should be considered as importation of cover material could generate significant additional traffic.

2.2.3 ENVIRONMENTAL IMPACT ASSESSMENT

The examination of the environmental impacts of the proposed development will require the installation of monitoring stations, boreholes, piezometers or similar equipment so that a baseline can be established against which future development can be evaluated. It may also require the establishment of a baseline air quality monitoring programme. The requirements of the proposed European Union Directive on landfilling of waste should be considered when baseline monitoring is being established.

The Environmental Impact Statement should reflect the operational policy of the operator and/or developer of the site and how criteria in respect of groundwater, surface water, landfill gas, visual amenity etc. are to be met.

Baseline data should be representative and include a minimum of one year's measurements and/or at least a seasonal evaluation of fluctations.

3. PLANNING AND PROCUREMENT

Once the objectives and scope of the investigations are decided, the next phase involves the planning, design and procurement of an investigation contractor.

3.1 PLANNING

The planning phase includes engaging the appropriate staff (or consultants), preparing the specification and bill of quantities, obtaining and adjudicating on tenders through to agreeing a work programme with the selected contractor.

3.1.1 KEY STAFF

The client's principal technical adviser will advise on all aspects of the investigation and will ultimately be responsible for ensuring that an adequate investigation is carried out.

This person may be a member of the client's staff or a consultant employed for the duration of the project. The principal technical adviser will be required to establish a project team that will undertake various aspects of the investigation and may include a Geotechnical Engineer, Civil Engineer, Ecologist, Engineering Geologist, Hydrologist, Hydrogeologist, Geophysicist, Archaeologist, Agriculturist, Chemist, Biologist, Landscape Architect, Architect and Public Relations Expert.

The use of appropriately qualified and experienced people is essential in ensuring the quality control of the investigation and in carrying an investigation through all stages, including a possible public inquiry or oral hearing where team members may be required to give evidence.

3.1.2 PRINCIPAL ELEMENTS OF THE INVESTIGATION

The investigation of a potential site and its environs should proceed in logical stages and should ideally include the following elements:

- initial appraisal with design team and development team;
- desk study;
- walk-over survey;
- geophysical survey (where justified);
- preliminary assessment;
- definition of the objectives of detailed assessment;
- design of detailed assessment;
- work programme for detailed assessment;
- installation of monitoring equipment;
- reporting;
- interaction with project team, design team and development team; and
- conclusions and recommendations in relation to the sites examined.

These elements will be dealt with in more detail in later sections of this manual.

3.1.3 INITIAL APPRAISAL

Once the project team is established the planning of the investigation will begin. The initial appraisal involves a meeting between the project team, the design team and the development team.

This meeting provides an opportunity for the project team to provide an initial appraisal of the expected conditions, define the objectives of the investigation, and potential geotechnical and environmental problems, for the design team to detail the required design parameters, and the development team to outline the site boundaries and logistical issues, such as land ownership and access rights.

3.1.4 PRELIMINARY AND DETAILED ASSESSMENT

Once the initial appraisal is undertaken the preliminary assessment can commence. The preliminary assessment will collate the existing information and will enable a basic understanding of the ground (subsoil and bedrock), its behaviour and the flows through it to be developed, which will assist in understanding the environmental impacts of the development. The detailed assessment will then be planned on the results of the preliminary assessment.

The specification for the detailed assessment needs to be concise, clear and unambiguous and should include consideration of the following elements.

Budget

At the outset it is important to establish the budget for the investigation phase. It is rare to have too much money available and more common to not have enough. However, a compromise situation can generally be reached from where an adequate investigation can be designed.

The contractor's price will always determine the amount of money expended and, hence, accurate estimation is required at the planning stages to ensure that adequate resources are available.

Accuracy

The specification should be clear and comprehensive. It should be prepared by persons experienced in investigations and should be similar to "Specification for Ground Investigation" (SISG, 1993B). The bill of quantities should be equally clear and concise and should be prepared in accordance with a standard method of measurement, such as that recommended in the Specification for Ground Investigation published by ICE, UK

Reference should be made to national or international protocols on sampling, monitoring and investigation techniques, where such protocols are available.

Relevance

There is a wide variety of techniques available for the investigation of the ground. However, choosing the most relevant and appropriate techniques is important. Only if the specification is relevant, can the results of the investigation fulfil the objectives. The choice of appropriate techniques should be made by persons who are aware of the design information requirements. This requires a knowledge of the design process and design parameters, and experience in the design, construction and operation of landfills.

Techniques for investigation of other aspects, such as the ecology and archaeology, should be identified by the specialist advisers.

3.2 PROCUREMENT

Successful investigation requires a systematic approach to the procurement of a contractor, based on a number of factors in addition to price, such as:

- the expertise available for measurement, logging and interpretation of data;
- the size of the contractor's operation should be suitable for the scale of the investigation proposed;
- the contractor should be capable of providing the required level of resources, in terms of staff, plant, equipment and laboratory facilities;
- the contractor's staff should have previous experience of similar work;
- key senior staff should be suitably qualified and experienced for the task in hand; and
- the contractor should operate a quality management system, preferably with accreditation for drilling/testing /reporting.

The investigation contractor will require specialist expertise, such as a hydrologist, geologist, ecologist etc. and the experts proposed should be identified in the tender. Where particular specialists are required, this should be clearly stated as a specified requirement in the tender documents. For example, expertise in water sampling, monitoring and analysis, air and gas flow sampling, archaeology and ecology may be required.

The method of selection of a contractor should be based on published guidelines for contract works. It is important that a schedule of rates for work outside the initial scope of the contract is agreed or included in the tendered Bill of Quantities to avoid potential cost over-runs.

3.3 WORK PROGRAMME

Once the contractor has been selected it is important to agree a work programme which will be based on the programme submitted as part of the tender.

It is essential that access to property is agreed, that the logistics of mobilising plant are considered and that a procedure for daily reporting is put in place.

The work programme will need to be monitored and updated on a daily basis during the investigation. Regular weekly meetings to monitor and direct the work should be included in the programme.

The work programme should be sufficiently flexible to ensure that the investigation can be varied to take account of :

- ground conditions encountered as the investigation proceeds;
- the available investigation equipment;
- the available personnel;
- the investigation budget;
- existing pollutants; and
- safety requirements.

When the investigation is to be carried out on a site where the employer is not the owner, the responsibilities of the employer and the contractor should be clearly defined. In particular:

- the extent of the investigation works proposed;
- the option to leave monitoring boreholes, piezometers and similar equipment in place on completion;
- the commencement date; and
- duration of possession of the site.

will need to be considered before a programme for the works can be finalised.

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4 PRELIMINARY ASSESSMENT

4.1 INTRODUCTION

A preliminary assessment is undertaken to allow comparison between a number of possible areas and subsequently sites and to provide information on the preferred areas and sites.

Although the geotechnical/hydrogeological aspects are an important part of site selection it should be pointed out that the most suitable site from a geotechnical/ hydrogeological point of view may not ultimately be the chosen site when other factors are taken into account.

Such factors could include site location, ecology, access, use of adjacent lands etc.

4.2 OBJECTIVES

The aim of the preliminary assessment is to gather
information on the local topog- raphy and geological setting, including the following principal aspects:

- characteristics of the topography;
- type and distribution of the geology;
- land uses in and adjacent to the site;
- distribution of the subsoils;
- distribution, protection policies, relative importance and vulnerability of aquifers;
- groundwater flow regime, probable levels, gradients and directions of flow:
- meteorology;
- major groundwater and surface water abstractions;
- surface waters hydrology including designation and amenity uses; and
- area designations (if any).

4.3 EXTENT OF INVESTIGATIONS

4.3.1 GENERAL

The preliminary assessment usually comprises a desk study of the available information combined with a walk-over survey of the site. Under certain circumstances additional investigations, such as trial pitting, geophysical surveys or limited boring, may be necessary. The following is a general approach to the preliminary assessment. The desk study should be completed followed by a walk- over survey and such additional investigation work as the project team determine is required to reduce the number of areas and sites being considered to between three and five. These sites should then be considered for detailed assessment.

4.3.2 DESK STUDY

The desk study should include a compilation of all available information from archives, including geological (solid and drift) and topographical maps, archaeological maps and records, land cover, area designations, meteorological data, aerial or remote photographs, surface and groundwater data including data on local abstractions and water quality.

Topographical maps

The 1:126,720 (half inch to a mile) scale maps can be used to give the regional topographic setting of each potential site.

