Environment Agency

Evidence

Exposure Assessment of Landfill Sites
Volume 1: Main report

Report: P1-396/R

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Evidence at the Environment Agency

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- **Carrying out research**, either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available.

Miranda Kavanagh

Director of Evidence

Executive Summary

The possible health effects of landfill sites have been investigated over the past two decades, with detailed research being carried out in this area since 1998. Studies have looked in particular at whether landfill sites could contribute to increased rates of cancer or congenital anomalies in people living close to the sites. Further investigation of these issues has been hindered because of a lack of information on exposure of local people to substances emitted from landfill sites.

This report describes a study of two typical landfill sites which accept mostly household and similar waste. The study was designed to give information on the substances emitted from the landfill sites. Using this information, the study investigated whether there could be any concerns with regard to health effects associated with these substances, based on our knowledge of their effects on health. It was found to be very difficult to analyse the environmental information to draw robust conclusions about potential health effects.

A study of risks due to exposure via groundwater indicated that there was minimal risk of adverse health effects due to these pathways.

This study included a detailed measurement programme of airborne chemicals, dusts and micro-organisms at the edge of the two landfill sites. The substances were chosen on the basis of previous research which showed that they could be present in emissions from landfill sites. Over ninety different substances were measured. This work was carried out between November 2001 and September 2003.

These measurements were then analysed to evaluate whether the measured levels of the substances included in the survey could require further assessment with regard to health. This included consideration of exposure directly (e.g. by breathing air containing these substances), or by indirect routes (e.g. eating locally produced foods).

We found that none of the substances studied would be expected to give rise to an increased rate of congenital anomalies in children born to families living near to the landfill sites. We found that we could discount most of the substances and groups of substances measured from having any significant adverse effects on health at the two sites under consideration. We identified 52 substances which were given a low priority in this way.

Health effects associated with some substances could not be completely ruled out. 8 substances and substance groups fall into this category.

These substances should form the focus of further investigations:

- Arsine
- Carcinogenic polycyclic aromatic hydrocarbons (group of 6 substances)
- Formaldehyde
- Styrene

- Stibine
- Toluene

Two other substances (1,2-dichloroethane and chromium) were close to the threshold used to determine whether further investigation was appropriate.

Some of these substances are possible or proven carcinogens, although they were found to present at such low levels that they would not give rise to a significant or detectable increase in the incidence of cancer at the measured concentrations. Any increased risk is much lower than would be detectable in a field study of the rates of cancer in populations living near landfill sites. This is consistent with the results of studies of the rates of cancer in people living near landfill (for example, a detailed research study carried out by Imperial College, London in 2002). These studies could not detect any consistent increase in the rate of cancer in people living near UK landfill sites accepting household waste. In view of the low level of any increase in risk, we do not recommend that any specific additional steps are needed at this stage, other than continuing to manage landfill sites in accordance with best practice.

In addition we monitored the concentration levels of micro-organisms (bacteria and fungi) at both sites. However, such micro-organisms are ubiquitous in the environment and the relationship between exposure and health effects is not known.

Some substances emitted from landfill sites could contribute to the incidence of symptoms like eye irritation, coughs and odours for nearby residents. Again, the best approach to controlling these effects is to use best practice techniques for running landfill sites.

We recommend that research should be carried out in the following areas:

- Take measurements of the substances listed above at properties close to typical landfill sites to establish the actual exposure of local people.
- Investigate the rates of respiratory disease in people living close to landfill sites
- Take further measurements of dioxins and furans at a wider range of landfill sites
- Study emissions of PAHs from landfill sites in more detail. The most likely source of PAHs is in emissions from landfill gas flares and engines.
- Carry out a similar study for landfills for hazardous wastes.

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Project Board

Representatives from the Environment Agency, the Department for Environment, Food and Rural Affairs, the Department of Health (this role was subsequently taken over by the Health Protection Agency), Enviros Consulting Ltd and other project team members as appropriate

Main Contractor team

Enviros Consulting Ltd
Lead consultant; project management; evaluation of measured data; meteorological monitoring; source gas sampling; dispersion modelling; groundwater risk assessment; reporting
Resource and Environmental Consultants Ltd
Installation and operation of continuous monitoring stations; intensive surveys
Medical Research Council Institute for Environment and Health, University of Leicester
Toxicology; exposure assessment
Countryside Planning and Management Ltd
Farm survey

Other Contributors

Scientific Analysis Laboratories (sub-contractor to REC)
Laboratory analysis of air samples
Health and Safety Executive/Health and Safety Laboratories (sub-contractor to Enviros)
Information on micro-organisms; laboratory analysis of micro-organisms
Law Laboratories (sub-contractor to REC)
Laboratory analysis of micro-organisms
Komex UK Ltd (sub-contractor to Enviros)
Sampling of trace components of landfill gas
Harwell Scientifics Ltd (sub-contractor to Komex)
Laboratory analysis of trace components of landfill gas
University of Surrey (sub-contractor to Enviros)
Initial phase of toxicology and exposure assessment
Site operator
Access to sites; provision of supporting information on sites
Environment Agency National Compliance Assessment Service
Review of continuous monitoring station operating procedures and practices
Cranfield University Integrated Waste Management Centre
Specialist risk assessment expertise

The report has been subject to independent peer review by experts retained by the Environment Agency.

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1 Introduction

1.1 Overview and context

This report is a study of substances present in the environment at two municipal waste landfills. Based on measured and published levels of these substances, a semi-quantitative risk assessment of the public exposures that might result from releases was carried out. This enabled the substances which were the subject of the study to be prioritised in terms of their potential to members of the public. The research was commissioned to inform the ongoing scientific debate on the risks to public health, including the risk to workers on landfill sites from exposures to the substances in landfills accepting municipal waste.

The research was undertaken between 2001 and 2005 by a research consortium led by Enviros Consulting Limited (Enviros) and funded by the Department for the Environment, Food and Rural Affairs (Defra) and the Environment Agency of England and Wales. Following completion of the work programme, a peer review programme was carried out by the Environment Agency. The draft report was also presented to the Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT) to support the Committee in developing its second statement on landfill sites. As part of this process, the COT reviewed and in some cases revised the health criteria values set out in this report.

The study sought to achieve the following:

- To understand the nature of trace substances released from the two municipal waste landfills studied;
- To consider the findings of risk assessments obtained using established techniques and data where these are sufficient;
- To measure the concentrations of priority substances in emissions from landfill sites, where existing data are not adequate;
- To use the measurements to assess the potential exposure from different substances at the landfill boundary; identify which substances can be ruled out from further assessment, and identify which substances should be a priority for further study;
- To identify what additional research might be required to better characterise exposures from landfills in light of the study.

This study did not:

- Model any change in concentration of the substances measured with increased distance to estimate potential population exposure. Although estimates of population exposure were developed, it was found that these were not sufficiently reliable to use in the study;
- Provide a generalised risk assessment that can be applied to all municipal waste landfills;
- Provide health risk estimates for populations living in the vicinity of municipal waste landfills;
- Address emissions from historic or current hazardous wastes landfills; or
- Take account of changes in waste management practices after July 2004 (the implementation date of many of the Landfill Directive requirements)

This study took place in the context of a number of related studies attempting to understand the significance of risks to human health from exposure to landfill emissions. It should be read alongside these other studies and, in particular:

- Environment Agency studies of, and guidance relating to, emissions to air of landfill gas, gas engine emissions, and gas flare emissions;
- studies of exposure to micro-organisms at waste management facilities;
- Defra studies of health and environmental effects of waste management;
- the Defra waste and resources research programme;
- the current status of environmental epidemiological research;
- a subsequent landfill air quality monitoring survey carried out at the request of the Committee on Toxicity in 2009 (Environment Agency, 2010a); and
- the Committee on Toxicity's Second Statement on Landfill Sites (COT, 2010).

Studies carried out following completion of the survey work for this study are referred to where relevant in this report.

1.2 Introduction and approach

The disposal of wastes to landfill has been the mainstay of waste management in the UK. Wastes from households, commercial and trade premises are collected periodically, transported to transfer stations and disposed of at municipal waste landfills (Figure 1.1). Wastes are by their very nature heterogeneous collections of materials and, whilst certain areas of a landfill may be reserved for specific waste types, the disposed mass of waste is a complex aggregation of multiple materials from thousands of individual sources that, over time, degrades to various degrees into its component parts.

Figure 1.1 Construction of a new landfill cell with the active cell receiving waste in the background

Within the waste mass, the infiltration of water produces leachate that requires control and the degradation of wastes produces gases within the landfill and are either captured or released. Modern landfills are lined and capped to control these by-products. Leachate is disposed of by

using on-site leachate treatment plants or off-site facilities. Gas combustion units are used to burn the methane and other gases produced in the landfill to produce electricity for the national grid. However, a proportion of the gas is not collected and is emitted to the atmosphere without being burnt.

These physical, environmental and engineering processes taking place within a landfill are further affected by meteorological conditions. Daily rainfall affects the amount of infiltration into an active landfill and daily changes in atmospheric pressure result in fluctuations in the amount of gas produced at the surface. Gas that does escape is carried by the winds at various speeds across the localised landscape where, depending on diurnal (overnight) fluctuations in temperature and wind it may linger or be dissipated. Thus the emissions released from landfills are particular to an individual site and a function of:

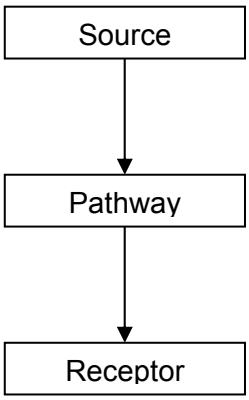
- the waste types and volumes entering the site;
- the site design and construction;
- the operational practices at the site – in particular, how leachate and landfill gas are managed;
- how long the waste has been in place at the site;
- the local environmental setting; and
- climatic, seasonal and local weather conditions.

Because landfill sites are such complex systems, no study of emissions could adopt an approach of standardising the variables and looking systematically at each in turn. A field study can only take ‘snapshots’ of the situation in time as these processes act together in concert. Furthermore, landfills are rarely isolated from other activities that may contribute to pollutant load (e.g. major roads, quarries, agriculture, or industrial estates), and which may be less closely regulated than the landfill site. It is not easy to disaggregate these separate contributions to the emissions measured at any single point. We must view any analysis therefore with caution, in full recognition of the complexity and its dynamics and attempt to separate out the higher priority aspects for further study. The approach adopted in this study is to use a risk assessment framework to guide the work on the key issues.

1.3 Risk and exposure assessment

Environmental risk assessment is a management tool. It involves assessing the likelihood and consequences of undesirable events to inform decisions about the significance of risks to the environment. It helps identify how best to manage unacceptable risks and requires an understanding of sources of a hazard, potential receptors (those components of the environment which need to be protected) and the pathways by which hazards might affect receptors (Figure 1.2).

Figure 1.2 The source, pathway, receptor approach to risk assessment



- the **source** of a hazard – the processes, events or substances which, if they occur or are released, may harm something of value.
  (*e.g.* trace chemicals present in landfill gas)
- the means, or **pathway**, by which a receptor may be affected by the hazard –how the receptor may come into contact with, or be exposed to, the source of the hazard.
  (*e.g.* movement of a gas plume in air to a local residence)
- the characteristics of an environmental **receptor** that may be at risk from that hazard – those components of the

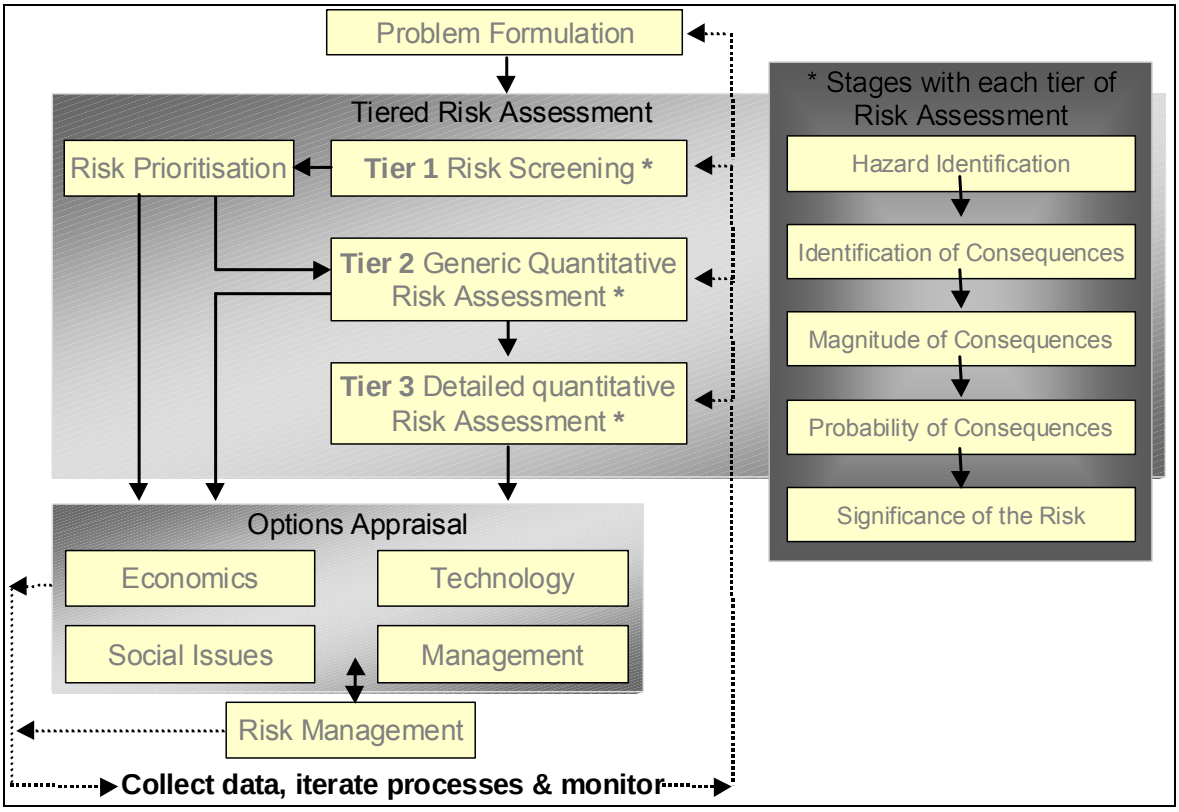
In brief, environmental risk management typically involves answering the following questions.

- what hazards are present and what are their properties – what substances, agents or processes are present with a potential to cause harm?
- how might receptors become exposed to the hazards and what is the probability and magnitude of exposure? – how might releases to the environment, or exposure, occur?; how likely are they?: and what level of exposure might occur?
- given exposure occurs at the above probability and magnitude, what is the probability and scale of harm – what harm might be caused and how likely is it?
- taking probability and consequence together, how significant is the risk and what are the uncertainties – do I need to worry about it?
- what options are available to prevent, control or minimise the risk – how can I best manage the risk?

A full description of these principles is provided in DETR *et al.* (2000). The Government's environmental risk management framework (Figure 1.3) emphasises:

- the importance of good problem definition prior to risk assessment – understanding what is at risk, what it is at risk from and the aspects that are included and excluded from the assessment;
- the importance of developing a 'conceptual model' that is reviewed and updated as new information is collected – in this context, having a firm understanding of the landfill process and its environmental setting;
- the need to screen and prioritise all actual and potential risks – ensuring good coverage of the risks early on and in advance of conducting quantitative analysis;
- the need to match effort and resources in evaluating potential risks to the magnitude of environmental damage that could result – the concept of proportionality;
- the need for an appropriate level of measures to manage the risks to acceptable levels, and;
- the iterative nature of the process, with monitoring and periodic reviews being integral to the risk assessment.

Figure 1.3 Risk management framework (after DETR, IEH and Environment Agency, 2000)



An important feature of any risk assessment is an assessment of exposure because without an exposure there can be no risk. This report deals with the potential public exposure to the substances emitted from landfills. Substances emitted from two landfill sites were measured and used to estimate exposure to the population living in the vicinity of the two sites. This data was then used to assess the significance of the estimated exposures with respect to the potential for adverse health effects. The study provides the following:

- a data set of substances detected in air at the boundary of the two landfill sites;
- a data set of estimated concentrations of substances detected in the environment around the example landfill sites;
- a list of substances unlikely to have any potentially significant health effects, when judged against the health criteria values developed for this project.
- a list of substances found to be above the health criteria values developed for this project;
- a list of substances for which the potential for adverse health effects could not be ruled out, when judged against health criteria values developed for this project;
- an assessment of risks to health posed by possible releases of waterborne pollutants;
- recommendations for matters where operator control, regulatory attention or further research should be focused.

1.4 Study rationale and report structure

We have adopted a risk assessment approach to the study, applying the framework in Figure 1.3 above where possible. The study consists of two volumes. Volume 1 (this document), contains the study methods, key data, risk assessments and supporting conclusions, with more detailed tables provided in Annex 1. Volume 2 (Appendices) provides a full record of all methods, measurements and other data generated during the course of the study.

Following this introduction, Chapter 2 describes in detail the formulation of the problem under study and the study design, including site selection. Chapter 3 provides information on risk screening. Chapter 4 sets out the experimental and field information obtained during the course of the study. Chapter 5 describes the analysis of data, leading to the characterisation of risk associated with the landfill sites being studied. Chapters 4 and 5 discuss the quality and reliability of measurement data and analysis carried out during the course of the project. Chapter 6 sets out the study conclusions and recommendations, with a glossary, abbreviations, list of chemicals provided in Chapter 7, and references in Chapter 8.

The intention was to analyse the data further using a conceptual model of emissions from the site to investigate emissions from the site, and the potential exposure of people located off-site to exposure to the released substances. It was found that the available data and methods did not support this approach. However, a record of the exposure assessment work carried out is provided in Appendix 9 (Volume 2).

This report should be read in conjunction with a report into a subsequent landfill air quality monitoring survey carried out at the request of the Committee on Toxicity in 2009 (Environment Agency, 2010a), and the Committee on Toxicity's Second Statement on Landfill Sites (COT, 2010).

2 Study Design

2.1 Study objectives

Defining the study objective (or "problem formulation") is a critical first step in any risk assessment and sets out the question being addressed by the study in terms of "what is at risk" and "what is it at risk of"? The overall objective of this project was to answer the question:

> *What is the magnitude and consequence of human exposure to substances released from two example landfill sites?*

This overall objective was bounded by the following:

- The study would focus on two sites, selected to be typical of UK landfill sites accepting municipal waste.
- The substances to be studied would be defined on the basis of research being carried out by the Department of Health and the Environment Agency.
- The study would use information on the two sites that could be made available by the operator – for example, borehole monitoring records.
- The quantification would be carried out by estimating public exposure to the emitted substances, and comparing these estimated emissions to health criteria values established on the basis of managing physiological health effects derived for the purposes of this study.
- The study would investigate direct effects associated with specific substances emitted from the landfill sites. Non-specific health effects (e.g. reported stress resulting from traffic travelling to/from a landfill site) were not assessed in this study.

Field work and analytical investigations carried out in order to collect the information needed to answer questions such as that set out above question are typically expensive and time-consuming. Consequently, risk analysis studies are carried out by attempting to understand as much about the problem in advance of the experimental work so as to ensure an efficient experimental design. The needs of the risk assessment are central in driving the identification of appropriate sampling and analytical methods, and exposure modelling techniques.

In this study, we employed a combination of literature review, site reconnaissance and technical discussions with policy and regulatory experts in advance of on-site analytical work and exposure modelling to ensure the experimental studies were targeted on the appropriate substances and with the most appropriate techniques available.

2.2 Review of health studies and substances emitted from landfills

In this study, we were principally concerned to determine whether or not chemicals from landfills are emitted in concentrations and patterns which could give rise to adverse effects to human health due to exposure of populations living nearby. Over the years, questions have been raised about the possible health effects of living close to landfill sites. These questions arose from anecdotal observations of occasional clusters of unusual health outcomes in towns and villages near to landfill sites. These clusters were investigated using epidemiological techniques to assess whether these clusters were associated with random fluctuations in the occurrence of the health effects or if they could possibly be associated with the presence of landfill sites or some other cause.

As a preliminary to this study, a literature review was undertaken to establish the current understanding of the potential health effects that may arise from exposure to contaminants from landfill sites. A number of epidemiological studies have been undertaken and the findings are summarised below. The full literature review is presented in Appendix 1 (Volume 2 of this report). A number of studies have also been undertaken to measure chemical emissions from landfill sites. Information on this is also presented below.

More recent literature review information in relation to toxicological issues is provided in the COT Second Statement on Landfill Sites (COT, 2010)

2.2.1 Epidemiological studies

The published literature in relation to the health risks associated with landfill sites were evaluated in the literature review carried out for this project, and in a subsequent research report published by Defra in 2004 (Defra, 2004a). The executive summary for the literature review carried out for this project is provided in Appendix 1 (Volume 2 of this report). The relevant section of the Defra study is also provided in Appendix 1.

The main priority area for epidemiological studies in relation to landfill sites has been the theoretical possibility that some of these substances could give rise to a slight increase in the risk of contracting cancer in people living near to the landfill sites. The increased risk is much lower than would be detectable in a field study of the rates of cancer in populations living near landfill sites. This is consistent with the results of studies of the rates of cancer in people living near landfill (Jarup *et al.*, 2002). These studies could not detect any consistent increase in the rate of cancer in people living near UK landfill sites accepting household waste.

A number of epidemiological studies indicate that landfill sites may be associated with a slight increase in the risks of congenital anomalies (e.g. Dolk *et al.*, 1998; Elliott *et al.*, 2001; Vrijheid *et al.*, 2002). The most detailed study carried out by Elliott *et al.* identified a possible small association between proximity to landfill sites and the occurrence of congenital anomalies, but several indications suggest that any increase is due at least partly to factors other than the landfill site. A detailed study of the incidence of cancers around landfill sites did not detect any significant increase in risk (Jarup *et al.*, 2002).

A limitation of such studies to date is that they typically use the distance of residence from a landfill site (the proximity to a site) as a surrogate for the exposure to undefined substances that may be emitted from landfills, rather than estimating the exposure of the population in the studies to specific substances emitted from landfill sites. Researchers recognise this and epidemiological studies into the health effects of landfill sites have been unanimous in calling for information on the exposure of the public to substances likely to be emitted from the landfill sites. An investigation of this nature should help to establish whether a significant level of exposure could occur.

2.2.2 Trace substances released from landfills

Emissions from landfill sites have been studied in detail over recent years. The main sources of emissions from landfill sites are as follows:

- The waste materials as they are brought onto site, normally in heavy goods vehicles. At some sites, waste is transported by rail or by water.
- The waste materials as they are tipped or placed into the landfill site.
- The waste materials which have previously been deposited in a landfill site
- Any leachate produced as the waste breaks down
- The discharges from any processes used to treat the leachate
- Any gas generated as the waste breaks down, which is not collected and treated

- The emissions from any combustion plant used to handle landfill gas, including gas flares or engines

The substances released from these sources could potentially affect people living close to the site via a number of pathways. These could include transport of substances in the air, movement of substances in surface water or groundwater, or deposition of substances onto the land, and subsequent consumption by livestock. These sources and pathways are discussed in more detail in Sections 3.1 and 3.3.

The Department of Health sponsored a study of substances known to be present in landfill gas (Department of Health, 2001; (Table 2.1). The aim of their study was to classify these substances according to their potential for developmental toxicity, which could in theory contribute to the congenital anomalies highlighted by the EUROHAZCON study (Dolk *et al.*, 1998) and other research.

Table 2.1 Chemicals with potential for developmental toxicity (Department of Health, 2001)

Classification	Substance
Chemicals of possible interest	benzene, 1,3-butadiene, carbon disulphide, chloroform, 1,2-dichloroethene, ethylbenzene, formaldehyde, chloromethane, tetrachloroethylene, trichloroethene, chloroethene
Chemicals of less likely interest	alpha-terpinene, dichlorobenzene, 2-ethyl-1-hexanol, hydrogen sulphide, 2-butanone, toluene, xylenes
Chemicals of no/unlikely interest	acetone, 2-butanol, carbon tetrachloride, dichloromethane, ethanol, limonene, 1-propanol, styrene, vinyl acetate
Insufficient data to classify	1,1-dichloroethane, dichlorofluoromethane, ethanethiol, methanethiol, 2-methyl furan, nitromethane

Note: Chloroethene is also known as vinyl chloride
Chloroform is also known as trichloromethane
2-butanone is also known as methyl ethyl ketone
Methanethiol is also known as methyl mercaptan
Ethanethiol is also known as ethyl mercaptan
Formaldehyde is also known as “methanal”

The operator of each landfill site permitted by the Environment Agency has for some time been required to undertake a risk assessment of releases to groundwater and the safety aspects of landfill gas management. More recently, risk assessments of the trace components and combustion products of landfill gas have been required.

Landfill leachate

There is now a considerable body of evidence available on the constituents of landfill leachate. This was consolidated in research work carried out by the Environment Agency (Environment Agency, 2001b; Environment Agency, 2003a). Together with the site-specific risk assessments and actions taken to minimise risks of exposure to substances emitted from landfills, the risks from exposure to emissions from landfill via groundwater are relatively well understood. The Environment Agency research (2003a) identified those substances found in more than 5% of samples of landfill leachate. This range of substances was used as the starting point for the present research, as set out in Table 2.2.

Table 2.2 Priority substances in landfill leachate

Aniline	Dichloromethane	biphenyl
methyl tertiary butyl ether	Nitrogen	mecoprop
Cyanide	Organotin	naphthalene
di (2-ethyl hexyl) phthalate	phenols	pentachlorophenol
Ethylbenzene	phosphorus	toluene
Fluoride	polycyclic aromatic hydrocarbons	xylenes
methyl chlorophenoxy acetic acid	nonyl phenol	Arsenic

Landfill gas

The literature review carried out at the outset of the project highlighted a wide range of substances which have been found in landfill gas (Appendix 1). In parallel with this project, the Environment Agency conducted a detailed research project into the trace constituents of landfill gas (Environment Agency, 2002). A similar database was produced using landfill tax credit funding by Redfearn *et al* (2000). The Environment Agency research updated and developed the literature review carried out for the present project to provide:

- a database of substances measured in landfill gas based on a literature review;
- development, validation and testing of methods for measuring the trace components of landfill gas;
- measurements of trace components of landfill gas using the newly validated techniques to feed into the measurement database; and
- an initial prioritisation of the trace components to indicate the highest priority substances from the perspective of toxicity and odour. This was carried out by evaluating the database records against available air quality standards and guidelines, and published odour threshold data.

The highest priority substances identified from the perspective of toxicity are summarised in Table 2.3

Table 2.3 Priority substances in landfill gas

1,1-dichloroethane	Toluene	acetone
chloroethane	trichloroethene	tetrachloromethane
chloroethene	n-butane	dichlorodifluoromethane
hydrogen sulphide	1,2-dichloroethene	trans-1,2-dichloroethene
chlorobenzene	1,2-dichloroethane	dichlorofluoromethane
tetrachloroethene	Dichloromethane	ethylbenzene
1,1,1-trichloroethane	n-hexane	1,2-dichlorotetrafluoroethane
chlorodifluoromethane	cis-1,2-dichloroethene	
benzene	carbon monoxide	

During the course of the project, research carried out at landfill sites in the United States indicated that emissions of organic mercury compounds, antimony trihydride (stibine) and arsenic trihydride (arsine) in landfill gas could be significant (Lindberg *et al*., 2001). The information on organic mercury was subsequently found to be flawed (ESART, 2003). In view of this, measurements of organic mercury compounds were not carried out as part of this project.

Landfill gas flares / engines

Most modern landfills have landfill gas engines which burn the gas to generate electricity, and/or flares which burn landfill gas. There has been considerable research into the emissions from landfill gas engines. A detailed study was undertaken by Land Quality Management Ltd for Shanks First, Biffaward and Viridor (Gillett *et al.*, 2002). This provided a database of information on emissions from flares and engines. Landfill gas engines were found to be effective at destroying volatile organic compounds with a typical efficiency of 96 per cent - 99.9 per cent. The lower destruction efficiencies were for substances that were at a low inlet concentration and may thus have been linked to the detection limit of the measurement techniques. One of the flares studied was found to have a relatively poor methane destruction efficiency of 84 per cent. It was found that emissions of dioxins and furans from landfill gas engines were very low; generally close to the detection limit of the analytical techniques. However, crankcase breathing losses were found to be potentially significant sources of volatile organic compounds (VOCs) and sulphur dioxide.

Further research was carried out by the Environment Agency into the methods for measuring emissions from landfill gas flares and engines and supported the development of guidance to operators on taking these measurements (Environment Agency, 2002b). The available information on emissions to air from landfill gas flares and engines was drawn together in a DEFRA review (DEFRA, 2004a tables 2.35 and 2.36). This report identified data on emissions of combustion products. Where data were available for other components (e.g. VOCs), this study confirmed that emissions were at a relatively low level. In view of this evaluation, the highest priority substances in emissions from landfill gas engines and flares were identified as combustion products, together with any metals present in the landfill gas which may be emitted following the combustion process. These substances are summarised in Table 2.4.

Table 2.4 Highest priority substances in emissions from landfill gas engines and flares

nitrogen oxides	fine particulates (PM_{10})	metals
sulphur dioxide	dioxins and furans	polycyclic aromatic hydrocarbons
carbon monoxide		

The research into emissions from flares and engines, and the trace constituents of landfill gas provided detailed information on the range of substances likely to be emitted from landfill sites. This information was made available during the planning and field work phases of the present project and, where possible, the monitoring programme was adapted to respond to the emerging science in this area.

Other emissions to air

Emissions to air can also result from the transportation of waste to landfill sites and from the tipping of waste at landfill sites. Tipping of waste is, in theory, likely to give rise to higher emissions at increased concentrations, albeit of shorter duration. The priority substances include micro-organisms, dusts and volatile organic compounds (VOCs). There is no published information on emissions from tipping of waste materials at landfill sites. However, useful information on these emissions can be gained from studies of air quality within materials transfer stations. The Health and Safety Laboratory has published research in this area that indicates the range of micro-organisms which need to be considered (Health and Safety Executive, 2003). The

priority substances in emissions to air from tipping of waste at landfill sites are summarised in Table 2.5.

Table 2.5 Priority substances from waste tipping

Micro-organisms	Volatile organic compounds	Dust and airborne particulate matter

In summary, airborne levels of the substances listed in Table 2.6 were measured in this study. A full list of the chemicals measured in the study with chemical formulae and CAS numbers is provided in Section 7.

Table 2.6 Substances measured in the air during the course of this study

1,1,1-Trichloroethane	Carbon disulphide	Entrobacteriaceae	PCBs
1,1-Dichloroethane	Chlorobenzene	Ethyl mercaptan	Penicillia
1,2-Dichloroethane	Chlorodifluoromethane	Ethylbenzene	Phenanthrene
1,2-Dichloroethene	Chloroethane	Fibres	PM_{10}
1,3-butadiene	Chloroethene	Fluoranthene	Pyrene
2-butanone	Chloroform	Fluorene	Stibine
2-Ethyl-1-hexanol	Chloromethane	Formaldehyde	Styrene
2-Methylfuran	Chromium	Gram negative bacteria	Sulphur dioxide
Acenaphthene	Chrysene	Hydrogen sulphide	Tetrachloroethene
Acenaphthylene	Cobalt	Indeno (123-cd) pyrene	Thallium
alpha-Terpinene	Copper	Lead	Thermophilic Bacteria
Anthracene	Dibenzo (ah) anthracene	m+p Xylene	Thermophilic fungi
Antimony	Dichlorobenzene	manganese	Thermophilic fungi and yeasts Malt
Arsenic	Dichlorodifluoromethane	Mercury	Tin
Arsine	Dichlorofluoromethane	Mesophilic Aerobes	Toluene
Aspergillus fumigatus	Dichloromethane	Methyl mercaptan	Total Bacteria
Benzene	Dichloromethane	Moulds	Total fungi and yeasts DG18
Benzo (a) anthracene	Dimethyl disulphide	Naphthalene	Total fungi and yeasts Malt
Benzo (a) pyrene	Dimethyl sulphide	Nickel	Trichloroethene
Benzo (b/k) fluoranthene	Dioxins and furans	Nitrogen dioxide	Trimethylbenzene
Benzo (ghi) perylene	Dioxins, furans and dioxin-like PCBs	Nitromethane	Vanadium
Cadmium	Endotoxins	o Xylene	Yeasts

2.3 Site selection and description

Having identified the priority compounds and their health criteria values, candidate sites for investigation needed to be identified and the conceptual model of exposure for each developed. The number of sites to be studied in the project was discussed at the outset. It was decided that two sites would be studied. The sites are referred to as “Site A” and “Site B”. The sites were selected to be typical of those taking municipal waste so far as possible, on the basis of

conformance with criteria specified by the Environment Agency at the outset. These criteria are set out in Table 2.7.

Table 2.7 Specification of landfill sites

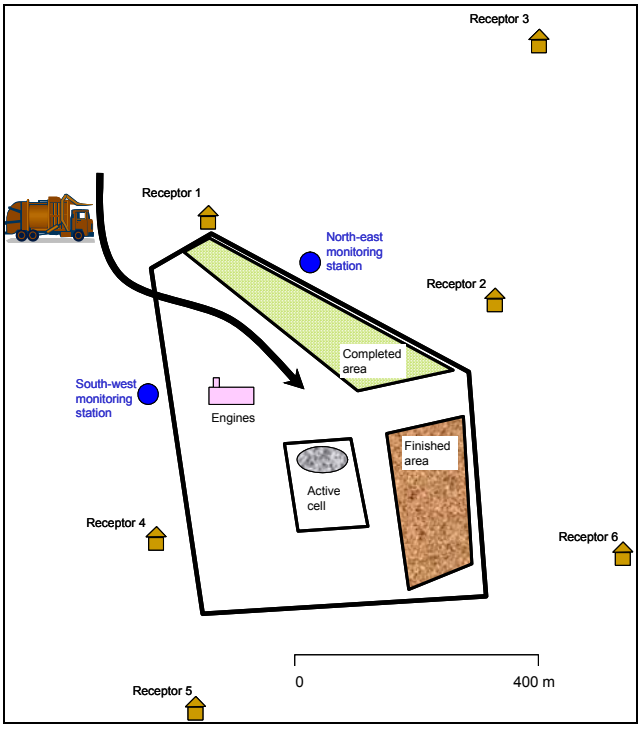
Description	Criterion	Site A	Site B
Operational status	Open preferred	Open, with some restored areas	Open, with some restored areas
Throughput	>100,000 tpa	80,000 tpa	80 - 100,000 tpa
Landfill Gas control mode	One site with utilisation One site with flaring	Landfill gas collection system in place Mostly utilisation (estimated 75% of landfill gas collected) with two engines normally operating plus one on standby. Balance of landfill gas to enclosed flare	Landfill gas collection system in place Flaring (one enclosed flare unit operating at approx 1500 m3 per hour; estimated 75-80% collection) from commencement of study to early 2003. Two engines installed early 2003. Enclosed flare operating on stand-by basis.
Waste description	Predominantly domestic	Predominantly domestic + 30% commercial/ industrial	Predominantly domestic + 30% commercial/ industrial
Volume of waste in place (end 2001)	-	1,900,000 tonnes	1,580,000 tonnes
Local area description	Populated areas preferred	Residential areas within 30 metres of site boundary	Mainly rural; isolated properties close to the site
Proximity of groundwater table	Within 10 metres preferred	Phase 1 over groundwater within 10 metres.	Minor aquifer in boulder clay within 10 metres; also close to major sandstone aquifer
Proximity of surface water	Within 50 metres preferred	Class 1 spring located within 500 metres, which is believed to be linked to groundwater at the site (not investigated as part of this study). River located within 500 metres.	Streams located in the immediate vicinity of the site, discharging into ponds to north and south of site, and then to river

2.3.1 Site A summary

Waste receipts at Site A in a typical year were: 77000 tonnes domestic waste; 32000 tonnes, industrial/commercial waste; 9000 tonnes special[1]/difficult waste; and 3000 tonnes, builder/demolition waste. The site operated three 1MW landfill gas generator sets, with an enclosed flare as stand-by. This arrangement was in place throughout the time of the study. The flare was operated for less than 3% of the time, when the engines were off-line. Modelling of the rate of production of landfill gas carried out in support of the site's PPC application indicated that the engines utilise at least 75% of the gas theoretically generated from in-situ wastes. A schematic diagram of Site A is shown in Figure 2.1.

[1] Special waste was the term used to define the most hazardous wastes. It has now been replaced by hazardous waste: since July 2004, hazardous waste can no longer be disposed of in landfill with non-hazardous waste.

Figure 2.1 Schematic diagram of Site A



Site A was located in a predominantly rural area. Consequently, there were relatively few potentially significant sources of pollution in the local area. Other potential sources of pollution comprised the following:

- Quarrying activities: quarrying took place on a significant scale at quarries located approximately 1 km to the west of Site A, and 7 km east of Site A. This could have influenced groundwater quality in the local area, and was also likely to result in the generation of airborne dust.

- A trunk road ran to the north of the site. Traffic using this road and local roads in villages to the north, west and east of Site A gave rise to emissions of airborne pollutants including oxides of nitrogen, particulate matter, carbon monoxide, sulphur dioxide and benzene. These emissions were assessed by the local authority under its Air Quality Review and Assessment responsibilities and not found to give rise to levels of air pollutants at levels above air quality objectives.

- There were scattered industrial processes in the local area. These could have resulted in discharges to air, land and water in the local area. The most significant sources of pollution were regulated by the Environment Agency. A non-ferrous metals process was located 16 km to the west of Site A. This distance is sufficient for significant effects on environmental conditions at Site A to be unlikely. There was a number of small-scale processes regulated by the local authority within 5 km of Site A, including vehicle spraying, waste oil burning, cement batching, a tannery and several petrol stations. These were mostly located to the north and north-east of the site. There were two hospitals located 5 km and 10 km from the site, but these do not have regulated incinerator or boiler processes.

- The local land-use was predominantly agricultural. Farming activities have the potential to affect surface water and groundwater through the use of pesticides and/or fertilisers. Animal wastes can result in increased eutrophication.

Site A accepted mainly municipal waste with some commercial/industrial wastes and small amounts of other waste streams. The amount of waste accepted was typical of UK sites;

Local land-uses were typical of rural sites in the UK, with a mix of agriculture and residential properties, together with a small amount of commercial and light industrial usage. However, Site A was also located within 1 kilometre of a coastline, which could have affected the groundwater regime at the site, and could also have resulted in an increased prevalence of onshore breezes. Anecdotal evidence was that the prevailing wind direction was south-westerly at the site. Site-specific wind direction information was collected by the weather station, and incorporated into exposure assessment. The influence of the coastline on the groundwater regime has been investigated as part of the study. Although the coastline did influence the groundwater regime, the influence is not so great as to render the groundwater risk assessment atypical of UK sites.

The terrain around the site was complex, with the completed areas of the landfill higher than the nearest properties to the site, although most operations took place below the rim of the quarry. Again, terrain could have affected the influence of the site on groundwater quality, and this has been addressed as part of the study. Although many landfill sites are located in flat terrain (exemplified by Site B), it is not unusual to find landfill sites located in hilly areas. Because of the effects of terrain on rainfall and wind patterns, sites located in exposed upland areas can experience unforeseen or complex emissions dispersal patterns.

The site had a depth of up to approximately 30 m. This is deeper than the average landfill, and makes management of the landfill more complex from an engineering perspective.

Approximately 75 per cent of the landfill gas generated at the site was estimated to be captured and combusted. This is typical of an operational municipal waste landfill in the UK.

The fissured limestone geology had an influence on the effect of the site on groundwater flows. Because of this, local groundwater has been studied in detail in the past. While the geology is not unusual in the UK, every site has an individual hydrogeological regime. It would therefore not be possible to identify a single site to be representative of landfill sites in the UK as a whole. The two sites chosen for this study exemplify a range of typical geological strata and sensitivities.

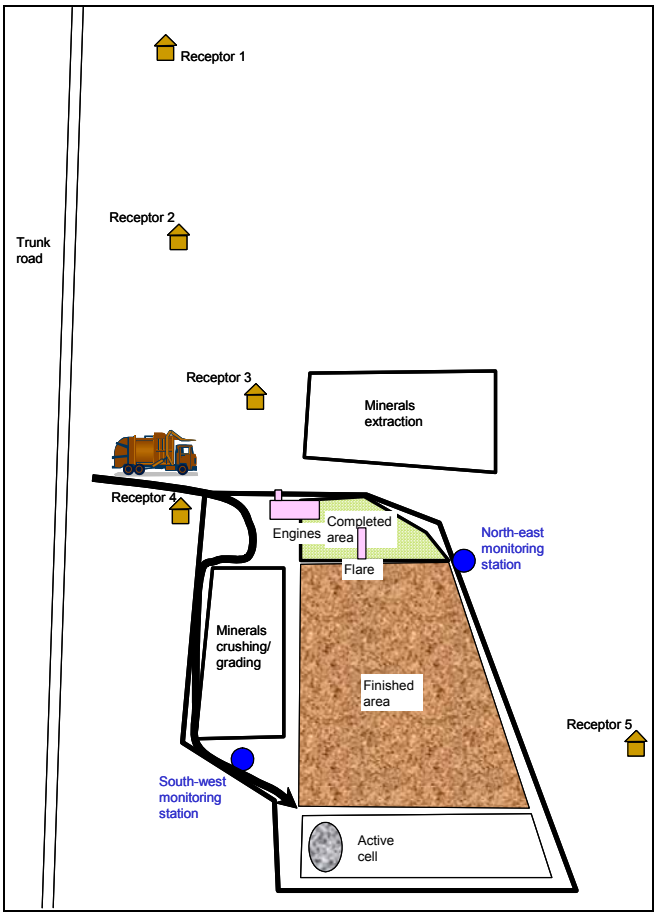
Finally, the site had in the past been subject to regulatory activity relating to landfill gas migration and leachate control. These historical issues had largely been dealt with prior to commencement of this study. Measures were taken at the site to construct a temporary cap on completed waste faces to contain landfill gas and minimise risks associated with leachate outbreaks. Also, following earlier problems, the site maintained the leachate level within the levels identified in the site licence, generally within 2m of the site base. An on-site leachate treatment plant has been constructed to avoid the need to transport leachate to off-site sewage treatment works.

The monitoring data were evaluated to establish whether the trace components observed to be present in landfill gas at Site A were typical of those observed at other UK landfill sites. This is described in Chapter 4.

2.3.2 Site B summary

Waste receipts at Site B in a typical year were: 70000 tonnes domestic waste; 2000 tonnes inert waste; and 60000 tonnes industrial/commercial. This was almost entirely domestic-like waste (e.g. hotels/restaurants) in the absence of heavy industry in the catchment. A schematic diagram showing the location of Site B is given in Figure 2.2.

Figure 2.2 Schematic diagram of Site B



The site was surrounded by agricultural land and surface water bodies, which provided a case study of potential exposures via ingestion. There were three farm properties within 500 metres of the site. The nearest village was 3 kilometres from the site, and the nearest town was 6 kilometres away.

The site fulfilled the criterion of dealing with landfill gas by flaring in an enclosed flare for the first part of the survey. The site flared approximately 2000 m^3 per hour of landfill gas, an estimated 75 per cent of the available gas. During 2002, the flare was replaced with three 1MW generator sets, of which two were normally operational at any time. An enclosed flare for back-up use was also provided.

At the start of the survey, waste was deposited towards the southern end of the area marked “Finished Area” in Figure 2.2. Waste deposition moved on to the area marked “Active cell” during the course of the study. Towards the end of the study period, the temporary cap at the northern end of the Finished Area was stripped back and waste surcharged to these areas to enable the final restoration contours to be achieved. The prevailing wind direction at the site was reported to be from the west/south-west. Neither the site operators nor the Environment Agency had ever received a complaint of dust or odour related to the site since operation commenced. All cells were fully lined, and there were no known leachate quality or landfill gas migration problems. Leachate was both recirculated within the waste and tankered off-site (approximately 3 tankers per week).

There were relatively few potentially significant sources of pollution in the local area. Potential sources of pollution comprised the following:

- Quarrying activities: the site was located in the worked-out part of an operational quarry. Sand and gravel extraction took place to the north of the landfill area, and

crushing/grading and concrete batching take place to the west of the landfill. This is likely to result in the generation of increased airborne dust in the local area, and could also influence local groundwater quality.

- A trunk road ran to the west of the site. Traffic using this road emitted airborne pollutants including oxides of nitrogen, particulate matter, carbon monoxide, sulphur dioxide and benzene. These emissions were assessed by the local authority under its Air Quality Review and Assessment responsibilities and not found to give rise to levels of air pollutants at levels above air quality objectives.

- There were scattered industrial processes in the local area. These could result in discharges to air, land and water in the local area. The most significant sources of pollution were regulated by the Environment Agency. Three sewage works were located between 5 km and 10 km of the site. A waste transfer station was located 8 km from the site, and an inorganic chemicals production plant was located 17 km north of the site. None of these operations would be expected to have a significant effect on environmental conditions at the site. A process generating iso-cyanates and chlorinated VOCs was located 13 km south-west of the site. While this is a considerable distance from the site, the potential effects of emissions from this process were taken into account when considering measured levels of chlorinated VOCs. A preliminary dispersion modelling analysis indicated that emissions of chlorinated VOCs from this process could give rise to individual VOCs at Site B at levels up to 0.03 $\mu g/m^3$.

  There were several, small-scale processes regulated by the local authority within 5 km of Site B, including vehicle spraying, waste oil burning, minerals crushing and grading, di-isocyanate processes, and several petrol stations. These were mostly located to the west of the site. A hospital was located 10 km from the site, but it did not have a regulated incinerator or boiler process.

- The local land-use was predominantly agricultural. Farming activities has the potential to affect surface water and groundwater through the use of pesticides and/or fertilisers. Animal wastes can result in increased eutrophication.

The conceptual model for exposure of local people to substances emitted from landfill is set out in Chapter 2 and explored in more detail in Chapter 3. Consideration of the circumstances of Site B indicates that there are no specific circumstances of Site B which would require adaptation of the conceptual model used in this project.

Like Site A, Site B is typical of landfill sites accepting municipal waste in the UK in many respects. The rate of waste acceptance is typical of UK sites. The type of wastes accepted is a typical mix of mainly municipal waste with some commercial/industrial wastes and small amounts of other wastes. Local land-uses were typical of rural sites in the UK, being predominantly agricultural, together with scattered residential properties.

A trunk road ran 250 metres west of the location of the south-west monitoring station. The trunk road was 450 metres from the north-east monitoring station. Road traffic emissions would not be expected to have a significant effect on air quality at this distance (Highways Agency, 2003); however, the presence of the trunk road needs to be taken into account in interpreting the study results.

The quarrying activities noted above are in fact a common feature of landfill sites, which have historically been located in voids created by minerals excavation. The presence of these operations could conceivably lead to an increase in levels of particulate matter at the air monitoring stations. However, the majority of the particulate matter released from minerals excavation and processing is in the fraction larger than PM_{10}. This fraction settles out close to the source, and is not associated with adverse health effects. To ensure that this source could be taken into account, an additional set of determinations of dust levels was taken at a location

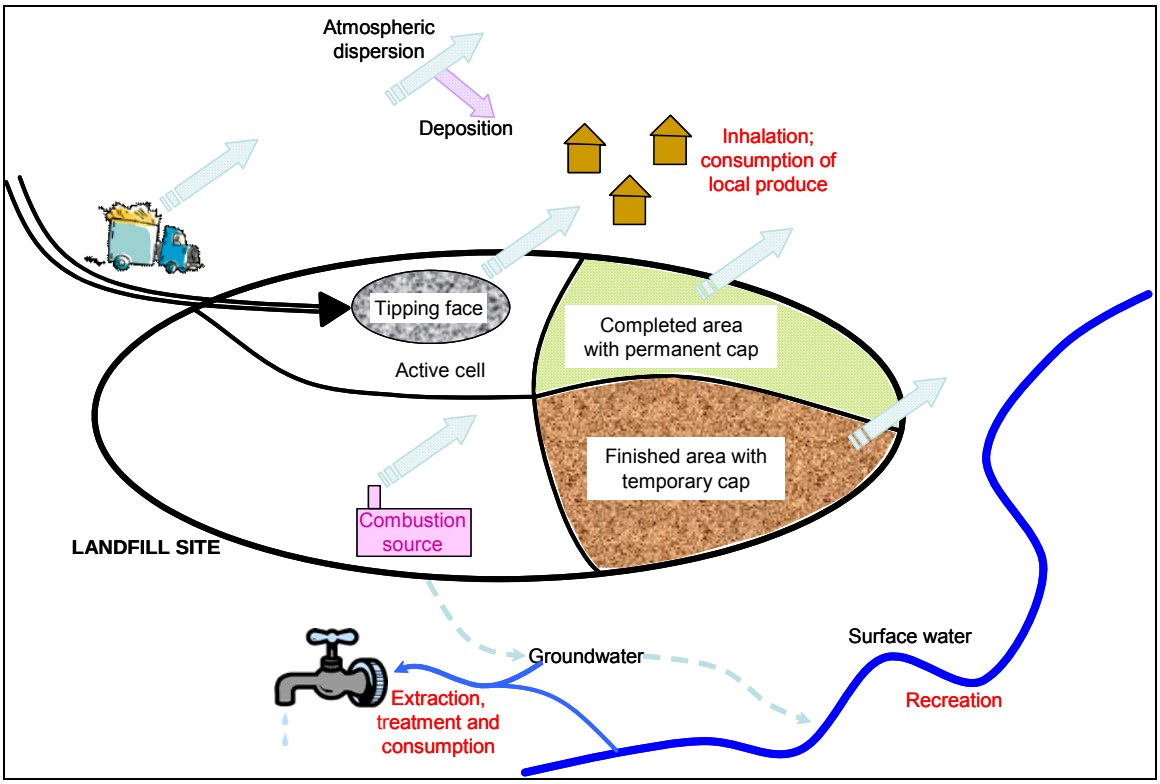
between the minerals processing area and the completed landfill area. Levels of dust detected at the south-west and north-east monitoring location were compared with the level measured close to the minerals processing area to establish the significance of any contribution of the minerals processing area to levels of dust at and near to the landfill site boundary.

