Environment Agency

Evidence

Exposure Assessment of Landfill Sites
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Authors:
Enviros Consulting Ltd (M Broomfield and J Davies)
Resource and Environmental Consultants Ltd (P Furmston)
MRC Institute for Environment and Health (L Levy)
Cranfield University Integrated Waste Management Centre (SJT Pollard, R Smith)

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Research Contractor:
Enviros Consulting Ltd, Enviros House, Shrewsbury Business Park, Shrewsbury SY2 6LG Tel. 01743 284800

Environment Agency's Project Manager:
Chris Peters, Environment Agency
and from 2008,
Terry Coleman, Environment Agency Evidence Directorate

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Evidence underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us, helps us to develop tools and techniques to monitor and manage our environment as efficiently and effectively as possible. It also helps us to understand how the environment is changing and to identify what the future pressures may be.

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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

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Appendix 1 : Literature Review

This appendix contains the Executive Summary of a literature review carried out in 2000 as the first stage of the project. The appendix then contains a more recent evaluation of the health effects of landfill sites reproduced from a report carried out on behalf of DEFRA.

EXECUTIVE SUMMARY OF ORIGINAL LITERATURE REVIEW

1 A review of recent studies of potential health effects due to emissions from landfill sites has been carried out. The aim of the literature review was to address the following questions:

(a) Is there a link between landfill sites and adverse health effects?

(b) If there is a link, do landfill emissions cause the adverse health effects?

2 This subject has recently been the subject of considerable debate, due to a number of high-profile publications and studies. Much of the available research has been carried out in the United States, where significant differences in landfilling practices mean that the research is not directly applicable to the UK.

3 The relevant research may be broadly broken down into those that focus on measuring landfill emissions and public exposures; and those which study health consequences. Measurements of emissions are mainly carried out in the field; and studies of health effects being carried out in the laboratory or using medical/community records.

4. A wide range of different health effects has been considered in studies of health effects associated with landfill sites. However, consistent patterns fail to emerge Many studies examine a broad range of health effects, yet report evidence for increased likelihood of occurrence in only a small subset. There is no consistent pattern of possible causes underlying the reported health effects. This may reflect the difficulties of undertaking health effects studies with large enough sample sizes to obtain statistically significant results. Any effects are more likely to be due to very long term exposure to low levels of released substances than due to exposure to short-term peaks in levels of released substances.

5. Four studies have been considered in more depth in this review:

- The “EUROHAZCON” study: this study identified a link between between birth defects and hazardous waste landfills in Europe. However, the study did not include a detailed allowance for the possible influence of emissions from other sources. No consistent pattern of effects was observed for sites in England.

- A study of the Nant-y-Gwyddon landfill in South Wales: this study identified elevated levels of some health effects in the vicinity of this landfill, but again, other local sources of pollution are likely to have had a similar influence to any landfill emissions. Relatively high incidences of some health consequences were identified in this area before the start of landfilling operations at this site.

- A study of chromium waste tips in Glasgow: this study highlighted the influence of individual perceptions in reporting of symptoms.

- A study of municipal waste sites in the US: this study reported a higher incidences of cancer in the immediate vicinity of some of the sites considered.

6. Emissions from landfill sites can be transported through air, water and soil pathways. As well as direct exposure routes, consideration has also been given to exposure via rodents and other pests, and via road traffic. The substances of concern include pesticides, toxic organic substances, solvents, cyanides, metals, plastics and derivatives, volatile organic compounds. The literature review indicates that potentially significant emissions include leachate, landfill gas and wind blown dust. The potential also exists for emissions of micro-organisms by air. Rodents and other vermin have not been found to be a major pathway for landfill emissions, and there is little information available on emissions from transportation of wastes to landfill sites, or via wind blown dust.

7. In summary, there is extensive evidence relating to the substances which may be emitted from landfill sites via leachate and landfill gas. Other emissions have been much less extensively studied. There is little information available at present on exposures of local populations to the substances emitted from landfills. There are no plausible mechanisms for the possible adverse health outcomes at present. A large number of population-based studies have been carried out, with the aim of identifying any statistical links between proximity to landfills and health consequences. These studies have not provided consistent evidence of adverse health effects.

8. Future work should be aimed firstly towards fully characterising landfill emissions. These measurements should be evaluated to assess population exposures to landfill emissions. Secondly, further work should be carried out to establish whether these exposures could give rise to adverse health consequences.

Key words list
Landfill, Waste, Refuse, Emissions, Health, Epidemiology, Leachate, Literature Review

Excerpt from DEFRA funded research into the health and environmental effects of waste management, May 2004.