These maps are contoured and show surface water features and other topographical features that might influence the location of a landfill. Maps at scales of 1:63,360 and 1:500,000 are also available for most of the country.

A new series of Discovery Maps at a scale of 1:50,000 are available for some counties. For more site specific detail the 1:10560 (six inches to a mile) maps are more useful. Some details on sink holes, springs, and local drainage are given on these maps.

The extent of river catchments and their amenity potential (e.g. salmonoid rivers) should be established.

Areas subject to flooding and below the high water mark may also be identified.

Bedrock and Subsoils Maps

The Geological Survey of Ireland (GSI) is the best source of geological data, although third level colleges and other public sector organisations, such as Teagasc, Local Authorities, and OPW, may also have data. In addition, maps prepared by mining companies for specific areas may be available. The GSI also provides a groundwater and geotechnical information service which allows access to well and site investigation records and subsoils data held at GSI. The soil survey maps produced by Teagasc are also of use. It will also become increasingly important and, indeed, essential to consult groundwater protection plans and vulnerability maps (currently in preparation by the GSI for a number of counties).

Meteorological and Hydrological data

Past records allow the determination of available recharge for groundwater and surface water. Whilst a site is being actively monitored, rainfall data are used to distinguish between wetter and drier sites, calculate the potential quantities of leachate that could be generated, and establish response times of surface and groundwater levels to various rainfall events. These data can also be used to calibrate models (used at the design stage) to evaluate leachate volumes generated in the landfill. The exposure of the site to prevailing winds should be considered.

Aerial Photographs

Aerial photographs provide a detailed and definitive picture of the topography, surface drainage, land use, vegetation, erosion and instability which may be interpreted in geotechnical and geological terms. The use of stereo pairs should be considered if they are available. Some features may be obscured or hidden by vegetation. The use of stereo pairs improves the interpretation of slope gradients, landforms, drainage patterns, poorly drained ground, landslip activity, collapse features and sink holes. These photographs can be obtained from the Ordnance Survey (OS) or the GSI.

Archaeology

A desk study should be undertaken to establish the proximity and relative archaeological importance of potential sites. The Sites and Monuments Records (SMR) prepared by the National Monuments Section of the OPW should be consulted.

A check should be carried out by walking the site and noting any item of potential archaeological significance. The National Monuments Section of the OPW should be advised that investigation is proposed on the site and any archaeological information available forwarded for their observations.

This will help identify items of potential archaeological significance and enable precautionary measures to be taken in areas where these are anticipated.

Landscape

Existing land uses and the existing aesthetic quality of the landscape should be examined. The sensitivity of the landscape and its visual absorption capacity should be considered. The extent and diversity of tree lines and hedges should be noted.

Ecology

Area designation maps prepared by the OPW, identifying 'National Heritage Areas' should be consulted to determine if the locations being considered are ecologically significant or of special interest.

It should be determined whether or not there are important habitats in the areas with a view to avoiding or minimising deterioration of such habitats. Where habitats are considered significant the National Parks and Wildlife Service of the OPW should be contacted.

4.3.3 WALK-OVER SURVEY

The walk over survey involves a visual inspection of the site and surrounding area. The following features should be inspected.

Topography

General features of geomorphology and topography should be detailed and observations made of slope angles, type of slope (convex or concave) and sudden changes in slope angle.

Glacial features should be examined, noting the presence of mounds or these hummocks or depressions.

The presence of hummocky, broken or terraced ground on hill slopes should be noted as this may indicate possible landslipping.

Archaeological features, housing, access for investigation, ground conditions, overhead cables and pylons should be noted.

Surface drainage features, such as rivers, streams, ponds, should be noted.

Geology/Hydrogeology

Geological and hydrogeological aspects should be recorded.

Exposures of rock should be examined and described. Subsoil deposits can be inspected in road or rail cuttings or gravel pits.

The presence of springs, seepages and collapse features, e.g. sink holes (swallow holes) should be noted.

Groundwater and surface water usage should also be noted.

4.3.4 ADDITIONAL WORK

If the desk study and walk-over survey need clarification it may be necessary to carry out some preliminary ground investigation using techniques such as trial pitting, geophysics or shallow probing. It may be necessary to establish monitoring to provide a baseline with which potential future activities can be compared.

Under the EU proposal for a landfill directive, baseline monitoring will be required to identify the effectiveness of measures taken to mitigate potential pollution.

Trial Pits

Excavation of trial pits can be carried out at a small number of locations. Samples taken may be used to prepare particle size distribution grading charts and a preliminary assessment of subsoil suitability can be made by observation.

Geophysics

Geophysical investigations are useful where a large area of ground needs to be surveyed quickly or where access for trial pitting or boreholes is limited. All geophysical surveys should include for some boreholes to calibrate the findings of the surveys. Otherwise the reliability of the data obtained may be suspect. Consequently, in the preliminary assessment phase geophysical techniques that can be rapidly deployed, such as electromagnetic, resistivity, and seismic methods, are more suitable.

Probing

Equipment, such as the cobra probe, borris probe or hand auger, can be used to establish the basic subsoils distribution. Empirical relationships may be established between the blow count and relative density to estimate the bearing capacity of the soil.

Monitoring

If there is sufficient lead in time to the detailed assessment it is prudent to establish baseline surface and groundwater monitoring at those sites which are likely to be assessed in detail. Existing boreholes and weirs may be used or it may be necessary to install dedicated systems.

4.3.5 OUTCOME OF PRELIMINARY ASSESSMENT

In the assessment of potential areas, the number of areas and sites being considered are reduced progressively as the desk studies and preliminary investigations are completed. At the conclusion of the preliminary assessment phase a maximum of three sites at which detailed investigations could be undertaken should remain. Whilst one of these sites may be the obvious choice at this stage, detailed investigations will be required to confirm this and provide the information required to either reject the site or confirm its suitability.

The information obtained from the investigation should be used in the site selection procedure as set out in the module on 'Site Selection'. The investigation and site selection processes operate in parallel with each other and overlap to some extent. Hence, the information obtained in the preliminary assessment will be used to reduce the number of sites being considered and short list the sites at which detailed investigations should be contemplated.

5. DETAILED ASSESSMENT

5.1 INTRODUCTION

The investigation for a landfill commences with a desk study which leads to the production of a programme for field investigations and laboratory testing. The scope of the detailed investigations are often not decided until the preliminary assessment is completed.

It should be noted that obviously unsuitable sites have already been eliminated and that the remaining sites are, subject to detailed investigation, considered suitable for use as landfill sites.

5.2 OBJECTIVES

The objective of the detailed assessment is to establish comprehensive details of the topography, geology, subsoils, geotechnics, hydrology, hydrogeology, archaeology, ecology and landscape at the short list sites, which will assist in the selection, planning, development and management of a landfill .

5.3 INFORMATION REQUIRED FROM THE INVESTIGATIONS

The information required can be grouped as set out below.

5.3.1 TOPOGRAPHY

details and plans of the topography at the site;

contours, shape of slopes (concave/convex) on plans;

site drainage patterns on plans;

topographical expression of sub- surface features;

land use patterns;

site features, such as hedges, ditches, rock outcrops;

roads and scenic routes;

population/residences; and

development plan.

5.3.2 GEOLOGY

Bedrock

type of rock, mineralogical composition and stratigraphy;

solubility in water and in leachate;

type and position of geological boundaries;

extent, degree, and separation of discontinuities;

risk of karstification and subsidence;

deformation behaviour of the rock mass; and

rock permeability (packer tests).

Subsoil

composition and physical properties of the strata;

lateral and vertical continuity and distribution of strata;

resistance to erosion and loss of fines;

stress and deformation behaviour;

reusability/workability for earthworks and cover material;

leachability tests;

soil moisture characteristics; and

contamination.

5.3.3 METEOROLOGY

daily precipitation;

direction and force of prevailing winds;

atmospheric humidity;

rainfall regime; and

evaporation and evapotranspiration regime.

5.3.4 SURFACE WATER

- status of surface water (including amenity and recreational uses);
- surface water drainage patterns;
- details of on-site ponding and streams;
- flow regime in watercourses;
- water quality management plan;
- temporal variations in flow and quality;
- abstractions;
- background surface water quality; and
- possibility of flooding.