The monitoring data were evaluated to establish whether the trace components observed to be present in landfill gas at Site B were typical of those observed at other UK landfill sites.

2.4 Conceptual model development

Human exposure occurs when people come into contact with something that could cause harm, *e.g.* a chemical. Estimating the exposure requires and understanding of the number and various categories of exposure pathways that might be available at each location. The starting point for this study was a conceptual model of exposure to emissions from landfill sites (Figure 2.3). This was developed into a set of potential source-pathway-exposure linkages, as described in Chapter 3.

Figure 2.3 Generic representation of landfill emissions



3 Risk screening and risk prioritisation

3.1 Screening sources, pathways and receptors

Chapters 1 and 2 established a generalised conceptual model for emissions from landfill in the form of source-pathway-receptor relationships (Figure 1.2). Without these relationships exposure cannot occur.

The initial conceptual model for exposure to emissions from landfill sites was developed to provide a model of source – pathway relationships for landfill emissions (Figure 3.1).

Figure 3.1 Generalised conceptual model for this study

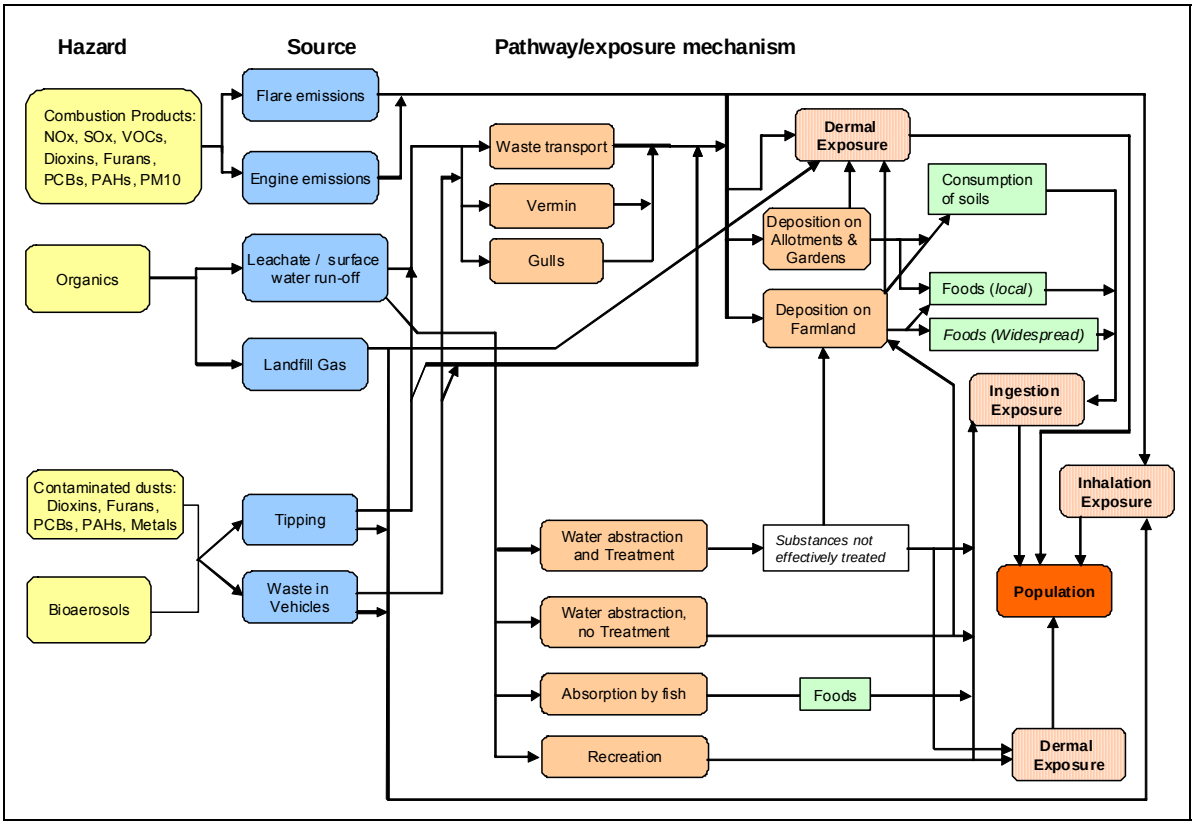


Figure 3.1 is the basis for much of the work that follows. This model sets the context for the site and analytical work used to gather data for the exposure assessment. An exhaustive list of source-pathway-linkages was constructed on the basis of the conceptual model shown in Figure 3.1. This resulted in the identification of 134 potential linkages. Table 3.1 in Annex 1 sets out the full set of linkages developed from the conceptual model.

Analysis of the entire set of 134 linkages is not practically possible and a conventional approach within environmental risk assessment is to screen and prioritise these relationships and focus more detailed investigative work on those linkages considered more likely to result in significant exposures (see Figure 1.3). This is described in Section 3.2 below.

3.2 Prioritising source-pathway-receptor linkages

The risk associated with each of these routes is a result of the **probability** of exposure via this route, combined with the possible **consequences** of exposure to the substances under consideration.

Exposure routes with a relatively high probability of occurrence, and potentially severe consequences are the highest priority, and are candidates to be studied in most detail. Conversely, exposure routes with a relatively low probability of occurrence, and mild or negligible consequences are a lower priority. In order to screen the risks, the probability and consequence of each pathway were classified on a qualitative basis, following the approach set out in DETR/Environment Agency (2000) using the approach summarised in Table 3.2 below.

This evaluation was used to establish the risk significance of the exposure pathways identified in Table 3.1. The significance is a combination of the probability of local people becoming exposed to the hazard, and the consequences of this exposure. Having carried out this risk screening at the outset of the project, the risk screening was revisited later, in the light of the data analysis, to establish whether the conceptual model and prioritisation of potential exposure pathways was borne out by the field data (Chapter 5).

Exposure routes with a risk screening estimate of “near zero” or “low” are unlikely to contribute to significant health effects. This situation might occur in the case of hazards that are potentially severe, but are extremely unlikely to be realised in practice. For example, the release of carbon monoxide in sufficient quantities to cause asphyxiation is a severe hazard, but the probability that this could occur as a result of off-site exposure to landfill gas is extremely low. This situation might also occur in the case of a hazard which is likely to occur, but which has very mild consequences. For example, it is common to detect the odour of recently deposited waste close to vehicles transporting waste, but this would not be expected to have any significant effects on health.

Exposure routes rated as “near zero” or “low” risk were excluded from further consideration in the risk assessment.

Table 3.2 Basis for screening out low risk exposure/pathway combinations

Significance of risk decreasing ↘	**Consequence**			
	Severe	Moderate	Mild	Negligible
Probability	**Risk screening classification**			
High	High	high	medium/low	near zero
Medium	High	medium	Low	near zero
Low	high/medium	medium/low	Low	near zero
Negligible	high/medium/low	medium/low	Low	near zero

(after DETR/Environment Agency/IEH, 2000)

The initial 134 source-pathway-receptor linkages set out in Table 3.1 were prioritised on a qualitative basis using expert judgment. This resulted in the identification of 35 potential exposure pathways which could be significant in terms of potential population exposure. These are set out in Table 3.3 (Annex 1). A summary of the key pathways is provided in Table 3.4 below.

Table 3.4 Summary of potentially significant pathways for exposure of local people

Hazard	Source	Medium of Exposure	Health effect	Initial risk rating
Acid gases	Flare/Engine Emissions	Inhalation exposure	Eye irritation, mild respiratory effects	Low
Toxic Organic Micro-pollutants	Flare/Engine Emissions	Inhalation or ingestion exposure	Some carcinogens, some developmental toxins	High/Medium
Organics	Flare/Engine Emissions	Inhalation exposure	Some carcinogens; some developmental toxins	High/Medium
Organics	Leachate/ Surface water runoff	Inhalation or ingestion exposure	Some carcinogens; some developmental toxins	High/Medium
Organics	Landfill Gas	Inhalation exposure	Some carcinogens; some developmental toxins	High/Medium
Dusts + metals/ Toxic Organic Micro-pollutants	Tipping	Inhalation or ingestion exposure	Respiratory ill health; Some metals carcinogenic; some TOMPS[2] carcinogenic or possibly developmental toxins	High/Medium/ Low
Dusts + metals/ Toxic Organic Micro-pollutants	Waste in Vehicles	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly developmental toxins	High/Medium
Bioaerosols	Tipping	Inhalation Exposure	Possible infection or mild ill-health	Low
Bioaerosols	Waste in Vehicles	Inhalation Exposure	Possible infection or mild ill-health	Low

Thus, in summary, the risk prioritisation study indicated that the potentially significant exposure pathways are likely to be the following:

- the inhalation of airborne pollutants (organics, particulates, metals and toxic organic micropollutants);
- the consumption of locally produced food and water contaminated with toxic organic micropollutants and (to a lesser extent) metals; and
- the consumption of food and water contaminated with pollutants transmitted via groundwater.

3.3 Experimental design

The preliminary qualitative risk screening and prioritisation of risk, based on the conceptual model developed by reference to the layout and environmental setting of the two sites provides essential information for the design of experimental and analytical work. The experimental study was designed to provide information on these potentially significant pathways for exposure to landfill emissions.

Waterborne exposure pathways could potentially comprise releases of leachate through a landfill liner, runoff of contaminated rainwater, and release of landfill leachate before or after treatment. These may be potentially significant routes for public exposure (Paustenbach, 2000). Since the late 1970s, the focus of landfill environmental control systems has been on control of water contamination, and in particular, groundwater. This has been embodied in successive legislation and good practice guidance documents used to limit the release of contaminants to groundwater.

[2] Toxic organic micropollutants

Groundwater and surface water is subject to treatment before distribution to the public water supply and almost all drinking water is drawn from protected supplies.

Information on the potential emissions from landfill sites via waterborne pathways is available under the permitting arrangements for most landfill sites accepting municipal waste. This is the case for the two sites that were the subject of this study. Information was available on local geology and hydrogeology. Substances that are indicators of landfill leachate are regularly measured in boreholes surrounding each site. This information was subsequently used to carry out a risk assessment of possible exposure of local residents to substances via waterborne pathways.

The major pathways for which quantitative monitoring data is needed, therefore, are those that commence with a release to air. For the majority of substances, subsequent inhalation will be the only pathway that needs to be considered. For a subset of substances, exposure via indirect pathways also needs to be considered. These indirect pathways comprise mainly deposition to land or vegetation, followed by consumption of vegetation and soil by cattle, pigs or sheep and subsequent consumption of meat or milk products from exposed animals. These pathways would be more significant for an individual consuming produce grown locally to a particular landfill site such as the sites under consideration in this study. Indirect pathways would be less significant for individuals who consume products from sources located further from a particular landfill site.

The key pathways are listed in Annex 1, Tables 3.1 and 3.3. It was found that data were available to enable risks to be characterised for a number of these pathways – in particular, risks via groundwater and surface water pathways have been studied in detail, and techniques for their assessment are well developed. In contrast, techniques for assessing exposures via airborne pathways are not well developed, and have not been studied in such detail. Consequently, the main potential exposure pathway for which data were lacking was exposure via the dispersion of airborne emissions.

The principal measurement component of the project was therefore designed to provide an assessment of exposure to substances emitted to air from landfill sites. This would need to be based on measurements at or around one or more operational landfill sites. There were a number of ways that this could have been carried out:

- measuring concentrations of substances which might have been released from the landfill sites at properties situated at varying distances in varying directions from landfill sites;

- measuring concentrations of substances released from the landfill sites at the boundary of the sites, and estimating possible exposure of local people on the basis of these measurements;

- measuring/estimating emissions from the landfill site and estimating possible exposure of local people using these measurements.

The key advantages and disadvantages are set out in Table 3.5

Table 3.5 Possible study approaches

Approach	Advantages	Disadvantages
1. Measurement at properties	Gives a measure of actual exposure to substances released from landfill sites Estimates more representative of the overall exposure of the local population	Can not be used to distinguish site contribution from background or from other sites – particular problem for substances with a wide range of sources (e.g. bio-aerosols, fine particulate matter). Only gives data for the specific points at which concentrations are measured Very low detection limits may be needed to obtain meaningful results May increase public concern unnecessarily
2. Measurement at site boundary For approach 2 and 3 there is an issue of accuracy of exposure modelling.	Gives information on the net effect of all emissions and processes on site Can in theory be used to give an estimated source term from the site Can be cross-checked against information on sources and environmental concentrations Less stringent demands on detection limits compared to Approach 1.	Relies on assumptions regarding the source of substances detected More stringent demands on detection limits compared to Approach 3. Measured levels may be an over-estimate of levels emitted from site. Background contribution could be significant for some substances
3. Measurement of total emissions from the site	Based on actual emissions from the site Could draw on ongoing research into emissions from landfill sites	Can not be sure that all sources are included Does not account for fate and behaviour of individual compounds once emitted Measured emissions likely to be moderated by other processes (e.g. surface oxidation of landfill gas; combustion in flare downstream of measurement)

Approach 2 was selected because this approach provides an indication of airborne levels of pollutants from the site as a whole, with minimal interference caused by emissions from other sources. This approach can be used to provide measurement data representative of the highest possible levels of exposure to the local population. The data measured at the boundary provide a worst-case estimate of exposure to airborne pollutants – that is, the highest levels of exposure of local people likely to occur, assuming that people could theoretically experience similar levels of exposure to those measured at the site boundary.

These site boundary measurements were supplemented by on-site measurements and data collection. These were designed to assist in interpreting and verifying the site boundary data and assessment of potential exposure.

The intention was to analyse the data further using a conceptual model of emissions from the site to investigate emissions from the site, and the potential exposure of people located off-site to exposure to the released substances. This approach involved the use of a dispersion model to estimate the emissions from the site that would give rise to the observed site boundary levels. The dispersion model could then be used to estimate the levels at other locations that would result from these emissions. This data analysis component of Approach 2 relied on the quality of the conceptual model and assessment tools. In view of this, the importance of reviewing the reliability of this model and taking into account uncertainties introduced by any inaccuracy of the model was borne in mind during the study.

This review was carried out by cross-checking the results of data analysis against other information where possible. This included comparing estimates of site emissions from different approaches; reviewing the range of substances measured at the site boundary fence against the range of substances detected in landfill gas; reviewing the source gas and emissions measurements made as part of this project against those obtained in other studies; and comparing estimated baseline levels of the substances under consideration against baseline measurements made elsewhere in the UK. This highlighted areas where the conceptual model needed to be revised, or was in some way deficient. As discussed later in the report, these cross-checks demonstrated that the conceptual model did not give a robust representation of emissions from Sites A and B, and therefore could not be relied on to give estimates of exposure at off-site locations. The study conclusions are therefore based solely on the measured levels, although the findings of the modelling analysis are provided in Appendix 9 for the record.

Approach 1 would have introduced substantial uncertainty in interpreting the data, due to the difficulty of establishing the contribution of emissions from the site to measured levels of airborne pollutants. It would also not have been possible to be confident that any derived exposure levels represented a worst-case level. It would also have run the risk of increasing public concern, and discussions indicated it would not have been possible to secure the agreement of any site operator to this approach.

Approach 3 would have relied on the representation of emissions from the landfill site being accurate and complete. Uncertainty in the dispersion of these emissions in the environment would reduce confidence in the results gained by this approach. Also, if emissions could take place from sources other than those measured, this would cast doubt on the reliability of the study results. Approach 3 would also add little to detailed studies of landfill emissions being carried out under research initiatives funded by Defra and others, and as part of the regulatory processes.

4 Experimental investigations

4.1 Introduction

Chapters 1-3 of this report provide the rationale and design basis for the major part of this research study. It is essential that experimental investigations are designed on the basis of a preliminary qualitative, risk assessment. This ensures resources are targeted at characterising the exposure pathways of greatest significance to the risk. The major part of this study therefore was focused on obtaining field data on airborne and deposited concentrations of substances that could be emitted from landfill sites accepting municipal waste.

A further feature of risk assessment practice is the importance of developing an iterative approach (section 1.3 above). In this study, as additional substances were identified during the field work phase, the scope of the analytical study was updated. The conceptual model and risk screening was also revisited after analysis of the site data to test the conceptual model against monitoring data.

4.2 Monitoring strategy

4.2.1 Sample periods and supporting studies

Inhalation exposures can occur through the off-site inhalation of substances emitted from the landfill and transported in air to the point of exposure. This occurs through a complex set of release, environmental transport and inhalation processes that introduce substantial uncertainty to the assessment of exposure at the receptor. A structured air quality assessment methodology was required to assess substance concentrations at various points between the landfill and the receptors being considered (Figures 2.1 and 2.2). These concentrations act as the input for the risk assessment that follows in Chapter 5.

A monitoring strategy was developed by the project team in consultation with the project board members. The monitoring programme was designed to provide information on the concentrations of substances that could potentially be released from landfill sites accepting municipal waste. This required an intensive monitoring programme to provide a detailed and wide-ranging dataset.

It was considered valuable to obtain information on concentrations of airborne pollutants during both the winter and summer, because the make-up, amount and dispersion of substances emitted from landfill sites could be affected by seasonal factors. Addtionally, it was considered valuable to obtain hour-by-hour information on concentrations of airborne pollutants throughout the year. This would allow an assessment of how representative the intensive survey measurements were of concentrations likely to be encountered during the year as a whole. It would also allow specific episodes of high concentrations of airborne pollutants to be investigated where required. A range of monitoring techniques was adopted to permit concentrations to be recorded over different averaging periods (continuous monitoring) and sample durations (discrete monitoring).

So far as possible, monitoring was performed over a time period relevant for the health consequence of interest. The relevant period varied from a few minutes' duration for impacts related to exposure to sulphur dioxide, to sample periods of 72 hours for potentially carcinogenic substances and other substances where the limit of detection had to be very low. The selection of sample durations took into account the following:

(i) Detection limits and measurement reliability needed to be adequate to enable substances to be assessed with the minimum of uncertainty introduced as a result of measurement inaccuracy or lack of sensitivity, so far as could be judged.
(ii) Monitoring was undertaken for a sufficient period to provide representative data.
(iii) It was important to ensure that a cost-effective survey was designed, bearing in mind the above considerations.

The overall study design is shown conceptually in Figure 4.1 The key analytical studies performed were as follows:

- **Continuous measurements/full study periods**.
  Three analysers were located on the north-east boundary of each site for a full year, measuring concentrations of total hydrocarbons, oxides of nitrogen and fine particulate matter (PM_{10}) every 15 minutes. These substances were of interest in their own right, and were also selected as "indicators" of releases from landfill gas, combustion and fugitive dust sources respectively.

- **Continuous measurements/intensive survey periods**.
  The survey included two “one-month” periods of intensive monitoring at each site. During this time, continuous analysers were used to measure boundary fence concentrations of oxides of nitrogen, sulphur dioxide/hydrogen sulphide, total hydrocarbons and PM_{10} at locations to the northeast and south west of each site.

- **Discrete measurements/intensive survey periods**.
  Measurements of a wide range of substances were made during a “one month” period at each site in the winter and a one month period at each site in the summer. Sample durations for VOCs, micro-organisms and fibres were normally of the order of 4 to 8 hours. For toxic organic micropollutants and metals, sample periods were approximately 72 hours.

- **Continuous period averaged measurements**.
  Airborne concentrations of nitrogen dioxide and sulphur dioxide, together with deposition of dust, were measured to give an average value over the intensive survey periods.

The boundary fence measurements described above were supported by a series of additional studies, undertaken to provide information that would aid the interpretation of the monitoring data. These were:

- **Measurements of emissions from landfill gas flare and engines**.
  These were carried out to obtain a direct measurement of emissions from the site from landfill gas combustion plant.

- **Measurements of the trace components of landfill gas.**
  These werecarried out to provide a set of data against which the boundary fence measurements could be compared. Volatile organic compounds detected in significant quantities at the site boundary would be expected to be present in the landfill gas itself. If they were not found in landfill gas, they would not be expected to be present in significant quantities at the boundary fence, unless there were some alternative source of VOCs. This information was used to evaluate the conceptual model used in the project.

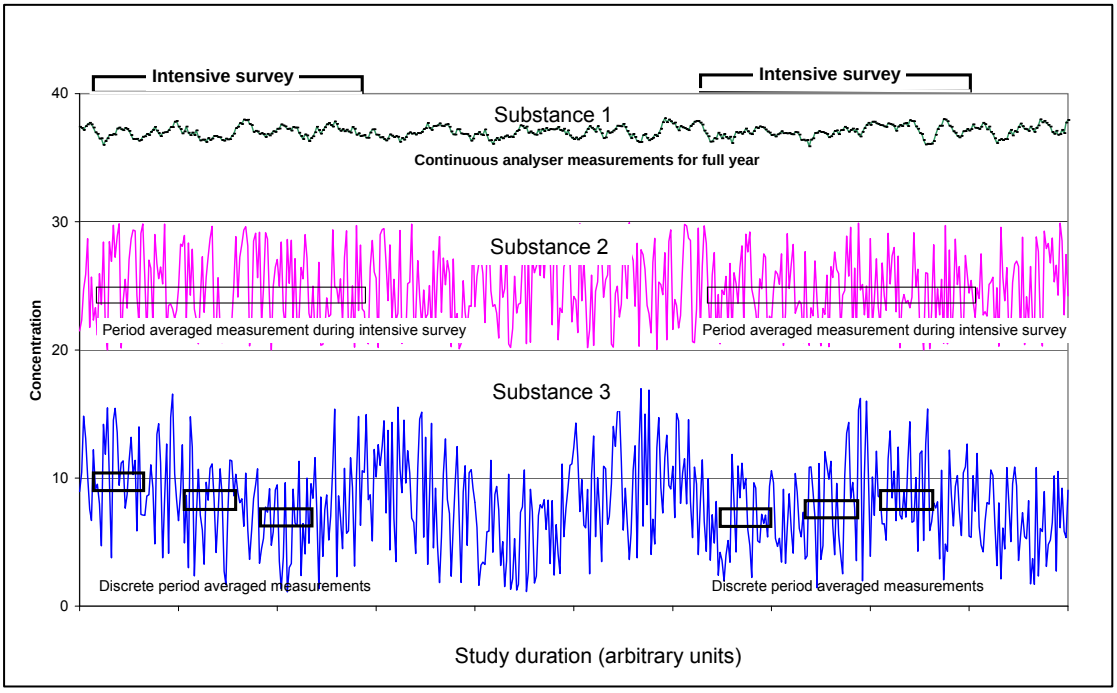
- **Measurements of the rate of emission of methane through the surface of the landfill.**
  These were carried out during both the winter and summer intensive survey periods. The surface emissions measurements were used as a cross-check on the estimated emissions from the site based on the boundary fence data. This was one means of verifying the conceptual model of the site.

- **Measurements of methane at the site boundary and at locations across each site**. This survey was carried out to assist in interpreting the measurements made at the north-east and south-west site boundaries. The survey data allowed the measured concentrations of methane/total hydrocarbons and individual VOCs to be interpreted to give an indication of the highest concentrations that could arise at the site boundary.

- **Measurements of dioxins and furans in soils at the NE and SW perimeters of the site.**
  These measurements were taken to allow the estimated exposure to dioxins and furans via indirect pathways to be verified.

- **Surveys of local farming activities.**
  The aim of these surveys was to establish the local patterns for consumption of produce from nearby farms, and to investigate whether agriculture could act as a vector between the landfill site and the surrounding population.

Figure 4.1 Illustration of measurement sample periods



4.2.2 Substances measured

The substances for analysis were identified from the literature review at the project risk screening stage in consultation with the Environment Agency's National Compliance Assessment Service (NCAS) and Centre for Risk and Forecasting (CRF). The guidance in Environment Agency Technical Guidance Notes M8 and M9 was considered (Environment Agency, 2000a and 2000b). The following substance groups were identified:

Acid gases
The substances under consideration are those resulting from the combustion of landfill gas, and also arising from the use of diesel-engined vehicles at the sites. Consequently, concentrations of nitrogen dioxide and sulphur dioxide were measured.

Toxic organic micropollutants (TOMPS)
There are a total of 75 chlorinated dibenzodioxins and 135 chlorinated dibenzofurans. Human toxicity is associated with dioxins and furans having chlorine present in the 2,3,7 and 8 positions (CDC, 2003). There are 7 dioxins and 10 furans with chlorine in these positions, and these congeners were measured during the course of the study. The combined concentration of dioxins and furans was measured as a toxic equivalent (TEQ) by adding the measured concentration of individual congeners multiplied by a factor reflecting the toxicity of each congener. The factors used for this evaluation were the factors for human health risks current at the time the study was carried out, published by the World Health Organization (WHO, 1998a).

There are a total of 209 polychlorinated biphenyls. The most toxic to humans are the coplanar PCBs, which are those having four or more lateral chlorine atoms and no more than one chlorine atom in the ortho position (CDC, 2003; European Food Safety Authority, 2005). It was these 12 PCBs which were measured in this project. The combined concentration of PCBs was measured as a toxic equivalent by adding the measured concentration of individual congeners multiplied by a factor reflecting the toxicity of each congener. The factors used for this evaluation were those published by the World Health Organization (WHO, 1998a)

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic chemicals made up of hydrogen and carbon in the form of fused benzene rings. More than 600 members of the PAH group have been identified and studied. In this study, the 15 members of the PAH family measured in the UK air quality network were determined. These are the most commonly occurring PAHs in the UK, and includes all PAHs that are classified as probable or possible human carcinogens by the International Agency for Research on Cancer (IARC, 2002).

Volatile organic compounds (VOCs)
Volatile organic compounds include a wide range of substances with potential environmental and health effects. Concentrations of methane and total hydrocarbons were measured continuously to provide an indication of the overall level of landfill gas present in the atmosphere. Concentrations of total hydrocarbons were also measured at locations around the site boundary and at locations across the sites.

The starting-point for identifying other volatile organic compounds to be studied in this project was research into the trace components of landfill gas. The Department of Health published research into the trace components of landfill gas which classified a number of substances as with regard to their developmental toxicity (that is, their potential for causing certain congenital anomalies) (Department of Health, 2001). This work classified substances found in landfill gas, including VOCs, into four groups: chemicals of possible interest; chemicals of less likely interest; chemicals of no/unlikely interest; insufficient data to classify. The VOCs measured during the first phase of monitoring (Winter 2001/02) were the substances in the first, second and fourth groups, as follows (that is, the group of chemicals identified as being no/unlikely interest was not included; see also Chapter 2).

Possible interest: benzene, 1,3-butadiene, carbon disulphide, chloroform, 1,2-dichloroethene, ethylbenzene, formaldehyde, chloromethane, tetrachloroethene, trichloroethylene, chloroethene

Less likely interest: alpha-terpinene, dichlorobenzene, 2-ethyl-1-hexanol, hydrogen sulphide, 2-butanone, toluene, xylenes

Insufficient data: 1,1-dichloroethane, dichlorofluoromethane, ethanethiol, methanethiol, 2-methyl furan, nitromethane

A number of further substances were added to this list in the light of information gained during the literature review phase of the project. These were substances that had been demonstrated as being present in landfill gas at UK landfill sites accepting municipal waste, and which were considered worth including in the study, in view of their toxicological properties. These

substances were dichloromethane, styrene, trimethylbenzene, dimethyl sulphide and dimethyl disulphide.

Levels of this suite of substances were measured in air, and also in landfill gas.

Additionally, screening samples were taken at each site. These samples were analysed to establish the substances present in highest concentration. Although the detection limit of these samples was higher than the detection limits that could be achieved with the targeted analyses, the screen samples provided an indication of whether any other substances were present at concentrations which could be significant. The nature of the screening measurements meant that they were less reliable than the targeted measurements which formed the majority of the survey of VOCs. Consequently, the screening measurements were not used in the interpretation stages of the project,

The range of VOCs to be measured during the second phase of monitoring (Summer 2003) was reviewed in the light of emerging information and the results of the first phase. Research carried out by the Environment Agency (Environment Agency, 2002a) provided a ranking of substances in landfill gas in terms of their potential for adverse health effects. The ten highest priority substances identified in this project were: 1,1,1-trichloroethane; 1,1-dichloroethane; benzene; chlorobenzene; chlorodifluoromethane; chloroethane; dichloromethane; hydrogen sulphide; tetrachloroethene; and chloroethene.

An extended list of VOCs was obtained by combining the list of VOCs measured during the first phase of the project with these ten substances. This gave a range of substances which was too great to determine without taking additional airborne samples. It was therefore decided to reduce the scope of the VOC survey by four substances. The substances selected were 2-butanone, dichlorobenzene, 2-ethylhexanol and alpha-terpinene, on the basis that these had been identified as being of “less likely interest” by the Department of Health (DOH, 2001) and none of them had been detected at significant concentrations during the first phase. Additionally, 2-methylfuran and nitromethane could not be included as they were outside the range of substances that could be detected by the mass spectrometer instrument, following changes to the instrumental technique. These two substances had not been detected during the first phase of monitoring.

Emerging information during the course of the project indicated that arsine and stibine had been identified in landfill gas generated at sites accepting municipal waste at concentrations which could be significant with regard to potential health impacts (Lindberg *et al*., 2001a and 2001b). In view of this, concentrations of arsine and stibine were measured during Phase 2 of the project.

This resulted in the following range of substances which were measured during the second phase of the project:

> 1,1,1-trichloroethane, 1,1-dichloroethane, benzene, 1,2-dichloroethane, chlorobenzene, chloroethane, chloroform, dichloromethane, tetrachloroethene, toluene, ethylbenzene, xylenes, 1,2-dichloroethene, styrene, methanethiol, ethanethiol, chloroethane, chlorodifluoromethane, dichlorodifluoromethane, chloromethane, carbon disulphide, dimethyl sulphide, dimethyl disulphide, 1,3-butadiene, formaldehyde, arsine, stibine

The measurement of levels of trace volatile organic compounds in landfill gas was extended to include additional substances which had been identified as being of greatest significance from the perspective of health effects in Environment Agency research (Environment Agency, 2002a).

Dust and metals

These measurements fell into the following four categories.

- Airborne particulate matter;
- Dust deposition;
- Metal concentrations;

- Mineral fibres concentrations.

The UK air quality standard for airborne particulate matter is set on the basis of measurement of particulate matter with a diameter of 10 microns or less (PM_{10}). It was considered whether the study should additionally or alternatively measure concentrations of a finer fraction of particulate matter – for example, $PM_{2.5}$ or PM_1. A study carried out by the Expert Panel on Air Quality Standards (EPAQS, 2001) indicated that measurements of PM_{10} provided on balance the most useful information for evaluation of health effects. On this basis, concentrations of PM_{10} were measured.

The measurement of dust deposition was carried out to give an indication of the rate of deposition of larger dust particles. These might be generated during waste tipping, excavation, earth moving, placement of daily cover and as a result of associated quarrying activities at Site B.

Metals could be emitted in dusts from waste during tipping; in fugitive gas emissions; and/or in emissions from landfill gas combustion. The metals to be determined were derived from consideration of the Waste Incineration Directive (2000/76/EC). This Directive sets out a suite of 12 metals which could be emitted during the combustion of wastes including municipal waste. Emissions of tin are also commonly added to this list as a substance present in relatively high quantities in municipal waste. While other metals may be released in small quantities, the 12 metals listed in the Waste Incineration Directive were the highest priority substances with regard to their potential effects on health. The full suite of metals comprises antimony, arsenic, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, thallium, tin, vanadium.

Controls on asbestos-bearing wastes mean that concentrations of mineral fibres should not be elevated at the landfill sites. However, as a cross-check, mineral fibres were measured to verify the low concentrations expected to arise.

Bioaerosols
The range of bioaerosols measured in the course of this project was originally defined by reference to organisms commonly found as food contaminants. However, during the first survey at Site A, advice was taken from the Health and Safety Executive on the range of micro-organisms measured during research into concentrations of bioaerosols at materials recycling facilities. This allowed the suite of determinands to be tailored to the species more likely to be encountered in practice at a landfill site accepting MSW. The species measured were as follows:

- Site A Winter (November and December) 2001:
    - Mesophilic aerobes:
    - moulds:
    - yeasts:
    - enterobacteriaceae:
    - endotoxins.

- Site B Winter (January and February) 2002 and Sites A and B Summer 2003:
    - total bacteria (25 ^{o}C and 37 ^{o}C):
    - total fungi and yeasts (25 ^{o}C, 40 ^{o}C):
    - total fungi and yeasts DG18 (25 ^{o}C):
    - gram negative bacteria:
    - endotoxins.

4.3 Analytical methods

The monitoring techniques used in this project were as follows:

- Continuous analyser – typically recording concentrations over averaging times from a few seconds to 24 hours. Three analysers were located on the north-east boundary of each site for a full year, measuring concentrations of total hydrocarbons, oxides of nitrogen and fine particulate matter (PM_{10}). As discussed above, these substances were selected to act as "indicator" species of releases from combustion sources and fugitive sources respectively. The measurements from the full survey period were correlated against the measurements made during the intensive surveys, to provide an indication of likely concentrations of other substances outside the intensive survey periods. The survey also included two one-month periods of intensive monitoring at each landfill site. During this time, continuous analysers were used to measure boundary fence concentrations of oxides of nitrogen, sulphur dioxide/hydrogen sulphide, total hydrocarbons and PM_{10} at locations north-east and south-west of the site.

- Discrete period averaged measurements – these comprised pumped air samples passed through an appropriate retention medium such as a polyurethane or paper filter (for particulate analysis), an adsorbate such as finely divided carbon (for analysis of trace organics), or a liquid (for analysis of soluble substances). The sampling period is determined by considerations such as the need to obtain a sufficient sample. Sample durations were normally of the order of 4 to 8 hours. For toxic organic micropollutants and metals, samples were taken over periods of approximately 72 hours to obtain sufficient sample. Single samples were taken at each location.

- Continuous period averaged measurements – these comprised sampling of materials onto a suitable adsorbate in a passive mode - that is, without active pumping of the air sample. The sampling periods for these measurements covered the one month intensive survey periods. Passive samplers were used to evaluate concentrations of nitrogen dioxide and sulphur dioxide around the perimeter of the sites in question.

- Deposition measurements – these consist of measurements of dust deposited over a period of four weeks. Samples are collected using a concave circular metal plate held horizontally and fitted with a drain and collection vessel to collect material deposited in rainwater.

Monitoring methods, certifications and detection limits are summarised in Table 4.1 (see Annex 1).

Before carrying out the intensive surveys, it was necessary to take all possible steps to ensure that the monitoring techniques to be applied in the project would provide information appropriate to support the investigation. This required an initial evaluation of required instrument detection limits against a preliminary view of exposure benchmarks. This evaluation is set out in Appendix 2.

A method statement for the air quality monitoring programme is provided in Appendix 3.

4.3.1 Trace components of landfill gas

Environment Agency research has developed methods for measuring concentrations of trace components in landfill gas (Environment Agency, 2001). The 2001 study also developed a database of substances likely to be present in landfill gas. For the present project, measurements of the concentrations in landfill gas of the trace volatile organic compounds listed above were made. The substances monitored were those identified as being potentially significant components of landfill gas at the outset of the project.

Additional monitoring was commissioned from the organisation that undertook research for the Environment Agency into methods for sampling trace components of landfill gas. This monitoring was carried out in February and March 2003.

Trace VOCs were sampled by pre-concentration onto dual adsorbent ATD tubes containing two adsorbents; Tenax TA and Spherocarb. Sulfinert ATD tubes were chosen to improve the recovery of labile organo-sulphur compounds. These tubes were thermally desorbed and analysed by GC-MS. Recent research (Environment Agency, 2001) showed that the very high background concentrations of other trace components present in landfill gas can affect the extraction and desorption efficiencies of ATD tubes. In view of this, 2 litre and 0.5 litre samples were taken at each location to improve the likelihood of getting good quality quantification, regardless of variations in trace compound concentrations. The ATD-GC-MS method was covered by UKAS accreditation for benzene, toluene, ethylbenzene, xylenes and chlorinated butadienes, but was not accredited specifically for other VOC compounds.

A number of substances were treated on an individual basis.

Formaldehyde polymerises when heated and is not therefore suited to gas chromatography. A sampling method involving in-situ derivatisation with dinitrophenylhydrazine (DNPH) was used to target formaldehye. The derivativised analytes were desorbed with acetontrile and analysised by High Pressure liquid Chromatography (HPLC) with ultra violet detection, based on USEPA TO-5. This is an established method which has been validated in the field of environmental monitoring, though not UKAS accredited.

Hydrogen Sulphide and Carbon Monoxide were analysed using a real-time hand held analyser. A real time hydrogen sulphide analyser (LMSxi) was used which can detect concentrations down to the parts per million range by electrochemical cell.

Arsenic was measured using a standard activated coconut charcoal sorbent tube, and the value given is for total arsenic. The determination of total inorganic arsenic is by NIOSH method 6001 issue 2 using Inductively Coupled Plasma – Mass spectroscopy (ICP-MS) for measurement.

Mercury was measured using a modified activated coconut charcoal sorbent tube (Frontier Mercury Solid Sorbent Traps), and the value given is for total mercury. These sample tubes were purchased from a specialist source, which guarantees a background level of mercury of 1-2 ng. The methodology to detect total mercury was based on NIOSH method 6009 issue 2 (NIOSH, 1994). The determination of total gaseous mercury is performed by ICP-MS.

Stibene was measured using a pre-treated silica gel tube following NIOSH method 6008. The determination of stibene was carried out using ICP-MS for measurement. This method (NIOSH6008) had not been evaluated for landfill gas and may have detected other antimony compounds.

Results from the measurement were expressed as the total mass of antimony per tube and then converted to an airborne concentration based on flow rates and duration of sampling.

4.3.2 Flare/engine emissions measurements

The substances monitored in emissions from landfill gas engines and flares were determined on the basis of Environment Agency guidance on emissions from these processes (Environment Agency, 2002c and 2002d).

The substances determined were:

Flare: Total VOCs; oxides of nitrogen; sulphur dioxide; carbon monoxide; carbon dioxide; oxygen

Engines: Total VOCs; oxides of nitrogen; sulphur dioxide; carbon monoxide; carbon dioxide; oxygen and dioxins/furans

It was not possible to sample emissions from the flare for determination of concentrations of dioxins and furans for safety reasons due to the open flame and very high temperatures. In-stack measurements of flare emissions are likely to be unrepresentative of final emissions from the flare because combustion and chemical conversion takes place over the full length of the flare. Combustion leading to chemical conversion is also likely to take place in the gases immediately above the flare, before dispersion and cooling of the flue gases quenches the combustion process.

4.3.3 Surface emissions measurements

The survey was carried out according to guidance given by the Environment Agency (Environment Agency, 2003b). A brief description of the survey procedure is given below:

Initially a desk study was carried in order to sub-divide the site into zones consistent with the different characteristics such as permanent capped areas or temporary covered areas. Using a Flame Ionisation Detector (FID), a walkover survey was carried out to identify discrete features or locations of relatively high or low methane emission concentrations within each zone to ensure that the subsequent flux measurement strategy was representative of all areas on the site surface.

Monitoring locations were set out in a grid throughout the zone to obtain full coverage of the area. Based on the results of the walkover survey further monitoring locations were added, if necessary, to obtain readings from intermediate areas which may be contributing to overall site flux in a manner that may not be detected by the grid survey, e.g. fissures in the cap.

A *Research Engineering Autofim FID* was used to measure volatile organic compounds (VOCs). The flux box is of a standard design as recommended by the Environment Agency protocol (Environment Agency, 2001c).

The flux box measurements were taken as follows:

1. FID started up in a safe area following the procedures described in the operating manual. VOC value allowed to stabilize as meter reaches optimum operating conditions. The FID was then tested using a certified zero (0 ppm) control gas, and the meter zeroed to ensure correct relative background concentration of methane.

2. Background readings near to the monitoring location were taken.

3. The flux box was then placed on the ground at the appropriate location and sealed to prevent background methane from entering the box.

4. The FID probe was then connected to the flux box. The taps for the FID connection and for the activated carbon filter were opened and an initial reading was taken.

5. Readings were then taken at regular time intervals until the methane concentration stabilized / dropped or until 30 minutes had elapsed.

The results, recorded in ppm against time, were entered into a spreadsheet for analysis and graphical display.

Data from a measurement location were considered acceptable if the correlation is satisfactory; there were at least five data points used in the correlation; and the change in concentration was greater than zero. Where these criteria were not satisfied, the data could not be used to determine the methane flux and the result was therefore reported as being at the lower detection limit of the method.

The average flux for each zone was derived using the mean of the calculated flux rates that were considered acceptable under the criteria given above. This mean flux density was then multiplied by the area of the zone to give the flux rate from the zone.

The total site flux was the sum of the average flux rates calculated for the monitored zones.

4.3.4 Locating air monitoring stations

As set out in Chapter 1 and 2, a detailed programme of monitoring of airborne pollutants was carried out principally at two locations at each site. These locations were on the north-east boundary and the south-west boundary of each site, because the prevailing wind direction in the United Kingdom is from the south-west. The next most common wind direction is from the north-east. This means that for the majority of the time, one of the two monitoring stations was expected to be upwind of the site, and the other monitoring station would be downwind of the site, giving the best opportunity to establish the contribution of the site to concentrations of airborne pollutants.

During the course of this project, meteorological measurements were made at the two landfill sites under consideration. At Site B, it was found that local climatic conditions resulted in a prevailing wind direction of south-easterly during the course of the measurement programme. Winds from the north-west were also relatively common. The effects of this wind pattern on the interpretation of measured data are discussed later in this chapter.

Following selection of the two sites, detailed consideration was given to the practicalities of locating the air monitoring stations. The monitoring stations needed to be located at points where they would not be disturbed by landfill activities for the duration of the project. It was important that the monitoring stations did not hinder the operation of the sites, or compromise health and safety at the sites – for example, by blocking access routes or resulting in cables being placed across working areas. The key practical constraint to locating the monitoring stations was the need to provide a power supply for the monitoring equipment. The use of mobile generator plant was discounted because of the emissions to air which would result from a generator. This set a practical limit on the location of the monitoring stations due to the length of cable runs from existing power supplies at the site, and safe locations for electrical cables.

The monitoring locations are described in Table 4.2 and are shown schematically in Figures 2.1 and 2.2 above.

Table 4.2 Description of air monitoring locations

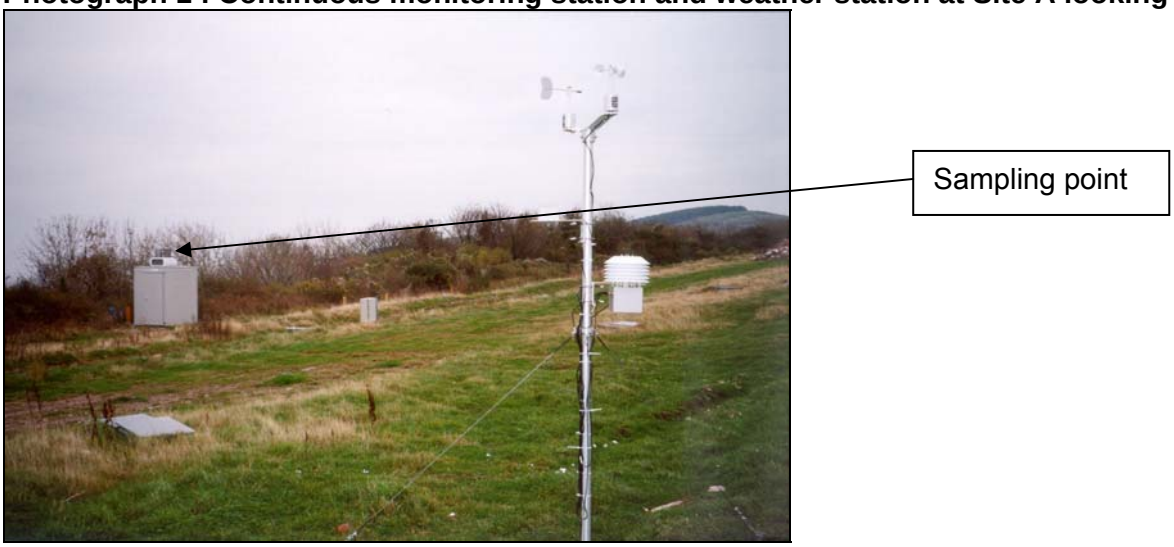
Monitoring station	Description
Site A, north-east	Monitoring station located adjacent to site perimeter road on quarry edge. Location is on north-east boundary of completed area of site. The ground slopes steeply downwards on the west side of the completed area, and very steeply towards residential properties to the north-east of the site boundary at this point The monitoring station location was not ideal as it would not have been directly downwind of emissions from the finished area of Site A under westerly or south-westerly wind conditions. This was considered likely to be the prevailing wind direction from the site, and was borne out by the meteorological measurements made at the site. It was not possible to move the site further to the south because of the need to provide an electrical power supply. However, it was well positioned to measure substances emitted from the finished area under southerly wind conditions, and to measure substances emitted from the completed area, the landfill gas engines and the currently active working area.

Monitoring station	Description
Site A, south-west	Monitoring station located adjacent to the site perimeter road on the quarry edge. Location is above and slightly to the north of the landfill gas engines and standby flare. The quarry edge to the east is a steep cliff face. To the west is undulating farmland leading to scattered properties and a small village. The monitoring station location was not ideal as it would not have been directly upwind of emissions from the finished area of Site A under southerly or south-westerly wind conditions. It was not possible to move the site further to the south because of the need to provide an electrical power supply. However, it was well positioned in view of the location of the completed area and the landfill gas engines.
Site B, north-east	Monitoring station located adjacent to site perimeter road on the north-east boundary of completed area of site. The ground is level in all directions from the monitoring location, with a belt of trees located immediately to the east of the monitoring station. The monitoring station location was as close to the ideal as possible given the layout of Site B. It was well positioned to measure substances emitted from the completed area, the finished area, and the landfill gas flare. It was situated some distance from the active working area for the majority of the project duration, and would not have been directly downwind of the landfill gas engines under southerly or south-westerly wind conditions. This was considered likely to be the prevailing wind direction from the site, although it was recognised that local meteorology could be influenced by the presence of the tree belt. The meteorological measurements made at the site subsequently indicated that the local prevailing wind direction during the course of the project was south-easterly, with a further component of winds from a north-westerly direction.
Site B, south-west	Monitoring station located between the landfill site access road and the minerals crushing/ grading area. The monitoring station was located 250 metres to the east of a trunk road. Further west is predominantly flat farmland and scattered properties. The monitoring station location was well positioned, as it would have been upwind of emissions from all parts of Site B under the expected prevailing wind conditions. The presence of other sources of pollution close to this monitoring station was considered when siting the station and interpreting the measurement data. These sources included the crushing/grading plant, diesel engined vehicles in the minerals processing area, refuse collection vehicles passing to and from the tipping area, and traffic using the trunk road.

The monitoring stations were at fixed points. Because of fluctuations in the wind direction, these were not always directly upwind and downwind of the landfill sites. By measuring the actual wind speed and direction at the sites, it was anticipated that the weather conditions at the time samples were taken could be taken into account. The aim was to use this information to estimate the concentrations of substances released from the sites at locations close to the landfill sites. This is described in more detail in Chapter 5.

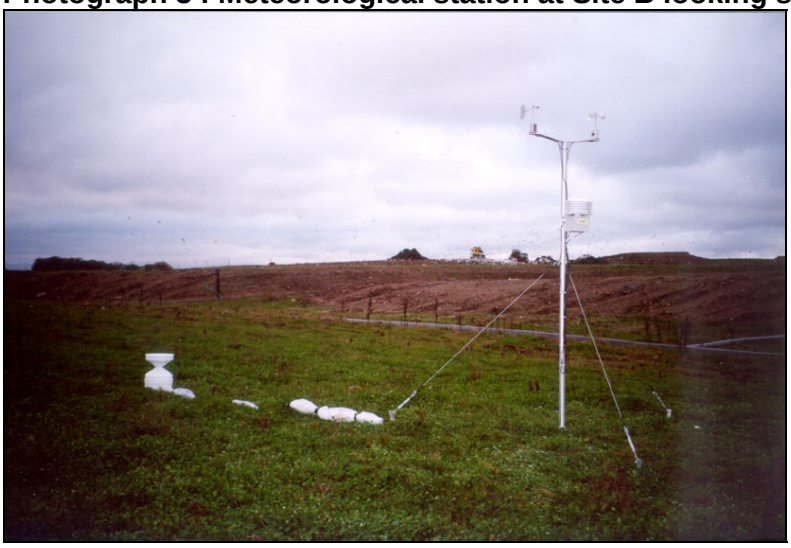
Photographs of the monitoring stations at Sites A and B are given in Photographs 1, 2 and 3 below.