Department for Environment, Food and Rural Affairs, *"Review of health and environmental effects of waste management – Phase 1 : MSW and similar wastes,"* report prepared by consortium led by Enviros Consulting Ltd and Birmingham University, May 2004 (the full report can be obtained from www.defra.gov.uk/environment/waste). Reproduced by permission of DEFRA.

Note: references which are published in the peer reviewed literature are marked in **bold**. References which have been reviewed by other means (e.g. Environment Agency research reports, or information published by reputable governmental bodies) are marked in *italics*. Other references are marked in normal type.

Extract taken from Section 3.7 of report (pp159 to 163) and Tables 3.17 to 3.22 (pp 182 – 189)

Chapter 3 – Review of Epidemiological Research

3.7 Landfill

Introduction

As described in Chapter 1, the practice of landfill involves the use or creation of contained void spaces. These are normally in the form of cells which can be lined, then filled with waste materials which are progressively compressed and enclosed with further soil, and eventually with a permanent cap. Since much of the waste is not processed prior to disposal in a landfill, biodegradable materials subsequently decay releasing landfill gas. Landfill gas comprises mainly methane and carbon dioxide, and is increasingly collected for combustion and energy conversion.

Detailed chemical analysis of landfill gas shows the presence of potentially toxic components to which of adjacent populations could be exposed due to incomplete collection of gas. Landfills are susceptible to the ingress of water principally from rainfall. Modern landfills are lined with a comprehensive low permeability system which limits seepage of leachate to surrounding soils to a level assessed to be acceptable, and capped when full. For older landfills, however, greater movement of leachate is a potential pathway for human exposure, as set out in Chapter 2.

Concern over the health effects of landfill stems in the main from historic poorly regulated industrial waste sites from which contamination of the local environment is in some cases well documented. As noted in the general introduction, however, municipal solid waste can include some hazardous materials from domestic sources. Both the disposal of hazardous materials and their production by biodegradation processes can lead to the potential for environmental releases of hazardous materials from municipal solid waste.

Review of Health Effects Studies

The majority of published research on the human health effects of landfill relates to landfill sites which accepted either hazardous waste or co-disposal of municipal and hazardous wastes. Such sites are outside of the scope of this study and therefore many superficially relevant studies have been deliberately excluded.

Redfearn and Roberts (2002) have presented a detailed review of the available epidemiological literature on landfill and health. They separate the available epidemiological studies into four categories as follows:

- Single site studies of waste sites including hazardous waste sites, illegal landfills or "in-house" landfills within the curtilage of industry;
- Multi-site studies of sites including hazardous waste sites, illegal landfills or "in-house" landfills within the curtilage of industry;
- Single site epidemiological studies of potential health effects associated with landfill including some sites accepting hazardous waste;
- Multi-site epidemiological studies of potential health effects associated with waste disposal sites, some accepting hazardous waste.

Redfearn and Roberts (2002), discounted the first two groups of studies as concerning sites which did not in any way parallel current UK landfill practice, and which were therefore not useful in interpretation of effects. The papers in the latter two categories are summarised in Tables 3.17 and 3.18. **Redfearn and Roberts (2002)** went on to analyse the outcomes of the various studies in terms of demonstration of excess risks. The summary table which they presented appears as Table 3.19. This categorises studies according to health outcome and whether the study indicated an excess risk for those residing in the vicinity of a landfill for that health outcome and those indicating no excess risk. Those reported as demonstrating excess risk showed a significant positive association between a health outcome and proximity to a landfill site. Those indicated as showing no excess risk did not show a statistically significant association, although the reason could be lack of statistical power to demonstrate such an association, in which case the lack of a demonstrated excess risk should not be taken necessarily as an absence of risk. The majority of the adverse health outcomes studied come under the categories of birth defects and other pregnancy outcomes, and cancers. The balance between studies with and without a positive finding appears more strongly in favour of outcomes with an excess risk in the case of birth defects as opposed to cancer. Thus, whilst Table 3.19 is useful in illustrating the diversity of results from the various studies, it should not be used to infer adverse effects caused by landfill. Rather, it is necessary to examine individual studies to draw conclusions in this matter. It must also be remembered (see Section 3.2.1) that statistically significant associations can occur purely by chance especially in studies where a large number of possible relationships are examined.

Many of the landfill sites listed in Table 3.17 are notorious toxic waste sites which are known to have caused problems of one kind or another. Sites such as the Nant-y-Gwyddon landfill in Wales which initially gave concern of malodorous emissions has been the subject of a number of studies and adverse health effects remain controversial. Many of the

other sites were in North America and had a long history of poorly controlled disposal of hazardous wastes. Table 3.18 includes some of the more modern and comprehensive multi-site studies including the pan-European EUROHAZCON study (**Dolk et al., 1998; Vrijheid et al., 2002**). With the exception of the **Elliott et al. (2001a,b)** studies, the research addressed hazardous waste sites explicitly and is not of direct and immediate relevance to this study of municipal waste disposal.