5.3.5 GROUNDWATER

- groundwater regime;
- permeability of all strata (based on piezometric data);
- transmissivities of subsoils and bedrock (max. and min. values);
- distribution, thickness and depth of subsoils and bedrock;
- location of springs, sink and swallow holes or other groundwater features;
- groundwater gradients, rates of flow, direction of flow;
- groundwater levels and variability;
- groundwater chemistry, natural problems;
- groundwater protection zones;
- groundwater abstractions;
- predicted influence of short/long term dewatering;
- relationship with surface waters;
- groundwater quality; and
- groundwater vulnerability and aquifer category.

5.3.6 ARCHAEOLOGY AND ANTIQUITIES

- details of any entries in the Sites and Monuments Records (SMR);
- details of previous site history;
- details of any artificial interference with the subsoil which may have resulted from previous activity on the site;
- details of any previous finds of artefacts or precious objects;
- details of any objects of archaeological significance on the site or discovered during the investigation; and
- effect of a landfill on the archaeological integrity of the site.

5.3.7 ECOLOGY

- existing ecology of the site, significant species, and habitats;
- aquatic and terrestial ecology;
- areas of Scientific Interest, National Heritage Areas, National Parks;
- implications for biological diversity; and
- ecological sensitivity of the area.

5.3.8 LANDSCAPE

- assessment of the aesthetic quality of the landscape;
- assessment of landscape sensitivity;
- assessment of visual absorption capacity;
- assessment of the vulnerability of the landscape; and
- development of aesthetic quality objectives matrix for determination of landscape vulnerability.

5.4 EXTENT OF INVESTIGATIONS

5.4.1 TOPOGRAPHY

The collection of topographical data is mainly undertaken during the land survey stage. The site boundaries should be marked on maps. Plans showing existing, proposed and finished contours should be prepared at this stage from landscape survey data. This may be particularly important on low relief sites where existing contour plans (if any) may be inadequate due to the spacing of contours. This information will allow the determination of the extent of earthworks and drainage measures required, which can be considered when planning the ground investigation programme.

The surrounding land use patterns should be studied in detail at this stage with information on crop rotation practices.This may require the input of an agricultural specialist (agronomist). A survey of the site should be undertaken, covering items such as the description of landforms, slopes, glacial features, and an assessment of the risk of slip or subsidence. This work should be undertaken by a suitably experienced geologist and a survey of 1-2 days per site should normally suffice.

5.4.2 GEOLOGY

The investigation of bedrock and subsoil most often involves the use of boreholes, trial pits or other probing methods and the use of geophysics.

However, detailed geological mapping can also be used to confirm and amplify the geological assessment made in the preliminary assessment.

Boreholes and trial pits give direct information on the subsoil and bedrock. The number of exploratory holes used is dependant on the variability expected and the budget. Anisotropies occurring because of changing subsoil conditions require a dense network of boreholes. Care should be taken to ensure that while boreholes penetrate into the bedrock sufficiently to prove its presence and the geological formations; that they do not punch through impermable layers.

Boreholes are the only direct means of assessing the deeper subsurface. Thus they provide the data necessary to characterise the hydrogeology and geology of a potential landfill site.

Trial pits and probes provide similar information although the accuracy of probing is limited.

It is recognised that the available budget will constrain both the scope and extent of the investigation. Although it is rarely possible to place borings close enough to detect every subtlety of the subsurface environment, an experienced geotechnical specialist will design a programme to achieve a desired level of confidence. A minimum of three boreholes per site is recommended but this is also dependent on the stage of the investigation and the number of existing boreholes.

The examination of the subsoil will include an assessment of its suitability and availability for use as 'cover' within the landfill site. The stockpiling of cover on site and the gradual use of the soil as intermediate and final cover layers should be examined.

Boreholes

The use of boreholes has the following objectives:

- the preparation of borehole logs to define the subsurface;
- provision of samples for analysis to provide key soil properties;
- preliminary information on groundwater;
- carrying out various *in situ* tests for permeability, etc; and
- installation of monitoring equipment.

Trial pits

Trial pits allow:

- in situ visual examination of soil fabric;
- observation of groundwater conditions;
- observation of soil stability;
- taking of samples for analysis; and
- *in situ* testing.

Trial pits are relatively inexpensive and eight to ten can normally be excavated in a day. It is essential that pits are photographed and that details are accurately recorded. Lands where trial pits are excavated should be restored to their original condition on completion.

Probing

Probing may involve the use of instruments such as the dynamic probing system, cone penetrometer system, hand augers or mackintosh probing and has the following uses:

- determination of soil types; and
- *in situ* measurement of soil strength, and permeability.

Probing may be limited by the presence of boulders.

Geophysics

Geophysical surveying involves the use of instruments that can measure various geophysical parameters on the surface or in boreholes. The variability in these parameters can be directly related to properties such as layering, strength and saturation in the ground. It is an indirect way of assessing the subsurface geology and hydrogeology.

Geophysical methods are traditionally used as a supplemental tool in the detailed site assessment phase and are used mainly to interpolate between exploratory holes. The borings are used to calibrate the geophysical method. The number of borings required for adequate definition of sub-surface conditions can be greatly reduced if the proper geophysical methods are chosen to supplement the direct investigation programme. The type of information available from a properly calibrated geophysical survey is as follows:

- depth to rock;
- stratification of subsoils over rock;
- location of buried channels in rock;
- location of buried karst features and caverns; and
- pollution plumes based on conductivity measurements.

It is important to select the most appropriate technique for the known soil conditions and the information required since the use of geophysics is comparatively expensive. It is also important to appreciate the limitations of geophysical methods. The various techniques are detailed in Appendix B.

5.4.3 SURFACE WATER

The investigation of surface water resources involves the assessment of flow and the measurement of water levels and background water quality.

The data are used to quantify the surface water component of the hydrological cycle to determine:

- variations in flow regime;
- low flow data for streams and rivers;
- dilutions available in the event of leaks or spillages;
- variability in the water quality parameter; and
- likelihood of flooding.

Water level and flow data are normally collected at hydrometric stations (gauges or weirs) and may be in the form of continuous measurement or periodic measurement. Water sampling for analysis should also be carried out a number of times during the year to establish temporal variations.

Local beneficial users and abstractions of surface water should be noted.

Information collected is likely to be used to model and determine the return periods and levels of floods at the design stage.

5.4.4 GROUNDWATER

Local beneficial users of groundwater will be established at this stage and comprehensive background monitoring of levels and quality should begin if access can be obtained to these abstractions.

A survey of wells will help to establish the local beneficial uses and may provide useful hydrogeological information.

Boreholes drilled for the investigation can be used for monitoring groundwater levels and quality within and in the vicinity of the site.

The location and depth of the piezometers should be chosen such that different groundwater levels or discrete water bearing strata can be clearly defined.

The measurement of groundwater levels , together with groundwater chemistry where appropriate, provides the necessary data for defining the groundwater regime and a groundwater model at the design stage.

Boreholes should be located so that they can also be used to monitor groundwater conditions during the operation of the site. At least one borehole should be up-gradient of the site and at least one down gradient of the site. A sufficient number of boreholes to characterise the groundwater regime will be required. However, it is recommended that a minimum of three monitoring boreholes be provided to obtain representative data on the state of the groundwater, as required in the current EU proposal for a landfill Directive. At least one borehole should be located off site for use as a reference (before and after) location.

Piezometers should be located in selected boreholes to analyse the relative strengths of surface water infiltration and groundwater flows; that is to obtain a three dimensional picture of vertical and lateral flows.

A water table map identifying seasonal fluctuations in groundwater levels should be produced.

Field tests will be necessary to obtain permeabilities and flow conditions; these may include:

test pumping; and

packer testing.

It may be necessary to construct specific boreholes for some of these tests and provision should be made in the investigation budget for these boreholes.

5.4.5 ARCHAEOLOGY AND ANTIQUITIES

Aspects of archaeological importance will be noted in the desk study phase and evidence of ground disturbance may be noted in the walk-over survey or the detailed site assessment phase of the investigation.

The National Museum or the National Monuments Section of the Office of Public Works should be consulted regarding any significant finds of artefacts in the area. However, it is important at this stage to introduce a professional archaeologist to review the situation and to identify the significance of any artefacts discovered.

The archaeologist, in conjunction with the O.P.W., should establish a plan for the protection of any significant archaeological locations within the boundary of the site.

The potential impact of a landfill on the archaeology would be to disturb and in some instances completely cover the remains. However, the actual impact can be minimised by adequate planning. If the archaeology of the site is significant it may be necessary to omit the site from further consideration.

The cultural heritage associated with the site should be considered in relation to its environmental impact.