Photograph 1 : Continuous monitoring station and weather station at Site A looking east



Photograph 2 : Continuous monitoring station at Site B looking south-east

Photograph 3 : Meteorological station at Site B looking south-west towards landfill



4.3.5 Landfill gas measurements

Measurements of the trace components of landfill gas were carried out at locations selected to give concentrations typical of the range likely to be emitted from the site. The locations used are set out in Table 4.3. These measurements were made by drawing samples of landfill gas through tubes filled with an appropriate adsorbent substrate, as described in Section 4.2.2.

Table 4.3 Source gas monitoring locations

	Site A	Site B
December 2001 to February 2002	Phase 1 gas collection system; immediately upstream of engine	Site gas collection system; immediately upstream of flare
	Phase 2 gas collection system; immediately upstream of engine	Site gas collection system; immediately upstream of flare
	Landfill surface, Phase 2 (active working area)	Landfill surface, Phase 3 (temporary capped area)
	Leachate well, Phase 2	Landfill surface, Phase 5 (active working area)
		Leachate well, Phase 5 (active working area)
		Landfill surface, Phase 3 (temporary capped area)
February – March 2003	Phase 1 (older completed phase) main into landfill gas compound	Site carrier main feed into landfill gas compound
	Phase 2 (more recent capped phase) main into landfill gas compound	Gas feed into operational engine, downstream of filter unit
	Gas feed into operational engine, downstream of filter unit	Linear gas collection pipework (“Spine main”) serving older part of completed area (Phase 2, north end; most northerly spine)
	Circular gas collection pipework (“Ring main”) serving Phase 2, at older (north) end	Spine main serving newer part of completed area (Phase 4, north end; most southerly spine, labelled STPT7)
	Ring main serving Phase 2, at more recent (south) end	Spine main serving capped area (Phase 5, labelled STPT9)

Measurements were carried out of the flux of landfill gas through the surface of the site. Landfill gas can be released from parts of the site which are not connected to the landfill gas collection network, or from parts of the site where gas extraction is not completely effective. Other factors being equal, surface emissions of landfill gas would be expected to be relatively low from surfaces with a specifically designed and installed impermeable cap, and relatively high from surfaces without a cap designed to current standards, or from cracked surfaces. For measurement of surface emissions, each site was divided into four zones described in Table 4.4 below. The sampling areas were not the same for the winter and summer surveys, because the landfill had evolved over this period. For example, temporary capping of some areas had been completed, and the active area had moved. Consequently, the second survey was carried out at locations that were most similar in age and capping to those sampled during the first survey.

There were areas of the site which could not be monitored for access and safety reasons – for example, parts of the active tipping areas, and parts of the site with steep slopes or unstable surfaces. The total fluxes for each zone and for the site have been calculated based on average flux from the sampled area within each zone.

The winter monitoring survey at Site A was undertaken between 19th – 20th December 2001, the summer survey between the 28th – 30th July 2003. The winter survey at Site B was undertaken between 22nd – 23rd January 2002, the summer survey between the 21st – 23rd July 2003.

Table 4.4 Description of zones

Zone	Description	Zone size (m^2)	
		Winter '01/'02	Summer '03
Site A Permanent cap	Completed capped area, with grass cover.	10,600	10,600
Site A Permanent cap side slope	Sloping side of the competed cap area, with grass cover.	13,800	10,800[1]
Site A Temporary cap	Semi-restored area. HDPE cap and 1m of clay cover.	30,500	22,900[2]
Site A Active area	Active tipping face and surrounding area	14,800	20,000
Site B Permanent cap	Completed capped area, with grass cover.	4,300	4,300
Site B Temporary cap Side slope	Sloping side of the temporary cap area. HDPE cap and 1m of clay cover	11,000	11,000
Site B Temporary cap	Semi-restored area. HDPE cap sheets not welded.	89,000	19,400[3]
Site B Active area	Active tipping face and surrounding area	21,600	14,700

[1]A section of the side slope monitored during the winter survey had a liner laid over it. Waste was being filled against the slope. This meant that the zone areas monitored during the two surveys were not identical.
[2]There were two sections of temporary cap at the site during the summer. The surface area of the sampled section is given in the table. The total temporary capped zone area was 53,400 m^2
[3] There were two areas of temporary cap at the site during the summer. The area of the zone sampled is given in the table. The nature of the capping on the second temporary capped area was similar to the capping on the side slope. The surface area of the second zone, including the side slope is 73,100 m^2. The monitoring data from the side slope was used to represent the whole area.

The survey technique is designed for capped areas, and may not provide reliable data for uncapped areas such as the active tipping area.

Each of the site zones identified by the desk study was traversed in a systematic manner using a hand held portable flame ionisation detector (FID). The FID probe inlet was held as close to the surface as possible (<5cm). Features such as surface fissures, monitoring wells, gas collection pipework and leachate wells were also scanned using the FID. Any locations which were identified as having particularly high methane emissions were marked using poles for subsequent monitoring during the flux box survey.

4.3.6 Practical issues

This project provided a number of insights into measurement of airborne pollutants around landfill sites.

- To take reliable measurements of metals and TOMPS (such as dioxins and furans), or to use continuous monitoring instrumentation, a reliable and safe power supply is needed. This can present considerable financial and practical demands if the monitoring is to be

carried out away from available sources of power. These will need to be borne in mind when considering installing an air monitoring station. The cost of cabling may be budgeted at around £25 per metre of cabling required for a cable run of more than 100 metres (2001 prices).

- Reliable operation of continuous monitoring instrumentation requires skilled and experienced operators. Operators should be familiar with the operating procedures and QA/QC requirements of the national air monitoring networks. Many organisations will have experience of operating the instruments used in national monitoring networks. Relatively few organisations have experience of using continuous methane/total hydrocarbon analysers at the low concentrations required for assessing population exposure. This experience can, if required, be obtained "on the job" with suitable mentoring, but this may result in some down-time during the initial phases of a project.

- Consistent measurements of methane/total hydrocarbons using continuous instrumentation is difficult to achieve in practice, even for experienced operators. Project managers should allow for a higher level of instrument downtime than would be the case for other instruments. Measurements using more widely used instruments such as continuous PM_{10}, NO_x and sulphur dioxide monitors can be carried out with less down-time – 90 per cent or higher availability should be readily achievable following a commissioning phase. However, this study indicated that there is no need for further, continuous monitoring to be carried out at the two sites under consideration in this project. Continuous monitoring may, however, be appropriate at other sites, such as sites located in urban areas or close to other sources of pollution; sites accepting wastes other than municipal waste; sites with high concentrations of sulphur containing compounds in landfill gas; or sites with more extensive landfill gas combustion plant.

- Measuring individual VOCs with sufficient resolution required detection limits of the order of 0.01 $\mu g/m^3$ to 0.1 $\mu g/m^3$. This is likely to require specialist laboratory equipment. Using a GC-MS system at its limit of detection in this way means that it is likely that some loss of samples will occur, usually because of excessive moisture on a sample tube. Monitoring programmes should be designed with this in mind.

- One potentially appropriate approach to measurement of trace VOCs in air at a landfill sites would be to carry out a walkover survey of the site with a hand-held FID instrument. This survey can be used to identify areas where concentrations of methane/total hydrocarbons are relatively high. Samples can be taken at these locations for laboratory analysis for trace VOCs.

- The detailed surface emissions measurements carried out for this project were of limited value. The surface emissions were dominated by releases from the active working area, from gas and leachate wells, and from individual joints and cracks in the landfill surface. The measured emissions were strongly dependent on whether these joints and cracks were sampled in the survey. The surface emissions measurements could not in any case be used to measure emissions from gas and leachate wells.

4.3.7 Landfill gas modelling

To support the study, a model of landfill gas generation was developed for each site. The Environment Agency's GasSim version 1.02 model was used to provide a quantitative estimate of landfill gas generation at each site. The model used information on the site design together with the quantities and type of waste accepted at the site. The model output is an estimate of the quantity of landfill gas produced at each site. The GasSim model records are provided in Appendix 7. The landfill gas forecasts are shown in Annex 1 in Table 4.5 (overall gas generation rates) and Table 4.6 (forecast generation rate of trace components of landfill gas).

The landfill gas generation rate at Site B predicted using GasSim was significantly lower than the metered landfill gas generation rate. The metered gas generation rate during March – May 2002 was 1200 m^3 per hour, approximately 70 per cent higher than the GasSim forecast. In view of this, further evaluation of emissions of trace substances was based on the metered rate of production of landfill gas, rather than the GasSim forecast value.

4.3.8 Farm Surveys

Surveys of local farming activities were carried out. The aim of this was to establish the local patterns for consumption of farm produce from the vicinity of the sites, and to investigate any practices or circumstances which could influence the role of agriculture as a vector between the landfill site and the surrounding population. One farm located within 2 km of each landfill site and two farms located between 2 to 7 km of each landfill site were surveyed.

The surveys were undertaken in January 2002 and, as a result of the timing, livestock farmers were obliged to modify their normal practices to comply with Foot and Mouth Disease (FMD) restrictions. All livestock farmers questioned had previously used the local auction to market virtually all of their livestock. Animals bought in for fattening were usually also sourced from the auction. Under the restrictions, most farmers were sending livestock direct to slaughterhouses across the country whenever possible. Two of the farmers interviewed had responded to the restrictions by selling some or all of their stock to a local butcher.

For the purposes of the assessment, the area surrounding the studied landfill sites was split into two zones. The first was within a two kilometre radius of the landfill centre point. The second was between two and seven kilometre radius. A number of farm businesses within these zones were identified using the Yellow Pages. Of those farmers who were willing to be surveyed, two farms were selected for the inner zone and one for the outer for each of the landfill sites. Farmers were advised that the interview was for research being conducted on behalf of the Environment Agency.

For each farm business, the assessment consisted of an interview and a short inspection of the farm holding. A questionnaire was used as an aide-memoire by the interviewer, but the farmers themselves were not provided with this questionnaire. The interviews were not strictly limited to the topics listed within the questionnaire. Some farm holdings straddle the two kilometre boundary. Where this was the case a distinction was made between the land and farm operations within each zone.

Following the visits to each farm holding and the farmer interviews, the interviewer assessed the potential pathways offered by the farming activites for landfill emissions to be transmitted to local populations.

The survey results are summarised in Chapter 5, and the full report is provided in Appendix 6.

4.4 Measurement schedule

The schedule of measurements carried out is set out in Table 4.7.

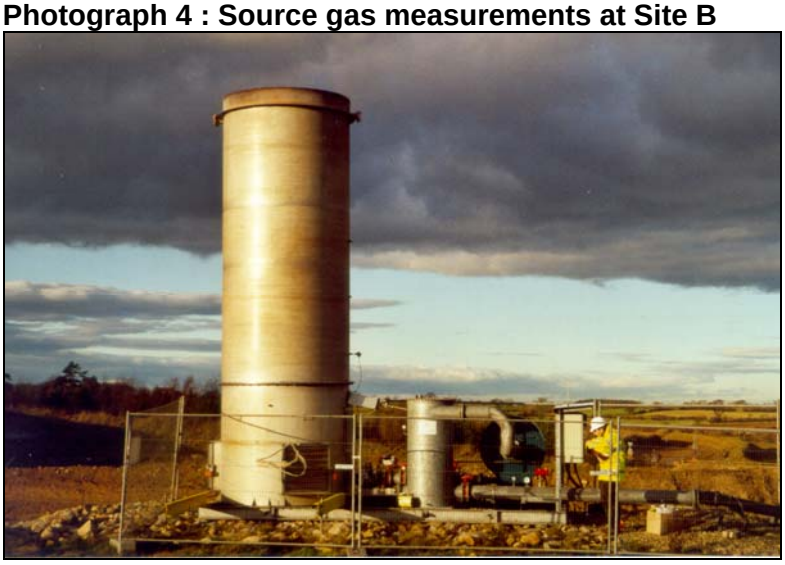
Table 4.7 Measurements carried out for this project

Measurement	Locations	Survey Duration	Survey pattern	Total number of samples (both sites)
NO_x, VOCs, PM_{10} + cabins (1 location 2 sites, 12 months)	North-east site boundary	1 year	Continuous monitoring at 15 minute intervals	
NO_x, VOCs, PM_{10} (additional location, 2 sites, 1 month)	South-west site boundary	1 month in summer 1 month in winter	Continuous monitoring at 15 minute intervals	
SO_2, H_2S, (2 locations, 2 sites, 1 month)	North-east site boundary; south-west site boundary		Continuous monitoring at 15 minute intervals	
Dust deposition gauges	North-east site boundary; south-west site boundary		1 monthly mean measurement per location in summer 1 monthly mean measurement per location in winter	8
Particulates and metals (high flow pumps)	North-east site boundary; south-west site boundary		14 per location in summer 14 per location in winter	112
Particulates and metals (battery operated pumps)	At tipping face		14 per location in summer 14 per location in winter	56
Total particulates on battery operated pumps	Between site and quarry at Site B only		8 per location in summer 8 per location in winter	16
Dioxins and furans	North-east site boundary; south-west site boundary		8 per location in summer 8 per location in winter	64
PCBs	North-east site boundary; south-west site boundary		8 per location in summer 8 per location in winter	64
PAHs	North-east site boundary; south-west site boundary		8 per location in summer 8 per location in winter	64
VOC semi-quantitative screens on tenax by GC/MS	North-east site boundary; south-west site boundary		14 per location in summer 14 per location in winter	112
Target VOCs on tenax tubes by GC/MS	North-east site boundary; south-west site boundary		14 per location in summer 14 per location in winter	112
Target VOCs on Molecular Sieve substrate by GC/MS	North-east site boundary; south-west site boundary		8 per location in summer 8 per location in winter	55
Micro-organisms on sterile filters	North-east site boundary; south-west site boundary; At tipping face		14 per location in summer 14 per location in winter	168
Sulphur dioxide and nitrogen dioxide diffusion tubes	North-east site boundary; south-west site boundary		1 monthly mean measurement per location in summer 1 monthly mean measurement per location in winter	8
1,3-butadiene on XAD-2 tube by GC/MS	North-east site boundary; south-west site boundary		14 per location in summer 14 per location in winter	112
Formaldehyde on treated carbon tube by GC/MS	North-east site boundary; south-west site boundary		4 per location in summer Winter measurements not used because limit of detection was too high to give useful data compared to level of potential concern (Environment Agency, 2010b)	16
Mineral fibres	North-east site boundary; south-west site boundary		4 per location in summer 4 per location in winter	32
Arsine and stibine	North-east site boundary; south-west site boundary		4 per location in summer only	16

Measurement	Locations	Survey Duration	Survey pattern	Total number of samples (both sites)
Engine Emission Sampling - Particulate Matter; Metals; PCBs and PAHs; dioxins and furans; Total VOCs; Hydrogen Chloride; Sulphur dioxide; Nitrogen dioxide; Carbon monoxide	Engine (Site A)	1 day	Particulate matter: 2 samples Metals: 1 sample PCBs: 1 sample PAHs: 1 sample Dioxins and furans: 1 sample Total VOCs: continuous 1 hour Hydrogen Chloride: 1 sample Sulphur dioxide: continuous 1 hour Nitrogen dioxide: continuous 1 hour Carbon monoxide: continuous 1 hour	
Flare Emission Sampling - Total VOCs; Hydrogen Chloride; Sulphur dioxide; Nitrogen dioxide; Carbon monoxide	Flare (Site B)	1 day	Total VOCs: continuous 1 hour Hydrogen Chloride: 1 sample Sulphur dioxide: continuous 1 hour Nitrogen dioxide: continuous 1 hour Carbon monoxide: continuous 1 hour	
Soils and herbage sampling and analysis	North-east site boundary; south-west site boundary	1 month in winter	4 per location in winter at Site A (Discontinued and replaced with national survey data)	8
Methane emissions from landfill surface by flux box method	As specified in Environment Agency guidance	2 days in summer 2 days in winter	Survey of 4 zones in winter; survey of 4 zones in summer;	16 zones
Speciated VOC measurements in landfill gas by GC/MS	2 surface emissions; 2 LFG vents; 2 from feed upstream of flare/engine	1 day in winter	6 during one "flux box" campaign	12
Further speciated VOC measurements in air by GC/MS	Variable: locations where the highest concentrations of methane measured in site walkover survey	2 days in winter	Two measurements at each of five locations	20
Further speciated VOC measurements in landfill gas by GC/MS	Four points in landfill gas collection system	1 day in winter	Four measurements at each of four locations	32

Photograph 4 shows source gas measurements being carried out at Site B

Photograph 4 : Source gas measurements at Site B



The majority of the sampling and monitoring work was carried out successfully. However, the following exceptions occurred where difficulties were encountered with continuous analysers, sampling equipment or laboratory analysis:

- It was found that the most difficult VOC to measure and report with reasonable validity was dichloromethane, which had significant and highly variable blank concentrations. This meant that dichloromethane concentrations were non-determinate during the winter

survey. Procedures were improved for the summer survey, allowing positive detections to be obtained.

- The presence of excessive moisture on the sample tube meant that analysis could not be completed for the following samples taken for determination of VOCs:
  Tenax tube sample taken on 14 December 2001 at Site A
  Molecular sieve tube samples taken on 5, 7, 8 and 11 February 2002 at Site B
  Molecular sieve tube sample taken on 24 July 2003 at Site A
  Tenax tube samples taken on 26, 27 and 30 July 2003 at Site B

- A molecular sieve tube used to take a sample on 31 January 2002 at Site B was found to be faulty.

- The GC-MS instrument failed during the analysis of a molecular sieve sample taken on 1 February 2004.

- 18 out of the 28 endotoxin samples taken at Site A during the winter survey could not be determined.

Data capture rates for the continuous monitoring instrumentation are set out in Table 4.8 (see Annex 1). The data capture rates are compared to the mean rates for the UK automated network. The information in Table 4.8 indicates that measured concentrations performed well by comparison with the UK automated network. The exception was oxides of nitrogen and hydrocarbons measured at Site A in 2002. As with any complex equipment, problems are most likely to arise during and immediately after installation. This was the case with these analysers. The principal difficulties encountered were with data interpretation from the hydrocarbon analysers, and with occasional malfunctions of the data collection equipment.

4.5 Presenting data and managing uncertainty

The complexity of the landfill processes was summarised in section 1.2. This complexity forces a series of uncertainties on any data set from landfill monitoring. These uncertainties are an inevitable consequence of evaluating a heterogenous environmental system. Uncertainties in the data in this report are presented in two ways. Firstly, an estimated uncertainty range is provided for each value. This is in the form of a estimated confidence range expressed as a factor (e.g. 20%) or numerical interval (e.g. ± 5 $\mu g/m^3$) for each individual value. The confidence range covers the estimated uncertainty in the measurement and takes account of sampling and analytical uncertainty, together with uncertainties introduced by the data analysis methods used. For substances which were not detected, a limit of detection is shown. This is the highest concentration that could be present without giving an unambiguous determination.

The sites were selected to be typical of typical UK landfill sites accepting predominantly municipal waste at the time of the survey. However, every landfill site has unique features, and so the findings of this study may not be directly applicable to other landfill sites. Landfill practices have undergone significant change during and after the survey period. It is also important to bear in mind that the measurements made during the course of this project represent a snapshot of the situation at the sites under the operational and environmental conditions prevalent at the time of the survey. The approach to data analysis described in Chapter 5 below was designed to develop the measurements for application to a wider range of circumstances.

For measured values, the limit of detection is in most cases imposed by the analytical method. As discussed below, in the case of some measurements of dichloromethane, a higher limit of detection was imposed by the presence of detectable concentrations of a substance on sample blanks. This means that it is not possible to say whether an observed amount of the substance at this level was already present on the sample medium before sampling started, or was collected during the sampling.

The second approach to describing confidence in measured values and other data considers the data "Pedigree." The "Pedigree" is a description of the reliability of the information from which numerical data have been derived (Funtowicz and Ravetz, 1990). It goes beyond the numerical evaluations described below, to consider the following aspects of the quality of information (derived from van der Sluijs *et al.*., 2001):

- Proxy – is the value based on a direct measurement of the parameter in question, or on some other measurement which is correlated more or less well with the parameter?
- Empirical basis – is the value based on a large number of field measurements, a smaller number of field measurements, modelled values, estimates or speculation?
- Methodological rigour – is the data obtained using best practice, widely used approaches, laboratory or research tools, or is no information provided on these methods?
- Validation – can the data be cross-checked extensively, to a limited or indirect extent, or not at all?

The pedigree of the measured data was estimated by scoring the values between 0 and 4 on the above four aspects, using the framework described by van der Sluijs *et al.*. (2001). The key inputs to each set of measurements were identified, and the Pedigree was established from the lowest score for any of these key inputs. A score of 0 – 4 was described as "poor", 5 – 8 "moderate"; 9 – 12 "good" and 13 – 16 "very good".

Table 4.9 sets out the data pedigree for the air pathway measurements.

Table 4.9 : Pedigree of air pathway measurements

Substance	Pedigree
Metals	Very Good (13)
Dioxins and furans/PAHs/PCBs	Very Good (13)
VOCs (except as noted below)	Good (10)
1,3-butadiene and formaldehyde	Good (10)
Micro-organisms	Moderate (8)
Fibres	Good (12)
Arsine/Stibene	Moderate (7)
PM_{10} (continuous analyser)	Very Good (15)
Oxides of nitrogen (continuous analyser)	Very Good (15)
Sulphur dioxide (continuous analyser)	Very Good (13)
Hydrogen sulphide (continuous analyser)	Good (12)
Methane/total hydrocarbons (continuous analyser)	Good (9)
Non-methane hydrocarbons (continuous analyser)	Moderate (6)
Walkover survey with methane analyser	Good (9)
Surface emissions measurements	Moderate (5)

4.6 Results of the experimental investigation

The suite of substances monitored is set out in Tables 4.10 to 4.21 in Annex 1. The method statement for the monitoring survey is set out in Appendix 3, and the methods used are summarised in Section 4.2.2. The monitoring methods were based on established UK and international protocols, where these were available. Appendix 3 sets out the sampling and analytical techniques used for the airborne sampling and analysis; the surface emissions monitoring; engine and flare emissions monitoring; and source gas testing. It also sets out the

working plans used to carry out the measurements; and the method used for rectification of continuous monitoring data to account for drift in zero and baseline.

Detailed data for all measurements are provided in Appendix 8.

4.6.1 Continuous monitoring data

Tables 4.10 and 4.11 provide a summary of the continuous analyser measurements at Sites A and B respectively (see Annex 1). Levels of six substances/groups are set out in these tables (oxides of nitrogen, nitrogen dioxide, sulphur dioxide, hydrocarbons, PM_{10} and hydrogen sulphide). All measured levels in both 2002 and 2003 were in compliance with the relevant Health Criteria Values where applicable, with the exception of PM10 levels at Site A in 2003. This is discussed further in Chapter 5.

Methane/hydrocarbons episodes
Peaks and troughs were observed in the measured methane and total hydrocarbon concentrations. Periods when methane levels are at their highest are referred to as "episodes." These were investigated by considering the variation of methane and total hydrocarbon concentrations with changes in air pressure and wind direction. Figures 4.2, 4.3 and 4.4 show three example methane episodes.

Figure 4.2 Methane episode at Site A, north-east boundary, December 2001

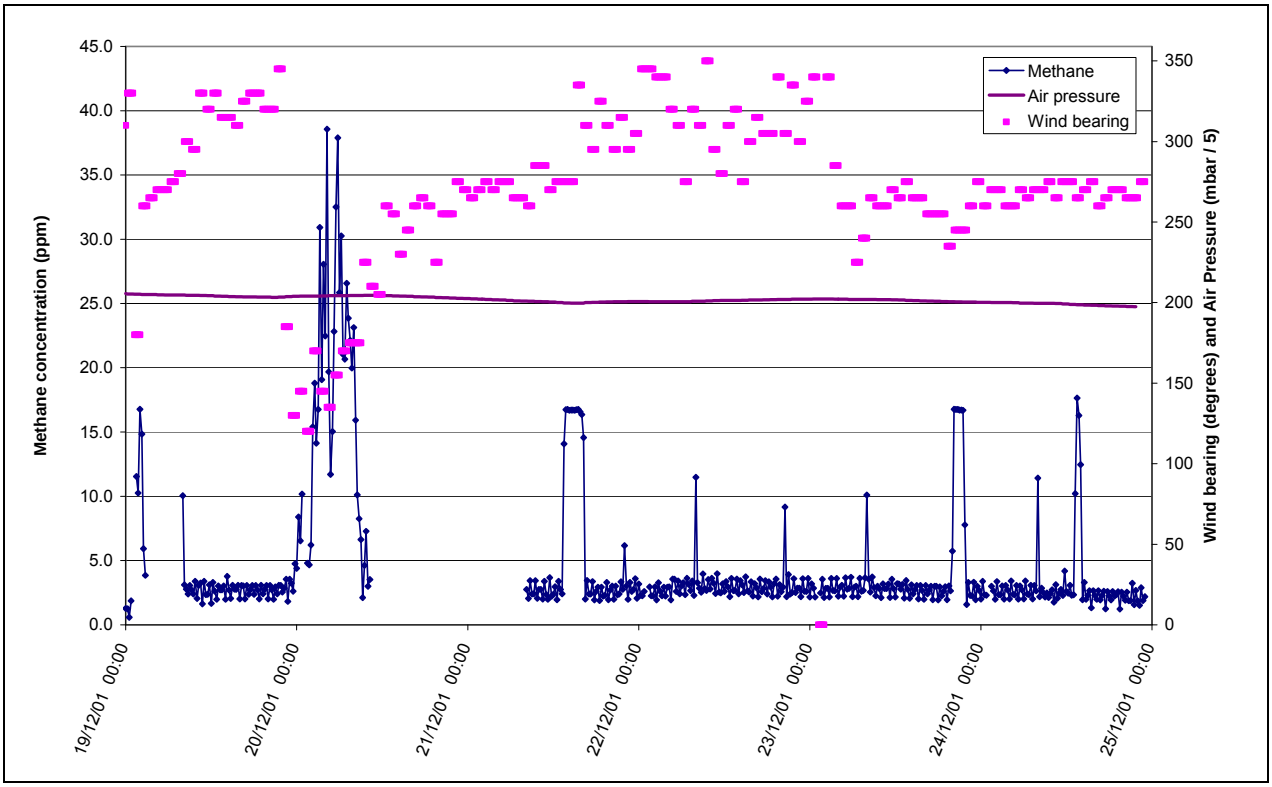


Figure 4.3 Methane episode at Site B, north-east boundary, June 2003

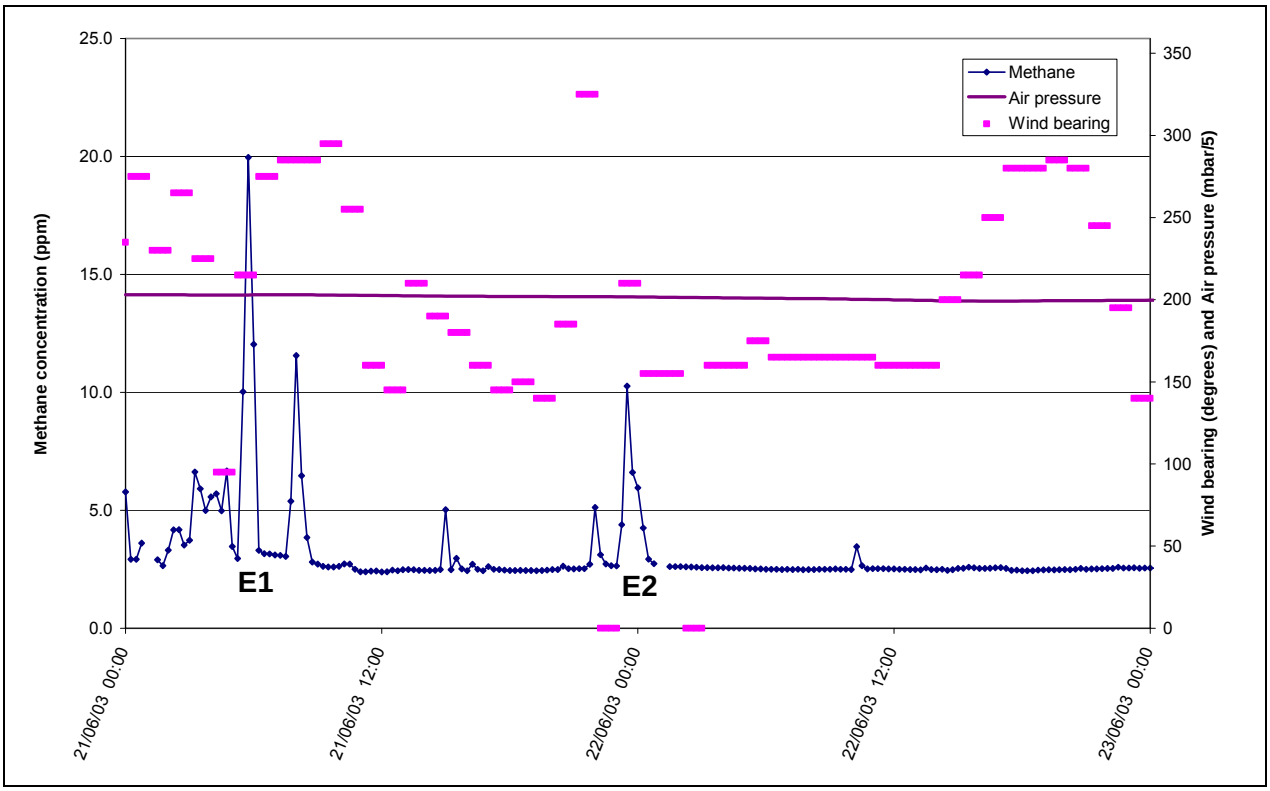
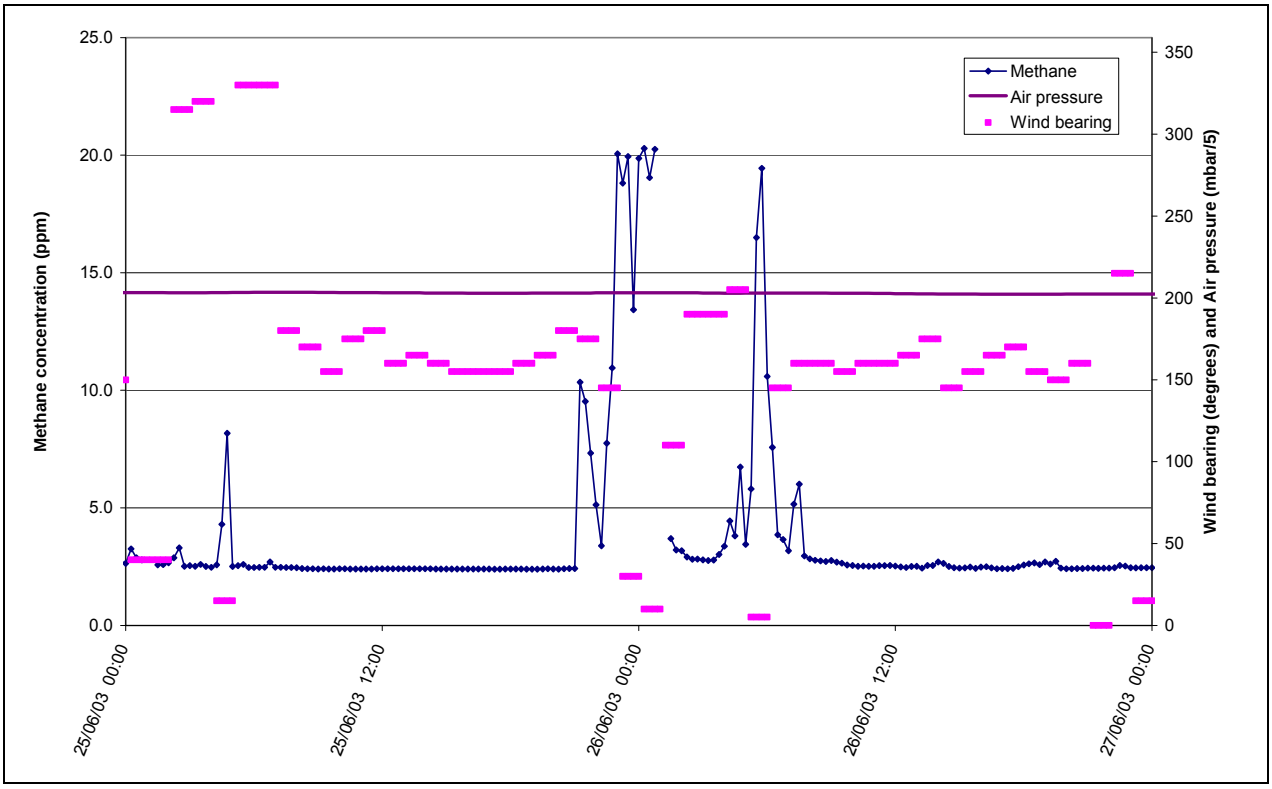


Figure 4.4 Methane episode at Site B, north-east boundary, June 2003



The methane episode shown in Figure 4.2 began when the wind direction backed from north-westerly to south-easterly. There were no significant changes in air pressure during the course of the episode. The concentration then dropped as the wind direction veered to westerly. This

suggests that the source of this episode was the active area which was located south-east of the monitor during this period.

During the period shown in Figure 4.3, the active working area was located between 150 and 225 degrees (approximately south-east to south-west) from the continuous monitor. There were no significant changes in air pressure during this period. Episodes on 21 June 06:00 to 07:00 (E1) and on 21 June 23 23:00 to 22 June 00:30 (E2) correspond to a change in wind bearing to this sector

The episodes shown in Figures 4.2 and 4.3 demonstrate the effect of changes in wind bearing on measured methane concentrations. As the wind blows from the site towards the monitor (wind bearing of 100° to 200°), a peak in measured concentrations of methane was observed. Before and after this period, when the wind blows from a different direction, relatively low concentrations of methane are observed.

Figure 4.4 demonstrates that other factors can also be significant. In this case, an increase in the methane concentrations is observed which is not due to the wind blowing from the site. The three peaks in measured methane levels shown in Figure 4.4 all occured during periods when the wind was coming from the north-east. The active area of the landfill was located south-east to south-west of the monitor at this time, suggesting that wind direction is not a primary influence on the occurrence of these episodes. There were no significant changes in air pressure during this period. However, on the occasions when high methane levels were recorded, the wind speed dropped to less than 0.2 metres per second, suggesting that this episode is likely to have been caused wholly or partly by low wind speeds during the period of the episode. This may have resulted in poor dispersion of emissions from the site.

4.6.2 Discrete air quality measurements

Tables 4.12 and 4.13 in Annex 1 provide a summary of the discrete air quality measurements recorded at Sites A and B respectively. These measurements were obtained using the methods described in Section 4.2.2. These tables provide a summary of between 14 and 65 measurements of approximately 80 substances. Tables 4.12 and 4.13 provide data for the datasets from the two monitoring locations at each site combined. The individual measurements are provided in Volume 2 Appendix 8.

4.6.3 Source gas measurements

Tables 4.14 and 4.15 set out the source gas measurement data (see Annex 1). These measurements were obtained using the methods described in Section 4.2.2. The numbers of samples taken are set out in Table 4.14, with the measured levels of 71 substances summarised in Table 4.15.

4.6.4 Surface emissions measurements

Table 4.16 (Annex 1) sets out the results of the surface emissions measurements. The data are presented for each site broken down into four distinct areas, during the winter and summer intensive survey periods. There are significant differences between different areas, and between the winter and summer periods. These are discussed further in Chapter 5.

4.6.5 On-site methane and airborne VOCs survey

Site walkover surveys were carried out to identify the variation in levels of methane in the air across the site. Five locations were identified at each site, at which levels of methane were higher than the typical levels. Additional air sampling for individual VOCs was carried out at these

locations, referred to as A1 to A5 (site A) and B1 to B5 (site B). The substances to be sampled were selected from three sources:

(a) Those substances identified as being of highest significance from the winter survey
(b) The ten substances identified as being of greatest significance in research carried out for the Environment Agency (Environment Agency, 2002a).
(c) Substances which had emerged as potential issues since the commencement of the project.

This gave a total of 18 substances. Tables 4.17 and 4.18 (Annex 1) set out the results of the monitoring carried out at these points.

4.6.6 Flare/engine emissions measurements

Measurements of emissions from the landfill gas flare and engines are set out in Table 4.19 (Annex 1). Measurements were made of emissions of volatile organic compounds, oxides of nitrogen, sulphur dioxide, carbon monoxide, carbon dioxide and dioxins and furans together with other relevant parameters.

4.6.7 Measurements at the tipping face

The measured concentrations of metals and micro-organisms at the tipping face are set out in Tables 4.20 and 4.21 (Annex 1).

4.6.8 Meteorological measurements

Weather conditions were measured at each site. A summary of the meteorological measurements is given in Table 4.22 (Annex 1). Wind roses for the two sites are given in Figures 4.5 and 4.6 below.

The prevailing wind direction at Site A was observed to be from the south-west, typical of meteorological conditions at most locations in the UK. The wind direction at Site B was more variable but the prevailing direction was from the south-east, rather than the south-west. There was also a relatively strong component of wind from the north-west.

It is possible that the north-south alignment of the tree belt may have resulted in an increased prevalence of southerly and northerly winds, at the expense of south-westerly winds. The presence of the tree belt was considered as a factor in the location of the monitoring stations during the planning stage of the project. The meteorological monitoring station was located as far from the tree belt as practicable, without encroaching on any areas of the landfill likely to be disturbed during the study.

The observed wind pattern at Site B has implications for the interpretation of the monitoring data collected, which are discussed in Chapter 5.

Figure 4.5 Wind rose for Site A

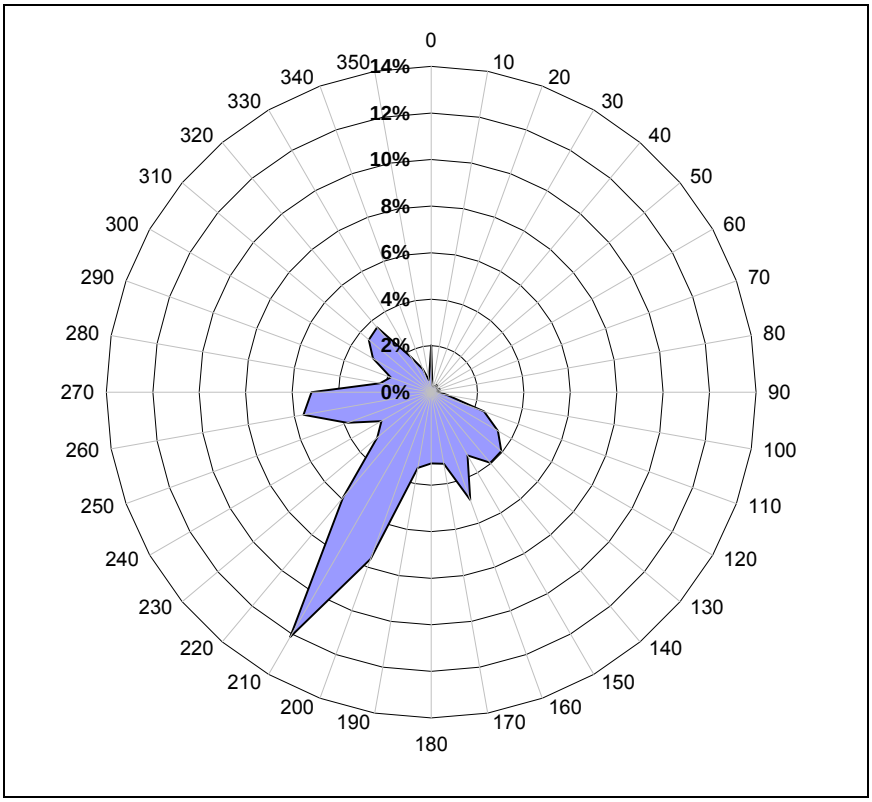
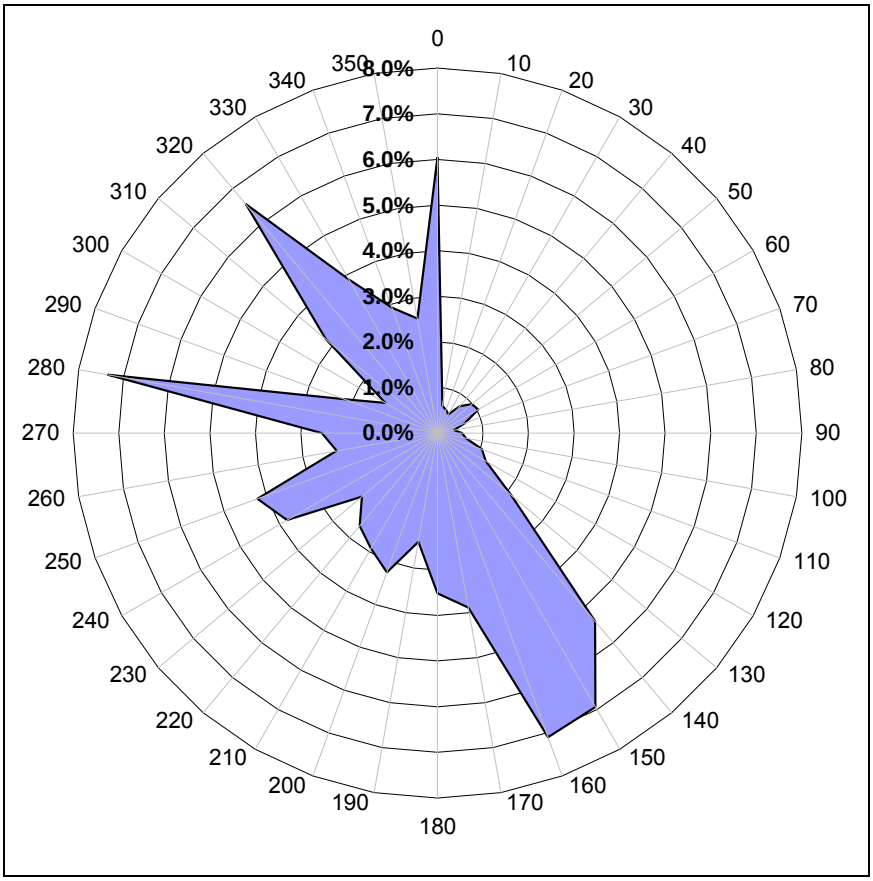


Figure 4.6 Wind rose for Site B



4.6.9 Leachate quality data

As discussed in Chapters 1 and 2, existing information on leachate and groundwater quality was used to support the Groundwater Risk Assessment. Data on approximately 30 substances are set out in Table 4.23 in Annex 1. The information was taken from a review of the health and environmental effects of waste management carried out on behalf of Defra (Defra, 2004a). At Site B, this was supplemented by site measurements for arsenic, chlorides, chromium, copper, lead, nickel and zinc.

4.7 Measurement data quality checks

A number of cross-checks on the quality of data produced in the course of the project were built into the study. These checks allowed the measured values to be evaluated to establish their validity.

The following cross-checks were carried out on the measured data:

1. Substances measured in source gas were compared with a national database of substances in landfill gas. Major discrepancies with this database would suggest that the landfill sites are not typical of UK sites accepting municipal waste and/or that there were problems with the analytical measurements.

2. Substances detected at the site boundary were compared with those detected in landfill gas.

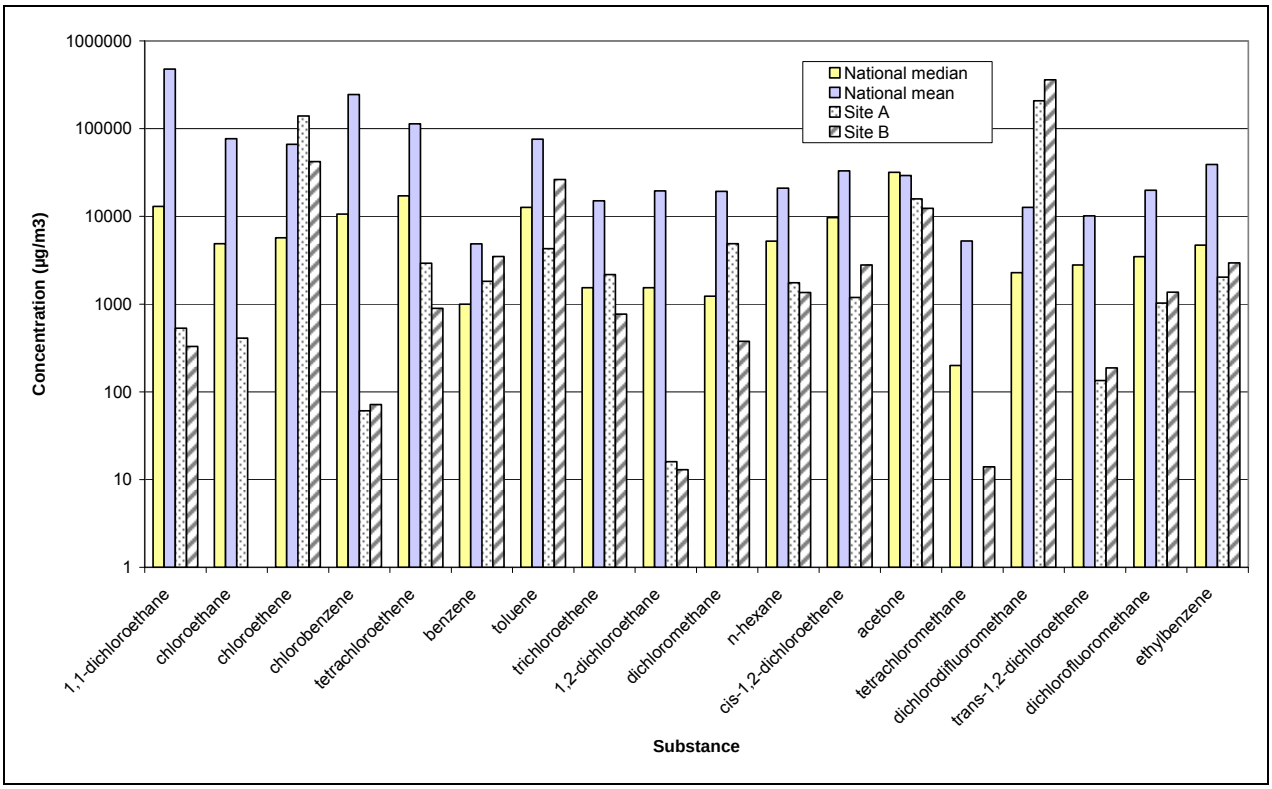
3. Measured concentrations of total hydrocarbons at the boundary fence were evaluated against the measured surface emissions. A correspondence between these two data sets would be expected.

4. The congener profile of dioxins measured at the boundary fence was evaluated to determine whether the pattern of dioxins and furans was representative of waste-related processes.

4.7.1 Comparison of source gas concentrations with national database

Figure 4.7 provides a comparison of source gas concentrations with the concentrations of substances in the national landfill gas database assembled for the Environment Agency (Environment Agency, 2002).

Figure 4.7 Comparison of measured source gas concentrations against national database



Inspection of Figure 4.7 indicated good agreement between the national database and concentrations measured at Sites A and B for chloroethene, benzene, toluene, trichloroethene and acetone.

Adequate agreement was observed for tetrachloroethene, dichloromethane, n-hexane, 1,2-dichloroethene, dichlorofluoromethane and ethylbenzene

Concentrations at Site A and Site B were observed to be lower than the national data for chloroethane, chlorobenzene, 1,2-dichloroethane and tetrachloromethane

Concentrations at Site A and Site B were observed to be high relative to the national data for dichlorodifluoromethane

Bearing in mind the wide variations in concentrations of trace components of landfill gas from site to site, it is concluded that the trace components of landfill gas at Sites A and B are broadly typical of those observed at other sites accepting municipal waste in the UK.

4.7.2 Comparison of site boundary and landfill gas measurements

Almost all the substances which were detected at the site boundary were also detected in landfill gas, except for chloroform, chloromethane and methanethiol (Site A), and methanethiol (Site B). These substances were not detected in the landfill gas. Also, the measured site boundary concentrations of formaldehyde at Site B were higher than would be expected given the relatively low concentrations recorded in the landfill gas. These observations indicate that there may possibly be other local sources of chloroform, chloromethane, methanethiol and formaldehyde which contributed to the measured levels at the site boundary.