The key study in the UK context is that by the Small Area Health Statistics Unit (**Elliott et al., 2001**). This was a study of adverse birth outcomes in populations living near landfill sites where the "exposed" population was defined as living within 2 km of one of 9565 landfill sites operational at some time between 1982 and 1997, when compared with those living further away. All of the landfill sites were located in Great Britain and the study examined 124,597 congenital anomalies (including terminations) amongst over 8.2 million live births and 43,471 stillbirths.

The sole criterion used by Elliott et al. (2001) for judging exposure to the landfill activity was proximity of residence. For 70% of landfill sites, distances were measured from the site centroid whilst for the remainder the location of the site gateway at the time of reporting was used. A 2 km zone was constructed around each landfill site corresponding to an assumed likely limit of dispersion for landfill emissions. Persons with residential postcodes within the 2 km zone were classified as within the exposed population, whilst people living more than 2 km from all known landfill sites during the study period comprised the reference population. Fifty-five percent of the national population resided within the 2 km zones around the 9565 landfill sites operational between 1982 and 1987, which comprised 774 sites for hazardous waste, 7803 sites for non-hazardous waste and 988 sites which handled unknown wastes. Congenital anomalies which were examined included neural tube defects, cardiovascular defects, abdominal wall defects, hypospadias and epispadias, surgical correction of hypospadias and epispadias and surgical correction of gastroschisis and exomphalos. The instances of low and very low birth weights defined as less than 2500 g and less than 1500 g respectively were also examined.

Risks for the population within 2 km of landfill relative to the reference population were calculated by indirect standardisation assuming a common relative risk for all landfill sites. The regression function included year of birth, administrative region, sex, (for birth weight and still births) and deprivation. The latter was based on the national distribution of the Carstairs deprivation index based on 1991 census statistics at enumeration district level. The results for risks of congenital anomalies, stillbirths and low birth weights during operation or after closure of a landfill site combining all waste types appear in Table 3.20. After the important adjustment for deprivation, there remains a small but nonetheless statistically significant excess relative risk for those living within 2 km of a landfill site for all congenital anomalies, neural tube defects, hypospadias and epispadias, abdominal wall defects, surgical correction of gastroschisis and exomphalos, low birth weight and very low birth weight.

The analysis was also carried out separately for sites handling special (i.e. hazardous) waste and non-special waste as well as for sites that opened during the study period, relative risks before opening and during

operation or after closure. The results appear in Table 3.21. The authors comment that sites listed as handling special (i.e. hazardous waste) due to the UK practice of co-disposal of special and non-special wastes may in fact only handle small volumes of hazardous waste; they are likely to be subject to stricter management and design standards than other UK sites therefore minimising pollutant releases and exposure of the local population. On the other hand, the authors raise the possibility that hazardous waste may have been disposed of unreported in non-special waste sites. Given the strict regulatory regime in place, this appears unlikely to have occurred in practice in recent years. The results indicate that for the statistically significant associations of birth outcomes with residence within 2 km of a landfill site, the relative risk appears to be greater for special waste than non-special waste sites. Those birth outcomes which show an excess of disease for non-special waste sites are all congenital anomalies combined, neural tube defects, hypospadias and epispadias, surgical correction of gastroschisis and exomphalos, low birth weight and very low birth weight. For the latter two outcomes the relative risk is marginally higher for non-special waste sites than for special waste sites.

When risks associated with sites that opened during the study period (irrespective of waste type) were compared over the periods before opening with those during operation or after closure, rather few of the estimated relative risks were significant. Whilst relative risks were higher for some birth outcomes during operation or after closure of the site, for certain birth outcomes, most notably abdominal wall defects, the relative risk before opening of the site was greater than during operation or after closure. Whilst stillbirths, low birth weights and very low birth weights were all significantly associated with residence within 2 km of a landfill site during operation or after closure, prior to opening none was significantly associated. The authors comment that this latter kind of analysis involving rates of disease both before and after the opening of landfill sites being restricted to one set of areas is less subject to confounding by socio-demographic factors than comparisons between different areas, although confounding by temporal trends is possible.

Commenting on the paper by **Elliott *et al.* (2001), McNamee and Dolk (2001)** drew attention to the fact that small errors in adjusting for confounding, for example, by socio-economic class could increase or decrease relative risk for landfill versus reference areas quite appreciably. They also questioned whether residence within 2 km of a landfill was the best measure of exposure and pointed out various reasons why misclassification of exposure might have occurred. For example, because the study was based on residence at pregnancy outcome, misclassification would occur if women moved home between the critical period of early pregnancy and the end of pregnancy.