5.4.6 METEOROLOGY

The annual rainfall, wind direction, wind speed, evaporation and evapotranspiration rates at the site must be established by physical measurement or use of measurements taken by the Meteorological Service on sites in the vicinity of that being investigated. These measurements are of major significance in relation to the application of the water balance equations to determine the annual production of leachate. It is essential that accurate measurements are available and that the accuracy of the measurements is established. A preliminary water balance should be completed for each of the short- listed sites to determine the quantity of leachate likely to be generated.

Data obtained are also used in site design, and, in particular, in the selection of cell size.

A wind sock should be erected on site to establish wind direction and site exposure should be considered as it will influence the choice of litter containment screens and nets.

5.4.7 ECOLOGY

Where the aquatic or terrestial ecology aspects of site developments are considered to be significant, an appropriately qualified professional ecologist should be employed to evaluate the potential effects and to identify amelioration measures.

Habitats on the site of the proposed developments should be evaluated using standard survey techniques such as those approved by the National Parks and Wildlife Service of the OPW. Where such techniques are not applicable, a recognised quantitative methodology should be used.

The status of the area being considered, (e.g. natural heritage area, area of special interest etc.) should be established by reference to designation maps prepared by the OPW.

Measures to avoid or minimise the potential effects on important habitats should be identified.

5.4.8 LANDSCAPE

All landfills will have some visual/aesthetic impact on the surrounding landscape. This may result from its projection over existing ground levels, its overall height, or ongoing operations on the site. The construction and on-going filling at a landfill site will alter the aesthetic quality of the landscape.

Hence the sensitivity of the landscape, its vulnerability and absorptive capacity must be considered.

The identification of sensitive views and an assessment of the aesthetic quality of the proposal (including its visual impact) should be completed.

This may include the preparation of an aesthetic quality objectives matrix for determination of landscape vulnerability, determination of distance view zones and computation of the visual impact of the landfill on the landscape. Photorealistic simulation of the existing landscape and the landfill at various stages of development should be completed. Measures to mitigate or ameliorate the visual impact of the landfill and enhance the landscape should be identified. An inventory of landscape views, sensitivities and vulnerabilities should be completed for each site being considered.

Comparison of alternative sites should be completed on a qualitative and/or quantitative basis using a methodology which includes the above techniques.

6. CONTRACT DOCUMENTS AND CONTRACTOR SELECTION

6.1 CONTRACT DOCUMENTS

The contract documents include:

- instructions to tenderers;
- specification;
- contract drawings;
- bill of quantities;
- conditions of contract; and
- forms of tender, bond and agreement.

The documents should be based on standards used in the industry and should be prepared using standard specifications and methods of measurement.

Clear, concise and accurate documents will enable the employer to estimate accurately the cost of the investigation works, the contractor to price the work more accurately and will enable the staff involved in the investigation to execute the work efficiently.

Document preparation is best completed in the following order; contract drawings are first completed followed by the specification, followed by the conditions of contract including any special conditions, followed by the bill of quantities followed by forms of tender, bond and agreement. Instructions to tenderers are prepared prior to issue of the contract documents for pricing and should clearly state the basic contract requirements.

6.2 CONTRACTOR SELECTION

Factors which should be considered in the selection of a contractor (in addition to price) include:

- resources available to the contractor. These include plant, equipment and personnel;
- the workload/ongoing projects in which the contractor is engaged;
- the specialist expertise/equipment available to the contractor;
- the projects completed by the contractor and the record of the contractor as authenticated by existing/previous employers;
- the flexibility of the contractor in relation to programming and execution of the work;
- the ability of the contractor to complete the project within the contract period;
- the availability of a bond to the contractor (if client requires a bond);
- the qualifications and experience of the contractor's supervisory staff;
- the laboratory and testing facilities at the contractor's disposal;
- the implementation of a quality management system by the contractor; and
- the most economically advantageous tender from the client's viewpoint.

In the evaluation of tenders regard must be had to the price, the equipment and the personnel proposed for the investigation by the contractor. The selection must be completed with great care to ensure that the contractor employed is capable of executing the investigation to the standard required.

Poor quality information or information that is inaccurate is worthless and may result in the employer incurring additional costs during the construction stage if claims are made by the contractor. In addition, incorrect or inadequate information used to select design parameters could result in errors and significant long term costs to the employer.

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7. INVESTIGATION MANAGEMENT

The first step to achieving a good quality investigation is engagement of the appropriate staff to plan, manage and interpret the investigation. A structured approach to management of an investigation is likely to prevent oversights and to be more efficient.

An investigation should be an interactive, flexible process and it requires a positive contribution from all participants. Failure to use persons with appropriate professional/technical expertise will reduce the likelihood of a thorough investigation being completed. The investigation must be managed in a manner which will ensure that a full and clear understanding of the hazards and risks associated with the proposed development is reached.

The lines of communication between the employer, the client's site supervisor, the contractor and the contractor's site supervisor, together with their assistants, should be clearly set out in the contract documents to avoid misunderstandings and ensure that all participants are aware of their responsibilities and reporting structures.

7.1 WORK PROGRAMME

A proposed work programme should be submitted as part of the contractor's tender submission. This should be vetted by the client's representative. Once the contractor is appointed then the work programme can be finalised.

For larger investigations it may be necessary to prepare the programme on a spreadsheet so that progress reports and adjustments can be readily incorporated. This may include weekly updates and the provision of 'S' curves to compare performance to the proposed programme.

Purpose-designed software is now available to assist in the scheduling, the control of project activities and the allocation of resources. Such software should be used on all projects.

7.2 CONTRACTOR'S SITE SUPERVISION

Quality control of investigation work can be carried out only while the work is in progress. Therefore, to ensure quality it is imperative that the contractor provides an appropriately qualified and experienced person on site to supervise the investigation and liaise with the client's representative.

As unexpected conditions can often arise, it should be possible by consensus on site to vary the type and scope of the investigation as it proceeds. This will be possible only when the contractor's site supervisor and the client's site supervisor have the experience and technical knowledge which will enable them to evaluate the work and the ground conditions encountered.

The contractor's site supervisor should be on site for the full duration of the investigation and should be responsible for the production of all site information to the required degree of accuracy. Mistakes in recording site data are all too common and constant vigilance should be kept to minimise errors in recording, plotting and reporting information obtained in the investigation.

7.3 CLIENT'S SITE SUPERVISION

The client should engage a site supervisor for the investigation who should have geotechnical expertise and experience as well as practical knowledge of the different techniques. The client's site supervisor should report directly to the client's chief technical advisor and be delegated sufficient authority to supervise the works.

The client's site supervisor should be capable of making decisions on site concerning the technical aspects of the investigation or be capable of advising the client on the progress of the technical aspects of the investigation and the expenditure on the investigation.

The client's site supervisor should ensure that the investigation works are completed in accordance with the agreed work programme and any authorised variations. As the investigation proceeds information obtained will require regular assessment. It is essential that personnel likely to be involved in the design and construction phases are consulted in regard to proposed variations to the investigation and that variation orders issued are consistent with the information requirements previously established.

The client's site supervisor should agree the investigation records on a daily basis to ensure that information is accurately recorded. Where the contractor has a quality management system in place the client's site supervisor should ensure that he is familiar with the system prior to contract commencement, and that the system operated on site by the contractor produces the investigation information within a defined period.

7.4 QUALITY MANAGEMENT

Everyone involved in the project, including the client and the contractor's site operatives, should be part of the quality plan for the whole project and the plan should include the following activities:

- recording of data, tests, calibrations, etc.;
- site safety;
- sample handling and storage;
- operational field activities;
- field instrumentation; and
- reporting.

It may be necessary to prepare a project- specific quality plan which would incorporate quality statements from the various contractors and sub-contractors employed.

Contractors who are accredited to the ISO 9000 series or equivalent standards will have the required management systems in place.

7.5 COMPLETION AND SUBMISSION OF RECORDS

The contractor should prepare a log of each exploratory task completed using an agreed preprepared record sheet. The location of all exploratory tasks completed should be clearly marked on the layout drawings.

In situ test records should be provided fully calibrated and processed.

Geophysical data should be provided in fully processed form unless otherwise agreed.

Daily log sheets should be submitted to the client's site supervisor (representative) within 24 hours of completion of that day's work.

On larger projects, daily and weekly progress reports should be provided detailing activities in progress with preliminary details of findings. These reports will allow the client to monitor performance in addition to updating costs.