4.7.3 Estimated total hydrocarbon emissions

Measured total hydrocarbon concentrations and measured surface emissions during the summer and winter surveys are set out in Table 4.24 below This average value does not represent a specific emission but is provided to give an indication of typical estimated release rates of substances associated with landfill gas.

Table 4.24 : Measured total hydrocarbon concentrations and surface emissions

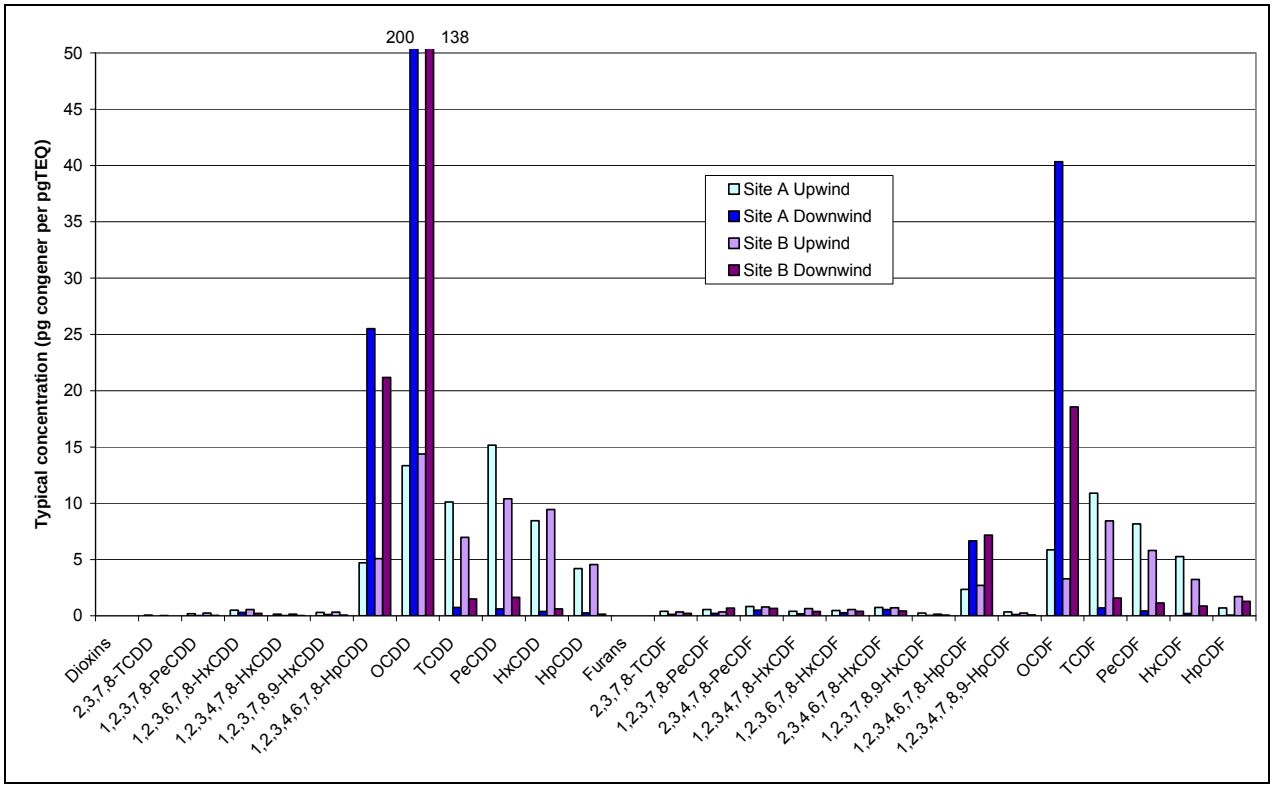
Period	Total surface emissions from flux box measurements	Measured THC (North-east)	Measured THC (South-west)
Site A Winter	76 mg carbon/s	7.2 ppm	No data
Site A Summer	7090 mg carbon /s	3.1 ppm	1.7 ppm
Site B Winter	630 mg carbon /s	2.8 ppm	2.5 ppm
Site B Summer	794 mg carbon /s	3.6 ppm	2.6 ppm

There are significant differences in the estimated total surface emissions from the different sites and from winter to summer surveys shown in Table 4.24. These differences are not reflected by similar changes in measured total hydrocarbon concentrations. In particular, the relatively high surface emissions at Site A during the summer survey was not reflected in high measured concentrations of total hydrocarbons. This may be indicative of shortcomings in the surface emissions measurements, as the majority of surface emissions tend to occur at specific locations on the landfill surface – for example, cracks, fissures or joints in temporary caps; gas vents or leachate wells. A significant proportion of emissions take place from locations which cannot be measured using the flux box technique, and therefore, the estimated surface emissions could be a significant under-estimate of the total releases from the landfill surface.

4.7.4 Investigation of dioxin and furan congener profile in air

The profile of dioxin congeners in air upwind and downwind of the sites at the time of measurement was investigated to determine whether there was any change to the dioxin congener profile could be observed which might be characteristic of the effect of the landfill sites. The average congener profile upwind and downwind of the two sites is shown in Figure 4.8.

Figure 4.8 Dioxin and furan congener profile upwind and downwind of Sites A and B



The changes in congener profile at Site A can be seen by the differences between the first two columns in each set (light blue and dark blue columns). The changes in congener profile at Site B can be seen by the differences between the third and fourth columns in each set (lilac and dark purple columns). The sites appear to be associated with an increase in 1,2,3,4,6,7,8-heptachloro dibenzo dioxin and octachloro dibenzo dioxin, together with the equivalent furan congeners, 1,2,3,4,6,7,8-heptachloro dibenzo furan and octachloro dibenzo dioxin. For reference, the median concentration measured overall at Site A was 15 fgTEQ/m^3.

The median concentration measured at Site B was 19 fgTEQ/m^3, although a single high value of 1839 fgTEQ/m^3 was recorded at Site B. A typical UK rural background concentration was estimated to be 10 fgTEQ/m^3, and a typical urban background level was estimated to be 40 fgTEQ/m^3 (Defra, 2004b). This value was subject to detailed further investigation with the site and laboratory personnel, and with the landfill site operator. No reason was found to doubt its veracity, other than the magnitude of the recorded value. No unusual wastes were being received or unusual activities being undertaken at the site at the time of the sample which could have given rise to the high value.

The observed congener profile is not representative of wood combustion or ferrous metals manufacture, in which furans tend to predominate over dioxins. Dioxins and furans from chemicals manufacturing typically shows higher concentrations of 1,2,3,7,8-pentachloro dibenzo dioxin, which were not observed at Sites A and B. Emissions from petrol-engined vehicles running on unleaded fuel have been found to have relatively high concentrations of 1,2,3,4,6,7,8-heptachloro dibenzo dioxin and octachloro dibenzo dioxin. These congeners are also produced from the decomposition of pentachlorophenol, used as a herbicide and in wood treatment. Road traffic and pesticide residues are therefore possible sources of the baseline concentrations of dioxin observed at the upwind monitoring stations.

The two dioxin congeners highlighted above (1,2,3,4,6,7,8-heptachloro dibenzo dioxin and octachloro dibenzo dioxin) are characteristic of emissions from many chemical manufacturing

and combustion sources, including municipal waste incinerators (Fiedler *et al*., 2000). This suggests that they might possibly be associated with emissions from waste management facilities at which combustion of waste, materials derived from waste, or gaseous fuels takes place. Concentrations of these substances were found to be higher downwind of the two sites than upwind. This suggests that a possible source of these congeners could be landfill gas combustion. Increases in the observed concentration of 1,2,3,4,6,7,8-heptachloro dibenzo dioxin and octachloro dibenzo dioxin account for the majority of the increase in dioxin concentrations expressed as a toxic equivalent between the upwind and downwind locations.

The project was able to draw on measurements made at the two landfill sites as part of a national survey of dioxins and furans in soils and herbage. The measured values at locations on the south-east and north-west boundaries of the two landfill sites are shown in Figure 4.9 (soils measurements) and Figure 4.10 (herbage measurements). The changes in congener profile from south west to north-east of Site A can be seen by the differences between the first pair of columns (light blue and dark blue columns). The changes in congener profile in herbage from south west to north-east of Site B can be seen by the differences between the third and fourth columns (lilac and dark purple columns). No dioxins and furans were detected in soils to the north-east of Site B.

Figure 4.9 Dioxin and furan congener profile in soils south-west and north-east of Sites A and B

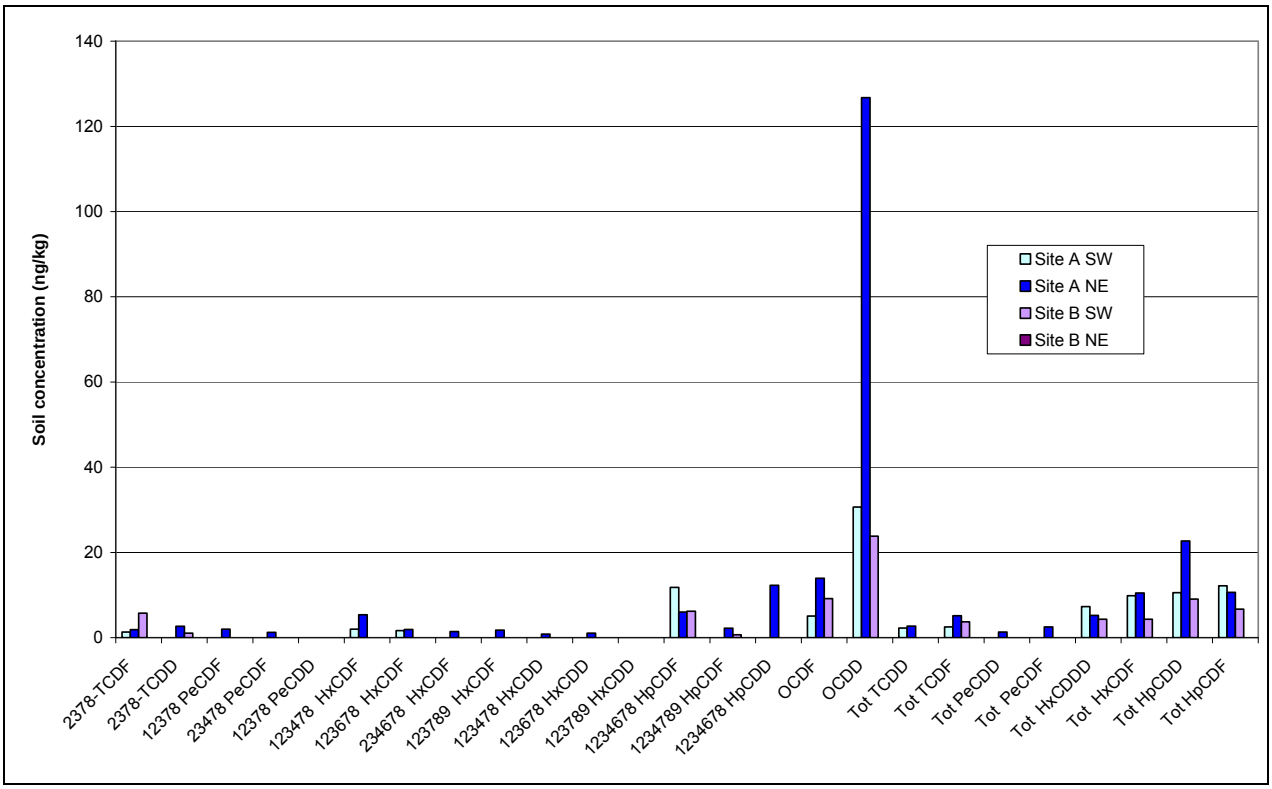
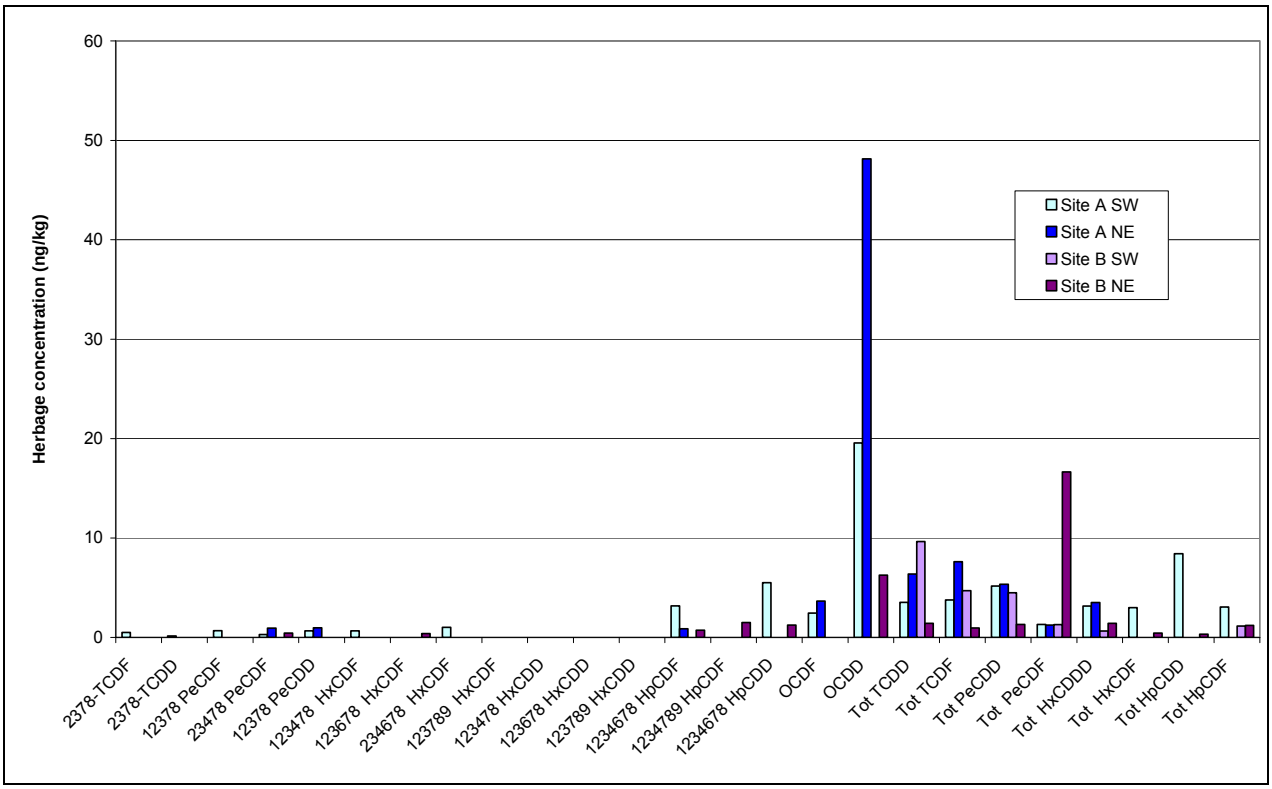


Figure 4.10 Dioxin and furan congener profile in herbage south-west and north-east of Sites A and B



The data in Figures 4.9 and 4.10 shows higher levels of octachloro dibenzo dioxin and octachloro dibenzo furan to the north-east of Site A than to the south-west. A similar increase was observed in herbage at Site B, but dioxins and furans were not present at detectable levels in soils on the north-east side of Site B. Higher levels to the north-east would be consistent with the observed wind patterns at site A, with the most predominant wind directions being from the south-east and from the north-west. Winds from these directions would not be expected to result in deposition of any released substances in soils to the north-east of the site.

One of the measured levels of airborne dioxins and furans at Site B was much higher than any other at either Site A or Site B. The measured levels of dioxins and furans in soils indicate that the single high measurement of airborne dioxins and furans recorded at Site B is not a common occurrence. The long-term picture of dioxin emissions from Site B is likely to be better represented by the data with the single high value excluded.

4.7.5 Summary

The trace composition of landfill gas at both sites A and B is typical of that found at municipal waste landfill sites in the UK. The levels of volatile organic compounds measured at the site boundaries (Table 4.12 and Table 4.13 in Annex 1) are consistent with the measured levels of trace gas components during a site walkover survey (Table 4.17 and Table 4.18 in Annex 1). The range of substances detected at the site boundary is consistent with the range of substances present in landfill gas with a limited number of exceptions.

The profile of dioxins and furans recorded at Sites A and B is consistent with emissions from a combustion process such as landfill gas engine or flare.

5 Risk assessment

5.1 Introduction and approach

This study has been conducted as far as is possible by reference to Government guidelines on environmental risk assessment and management (Figure 1.3). The experimental approach to identifying substances under consideration at various locations on site and at the site boundaries of study sites A and B is described in Chapter 4. The data produced from the investigations reported in Chapter 4 provide concentrations of substances under consideration at various locations and in the air, soils, plants, landfill gas and in emissions from gas combustion plant.

The principal concern of this study has been to assess the significance of public exposure to substances emitted from landfills (section 1.1). The significance of the risk posed by exposure to these substances at locations of increasing distance away from the in-place waste can be evaluated by reference to a health criteria value (HCV). This is consistent with the conventional approach to assessing the environmental significance of chemicals by comparing measured concentrations to appropriate criteria at various exposure points. In this study, we have considered the significance of substance concentrations measured:

(i) in the source gas;
(ii) as landfill surface or combustion plant emissions; and
(iii) at the landfill boundaries.

As described in Section 2, the study considered all potential exposure pathways at the outset. Following a screening stage, it was identified that the key exposure pathway requiring assessment as part of this study was an assessment of airborne exposures.

The first stage in the assessment of risk was to compare the measured concentrations of substances against one percent of the health criteria value (HCV) used in this study (section 5.3). A value of one per cent of the HCV was selected to be a very conservative basis for screening out substances from further analysis. The HCVs themselves are specified with a significant margin of safety for threshold substances, and to represent a minimal risk to health for non-threshold substances. Selecting one per cent of the HCVs as the basis for prioritising substances for further investigation gives a high degree of confidence that there will be no significant health risks associated with the substances screened out at this stage.

Additionally, the measured concentrations at the landfill boundaries may include a component due to emissions from other sources. The proportion of the measured concentration which is likely to be attributable to the landfill site depends on the prevalence of other sources of each of the substances considered. The landfill site is likely to account for most or all of the measured levels of less common substances which are characteristic of emissions from landfill sites, such as chlorinated VOCs. However, emissions from the landfill sites will account for a smaller proportion of the measured levels of more widespread substances such as lead or nitrogen dioxide.

In the event that exposure occurs at a level above the HCV, it does not necessarily follow that an adverse health effect would arise. This is an indicator that more detailed investigation is required.

5.2 Quantitative Risk Modelling

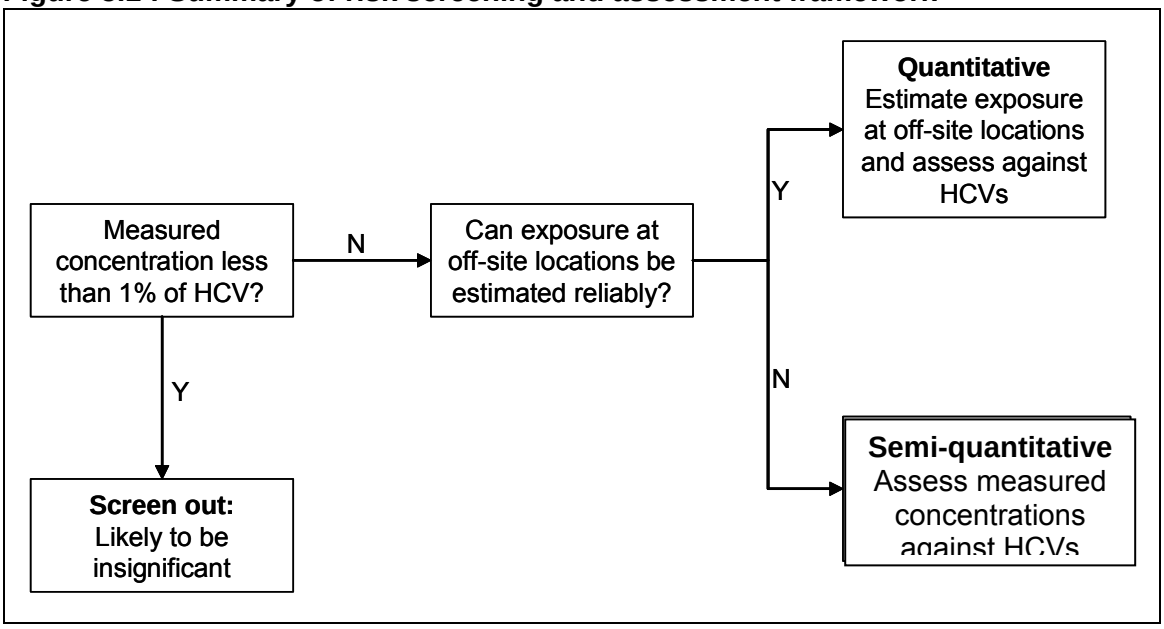
The original intention was to carry out an exposure modelling study to evaluate exposure at the nearest off-site human receptor (Figures 2.1 and 2.2)

This exposure study was based on dispersion modelling and required a reliable conceptual model of emissions from the site. An integral part of the exposure study was to assess whether the conceptual model provided an adequate representation of emissions from the site. If the conceptual model was found to be inadequate, exposure would be estimated by assessing the boundary fence measurements.

Chemicals were categorised on the basis of a comparison of the measured or modelled levels to the HCVs, and the potential significance of the health effects on which the HCVs were based.

The assessment method is summarised in Figure 5.1.

Figure 5.1 : Summary of risk screening and assessment framework



A dispersion modelling approach was developed for the quantitative exposure and risk assessment component of the study. This is discussed in more detail in Appendix 9 which includes the dispersion modelling study method, the provisional findings and the evaluation of reliability of the exposure estimates. It was found that the estimated release rates obtained using the modelling approach were in general likely to be significant over-estimates of the true release rates by one to two orders of magnitude. Further cross-checks were carried out, including consideration of the trace substances measured in source gas; comparison of estimated and measured emission rates from combustion sources; comparison of estimated background concentrations against national records; and review of site walkover measurements of the trace components of landfill gas. These indicated that the modelling method was not satisfactory.

It was concluded that the conceptual model needed to form the basis of this study was not adequate. In view of this, potential exposures were estimated using the semi-quantitative approach on the basis of the boundary fence measurements. Chemicals were categorised on the basis of a comparison of the measured levels to the HCVs, and the potential significance of the health effects on which the HCVs were based.

5.3 Health criteria values

In carrying out an environmental risk assessment, it is common practice to establish criteria which can be used to establish whether a particular effect or exposure could be significant. For the purposes of this project, a set of concentrations was identified, above which risks to human health might be deemed to be more significant and warrant further investigation. These concentration values were referred to as “Health criteria values”, or HCVs.

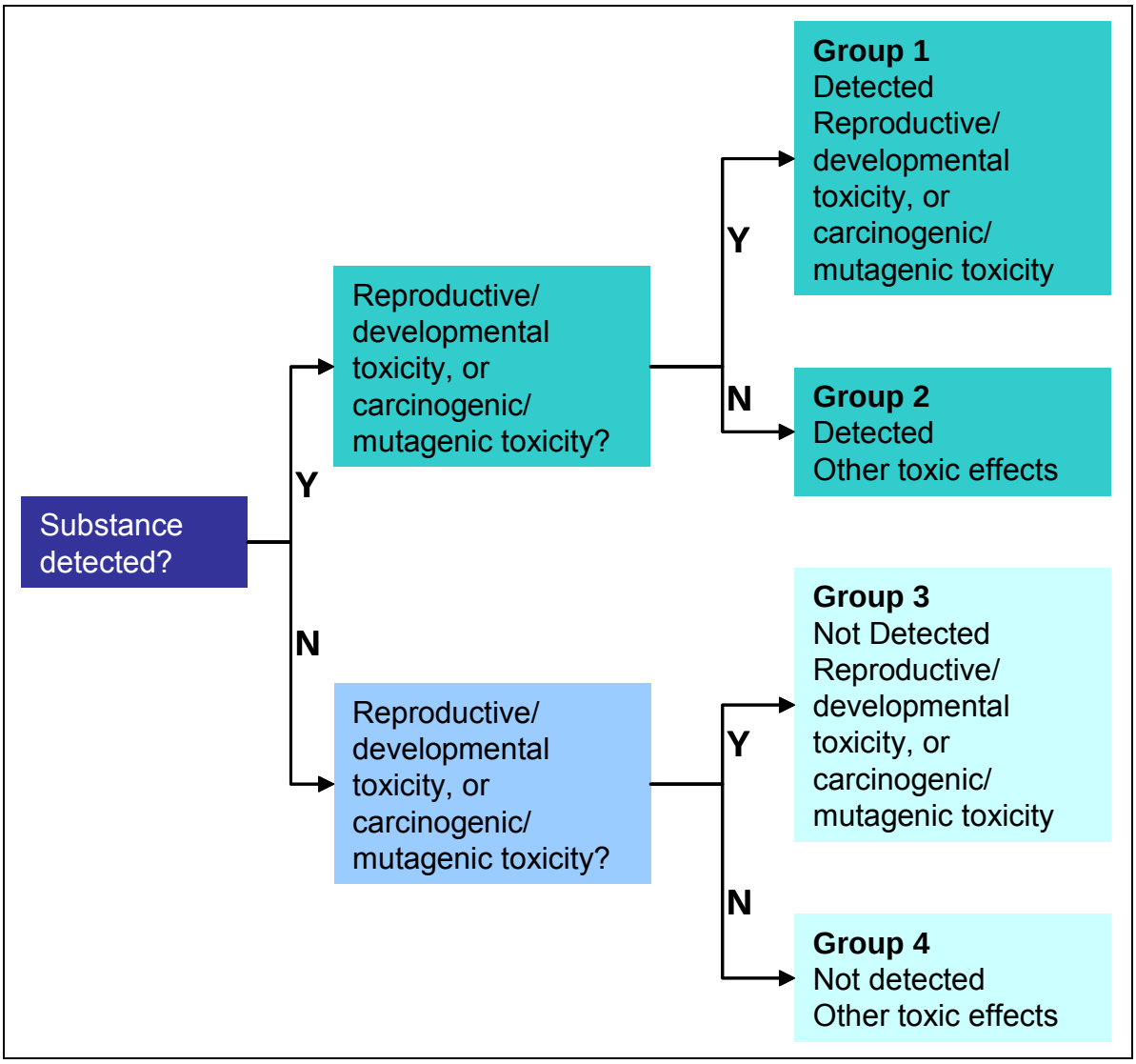
The term "*Health criteria value*" is a generic term developed in the context of soil contamination. It indicates a level of exposure to the contaminant in soil which is either without significant risk over a lifetime (in the case of contaminants with threshold toxicity) or which presents a minimal risk to health (in the case of contaminants with non-threshold toxicity). Health criteria valuesare specified on an appropriate basis for contaminants with a threshold for their effects (tolerable daily intake values) and without a threshold for their effects (index doses). However, and in addition, it is recommended that it is still necessary to reduce exposures from all routes to non-threshold contaminants to as low as reasonably practicable (ALARP), so that even the minimal risk represented by the health criteria is further diminished (see Defra/Environment Agency 2002a for further information on health criteria values for soil contaminants).

The HCVs derived for use in this project were derived on a precautionary basis intended to protect vulnerable individuals, such as for example the unborn child, the elderly, or those with pre-existing ill health. Consequently, the HCVs are over-protective for the general population

Having identified the priority compounds, the next step was to determine and agree the health criteria values (HCVs) for these compounds. A scheme for establishing health criteria values was developed and applied to the substances under consideration. Where available, the HCVs were taken from standards, guidelines and other recommendations produced by authoritative national and international organisations. The approach adopted here for the identification of health criteria values is consistent with the principles summarised in the Government's contaminated land guidance, CLR 9, (Defra and Environment Agency, 2002). CLR9 is concerned with selecting health criteria in the context of contaminated soils whereas the HCVs derived here primarily relate to inhalation exposures from landfill sites. This means that the information sources used to derive the health criteria are likely to differ. However, despite these differences, a similar overall approach to identifying health criteria values was adopted.

Those compounds for which no appropriate HCV was available were prioritised following the procedure set out in Figure 5.2. Because of the large number of chemicals that may be emitted from landfills, there was a need to prioritise substances to focus on those of highest priority from a toxicological perspective. This was achieved through the development of a prioritisation framework which took into account the toxicity of compounds and their presence at landfill sites. A limited budget was available for derivation of *"de-novo"* HCVs by reference to original research. This budget was sufficient for the derivation of HCVs for the seven highest priority substances. Further detail on the methodology used and prioritised substances is presented in Appendix 10.

Figure 5.2 Prioritisation framework of chemicals for the derivation of HCVs



HCVs were established on the basis of the following principles:

- In establishing the most appropriate HCV for each compound, a value was chosen which would be protective of all health endpoints, based on current knowledge. Uncertainty factors were used to account for data gaps where appropriate (IGHRC, 1999).

- Inherent in the derivation of HCVs is the principle that the specified intake is of minimal risk to health over a lifetime and is protective of the whole population, including the unborn child.

- HCVs set on the basis of non-threshold effects follow the approach outlined in CLR9, in which an "Index Dose" is identified. An index dose is defined as "*a dose which can be considered to present a minimal human health risk from a single source of exposure to that contaminant.*" For substances which do not have a threshold for their effects, CLR9 goes on to state: *"However, and in addition, efforts are still needed to reduce exposures from all routes to as low as reasonably practicable, so that even this minimal risk is further diminished".*

- Attention was given to ensuring that HCVs were appropriate to the route of exposure for the substances under consideration.

- HCVs for threshold substances were also based on the approach set out in CLR9. When dealing with threshold effects, the intake that can be tolerated without adverse effect is referred to as the tolerable daily intake (TDI). This is defined as "*an estimate of the amount of a contaminant, expressed on a body weight basis that can be ingested daily over a lifetime without appreciable health risk."* Where necessary, the CLR9 approach was adapted to be applicable to the derivation of HCVs for airborne exposure rather than soil contamination.

- Health criteria values were expressed in the most appropriate terms. For example, where the main exposure arises from airborne pollutants, these may be expressed as an air concentration (e.g. micrograms per cubic metre, $\mu g/m^3$) and/or as an intake per unit body weight per unit time (e.g µg/kg bw/day).

- The assignment of non-genotoxic agents with evidence of carcinogenic potential in animals was considered on a case-by-case basis.

The Committee on Toxicity has subsequently reviewed some of the HCVs developed for this study. Further detail is provided in the COT Second Statement on Landfill Sites (COT, 2010).

In order to identify the most appropriate HCVs a brief toxicological assessment was undertaken to identify the most appropriate values derived by authoritative organisations. Expert judgement was used in selecting the most appropriate values for this project, but in general the following reference sources were used in descending order of priority.

1. Soil guideline values as derived for contaminated land (DEFRA/Environment Agency, 2002-3). Supporting documentation for the derivation of Soil Guideline Values is contained in the "TOX" series of reports (Defra/Environment Agency, 2002-3). The TOX reports consider exposures via all potentially significant routes. For substances which have been covered by the TOX series of reports, the TOX reports were reviewed. The most relevant information for use in this study was taken from the TOX reports.

2. Recommendations produced by authoritative bodies in the UK such as the Committee on Toxicity (COT), Committee on Consumer Products and the Environment (COC) or the Expert Panel on Air Quality Standards (EPAQS).

3. Recommendations made by the European Commission Scientific Committee on Food (SCF), or the Scientific Committee for Toxicity, Ecotoxicity and the Environment.

4. Recommendations made by international authoritative organisations, such as the Joint FAO/WHO Expert Committee on Food Additives (JECFA), the WHO Environmental Health Criteria, the WHO air quality guidelines or the WHO Guidelines for Drinking Water Quality.

5. Health criteria/recommendations prepared by other national organisations, such as the USEPA (via its on-line database, the Integrated Risk Information System, IRIS) or the toxicological profiles of the US Public Health Service's Agency for Toxic Substances and Disease Registry (ATSDR).

6. Health criteria values derived from recommendations made by authoritative organisations for different purposes (e.g. a health criterion applicable to an alternative exposure pathway).

7. Health criteria values derived from standards/guidelines for occupational exposure on a case-by-case basis. Where occupational levels are used as HCVs, detected exposure greater than 1% of these values triggered further consideration of the data.

HCVs are specified so as to be protective of public health. This is achieved by erring on the side of caution in selecting the end-point for derivation of a HCV. The factors used to adapt laboratory or field data for use in setting HCVs incorporate a substantial margin of safety. This reflects uncertainties in the toxicology, and differences in response for different individuals. Consequently, the HCVs are set at a level at or below which no significant adverse effects on health would be expected. If exposure occurs at a level above the HCV, it does not necessarily follow that an adverse health effect would arise; however, this should be considered as an indicator that more detailed investigation is required.

The Health Criteria Values developed for this study are set out in Appendix 10. The basis for each HCV is given in Table A10.2 in Appendix 10, and the values themselves are set out in Annex 1 Table 5.1 (summary), Table 5.2 (values derived from published literature) and Table 5.3 (values derived for this project). No specific uncertainty value can be assigned to the individual HCVs, but it should be borne in mind that they are likely to be indicative of levels of exposure that would not give rise to a significant risk of adverse health effects. The HCVs have been developed specifically for use in this project and should not be used in other contexts without expert advice.

5.4 Screening

The measured boundary fence concentrations were screened as described above. The screening assessment is set out in Table 5.4 (Annex 1). The substances which were below one per cent of the HCV at both sites were screened out from more detailed assessment. These substances were the following:

Antimony
Mercury
Thallium
Tin
Vanadium
Naphthalene
Acenaphthene
Fluorene
Anthracene
Fluoranthene
Pyrene
1,1,1-Trichloroethane
1,1-Dichloroethane
Chlorobenzene
Chloroethane
1,2-Dichloroethene
Nitromethane
2-Butanone (methyl ethyl ketone)
Trimethylbenzene
Dichlorobenzene
Chlorodifluoromethane
Dichlorodifluoromethane
Chloromethane

5.5 Semi-quantitative assessment for inhalation exposure

5.5.1 Introduction

Inhalation is a direct exposure pathway meaning that air containing substances released from landfill sites could be inhaled by a human receptor. Such exposures are reduced by dispersion and dilution in the air before the substances of concern reach the individual(s). The objectives of the inhalation exposure assessment were to assess the potential effects of exposure of receptors to the site-specific measured concentrations of pollutants at two example landfill sites.

As discussed in Section 5.2 and in Appendix 9, the measurement database, conceptual model and dispersion modelling methodology did not support the assessment of exposure at off-site locations. Consequently, a semi-quantitative assessment was carried out on the basis of a comparison of the measured boundary fence concentrations against the HCVs.

5.5.2 Risk classification scheme

A semi-quantitative assessment of those substances which were not screened out was carried out by comparing the boundary fence concentrations against the HCVs. This was carried out as follows.

(a) A database of all measured concentrations at each site was assembled.
(b) The highest of these values at each site was identified from the database.
(c) The average of these values at each site was identified from the database.
(d) The highest value recorded at each site was assessed against HCVs specified in relation to acute health issues. In particular, potential development toxic effects are of particular concern with regard to landfill sites (Elliott et al., 1996). These effects could potentially be caused by short term exposure to a limited number of chemicals. Consequently, HCVs specified in relation to potential developmental toxic effects were assessed on the basis of the highest value recorded at each site.
(e) The average value recorded at each site was assessed against HCVs specified in relation to long-term health issues. In particular, HCVs specified in relation to potential carcinogenic effects were assessed on the basis of the average value recorded at each site.

The potential health outcome (i.e. the hazard) associated with each substance was also considered, and a risk classification scheme produced, as set out in Table 5.5. Substances were then classified with regard to their potential for health effects. The substance hazard assessment is set out in Table 5.6 (see Annex 1). A summarised form of Table 5.6 is provided as Table 5.6A below. Table 5.6 sets out the principal health effect on which the HCV is based, together with the HCV itself.

Table 5.5 Semi-quantitative risk classification scheme

Classification	Measured concentration[1]	Health outcome
A	Measured concentration over the appropriate period above HCV	Possible/probable/proven genotoxic carcinogen or developmental effect
B	Measured concentration over the appropriate period above HCV	No evidence for carcinogenic or developmental toxic activity
C	Measured concentration over the appropriate period below HCV	Possible/probable/proven genotoxic carcinogen or developmental effect
D	Measured concentration over the appropriate period below HCV	No evidence for carcinogenic or developmental toxic activity

Note 1: If exposure occurs at a level above the HCV, it does not necessarily follow that an adverse health effect would arise. This indicates that more detailed investigation is required.
Note 2: Carcinogenic PAHs were assessed on the basis of their relative potency by comparison to benzo(a)pyrene. The concentrations of individual PAHs relative to the HCVs were added to give an overall indication of risk associated with exposure to carcinogenic PAHs.

Table 5.6A Principal health effects of substances in semi-quantitative risk assessment

Substance	Principal health effect	Substance	Principal health effect
1,2-Dichloroethane	Genotoxic carcinogen	Ethyl mercaptan	Acute toxicity; irritant
1,3-butadiene	Genotoxic carcinogen	Ethylbenzene	CNS toxicity
2-Ethyl-1-hexanol	CNS toxicity; irritant	Fibres	Lung cancer (mesothelioma) (assuming asbestos)
2-Methylfuran	No data	Fluoranthene	Renal and hepatic toxicity; no concern regarding carcinogenicity
Acenaphthylene	No data	Formaldehyde	Nasal carcinogen
alpha-Terpinene	Foetal developmental effects; irritant	Gram negative bacteria	Respiratory disease
Anthracene	Subchronic toxicity; no concern regarding carcinogenicity	Hydrogen sulphide	Acute toxicity, irritant
Arsenic	Lung cancer and skin cancer	Indeno (123-cd) pyrene	Concern regarding carcinogenicity
Arsine	Haemolytic agent	Lead	Anaemia and effects on the nervous system, e.g. cognitive impairment in children
Aspergillus fumigatus	Respiratory disease	m+p Xylene	Developmental neurotoxicity (NB: draft evaluation recommends HCV of 220 µg/m3)
Benzene	Leukaemia	manganese	Neurotoxic
Benzo (a) anthracene	High concern regarding carcinogenicity	Mesophilic Aerobes	Respiratory disease
Benzo (a) pyrene	High concern regarding carcinogenicity	Methyl mercaptan	Acute toxicity; irritant
Benzo (b/k) fluoranthene	Concern regarding carcinogenicity	Moulds	Respiratory disease
Benzo (ghi) perylene	Concern regarding carcinogenicity	Nickel	Carcinogenic; reproductive or foetal toxicity
Cadmium	Lung cancer and kidney toxicity	Nitrogen dioxide	Irritation of the lungs/respiratory tract
Carbon disulphide	CNS effects	o Xylene	Developmental neurotoxicity (NB: draft evaluation recommends HCV of 220 µg/m3)
Chloroethene	Genotoxic carcinogen	PCBs	Reproductive toxicity, immunotoxcity and non-genotoxic carcinogenicity
Chloroform	Liver toxicity	Penicillia	Respiratory disease
Chromium	Lung cancer; foetal and embryo toxicity	Phenanthrene	No data; no concern regarding carcinogenicity
Chrysene	Concern regarding carcinogenicity	PM_{10}	Increase in mortality/morbidity possibly via pulmonary inflammatory response
Cobalt	Cardio-vascular effects, respiratory sensitisation, developmenta/reproductive effects	Stibine	Haemolytic agent
Copper	Liver toxicity; anaemia; immunotoxicity	Styrene	Carcinogenicity, neurological effects

Substance	Principal health effect	Substance	Principal health effect
Dibenzo (ah) anthracene	High concern regarding carcinogenicity	Sulphur dioxide	Respiratory irritant
Dichlorofluoromethane	Low toxicity, but general effects on CNS, liver, CV and respiratory effects	Tetrachloroethene	Kidney and CNS effects, non-genotoxic carcinogen,
Dichloromethane	Carcinogenic, CNS effects and causes carboxyhaemoglobinaemia	Thermophilic Bacteria	Respiratory disease
Dichloromethane	Carcinogenic, CNS effects and causes carboxyhaemoglobinaemia	Thermophilic fungi	Respiratory disease
Dimethyl disulphide	Acute toxicity; irritant	Thermophilic fungi and yeasts Malt	Respiratory disease
Dimethyl sulphide	Acute toxicity; irritant	Toluene	CNS toxicity
Dioxins and furans	Reproductive toxicant and developmental toxin; effects on sperm production and developmental/ reproductive effects	Total Bacteria	Respiratory disease
Dioxins, furans and dioxin-like PCBs	Reproductive toxicant and developmental toxin; effects on sperm production and developmental/ reproductive effects	Total fungi and yeasts DG18	Respiratory disease
Endotoxins	Respiratory disease	Total fungi and yeasts Malt	Respiratory disease
Entrobacteriaceae	Respiratory disease	Trichloroethene	Carcinogen, liver and CNS damage, possible developmental toxin
Ethyl mercaptan	Acute toxicity; irritant	Yeasts	Respiratory disease

5.5.3 Semi-quantitative risk characterisation

Having established a risk classification scheme and identified the hazard associated with the substances under consideration, the boundary fence measurements carried out during the course of the project were assessed in accordance with the scheme. This assessment is shown in Annex 1 Table 5.7 (Site A) and Table 5.8 (Site B)). These tables set out the average measured concentrations over all samples at each site, and also provide the maximum measured concentration from any sample at each site. These average and maximum measured concentrations are then assessed against the project HCVs and the substances classified in accordance with the scheme set out in Table 5.5.

Table 5.9 shows a summary of the classification of the measured substances.

Table 5.9 Summary of Semi-quantitative risk characterisation

Classification	Substances identified at Site A	Substances identified at Site B
Class A	1,2-Dichloroethane ** Formaldehyde *** Styrene *	1,2-Dichloroethane ** Arsine *** Carcinogenic PAHs *** Formaldehyde ***
Class B	Dimethyl disulphide Dimethyl sulphide Methyl mercaptan Stibine Toluene	Dimethyl disulphide Dimethyl sulphide Methyl mercaptan
Class C	1,3-butadiene *** alpha-Terpinene Arsenic *** Arsine *** Benzene *** Cadmium *** Carcinogenic PAHs *** Chloroethene *** Chromium *** Cobalt * Dichloromethane * Fibres *** Lead ** m+p Xylene Nickel *** o Xylene PCBs ** Trichloroethene **	1,3-butadiene *** alpha-Terpinene Arsenic *** Benzene *** Cadmium *** Chloroethene *** Chromium *** Cobalt * Dichloromethane * Fibres *** Lead ** m+p Xylene Nickel *** o Xylene PCBs ** Styrene * Trichloroethene **
Class D	2-Ethyl-1-hexanol Anthracene Carbon disulphide Chloroform Copper Dichlorofluoromethane Ethyl mercaptan Ethylbenzene Fluoranthene manganese Tetrachloroethene	2-Ethyl-1-hexanol Anthracene Carbon disulphide Chloroform Copper Dichlorofluoromethane Ethyl mercaptan Ethylbenzene Fluoranthene manganese Stibine Tetrachloroethene Toluene
No HCV	2-Methylfuran, Acenaphthylene, Aspergillus fumigatus, Benzo (b/k) fluoranthene, Dioxins and furans, Dioxins, furans and dioxin-like PCBs, Endotoxins, Entrobacteriaceae, Gram negative bacteria, Mesophilic Aerobes, Moulds , Penicillia, Phenanthrene, Thermophilic Bacteria, Thermophilic fungi, Thermophilic fungi and yeasts Malt, Total Bacteria, Total fungi and yeasts DG18, Total fungi and yeasts Malt, Yeasts	

Note: *: Proven human carcinogen ** Probable human carcinogen *** Possible human carcinogen

Carcinogenic PAHs: Benzo (a) anthracene ***, Benzo (ghi) perylene *, Benzo (a) pyrene ***
Chrysene *, Dibenzo (ah) anthracene **, Indeno (123-cd) pyrene *

Further research should include an evaluation of the substances identified in this assessment as being in Class A and Class B. This is discussed further in Section 6.3.

5.5.4 Substance groups

Several substance groups were considered in more detail, particularly where there were no HCVs defined for these groups.

Micro-organisms
Site A: For the winter period, eight sample sets were taken from Site A. The measured levels of mesophilic aerobes and moulds were found to be elevated. Endotoxin concentrations were not elevated. For the summer, eight sample sets were analysed. The mesophilic aerobes and total fungi and yeast numbers were elevated but bacteria capable of growth at 37°C and thermophilic fungi were absent. Endotoxin concentrations were not elevated.

Site B: Seven sample sets were taken in the winter period from Site B. None of the samples showed bacterial or fungal concentrations above the baseline values. Endotoxin concentrations are not reported. Eight sample sets were taken in the summer period. Total bacterial counts were raised although thermophilic fungi and enterobacteriaceae were not. Mesophilic fungi concentrations were elevated. Endotoxin concentrations were not elevated.

Overall, the microbiological findings were elevated during the winter and summer sampling period at Site A, and the summer sampling period at Site B. The most likely sources for these observed levels of bioaerosols are the handling of biodegradable wastes at the landfill sites. Local agriculture may also have contributed to the recorded levels of bioaerosols.

Although elevated numbers of micro-organisms for both bacteria and fungi were detected, there appears to be limited consensus in the literature regarding threshold limit values and risk to human health (Lundholm and Rylander 1980; Mansdorf, 1982; Clark *et al.*. 1983; Malmros 1990). This lack of any defined dose-response relationship has prevented the setting of exposure thresholds, apart from advising that exposure should be minimised. However, from the limited existing data, tentative health criteria values (HCVs) for airborne micro-organisms are 1000 colony forming units (CFU)/m^3 for bacteria, 300 CFU/m^3 for Gram-negative bacteria and 1000 CFU/m^3 for fungi (Rylander *et al.*. 1983; Palchak *et al.*. 1990; Lacey 1981, Environment Agency 2001). Based on the published recommendations, the values obtained for total bacteria and fungi from the samples at Site A were above the tentative health criteria values in the winter and summer. The same is true for the samples at Site B in the summer.

The sensitisation level for fungi (arising from allergenic glycans in their cell walls) is uncertain but Rylander (1986) and Lacey *et al.*. (1990) suggested that concentrations of around 100 CFU/m^3 were significant. However, individual responses are highly variable and sensitisation or adverse health effects could potentially be caused at lower concentrations (Cliver 1980). Rao and Chang (1996) suggested that exposure limits for fungi range between 100 to 1000 CFU/m^3, further highlighting the uncertainty within the scientific community regarding this matter. Bacteria in bioaerosols may cause similar health effects to those caused by fungi. These effects include mild, transitory effects such as runny nose, throat irritation, cough and sneeze, to more severe chronic effects such as sinusitis or exacerbation of asthma. It is possible that populations living in close proximity to Sites A and B might experience an increased incidence of these health effects as a result of inhaling bioaerosols released from the sites.

Continuous monitoring data
The measured concentrations determined by continuous monitoring are set out in Section 4.4.1. Possible health effects resulting from the concentrations observed were assessed for nitrogen dioxide (NO_2), sulphur dioxide (SO_2), particulate matter (PM_{10}) and hydrogen sulphide (H_2S) by comparison to appropriate health criteria values (HCVs).

Table 5.10 sets out the health criteria values against which the monitoring data were assessed.

Table 5.10 : HCVs for comparison with exposure estimates over different time periods

Substance	Annual HCV	24-hour HCV	1 hour HCV	15 minute HCV
NO_2	40 µg/m^3 [21 ppb] (EC, 1999)	N/A	200 µg/m^3 [105 ppb] (EC, 1999)	N/A
SO_2	N/A	125 µg/m^3 [47 ppb] (EC, 1999)	266 µg/m^3 [100 ppb] (EPAQS, 1995)	266 µg/m^3 [100 ppb] (EPAQS, 1995)
PM_{10}	40 µg/m^3 (EC, 1999)	50 µg/m^3 (EPAQS, 2001)	N/A	N/A
H_2S	N/A	150 µg/m^3 (WHO, 2000)	N/A	N/A

Nitrogen dioxide (NO_2)

The EU Air Quality Daughter Directive 1999/30/EC recommends a short-term limit value for NO_2 of 200 µg/m^3 (105 ppb), averaged over 1 hour. This limit value has now been incorporated into UK law and is included as an Objective in the Air Quality Strategy. A standard intended to protect against adverse effects of chronic exposure to NO_2 was also specified by the EU: 40 µg/m^3 (21 ppb) as an annual mean. This EU standard has also now been incorporated into UK law and is included as an Objective in the Air Quality Strategy. All of the concentrations of NO_2 measured during the continuous monitoring periods at both sites comply with these HCVs and are therefore unlikely to present a health problem, either to nearby residents or site workers.

Sulphur dioxide (SO_2)

EPAQS (1995) recommend a standard for SO_2 of 100 ppb (266 µg/m^3) averaged over 15 minutes, based on protecting vulnerable individuals (particularly asthmatics) from the adverse health effects of SO_2 as broncho-constriction can be very rapid in onset following exposure this gas.

EU limit values of 350 µg/m^3 (132 ppb) averaged over an hour and 125 µg/m^3 (47 ppb), as a 24-hour average, have been incorporated into UK law and are included as Objectives in the Air Quality Strategy, to be achieved by 31 Dec 2004. Member states must ensure that their legislation is at least as stringent as EU Directives, and can establish stricter national standards. The EPAQS recommendation has, therefore, also been included as an Objective in the Strategy and UK law, to be achieved by 31 Dec 2005. For the purposes of this project, the EPAQS guideline for a 15 min exposure averaging period has also been used to assess concentrations averaged over an hour as it is more stringent that the recommendation included in the EU Daughter Directive (EC, 1999).

All concentrations of SO_2 measured during the continuous monitoring periods were below the selected HCVs, except for the 100th percentile value (182 ppb) for concentrations measured at Site B during winter. This is nearly two orders of magnitude higher than the 90th percentile value for the same period (2.7 ppb) because there was an isolated 15 minute period when the measured concentration of SO_2 was 182 ppb, compared to the 15 minute HCV of 100 ppb. This was accompanied by an increase in levels of hydrogen sulphide measured by the same instrument, but there was no similar increase in measured levels of oxides of nitrogen or PM_{10}. There was no other indication of abnormal instrument operation (e.g. operational alarm status). Although this elevated measurement was unusually high and an isolated incident, it was retained in the measurement database.

There was also an episode at Site A, in which two values were above 100 ppb. The higher of these two values was 304 ppb. These concentrations of SO_2 are nearly twice the EPAQS recommendation of 100 ppb, averaged over 15 min, and if experienced by an asthma sufferer, could put an individual at a greater risk of having an asthmatic episode. These episodes could have resulted from the combustion of sulphur-containing fuels, for example, in a landfill gas engine or flare, or in a vehicle engine or generator motor. The very short duration of thes

episodes (up to two 15 minute periods) compared to the overall monitoring period (8,000 15 minute periods) should be borne in mind when considering the significance of these events.

Fine Particulate Matter (PM_{10})
All concentrations of PM_{10} measured during the continuous monitoring periods are below the selected HCVs, except for the 98th percentile 24 hour mean at Site A in 2003 (59 µg/m^3) which exceeds the EPAQS recommendation (50 µg/m^3) for this exposure averaging time. However the measured PM_{10} concentration complied with the current air quality standard of 50 µg/m^3 to be achieved 90.4% of the time.

Although there is a range of cardio-respiratory effects linked to increases in particulate matter, the basis for the 50 µg/m^3 recommendation was the finding that a rise from a daily average level of 20 to 50 µg/m^3, a concentration which was exceeded on average one day in ten in a study in Birmingham conducted over two years, would be expected to be associated with just over one extra patient on average being admitted to hospital with respiratory disease daily in a population of one million. This finding indicates that levels of PM_{10} measured at the landfill site are comparable to those encountered in many parts of the UK, and not likely to have any significant or measurable effects in the area adjacent to a landfill site.

Hydrogen sulphide (H_2S)
The WHO (2000) recommends an air quality guideline for H_2S of 150 µg/m^3 over a 24 hour averaging period. The WHO also recommends a value of 7 µg/m^3, with a 30 min averaging period, in order to avoid substantial complaints about odour annoyance among the exposed population. These values were used as HCVs for this project.

Concentrations of H_2S measured during the continuous monitoring period at both sites were below the HCV, but the 90th and 100th percentile values at Sites A and B in winter and 100th percentile value at Site A in winter, for 15 min means, above the World Health Organisation odour-based recommended level. This indicates that there is the potential for odours due to H_2S to affect nearby residents.

Substances with potential developmental toxic effects
A number of substances considered in this study could potentially affect unborn children (these substances are referred to as “developmental toxins”). These substances are discussed below.

Dioxins and furans
These are discussed in Section 5.4 below.

Ethyl benzene
There have been reported increases in fetotoxic and teratogenic effects due to ethyl benzene in animal experiments, albeit at maternally toxic doses. The lowest concentration at which an effect was detected was 430 mg/m^3, and no no observed adverse effect levels (NOAELs) have yet been demonstrated. The HCV of 595 µg/m^3 is approximately one thousandth of the lowest observed adverse effect level (LOAEL) for these effects. The highest measured concentration in this study was 104 µg/m^3. In view of these observations, exposure to ethyl benzene emissions from the landfill sites is considered unlikely to pose any risk of fetotoxic or teratogenic effects.

Trichloroethene
There is evidence that trichloroethene, at very high doses, can cause developmental effects and embryo-toxicity in the absence of maternal effects. Inhalation of up to 1620 mg/m^3 in mice and 9720 mg/m^3 in rats had no effect on prenatal development, and had only a minor and inconsistent effect on post-natal development. The highest measured level in this study was 2.8 µg/m^3. This is approximately 12per cent of the HCV of 23 µg/m^3, which was derived from separate animal experiments on carcinogenicity of trichloroethene. In view of these observations, exposure to ethyl benzene is considered unlikely to have any significant teratogenic effects.

Chloroethene
Chloroethene is a genotoxic carcinogen to the liver (haemangiosarcoma) and the brain. It is embryotoxic in mice and possibly rats, but only at concentrations which would also result in harm to the mother. The level below which no adverse effects were observed is around 520 mg/m^3. This is much higher than the HCV, which is set at 1 μg/m^3 to protect against potential carcinogenic effects. In this study the highest measured long-term mean level of chloroethene was 9 per cent of the HCV. In view of these observations, exposure to chloroethene is considered unlikely to have any significant teratogenic effects.

1,3-Butadiene
1,3-butadiene is a recognised genotoxic carcinogen. It is not considered to be teratogenic, but it is fetotoxic at concentrations which are high enough to cause maternal toxicity. The concentrations below which no adverse effects were observed were 2200 mg/m^3 in rats, and 88 mg/m^3 in mice. The HCV of 2.21 μg/m^3 is much lower than these values, and was based on protection against the risk of lymphomas and leukaemias. The highest measured long-term mean level of 1,3-butadiene in this study was 56 per cent of the HCV. In view of these observations, exposure to 1,3-butadiene is considered unlikely to have any significant teratogenic effects.

2-Ethyl-1-hexanol
2-ethyl-1-hexanol has been found to be embryotoxic, fetotoxic and teratogenic in rats at concentrations which also caused marked maternal toxicity. The highest measured concentration in this study was 86 μg/m^3, approximately 15 per cent of the HCV. In view of these observations, exposure to 1-ethyl 1-hexanol is considered unlikely to have any significant teratogenic effects.

5.6 Indirect exposures

Estimates were also made of population exposure to substances by routes other than inhalation. These were performed for dioxins and furans and six of the 13 metals under consideration (arsenic, mercury, cadmium, lead, copper and tin) because metals such as these are likely to be released in particulate form and could be deposited on nearby farmland, gardens or allotments. There are dairy and sheep farms in the vicinity of Sites A and B, and also local fishing resources. This indicates that, following deposition, substances such as these could be accumulated in vegetation and livestock and subsequently consumed by local residents.

5.6.1 Direct and indirect exposure to dioxins and furans

The likely exposure of individuals to these substances was estimated using models to describe their passage through the environment. For dioxins and furans, the Environment Agency model “Dioxin Risk and Exposure Assessment Model” (DREAM) version 1.0x was used (Environment Agency/University of Lancaster, 2004). This model provided estimated exposures to dioxins and furans, based on a given airborne concentration profile, on the basis of a set of detailed assumptions about the consumption of different types of food, body weights etc. Using this information, the model provides estimated exposures for individuals aged 1.5 – 2.5 years; 2.5 – 3.5 years; 3.5 – 4.5 years; school children and adults.

The typical profile of dioxins and furans at each site was evaluated by identifying the downwind monitoring station for each of the dioxin/furan sampling periods. The concentrations of each congener measured at the downwind monitoring station were averaged over each intensive survey period to give a typical profile of dioxins and furans due to site emissions. This profile was used in the “DREAM” model to provide estimated values for exposure to dioxins and furans due to emissions from the site.

The estimated exposures to dioxins and furans by all routes (direct inhalation together with indirect pathways) are set out in Table 5.11.

Table 5.11 Estimated exposures to dioxins and furans

Population group	Site A	Site B	Site B (excluding single high value)
	picograms TEQ per kg body weight per day		
Children aged 1.5 – 2.5	1.80	7.74	1.63
Children aged 2.5 – 3.5	1.52	6.52	1.37
Children aged 3.5 – 4.5	1.35	5.77	1.22
School children	0.56	2.47	0.52
Adults	0.30	1.29	0.27

The estimated exposure to dioxins and furans at Site A due to the measured airborne levels of dioxins and furans at the site boundary is within the Tolerable Daily Intake level of 2 pg TEQ per kg body weight per day. The estimated exposure to dioxins and furans at Site B is within the TDI if the single high value recorded in the summer survey is excluded, but above the TDI if this value is included.

As discussed in Chapter 4, the single very high value has been subject to rigorous further investigation with the site and laboratory personnel, and with the landfill site operator. No reason was found to doubt its veracity, other than the magnitude of the recorded value. The analysis of dioxins and furans in soil and herbage described below indicates that there is no long-term increase in dioxins and furans in soils or herbage downwind of Site B. The single high value is therefore unlikely to be typical of emissions from Site B, although there remains a possibility that it represent a short-term fluctuation in site emissions. This is considered to be unlikely in practice, as the increase in emissions would need to be sustained over a period of 72 hours for this to be a valid data point. Table 5.11 includes the values that would be estimated if the single high value were excluded from the analysis.

5.6.2 Indirect exposure to metals

The DREAM model cannot be used to carry out similar calculations for exposure to emissions of metals. To do this, an earlier model prepared for Her Majesty's Inspectorate of Pollution (HMIP, 1996) was adapted to allow exposure to metals via indirect pathways to be evaluated. This evaluation allowed us to assess whether exposure to metals via routes other than inhalation could potentially be significant.

It was found that exposure to metals via indirect pathways is unlikely to result in a significant increase in exposure over and above exposure via direct inhalation. Exposure via inhalation was found to account for between 87 per cent and 99 per cent of total exposure. Inhalation accounted for 93 per cent or more of exposure to all substances except for copper. On this basis, indirect exposures to metals were not assessed further as part of this study, as the estimated inhalation exposures account for the majority of population exposure.

5.6.3 Farm survey data

The feasibility of indirect exposures through local farm produce can be a significant issue in environmental exposure assessment. Rather than relying on a theoretical analysis, this research sought to undertake farm surveys of local farm to assess the likelihood of uptake through locally grown and sold produce.

All surrounding agricultural land could potentially be exposed to airborne landfill emissions. These may settle on crops or if soluble, be taken up by the growing crop from the soil. On the farms studied, all field crops that may be consumed by humans (wheat, potatoes, sugar beet and beans) will undergo some form of processing prior to consumption. Sugar beet is processed

immediately following harvest, other arable crops may be stored (grain being dried), often on farm awaiting a favourable market price.

Livestock grazing a pasture will ingest any substances settled on the sward as well as those taken up by the growing crop. In addition the animal will ingest a small volume of soil material. Barley fed to livestock will have been dried and stored post harvest. Hay is also dried. Silage is stored in an anaerobic and acidic condition.

In most instances, all of the farm output is distributed over a very wide and variable area. This was particularly the case for livestock at the time of the survey under the FMD restrictions as without local auctions, farmers sent stock to any slaughterhouse that will pay an adequate price.

Milk is perishable and requires frequent collections. As a result, fresh milk tends to be marketed through local dairies. The vast majority of this milk, including that which will be processed into dairy products, is pasteurised.

The activities which could affect the way in which farm produce acts as a vector for landfill emissions to the human population are set out below.

Landfill Site A

Farm Business 1: The direct sale of milk provides a potential year round pathway from the farm to the local population. Furthermore, as the farm delivers direct to some domestic customers it may be possible to identify individuals who may be exposed in this way. None of the farm's activities appear to modify the exposure of the land or livestock to landfill emissions.

Farm Business 2: In some fields livestock can drink from river water. In addition, housed livestock are given rainwater collected from the building roofs. River water down stream of the landfill site could potentially carry substances from the landfill site. These may be in the form of a solute or sediment. Rainwater collection tanks could also contain dissolved substances from the landfill, although this would be less likely to be a significant exposure pathway. These sources of drinking water may therefore provide exposure routes for livestock to landfill emissions at this farm unit.

Farm Business 3: This farm has fields adjoining landfill site A. As a result it experiences problems with vermin arising in part from the landfill. The vermin may be transporting some material from the landfill site to the adjoining farmland but this will on the whole be material from the filling cells where the animals are foraging in waste material. Vermin would not therefore be expected to be a significant vector for any of the landfill emissions being monitored in air or which could potentially arise in groundwater. However, the presence of rats could potentially constitute a possible vector for health effects. As a response to the FMD restrictions, some of the finished lamb produced was sold to a butcher in a nearby town and will be consumed locally as a result.

Landfill Site B

Farm Business 4: There is no apparent interaction with the landfill site that is specific to this farm business, either within the inner or outer zones. The outer zone does contain an area of peaty land in arable use where the groundwater has been lowered. Crops grown on this peaty land could possibly have greater access to groundwater (as opposed to surface rainwater) and as a result, greater exposure to any dissolved landfill emissions present in the groundwater.

Farm Business 5: As for Farm Business 4, there is no apparent interaction between Farm Business 5's activities and landfill emissions. Following FMD restrictions, all finished beef cattle were sold through a butcher in a nearby town. The farmer intended to continue selling to the same butcher after restrictions have been lifted. Most of the beef produced by this unit will therefore be consumed locally.

Farm Business 6: This farm occupies agricultural land adjoining landfill site B. This estate operates four bore holes, abstracting groundwater. One of these serves the housed pig unit. The remaining three provide irrigation water for the potato crop. If any landfill emissions are present

within the abstracted groundwater, these could therefore be passed on to the sows, potato crop and irrigated soil. As slurry from the pig unit is disposed of on the estate land, abstracted water used for washing down the livestock pens will in turn be spread on the arable land. In addition to the farming activity on the estate, angling groups fish the ponds and game is shot commercially. The fish ponds lie down stream of the landfill site and in addition to carrying any dissolved landfill emissions, may also be carrying suspended sediment. As the ponds are fished by local angling groups, the fish caught may be consumed locally.

In conclusion, some interactions between the farm businesses and landfill operations/emissions were identified. These practices include the use of water abstracted for animal husbandry from a source which could potentially be affected by landfill emissions rather than the mains, and abstracting groundwater for irrigating crops.

The majority of farm produce is marketed nationwide. One dairy farmer was however selling some pasteurised milk direct to local households and retail outlets, as well as to a dairy. Two livestock farmers had started selling a small number of lambs and beef cattle direct to local butchers. Such direct local sales may be influencing the exposure of the local population to landfill emissions reaching farmland.

No farmer interviewed was aware of any air or water borne landfill emissions (other than litter) affecting their farm business. No such influences were observed during the surveys.

5.6.4 Exposure to groundwater

This section provides a summary of the groundwater risk assessment. The full report is provided in Appendix 5. Landfill risk assessment is based on development of a conceptual model for the site. This is a representation of the relationship between contaminant sources, pathways and receptors developed on the basis of hazard identification.

Approach to groundwater risk assessment
This part of the study considers the possible effects of landfills on human health, via groundwater pathways. This limits the potential sources to landfill leachate. Specific chemicals of potential concern were identified from analysis of water quality data at locations where people might come into contact with water affected by emissions from the site, together with other pollutants for which there is no off-site measurement data.

The extent of any exposure of human receptors to waterborne emissions from the landfills was quantified or estimated to the extent that the data allowed. This required assessment of, for instance the quality of leachate entering groundwater, the effects of retardation, attenuation and degradation within the geosphere, concentrations at the receptor and the potential for intake at each receptor. The concentrations of substances released from the landfill were based on either measured concentrations or estimated concentrations from a leachate quality database, together with calculated dilution rates. The estimated exposure concentrations were assessed against widely used benchmarks for groundwater and drinking water quality to establish the significance of the estimated exposure concentrations.

A qualitative risk assessment was undertaken for potential source-pathway-receptor linkages. This assessment characterised risks on the following basis:

Very high risk	There is a high probability that severe harm could arise to a designated receptor from an identified hazard at the site without appropriate remedial action.
High risk	Harm is likely to arise to a designated receptor from an identified hazard at the site without appropriate remedial action.

Moderate risk It is possible that without appropriate remedial action harm could arise to a designated receptor but it is relatively unlikely that any such harm would be severe, and if any harm were to occur it is more likely that such harm would be relatively mild.

Low risk It is possible that harm could arise to a designated receptor from an identified hazard but it is likely that at worst, that this harm if realised would normally be mild.

Negligible risk The presence of an identified hazard does not give rise to the potential to cause significant harm to a designated receptor.

For the risks assessed as moderate / low identified by the qualitative risk assessment, and where actual data is not available at the receptor, further analysis has been undertaken to quantify the concentration of the contaminants at the receptor. Using the limited data available, a dilution factor between the leachate and the groundwater at the downstream boreholes and the spring can be calculated using a simple mass balance calculation which also considers the background concentration in the local groundwater. Chloride has been used as a conservative parameter being highly mobile and generally unaffected by retardation within the aquifer. The highest concentrations of substances which are often found in leachate and that were likely to arise at off-site receptors were estimated relative to the calculated chloride concentration. The concentrations were compared to drinking water standards to assess their significance.

Potential sources of contaminants
The base of Site A is above groundwater level, and there is no surface water runoff discharging into the site. The primary source of water input which could provide the potential for water borne emissions is therefore direct rainfall input to the landfill. Most of the water which enters the wastes will become leachate, and leachate at both sites is managed to ensure that no significant adverse impacts arise. Any liquid wastes which may have entered the landfill would also contribute to the generation of landfill leachate.

Waterborne emissions are normally controlled by:

- routing surface water away from the site, capping wastes and separating surface water from wastes where possible;
- construction of engineered barriers to minimise escape of leachate into the geosphere;
- collection of leachate to reduce the load on the engineered barriers; and
- treatment of leachate followed by consented discharge.

Wastes will degrade to produce gas over many decades. Leachate generation is a combination of degradation, and flushing by water. Wastes will biodegrade and dissolve in water over centuries. The less water that enters the site, the longer process will take. In addition, while travel times to potential receptors are rapid for surface water runoff, movement into and through the geosphere will be slower, the timescale being dependent on the construction and geology and hydrogeology of the landfill site.

Potential groundwater exposure routes
There are a number of potential exposure routes via groundwater at Site A. These comprise:

- A spring emerging from an aquifer to the east of the site;
- Groundwater just below the ground surface in a nearby village which could be abstracted directly;
- Surface water partially fed by groundwater in a nearby river; and
- Livestock could consume surface water affected by any discharges in groundwater, and dairy or meat products from these livestock could potentially contain substances released from the landfill site.

At Site B, potential exposure routes comprise the following:

- Farm workers handling abstracted water;
- Livestock (e.g. pigs) given abstraction water;
- Crops irrigated using abstracted water and agricultural workers; and
- Users of nearby ponds as the concentrations of these surface water bodies are increased using abstracted water.

Groundwater risk assessment findings

A qualitative risk assessment was undertaken for potential source-pathway-receptor linkages (Annex 1 Tables 5.12 and 5.13). More detailed analysis where required is set out in Tables 5.14 and 5.15 in Annex 1.

Site A exhibits most of the criteria specified by the Environment Agency for the study. The landfill is lined although the lining of the older part of the site is of a lower standard and more leachate is likely to be emitted from this area of the site. Groundwater flow is affected by the fissure flow nature of the aquifer and the presence of faults. Flow rates are high with little potential for attenuation of contaminants. There is a 20 metre unsaturated zone beneath the base of the landfill. The steep local topography results in the re-emergence of groundwater in two types of locality: where the water table is close to the groundwater; and via a local fault feature to a spring several hundred metres from the site.

The monitoring network for the site includes upstream boreholes, down stream boreholes, leachate collection points and surface water monitoring. Monitoring data has indicated elevated concentrations of some determinands in the groundwater: Ammoniacal nitrogen was elevated in both the upstream and downstream boreholes. This indicates that there are likely to be other sources of ammoniacal nitrogen in the area, such as agricultural livestock. However, the concentrations were greater in the downstream borehole indicating that the landfill or other adjacent sources such as farmland may be contributing to this contamination. Iron and manganese were also elevated in the downstream borehole but at similar concentrations to the landfill leachate. Given the distance to the monitoring boreholes and that the alkaline conditions in the aquifer are not conducive to transport of metals, these are likely to be partly naturally derived.

Elevated concentrations of some determinands were also detected in surface water. While metal concentrations in the spring water were generally low, indicating that conditions in the aquifer are not conducive to the transport of metals, the median concentrations of sodium, potassium and ammoniacal nitrogen were elevated in the spring water, along with alkalinity. However, concentrations in the river were similar upstream and downstream of where the spring discharged, indicating that although the spring could be affected by leachate, the dilution from the river negates any further potential health impact.

The impact of other contaminants which are typically found in leachate, but were not measured in the leachate at Site A, were calculated at the identified receptors. Their predicted concentrations were not significant when compared to available drinking water standards.

Site B exhibits most of the criteria specified by the Environment Agency for the study. However, low permeability drift prevents continuity between surface water and groundwater. The monitoring network for the site includes upstream boreholes, down stream boreholes, leachate collection points and surface water monitoring. Monitoring data has been compared with results of groundwater sampling before the landfilling commenced. Elevated concentrations of ammonia and heavy metals are present in groundwater, and elevated concentrations of chloride, chloroethane, ammonia and metals have also been detected sporadically. This could relate to changes in sampling methods or to sampling from different concentrations.

The impact of other contaminants which are typically found in leachate, but were not measured in the leachate at Site B, were calculated at the identified receptors. Their predicted concentrations were not significant when compared to available drinking water standards.

Groundwater risk assessment conclusions
For Site A, it was found that the available dilution means that the concentrations of contaminants in waters to which local residents would have access comply with drinking water standards, even without further treatment. On this basis, it is concluded that releases to groundwater from Site A do not have any significant adverse effects on health.

For Site B, it was found that there is evidence for trace contaminants from leachate being found in detectable concentrations in local groundwater. The available dilution means that the concentrations of all contaminants with the exception of ammoniacal nitrogen in waters to which local residents would have access were estimated to comply with drinking water standards, even without further treatment. Estimated concentrations of ammoniacal nitrogen in groundwater were above the drinking water standard (about five times the standard value). In practice, because of the dilution of groundwater and likely treatment of water before consumption, the levels of ammoniacal nitrogen experienced by local residents are expected to comply with the drinking water standard. On this basis, it was concluded that releases to groundwater from Site B are unlikely to have any significant adverse effects on health.

5.7 Risk assessment conclusions

A wide range of substances were investigated during an intensive study of two landfill sites. Airborne levels of substances which could be released from the landfill sites were measured at the site boundary. Potential direct and indirect exposures were assessed via a screening and semi-quantitative assessment.

A quantitative exposure assessment and risk characterisation study using air dispersion modelling was undertaken, but the results from that assessment were not considered to be reliable.

It was found that the risk to health posed by the levels of the following substances at the site boundaries could be ruled out as being insignificant (Table 5.16).

Table 5.16 Substances ruled out as insignificant

Antimony	1,1-Dichloroethane
Mercury	Chlorobenzene
Thallium	Chloroethane
Tin	1,2-Dichloroethene
Vanadium	Nitromethane
Naphthalene	2-Butanone (methyl ethyl ketone)
Acenaphthene	Trimethylbenzene
Fluorene	Dichlorobenzene
Anthracene	Chlorodifluoromethane
Fluoranthene	Dichlorodifluoromethane
Pyrene	Chloromethane
1,1,1-Trichloroethane	

The semiquantitative assessment of measurements at the site boundary was carried out by comparing measured levels of released substances to health criteria values. This is a conservative approach, because exposure of members of the public is likely to be at a much lower level than those measured directly adjacent to a landfill site. The Committee on Toxicity further modified this and adopted a threshold of 75 per cent of the health criteria value, for its detailed consideration of the results of this study, rather than 100 per cent of the health criteria value used here.

The measured levels were classified as follows:

Class A (Highest measured concentration over relevant period above HCV; Possible/probable/proven genotoxic carcinogen or developmental effect)

Arsine	Carcinogenic PAHs	Formaldehyde
Styrene	Dioxins and furans (no HCV – see below)	

Class B: (Highest measured concentration over relevant period above HCV; No evidence for carcinogenic or teratogenic activity)

Dimethyl disulphide	Dimethyl sulphide	Methyl mercaptan
Stibine	Toluene	Micro-organisms

Class C (Highest measured concentration over relevant period below HCV; Possible/probable/proven genotoxic carcinogen or developmental effect)

1,2-Dichloroethane	1,3-butadiene	alpha-Terpinene
Arsenic	Benzene	Cadmium
Chloroethene	Chromium	Cobalt
Dichloromethane	Dichloromethane	Fibres
Lead	m+p Xylene	Nickel
o Xylene	PCBs	Trichloroethene

Class D (Highest measured concentration over relevant period below HCV; No evidence for carcinogenic or teratogenic activity)

2-Ethyl-1-hexanol	Anthracene	Carbon disulphide
Chloroform	Copper	Dichlorofluoromethane
Ethyl mercaptan	Ethylbenzene	Fluoranthene
Manganese	Tetrachloroethene	

Assessment of continuous monitoring data indicated that there are no significant concerns with regard to the potential effects on health due to exposure to levels of nitrogen dioxide, fine particulate matter (PM_{10}) or sulphur dioxide. Levels of hydrogen sulphide could give occasional odours, and attention should continue to be focused on odour control at landfill sites.

It was concluded that releases to groundwater are unlikely to pose a significant risk of adverse effects on on health.

The farm survey identified some interactions between the farm businesses and landfill operations/ emissions. Most farm produce was marketed nationwide, but limited local sales could potentially provide a route for exposure of local populations.

There were no HCVs for some substances – a number of VOCs, dioxins and furans and micro-organisms. These were addressed as follows:

- An assessment was carried out of volatile organic compounds with the potential to harm unborn children. It was found that none of the substances were measured at levels which would have any significant adverse effect in this way, based on our current understanding.

- An assessment was made of indirect exposures to dioxins and furans. Excluding a single relatively high measured airborne level of dioxins and furans, it was found that exposure to the levels of dioxins and furans measured at the site boundary would not be expected to result in a tolerable daily intake above the Committee on Toxicity recommended Tolerable Daily Intake. In view of this, it was concluded that no significant adverse effects on health due to exposure to dioxins and furans would be expected to occur. However, in view of the single high measured value of dioxins and furans, attention should continue to be focused on levels of dioxins and furans. Dioxins and furans were therefore placed in Class A.

- For micro-organisms, it was found that populations living in close proximity to Sites A and B might experience an increased incidence of short-term health effects as a result of inhaling bioaerosols released from the sites. In view of this, attention should continue to be focused on levels of micro-organisms at landfill sites. Micro-organisms were therefore placed in Class B.

6 Conclusions and recommendations

6.1 Risk screening

This study has sought to inform the debate over the potential risks to public health that may arise from landfill emissions. An exposure assessment for two example landfill sites accepting municipal waste has been conducted. The principal health effects raised at the outset of the project were teratogenicity (that is, the potential for chemicals to increase the risk of congenital anomalies in newborn infants) and carcinogenicity (that is, the potential for chemicals to increase the risk of cancer in anyone exposed to the chemical).

The study considered over 60 substances and substance groups. On the basis of the assessment set out in this report, it is concluded that 23 substances can be screened out of further consideration. This is because measured levels of these substances were below 1% of the project-specific Health Criteria Values (HCVs). No significant adverse health effects are likely to arise from a further 29 of these substances and substance groups.

Any attention should be focused on the remaining substances and substance groups.

The intention was to analyse the data further using a conceptual model of emissions from the site to investigate emissions from the site, and the potential exposure of people located off-site to exposure to the released substances. However, it was found that the conceptual model, survey data and assessment methods did not give results which were sufficiently robust to draw reliable conclusions.

6.2 Substances requiring further attention

Some of the substances and substance groups assessed were found to require more detailed investigation because the measured boundary fence concentrations over the appropriate averaging period were above the project-specific health criteria values. Most HCVs were derived from existing guidelines, while a limited number of HCVs were developed specifically for this project. A measured concentration above the HCV does not mean that an adverse health effect would arise, but rather that more detailed investigation is required.

These substances and substance groups were:

Class A (Highest measured concentration above HCV; Possible/probable/proven genotoxic carcinogen or developmental effect)

Arsine	Highest measured concentration sixteen times the HCV. Proven human carcinogen
Carcinogenic PAHs	Overall assessment based on relative potencies for 6 substances indicates measured concentration 100 per cent of HCV Possible/probable/proven human carcinogens
Formaldehyde	Highest measured concentration fourteen times the HCV. Proven human carcinogen

Styrene	Highest measured concentration twice the HCV. Possible human carcinogen
Dioxins and furans	No HCV, but the highest estimated exposure eight times the TDI if the single outlier is included; estimated exposure is within the TDI if outlier is excluded. Proven human carcinogen

Class B: (Highest measured concentration above HCV; No evidence for carcinogenic or teratogenic activity)

Dimethyl disulphide	Highest measured concentration eleven times the HCV set on the basis of odour
Dimethyl sulphide	Highest measured concentration 75 times the HCV set on the basis of odour
Methyl mercaptan	Highest measured concentration five times the HCV set on the basis of odour
Stibine	Highest measured concentration forty-four times the HCV
Toluene	Highest measured concentration four times the HCV
Micro-organisms	No HCVs

In addition to the substances listed in Classes A and B above the Committee on Toxicity also considered 1,2-dichloroethane and chromium in detail, due to adopting a threshold of 75 per cent of the HCV.

The assessment of risks associated with exposure to landfill site is driven firstly by the relatively low HCVs derived for a number of substances. The HCVs for genotoxic carcinogens were set at concentrations which represent extremely low risks to health, following the “index dose” approach adopted for the assessment of health risks associated with contaminated land (Defra and Environment Agency, 2002a).

Also, a very low Tolerable Daily Intake value has been set for dioxins and furans reflecting their attributed endocrine disrupting properties with possible implications for child development. This resulted in their identification as a priority for investigation at both sites. However, the concentrations measured in this study with the exception of a single high value at Site B were typical of concentrations measured at urban and rural sites in the UK.

6.3 Recommendations

It is recommended that further investigation of the higher priority substances highlighted in the semi-quantitative risk assessment should be carried out. The highest priority substances identified in this project are carcinogens. The HCVs for these substances are specified at a level which represents a minimal risk to health, and consequently the measured concentrations are not likely to give rise to any significant or detectable adverse health effects in local populations.

Any further investigation should be focused on verifying whether levels of these substances are present in the vicinity of landfill sites at levels of potential concern. Possible sources of these substances should also be investigated. The concentrations and exposure intakes of these substances at receptors within close proximity to landfill sites accepting municipal waste should be evaluated. If needed, appropriate monitoring, emissions reduction and/or regulatory measures could then be designed and implemented.

The HCVs used in this study are set at a level at which any increase in carcinogenic risk is exceedingly low. In view of this, pending any further investigation, it is not recommended that additional control measures should be implemented, over and above the best practice controls on landfill gas collection and combustion that should be employed at landfill sites throughout the UK.

Chromium was identified as a potential carcinogen, although not at levels sufficient to make it a priority for further investigation. Chromium can exist in a number of oxidation states, referred to as chromium (II), chromium (III) and chromium (VI). Only chromium (VI) is a potential carcinogen, but chromium is not commonly encountered in this form. For the purposes of this study, it was assumed that chromium was present as chromium (VI). A study to investigate the speciation between chromium (II), chromium (III) and chromium (VI) at landfill sites is recommended.

6.4 Other observations

6.4.1 Dioxins and furans

The study found a single high level of dioxins and furans – that is, one sample out of the 64 measurements taken. There is no evidence of any unusual activity at the site which could have given rise to the high reading.

However, if this high concentration is representative of levels close to the site, it would be expected that dioxins and furans would be deposited in the soils in this area, and would accumulate because of their persistence in soils and vegetation. It would therefore be expected that levels of dioxins and furans in the soils in this area would be elevated. However, low levels of dioxins and furans were measured in soils on the north-east side of Site B near to where the high airborne concentration was measured. This indicates that the single high value is not representative of long-term operations at the site.

The study found that concentrations of four particular dioxin and furan congeners were higher downwind of the sites than upwind of the sites:

- 1,2,3,4,6,7,8-heptachloro dibenzo dioxin
- octachloro dibenzo dioxin
- 1,2,3,4,6,7,8-heptachloro dibenzo furan
- octachloro dibenzo furan

6.4.2 Bacteria and fungi

The values obtained for total bacteria and fungi at Sites A and B were above the tentative health criteria values. This suggests that people living in close proximity to landfill sites similar to Sites A and B might experience an increased incidence of effects such as runny nose, throat irritation, cough, sneeze, or exacerbation of asthma.

6.4.3 Sulphur dioxide and PM_{10}

The continuous monitoring data suggested that there are rare episodes when total sulphur dioxide concentrations exceed the HCV. This could potentially put asthmatics at a greater risk of experiencing an asthmatic episode. In addition, it is possible that total peak concentrations of PM_{10} could present a slight increase in risk of adverse effects for individuals with compromised cardio-respiratory function. However, the measured concentrations were comparable to those that would be identified at many other urban and rural locations in the UK. Also the measured levels of these substances included a proportion of exposure due to emissions from sources

other than the landfill sites, such as road traffic. In view of this, they are not viewed as priorities for further investigation.

6.4.2 Practical issues

This project provided a number of insights into measurement of airborne pollutants around landfill sites. Some key issues are discussed in Section 4.2.5.

The surface emissions monitoring protocol could helpfully have provided for an initial walkover survey to identify the principal sources of surface emissions. These can then be tested specifically, and worked up to provide an overall site emission estimate if required. This would be a better use of resources than the present system which required large numbers of measurements to be made, many of which may be redundant. These measures have been implemented in subsequent revisions to the Environment Agency guidance.

6.5 Further research

1 It is recommended that the next step in this research should be to take measurements at nearby receptor locations for the specific priority substances highlighted in this report. Meteorological measurements would need to be taken concurrently to allow the results to be properly interpreted. The measurement techniques developed in this project would give sufficient resolution for a study of this nature. The study would need to be carefully designed to provide results suitable for assessing the contribution of the landfill to the measured concentrations.

2 The incidence of respiratory disease in people living close to landfill sites should be investigated. Work in this area should be designed to distinguish the influence of the landfill site from other actual or perceived sources of symptoms, or other genetic or environmental factors. The study should also be designed to avoid the risk of skewing as a result of individuals incorrectly assigning the cause of respiratory symptoms to the landfill site.

3 Further source and site boundary measurements of dioxins and furans are recommended, at a wider range of landfill sites. This would provide evidence as to whether the single high value measured in this project is representative of landfills more widely, or whether it is not indicative of a widespread issue.

4 It is recommended that emissions of PAHs from landfill sites should be studied in more detail. The most likely source of PAHs is emissions from landfill gas flares and engines.

5 There are no additional health concerns for which epidemiological investigation is indicated by the results of this study.

Finally, a study of sites accepting wastes other than municipal solid waste is recommended. This could develop the techniques used in the present study. Any such research would need to take account of the current change in disposal practice away from co-disposal of household and hazardous wastes to disposal in segregated facilities with pre-treatment of biodegradable wastes.

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Glossary

Abstraction: The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality.

Acid gases: Any substance that dissolves in water to give an acid.

Aerobe: An organism that requires oxygen.

Ambient air: Outdoor air in the troposphere, excluding work places.

Assessment: Any method used to measure, calculate, predict or estimate the level of a pollutant.

Aquifer: An underground water-bearing layer of porous rock in which water can be stored and through which it can flow, after it has infiltrated from either the surface or another underground source.

Arbitrary release rate: A specified release rate used in a modelling study to allow the results to be factored to give an actual release rate.

Atmospheric modelling: A 3-D representation of the potential pathways and fate of pollutants in the atmosphere.

Attenuation: General term for a reduction in magnitude/intensity/concentration of a substance dispersed in a gaseous or liquid medium.

Bacteria: A group of micro–organisms with a primitive cellular structure, in which the genetic material is not retained within an internal membrane (nucleus).

Baseline: In the context of environment quality, a measure of environmental quality with the influence of the source under consideration removed

Bioaerosols: Biologically derived airborne particles that are living or originate from living organisms, including microorganisms that are culturable, nonculturable or dead. Bioaerosols are ubiquitous in nature and may be modified by human activities.

Biodegradable: A material which is capable of being broken down, usually by micro-organisms, into basic elements.

Congenital anomalies: Any anomaly, functional or structural, that presents in infancy or later in life and is caused by events preceding birth, whether inherited or acquired.

Borehole: A hole drilled into the ground to monitor the abstraction/pollution concentrations in aquifers.

Carcinogen: Something which causes cancer to occur by causing changes in cell DNA.

Carcinogenicity: A measure of the potential of a substance to cause cancer.

Chemical conversion: The changing of one substance or compound to another by chemical means.

Chromosomal anomalies: Structural abnormality in DNA.

Combustion: A chemical reaction in which fuel combines with oxygen with the evolution of oxygen, burning.

Conceptual model: A representation of a process, often presented pictorially, to assist in understanding and evaluation of the process. Here, the Conceptual Model was used to identify potential sources of emissions; to contribute to the design of survey work; and to develop methods for evaluating the data.

Confidence concentrations: a measure of the uncertainty associated with a numerical value, or the likely range of its values

Congener: In this report, one of the group of closely-related chemicals which makes up the family of 70 dioxins and 135 furans.

Congener profile: The pattern of congeners in an environmental sample containing dioxins and furans

De novo: Production from anew – for example, the generation of a numerical value from first principles or original research

Degradation: The loss of resilience or characteristics of a material

Detection limits: The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.

Deposition: The process of removing air pollutants from the atmosphere by impingement on the ground or surface features– either in precipitation ("wet deposition") or as airborne substances ("dry deposition").

Diffusion tube: A tube used to measure pollutant concentrations in ambient air by adsorbing suspended or dissolved particles from the air onto a substrate for subsequent analysis.

Dioxins and furans: A family of highly toxic chlorinated organic compounds formed when compounds containing carbon and chlorine are burned at relatively low temperatures. There are 70 dioxins and 135 furans

Dispersion: The dilution and reduction of concentration of pollutants in air, water or other medium.

Dose: The quantity of a substance or the amount of energy either in a single application or experienced over an interval of time.

Down's syndrome: A chromosomal anomaly that occurs in 1.3 per 1000 births where an error in cell development results in 47 chromosomes rather than the usual 46. The extra gene material slightly changes the orderly development of the body and brain.

Dust: Solids suspended in air as a result of the disintegration of matter; often called airborne particulate matter.

Emission rate: The amount of pollutant discharged per unit time.

Endotoxin: Certain (toxic) substances found within bacterial cells and which are released only following damage to cells.

Epidemiology: A scientific process which attempts to link the effects of factors such as lifestyle or exposure to toxic chemicals to disease and, if relevant, mortality. Statistical correlations are

developed whose purpose is ultimately to indicate the degree of risk that someone with a particular exposure pattern, lifestyle or genetic profile has of contracting a specific disease.

Epispadias: Epispadias is a rare congenital (present from birth) defect in which the opening of the urethra is in an abnormal location. In boys with epispadias, the urethra generally opens on the top or side, rather than the tip, of the penis, though it is possible for the urethra to be open the entire length of the penis. In girls, the opening is usually between the clitoris and the labia but may be in the abdomen

Exposure: Contact with a chemical, biological or physical hazard.

Flare: The flame produced by the burning of surplus and residual gases within or above a flame pipe at an oil refinery, chemical factory or landfill site.

Flue gas: The air coming out of a chimney after combustion or any other process

Food chain: A series of organisms through which energy is transferred with each link feeding on the one below it and forming the prey by the one above it.

Fugitive emissions: Any chemical or mixture of chemicals in any physical form which represents an unanticipated or uncontrolled leak from an industrial process.

Fungi: A group of micro–organisms with a more complicated cellular structure than bacteria, in which the hereditary genetic material is retained within an internal membrane, forming a nucleus.

Genotoxic: Chemicals which are capable of causing damage to DNA.

Geology: the study of the rocks and similar substances that make up the Earth's surface

Geosphere: All 4 spheres of the earth taken together (lithosphere, hydrosphere, atmosphere, biosphere). It therefore extends from the bottom of lithosphere to the top of atmosphere.

Gram-negative bacteria: Bacteria with a more complex cell wall than Gram-positive bacteria. Many Gram-negative bacteria are pathogens – that is, they can cause disease in a host organism

Groundwater: Water occurring within the saturation zone of an aquifer and can be considered as a large natural reservoir.

Hazard: A circumstance that may pose a risk of harm

Health Criteria Value (HCV): A value for a substance such as an airborne concentration which can be used to establish whether a particular effect or exposure could be significant. For the purposes of this project, the HCVs were identified to represent the levels of substances above which risks to human health might be deemed to be more significant and warrant further investigation.

Hydrocarbon: An organic compound containing the elements hydrogen and carbon.

Hydrogeology: The study of groundwater.

Hypospadias: An abnormality of the penis in which the urethra opens on the underside.

Irrigation: The application of water to arable soils so that plant growth may be initiated or maintained.

Landfill gas (LFG): Landfill gas is generated in landfill sites by the anaerobic decomposition of domestic refuse. It consists of a mixture of gases and is colourless with an offensive odour due to the presence of trace organic compounds.

Landfill site: A site for the disposal of controlled wastes.

Leachate: The liquid generated within a landfill site as a result of rain falling on the site, and the moisture contained in the waste itself.

Linear correlation: A direct relationship between one variable and another

Maternal toxicity: An effect in a pregnant/lactating female that differs in nature or degree from that of a non pregnant/lactating female receiving the same dosage.

Mesophilic: Describing an organism which grows best in temperatures between 10°C and 50°C

Micro-organisms: A living organism of microscopic or ultramicroscopic size.

Mould: Certain multicellular fungal organisms, characteristically having bodies composed of a cottony mass.

Municipal Solid Waste: The common name given to the combined residential and commercial waste material normally collected by a local authority

Neurotoxic: A chemical whose primary action is on the CNS (Central Nervous System).

Non-chromosomal anomalies: Defects that are not attributable to abnormalities in DNA structure

Non-genotoxic mechanism: The mechanism whereby a large group of apparently non-related compounds can cause malignant tumours despite a lack of demonstrable ability to interact directly with DNA

Occupational exposure standards: The concentration of an airborne substance, averaged over a reference period, for which, according to current knowledge, there is no evidence that it is likely to be injurious to employees if they are exposed by inhalation, day after day, and which is specified in an approved list.

Organic compounds: Naturally occurring or synthetic substances containing carbon together with mainly hydrogen, nitrogen, oxygen, chlorine and/or sulphur.

Pathway: The physical course a chemical or pollutant takes from its source to the exposed organism.

Pedigree: In the context of this project, a measure of the quality or reliability of a piece of data

Percentile: If a set of values is placed in order from the lowest to the highest, the Nth percentile value is the value lying *N%* of the way from the lowest to the highest value.

Permeability: A measure of the speed with which water can move through a solid medium.

$PM_{2.5}$: Particulate matter with a diameter less than 2.5µm which can be inhaled beyond the larynx and penetrate to the inner lungs, also called respirable particles.

PM_{10}: Particulate matter with a diameter less than 10µm which can be inhaled beyond the larynx.

Polychlorinated Biphenyls (PCBs): Chlorinated hydrocarbons, highly persistent bioaccumulative pollutants, formerly used as plasticizers and in transformer-cooling oils to enhance flame retardance and insulating properties.

Polycyclic Aromatic Hydrocarbons (PAHs): A large group of organic compounds widely distributed in the atmosphere, whose molecular structures contain two or more aromatic rings fused together.

Potable: water suitable for drinking and cooking.

Receptor: In the context of this project, an individual, group of people, ecosystem or other location which could be affected by a source of pollution.

Respiratory sensitisation: When substances, such as isocyanates, are inhaled they can induce changes in the body's immune system. This may mean that the next time a person is exposed to the same substance their body reacts very dramatically, even if they have only been exposed to a very small amount of the substance. If this happens, the person is said to suffer from respiratory sensitisation.

Risk assessment: A study of the likelihood and severity of a particular hazard occurring.

Risk drivers: Main factors that contribute to a particular level of risk.

Source: The place, places or areas from where a pollutant is released into the atmosphere or water, or where noise is generated.

Teratogen: Any medication, chemical, infectious disease, or environmental agent that might interfere with the normal development of a foetus and result in the loss of a pregnancy, a birth defect or a pregnancy complication.

Teratogenicity: The risk of production of non-heritable reproductive defects of, relating to, or causing developmental malformations. Substances such as chemicals or radiation that cause abnormal development of an embryo.

Tipping face: That part of the landfill where newly arrived waste is placed.

Toxic equivalent: Dioxins and furans are found in the food chain as complex mixtures of congeners. To account for this, a system of toxic equivalents is used to weight the toxicity of the less toxic congeners as fractions of the toxicity of the most toxic 2,3,7,8-TCDD.

Toxicity: The degree to which a chemical substance elicits an adverse effect upon the biological system of an organism exposed to the substance over a designated time period

Toxicology: The scientific study of the characteristics and effects of chemicals on health.