Where data are required in digital form an agreed format should be used for transfer.

7.6 VARIATIONS AND CLAIMS

Due to the uncertain nature of investigation work, variations to the original programme may need to be considered. It is important, therefore, to have procedures in place to deal with variations so that claims are minimised.

Claims do arise, however, and in order to deal effectively with claims it is important that the contract documentation is complete. This emphasises the need for on-site supervision and clear communications at site level between the client and contractor.

8. RESULTS OF THE INVESTIGATION

The only tangible end product of an investigation is a report. Its value depends on how others use it, as well as its own inherent qualities. A good report will identify potential problems, outline potential solutions, assist the client in preparation of the design and the contractor in the construction phase.

The client's principal technical adviser should receive all reports on the results and interpretation of the investigation within an agreed time and be satisfied that the objectives of the investigation have been achieved. There are usually three stages of reporting as detailed below. In smaller projects these are combined into a single document.

8.1 PRELIMINARY ASSESSMENT

The report on the preliminary assessment should:

- define briefly the scope of the project;
- summarise the findings of the desk study and walk-over survey;
- assess the groundwater conditions and groundwater usage;
- summarize the findings of any preliminary investigation works undertaken; and
- make recommendations for the scope of the detailed investigation.

8.2 DETAILED ASSESSMENT - FACTUAL REPORT

The factual report should describe concisely and accurately:

- the site;
- the investigation work carried out;
- the findings and results of the work carried out; and
- the results of monitoring and laboratory testing.

The report will be prepared by the contractor's staff and should contain all factual information generated during the investigation. This information will typically include:

- drawings, maps of the site and its environs;
- topographical and geological maps of the site;
- probes, trial pits and boreholes logged in scheduled format;
- penetrometer test results and plots;
- groundwater contour maps showing seasonal variations;
- pumping test records and analysis;
- monitoring records and results;
- meteorological records;
- Laboratory test results;
- archaeological, ecological and landscape assessments;
- specialist survey test results; and
- photographs.

8.3 DETAILED ASSESSMENT - INTERPRETATIVE REPORT

The interpretative report should:

- draw together and review all the information obtained during the preliminary and detailed assessments;
- confirm or modify the preliminary understanding of the ground. This will include cross sections and plans of the subsoils and solid geology;
- include an assessment of the suitability of natural strata for landfill lining, covering, cell construction and an evaluation of the subsoil as a natural barrier for the site;
- include an assessment of the safety aspects, including slope stability, leachate control, probability of failure of the waste mass;

- include a recommendation on whether the site is suitable for landfilling of waste and/or whether additional sites or futher investigation should be undertaken;
- include an assessment of the quantity of leachate likely to be generated and its likely range taking into account the proposed method of operation of the site;
- include an assessment of the temporary works required to facilitate construction of the landfill;
- include an assessment of the ecology inclusive of biodiversity, sensitivity and habitats;
- provide groundwater maps and an assessment indicating known aquifers, catchment boundaries, flow directions, abstraction rates, groundwater contours, and water quality data. A model may be used at design stage to predict the effects of the project on the groundwater and form part of the risk assessment for the project. It will require the information included on the above map;
- provide the parameters required for design purposes, including bearing capacities and deformation behaviour of subsoil;
- identify the potential geotechnical and environmental problems;
- provide a range of design solutions to the problems; and
- provide data for the design of aftercare measures to include monitoring and pollution control measures, restoration, drainage and gas control.

The interpretative report may be prepared by the contractor carrying out the investigation work if he has sufficient technical expertise.

In many instances, however, the report is prepared by the client's own supervisory team or the consultant supervising the investigation.

The persons and/or organisations who are to complete this report and the extent of this report should be set out in the contract documents. Where specialist advice is obtained, the reports of such specialists should be incorporated.

It should not be assumed that the site will be suitable for landfilling of waste because detailed investigations have been completed. The possibility of site rejection should remain until the other available sites have been investigated and/or eliminated for other reasons.

8.4 DISSEMINATION OF DATA

Interaction with the design and development team will be necessary to ensure that their requirements have been satisfied and that the information available from the investigation is sufficient.

A copy of the investigation reports should be forwarded to the GSI who maintain copies of groundwater and site investigation data in their Groundwater Section.

8.5 INVESTIGATION RECORDS

On completion of the investigation, soil samples, cores, recorder charts and similar material should be returned to the employer for storage. All material should be clearly labelled and it should carry the same reference number as the chart or log included in the factual report.

Such records are often invaluable to the design/construction teams. This is particularly true when the timescale from commencement to completion of a project extends over a number of years, as it inevitably results in personnel changes within the project team.

APPENDIX A: INVESTIGATION OF EXISTING LANDFILL SITES

A1. INTRODUCTION

Existing or completed landfill sites are investigated for two main reasons. One relates to the redevelopment of the land and the second to an assessment of the impact that the site is having on the surrounding environment.

An investigation at an existing landfill site should be approached in the same way as an investigation of a contaminated site and similar precautions need to be taken.

Investigations of existing landfill sites or dumps should include the identification of measures required for rehabilitation and integration of the sites into the surrounding landscape. This is particularly important as the public perception of existing sites is based mostly on visual unattractiveness and the presence of birds, vermin, etc.

This appendix outlines an approach to the investigation of existing landfill sites and identifies the procedures that need to be adopted.

A2. WHY INVESTIGATE

An investigation of a disused or existing site may be required where:

- the impact of the site on the environment needs to be assessed;
- extension of the landfill site is proposed;
- the landfill site is proposed for redevelopment;
- the operator is preparing a site conditioning plan; or
- the operator wishes to close the site and surrender the licence/permit.

A3. OBJECTIVES

The objectives of the investigation will/may include the following needs:

- to determine the shape, extent and dimensions of the site and deposited waste;
- to determine the stability of the site itself and the state of the surrounding environment;
- to assess the general suitability of the site for a proposed end use or to consider the options for the use of the site;
- to select or design appropriate containment or remedial measures for the site;
- to identify the potential hazards to workers on the site or to persons or animals on adjacent land; and
- to assist in the development of a long-term aftercare and monitoring programme.

A4. PHASED APPROACH

A phased approach should be adopted to obtain maximum benefit.

The investigation work should be completed in two phases. Phase 1 should include a desk study and a walk-over survey of the site. Phase 2 should comprise a thorough investigation of the site based on the conclusions reached in the Phase 1 investigation.

A4.1 PHASE 1 INVESTIGATIONS

Desk study

A landfill site is normally considered by the public to mean an area of land where waste has been disposed of in a controlled manner. Unplanned sites do also occur where, for instance, a site has arisen by fly tipping or where a site evolved over the years where waste has been disposed of in an uncontrolled manner.

The past uses of a site can sometimes be determined from old maps, aerial photographs, local authority records, library records or historical society records. Informal enquiries to local people or to local historians can also be helpful.

Once the location of the site has been established it is important to obtain information and all available records detailing what may have been disposed of at the site. Even where records for a site appear complete they may not have recorded all activities at the site or the correct quantities or types of wastes deposited. In general, the following information should be compiled:

- the nature of the site and a record of its owners and occupiers;
- the layout of the site at different stages of its development;
- all the activities carried out at the site;
- the extent and results of any previous monitoring carried out on the site or in the surrounding environment;
- relevant information on the site geology, soils and hydrology to help distinguish natural conditions from artificially created ones; and
- an assessment of the engineering implications of the site conditions.

Walk-over survey

The desk study phase should include a walk-over survey of the site to identify the positions of old buildings, or the site boundaries. This is best completed after a desk study has been made of the available site records. The investigators will by then have a better idea of what to look for and be better able to recognise and interpret visual information. The walk-over survey should investigate the site itself and as much as possible of the surrounding area. Items of importance include seepage of contaminated water or leachate, vegetation changes (indicating gas leaks beneath the ground), visible signs of surface water pollution, the presence of landfill gas and any major changes in ground level within the site.

A limited amount of sampling of streams, boreholes and soils should be undertaken at this stage to establish current environmental conditions.

Report

The desk study report should present and analyse the information obtained regarding the history and the present state of the site and make recommendations for the investigation work required. A preliminary assessment of the type of hazards to be expected and highlighting essential precautions should also be made.