TOMPS: toxic organic micropollutants – a group of chemicals including polycyclic aromatic hydrocarbons (PAHs), dioxins and furans, and polycyclic biphenyls (PCBs)

Volatile Organic Compounds (VOCs): Organic compounds which have a significant vapour pressure at ambient temperatures

Yeasts: A species of single-celled fungi

List of abbreviations

BaP	Benz(a)Pyrene
CAS number	Chemical Abstracts Service Registry number, a unique number identifying an individual chemical compound
CNS	Central Nervous System
DETR	Department of the Environment, Transport and the Regions
DREAM	Dioxin Risk and Exposure Assessment Model
EBS	Engineering Barrier System
EPAQS	Expert Panel on Air Quality Standards
ESART	Environment Services Association Research Trust
HCl	Hydrogen chloride
HCV	Health Criteria Value
HF	Hydrogen Fluoride
HMIP	Her Majesty's Inspectorate of Pollution
H_2S	Hydrogen Sulphide
GC-MS	Gas Chromatography/Mass Spectrometry
HCV	Health Criteria Value
HSE	Health and Safety Executive
IEH	Institute for Environment and Health
JECFA	Joint Expert Committee on Food Additives
LFG	Landfill Gas
LOAEL	Lowest Observed Adverse Effect Level
MW	Molecular Weight
NCAS	National Compliance Assessment Service
NCRAOA	National Centre for Risk Assessment and Options Appraisal
NMHC	New Modular Hyperelliptic Curves
NOAEL	No Observed Adverse Effect Level
NO_x	Nitrogen oxides
OEL	Occupational Exposure Limit
PAH(s)	Polycyclic aromatic hydrocarbons
PCB(s)	Polycyclic biphenyls
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter less than 2.5 microns
PM_{10}	Particulate Matter with an aerodynamic diameter less than 10 microns
RfD	Reference Dose
SO_2	Sulphur Dioxide
TDI	Tolerable Daily Intake
TOMPS	Toxic Organic Micropollutants
USEPA	United States Environmental Protection Agency
VOC(s)	Volatile Organic Compounds

List of chemicals

CAS Number	Name	Formula
83-35-9	acenaphthene	$C_{10}H_6$-1,8-CH_2CH_2
83-32-9	acenaphthylene	$C_{10}H_6$-1,8-CH_2CH_2
75-07-0	acetaldehyde	C_2H_4O
67-64-1	acetone (propanone)	$(CH_3)_2CO$
62-53-3	aniline	C_6H_7N
120-12-7	anthracene	$C_{14}H_{10}$
7440-36-0	antimony	Sb
7400-38-2	arsenic	As
7784-42-1	arsine	AsH_3
71-43-2	benzene	C_6H_6
56-55-3	benzo (a) anthracene	$C_{20}H_{12}$
50-32-8	benzo (a) pyrene	$C_{20}H_{12}$
205-99-2	benzo (b) fluoranthene	$C_{20}H_{12}$
191-24-2	benzo (ghi) perylene	$C_{22}H_{12}$
207-08-9	benzo (k) fluoranthene	$C_{20}H_{12}$
92-52-4	biphenyl	C_6H_5-C_6H_5
74-96-4	bromoethane	C_2H_5Br
106-99-0	1,3-butadiene	C_4H_6
71-36-3	butan-1-ol	$C_4H_{10}O$
78-92-2	butan-2-ol	$C_4H_{10}O$
109-79-5	butanethiol	$C_4H_{10}S$
78-93-3	2-butanone (2-butanol)	C_4H_8O
111-76-2	2-butoxyethanol	$CH_3(CH_2)_3OCH_2CH_2OH$
123-86-4	butyl acetate	$CH_3COOCH_2CH_2CH_2CH_3$
107-92-6	butyric acid	$C_4H_8O_2$
7440-43-9	cadmium	Cd
75-15-0	carbon disulphide	CS_2
630-08-0	carbon monoxide	CO
108-90-7	chlorobenzene	C_6H_5Cl
75-45-6	chlorodifluoromethane	$CHClF_2$
75-00-3	chloroethane	C_2H_5Cl
75-01-4	chloroethene (vinyl chloride)	C_2H_3Cl
67-66-3	chloroform (trichloromethane)	$CHCl_3$
74-87-3	chloromethane	CH_3Cl
7440-47-3	Chromium	Cr
218-01-9	Chrysene	$C_{18}H_{12}$
7440-48-4	Cobalt	Co
7440-50-8	Copper	Cu
57-12-5	cyanide compounds	CN HCN
124-18-5	decane	$C_{10}H_{22}$
53-70-3	dibenzo (a,h) anthracene	$C_{20}H_{12}$
95-50-1	1,2-dichlorobenzene	$C_6H_4Cl_2$
106-46-7	1,4-dichlorobenzene	$C_6H_4Cl_2$
75-71-8	dichlor(o)difluoromethane	CCl_2F_2
75-34-3	1,1-dichloroethane	$C_2H_4Cl_2$

CAS Number	Name	Formula
107-06-2	1,2-dichloroethane	$C_2H_4Cl_2$
156-59-2	1,1-dichloroethene (cis-1,2-dichloroethylene)	$C_2H_2Cl_2$
156-59-2	1,2-dichloroethene (cis-1,2-dichloroethylene)	$C_2H_2Cl_2$
156-60-5	trans-1,2-dichloroethene (trans-1,2-dichloroethylene)	$C_2H_2Cl_2$
75-09-2	dichloromethane	CH_2Cl_2
78-87-5	1,2-dichloropropane	$C_3H_6Cl_2$
352-93-2	diethyl sulphide (ethyl sulphide)	$C_4H_{10}S$
75-45-6	difluorochloromethane (chlorodifluoromethane)	$CHClF_2$
624-92-0	dimethyl disulphide (methyl disulphide)	$C_2H_6S_2$
75-18-3	dimethyl sulphide (methyl sulphide)	C_2H_6S
75-08-1	ethanethiol (ethyl mercaptan)	C_2H_6S
141-78-6	ethyl acetate	$CH_3COOC_2H_5$
100-41-4	ethylbenzene	C_8H_{10}
105-54-4	ethyl butyrate	$C_6H_{12}O_2$
1678-91-7	ethylcyclohexane	C_8H_{16}
104-76-7	2-ethyl-1-hexanol	$C_8H_{18}O$
622-96-8	p-ethyltoluene	C_9H_{12}
206-44-0	fluoranthene	$C_{16}H_{10}$
7782-41-4	fluorine	F_2
50-00-0	formaldehyde (methanal)	CH_2O
142-82-5	heptane	C_7H_{16}
110-54-3	hexane	C_6H_{14}
7647-01-0	hydrogen chloride	HCl
7783-06-4	hydrogen sulphide	H_2S
193-39-5	indeno (123-cd) pyrene	$C_{22}H_{12}$
7439-92-1	lead	Pb
138-86-3	limonene	$C_{10}H_{16}$
7439-96-5	manganese	Mn
7085-19-0	mecoprop (-)-2-(4-chloro-o-tolyloxy) propionic acid	
7439-97-6	mercury	Hg
74-82-8	methane	CH_4
74-93-1	methanethiol (methyl mercaptan)	CH_4S
74411-14-6	methyl chlorophenoxy acetic acid (methyl 3-chlorophenoxyacetate)	
108-87-2	methylcyclohexane	C_7H_{14}
78-93-3	methylethylketone (2-butanone)	C_4H_8O
534-22-5	2-methylfuran	C_5H_6O
108-10-1	methyl isobutyl ketone	$CH_3COCH_2CH(CH_3)_2$
1634-04-4	methyl tert-butyl ether (MTBE)	$C_5H_{12}O$
91-20-3	naphthalene	$C_{10}H_8$
7440-02-0	nickel	Ni
10102-44-0	nitrogen dioxide	NO_2 or N_2O_4

CAS Number	Name	Formula
75-52-5	nitromethane	CH_3NO_2
10024-97-2	nitrous oxide	N_2O
111-84-2	nonane	C_9H_{20}
104-40-5	nonylphenol	$C_{15}H_{24}O$
111-65-9	octane	C_8H_{18}
87-86-5	pentachlorophenol	C_6HCl_5O
109-67-1	1-pentene	C_5H_{10}
85-01-8	phenanthrene	$C_{14}H_{10}$
108-95-2	phenol	C_6H_6O
7723-14-0	phosphorus	P
117-81-7	bis (2-ethyl hexyl) phthalate	$C_{24}H_{38}O_4$
75-33-2	propanethiol (isopropyl mercaptan)	C_3H_8S
67-63-0	propan-2-ol	$CH_3CHOHCH_3$
103-65-1	propylbenzene	C_9H_{12}
129-00-0	pyrene	$C_{16}H_{10}$
100-42-5	styrene	C_8H_8
7446-09-5	sulphur dioxide	SO_2
99-86-5	alpha-terpinene	$C_{10}H_{16}$
79-34-5	1,1,2,2-tetrachloroethane	$C_2H_2Cl_4$
127-18-4	tetrachloroethene (tetrachloroethylene)	C_2Cl_4
56-23-5	tetrachloromethane (carbon tetrachloride)	CCl_4
95-93-2 (1,2,4.5) 488-23-3 (1,2,3,4)	tetramethylbenzene	$C_{10}H_{14}$
7440-28-0	thallium	Tl
7440-31-5	tin	Sn
108-88-3	toluene	C_7H_8
71-55-6	1,1,1-trichloroethane	$C_2H_3Cl_3$
79-01-6	trichloroethene (trichloroethylene)	C_2HCl_3
75-69-4	trichlorofluoromethane (fluorotrichloromethane)	CCl_3F
95-63-6	1,2,4-trimethylbenzene	C_9H_{12}
7440-62-2	vanadium	V
108-38-3	m-xylene	C_8H_{10}
95-47-6	o-xylene	C_8H_{10}
106-42-3	p-xylene	C_8H_{10}
7440-66-6	zinc	Zn

Annex 1: Tables

Tables from Chapter 3: Risk screening and risk prioritisation

Table 3.1 Screening of potential exposure pathways

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
1	Acid gases	Flare Emissions	Atmospheric transport	None	None	Inhalation Exposure	Eye irritation, mild respiratory effects	Mild	Medium	Low	Assessed notwithstanding initial risk rating
2	Acid gases	Engine Emissions	Atmospheric transport	None	None	Inhalation Exposure	Eye irritation, mild respiratory effects	Mild	Medium	Low	Assessed notwithstanding initial risk rating
3	Acid gases	Flare Emissions	Deposition on Allotments & Gardens	None	None	Ingestion Exposure	Damage to plants	Negligible	Low	Near zero	No human health implications
4	Acid gases	Engine Emissions	Deposition on farmland	None	None	Ingestion Exposure	Damage to plants	Negligible	Low	Near zero	No human health implications
5	TOMPS	Flare Emissions	Atmospheric transport	None	None	Inhalation Exposure	Some carcinogens, some teratogens	Severe	Low	High/ Medium	Assessed
6	TOMPS	Flare Emissions	Deposition on Allotments & Gardens	None	None	Dermal Exposure	Some carcinogens, some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
7	TOMPS	Flare Emissions	Deposition on Allotments & Gardens	Consumption of Soils	None	Ingestion Exposure	Some carcinogens, some teratogens	Severe	Low	High/ Medium	Assessed
8	TOMPS	Flare Emissions	Deposition on Allotments & Gardens	Foods (local)	None	Ingestion Exposure	Some carcinogens, some teratogens	Severe	Low	High/ Medium	Assessed
9	TOMPS	Flare Emissions	Deposition on Farmland	None	None	Dermal Exposure	Some carcinogens, some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Public access to farmland not likely to be significant.
10	TOMPS	Flare Emissions	Deposition on Farmland	Consumption of Soils	None	Ingestion Exposure	Some carcinogens, some teratogens	Severe	Negligible	Low	Consumption of farm soils not likely to be significant following washing/cooking of produce. Public access to farmland not likely to be significant.
11	TOMPS	Flare Emissions	Deposition on Farmland	Foods (local)	None	Ingestion Exposure	Some carcinogens, some teratogens	Severe	Low	High/ Medium	Assessed

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
12	TOMPS	Flare Emissions	Deposition on Farmland	Foods (widespread)	None	Ingestion Exposure	Some carcinogens, some teratogens	Severe	Low	High/ Medium	Assessed
13	TOMPS	Engine Emissions	Atmospheric transport	None	None	Inhalation Exposure	Some carcinogens, some teratogens	Severe	Low	High/ Medium	Assessed
14	TOMPS	Engine Emissions	Deposition on Allotments & Gardens	None	None	Dermal Exposure	Some carcinogens, some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
15	TOMPS	Engine Emissions	Deposition on Allotments & Gardens	Consumption of Soils	None	Ingestion Exposure	Some carcinogens, some teratogens	Severe	Low	High/ Medium	Assessed
16	TOMPS	Engine Emissions	Deposition on Allotments & Gardens	Foods (local)	None	Ingestion Exposure	Some carcinogens, some teratogens	Severe	Low	High/ Medium	Assessed
17	TOMPS	Engine Emissions	Deposition on Farmland	None	None	Dermal Exposure	Some carcinogens, some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Public access to farmland not likely to be significant.
18	TOMPS	Engine Emissions	Deposition on Farmland	Consumption of Soils	None	Ingestion Exposure	Some carcinogens, some teratogens	Severe	Negligible	Low	Consumption of farm soils not likely to be significant following washing/cooking of produce. Public access to farmland not likely to be significant.
19	TOMPS	Engine Emissions	Deposition on Farmland	Foods (local)	None	Ingestion Exposure	Some carcinogens, some teratogens	Severe	Low	High/ Medium	Assessed
20	TOMPS	Engine Emissions	Deposition on Farmland	Foods (widespread)	None	Ingestion Exposure	Some carcinogens, some teratogens	Severe	Low	High/ Medium	Assessed
21	Organics	Flare Emissions	Atmospheric transport	None	None	Inhalation Exposure	Some carcinogens; some teratogens	Severe	Low	High/ Medium	Assessed
22	Organics	Engine Emissions	Atmospheric transport	None	None	Inhalation Exposure	Some carcinogens; some teratogens	Severe	Low	High/ Medium	Assessed

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
23	Organics	Leachate/ Surface water runoff	Groundwater	Surface water	Abstraction without treatment	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Low	High/ Medium	Assessed
24	Organics	Leachate/ Surface water runoff	Waste Transport	Deposition on Allotments & Gardens	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Not likely to accumulate.
25	Organics	Leachate/ Surface water runoff	Waste Transport	None	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Dermal exposure inefficient and unlikely to occur.
26	Organics	Leachate/ Surface water runoff	Waste Transport	Deposition on Allotments & Gardens	Consumption of Soils	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate.
27	Organics	Leachate/ Surface water runoff	Waste Transport	Deposition on Allotments & Gardens	Foods (local)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Not likely to accumulate.
28	Organics	Leachate/ Surface water runoff	Waste Transport	Deposition on Farmland	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Public access to farmland not likely to be significant.
29	Organics	Leachate/ Surface water runoff	Waste Transport	Deposition on Farmland	Consumption of Soils	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate. Consumption of farm soils not likely to be significant following washing/cooking of produce. Public access to farmland not likely to be significant.
30	Organics	Leachate/ Surface water runoff	Waste Transport	Deposition on Farmland	Foods (local)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate.
31	Organics	Leachate/ Surface water runoff	Waste Transport	Deposition on Farmland	Foods (widespread)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate.
32	Organics	Leachate/ Surface water runoff	Waste Transport	Inhalation	None	Inhalation Exposure	Some carcinogens; some teratogens	Severe	Low	High/ Medium	Assessed
33	Organics	Leachate/ Surface water runoff	Land based vermin e.g. rats e.g. rats	None	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
34	Organics	Leachate/ Surface water runoff	Land based vermin e.g. rats e.g. rats	Deposition on Allotments & Gardens	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
35	Organics	Leachate/ Surface water runoff	Land based vermin e.g. rats e.g. rats	Deposition on Allotments & Gardens	Consumption of Soils	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate.
36	Organics	Leachate/ Surface water runoff	Land based vermin e.g. rats e.g. rats	Deposition on Allotments & Gardens	Foods (local)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate.
37	Organics	Leachate/ Surface water runoff	Land based vermin e.g. rats e.g. rats	Deposition on Farmland	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Public access to farmland not likely to be significant.
38	Organics	Leachate/ Surface water runoff	Land based vermin e.g. rats	Deposition on Farmland	Consumption of Soils	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate.
39	Organics	Leachate/ Surface water runoff	Land based vermin e.g. rats	Deposition on Farmland	Foods (local)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate.
40	Organics	Leachate/ Surface water runoff	Land based vermin e.g. rats	Deposition on Farmland	Foods (widespread)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate.
41	Organics	Leachate/ Surface water runoff	Avian vermin e.g. gulls	None	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
42	Organics	Leachate/ Surface water runoff	Avian vermin e.g. gulls	Deposition on Allotments & Gardens	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
43	Organics	Leachate/ Surface water runoff	Avian vermin e.g. gulls	Deposition on Allotments & Gardens	Consumption of Soils	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate.

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
44	Organics	Leachate/ Surface water runoff	Avian vermin e.g. gulls	Deposition on Allotments & Gardens	Foods (local)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Not likely to accumulate.
45	Organics	Leachate/ Surface water runoff	Avian vermin e.g. gulls	Deposition on Farmland	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Public access to farmland not likely to be significant.
46	Organics	Leachate/ Surface water runoff	Avian vermin e.g. gulls	Deposition on Farmland	Consumption of Soils	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	A
47	Organics	Leachate/ Surface water runoff	Avian vermin e.g. gulls	Deposition on Farmland	Foods (local)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	A
48	Organics	Leachate/ Surface water runoff	Avian vermin e.g. gulls	Deposition on Farmland	Foods (widespread)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	A
49	Organics	Leachate/ Surface water runoff	Water Abstraction & Treatment	None	None	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Likely to be destroyed during water treatment.
49a	Organics	Leachate/ Surface water runoff	Water Abstraction & Treatment	Washing	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Likely to be destroyed during water treatment; dermal exposure likely to be minimal
50	Organics	Leachate/ Surface water runoff	Water Abstraction & Treatment	Use on Farmland	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Likely to be destroyed if mains water used. Transfer of contaminants through the skin is inefficient and unlikely to occur. Public access to farmland not likely to be significant.
51	Organics	Leachate/ Surface water runoff	Water Abstraction & Treatment	Use on Farmland	Consumption of Soils	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Likely to be destroyed if mains water used. Public access to farmland not likely to be significant. Consumption of farm soils not likely to be significant following washing/cooking of produce.
52	Organics	Leachate/ Surface water runoff	Water Abstraction & Treatment	Use on Farmland	Foods (local)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Likely to be destroyed if mains water used. Likely to be removed during washing/cooking of produce.

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
53	Organics	Leachate/ Surface water runoff	Water Abstraction & Treatment	Use on Farmland	Foods (widespread)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Likely to be destroyed if mains water used. Likely to be removed during washing/cooking of produce.
54	Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	None	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
55	Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	None	None	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Low	High/ Medium	Assessed
56	Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	Use on allotments & gardens				Severe	Low	High/ Medium	Assessed
57	Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	Use on Farmland	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Public access to farmland not likely to be significant.
58	Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	Use on Farmland	Consumption of Soils	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Public access to farmland not likely to be significant. Consumption of farm soils not likely to be significant following washing/cooking of produce.
59	Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	Use on Farmland	Foods (local)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Low	High/ Medium	Assessed
60	Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	Use on Farmland	Foods (widespread)	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Low	High/ Medium	Assessed
61	Organics	Leachate/ Surface water runoff	Absorption by Fish	Foods	None	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Low	High/ Medium	Assessed
62	Organics	Leachate/ Surface water runoff	Recreation	None	None	Ingestion Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Significant exposure during recreation unlikely
63	Organics	Landfill Gas	None	None	None	Dermal Exposure	Some carcinogens; some teratogens	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
64	Organics	Landfill Gas	None	None	None	Inhalation Exposure	Some carcinogens; some teratogens	Severe	Low	High/ Medium	Assessed
65	Dusts + metal/ TOMPS	Tipping	Land based vermin e.g. rats	None	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
66	Dusts + metal/ TOMPS	Tipping	Land based vermin e.g. rats	Transmission to Allotments & Gardens	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	No reports to site of vermin on gardens/allotments. Transfer of contaminants through the skin is inefficient and unlikely to occur.
67	Dusts + metal/ TOMPS	Tipping	Land based vermin e.g. rats	Transmission to Allotments & Gardens	Consumption of Soils	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	No reports to site of vermin on gardens/allotments.
68	Dusts + metal/ TOMPS	Tipping	Land based vermin e.g. rats	Transmission to Allotments & Gardens	Foods (local)	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	No reports to site of vermin on gardens/allotments.
69	Dusts + metal/ TOMPS	Tipping	Land based vermin e.g. rats	Transmission to Farmland	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Public access to farmland not likely to be significant.
70	Dusts + metal/ TOMPS	Tipping	Land based vermin e.g. rats	Transmission to Farmland	Consumption of Soils	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Public access to farmland not likely to be significant. Consumption of farm soils not likely to be significant following washing/cooking of produce.
71	Dusts + metal/ TOMPS	Tipping	Land based vermin e.g. rats	Transmission to Farmland	Foods (local)	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Needs to be assessed
72	Dusts + metal/ TOMPS	Tipping	Land based vermin e.g. rats	Transmission to Farmland	Foods (widespread)	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Needs to be assessed

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
73	Dusts + metal/ TOMPS	Tipping	Avian vermin e.g. gulls	None	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
74	Dusts + metal/ TOMPS	Tipping	Avian vermin e.g. gulls	Transmission to Allotments & Gardens	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	No reports to site of vermin on gardens/allotments. Transfer of contaminants through the skin is inefficient and unlikely to occur.
75	Dusts + metal/ TOMPS	Tipping	Avian vermin e.g. gulls	Transmission to Allotments & Gardens	Consumption of Soils	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	No reports to site of vermin on gardens/allotments.
76	Dusts + metal/ TOMPS	Tipping	Avian vermin e.g. gulls	Transmission to Allotments & Gardens	Foods (local)	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	No reports to site of vermin on gardens/allotments.
77	Dusts + metal/ TOMPS	Tipping	Avian vermin e.g. gulls	Transmission to Farmland	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Public access to farmland not likely to be significant.
78	Dusts + metal/ TOMPS	Tipping	Avian vermin e.g. gulls	Transmission to Farmland	Consumption of Soils	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Public access to farmland not likely to be significant. Consumption of farm soils not likely to be significant following washing/cooking of produce.
79	Dusts + metal/ TOMPS	Tipping	Avian vermin e.g. gulls	Transmission to Farmland	Foods (local)	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Needs to be assessed
80	Dusts + metal/ TOMPS	Tipping	Avian vermin e.g. gulls	Transmission to Farmland	Foods (widespread)	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Needs to be assessed

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
81	Dusts + metal/ TOMPS	Tipping	None	None	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
82	Dusts + metal/ TOMPS	Tipping	None	None	None	Inhalation	Respiratory ill health; Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Moderate/Severe	Low	High/ Medium/Low	Assessed
83	Dusts + metal/ TOMPS	Tipping	Deposition on Allotments & Gardens	None	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
84	Dusts + metal/ TOMPS	Tipping	Deposition on Allotments & Gardens	Consumption of Soils	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Assessed
85	Dusts + metal/ TOMPS	Tipping	Deposition on Allotments & Gardens	Foods (local)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Assessed
86	Dusts + metal/ TOMPS	Tipping	Deposition on Farmland	None	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
87	Dusts + metal/ TOMPS	Tipping	Deposition on Farmland	Consumption of Soils	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Consumption of farm soils not likely to be significant following washing/cooking of produce. Public access to farmland not likely to be significant.
88	Dusts + metal/ TOMPS	Tipping	Deposition on Farmland	Foods (local)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Assessed

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
89	Dusts + metal/ TOMPS	Tipping	Deposition on Farmland	Foods (widespread)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Assessed
90	Dusts + metal/ TOMPS	Tipping	None	None	None	Inhalation Exposure	Respiratory ill health; Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Moderate/Severe	Low	High/ Medium/Low	Assessed
91	Dusts + metal/ TOMPS	Waste in Vehicles	None	None	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	On-site traffic may be relevant; off-site traffic outside scope. Transfer of contaminants through the skin is inefficient and unlikely to occur.
92	Dusts + metal/ TOMPS	Waste in Vehicles	Deposition on Allotments & Gardens	None	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
93	Dusts + metal/ TOMPS	Waste in Vehicles	Deposition on Allotments & Gardens	Consumption of Soils	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Assessed. On-site traffic may be relevant; off-site traffic outside scope.
94	Dusts + metal/ TOMPS	Waste in Vehicles	Deposition on Allotments & Gardens	Foods (local)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Assessed. On-site traffic may be relevant; off-site traffic outside scope.
95	Dusts + metal/ TOMPS	Waste in Vehicles	Deposition on Farmland	None	None	Dermal Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	On-site traffic may be relevant; off-site traffic outside scope. Transfer of contaminants through the skin is inefficient and unlikely to occur.
96	Dusts + metal/ TOMPS	Waste in Vehicles	Deposition on Farmland	Consumption of Soils	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Negligible	Low	Consumption of farm soils not likely to be significant following washing/cooking of produce. Public access to farmland not likely to be significant.

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
97	Dusts + metal/ TOMPS	Waste in Vehicles	Deposition on Farmland	Foods (local)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Assessed. On-site traffic may be relevant; off-site traffic outside scope.
98	Dusts + metal/ TOMPS	Waste in Vehicles	Deposition on Farmland	Foods (widespread)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Severe	Low	High/ Medium	Assessed. On-site traffic may be relevant; off-site traffic outside scope.
99	Dusts + metal/ TOMPS	Waste in Vehicles	None	None	None	Inhalation Exposure	Respiratory ill-health; Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	Moderate/Severe	Low	High/ Medium/Low	Assessed. On-site traffic may be relevant; off-site traffic outside scope.
100	Bioaerosols	Tipping	Land based vermin e.g. rats	None	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
101	Bioaerosols	Tipping	Land based vermin e.g. rats	Transmission to Allotments & Gardens	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. No reports to site of vermin on gardens/allotments.
102	Bioaerosols	Tipping	Land based vermin e.g. rats	Transmission to Allotments & Gardens	Consumption of Soils	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	No reports to site of vermin on gardens/allotments.
103	Bioaerosols	Tipping	Land based vermin e.g. rats	Transmission to Allotments & Gardens	Foods (local)	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	No reports to site of vermin on gardens/allotments. Micro-organisms not persistent.
104	Bioaerosols	Tipping	Land based vermin e.g. rats	Transmission to Farmland	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Public access to farmland not likely to be significant. Transfer of contaminants through the skin is inefficient and unlikely to occur.
105	Bioaerosols	Tipping	Land based vermin e.g. rats	Transmission to Farmland	Consumption of Soils	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Public access to farmland not likely to be significant. Consumption of farm soils not likely to be significant following washing/cooking of produce.

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
106	Bioaerosols	Tipping	Land based vermin e.g. rats	Transmission to Farmland	Foods (local)	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Micro-organisms not persistent. Likely to be destroyed during food preparation.
107	Bioaerosols	Tipping	Land based vermin e.g. rats	Transmission to Farmland	Foods (widespread)	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Micro-organisms not persistent. Likely to be destroyed during food preparation.
108	Bioaerosols	Tipping	Avian vermin e.g. gulls	None	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
109	Bioaerosols	Tipping	Avian vermin e.g. gulls	Transmission to Allotments & Gardens	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. No reports to site of vermin on gardens/allotments.
110	Bioaerosols	Tipping	Avian vermin e.g. gulls	Transmission to Allotments & Gardens	Consumption of Soils	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	No reports to site of vermin on gardens/allotments.
111	Bioaerosols	Tipping	Avian vermin e.g. gulls	Transmission to Allotments & Gardens	Foods (local)	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	No reports to site of vermin on gardens/allotments. Micro-organisms not persistent.
112	Bioaerosols	Tipping	Avian vermin e.g. gulls	Transmission to Farmland	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Public access to farmland not likely to be significant. Transfer of contaminants through the skin is inefficient and unlikely to occur.
113	Bioaerosols	Tipping	Avian vermin e.g. gulls	Transmission to Farmland	Consumption of Soils	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Public access to farmland not likely to be significant. Consumption of farm soils not likely to be significant following washing/cooking of produce.
114	Bioaerosols	Tipping	Avian vermin e.g. gulls	Transmission to Farmland	Foods (local)	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Micro-organisms not persistent. Likely to be destroyed during food preparation.
115	Bioaerosols	Tipping	Avian vermin e.g. gulls	Transmission to Farmland	Foods (widespread)	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Micro-organisms not persistent. Likely to be destroyed during food preparation.
116	Bioaerosols	Tipping	None	None	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
117	Bioaerosols	Tipping	Deposition on Allotments & Gardens	None	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
118	Bioaerosols	Tipping	Deposition on Allotments & Gardens	Consumption of Soils	None	Ingestion Exposure	Possible infection or mild ill-health	Mild	Low	Low	
119	Bioaerosols	Tipping	Deposition on Allotments & Gardens	Foods (local)	None	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Micro-organisms not persistent. Likely to be destroyed during food preparation.
120	Bioaerosols	Tipping	Deposition on Farmland	None	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Public exposure to farmland not likely to be significant
121	Bioaerosols	Tipping	Deposition on Farmland	Consumption of Soils	None	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Public exposure to farmland not likely to be significant Consumption of farm soils not likely to be significant following washing/cooking of produce.
122	Bioaerosols	Tipping	Deposition on Farmland	Foods (local)	None	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Micro-organisms not persistent. Likely to be destroyed during food preparation.
123	Bioaerosols	Tipping	Deposition on Farmland	Foods (widespread)		Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Micro-organisms not persistent. Likely to be destroyed during food preparation.
124	Bioaerosols	Tipping	None	None	None	Inhalation Exposure	Possible infection or mild ill-health	Mild	Medium	Low	Assessed
125	Bioaerosols	Waste in Vehicles	None	None	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
126	Bioaerosols	Waste in Vehicles	Deposition on Allotments & Gardens	None	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur.
127	Bioaerosols	Waste in Vehicles	Deposition on Allotments & Gardens	Consumption of Soils	None	Ingestion Exposure	Possible infection or mild ill-health	Mild	Low	Low	On-site traffic may be relevant; off-site traffic outside scope.

SPR combination number	Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Consequence (Significance of Hazard)	Probability	Initial Risk Rating	Comment
			Pathway 1	Pathway 2	Pathway 3						
128	Bioaerosols	Waste in Vehicles	Deposition on Allotments & Gardens	Foods (local)	None	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Likely to be destroyed during food preparation.
129	Bioaerosols	Waste in Vehicles	Deposition on Farmland	None	None	Dermal Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Transfer of contaminants through the skin is inefficient and unlikely to occur. Public exposure to farmland not likely to be significant
130	Bioaerosols	Waste in Vehicles	Deposition on Farmland	Consumption of Soils	None	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Public exposure to farmland not likely to be significant Consumption of farm soils not likely to be significant following washing/cooking of produce.
131	Bioaerosols	Waste in Vehicles	Deposition on Farmland	Foods (local)	None	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Micro-organisms not persistent. Likely to be destroyed during food preparation.
132	Bioaerosols	Waste in Vehicles	Deposition on Farmland	Foods (widespread)	None	Ingestion Exposure	Possible infection or mild ill-health	Mild	Negligible	Low	Micro-organisms not persistent. Likely to be destroyed during food preparation.
133	Bioaerosols	Waste in Vehicles	None	None	None	Inhalation Exposure	Possible infection or mild ill-health	Mild	Low	Low	Assessed. On-site traffic may be relevant; off-site traffic outside scope.

Note: SPR: Source / Pathway / Receptor
Emissions grouped into acid gases; toxic organic micropollutants (TOMPS); dust/particulates; metals; organic compounds; bioaerosols

Table 3.3 Potentially significant pathways for exposure of local people

Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Initial risk rating	Comment
		Pathway 1	Pathway 2	Pathway 3				
Acid gases	Flare Emissions	Atmospheric transport	None	None	Inhalation Exposure	Eye irritation, mild respiratory effects	Low	Assessed in this study notwithstanding initial risk rating
Acid gases	Engine Emissions	Atmospheric transport	None	None	Inhalation Exposure	Eye irritation, mild respiratory effects	Low	Assessed in this study notwithstanding initial risk rating
TOMPS[1]	Flare Emissions	Atmospheric transport	None	None	Inhalation Exposure	Some carcinogens, some teratogens	High/Medium	Assessed in this study
TOMPS[1]	Flare Emissions	Deposition on Allotments & Gardens	Consumption of Soils	None	Ingestion Exposure	Some carcinogens, some teratogens	High/Medium	Assessed in this study
TOMPS[1]	Flare Emissions	Deposition on Allotments & Gardens	Foods (local)	None	Ingestion Exposure	Some carcinogens, some teratogens	High/Medium	Assessed in this study
TOMPS[1]	Flare Emissions	Deposition on Farmland	Foods (local)	None	Ingestion Exposure	Some carcinogens, some teratogens	High/Medium	Assessed in this study
TOMPS[1]	Flare Emissions	Deposition on Farmland	Foods (widespread)	None	Ingestion Exposure	Some carcinogens, some teratogens	High/Medium	Assessed in this study
TOMPS[1]	Engine Emissions	Atmospheric transport	None	None	Inhalation Exposure	Some carcinogens, some teratogens	High/Medium	Assessed in this study
TOMPS[1]	Engine Emissions	Deposition on Allotments & Gardens	Consumption of Soils	None	Ingestion Exposure	Some carcinogens, some teratogens	High/Medium	Assessed in this study
TOMPS[1]	Engine Emissions	Deposition on Allotments & Gardens	Foods (local)	None	Ingestion Exposure	Some carcinogens, some teratogens	High/Medium	Assessed in this study
TOMPS[1]	Engine Emissions	Deposition on Farmland	Foods (local)	None	Ingestion Exposure	Some carcinogens, some teratogens	High/Medium	Assessed in this study
TOMPS[1]	Engine Emissions	Deposition on Farmland	Foods (widespread)	None	Ingestion Exposure	Some carcinogens, some teratogens	High/Medium	Assessed in this study
Organics	Flare Emissions	Atmospheric transport	None	None	Inhalation Exposure	Some carcinogens; some teratogens	High/Medium	Assessed in this study
Organics	Engine Emissions	Atmospheric transport	None	None	Inhalation Exposure	Some carcinogens; some teratogens	High/Medium	Assessed in this study
Organics	Leachate/ Surface water runoff	Groundwater	Surface water	Abstraction without treatment	Ingestion Exposure	Some carcinogens; some teratogens	High/Medium	Assessed in this study
Organics	Leachate/ Surface water runoff	Waste Transport	Inhalation	None	Inhalation Exposure	Some carcinogens; some teratogens	High/Medium	Assessed in this study
Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	None	None	Ingestion Exposure	Some carcinogens; some teratogens	High/Medium	Assessed in this study
Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	Use on allotments & gardens		Ingestion Exposure	Some carcinogens; some teratogens	High/Medium	Assessed in this study
Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	Use on Farmland	Foods (local)	Ingestion Exposure	Some carcinogens; some teratogens	High/Medium	Assessed in this study
Organics	Leachate/ Surface water runoff	Water Abstraction & No Treatment	Use on Farmland	Foods (widespread)	Ingestion Exposure	Some carcinogens; some teratogens	High/Medium	Assessed in this study
Organics	Leachate/ Surface water runoff	Absorption by Fish	Foods	None	Ingestion Exposure	Some carcinogens; some teratogens	High/Medium	Assessed in this study
Organics	Landfill Gas	None	None	None	Inhalation Exposure	Some carcinogens; some teratogens	High/Medium	Assessed in this study
Dusts + metal/ TOMPS[1]	Tipping	None	None	None	Inhalation	Respiratory ill health; Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium/ Low	Assessed in this study

Hazard	Source	Sequence of pathways			Medium of Exposure	Health effect	Initial risk rating	Comment
		Pathway 1	Pathway 2	Pathway 3				
Dusts + metal/ TOMPS[1]	Tipping	Deposition on Allotments & Gardens	Consumption of Soils	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium	Assessed in this study
Dusts + metal/ TOMPS[1]	Tipping	Deposition on Allotments & Gardens	Foods (local)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium	Assessed in this study
Dusts + metal/ TOMPS[1]	Tipping	Deposition on Farmland	Foods (local)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium	Assessed in this study
Dusts + metal/ TOMPS[1]	Tipping	Deposition on Farmland	Foods (widespread)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium	Assessed in this study
Dusts + metal/ TOMPS[1]	Tipping	None	None	None	Inhalation Exposure	Respiratory ill health; Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium/ Low	Assessed in this study
Dusts + metal/ TOMPS[1]	Waste in Vehicles	Deposition on Allotments & Gardens	Consumption of Soils	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium	On-site traffic may be relevant and assessed in this study; off-site traffic outside scope.
Dusts + metal/ TOMPS[1]	Waste in Vehicles	Deposition on Allotments & Gardens	Foods (local)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium	On-site traffic may be relevant and assessed in this study; off-site traffic outside scope.
Dusts + metal/ TOMPS[1]	Waste in Vehicles	Deposition on Farmland	Foods (local)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium	On-site traffic may be relevant and assessed in this study; off-site traffic outside scope.
Dusts + metal/ TOMPS[1]	Waste in Vehicles	Deposition on Farmland	Foods (widespread)	None	Ingestion Exposure	Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium	On-site traffic may be relevant and assessed in this study; off-site traffic outside scope.
Dusts + metal/ TOMPS[1]	Waste in Vehicles	None	None	None	Inhalation Exposure	Respiratory ill-health; Some metals carcinogenic; some TOMPS carcinogenic or possibly teratogenic	High/Medium/ Low	On-site traffic may be relevant and assessed in this study; off-site traffic outside scope.
Bioaerosols	Tipping	None	None	None	Inhalation Exposure	Possible infection or mild ill-health	Low	Assessed in this study
Bioaerosols	Waste in Vehicles	None	None	None	Inhalation Exposure	Possible infection or mild ill-health	Low	On-site traffic may be relevant and assessed in this study; off-site traffic outside scope.

Note 1: TOMPS: Toxic Organic Micropollutants, comprising dioxins and furans, polycyclic biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs)
For risk screening, emissions are considered in groups: acid gases; toxic organic micropollutants (TOMPS); dust/particulates; metals; organic compounds; bioaerosols

Tables from Chapter 4: Experimental Investigations

Table 4.1 Air monitoring methods

Parameter	Test Method	Certific-ation	Calibration	Test Method	Referred to in TG9?	Detection limit
Initial VOC trial sampling	Adsorption tubes – GC/MS	UKAS	Lab Standard Operating Procedures	US EPA Method TO-1	Yes	50 µg/m^3
NO_x	Chemilumin-escence analyser	None available	Calibration gas traceable to national standards	Manufacturer's instructions/UK Automatic Network Site Operators Manual (where appropriate)	Yes	1 µg/m^3
Total volatile organic compounds	Flame Ionisation Detection analyser	None available	Calibration gas traceable to national standards	Manufacturer's instructions	Yes	1 µg/m^3
PM_{10}	Tapered Element Oscillating Microbalanc e (TEOM)	None available	Lab SOPs	Manufacturer's instructions/UK Automatic Network Site Operators Manual (where appropriate)	Yes	1 µg/m^3
SO_2, H_2S	UV fluorescence detector	None available	Calibration gas traceable to national standards	Manufacturer's instructions/ UK Automatic Network Site Operators Manual (where appropriate)	Yes	1 µg/m^3
Dust deposition	Gauges to BS 1747	UKAS	Lab Standard Operating Procedures	BS1747	Yes	2 mg/m^2-day
PCDDs/ PCDFs and PAHs/PCBs	High Vol. Samplers / GC/MS	UKAS	Lab Standard Operating Procedures	USEPA Method TO9	Yes	10 fg/m^3 max
Particulates/ Metals	High Vol. Samplers / AAS	UKAS	Lab Standard Operating Procedures	USEPA Method TO9 (adapted)	Yes	0.01 µg/m^3
Speciated target VOCs, in particular chlorinated VOCs	Charcoal adsorption tubes - GC/MS	UKAS	Lab Standard Operating Procedures	US EPA Method TO-1	Yes	Variable
Organo-sulphur compounds	Molecular sieve adsorption tubes - GC/MS	None available	Lab SOPS based on Analytical Chemistry 1984, 56, 1432-1436	US EPA Method TO-1	Yes	Variable
Bio-aerosols	Sterile filter /bubbler	None available	Lab Standard Operating Procedures	Internal Standard Operating Procedures	No	100 cfu/m3 typical
Particulates/ metals	Battery operated pumps / AAS	UKAS	Lab Standard Operating Procedures	MDHS 14/3	Yes	1.0 µg/m3

Table 4.5 Landfill gas generation rates estimated using GasSim

Year	95th percentile gas generation rate (Site A)	95th percentile gas generation rate (Site B)
2001	1590 m^3/hr	720 m^3/hr
2002	1740 m^3/hr	700 m^3/hr

Table 4.6 Trace gas generation rates estimated using GasSim (2002)

Substance	Estimated release rate (mg/s) at Site A		Estimated release rate (mg/s) at Site B	
	50th %ile	95th %ile	50th %ile	95th %ile
1,2-dichloroethane	0.55	18	0.20	4.9
1,3-butadiene	0.30	2.1	0.12	0.63
Benzene	0.64	9.9	0.22	17
Carbon disulphide	0.19	3.5	0.11	0.95
Chloroform (trichloromethane)	0.27	2.8	0.096	1.1
Chloromethane	0.85	47	0.26	18
Dichlorofluoromethane	4.2	56	0.33	11
Dichloromethane	2.4	150	1.1	53
Dimethyl disulphide	0.42	3.6	0.16	1.3
Dimethyl sulphide	0.60	13	0.25	4.5
Ethanethiol (ethyl mercaptan)	0.66	7.3	0.20	3.1
Ethylbenzene	0	0	0	0
Formaldehyde (methanal)	0.012	0.14	0.10	1.4
2-butanone (methyl ethyl ketone)	0	0	0	0
Methanethiol (methyl mercaptan)	0.10	7.6	0.033	5.1
Tetrachloroethene	1.5	81	0.40	27
Toluene	3.5	130	0.93	38
Trichloroethene	1.9	6.4	0.48	7.4
Trimethylbenzene	0.032	5.3	0.011	1.7
Chloroethene (vinyl chloride)	0.89	1.4	0.41	6.4
Xylene (all isomers)	2.0	90	0.52	19
Hydrogen sulphide	3.4	91	0.42	180

Table 4.8 Data capture rates for continuous monitoring instrumentation

Station	Oxides of nitrogen	Nitrogen dioxide (hourly mean)	Hydro-carbons	PM_{10}	Sulphur dioxide	Hydrogen sulphide
Site A Jan – Dec 2002 North-east	74%	71%	50%	100%	Not measured	Not measured
Site A Jan – Aug 2003 North-east	95%	93%	88%	93%	Not measured	Not measured
Site A winter survey North-east	96%	93%	83%	97%	96%	52%
Site A winter survey South-west	97%	97%	0%	97%	99%	97%
Site A summer survey North-east	98%	98%	96%	98%	76%	76%
Site A summer survey South-west	99%	99%	99%	99%	99%	99%
Site B Jan – Dec 2002 North-east	94%	92%	65%	94%	Not measured	Not measured
Site B Jan – Aug 2003 North-east	97%	95%	56%	100%	Not measured	Not measured
Site B winter survey North-east	97%	94%	60%	97%	63%	87%
Site B winter survey South-west	75%	75%	32%	37%	75%	74%
Site B summer survey North-east	98%	96%	98%	100%	85%	85%
Site B summer survey South-west	98%	98%	65%	98%	98%	98%
UK Automated Network mean data capture (2002)		*92%*	*78% (Oct – Dec)*	*94%*	*94%*	

Table 4.10 Summary of continuous monitoring data (Site A)

Measured value (µg/m^3 except where stated)	Substance	Site A NE 2002 Annual	Site A NE 2003 Annual	Site A NE Winter intensive (1 month)	Site A SW Winter intensive (1 month)	Site A NE Summer intensive (1 month)	Site A SW Summer intensive (1 month)	Health Criteria Value
Annual Mean	Oxides of nitrogen	21.0	15.0	21.0	37.5	8.7	14.1	
	Nitrogen dioxide	13.1	8.9	15.1	22.8	10.1	9.9	40
	Sulphur dioxide	1.9	3.6	8.8	5.0	3.3	5.2	
	Total hydrocarbon (ppm)	3.2	0.7	7.2	No data	3.1	1.7	
	PM_{10}	13.8	14.3	10.2	10.6	22.7	15.1	40
	Hydrogen sulphide	5.6	2.5	8.6	2.5	2.1	4.1	
50th percentile	Oxides of nitrogen	9.5	2.4	11.1	14.1	3.2	8.1	
	Nitrogen dioxide	7.3	6.1	9.7	11.5	7.3	5.9	
	Sulphur dioxide	3.3	2.8	5.0	2.5	2.8	4.4	
	Total hydrocarbon (ppm)	2.6	0.0	3.9	0.0	2.0	1.6	
	PM_{10}	11.5	10.9	9.2	9.7	15.4	8.9	
	Hydrogen sulphide	4.5	2.2	8.6	2.5	1.9	3.5	
99.8 percentile of 1 hour means	Nitrogen dioxide	74	59	66	178	61	66	200
90.4 percentile of 24 hour means	PM_{10}	22	28	15	16	53	33	50
98 percentile of 24 hour means	PM_{10}	39	59	18	19	68	54	50
99.9 percentile of 15 minute means	Sulphur dioxide	62	23	63	63	19	23	266
99.7 percentile of 1 hour means	Sulphur dioxide	46	15	45	93	12	19	350
99.2 percentile of 24 hour means	Sulphur dioxide	13	7	15	17	6	12	125
100 percentile of 24 hour means	Hydrogen sulphide	42	5	14	10	3	9	150

Approximate number of data values

	2002	**2003**
NOx and PM10 annual:	37000	11000
Sulphur dioxide and hydrogen sulphide annual:	3300	4500
Total hydrocarbons annual:	20000	8000
NOx, PM10, Total Hydrocarbons, intensive survey:	2400	3000
Sulphur dioxide and hydrogen sulphide, intensive survey:	1100	3000

Table 4.11 Summary of continuous monitoring data (Site B)

Measured value (µg/m^3 except where stated)	Substance	Site B NE 2002 Annual	Site B NE 2003 Annual	Site B NE Winter intensive (1 month)	Site B SW Winter intensive (1 month)	Site B NE Summer intensive (1 month)	Site B SW Summer intensive (1 month)	Health Criteria Value
Annual Mean	Oxides of nitrogen	26.6	16.7	26.8	34.1	16.7	40.9	
	Nitrogen dioxide	16.3	9.1	17.8	22.4	8.9	22.2	40
	Sulphur dioxide	4.4	3.6	3.9	1.7	3.0	6.1	
	Total hydrocarbon (ppm)	3.0	3.0	2.8	2.5	3.6	2.6	
	PM_{10}	15.8	15.4	12.4	11.7	18.3	74.6	40
	Hydrogen sulphide	5.3	1.3	7.0	5.4	1.2	4.5	
50th percentile	Oxides of nitrogen	16.3	10.3	18.4	22.0	9.9	32.1	
	Nitrogen dioxide	12.1	6.9	13.5	15.5	6.5	19.4	
	Sulphur dioxide	2.5	3.0	3.6	1.1	2.8	4.1	
	Total hydrocarbon (ppm)	2.2	2.3	2.5	2.2	2.5	1.8	
	PM_{10}	13.4	12.4	11.9	11.3	13.9	14.6	
	Hydrogen sulphide	4.8	1.2	6.3	5.3	1.2	3.4	
99.8 percentile of 1 hour means	Nitrogen dioxide	67	52	69	84	51	72	200
90.4 percentile of 24 hour means	PM_{10}	25	27	18	16	32	150	50
98 percentile of 24 hour means	PM_{10}	35	33	21	18	39	207	50
99.9 percentile of 15 minute means	Sulphur dioxide	172	51	22	30	22	67	266
99.7 percentile of 1 hour means	Sulphur dioxide	116	32	15	24	17	51	350
99.2 percentile of 24 hour means	Sulphur dioxide	41	11	8	11	5	18	125
100 percentile of 24 hour means	Hydrogen sulphide	15	2	15	8	2	9	150

Approximate number of data values

	2002	**2003**
NOx and PM10 annual:	37000	7000
Sulphur dioxide and hydrogen sulphide annual:	8000	3800
Total hydrocarbons annual:	20000	8000
All measurements, intensive survey:	3000	3000

Table 4.12 Summary of discrete air quality measurements taken (Site A)

Substance	Number of measure-ments	Number of positive detections	Number of non-detects	Units	Measured concentrations				Typical measure ment uncert-ainty	Pedigree
					Min	Mean	Median	Max		
Metals										
Antimony	32	16	16	ng/m^3	0.14	0.46	0.40	1.4	±0.1	Very good
Arsenic	32	14	18	ng/m^3	0.10	0.37	0.32	1.0	±0.1	Very good
Cadmium	32	6	26	ng/m^3	0.11	0.29	0.29	0.41	±0.1	Very good
Chromium	32	19	13	ng/m^3	0.21	1.09	0.71	3.9	±0.1	Very good
Cobalt	32	8	24	ng/m^3	0.08	1.01	0.20	6	±0.1	Very good
Copper	32	30	2	ng/m^3	1.00	70	24	298	±0.1	Very good
Lead	32	28	4	ng/m^3	0.39	2.36	1.9	7.9	±0.1	Very good
Manganese	32	25	7	ng/m^3	0.69	7.88	2.1	51	±0.1	Very good
Mercury	32	0	32	ng/m^3					±0.1	Very good
Nickel	32	31	1	ng/m^3	0.20	1.4	1.4	3.0	±0.1	Very good
Thallium	32	0	32	ng/m^3					±0.1	Very good
Tin	32	14	18	ng/m^3	0.08	0.48	0.28	2.0	±0.1	Very good
Vanadium	32	5	27	ng/m^3	0.14	0.61	0.54	1.2	±0.1	Very good
Dioxins and furans, PCBs, PAHs										
Dioxins and furans	32	32	0	fgTEQ/m^3	1.5	20	14.5	77	±0.5	Very good
Dioxins, furans and PCBs	32	32	0	fgTEQ/m^3	5.7	29	25	92	±5	Very good
Naphthalene	32	26	6	ng/m^3	0.020	0.87	0.67	3.6	±0.1	Very good
Acenaphthylene	32	12	20	ng/m^3	0.010	0.43	0.30	1.7	±0.1	Very good
Acenaphthene	32	20	12	ng/m^3	0.013	0.30	0.13	0.95	±0.1	Very good
Fluorene	32	28	4	ng/m^3	0.039	0.70	0.48	3.4	±0.1	Very good
Phenanthrene	32	32	0	ng/m^3	0.200	2.50	1.93	14.5	±0.1	Very good
Anthracene	32	16	16	ng/m^3	0.031	0.76	0.28	5.0	±0.1	Very good
Fluoranthene	32	30	2	ng/m^3	0.100	0.72	0.56	2.2	±0.1	Very good
Pyrene	32	27	5	ng/m^3	0.092	0.63	0.38	1.8	±0.1	Very good
Benzo(a)anthracene	32	15	17	ng/m^3	0.141	0.69	0.41	3.8	±0.1	Very good
Chrysene	32	20	12	ng/m^3	0.051	0.60	0.28	4.1	±0.1	Very good
Benzo(b/k)fluoranthene	32	21	11	ng/m^3	0.040	0.29	0.18	0.92	±0.1	Very good
Benzo(a)pyrene	32	14	18	ng/m^3	0.010	0.22	0.11	1.32	±0.1	Very good
Indeno(123-cd)pyrene	32	11	21	ng/m^3	0.010	0.15	0.10	0.40	±0.1	Very good
Benzo(ghi)perylene	32	10	22	ng/m^3	0.010	0.19	0.16	0.48	±0.1	Very good
Dibenzo(ah)anthracene	32	4	28	ng/m^3	0.146	0.24	0.27	0.29	±0.1	Very good
Volatile organic compounds										
1,1,1-Trichloroethane	28	25	3	µg/m^3	0.006	0.040	0.028	0.27	50%/±0.01	Good
1,1-Dichloroethane	28	2	26	µg/m^3	0.007	0.008	0.008	0.009	50%/±0.01	Good
Benzene	56	39	17	µg/m^3	0.020	0.54	0.27	3.4	50%/±0.01	Good
1,2-Dichloroethane	56	17	39	µg/m^3	0.005	0.20	0.014	2.4	50%/±0.01	Good
Chlorobenzene	28	22	6	µg/m^3	0.008	0.031	0.020	0.09	50%/±0.01	Good
Chloroethane	28	20	8	µg/m^3	0.006	0.025	0.021	0.12	50%/±0.01	Good
Chloroform	56	28	28	µg/m^3	0.008	0.07	0.023	0.83	50%/±0.01	Good
Dichloromethane	56	28	28	µg/m^3	0.20	2.2	1.7	7.4	50%/±0.01	Good
Tetrachloroethene	56	35	21	µg/m^3	0.019	0.69	0.11	5.6	50%/±0.01	Good
Toluene	56	53	3	µg/m^3	0.27	65	7.6	923	50%/±0.01	Good
Ethylbenzene	56	41	15	µg/m^3	0.016	7.4	1.23	104	50%/±0.01	Good
m+p Xylene	56	46	10	µg/m^3	0.05	27	2.5	496	50%/±0.01	Good
o Xylene	56	38	18	µg/m^3	0.04	14	1.13	258	50%/±0.01	Good
1,2-Dichloroethene	56	1	55	µg/m^3	0.006	0.006	0.006	0.006	50%/±0.01	Good
Styrene	56	32	24	µg/m^3	0.06	7.7	0.20	109	50%/±0.3	Good
2-Methylfuran	28	0	28	µg/m^3					50%/±0.3	Good
Nitromethane	28	0	28	µg/m^3					50%/±2	Good
Methylethylketone	28	10	18	µg/m^3	0.6	0.9	0.9	1.4	50%/±0.01	Good
Trichloroethene	28	3	25	µg/m^3	0.6	1.4	0.7	2.8	50%/±0.3	Good
Trimethylbenzene	28	5	23	µg/m^3	0.6	1.3	1.1	2.0	50%/±0.3	Good
α-Terpinene	28	7	21	µg/m^3	0.9	1.8	1.5	4.1	50%/±0.3	Good
Dichlorobenzene	28	1	27	µg/m^3	0.6	0.6	0.6	0.6	50%/±0.3	Good
2-ethyl-1-hexanol	28	18	10	µg/m^3	0.6	7.4	1.4	86	50%/±0.3	Good
Formaldehyde	16	3	13	µg/m^3	70	163	205	213	50%/±20	Good
1,3-butadiene	28	0	28	µg/m^3					50%/±0.2	Good
Methanethiol	44	27	17	µg/m^3	0.082	3.3	1.2	22	50%/±0.1	Good
Ethanethiol	44	3	41	µg/m^3	0.053	0.34	0.15	0.80	50%/±0.1	Good
Chloroethene	44	5	39	µg/m^3	0.006	0.11	0.014	0.46	50%/±0.01	Good
Chlorodifluoromethane	28	19	9	µg/m^3	0.007	0.46	0.17	3.0	50%/±0.01	Good
Dichlorodifluoromethane	28	4	24	µg/m^3	0.007	0.008	0.009	0.009	50%/±0.01	Good

Substance	Number of measure-ments	Number of positive detections	Number of non-detects	Units	Measured concentrations				Typical measure ment uncert-ainty	Pedigree
					Min	Mean	Median	Max		
Chloromethane	44	4	40	µg/m^3	0.011	0.020	0.020	0.029	50%/±0.01	Good
Carbon disulphide	44	28	16	µg/m^3	0.073	4.0	0.64	48	50%/±0.1	Good
Dimethyl sulphide	44	21	23	µg/m^3	0.092	21.2	0.41	374	50%/±0.1	Good
Dimethyl disulphide	44	22	22	µg/m^3	0.080	3.4	0.61	56	50%/±0.1	Good
Dichlorofluoromethane	16	0	16	µg/m^3					50%/±0.01	Good
Other trace substances										
Fibres	30	28	2	fibre/ml	0.0000	0.0013	0.0010	0.0030	±0.001	Good
Arsine	8	0	8	µg/m^3					±1	Moderate
Stibene	8	5	3	µg/m^3	38	144	127	222	±10	Moderate
Bioaerosols										
Total Bacteria Nutrient 25 °C	16	16	0	CFU/m^3	0	119	49	893	50%/ ±1	Moderate
Total Bacteria Nutrient 37 °C	16	11	5	CFU/m^3	0	80	0	687	50%/ ±1	Moderate
Total fungi and yeasts Malt 25 °C	16	11	5	CFU/m^3	0	33	42	72	50%/ ±1	Moderate
Total fungi and yeasts Malt 40 °C	16	9	7	CFU/m^3	0	34	0	168	50%/ ±1	Moderate
Total fungi and yeasts DG18 25 °C	16	10	6	CFU/m^3	0	90	0	412	50%/ ±1	Moderate
Gram negative bacteria	16	8	8	CFU/m^3	0	0	0	0	50%/ ±1	Moderate
Endotoxins	44	14	30	EU/m^3	0.3	0.94	0.56	3.1	50%/ ±1	Moderate
Mesophilic Aerobes	28	18	10	CFU/m^3	15	23	19	77	50%/ ±1	Moderate
Moulds	28	17	11	CFU/m^3	17	37	36	67	50%/ ±1	Moderate
Yeasts	28	0	28	CFU/m^3					50%/ ±1	Moderate
Enterobacteriaceae	28	0	28	CFU/m^3					50%/ ±1	Moderate

Note: Measured concentrations exclude non-detects

Table 4.13 Summary of discrete air quality measurements taken (Site B)

Substance	Number of measure-ments	Number of positive detections	Number of non-detects	Units	Measured concentrations				Typical uncert-ainty	Pedigree
					Min	Mean	Median	Max		
Metals										
Antimony	32	19	13	ng/m^3	0.30	0.59	0.50	1.0	±0.1	Very good
Arsenic	32	14	18	ng/m^3	0.10	0.31	0.30	1.0	±0.1	Very good
Cadmium	32	12	20	ng/m^3	0.10	0.69	0.20	5.7	±0.1	Very good
Chromium	32	28	4	ng/m^3	0.30	2.16	1.00	28.0	±0.1	Very good
Cobalt	32	10	22	ng/m^3	0.10	0.26	0.30	0.40	±0.1	Very good
Copper	32	32	0	ng/m^3	5.7	26	21	59	±0.1	Very good
Lead	32	32	0	ng/m^3	0.40	2.6	2.0	8.0	±0.1	Very good
Manganese	32	32	0	ng/m^3	1.0	5.8	3.0	24	±0.1	Very good
Mercury	32	3	29	ng/m^3	0.10	0.37	0.30	0.70	±0.1	Very good
Nickel	32	32	0	ng/m^3	0.40	2.4	2.0	14	±0.1	Very good
Thallium	32	1	31	ng/m^3	1.0	1.0	1.0	1.0	±0.1	Very good
Tin	32	22	10	ng/m^3	0.10	0.68	0.55	2.0	±0.1	Very good
Vanadium	32	21	11	ng/m^3	0.10	1.96	1.0	7.1	±0.1	Very good
Dioxins and furans, PCBs, PAHs										
Dioxins and furans	32	27	5	fgTEQ/m^3	3.4	86	19	1839	±0.5	Very good
Dioxins, furans and PCBs	32	27	5	fgTEQ/m^3	11.1	128	71	1939	±5	Very good
Naphthalene	32	25	7	ng/m^3	0.07	0.48	0.36	1.4	±0.1	Very good
Acenaphthylene	32	9	23	ng/m^3	0.08	0.15	0.20	0.20	±0.1	Very good
Acenaphthene	32	14	18	ng/m^3	0.10	0.25	0.20	0.60	±0.1	Very good
Fluorene	32	25	7	ng/m^3	0.20	0.57	0.49	1.5	±0.1	Very good
Phenanthrene	32	31	1	ng/m^3	0.20	2.81	1.95	15.1	±0.1	Very good
Anthracene	32	13	19	ng/m^3	0.10	0.45	0.23	2.8	±0.1	Very good
Fluoranthene	32	31	1	ng/m^3	0.10	1.23	0.90	7.1	±0.1	Very good
Pyrene	32	30	2	ng/m^3	0.10	0.83	0.50	5.0	±0.1	Very good
Benzo(a)anthracene	32	14	18	ng/m^3	0.08	0.36	0.26	1.0	±0.1	Very good
Chrysene	32	19	13	ng/m^3	0.10	0.39	0.20	1.5	±0.1	Very good
Benzo(b/k)fluoranthene	32	18	14	ng/m^3	0.10	0.39	0.25	1.23	±0.1	Very good
Benzo(a)pyrene	32	6	26	ng/m^3	0.08	0.21	0.10	0.58	±0.1	Very good
Indeno(123-cd)pyrene	32	6	26	ng/m^3	0.16	0.39	0.30	0.81	±0.1	Very good
Benzo(ghi)perylene	32	2	30	ng/m^3	0.20	0.34	0.34	0.47	±0.1	Very good
Dibenzo(ah)anthracene	32	7	25	ng/m^3	0.10	0.38	0.28	0.81	±0.1	Very good
Volatile organic compounds										
1,1,1-Trichloroethane	22	20	2	µg/m^3	0.020	0.047	0.050	0.11	50%/±0.01	Good
1,1-Dichloroethane	22	2	20	µg/m^3	0.010	0.020	0.020	0.030	50%/±0.01	Good
Benzene	36	34	2	µg/m^3	0.030	0.66	0.31	3.2	50%/±0.01	Good
1,2-Dichloroethane	36	29	7	µg/m^3	0.010	0.38	0.060	1.5	50%/±0.01	Good
Chlorobenzene	22	11	11	µg/m^3	0.010	0.18	0.19	0.44	50%/±0.01	Good
Chloroethane	22	16	6	µg/m^3	0.010	0.021	0.010	0.09	50%/±0.01	Good
Chloroform	36	28	8	µg/m^3	0.010	0.28	0.030	1.50	50%/±0.01	Good
Dichloromethane	36	17	19	µg/m^3	0.020	0.84	0.85	2.1	50%/±0.01	Good
Tetrachloroethene	36	29	7	µg/m^3	0.020	0.41	0.40	1.10	50%/±0.01	Good
Toluene	36	36	0	µg/m^3	0.040	5.6	1.11	41	50%/±0.01	Good
Ethylbenzene	36	31	5	µg/m^3	0.010	0.86	0.50	5.4	50%/±0.01	Good
M+p Xylene	36	34	2	µg/m^3	0.030	3.0	1.44	19	50%/±0.01	Good
O Xylene	36	34	2	µg/m^3	0.020	1.7	0.95	13.8	50%/±0.01	Good
1,2-Dichloroethene	36	12	24	µg/m^3	0.010	0.26	0.30	0.50	50%/±0.01	Good
Styrene	36	32	4	µg/m^3	0.010	1.03	0.35	4.6	50%/±0.3	Good
2-Methylfuran	14	7	7	µg/m^3	1.0	1.3	1.2	2.0	50%/±0.3	Good
Nitromethane	14	7	7	µg/m^3	1.2	1.6	1.5	2.5	50%/±2	Good
Methylethylketone	14	13	1	µg/m^3	0.30	0.8	0.7	1.5	50%/±0.01	Good
Trichloroethene	14	9	5	µg/m^3	0.6	0.9	0.6	2.1	50%/±0.3	Good
Trimethylbenzene	14	10	4	µg/m^3	0.30	1.1	0.6	5.0	50%/±0.3	Good
α-Terpinene	14	9	5	µg/m^3	0.20	0.40	0.30	0.9	50%/±0.3	Good
Dichlorobenzene	14	7	7	µg/m^3	0.20	1.0	0.30	5.0	50%/±0.3	Good
2-ethyl-1-hexanol	14	14	0	µg/m^3	0.30	2.0	1.25	8	50%/±0.3	Good
Formaldehyde	16	6	10	µg/m^3	42	185	106	487	50%/±20	Good
1,3-butadiene	16	1	15	µg/m^3					50%/±0.2	Good
Methanethiol	56	27	29	µg/m^3	0.09	1.2	0.5	7	50%/±0.1	Good
Ethanethiol	56	11	45	µg/m^3	0.08	0.41	0.23	2.1	50%/±0.1	Good
Chloroethene	56	8	48	µg/m^3	0.010	0.63	0.010	4.9	50%/±0.01	Good
Chlorodifluoromethane	28	28	0	µg/m^3	0.010	0.13	0.06	0.7	50%/±0.01	Good
Dichlorodifluoromethane	28	0	28	µg/m^3					50%/±0.01	Good
Chloromethane	56	1	55	µg/m^3	0.010	0.010	0.010	0.010	50%/±0.01	Good

Substance	Number of measure-ments	Number of positive detections	Number of non-detects	Units	Measured concentrations				Typical uncert-ainty	Pedigree
					Min	Mean	Median	Max		
Carbon disulphide	56	16	40	µg/m^3	0.080	2.9	0.27	35	50%/±0.1	Good
Dimethyl sulphide	56	21	35	µg/m^3	0.090	6.4	0.72	59	50%/±0.1	Good
Dimethyl disulphide	56	21	35	µg/m^3	0.070	1.7	0.51	16	50%/±0.1	Good
Dichlorofluoromethane	28	0	28	µg/m^3					50%/±0.01	Good
Other trace substances										
Fibres	28	27	1	fibre/ml	0.0010	0.0019	0.0010	0.007	±0.001	Good
Arsine	8	2	6	µg/m^3	0.37	0.45	0.45	0.53	±1	Moderate
Stibene	8	0	8	µg/m^3					±10	Moderate
Bioaerosols										
Total Bacteria Nutrient 25 °C	30	23	7	CFU/m^3	0	635	52	4000	50%/ ±1	Moderate
Total Bacteria Nutrient 37 °C	30	22	8	CFU/m^3	0	220	52	2100	50%/ ±1	Moderate
Total fungi and yeasts Malt 25 °C	30	19	11	CFU/m^3	0	141	0	1376	50%/ ±1	Moderate
Total fungi and yeasts Malt 40 °C	30	17	13	CFU/m^3	0	38	0	355	50%/ ±1	Moderate
Total fungi and yeasts DG18 25 °C	30	21	9	CFU/m^3	0	38	0	275	50%/ ±1	Moderate
Gram negative bacteria	30	14	16	CFU/m^3	0	0	0	0	50%/ ±1	Moderate
Endotoxins	16	11	5	EU/m^3	1	3	2	9	50%/ ±1	Moderate
Penicillia	14	14	0	CFU/m^3	0	5	0	50	50%/ ±1	Moderate
Aspergillus fumigatus	14	14	0	CFU/m^3	0	45	0	500	50%/ ±1	Moderate

Note: Measured concentrations exclude non-detects

Table 4.14 Summary of source gas measurements taken

Substance	Number of measure-ments (Site A)	Number of positive detections (Site A)	Number of non-detects (Site A)	Number of measure-ments (Site B)	Number of positive detections (Site B)	Number of non-detects (Site B)
1,1,2,2-Tetrachloroethane	20	0	20	20	0	20
1,1-dichloroethane	20	18	2	20	18	2
1,1-dichloroethene	20	16	4	20	15	5
1,2,4-Trimethybenzene	26	18	8	26	24	2
1,2-Dichlorobenzene	26	4	22	26	8	18
1,2-Dichloroethane	6	1	5	6	2	4
1,2-dichloropropane	20	4	16	20	8	12
1,3-Butadiene	22	0	22	22	0	22
1,4-Dichlorobenzene	20	6	14	20	9	11
1-pentene	20	17	3	20	18	2
2-butanol	6	3	3	6	5	1
2-Butoxyethanol	20	0	20	20	0	20
2-ethyl 1-hexanol	6	4	2	6	6	0
Acetaldehyde	20	20	0	20	20	0
Acetone	20	18	2	20	20	0
Benzene	26	22	4	26	22	4
Bromoethane	20	1	19	20	2	18
Butan-1-ol	20	20	0	20	19	1
Butanethiol	20	0	20	20	0	20
Butyl acetate	20	14	6	20	19	1
Butyric acid	20	1	19	20	1	19
Carbon Disulphide	26	23	3	26	23	3
Chlorobenzene	20	8	12	20	14	6
Chloroethane	20	1	19	20	0	20
Chloroethene	26	18	8	26	20	6
Chloroform	26	0	26	26	5	21
Chloromethane	26	0	26	26	0	26
cis-1,2-dichloroethene	20	20	0	20	19	1
Decane	20	18	2	20	20	0
Dichlorodifluoromethane	20	12	8	20	12	8
Dichlorofluoromethane	26	17	9	26	21	5
Dichloromethane	26	20	6	26	20	6
Diethylsulphide	20	0	20	20	0	20
Dimethyl sulphide	6	0	6	6	2	4
Dimethyldisulphide	26	13	13	26	18	8
Ethanethiol	26	0	26	26	3	23
Ethyl acetate	20	12	8	20	10	10
Ethyl butyrate	20	18	2	20	19	1
Ethylbenzene	26	21	5	26	25	1
Ethylcyclohexane	20	18	2	20	20	0
Formaldehyde	22	19	3	22	14	8
Furan[1]	26	19	7	26	20	6
Heptane	20	15	5	20	20	0
Hexane	20	11	9	20	10	10
Limonene	20	18	2	20	20	0
Methanethiol	26	18	8	26	21	5
Methanethiol	20	0	20	20	0	20

Substance	Number of measure-ments (Site A)	Number of positive detections (Site A)	Number of non-detects (Site A)	Number of measure-ments (Site B)	Number of positive detections (Site B)	Number of non-detects (Site B)
Methylcyclohexane	20	19	1	20	20	0
Methylethylketone	20	20	0	20	20	0
Methylisobutylketone	20	16	4	20	19	1
m-xylene + p-xylene	26	21	5	26	25	1
Nitromethane	6	1	5	6	3	3
Nonane	20	19	1	20	20	0
Octane	20	18	2	20	19	1
o-Xylene	26	19	7	26	25	1
p-Ethyltoluene	20	16	4	20	19	1
Propan-2-ol	20	18	2	20	15	5
Propanethiol	20	5	15	20	11	9
Propylbenzene	20	13	7	20	19	1
Styrene	26	17	9	26	22	4
Tetrachloroethene	26	20	6	26	26	0
Tetrachloromethane	20	0	20	20	1	19
Tetramethylbenzene	20	2	18	20	2	18
Toluene	26	24	2	26	26	0
Total inorganic antimony	20	18	2	20	20	0
Total inorganic arsenic	20	9	11	20	20	0
Total mercury	20	17	3	20	6	14
trans-1,2-dichloroethene	26	17	9	26	17	9
Trichloroethene	26	20	6	26	21	5
Trichlorofluoromethane	20	18	2	20	20	0
α-terpinene	6	1	5	6	6	0

Note 1 : This is a commonly encountered organic chemical with the formula C_4H_4O, and is not in the same class of substances as polychlorinated dibenzo furans.

Table 4.15 Summary of measured source gas concentrations

Substance	Site A		Site B		Uncertainty	Pedigree
	Mean measured concentration (µg/m^3)	Maximum measured concentration (µg/m^3)	Mean measured concentration (µg/m^3)	Maximum measured concentration (µg/m^3)		
1,1,2,2-Tetrachloroethane	No detections	No detections	No detections	No detections		
1,1-dichloroethane	531	1900	330	2400	50%	Moderate
1,1-dichloroethene	1011	6100	1145	7300	50%	Moderate
1,2,4-Trimethybenzene	670	4000	21073	370000	50%	Moderate
1,2-Dichlorobenzene	63	180	209	1000	50%	Moderate
1,2-Dichloroethane	16	16	13	14	50%	Moderate
1,2-dichloropropane	23	47	42	180	50%	Moderate
1,3-Butadiene	No detections	No detections	No detections	No detections		
1,4-Dichlorobenzene	45	130	85	390	50%	Moderate
1-pentene	163506	1335000	36600	226000	50%	Moderate
2-butanol	51	140	100	240	50%	Moderate
2-Butoxyethanol	No detections	No detections	No detections	No detections		
2-ethyl 1-hexanol	64	200	1221	3800	50%	Moderate
Acetaldehyde	2.0	6.6	0.34	2.1	50%	Moderate
Acetone	15777	76000	12363	69000	50%	Moderate
Benzene	1823	14000	3497	40000	50%	Moderate
Bromoethane	37	37	99	150	50%	Moderate
Butan-1-ol	7594	43000	3046	19000	50%	Moderate
Butanethiol	No detections	No detections	No detections	No detections		
Butyl acetate	230	1100	243	1400	50%	Moderate
Butyric acid	55	55	37	37	50%	Moderate
Carbon Disulphide	602988	4681000	121971	1607000	50%	Moderate
Chlorobenzene	61	130	72	400	50%	Moderate
Chloroethane	410	410	No detections	No detections	50%	Moderate
Chloroethene	139722	497000	42242	280000	50%	Moderate
Chloroform	No detections	No detections	71	150	50%	Moderate
Chloromethane	No detections	No detections	No detections	No detections		
cis-1,2-dichloroethene	1195	4100	2792	18000	50%	Moderate
Decane	1829	8600	2541	16000	50%	Moderate
Dichlorodifluoromethane	208167	402000	361006	1594000	50%	Moderate
Dichlorofluoromethane	1030	4600	1365	8900	50%	Moderate
Dichloromethane	4898	30000	377	1600	50%	Moderate
Diethylsulphide	No detections	No detections	No detections	No detections		
Dimethyl sulphide	No detections	No detections	4650	6800	50%	Moderate
Dimethyldisulphide	457	2000	256	1000	50%	Moderate
Ethanethiol	No detections	No detections	96	120	50%	Moderate
Ethyl acetate	2153	9200	869	4500	50%	Moderate
Ethyl butyrate	3276	19000	1413	6400	50%	Moderate
Ethylbenzene	2035	10000	2947	15000	50%	Moderate
Ethylcyclohexane	1414	9900	1173	6000	50%	Moderate
Formaldehyde	0.04	0.09	0.04	0.08	50%	Moderate
Furan	5973	37000	1437	13000	50%	Moderate
Heptane	2481	8200	10085	98000	50%	Moderate
Hexane	1752	4600	1361	5300	50%	Moderate
Limonene	1549	7700	2159	13000	50%	Moderate
Methanethiol	8003	41000	11533	59000	50%	Moderate

Substance	Site A		Site B		Uncertainty	Pedigree
	Mean measured concentration (µg/m^3)	Maximum measured concentration (µg/m^3)	Mean measured concentration (µg/m^3)	Maximum measured concentration (µg/m^3)		
Methanethiol	No detections	No detections	No detections	No detections		
Methylcyclohexane	9873	73000	8034	71000	50%	Moderate
Methylethylketone	11909	66000	13944	72000	50%	Moderate
Methylisobutylketone	589	2400	613	4100	50%	Moderate
m-xylene + p-xylene	4292	22000	5779	31000	50%	Moderate
Nitromethane	2200	2200	349	940	50%	Moderate
Nonane	3445	24000	3305	17000	50%	Moderate
Octane	4929	37000	3003	17000	50%	Moderate
o-Xylene	1475	7100	2561	18000	50%	Moderate
p-Ethyltoluene	238	1100	423	2400	50%	Moderate
Propan-2-ol	7232	23000	3009	14000	50%	Moderate
Propanethiol	1673	4200	4346	45000	50%	Moderate
Propylbenzene	285	1000	335	2100	50%	Moderate
Styrene	229	920	222	1200	50%	Moderate
Tetrachloroethene	2925	21000	895	5200	50%	Moderate
Tetrachloromethane	No detections	No detections	14	14	50%	Moderate
Tetramethylbenzene	33	37	48	65	50%	Moderate
Toluene	4285	18000	26378	220000	50%	Moderate
Total inorganic antimony	0.0029	0.011	0.022	0.095	50%	Moderate
Total inorganic arsenic	0.0043	0.012	0.032	0.090	50%	Moderate
Total mercury	0.0011	0.0042	0.0003	0.0007	50%	Moderate
trans-1,2-dichloroethene	135	310	187	1200	50%	Moderate
Trichloroethene	2163	15000	770	5000	50%	Moderate
Trichlorofluoromethane	1663	4700	1436	7500	50%	Moderate
α-terpinene	4100	4100	23058	71000	50%	Moderate

Table 4.16 Measured surface emissions

Zone	Winter			Summer		
	Mean Flux Rate (mg carbon.$m^{-2}s^{-1}$)	Estimated Area (m^2)	Estimated Flux (mg carbon.s^{-1})	Mean Flux Rate (mg carbon.$m^{-2}s^{-1}$)	Estimated area (m^2)	Estimated Flux (mg carbon.s^{-1})
Site A Permanent Cap	<0.00005	10,600	0.5	0.00107	10,600	11.3
Site A Temporary Cap	0.00189	30,500	57.6	0.00243	53,400	130
Site A Sloping Permanent Cap	<0.00005	13,800	0.7	<0.00005	10,800	0.538
Site A Active Area	0.00115	14,800	17.0	0.347	20,000	6950
Site A Total	**-**		**75.9**	**-**		**7090**
Site B Permanent Cap	<0.00005	4,300	0.2	0.00091	4,300	3.9
Site B Temporary Cap	0.00013	89,000	11.5	0.00859	19,400	167
Site B Sloping Temporary Cap	0.03519	11,000	388	0.00329	73,100	241
Site B Active Area	0.01071	21,600	231	0.0261	14,700	383
Site B Total	**-**		**630**	**-**		**794**

Uncertainty in these values is hard to quantify, but is estimated to be approximately a factor of 3.

Table 4.17 Concentrations of trace gases at locations where high concentrations of methane were detected (Site A) (μgm^{-3})

Substance	A1		A2		A3		A4		A5		Mean
	Feb 03	Mar 03	Feb 03	Mar 03	Feb 03	Mar 03	Feb 03	Mar 03	Feb 03	Mar 03	
1,1,1-trichloroethane	0.17	0.04	0.10	0.05	0.00	0.04	<0.01	0.21	0.07	0.05	0.08
1,1-dichloroethane	<0.01	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	<0.01	<0.01	0.00
Arsine	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Butadiene	2.3	0.38	3.0	0.58	0.00	0.41	0.04	0.57	0.51	0.53	0.84
Butadiene	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	
Chlorobenzene	0.06	0.01	0.11	0.02	0.00	0.01	<0.01	0.03	0.14	0.01	0.04
Chlorodifluoromethane	<0.01	<0.03	<0.01	<0.03	<0.01	<0.03	<0.34	<0.03	<0.01	<0.03	
Chloroethene Monomer	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.04	<0.01	<0.01	<0.01	0.02
Chloroform	0.05	0.07	0.09	0.05	0.00	0.05	<0.01	0.10	0.04	0.08	0.06
Choroethane	<0.01	0.01	0.04	0.01	0.00	0.01	<0.01	0.02	0.02	0.01	0.01
Dichlorodifluoromethane	<0.01	<0.03	0.01	<0.03	0.37	<0.03	4.2	<0.03	<0.01	<0.03	1.53
Dichloromethane	<0.31	0.11	<0.31	0.13	0.00	0.27	<0.32	0.29	0.51	0.27	0.22
Ethanethiol	0.16	<0.11	<0.10	<0.11	<0.10	<0.11	<0.11	<0.11	<0.10	<0.11	0.16
Formaldehyde	<36.7	<33.6	<48.7	<42.4	<35.1	<35.3	34	<33.6	<38.4	<38.4	34
Hydrogen Sulphide	<0.16	<0.27	<0.16	<0.27	<0.16	<0.27	0.63	<0.27	<0.15	<0.27	0.63
Methanethiol	<0.10	<0.11	<0.10	<0.11	<0.10	<0.11	<0.11	<0.11	<0.10	<0.11	
Stibine	157	<11	<11	13.3	<11	<11	<11	<11	<10	<11	85
Trichloroethene	0.27	0.04	0.63	0.10	0.00	0.06	<0.03	3.45	0.19	0.19	0.55

Uncertainty: ±50% / ±0.01 μg/m^3

Table 4.18 Concentrations of trace gases at locations where high concentrations of methane were detected (Site B) (μgm^{-3})

Substance	B1		B2		B3		B4		B5		Mean
	Feb 03	Mar 03	Feb 03	Mar 03	Feb 03	Mar 03	Feb 03	Mar 03	Feb 03	Mar 03	
1,1,1-trichloroethane	0.12	0.11	0.17	0.29	0.06	0.05	0.03	0.05	0.85	0.08	0.18
1,1-dichloroethane	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Arsine	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
Butadiene	3.7	0.38	1.7	0.75	0.32	0.75	<0.03	0.59	0.64	0.52	1.04
Butadiene	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	
Chlorobenzene	0.20	0.01	0.08	0.02	0.02	0.02	<0.01	0.02	0.69	0.02	0.12
Chlorodifluoromethane	<0.01	<0.01	<0.01	<0.03	<0.01	<0.03	<0.34	<0.03	0.12	<0.03	0.12
Chloroethene Monomer	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	0.02
Chloroform	0.08	0.06	0.08	0.29	0.02	0.05	0.01	0.06	1.01	0.04	0.17
Choroethane	0.02	0.02	0.02	0.02	0.01	0.01	<0.01	0.01	<0.01	0.01	0.01
Dichlorodifluoromethane	<0.01	<0.01	<0.01	<0.03	0.30	<0.03	1.7	<0.03	1.16	<0.03	1.07
Dichloromethane	<0.32	0.05	<0.32	0.54	<0.32	0.07	<0.32	0.11	1.16	0.11	0.34
Ethanethiol	0.21	<0.11	1.06	<0.11	<0.11	<0.11	<0.11	<0.11	1.9	<0.11	1.06
Formaldehyde	85	<37.1	<37.1	<31.8	<54.7	<44.2	<42.4	<49.5	<53.0	<42.4	85
Hydrogen Sulphide	<0.16	<0.27	<0.17	<0.27	<0.17	<0.27	0.64	<0.27	0.69	<0.27	0.66
Methanethiol	<0.11	<0.11	<0.11	0.43	<0.11	<0.11	<0.11	<0.11	<0.11	0.22	0.33
Stibine	<11	539	<11	270	<11	<11	<11	10.7	<11	<11	273
Trichloroethene	1.32	0.20	0.49	1.08	0.26	0.45	0.04	0.28	1.06	0.17	0.54

Uncertainty: ±50% / ±0.01 μg/m^3

Table 4.19 Engine and flare emissions measurements

Measurement	Site A Engine 3	Site B Engine 2	Site B Flare	Number of measurements	Uncertainty
Oxygen (%)	6.2%	5.6%	18.2%	Engine Site A: Continuous 22 hours Engine Site B: Continuous 1 hour Flare Site B: Continuous 3.5 hours	± 10% of measured value
	Normalised to 5% oxygen, 273K, dry		*Normalised to 3% oxygen, 273K, dry*		
Volatile organic compounds (mg/Nm^3)	4	1	6		± 1
Oxides of nitrogen (mg/Nm^3)	484	623	27		± 10%
Sulphur dioxide (mg/Nm^3)	6	9	14		± 10%
Carbon monoxide (mg/Nm^3)	2933	2195	111		± 10%
Carbon dioxide (%)	14%	14%	2%		± 10% of measured value
Dioxins and furans (ng/Nm^3)	0.015	not measured	not measured	2.5 hour sample in duplicate	± 30%
Exhaust gas flow rate (Nm^3/s)	0.90	not measured	not measured		± 30%

Table 4.20 Average measured concentrations of metals at tipping face (µg/m^3)

Substance	Site A Winter	Site A Summer	Site B Winter	Site B Summer
Antimony	2.4	1.2	2.0	2.9
Arsenic	1.0	Not detected	Not detected	Not detected
Cadmium	Not detected	Not detected	Not detected	Not detected
Chromium	4.3	11.4	Not detected	2.0
Cobalt	Not detected	Not detected	Not detected	Not detected
Copper	35.1	7.1	1.7	2.2
Lead	Not detected	2.2	4.0	1.5
Manganese	8.0	3.2	14.9	2.2
Mercury	Not detected	1.9	Not detected	Not detected
Nickel	6.1	10.8	7.0	7.8
Thallium	Not detected	Not detected	Not detected	Not detected
Tin	14.0	3.0	4.0	Not detected
Vanadium	1.3	Not detected	1.0	Not detected

Note: All values based on 14 measurements

Table 4.21 Measured concentrations of micro-organisms at tipping face (Colony-forming Units per cubic metre, CFU/m^3)

Determinand	Site A Summer	Site B Winter	Site B Summer
Total Bacteria Nutrient 25oC	6,793 (8)	8,700 (6)	3,356 (8)
Total Bacteria Nutrient 37oC	4,480 (8)	4,500 (6)	1,028 (8)
Total fungi and yeasts Malt 25oC	1,104 (8)	8,900 (7)	7,227 (8)
Total fungi and yeasts Malt 40oC	319 (8)	Not measured	853 (8)
Total fungi and yeasts DG18 25oC	1,409 (8)	6,500 (7)	7,408 (8)
Gram negative bacteria VRBG	27 (8)	6,000 (7)	90 (8)
Endotoxins	4 (8)	Not measured	10 (7)
Thermophilic fungi	Not measured	770 (7)	Not measured
Penicillia	Not measured	6,200 (7)	Not measured
Aspergillus fumigatus	Not measured	161 (7)	Not measured

Note: Number of samples given in brackets

Table 4.22 Summary of meteorological measurements

	Site A						Site B					
	Temperature (°C)			Rainfall (mm)	Windspeed (m/s)		Temperature (°C)			Rainfall (mm)	Windspeed (m/s)	
Period	Max	Min	Mean	Total	Max	Mean	Max	Min	Mean	Total	Max	Mean
Uncert-ainty	± 0.1	± 0.1	± 0.1	± 15%	± 15%	± 5%	± 0.1	± 0.1	± 0.1	± 15%	± 15%	± 5%
Nov-01 (Part)	14.6	3.3	8.9	23.6	9.5	3.7	15.0	-1.3	7.1	6.5	7.8	2.0
Dec-01	12.6	-0.2	5.5	29.5	13.7	3.9	14.2	-5.3	3.5	23.8	11.6	2.3
Jan-02	12.4	-0.2	7.1	1.8	13.6	4.8	13.1	-8.5	5.0	43.6	12.8	2.9
Feb-02	12.9	1.7	7.3	0.0	14.9	6.3	13.9	-0.3	6.8	73.1	12.8	4.4
Mar-02	14.7	1.9	7.7	0.0	14.7	4.2	14.3	-1.3	6.6	36.6	9.6	2.1
Apr-02	14.6	1.3	8.1	2.8	8.1	2.6	20.1	-0.6	8.5	36.6	10.1	2.1
May-02	23.2	5.7	11.3	76.2	10.7	3.5	22.6	2.0	11.3	58.3	8.2	2.5
Jun-02	21.3	8.3	13.3	14.7	32.4	4.4	23.3	5.9	14.1	21.9	5.5	1.6
Jul-02	21.2	9.9	14.3	9.5	8.3	2.8	26.7	6.7	15.3	80.2	5.4	1.6
Aug-02	24.9	11.5	15.6	18.8	8.5	2.6	28.6	8.6	16.4	96.8	6.2	1.5
Sep-02	21.0	8.4	14.2	16.2	7.1	2.0	21.3	6.2	13.4	31.5	4.7	1.1
Oct-02	20.4	4.5	10.3	1.8	77.2	6.0	19.2	1.7	11.7	23.8	4.9	1.2
Nov-02	14.9	5.0	9.2	1.0	45.3	5.7	10.7	1.6	6.4	53.4	6.3	1.7
Dec-02	12.9	-0.2	5.9	13.5	12.7	3.2	11.6	-3.1	4.6	117.4	7.3	1.2
Jan-03	14.6	-2.7	5.7	23.4	12.0	3.8	12.4	-3.6	4.6	60.5	9.2	2.9
Feb-03	11.4	-2.8	4.7	No data	0.1	0.0	11.3	-4.2	3.1	No data	No data	No data
Mar-03	16.9	0.8	7.9	No data	26.0	0.9	16.2	-2.8	6.7	No data	No data	No data
Apr-03	24.1	0.1	9.8	No data	46.8	4.5	24.6	-2.2	9.1	No data	No data	No data
May-03	17.9	5.5	10.3	No data	41.0	9.0	25.2	3.0	11.9	8.1	3.9	1.5
Jun-03	23.2	10.9	15.5	37.2	8.6	2.9	27.2	7.4	15.7	14.9	6.0	1.8
Jul-03	28.7	11.9	16.5	38.6	7.5	3.1	27.8	9.5	17.1	No data	4.7	1.9
Aug-03	28.6	9.6	16.7	18.6	8.3	2.2	30.6	6.4	16.7	No data	6.1	1.4
Sep-03 (Part)	21.7	10.8	14.4	32.7	6.6	2.6	22.7	7.5	14.5	No data	3.5	1.1

Measurements recorded on a one hour basis, giving approximately 720 values per month

Table 4.23 Leachate quality data

Substance	Measured/estimated concentration in leachate (Site A)		Measured/estimated concentration in leachate (Site B)	
	Median	Mean	Median	Mean
Ammoniacal Nitrogen (N:mg/l)	1210	1172	520	549
Aniline (µg/l)	<1	<1.46	<1	<1.46
Arsenic (µg/l)	8	16	8	16
Biological Oxygen Demand (mg/L)	215	449	102	165
Biphenyl (µg/l)	0.1	0.46	0.1	0.46
Chemical Oxygen Demand (mg/L)	3470	3901	1430	1515
Chloride (mg/l)	1145	1425	1160	1123
Chromium (µg/l)	50	92	29	57
Copper (µg/l)	11	26	20	57
Cyanide (as CN) (mg/l)	<0.05	<0.05	<0.05	<0.05
Di (2ethyl hexyl) phthalate (µg/l)	<1	4.25	<1	4.25
Dichloromethane (µg/l)	<1	42.8	<1	42.8
Ethylbenzene (µg/l)	<10	19	<10	19
Fluoride (mg/l)	0.65	0.86	0.65	0.86
Lead (µg/l)	<50	60	30	50
Mecoprop (µg/l)	11	21.8	11	21.8
Methyl 1,1 dimethyl ethyl ether (methyl tertiary butyl ether) (µg/l)	<1	<1.38	<1	<1.38
Methyl chlorophenoxy acetic acid (µg/l)	<0.1	0.69	<0.1	0.69
Naphthalene (µg/l)	0.46	3.04	0.46	3.04
Nickel (µg/l)	60	159	112	115
Nitrogen (Total) (mg/l)	364	629	364	629
Nonyl phenol (µg/l)	1	4.9	1	4.9
Organo-tin (µg/l)	0.2	0.3	0.2	0.3
Pentachlorophenol & compounds (µg/l)	<0.1	0.32	<0.1	0.32
Phenols (mg/l)	0.03	0.35	0.03	0.35
Phosphorus (mg/l)	3	3.9	3	3.9
Polycyclic aromatic hydrocarbons (µg/l)	<5.25	<5.60	<5.25	<5.60
Toluene (µg/l)	21	87	21	87
Xylenes (µg/l)	35	59	35	59
Zinc (µg/l)	135	1246	270	563

Tables from Chapter 5: Risk assessment

Table 5.1 Summary of Project-specific Health criteria Values

Substance	HCV	Substance	HCV	Substance	HCV
1,1-dichloroethane	4.12 mg m^{-3}	Dichlorobenzene	1 mg m^{-3}	Indeno[123-cd]pyrene	(RP = 0.08)
1,1,1-trichloroethane	2.1 mg m^{-3}	Dichlorodifluoromethane	50.3 mg m^{-3}	dibenz[a,h]anthracene	(RP = 1.91)
1,2 dichloroethane	0.36 µg m^{-3}	Dichlorofluoro-methane	0.43 mg m^{-3}	dibenz[a,h]anthracene	(RP = 1.91)
1,2 dichloroethene(cis and trans isomers)	60 µg m^{-3}	Dichloromethane	0.45 mg m^{-3}	Naphthalene	0.003 mg m^{-3}
1,3-butadiene	2.21 µg m^{-3}	dimethyl disulphide	5 µg m^{-3}	acenaphthylene	No HCV
2-butanone (methyl ethyl ketone)	5 mg m^{-3}	dimethyl sulphide	5 µg m^{-3}	Acenaphthene	0.21 mg m^{-3}
2-ethyl-1-hexanol	570 µg m^{-3}	dioxins and furans	2 pg/kgBW-day	fluorene	0.14 mg m^{-3}
2-methyl furan	No HCV	Ethylbenzene	595 µg m^{-3}	Phenanthrene	No HCV
2-octanone	No HCV	ethanethiol (ethyl mercaptan)	0.01 mg m^{-3}	anthracene	1.05 mg m^{-3}
acetic acid	0.25 mg m^{-3}	Formaldehyde	10 µg m^{-3} (long-term exposure)	Fluoranthene	0. 044 mg m^{-3}
Acetone	31 mg m^{-3}	fibres(assuming asbestos)	1000 F m^{-3}	pyrene	0.105 mg m^{-3}
alpha terpinene	390 µg m^{-3}	formic acid	0.37 mg m^{-3}	Benzo[ghi]perylene	No HCV
Antimony	0.003 mg m^{-3}	Heptanone	1.66 mg m^{-3}	PCBs (Dioxin-like PCBs to be considered in combination with dioxins)	7 pg m^{-3} TEQ (for dioxin-like PCBs, in combination with dioxins)
arsenic	0.007 µg m^{-3}	hydrogen sulphide	150 µg m^{-3}	pentane	17.7 mg m^{-3} (All isomers)
Arsine	0.007 µg m^{-3}	Lead	0.25 µg m^{-3}	PM_{10}	40 µg m^{-3} *50 µg m^{-3}*
benzaldehyde	0.35 mg m^{-3}	Limonene	0.35 mg m^{-3}	stibine	5 µg m^{-3}
Benzene	3.2 µg m^{3}	manganese	0.15 µg m^{-3}	styrene	70 µg m^{-3}
Cadmium	0.005 µg m^{-3}	Mercury	1 µg m^{-3}	sulphur dioxide	*125* µg m^{-3} 267 µg m^{-3} (15 min averaging time)
carbon disulphide	100 µg m^{-3}	methanethiol (methyl mercaptan)	4 µg m^{-3}	tetrachloro-ethene	250 µg m^{-3}
chlorobenzene	0.5 mg m^{-3}	Nickel	0.020 µg m^{-3}	thallium	0.25 µg m^{-3}
chlorodifluoromethane	50 mg m^{-3}	nitrogen dioxide	40 µg m^{-3} *200 µg m^{-3}*	tin	20 µg m^{-3} (inorganic tin). 1 µg m^{-3} (organic tin).
chloroethane	10 mg m^{-3}	nitromethane	2.54 mg m^{-3}	toluene	0.26 mg m^{-3}
chloroform (trichloromethane)	52.5 µg m^{-3}	nonane	0.2 mg m^{-3}	trichloroethene	23 µg m^{-3}
chloromethane	0.018 mg m^{3}	PAHs	0.25 ng m^{-3} BAP, as a marker for PAHs.	trimethylbenzene	625 µg m^{-3}
Chromium	0.0025 µg m^{-3}	benzo[a]anthracene	(RP = 0.1)	vanadium	1 µg m^{-3}
Cobalt	0.1 µg m^{-3}	chrysene	(RP = 0.03)	chloroethene (vinyl chloride)	1 µg m^{-3}
Copper	0.002 mg m^{-3}	benzo[b/k]fluoranthene	(RP = 0.1)	xylenes	870 µg m^{-3}
Decane	0.2 mg m^{-3}	benzo[a]pyrene	(RP = 1) 0.25 ng m^{-3}		

Table 5.2 Project-specific health criteria values derived from published literature

Substance	HCV	Comments
1,1-dichloroethane	4.12 mg m^{-3}	HSE has recently adopted a workplace exposure standard. No toxicological basis is provided for this in the HSC consultation document cd156.
1,1,1-trichloroethane	2.1 mg m^{-3}	Based on the WHO drinking water guideline, which is derived from the findings of a 14-week mouse inhalation study which described a NOAEL of 1365 mg m^{-3} .
1,2 dichloroethane	0.36 µg m^{-3}	HCV for inhalation and oral exposure based on carcinogenic potency expressed as the dose causing a 5% increase in tumours ($TD_{0.05}$) from studies of animals exposed by gavage.
1,2 dichloroethene(cis and trans isomers)	60 µg m^{-3}	NOAEL of 17 mg kg^{-1} bw day^{-1} for increased serum alkaline phosphatase in male mice. This result was derived from a study using the trans-isomer. This result was used to derive a joint guideline for both isomers due to the lack of adequate toxicity data for the cis-isomer (WHO, 1996).
1,3-butadiene	2.21 µg m^{-3}	EPAQS (1994a) air quality standard is based on the risk of lymphomas and leukemias in a cohort study of workers exposed to 1,3-butadiene; deemed unlikely to be detectable below 1000 ppb.
2-butanone (methyl ethyl ketone)	5 mg m^{-3}	USEPA RfC is based on an adjusted LEC of 1,517 mg/m^3 for developmental toxicity (skeletal variations).
2-ethyl-1-hexanol		
2-methyl furan	No HCV	
2-octanone	No HCV	
acetic acid	0.25 mg m^{-3}	No OEL Summary available.
acetone	31 mg m^{-3}	Based on a LOAEL of 1,250 ppm for neurological effects in human volunteers.
alpha terpinene	*See Table 2.7*	
antimony	0.003 mg m^{-3}	Oral TDI based on a LOAEL of 43 mg kg^{-1} bw for decreased longevity and altered blood levels of glucose and cholesterol in rats given antimony in drinking water.
arsenic	0.007 µg m^{-3}	Lifetime lung cancer risk of 10^{-5} derived from epidemiological studies of smelter workers.Incidence of skin lesions (most sensitive indicator of systemic toxicity from chronic oral exposure to arsenic) measured from study of contaminated drinking water in Taiwan.
arsine	0.007 µg m^{-3}	NOAEL of 0.08 mg m^{-3} for increased haemolysis, abnormal RBC morphology and increased spleen weight from 13 week rat and mouse study (in combination with arsenic)
benzaldehyde	0.35 mg m^{-3}	NOAEL of 143 mg kg^{-1} bw day^{-1} (converted from 200 mg kg^{-1} bw day^{-1} for exposure schedule) for forestomach lesions in rats (supported by NOAEL for kidney toxicity in mice).
benzene	3.2 µg m^3	EPAQS (1994b) concluded that the risk of leukaemia in workers was not detectable when average exposures over a working lifetime were around 500 ppb (1600 µg m^{-3}).
cadmium	0.005 µg m^{-3}	WHO (2000b) set level of Cd in air (5 ng m^3) to prevent further increases of Cd levels in the kidney.
carbon disulphide	100 µg m^{-3}	The lowest concentration of CS_2 at which an adverse effect was observed in occupational exposure was about 10 mg m^{-3}; effects from long-term exposure to this level include sensory polyneuritis, increased pain threshold, depressed blood progesterone, increased estriol and irregular menstruation.
chlorobenzene	0.5 mg m^{-3}	LOAEL of 341 mg m^{-3} for decreased food intake, increased organ weight, lesions and changes in blood parameters.
chlorodifluoromethane	50 mg m^{-3}	USEPA (1993) RfC is based on an adjusted NOAEL of 5260 mg m^{-3} for increased kidney, adrenal and pituitary weights in rats.
Chloroethane	10 mg m^{-3}	USEPA RfC is based on a NOAEL of 4000 mg m^{-3} for delayed foetal ossification in mice.
Chloroform	52.5 µg m^{-3}	LOEL of 15 mg kg^{-1} bw day^{-1} for hepatotoxicity in beagles.WHO (2000b) indicate a cancer risk of 2 x 10^{-5} at 52.5 µg m^{-3}.
chloromethane	0.018 mg m^3	LOAEL of 103 mg m^3 derived from 2-year study for effects on the nervous system, corrected for continuous exposure.