A4.2 PHASE 2 INVESTIGATIONS

The objectives of the Phase 2 investigations should be set out to enable contract documents for the required works to be prepared and ultimately to guide contractors tendering in regard to appropriate expertise, plant, machinery and equipment. They should assist tenderers in the choice of materials and identify appropriate measures for protection of the environment and workers on the site during the construction period

Intended use

If the site is proposed for redevelopment then the first step is to identify the intended use of the site. This will assist in the identification of the environmental hazards that are likely to affect that use and in the determination of the contaminants. Similarly, geotechnical hazards can be identified. These could include structural damage due to poor bearing capacity or differential settlement.

It is the policy of some local authorities to prohibit the construction of any habitable or commercial building on landfill sites unless it is shown that satisfactory precautions against subsidence or gas emissions could be proven and installation professionally supervised and certified.

Objectives

Where an intended end use is identified then the objectives of the investigation can be focused on:

- the investigation of the presence of particular contaminants and hazards in the site and their location within the site;
- the establishment of the extent and topography of the site and the location of virgin ground beneath and beyond the site; and
- an assessment of the geotechnical properties of the site.

Scope of Investigation

Where the site conditions are uncertain, exploratory drilling and sampling may be required to provide the necessary information for the detailed drilling and sampling programme. The exploratory stage usually involves the drilling of a number of small diameter shallow holes in a grid pattern in the area containing the landfill. The results of the drilling and sampling provide data on the geometry of the landfill and on the identification and location of the various types of waste. Where the geometry of the site is already known this preliminary phase may not be required.

As part of the exploratory stage, a small number of deeper holes (minimum of three) should be drilled a short distance (not more than 100 m) from the landfill to define the local groundwater flow pattern.

The number of sampling points needs to be sufficient to identify the presence of contaminants and to determine their distribution with sufficient certainty. If too few sampling points are used the chances of finding local pockets of contamination are lessened, and these may cause difficulty when the site is developed.

On-Site Investigations

On-site investigation is used to determine the nature and extent of contaminants and materials and to determine the geometry of the site.

The two principal sampling patterns used are:

- random sampling (non systematic); and
- regular grid sampling (systematic).

The two sampling patterns are used in conjunction with either direct or indirect methods of investigation.

Direct Methods

Direct methods include trial pits and boreholes as described in the main text of this manual. Trial pits permit visual inspection of the conditions at shallow depths. Where deeper investigation is required, boreholes are preferred. Other direct methods include the use of cone penetration testing, the use of probes such as the temperature cone to determine the state of degradation of the waste, or the conductivity cone to define contamination plumes.

It should be noted that hazards exist on landfill sites in relation to the presence of explosive or toxic gases and that this should be taken into account in the selection of investigation methods.

Guidelines on field operations are summarised below:

- spoil from the boring needs to be disposed of in a responsible manner;
- equipment should be cleaned between boreholes to ensure that cross contamination does not occur;
- samples should be clearly labelled and colour-coded to indicate the nature and category of the material contained;
- the samples should be suitably contained to ensure that no spillages or deterioration occurs;
- the materials used for permanent monitoring installations should be designed to withstand the aggressive nature of the environment in which the installation is located;
- the drilling medium should be carefully selected and controlled to minimise contamination and danger to investigation personnel;
- the site should be left in a satisfactory and safe condition on completion of investigation works; and
- any boreholes that penetrate seals or low permeability layers must be appropriately sealed to maintain the integrity of the site.

Indirect Methods

Geophysics is the main indirect method used. As with investigations at proposed sites, selection of the most appropriate technique is important. Geophysical methods have been used to locate site boundaries, locate drums of special wastes within other wastes, or delineate contaminant plumes emanating from sites.

Off-Site Investigations

If no monitoring boreholes are available then purpose drilled boreholes will need to be provided, for soil, subsoil, leachate and groundwater sampling and monitoring. Samples from surface waters will also be required. Details of background concentrations (baseline data) will be required to compare with the findings from sampling. Techniques, such as cone penetration testing, surface geophysics, and downhole geophysics, may be useful in off-site investigations.

A4.3 HAZARD ASSESSMENT

A landfill site may be considered as a potentially contaminated site, until proven otherwise. Hence an appreciation of the likely hazards is essential.

Chemical

The types of waste or contaminated ground either known or expected to be found on a site should be categorised so that the associated degree of hazard can be clearly recognised. Appendix 3 of SISG (PART 4) 1994, presents a colour coding system (GREEN, YELLOW, RED) which can be applied to both landfills and contaminated land. The possibility of indiscriminate dumping must, however, be noted and procedures need to be put in place for dealing with the possibility of encountering unrecorded material. Leachate is produced by landfill and may be encountered during drilling.

Gases

Gas generated from landfilled waste may be encountered while drilling in landfill sites. Landfill gas usually contains methane, which is flammable and explosive, and carbon dioxide, which is an asphyxiant. Instruments capable of measuring the concentrations of gases such as methane, carbon dioxide and hydrogen sulphide should be available to facilitate regular checking during the investigation.

Biological Hazards

Biological and bacteriological risks may be present on sites. Good personal hygiene is required to minimise the risk. Protective clothing, such as masks, boots and all over suits, will be required.

Geotechnical

Due to the variable nature of landfilled waste, trafficking of machines may be hazardous, where soft pockets of material are intermingled with firmer material.

Safety Plan

A written safety plan incorporating safety and emergency procedures and good site practice guidelines should be prepared prior to the commencement of work. In addition, the use of staff experienced in working on contaminated sites is recommended. Staff should have regular medical check-ups and details of their state of health prior to working on any site should be recorded.

Should unknown or suspicious contaminants be encountered, such as a discharge of gases or unusual arisings or colouration, operations should cease until a specialist has inspected and assessed the hazard. Instructions given by the specialist should be followed when the investigation resumes.

APPENDIX B: INVESTIGATION TECHNIQUES

This section aims at providing a brief description of the most widely used direct and indirect investigation techniques. Only techniques deployed in the investigation of the ground are discussed here, as it is assumed that techniques for the investigation of topography and other aspects such as ecology and archaeology are described sufficiently in other publications. The techniques are described in six sections:

- direct methods of investigation;
- indirect methods of investigation;
- sampling;
- *in situ* testing;
- laboratory testing; and
- monitoring.

In the absence of an appropriate national standard it is recommended that work is carried out in accordance with BS 1377 and BS 5930.

B1. DIRECT METHODS OF INVESTIGATION

Two basic methods are available to allow direct investigation of the ground:

- examination *in situ*; and
- boring and drilling.

B1.1 EXAMINATION IN SITU

Trial pitting

Trial pits provide the best means of obtaining very detailed information on strength, stratification and discontinuities in soil. Very high quality block samples can be taken from trial pits.

Trial pits are mostly excavated using a wheeled or tracked excavator. The dimensions in plans are normally 1.5 m by 3.0 m and the normal limit of excavation is 3-4 m depth. Trial pits greater than 1.2 m deep should not be entered without form-work support to the excavation.

CCTV Inspection

TV cameras can be used in boreholes to examine features *in situ* such as joint and fault patterns and karst features that are not easily examined in core. CCTV inspection is a service best provided by a specialist sub-contractor.

B1.2 BORING AND DRILLING

A large number of methods are available for advancing boreholes to obtain samples or details of strata. The principal methods are:

- hand augering;
- probing;
- light percussion drilling;
- continuous flight uger drilling;
- rotary drilling; and
- cone penetration testing (CPT).

Hand Auger

Hand augers are advanced by manually rotating augers and rods into the ground using a crossbar. Various sizes of augers are used depending on the ground. The method is limited to the investigation of soft self-supporting strata and usually is limited to the top five metres of soil.

Probing

Probing includes various systems such as the Boris Probe, the Pionjar, the Cobra, and the Mackintosh Probe. The probes mostly comprise slender (15 mm to 20 mm diameter) rods which are 750 mm to 1000 mm in length and which can be threaded together to achieve the required depth. The rods are advanced by the use of a drop weight or a small rotary motor depending on the probe used.

Probing provides an economical method of examining soft to firm deposits or loose granular material. Approximately 80-100 m of probing can usually be achieved in a day in reasonable soils, although penetration is hindered by the presence of cobbles or boulders. The number of blows required to achieve a certain penetration can be related to the consistency or density of the material.

In cohesive material, samples can be recovered using a tube or split spoon sampler. In addition, shallow monitoring points can be installed using this method.

Light Percussion Drilling

This method of drilling is commonly called the shell and auger method.

The method is most suitable for boring in cohesive soils where samples can be recovered using the U100 (U4) tube.

It is common practice to use casings of different diameters in the same hole to allow greater depth of penetration, starting at say 250 mm and reducing to 200 mm and 150 mm at stages. The minimum casing size used is normally 150 mm. Monitoring wells can be constructed in these boreholes using 50 mm diameter casing, allowing for the placement of a filter pack in the annulus.

Various tools can be deployed in the boreholes to carry out *in-situ* tests such as SPT, shear vane and permeability tests.

Continuous Flight Auger (CFA) Drilling

The CFA is not commonly used for site investigation in Europe although widely used in the U.S.A. However, the technique is used in the piling industry to form cast *in situ* piles. The auger can be solid stem or hollow stem. The Hollow stem CFA has the advantage that tools and samples can be handled through the augers.

Rotary Drilling

Rotary drilling uses a rotary action combined with a downward force to grind away material in which the hole is to be made. Rotary methods may be applied to soil or rock, but are generally easier to apply to intact hard rock than to soft highly weathered rock or soil.

The most common use of rotary drilling in site investigation is to obtain intact cores as the hole is advanced. Different methods are used, depending on the material drilled and the type of recovery required.

Air is the most common drill fluid, but the use of water, muds and polymers is also common.

Cone Penetration Testing

Cone penetration testing (CPT) comprises pushing an instrumented probe or cone into the ground using the thrust capacity of a ballasted 20 tonne truck. The cone is constructed such that the cone tip resistance at the point and the sleeve friction along the side of the cone can be measured simultaneously. The combi- nation of these parameters allows the determination of soil type and the calculation of *in situ* shear strength. The maximum depth of penetration depends on the soil conditions but, generally, tests are terminated in soils which have a density with equivalent SPT N values of 40-70. Probes, such as conductivity measuring cones and groundwater sampling tubes, can be deployed with the system to obtain additional information on the soil and groundwater.

B2. INDIRECT METHODS OF INVESTIGATION

B2.1 GENERAL

The principal indirect method of investigation, involves the use of Geophysics, however, remote sensing or, aerial photography should also be considered. Aerial photographs should always be used if available from the Ordinance Survey or other organisations.

B2.2 GEOPHYSICAL METHODS

Geophysical methods allow the subsurface to be examined indirectly using either surface or downhole techniques.

Geophysical techniques should never be used in isolation. They are complementary to and depend on direct methods.

Preparation of a programme of geophysical surveying should be carried out by a person experienced in the use of geophysics who also understands the limitations of the techniques.

In selecting appropriate techniques there are a number of factors to be considered including:

the objective of the survey;

is it to determine the depth to rock?; the layering of strata?; the location of buried features?; correlate between boreholes?;

the relevance of the method; and

can the technique be used at this site?; is it cost effective?; would direct methods be more applicable?

Electrical Resistivity

Electrical resistivity methods rely on measuring subsurface variations of electric current flow which are manifest by an increase or decrease in electrical potential between two electrodes. This is represented in terms of electrical resistivity which may be related to changes in rock or soil types.

The electrical resistivity method is commonly used, therefore, to map lateral and vertical changes in strata. Clays and mudrocks have low resistivity while clean gravels and rock usually have higher resistivity.

Seismic

The seismic method quantifies the effect that ground has on a sound wave generated by an impulse source such as the detonation of a small charge or the impact of a hammer on a plate.

The refracted or reflected waves are detected by an array of geophones at the surface.

The seismic method is particularly well suited to the investigation of the depth and quality of soil and rock layers, or the depth to rockhead.

Magnetic Method

Magnetic methods are based on the measurement of local variations in the earth's magnetic field. Such variations are associated with differences in magnetic susceptibility or the presence of metalliferous objects in the ground.

The main advantage of the method is that measurements can be made extremely fast and hence the use of the method is cost effective. However, the application of the method for the investigation of landfill sites is limited to the location of buried artefacts or shafts and mine adits.

Gravity

The gravity method involves measuring lateral changes in the earth's gravitational field. Such variations are associated with near surface changes in density.

Because voids represent a local drop in density to that of air, water or soil the gravity method has been successful in locating voids, caverns and disused workings in rock and is particularly suitable for the investigation of karst features.

Electromagnetic

The Electromagnetic (EM) method is used in a number of types of equipment such as

ground conductivity (EM31, EM34 VLF);

transient EM; and

ground penetrating radar.

The method relies on the use of a transmitter which is energised with an alternating current. This induces small eddy currents in the earth. These in turn produce a weak secondary field which the instrument detects.

Natural Gamma

The ratio of the natural primary field to the secondary field value is read from the instrument as a direct reading of soil conductivity.

The method is useful for:

delineating gravel deposits;

determining the variation in bedrock topography;

locating buried river channels;

qualitative soil mapping; and

as a supporting method to other techniques.

Borehole Geophysical logging

Geophysical logging involves running various probes down boreholes to measure properties of the soil and rock. The types of logging used includes:

Caliper

- determines rugosity of the borehole wall and is used to locate fissures or zones of broken, weak or squeezing ground.

Temperature

- used to measure fluid temperature and to determine flow patterns in groundwater.

Conductivity

- used to determine changes in conductivity and flow patterns in groundwater;
- used to determine pollution plumes.

Flow

- quantifies flow in borehole.

Resistance

- used to determine strata boundaries and strata type based on resistivity;
- used to determine strata boundaries and is particularly useful for finding clay bands.

B3. SAMPLING

The various categories of samples are described below. The frequency of sampling is an important consideration and guidelines are provided in BS 5930 and SISG (1993).

Similarly, consideration should be given to the storage, cataloguing and transport of samples to ensure that requirements for testing are adhered to.

B3.1 SUBSOIL AND BEDROCK SAMPLING

Sampling of soil and rock is normally divided into two categories; disturbed and undisturbed.

Disturbed samples comprise what are generally termed bag or jar samples. Larger amounts (up to 25 kg) of granular material are usually required for a representative sample. Disturbed samples are mainly used for classification testing and the preparation of particle size distribution charts.

Undisturbed samples comprise either:

- block samples;
- open drive samples;
- piston samples; or
- cored samples.

In cohesive or cemented soils or rock it is normally possible to obtain undisturbed samples and samples taken every 1.5 m in a borehole are normally sufficient. In non-cohesive material it becomes extremely difficult. Samples are usually taken using tubes driven into the ground. After extraction the ends of the tubes are waxed and sealed.

Undisturbed samples are required for a variety of laboratory tests used to determine strength, compressibility and permeability characteristics.

Information on the different types of equipment available for undisturbed sampling can be found in soil mechanics text books.

B3.2 WATER SAMPLING

Sampling equipment should be selected such that it has a minimal effect on the quality of the water samples and consideration should be given to the required range of analyses before sampling.

Surface water sampling is straight forward except where depth samples are required, necessitating the use of specialised equipment.

Groundwater sampling, however, is more complex and there is a variety of techniques available for obtaining samples. In addition, it may be necessary to install multi-layered sampling points within boreholes if the aquifer is multi-layered.

Simple bailing tubes are suitable for rapidly obtaining samples without a high degree of accuracy from narrow diameter wells (50 mm). Bailers are available in different materials such as pvc, stainless steel, teflon, hdpe.

Larger diameter wells are more time consuming to bail and are more effectively sampled using a pump.

It is important to purge the well prior to obtaining a sample so that stagnant water is purged and representative water from the aquifer is allowed to enter the well. Normally, a minimum of three well volumes are bailed or pumped to remove stagnant water before samples are taken.

B4. *IN SITU* TESTING

Some types of material, such as very soft soils, stony soils, sands and gravels, soft, fissured or fractured rock, do not lend themselves to good sampling, or may require the use of expensive and complicated samplers. When these conditions are encountered an *in-situ* test may provide the best means of obtaining the information required. Similarly, to obtain quantitative data on groundwater conditions it is necessary to carry out *in situ* tests. Procedures for the following tests are detailed in BS 5930 "Code of practices for Site Investigations" and BS 1377, "Methods of test for soils for Civil Engineering Purposes".

B4.1 SOIL AND ROCK TESTS

The following tests are the most commonly carried out in *in situ* investigations:

in situ density (used to determine the density of soil *in situ*), and

standard penetration test (spt)

Used in a borehole to determine the 'N' (Number of blows) value in granular soils. The test involves driving a set of rods with a cone at the end into the soil using a drop weight. Samples may be recovered using a split spoon assembly in more cohesive materials;

vane shear strength

The vane is slowly rotated and the relationship between torque and angular rotation recorded. Typically, the maximum torque is used to obtain the undrained shear strength of the soil;

redox potential

Used to determine the corrositivity of the soil;

pressuremeter test

The pressuremeter in its basic form consists of a cylindrical membrane similar to a drillhole packer, which is inserted in a pre-formed hole. The changes in volume of the packer under increments of pressure are recorded, and may be interpreted to give various parameters, such as strength or compressibility.