Substance	HCV	Comments
Chromium	0.0025 µg m^{-3}	An excess lifetime risk of 10^{-4} for lung cancer is associated with 2.5 ng m^{-3}; derived from studies of chromate production workers (WHO 2000b).
Cobalt	0.1 µg m^{-3}	Based on a NOAEL of 5.3 µg m^{-3} for respiratory effects in diamond workers.
Copper	0.002 mg m^{-3}	No adverse effects (e.g. metal fume fever) noted in workers at exposures up to 0.4 mg m^{-3}; no evidence for harmful effects at 0.2 mg m^{-3}.
Decane	0.2 mg m^{-3}	RfC is based on a LOAEL, determined by MA DEP to be 2620 mg/m^3 (400 ppm), for neurotoxicity (indicated by sensory evoked potentials, and a decrease in motor activity during dark periods).
dichlorobenzene	1 mg m^{-3}	NOEL of 450 mg/m^3 for an increase in organ weight and urinary proteins.
dichlorodifluoromethane	50.3 mg m^{-3}	No OEL Summary available.
dichlorofluoro-methane	0.43 mg m^{-3}	No OEL Summary available.
dichloromethane	0.45 mg m^{-3}	Biological endpoint of interest is the formation of COHb; a level of dichloromethane in air was set that will not lead to more than an additional 0.1% COHb being formed.
dimethyl disulphide	*See Table 2.7*	
dimethyl sulphide	*See Table 2.7*	
dioxins and furans	2 pg/kgBW-day	TDI is based on effects on the sperm production and morphology in the offspring of dosed animals – LOAEL was a maternal TCDD body burden of 33 ng kg^{-1} bw in rats.
ethylbenzene	595 µg m^{-3}	NOAEL of 325 mg m^{-3}, based on hyperplasia of the pituitary gland in female mice (NTP 1999).
ethanethiol	0.01 mg m^{-3}	TLV-TWA is recommended in order to minimise the potential of irritation.
formaldehyde	10 µg m^{-3} (long-term exposure)	Chronic MRL is based on a LOAEL of 0.24 ppm for histological changes in nasal tissue specimens from workers employed for an average of 10 years.
fibres(assuming asbestos)	1000 F m^{-3}	Estimate that lifetime exposure to 1000 F m^{-3} in a population of whom 30% are smokers will result in an excess risk due to lung cancer of 10^{-6} to 10^{-5}.
formic acid	0.37 mg m^{-3}	No OEL Summary available.
heptanone	1.66 mg m^{-3}	NOAELs of 1000 ppm (4800 mg m^{-3}) and 700 ppm (3360 mg m^{-3}) for heptan-2-one and 3-one, respectively, for chronic effects, including neurotoxicity and minor changes in the kidney and liver, in animal inhalation repeat dose studies.
hydrogen sulphide	150 µg m^{-3}	HCV is based on a LOAEL of 15 mg m^{-3} for eye irritation.
lead	0.25 µg m^{-3}	EPAQS (1998) recommendation is intended to protect mental development of young children – measured by studies on blood lead concentration and IQ.JECFA observed that IQ is reduced by on average 1-3 points for each 10 µg dL^{-1} increment in blood lead.
limonene	0.35 mg m^{-3}	TDI_{oral} is based on a NOEL for increased liver weight of 10 mg kg^{-1} bw day^{-1} with uncertainty factor of 100.
manganese	0.15 µg m^{-3}	WHO air quality guideline is based on an estimated NOAEL of 30 µg m^{-3} for neurotoxic effects observed in occupationally exposed workers.
mercury	1 µg m^{-3}	WHO guideline value for air is based on an occupational study which observed objective tremor, kidney effects and 'non-specific symptoms' at levels of 10-30 µg m^{-3}.
methanethiol	*See Table 2.7*	
nickel	0.020 µg m^{-3}	Recommendation is based on a LOAEL of 0.6 mg m^{-3} for increased lung weight in rats.
nitrogen dioxide	40 µg m^{-3} *200 µg m^{-3}*	Limit value for the protection of human health *Adverse health effects are thought unlikely to occur even in subjects with asthma below a threshold of about 200 ppb; derived from studies on human volunteers*.
nitromethane	2.54 mg m^{-3}	No OEL Summary available.
nonane	0.2 mg m^{-3}	RfC is based on a LOAEL, determined by MA DEP to be 2620 mg/m^3 (400 ppm), for neurotoxicity in rats (indicated by sensory evoked potentials, and a decrease in motor activity during dark periods).
PAHs	0.25 ng m^{-3} BAP,	Carcinogenic potencies of PAHs relative to BaP were derived by

Substance	HCV	Comments
	as a marker for PAHs.	EPAQS on the basis of the dose-response relationships for the number of tumours observed in rat lungs following implantation of known concentrations of 6 PAHs. (BaA RP determined by comparing data on tumours following application mice skin).
benzo[a]anthracene	(RP = 0.1)	See above.
chrysene	(RP = 0.03)	See above.
benzo[b/k]fluoranthene	(RP = 0.1)	See above.
benzo[a]pyrene	(RP = 1) 0.25 ng m^{-3}	Inhalation HCV is based on the observation that cumulative exposure to 10-99 µg m^{-3}.yr of a mixture of PAHs represented by BaP was associated with a ~50% increase in the risk of lung cancer in smelter and coke over workers.
Indeno[123-cd]pyrene	(RP = 0.08)	See entries above.
dibenz[a,h]anthracene	(RP = 1.91)	See entries above.
naphthalene	0.003 mg m^{-3}	HCV based on a LOAEL of 9.3 mg m^{-3} for benign lung tumour induction.
acenaphthylene	No HCV	
acenaphthene	0.21 mg m^{-3}	RfD based on a NOAEL of 175 mg kg^{-1} day^{-1} for hepatotoxicity in mice.
fluorene	0.14 mg m^{-3}	Decreased packed cell volume and haemoglobin (NOAEL of 125 mg kg^{-1} day^{-1} in mice).
phenanthrene	No HCV	
anthracene	1.05 mg m^{-3}	USEPA RfD is based on a NOAEL of 1000 mg kg-^{1} day^{-1} from a subchronic toxicity study in mice (no observed effects).
Fluoranthene	0. 044 mg m^{-3}	USEPA RfD is based on a NOAEL of 125 mg kg^{-1} day^{-1} for nephropathy, increased liver weights and hematological alterations in mice. HCV is based on recommendation in draft CLR report.
pyrene	0.105 mg m^{-3}	USEPA RfD is based on a NOAEL of 75 mg kg^{-1} day^{-1} for kidney effects in mice (renal tubular pathology and decreased kidney weight).
Benzo[ghi]perylene	No HCV	
PCBs(Dioxin-like PCBs to be considered in combination with dioxins)	7 pg m^{-3} TEQ (for dioxin-like PCBs, in combination with dioxins)	See basis for dioxins; some PCBs are considered similar to dioxin owing to their flat structure (coplanar PCBs), with no or only one chlorine atom at an ortho position, and their similar toxicity.
pentane	17.7 mg m^{-3} (All isomers)	Occupational exposure limit is recommended to minimise the potential for irritative effects and narcosis. Controlled human exposure at 5000 ppm (14700 mg m^{-3}) for 10 mins failed to cause mucous membrane irritation and narcosis.
PM_{10}	40 µg m^{-3} *50 µg m^{-3}*	EPAQS standard for PM_{10} (set in 1995) was based on epidemiological evidence for a causative link between exposure to particulate air pollution in the urban environment and certain indices of ill-health, e.g. respiratory and cardiovascular diseases.
stibine		
Styrene	70 µg m^{-3}	WHO (2000b) air quality guideline of 70 µg m^{-3} as a 30 min average is based on the odour detection threshold.*Weekly average guideline is derived from a LOAEL of 107 mg m^{-3} for reductions in visuomotor accuracy and verbal learning skills and sub-clinical effects on colour vision in exposed populations*.
sulphur dioxide	*125* µg m^{-3} 267 µg m^{-3} (15 min averaging time)	Limit value for the protection of human health (as 24 hr mean) Most studies of lung function in human volunteers have shown no effect below about 250 ppb but occasional subjects have shown transient changes in measurement of lung function at lower concentrations insufficient to be associated with symptoms.
tetrachloro-ethene	250 µg m^{-3}	Inhalation HCV (WHO 2000b) is based on a long-term LOAEL for kidney effects of 102 mg m^{-3} in dry-cleaning workers.Oral HCV is based on a NOAEL for hepatotoxic effects of 14 mg kg^{-1} bw day^{-1} in rats.
Thallium	0.25 µg m^{-3}	USEPA RfD for thallium compounds is based on a NOAEL of 0.25 mg kg^{-1} bw day^{-1} in 90 day subchronic study of rats administered aqueous solution by gavage. The USEPA express low confidence in this RfD.
tin	20 µg m^{-3} (inorganic tin). 1 µg m^{-3}	No OEL Summary available.

Substance	HCV	Comments
	(organic tin).	
toluene	0.26 mg m^{-3}	Inhalation HCV (WHO 2000b) is based on a LOAEL of 332 mg m^{-3} for effects on the CNS.
trichloroethene	23 µg m^{-3}	WHO's air guideline is based on a unit risk estimate of 4.3 x 10^{-7} per µg m^{-3} derived on the basis of the most sensitive endpoint, Leydig cell tumours in rats.
trimethylbenzene		
Vanadium	1 µg m^{-3}	Inhalation HCV is based on a LOAEL of 20 µg m^{-3} for chronic upper respiratory tract symptoms observed in occupational studies.
vinyl chloride (chloroethene)	1 µg m^{-3}	Inhalation HCV (WHO 2000b) is based on a unit risk estimate of 1 × 10^{-6} per µg m^{-3} for excess cancer risk.
Xylenes	870 µg m^{-3}	'Guidance value' is based on a LOAEL of 200 ppm for developmental neurotoxicity in animal studies.TDI_{oral} based on decreased body weight in rats; NOAEL of 250 mg kg^{-1} bw day^{-1}. A value of 220 µgm^{-3} is recommended in a draft CLR Toxicity evaluation.

Key:

HCV : Health Criteria Value
HSE: Health and Safety Executive
CNS: Central Nervous System
RfD: Reference Dose
TDI : Tolerable Daily Intake
LOAEL: Lowest Observed Adverse Effect Level
NOAEL: No Observed Adverse Effect Level
OEL: Occupational Exposure Limit
BaP: Benz(a)Pyrene
JECFA: Joint Expert Committee on Food Additives
EPAQS: Expert Panel on Air Quality Standards
USEPA: United States Environmental Protection Agency

Table 5.3 De novo Health criteria values derived for this project

Compound	HCV (µg/m^3)	Basis
Alpha terpinene	390	Foetal development effects; irritant
2-ethyl 1-hexanol	570	Effects on central nervous system; irritant
Stibene	5	Haemolytic agent
Trimethyl benzene	625	Neurobehavioural effects
Methanethiol	4	Irritant
Dimethyl sulphide	5	Acute toxicity; irritant (jointly with dimethyl disulphide)
Dimethyl disulphide	5	Acute toxicity; irritant (jointly with dimethyl sulphide)

Table 5.4 Results of screening assessment

Substance	HCV (µg/m3)	Highest measured concentration (µg/m3)		Screen out at	
		Site A	Site B	Site A	Site B
Antimony	3	0.0014	0.001	Yes	Yes
Arsenic	0.007	0.0010	0.001	No	No
Cadmium	0.005	0.0004	0.0057	No	No
Chromium	0.0025	0.0039	0.028	No	No
Cobalt	0.1	0.0060	0.0004	No	Yes
Copper	2	0.2979	0.059	No	No
Lead	0.25	0.0079	0.008	No	No
Manganese	0.15	0.0510	0.0238	No	No
Mercury	1	<0.0002	0.0007	Yes	Yes
Nickel	0.02	0.0030	0.014	No	No
Thallium	0.25	<0.0002	0.001	Yes	Yes
Tin	20	0.0020	0.002	Yes	Yes
Vanadium	1	0.0012	0.0071	Yes	Yes
Naphthalene	3	0.0036	0.00137	Yes	Yes
Acenaphthylene		0.0017	0.0002	No HCV	No HCV
Acenaphthene	210	0.00095	0.0006	Yes	Yes
Fluorene	140	0.0034	0.0015	Yes	Yes
Phenanthrene		0.015	0.01511	No HCV	No HCV
Anthracene	1050	0.0050	0.00279	Yes	Yes
Fluoranthene	44	0.0022	0.00709	Yes	Yes
Pyrene	105	0.0018	0.005	Yes	Yes
Benzo (a) anthracene		0.0038	0.001	No HCV	No HCV
Chrysene		0.0041	0.00151	No HCV	No HCV
Benzo (b/k) fluoranthene		0.00092	0.00123	No HCV	No HCV
Benzo (a) pyrene		0.0013	0.00058	No HCV	No HCV
Indeno (123-cd) pyrene		0.00040	0.00081	No HCV	No HCV
Benzo (ghi) perylene		0.00048	0.00047	No HCV	No HCV
Dibenzo (ah) anthracene		0.00029	0.00081	No HCV	No HCV
1,1,1-Trichloroethane	2100	0.27	0.11	Yes	Yes
1,1-Dichloroethane	4120	0.009	0.03	Yes	Yes
Benzene	3.2	3.4	3.2	No	No
1,2-Dichloroethane	0.36	2.4	1.5	No	No
Chlorobenzene	500	0.09	0.44	Yes	Yes
Chloroethane	10000	0.12	0.09	Yes	Yes
Chloroform	52.5	0.83	1.5	No	No
Dichloromethane	450	7.4	2.09	No	Yes
Tetrachloroethene	250	5.6	1.1	No	Yes
Toluene	260	923	41.3	No	No
Ethylbenzene	595	104	5.4	No	Yes
m+p Xylene	870	496	19	No	No
o Xylene	870	258	13.8	No	No
1,2-Dichloroethene	60	0.006	0.5	Yes	Yes
Styrene	70	109	4.61	No	No
2-Methylfuran		<1	2	No HCV	No HCV
Nitromethane	2540	<2	2.5	Yes	Yes
2-Butanone (methyl ethyl ketone)	5000	1.4	1.5	Yes	Yes
Trichloroethene	23	2.8	2.1	No	No
Trimethylbenzene	625	2	5	Yes	Yes

Substance	HCV (µg/m3)	Highest measured concentration (µg/m3)		Screen out at	
		Site A	Site B	Site A	Site B
alpha-Terpinene	390	4.15	0.9	No	Yes
Dichlorobenzene	1000	0.57	5	Yes	Yes
2-Ethyl-1-hexanol	570	86	8.3	No	No
Formaldehyde	10	213	487	No	No
1,3-butadiene	2.21	<0.2	<0.2	No	No
Methanethiol	4	22	7.46	No	No
Ethanethiol	10	0.80	2.12	No	No
Chloroethene	1	0.46	4.93	No	No
Chlorodifluoromethane	50000	3.03	0.7	Yes	Yes
Dichlorodifluoromethane	50300	0.009	<0.020	Yes	Yes
Chloromethane	18	0.029	0.01	Yes	Yes
Carbon disulphide	100	48	35	No	No
Dimethyl sulphide	5	374	59	No	No
Dimethyl disulphide	5	56	16	No	No
Dichlorofluoromethane	430	<5	<7	No	No
Fibres	1.0E+09	3.0E+09	7.0E+09	No	No
Arsine	0.007	<0.66	0.53	No	No
Stibene	5	222	<18	No	No

Note: Substances highlighted in grey were screened out

Table 5.6 Characteristics of substances for semi-quantitative risk assessment

Substance	Principal health effect	HCV (µg/m^3)
1,1,1-Trichloroethane	Screened out	2.1
1,1-Dichloroethane	Screened out	4.12
1,2-Dichloroethane	Genotoxic carcinogen	0.36
1,2-Dichloroethene	Screened out	60
1,3-butadiene	Genotoxic carcinogen	2.21
2-butanone	Screened out	5000
2-Ethyl-1-hexanol	CNS toxicity; irritant	570
2-Methylfuran	No data	No HCV
Acenaphthene	Screened out	210
Acenaphthylene	No data	No HCV
alpha-Terpinene	Foetal developmental effects; irritant	390
Anthracene	Subchronic toxicity; no concern regarding carcinogenicity	1050
Antimony	Screened out	3
Arsenic	Lung cancer and skin cancer	0.007
Arsine	Haemolytic agent; lung cancer and skin cancer	0.007
Aspergillus fumigatus	Respiratory disease	No HCV
Benzene	Leukaemia	3.2
Benzo (a) anthracene	High concern regarding carcinogenicity	No HCV
Benzo (a) pyrene	High concern regarding carcinogenicity	0.00025
Benzo (b/k) fluoranthene	Concern regarding carcinogenicity	No HCV
Benzo (ghi) perylene	Concern regarding carcinogenicity	No HCV
Cadmium	Lung cancer and kidney toxicity	0.005
Carbon disulphide	CNS effects	100
Chlorobenzene	Screened out	500
Chlorodifluoromethane	Screened out	50000
Chloroethane	Screened out	10000
Chloroethene	Genotoxic carcinogen	1
Chloroform	Liver toxicity	52.5
Chloromethane	Screened out	18
Chromium	Lung cancer; foetal and embryo toxicity	0.0025
Chrysene	Concern regarding carcinogenicity	No HCV
Cobalt	Cardio-vascular effects, respiratory sensitisation, developmenta/reproductive effects	0.1
Copper	Liver toxicity; anaemia; immunotoxicity	2
Dibenzo (ah) anthracene	High concern regarding carcinogenicity	No HCV

Substance	Principal health effect	HCV (µg/m^3)
Dichlorobenzene	Screened out	1000
Dichlorodifluoromethane	Screened out	50300
Dichlorofluoromethane	Low toxicity, but general effects on CNS, liver, CV and respiratory effects	430
Dichloromethane	Carcinogenic, CNS effects and causes carboxyhaemoglobinaemia	450
Dichloromethane	Carcinogenic, CNS effects and causes carboxyhaemoglobinaemia	450
Dimethyl disulphide	Acute toxicity; irritant	5
Dimethyl sulphide	Acute toxicity; irritant	5
Dioxins and furans	Reproductive toxicant and teratogen; effects on sperm production and developmental/ reproductive effects	No airborne HCV
Dioxins, furans and dioxin-like PCBs	Reproductive toxicant and teratogen; effects on sperm production and developmental/ reproductive effects	No airborne HCV
Endotoxins	Respiratory disease	No HCV
Entrobacteriaceae	Respiratory disease	No HCV
Ethyl mercaptan	Acute toxicity; irritant	10
Ethylbenzene	CNS toxicity	595
Fibres	Lung cancer (mesothelioma) (assuming asbestos)	1 Fibres/ml
Fluoranthene	Renal and hepatic toxicity; no concern regarding carcinogenicity	44
Fluorene	Screened out	140
Formaldehyde	Nasal carcinogen	10
Gram negative bacteria	Respiratory disease	No HCV
Hydrogen sulphide	Acute toxicity, irritant	150
Indeno (123-cd) pyrene	Concern regarding carcinogenicity	No HCV
Lead	Anaemia and effects on the nervous system, e.g. cognitive impairment in children	0.25
m+p Xylene	Developmental neurotoxicity (NB: draft evaluation recommends HCV of 220 µg/m3)	870
Manganese	Neurotoxic	0.15
Mercury	Screened out	1
Mesophilic Aerobes	Respiratory disease	No HCV
Methyl mercaptan	Acute toxicity; irritant	4
Moulds	Respiratory disease	No HCV
Naphthalene	Screened out	3
Nickel	Carcinogenic; reproductive or foetal toxicity	0.02
Nitrogen dioxide	Irritation of the lungs/respiratory tract	40

Substance	Principal health effect	HCV (µg/m^3)
Nitromethane	Screened out	2540
o Xylene	Developmental neurotoxicity (NB: draft evaluation recommends HCV of 220 µg/m3)	870
PCBs	Reproductive toxicity, immunotoxcity and non-genotoxic carcinogenicity	0.000007
Penicillia	Respiratory disease	No HCV
Phenanthrene	No data; no concern regarding carcinogenicity	No HCV
PM_{10}	Increase in mortality/morbidity possibly via pulmonary inflammatory response	40
Pyrene	Screened out	105
Stibine	Haemolytic agent	5
Styrene	Carcinogenicity, neurological effects	70
Sulphur dioxide	Respiratory irritant	266
Tetrachloroethene	Kidney and CNS effects, non-genotoxic carcinogen,	250
Thallium	Screened out	0.25
Thermophilic Bacteria	Respiratory disease	No HCV
Thermophilic fungi	Respiratory disease	No HCV
Thermophilic fungi and yeasts Malt	Respiratory disease	No HCV
Tin	Screened out	20
Toluene	CNS toxicity	260
Total Bacteria	Respiratory disease	No HCV
Total fungi and yeasts DG18	Respiratory disease	No HCV
Total fungi and yeasts Malt	Respiratory disease	No HCV
Trichloroethene	Carcinogen, liver and CNS damage, possible teratogen	23
Trimethylbenzene	Screened out	625
Vanadium	Screened out	1
Yeasts	Respiratory disease	No HCV

Note 1: If exposure occurs at a level above the HCV, it does not necessarily follow that an adverse health effect would arise. This indicates that more detailed investigation is required.

Table 5.7 Semi-quantitative risk characterisation (Site A)

Substance	Units	Measured concentration		HCV	Measured concentration as % HCV		Carcinogen or developmental toxicity?	Classification
		Average	Maximum		Average	Maximum		
1,1,1-Trichloroethane	µg/m3	0.035	0.27	2.1	1.7%	13%	Screened out	Screened out
1,1-Dichloroethane	µg/m3	0.00056	0.0087	4.12	0.014%	0.21%	Screened out	Screened out
1,2-Dichloroethane	µg/m3	0.062	2.4	0.36	17%	n/a	Yes	C
1,2-Dichloroethene	µg/m3	0.00010	0.0058	60	0.00017%	0.010%	Screened out	Screened out
1,3-butadiene	µg/m3	0	0	2.21 Long term exposure	0%	n/a	Yes	C
2-butanone	µg/m3	0.32	1.4	5000	0.0064%	0.027%	Screened out	Screened out
2-Ethyl-1-hexanol	µg/m3	4.8	86	570	0.84%	15%	No	D
2-Methylfuran	µg/m3	0	0	No HCV	No HCV	No HCV	No	No HCV
Acenaphthene	ng/m3	0.19	0.95	210000 long term exposure	0.000090%	n/a	Screened out	Screened out
Acenaphthylene	ng/m3	0.16	1.72	No HCV	No HCV	No HCV	No	No HCV
alpha-Terpinene	µg/m3	0.44	4.1	390	0.11%	1.1%	Yes	C
Anthracene	ng/m3	0.38	5.02	1050000	0.000036%	0.00048%	No	D
Antimony	ng/m3	0.23	1.4	3000	0.0077%	0.045%	Screened out	Screened out
Arsenic	ng/m3	0.16	1.0	7 long term exposure	2.3%	n/a	Yes	C
Arsine	µg/m3	0	0	0.007	0%	n/a	Screened out	Screened out
Benzene	µg/m3	0.38	3.4	3.2 Long term exposure	12%	n/a	Yes	C
Benzo (a) anthracene	ng/m3	0.33	3.83	No HCV 2.5 based on RP	13%	n/a	Yes	C
Benzo (a) pyrene	ng/m3	0.095	1.32	0.25 Long term exposure	38%	n/a	Yes	C
Benzo (b/k) fluoranthene	ng/m3	0.19	0.92	No HCV 2.5 based on RP	8%	n/a	Yes	C
Benzo (ghi) perylene	ng/m3	0.059	0.48	No HCV	No HCV	No HCV	Yes	A
Cadmium	ng/m3	0.05	0.41	5 long term exposure	1.1%	n/a	Yes	C
Carbon disulphide	µg/m3	2.6	48	100	2.6%	48%	No	D
Chlorobenzene	µg/m3	0.025	0.085	500	0.0049%	0.017%	Screened out	Screened out
Chlorodifluoromethane	µg/m3	0.31	3.0	50000	0.00062%	0.0061%	Screened out	Screened out
Chloroethane	µg/m3	0.018	0.12	10000	0.00018%	0.0012%	Screened out	Screened out
Chloroethene	µg/m3	0.012	0.46	1 Long term exposure	1.2%	n/a	Yes	C
Chloroform	µg/m3	0.034	0.83	52.5 Long term exposure	0.065%	n/a	No	D

Substance	Units	Measured concentration		HCV	Measured concentration as % HCV		Carcinogen or developmental toxicity?	Classification
		Average	Maximum		Average	Maximum		
Chloromethane	µg/m3	0.0018	0.029	18	0%	0%	Screened out	Screened out
Chromium	ng/m3	0.65	3.9	2.5 Long term exposure	26%	n/a	Yes	C
Chrysene	ng/m3	0.38	4.09	No HCV 8.3 based on RP	5%	n/a	Yes	C
Cobalt	ng/m3	0.25	6.0	100	0.25%	6%	Yes	C
Copper	ng/m3	66	298	2000	3.3%	15%	No	D
Dibenzo (ah) anthracene	ng/m3	0.030	0.29	No HCV 0.13 based on RP	23%	n/a	Yes	C
Dichlorobenzene	µg/m3	0.020	0.57	1000	0.0020%	0.057%	Screened out	Screened out
Dichlorodifluoromethane	µg/m3	0.0012	0.0092	50300	0.0000024%	0.000018%	Screened out	Screened out
Dichlorofluoromethane	µg/m3	0	0	430	0%	0%	No	D
Dichloromethane	µg/m3	2.2	7.4	450	0.48%	1.6%	Yes	C
Dimethyl disulphide	µg/m3	1.7	56	5	34%	1127%	No	B
Dimethyl sulphide	µg/m3	10	374	5	202%	7477%	No	B
Dioxins and furans	fgTEQ/m3	20	77	No airborne HCV	No HCV	No HCV	Yes	No HCV
Dioxins, furans and dioxin-like PCBs	fgTEQ/m3	29	92	No airborne HCV	No HCV	No HCV	Yes	No HCV
Endotoxins	EU/m3	0.30	3.1	No HCV	No HCV	No HCV	No	No HCV
Enterobacteriaceae	CFU/m3	0	0	No HCV	No HCV	No HCV	No	No HCV
Ethyl mercaptan	µg/m3	0.023	0.80	10	0.23%	8.0%	No	D
Ethylbenzene	µg/m3	5.4	104	595	0.91%	18%	Yes	C
Fibres	Fibres/ml	0.0012	0.0030	1 Long term exposure	0.12%	n/a	Yes	C
Fluoranthene	ng/m3	0.67	2.24	44000	0.0015%	0.0051%	No	D
Fluorene	ng/m3	0.62	3.43	140000	0.00044%	0.0025%	Screened out	Screened out
Formaldehyde	µg/m3	61	213	10 Long term exposure	610%	n/a	Yes	A
Gram negative bacteria	CFU/m3	0	0	No HCV	No HCV	No HCV	No	No HCV
Indeno (123-cd) pyrene	ng/m3	0.051	0.40	No HCV 3.1 based on RP	1.6%	n/a	Yes	C
Lead	ng/m3	2.1	7.9	250 long term exposure	0.83%	n/a	Yes	C
m+p Xylene	µg/m3	22	496	870	2.5%	57%	Yes	C
manganese	ng/m3	6.2	51	150	4.1%	34%	No	D
Mercury	ng/m3	0	0	1000	0%	0%	Screened out	Screened out
Mesophilic Aerobes	µg/m3	15	77	No HCV	No HCV	No HCV	no	No HCV
Methyl mercaptan	µg/m3	2.0	22	4	50%	539%	No	B

Substance	Units	Measured concentration		HCV	Measured concentration as % HCV		Carcinogen or developmental toxicity?	Classification
		Average	Maximum		Average	Maximum		
Moulds	CFU/m3	22	67	No HCV	No HCV	No HCV	No	No HCV
Naphthalene	ng/m3	0.71	3.59	3000 long term exposure	0.024%	n/a	Screened out	Screened out
Nickel	ng/m3	1.3	3.0	20	6.6%	15%	Yes	C
Nitromethane	µg/m3	0	0	2540	0%	0%	Screened out	Screened out
o Xylene	µg/m3	9.7	258	870	1.1%	30%	Yes	C
PCBs	ng/m3	0	0	0.007 Long term exposure	0%	n/a	Yes	C
Phenanthrene	ng/m3	2.50	14.52	No HCV	No HCV	No HCV	No	No HCV
Pyrene	ng/m3	0.53	1.85	105000	0.00050%	0.0018%	Screened out	Screened out
Stibine	µg/m3	90	222	5	1805%	4449%	No	B
Styrene	µg/m3	4.4	109	70	6.3%	156%	Yes	A
Tetrachloroethene	µg/m3	0.43	5.6	250 Long term exposure	0.17%	n/a	No	D
Thallium	ng/m3	0	0	250	0%	0%	Screened out	Screened out
Thermophilic Bacteria	CFU/m3	55	687	No HCV	No HCV	No HCV	No	No HCV
Thermophilic fungi and yeasts	CFU/m3	19	168	No HCV	No HCV	No HCV	No	No HCV
Tin	ng/m3	0.21	2.0	20000	0.0011%	0.010%	Screened out	Screened out
Toluene	µg/m3	62	923	260	24%	355%	No	B
Total Bacteria	CFU/m3	119	893	No HCV	No HCV	No HCV	No	No HCV
Total fungi and yeasts DG18	CFU/m3	56	412	No HCV	No HCV	No HCV	No	No HCV
Total fungi and yeasts	CFU/m3	23	72	No HCV	No HCV	No HCV	No	No HCV
Trichloroethene	µg/m3	0.15	2.8	23 Long term exposure	0.64%	n/a	Yes	C
Trimethylbenzene	µg/m3	0.22	2.0	625	0.036%	0.32%	Screened out	Screened out
Vanadium	ng/m3	0.10	1.2	1000	0.010%	0.12%	Screened out	Screened out
Yeasts	CFU/m3	0	0	No HCV	No HCV	No HCV	No	No HCV

Note: Measurements below limit of detection assumed to be zero

Table 5.8 Semi-quantitative risk characterisation (Site B)

Substance	Units	Measured concentration		HCV	Measured concentration as % HCV		Carcinogen or developmental toxicity?	Classification
		Average	Maximum		Average	Maximum		
1,1,1-Trichloroethane	µg/m3	0.042	0.11	2.1	2.0%	5.2%	Screened out	Screened out
1,1-Dichloroethane	µg/m3	0.0018	0.030	4.12	0.044%	0.73%	Screened out	Screened out
1,2-Dichloroethane	µg/m3	0.31	1.5	0.36	86%	n/a	Yes	C
1,2-Dichloroethene	µg/m3	0.086	0.50	60	0.14%	0.83%	Screened out	Screened out
1,3-butadiene	µg/m3	1.24	20	2.21 Long term exposure	56%	n/a	Yes	C
2-butanone	µg/m3	0.76	1.5	5000	0.015%	0.030%	Screened out	Screened out
2-Ethyl-1-hexanol	µg/m3	2.0	8.3	570	0.36%	1.5%	No	D
2-Methylfuran	µg/m3	0.64	2.0	No HCV	No HCV	No HCV	No	No HCV
Acenaphthene	ng/m3	0.11	0.60	210000 long term exposure	0.000053%	n/a	Screened out	Screened out
Acenaphthylene	ng/m3	0.04	0.20	No HCV	No HCV	No HCV	No	No HCV
alpha-Terpinene	µg/m3	0.26	0.90	390	0.066%	0.23%	Yes	C
Anthracene	ng/m3	0.18	2.79	1050000	0.000017%	0.00027%	No	D
Antimony	ng/m3	0.35	1.0	3000	0.012%	0.033%	Screened out	Screened out
Arsenic	ng/m3	0.14	1.0	7 long term exposure	2.0%	n/a	Yes	C
Arsine	µg/m3	0.11	0.53	0.007	1607%	n/a	Yes	A
Aspergillus fumigatus	CFU/m3	45	500	No HCV	No HCV	No HCV	No	No HCV
Benzene	µg/m3	0.62	3.2	3.2 Long term exposure	19%	n/a	Yes	C
Benzo (a) anthracene	ng/m3	0.16	1.00	No HCV 2.5 based on RP	6%	n/a	Yes	C
Benzo (a) pyrene	ng/m3	0.039	0.58	0.25 Long term exposure	16%	n/a	Yes	C
Benzo (b/k) fluoranthene	ng/m3	0.22	1.23	No HCV 2.5 based on RP	9%	n/a	Yes	C
Benzo (ghi) perylene	ng/m3	0.021	0.47	No HCV	No HCV	No HCV	Yes	A
Cadmium	ng/m3	0.26	5.7	5 long term exposure	5.2%	n/a	Yes	C
Carbon disulphide	µg/m3	1.4	38	100	1.4%	38%	No	D
Chlorobenzene	µg/m3	0.088	0.44	500	0.018%	0.088%	Screened out	Screened out
Chlorodifluoromethane	µg/m3	0.072	0.70	50000	0%	0%	Screened out	Screened out
Chloroethane	µg/m3	0.015	0.090	10000	0.00015%	0.00090%	Screened out	Screened out
Chloroethene	µg/m3	0.090	4.9	1 Long term exposure	9.0%	n/a	Yes	C

Substance	Units	Measured concentration		HCV	Measured concentration as % HCV		Carcinogen or developmental toxicity?	Classification
		Average	Maximum		Average	Maximum		
Chloroform	µg/m3	0.22	1.5	52.5 Long term exposure	0.42%	n/a	No	D
Chloromethane	µg/m3	0.00018	0.010	18	0.0010%	0.056%	Screened out	Screened out
Chromium	ng/m3	1.9	28.0	2.5 Long term exposure	76%	n/a	Yes	C
Chrysene	ng/m3	0.23	1.51	No HCV 8.3 based on RP	3%	n/a	Yes	C
Cobalt	ng/m3	0.08	0.4	100	0.081%	0.40%	Yes	C
Copper	ng/m3	26	59	2000	1.3%	3.0%	No	D
Dibenzo (ah) anthracene	ng/m3	0.083	0.81	No HCV 0.13 based on RP	63%	n/a	Yes	C
Dichlorobenzene	µg/m3	0.49	5.0	1000	0.049%	0.50%	Screened out	Screened out
Dichlorodifluoromethane	µg/m3	0	0	50300	0%	0%	Screened out	Screened out
Dichlorofluoromethane	µg/m3	0	0	430	0%	0%	No	D
Dichloromethane	µg/m3	0.65	2.1	450	0.14%	0.46%	Yes	C
Dimethyl disulphide	µg/m3	0.64	16	5	13%	313%	No	B
Dimethyl sulphide	µg/m3	2.4	59	5	48%	1183%	No	B
Dioxins and furans	fgTEQ/m3	72	1839	No airborne HCV	No HCV	No HCV	Yes	No HCV
Dioxins, furans and dioxin-like PCBs	fgTEQ/m3	108	1939	No airborne HCV	No HCV	No HCV	Yes	No HCV
Endotoxins	EU/m3	1.9	9.1	No HCV	No HCV	No HCV	No	No HCV
Ethyl mercaptan	µg/m3	0.080	2.1	10	0.80%	21%	No	D
Ethylbenzene	µg/m3	0.74	5.4	595	0.12%	0.91%	Yes	C
Fibres	Fibres/ml	0.0018	0.0070	1 Long term exposure	0.18%	n/a	Yes	C
Fluoranthene	ng/m3	1.19	7.09	44000	0.0027%	0.016%	No	D
Fluorene	ng/m3	0.45	1.50	140000	0.00032%	0.0011%	Screened out	Screened out
Formaldehyde	µg/m3	139	487	10 Long term exposure	1390%	n/a	Yes	A
Gram negative bacteria	CFU/m3	0	0	No HCV	No HCV	No HCV	No	No HCV
Indeno (123-cd) pyrene	ng/m3	0.074	0.81	No HCV 3.1 based on RP	2%	n/a	Yes	C
Lead	ng/m3	2.6	8.0	250 long term exposure	1.0%	n/a	Yes	C
m+p Xylene	µg/m3	2.9	19	870	0.33%	2.2%	Yes	C
manganese	ng/m3	5.8	24	150	3.9%	16%	No	D
Mercury	ng/m3	0.034	0.7	1000	0.0034%	0.070%	Screened out	Screened out
Methyl mercaptan	µg/m3	0.59	7.5	4	15%	187%	No	B

Substance	Units	Measured concentration		HCV	Measured concentration as % HCV		Carcinogen or developmental toxicity?	Classification
		Average	Maximum		Average	Maximum		
Naphthalene	ng/m3	0.38	1.37	3000 long term exposure	0.013%	n/a	Screened out	Screened out
Nickel	ng/m3	2.4	14.0	20	12%	70%	Yes	C
Nitromethane	µg/m3	0.80	2.5	2540	0.031%	0.10%	Screened out	Screened out
o Xylene	µg/m3	1.6	14	870	0.18%	1.6%	Yes	C
PCBs	ng/m3	0	0	0.007 Long term exposure	0%	n/a	Yes	C
Penicillia	CFU/m3	5	50	No HCV	No HCV	No HCV	No	No HCV
Phenanthrene	ng/m3	2.73	15.11	No HCV	No HCV	No HCV	No	No HCV
Pyrene	ng/m3	0.78	5.00	105000	0.00074%	0.0048%	Screened out	Screened out
Stibine	µg/m3	0	0	5	0%	0%	No	D
Styrene	µg/m3	0.91	4.6	70	1.3%	6.6%	Yes	C
Tetrachloroethene	µg/m3	0.33	1.1	250 Long term exposure	0.13%	n/a	No	D
Thallium	ng/m3	0.031	1.0	250	0.013%	0.40%	Screened out	Screened out
Thermophilic Bacteria	CFU/m3	162	2100	No HCV	No HCV	No HCV	No	No HCV
Thermophilic fungi and yeasts	CFU/m3	21	355	No HCV	No HCV	No HCV	No	No HCV
Tin	ng/m3	0.47	2.0	20000	0.0023%	0.010%	Screened out	Screened out
Toluene	µg/m3	5.6	41	260	2.1%	16%	No	D
Total Bacteria	CFU/m3	487	4000	No HCV	No HCV	No HCV	No	No HCV
Total fungi and yeasts DG18	CFU/m3	26	275	No HCV	No HCV	No HCV	No	No HCV
Total fungi and yeasts	CFU/m3	89	1376	No HCV	No HCV	No HCV	No	No HCV
Trichloroethene	µg/m3	0.55	2.1	23 Long term exposure	2.4%	n/a	Yes	C
Trimethylbenzene	µg/m3	0.81	5.0	625	0.13%	0.80%	Screened out	Screened out
Vanadium	ng/m3	1.3	7.1	1000	0.13%	0.71%	Screened out	Screened out

Note: Measurements below limit of detection assumed to be zero

Table 5.12 Qualitative groundwater risk assessment (Site A)

Source	Pollutant	Receptors	Pathways to Receptor	Associated Hazard [Severity]	Likelihood of Occurrence	Potential Risk
Landfill leachate	Ammoniacal nitrogen	Local inhabitants	Migration via groundwater to the Spring followed by consumption of spring water	Effect on human health [Mild]	Medium likelihood. Elevated concentrations observed. Linkage proved by previous studies, but consumption unlikely to occur	Moderate – Low
			Migration via groundwater to surface followed by consumption of water	Effect on human health [Mild]	Medium likelihood. Elevated concentrations observed but conditions in the aquifer may be contributing pollutant from other sources, but consumption unlikely to occur	Moderate – Low
			Surface water receiving groundwater discharge followed by fishing or consumption of surface waters	Effect on human health [Mild]	Medium likelihood. Median concentrations in the stream similar downstream to upstream of the point where the spring discharges.	Moderate – Low
			Products from livestock drinking surface water	Effect on human health [Mild]	Low likelihood. Median concentrations in the stream similar downstream to upstream.	Low
	Metals	Local inhabitants	Migration via groundwater to the Spring followed by consumption of spring water	Effect on human health [Mild]	Medium Likelihood. Concentrations of metals in the spring are low. Consumption unlikely to occur	Moderate – Low
			Migration via groundwater to surface followed by consumption of water	Effect on human health [Mild]	Medium likelihood. Elevated concentrations observed but conditions in the aquifer may be contributing pollutant from other sources, but consumption unlikely to occur	Moderate – Low
			Surface water receiving groundwater discharge followed by fishing or consumption of surface waters	Effect on human health [Mild]	Medium likelihood. Concentrations of metals in the spring are low. Concentrations in river are similar upstream and downstream.	Moderate – Low
			Products from livestock drinking surface water	Effect on human health [Mild]	Low likelihood. Concentrations of metals in the spring are low. Concentrations in river are similar upstream and downstream.	Low
	Organics and other determ-	Local inhabitants	Migration via groundwater to the Spring followed by consumption of spring water	Effect on human health [Mild – Medium]	Medium Likelihood. Little data but none noted to date. Consumption unlikely to occur	Moderate – Low

Source	Pollutant	Receptors	Pathways to Receptor	Associated Hazard [Severity]	Likelihood of Occurrence	Potential Risk
	inands listed in DEFRA (2004)		Migration via groundwater to surface followed by consumption of water	Effect on human health [Mild – Medium]	Medium likelihood. No data but dilution with regional groundwater flow likely. Consumption unlikely to occur	Moderate – Low
			Surface water receiving groundwater discharge followed by fishing or consumption of surface waters	Effect on human health [Mild – Medium]	Unlikely - Low Likelihood. None noted in spring. Dilution with upstream water will occur.	Very Low – Low
			Products from livestock drinking surface water	Effect on human health [Mild – Medium]	Low Likelihood. None noted in spring. Dilution with upstream water will occur.	Very Low – Low

Table 5.13 Qualitative groundwater risk assessment (Site B)

Source	Pollutant	Receptors	Pathways to Receptor	Associated Hazard [Severity]	Likelihood of Occurrence	Potential Risk
Landfill leachate	Ammoniacal nitrogen, metals	Local inhabitants	Migration via groundwater to groundwater abstraction and consumption	Effect on human health [Medium]	Low likelihood. Migration over a long flow path, likely to result in significant degree of attenuation as well as dilution the well. Sporadic concentrations above drinking water standards.	Moderate / Low
			Migration via groundwater to water used for livestock drinking	Effect on human health [Medium]	Low likelihood. Livestock given water for drinking. Sporadic concentrations above human drinking water standards.	Moderate / Low
			Migration via groundwater to water used for irrigation	Effect on human health [Mild]	Low likelihood. Water used for irrigation. Sporadic concentrations above human drinking water standards.	Low
		Local amenity users	Exposure to groundwater used to increase concentrations in ponds	Effect on human health [Mild]	Low likelihood. Fishermen only likely to be periodically exposed, with limited ingestion of water. Sporadic concentrations above drinking water.	Low
			Consumption of fish from ponds	Effect on human health [Mild]	Low likelihood. Fishermen only likely to be periodically exposed. Sporadic concentrations above drinking water. Based on size on ponds impacts to fish likely to be based on average concentrations.	Low

Source	Pollutant	Receptors	Pathways to Receptor	Associated Hazard [Severity]	Likelihood of Occurrence	Potential Risk
		Farm workers	Migration via groundwater to water used for livestock drinking	Effect on human health [Mild]	Low likelihood. Farmers only likely to be periodically exposed, with limited ingestion of water. Sporadic concentrations above drinking water.	Low
			Migration via groundwater to water used for irrigation	Effect on human health [Mild]	Low likelihood. Farmers only likely to be periodically exposed, with limited ingestion of water. Sporadic concentrations above drinking water.	Low
Landfill leachate	Organics and other determ-inands listed in DEFRA (2004)	Local inhabitants	Migration via groundwater to groundwater abstraction and consumption	Effect on human health [Medium]	Low likelihood. Migration over a long flow path, likely to result in significant degree of attenuation as well as dilution the well. No data but dilution with regional groundwater flow likely	Moderate / Low
			Migration via groundwater to water used for livestock drinking	Effect on human health [Medium]	Low likelihood. Livestock given water for drinking. No data but dilution with regional groundwater flow likely	Moderate / Low
			Migration via groundwater to water used for irrigation	Effect on human health [Mild]	Low likelihood. Water used for irrigation. No data but dilution with regional groundwater flow likely	Low
		Local amenity users	Exposure to groundwater used to increase concentrations in ponds	Effect on human health [Mild]	Low likelihood. Fishermen only likely to be periodically exposed, with limited ingestion of water. No data but dilution with regional groundwater flow likely	Low
			Consumption of fish from ponds	Effect on human health [Mild]	Low likelihood. Fishermen only likely to be periodically exposed. No data but dilution with regional groundwater flow likely Based on size on ponds impacts to fish likely to be based on average concentrations.	Low
		Farm workers	Migration via groundwater to water used for livestock drinking	Effect on human health [Mild]	Low likelihood. Farmers only likely to be periodically exposed, with limited ingestion of water. No data but dilution with regional groundwater flow likely	Low
			Migration via groundwater to water used for irrigation	Effect on human health [Mild]	Low likelihood. Farmers only likely to be periodically exposed, with limited ingestion of water. No data but dilution with regional groundwater flow likely	Low

Table 5.14 Estimated concentrations of components of leachate (Site A)

Selected substances (DEFRA, 2004)	Leachate Quality from Database		Estimated concentration at downstream borehole		Estimated concentration at spring		DWS[1]/ WHO[2]/ other[3]
	Median	Mean	Median	Mean	Median	Mean	
Aniline (µg/l)	<1	<1.46	<0.01	<0.015	<0.0008	<0.0012	1[3]
Methyl 1,1 dimethyl ethyl ether (methyl tertiary butyl ether) (µg/l)	<1	<1.38	<0.01	<0.014	<0.0008	<0.0011	20-40[3]
Cyanide (as CN) (mg/l)	<0.05	<0.05	<0.0005	<0.0005	<0.00004	<0.00004	50[1]
Di (2ethyl hexyl) phthalate[5] (µg/l)	<1	4.25	<0.01	0.042	<0.0008	0.0034	8[2]
Fluoride (mg/l)	0.65	0.86	0.0065	0.009	0.00052	0.00069	1.5[1]
Methyl chlorophenoxy acetic acid (µg/l)	<0.1	0.69	<0.001	0.0069	<0.00008	0.00055	0.1[1,4]
Dichloromethane (µg/l)	<1	42.8	<0.01	0.43	<0.0008	0.034	20[2]
Organo-tin (µg/l)	0.2	0.3	0.002	0.003	0.00016	0.00024	
Phosphorus (mg/l)	3	3.9	0.03	0.039	0.0024	0.0031	2.2[1]
Polycyclic aromatic hydrocarbons (µg/l)	<5.25	<5.60	<0.052	<0.056	<0.0042	<0.0045	0.1[1]
Nonyl phenol (µg/l)	1	4.9	0.01	0.049	0.0008	0.0039	None available
Biphenyl (µg/l)	0.1	0.46	0.001	0.0046	0.00008	0.00037	None available
Pentachlorophenol and compounds (µg/l)	<0.1	0.32	<0.001	0.0032	<0.00008	0.00026	1[3]
Arsenic (µg/l)	8	16	0.08	0.16	0.0064	0.013	10[1]

1 = Drinking Water Standard 2000 or 1989
2 = WHO Guidelines v2
3 = other guidelines
4 = Value for pesticides used
5 = IUPAC name is 1,2-Benzenedicarboxylic acid bis(2-ethylhexyl) ester
Cells shaded grey exceed DWS

Table 5.15 Estimated concentrations of components of leachate (Site B)

Selected substances (DEFRA, 2004))	Leachate Quality from Database or site data		Estimated concentration in groundwater Beneath the site		DWS[1]/ WHO[2]/ other[3]
	Median	Mean	Median	Mean	
Aniline (µg/l)	<1	<1.46	<0.0033	<0.0048	13
Methyl 1,1 dimethyl ethyl ether (methyl tertiary butyl ether) (µg/l)	<1	<1.38	<0.0033	<0.0045	20-40[3]
Cyanide (as CN) (mg/l)	<0.05	<0.05	0.0002	0.0002	501
Di(2ethyl hexyl)phthalate (µg/l)	<1	4.25	<0.0033	0.014	82
Ethylbenzene (µg/l)	<10	19	<0.033	0.062	
Fluoride (mg/l)	0.65	0.86	0.0021	0.0028	1.51
Methyl chlorophenoxy acetic acid (µg/l)	<0.1	0.69	<0.00033	0.0023	0.1[1,4]
Dichloromethane (µg/l)	<1	42.8	<0.0033	0.14	202
Nitrogen (Total) (mg/l)	364	629	1.2	2.1	
Organo-tin (µg/l)	0.2	0.3	0.0007	0.0010	
Phenols (mg/l)	0.03	0.35	0.0001	0.0011	0.005
Phosphorus (mg/l)	3	3.9	0.0098	0.013	2.21
Polycyclic aromatic hydrocarbons (µg/l)	<5.25	<5.60	<0.017	<0.018	0.11
Nonyl phenol (µg/l)	1	4.9	0.0033	0.016	
Biphenyl (µg/l)	0.1	0.46	0.0003	0.0015	
Mecoprop (µg/l)	11	21.8	0.036	0.071	0.1
Naphthalene (µg/l)	0.46	3.04	0.0015	0.0099	
Pentachlorophenol and compounds (µg/l)	<0.1	0.32	<0.00033	0.0010	13
Toluene (µg/l)	21	87	0.069	0.28	
Xylenes (µg/l)	35	59	0.11	0.19	
Arsenic (µg/l)	8	16	0.026	0.052	10
Chloride (mg/l)	1160	1123	3.8	3.7	250
Chromium (µg/l)	29	57	0.095	0.19	50
Copper (µg/l)	20	57	0.065	0.19	2000
Lead (µg/l)	30	50	<0.16	0.16	25
Nickel (µg/l)	112	115	0.37	0.38	20
Zinc (µg/l)	270	563	0.88	1.8	
Ammoniacal Nitrogen (N:mg/l)	520	549	1.7	1.8	0.39

1 = Drinking Water Standard 2000 or 1989
2 = WHO Guidelines v2
3 = other guidelines
4 = Value for pesticides used
Cells shaded grey exceed DWS
Substances in **bold**: site data on leachate quality used

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