The tests should be carried out and reported in accordance with BS 1377.

B4.2 GROUNDWATER TESTS

Hydraulic tests are performed in boreholes specifically constructed for that purpose or in boreholes at various stages during their drilling.

The aims of such tests are to determine the hydraulic characteristics of

the well;

the soil and rock local to the well; and

the aquifer.

The tests can be divided into small scale tests which do not involve the removal of large volumes of water; large scale tests which do; and special tests which include tracer tests.

Small scale tests

Small scale tests are used to obtain values of permeability quickly and thus are used to investigate conditions close to the borehole. A number of tests can be undertaken per day.

Both rising head tests (rht) and falling head tests (fht) can be carried out on a variety of boreholes and involve the removal (rht) or addition (fht) of a known volume of water and the measurement of the response of the water level over time. These data can be analysed to give a permeability value for the test section.

Slug and bail tests are similar to the head tests except that the test section is assumed to extend over the entire saturated thickness of the aquifer.

When field values of hydraulic conductivity are too high to obtain reasonably accurate records of the rate of change of head in rising/falling or slug/bail tests, a constant head test is used. The test requires that steady state conditions are established and that the corresponding head and injection/abstraction rate are recorded.

Packer tests represent a special category of constant head tests which are popular in determining the hydraulic conductivity of fractured rocks.

Packer tests are sometimes called Lugeon tests. The principle of packer tests is to carry out constant head tests on small test sections of the well isolated by a packer or packers.

Large scale tests

For many hydrogeological assessments the limitations of the small scale tests may yield parameters inappropriate for the prediction of the more widespread, longer term behaviour of the aquifer. Larger scale, more extensive tests are required to gain such data. These tests are often referred to as pumping tests and usually involve the monitoring of the test well and observation wells for a number of days (generally 3 to 7 days).

The tests are divided into

- the step drawdown test;
- the constant rate test; and
- the recovery test.

The purpose of the step drawdown test is to determine the characteristics of the well (as opposed to the aquifer) and to prepare a yield/drawdown curve which may be used to specify the pumping plant in the case of dewatering works, or simply to decide on the appropriate constant pumping rate for the constant rate test.

The constant rate test is used to determine hydraulic parameters of the aquifer and to establish the extent of influence of the pumping and the interconnectivity with other features.

The constant rate test is the most important test used and should therefore be undertaken only by persons experienced in the design and operation of a pumping test. Analysis of tests is a major topic in its own right. A number of analytical solutions have been obtained to take account of a variety of hydrogeological circumstances such as:

- confined conditions;
- unconfined conditions; leaky aquifer; or
- recharge/barrier boundaries.

It is essential that the analysis of the pumping test results be completed using an appropriate solution. The recovery test is commonly carried out on completion of constant rate or step tests. Recovery tests can be regarded as a check on the data from the pumping phase.

Tracer tests

Tracing techniques are used to determine the direction of groundwater movement, its dilution, spatial dispersion or residence time distribution for a given pathway. There are two basic strategies used.

- Inject a tracer to obtain direct evidence of water movement. The substances used are dyes, radionuclides and biological tracers.
- Investigate the distribution of substances which already exist in the aquifer to deduce the movement of water by correlation techniques.

B5. LABORATORY TESTING

A schedule of tests should be prepared prior to commencement of work on site. Testing should begin before the site work is completed so that anomalies can be followed up. Laboratories which have obtained accreditation by ICLAB should be used where possible.

It is not possible to provide full details of all test procedures in this manual. The main tests are divided as set out below.

Soil testing

Soil is tested in order to assess its variability and in order to obtain particular geotechnical design parameters. The main groups of tests are:

classification tests;

strength tests;

consolidation tests;

permeability tests; and

chemical tests.

Rock testing

Rock is tested to assess its variability and the following groups of tests are used:

classification tests;

durability tests;

hardness tests;

aggregate tests; and

strength tests.

Water testing

Chemical testing of water samples allows background, surface and groundwater quality to be established and allows determination of any natural problems with water quality. Tests will include:

physical and phemical analysis;

bacteriological analysis; and

ionic balance.

B6. MONITORING

As the ground investigation proceeds it is important to put in place monitoring facilities that will be used to monitor the state of the environment prior to, during and after use of the landfill site. There are four main categories of monitoring:

soil and rock;

surface water, leachate and groundwater;

gas monitoring; and

meteorology.

B6.1 SUBSOIL AND BEDROCK

It may be necessary to monitor the performance of the subsoil or bedrock mass that comes in contact with the landfill site, particularly where slopes may have the potential for slip. In bedrock it may be necessary to monitor the performance of unstable ground or weak ground.

B6.2 SURFACE WATER, LEACHATE AND GROUNDWATER

Surface water monitoring involves the monitoring of flows, levels and quality. A series of weirs (hydrometric stations) should be placed on the most important watercourses and monitored regularly. It may be necessary in some circumstances to provide continuous monitoring of levels to provide data for the hydrological or hydrogeological analysis. Surface water samples should be taken regularly before, during and after site operation.

Leachate should be sampled and analysed where it is proposed to extend existing sites, where leachate migration is suspected, and where remedial or aftercare proposals are being prepared. Sampling should be completed at the point(s) of discharge from the site and/or prior to storage or treatment on site.

Groundwater monitoring involves the monitoring of groundwater levels and quality.

Groundwater level monitoring is achieved by installing standpipes or piezometers in boreholes.

Unless the standpipes are of at least 50 mm diameter then representative water samples are difficult to obtain. It is important to ensure that samples are representative of the aquifers monitored, which means that multi-piezometer systems are required for multi-aquifer systems.

Wells adjacent to the site should also be monitored if access can be obtained as this will give a wider spread of data.

B6.3 GAS MONITORING

In the investigating phase it is important that provision is made for the subsequent monitoring of landfill gas. Observation and monitoring locations should be installed during construction as it may be too late to install a system once the landfill begins to operate.

B6.4 METEOROLOGY

Rainfall at the proposed site, weather vane, evaporation and evapotranspiration rates should be measured.

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Environmental Protection Agency

ESTABLISHED
The Environmental Protection Agency Act, 1992, was enacted on 23 April, 1992 and under this legislation the Agency was formally established on 26 July, 1993.

RESPONSIBILITIES
The Agency has a wide range of statutory duties and powers under theAct. The main responsibilities of the Agency include the following:

- the licensing and regulation of large/complex industrial and other processes with significant polluting potential, on the basis of integrated pollution control (IPC) and the application of best available technologies for this purpose;
- the monitoring of enviromnental quality, including the establishment of databases to which the public will have access, and the publication of periodic reports on the state of the environment;
- advising public authorities in respect of environmental functions and assisting local authorities in the performance of their environmental protection functions;
- the promotion of environmentally sound practices through, for example, the encouragement of the use of environmental audits, the establishment of an eco-labelling scheme, the setting of environmental quality objectives and the issuing of codes of practice on matters affecting the environment;
- the promotion and co-ordination of environmental research; and generally overseeing the performance by local authorities of their statutory environmental protection functions.

STATUS
The Agency is an independent public body. Its sponsor in Government is the Department of the Environment. Independence is assured through the selection procedures for the Director General and Directors and the freedom, as provided in the legislation, to act on its own initiative. The assignment, under the legislation, of direct responsibility for a wide range of functions underpins this independence. Under the legislation, it is a specific offence to attempt to influence the Agency, or anyone acting on its behalf, in an improper manner.

ORGANISATION
The Agency's headquarters are located in Wexford and it operates five regional inspectorates, located in Dublin, Cork, Kilkenny, Castlebar and Monaghan.

MANAGEMENT
The Agency is managed by a full-time Executive Board consisting of a Director General and four Directors. The Executive Board is appointed by the Government following detailed procedures laid down in the Act.

ADVISORY COMMITTEE
The Agency is assisted by an Advisory Committee of twelve members. The members are appointed by the Minister for the Environment and are selected mainly from those nominated by organisations with an interest in environmental and developmental matters. The Committee has been given a wide range of advisory functions under the Act, both in relation to the Agency and to the Minister.