Whilst there are weaknesses in the Small Area Health Statistics Unit study (**Elliott *et al.*, 2001**), it is undoubtedly the strongest piece of epidemiological research carried out in the UK and probably internationally on the issue of risks of congenital anomalies in relation to landfill. The small positive association found between certain adverse birth outcomes and residence in proximity to a landfill cannot be stated with certainty to be causal, but provide the best currently available estimate of relative risk.

Although not included in the main published paper, the study also examined a number of cancer outcomes, specifically childhood and adult leukaemias, hepatobiliary cancers and cancers of bladder and brain. After controlling for socio-economic status, no excess risk for those living within 2 km of a landfill site was found for each of the cancer types studied (**Jarup et al., 2002**). This result must be viewed with less confidence than those relating to congenital malformations because of the likely latency period in developing a cancer. SAHSU used a lag period of one year for childhood leukaemia and five years for the other cancer outcomes which may be unduly short but was a pragmatic approach taken in order to increase the number of years of data available for analysis and to reduce the potential of dilution by migration. If, however, the latency period is longer, this index of potential exposure may be inappropriate leading to dilution of any potential effect (*Committee on Toxicity, 2001*).

3.4.3 Applicable Exposure-Response Functions from Literature Review

The available information regarding studies of landfill and the direct effects on the health of local populations has been reviewed.

For landfills, by far the most powerful UK-based study (**Elliott et al., 2001**) provides some evidence of an elevated relative risk for certain adverse birth outcomes for those resident within 2 km of a landfill. This information can be used for the development of quantitative estimates of effect, provided the study limitations are borne in mind. This study is used for the subsequent analysis because of its sophistication, high statistical power and the fact that unlike other studies it provides results relating to landfills accepting only municipal waste.

Elliott et al. (2001) provides quantitative estimates of excess risk of congenital anomalies, stillbirths and low and very low birth weights in populations living within 2 km of a landfill site. Based upon Table 7 of **Elliott *et al.* (2001)**, and the column referring to non-special waste sites, the attributable increments in adverse health outcomes for those living with 2 km of a landfill site are as shown in table 3.22.

Whilst the estimates of excess disease attributable to municipal waste landfills set out in Table 3.22 are the best currently available, they should be treated with some caution. The study was not able to state whether the observed increment was due to exposure to emissions from the landfill, or to some other cause or combination of causes. The relatively small scale of incremental health risks means that we are less confident that the reported effects are in fact caused by a particular cause or combination of causes such as the landfill sites studied. As discussed in the review of this paper, the results are sensitive to possible misclassifications of socio-economic status, and it is possible that the outcomes are the result of residual confounding rather than a true reflection of an excess of disease attributable to the landfill.

Furthermore, doubt is attached in some cases to the exact nature of waste that was being disposed: in those cases, there is some question as to whether the sites categorised as “non-special waste” may have received some hazardous wastes as part of, or in addition to municipal refuse. If this has occurred, this may have affected emissions from these sites. Finally, the study investigated sites which opened during the period

covered by the study, comparing the rates of disease before and after the sites opened. It was found that some of the outcomes considered were at a lower rate after the site opened than before it opened. This indicates that factors other than the landfill sites were at least contributing to the observed increases.

Table 3.22 Increments in adverse health outcomes for populations within 2 km of a landfill site

Outcome	Observed increment (99% confidence interval)
Neural tube defects	6% (1-12%)
Cardiovascular defects – no excess	No excess
Hypospadias and epispadias	7% (4-11%)
Abdominal wall defects	7% (-1-12%)
Gastroschisis and exomphalos (surgical corrections)[1]	18% (3-34%)
Stillbirths – no excess	No excess
Low birth weight	6% (5.2%-6.2%)
Very low birth weight	4% (3-6%)

Note 1: Note 3: Surgical correction of gastroschisis and exomphalos was included in the study of Elliot et al. as a cross-check on the data for abdominal wall defects. The cases in this category are also included in the wider category of abdominal wall defects.

Table 3.17 Single-Site Epidemiological Studies of Potential Health Effects Associated with Landfill Sites (from Redfearn and Roberts, 2002)

Site	Type of Waste Received/Years of Operation/Other Site Details	Primary Exposure Route / Chemicals of Concern	Reason for Initiation of Study and/or Site Closure	Area or Population Treated As Being Exposed / Study Period	Health Effects Examined	Presence of Association With Exposure
Nant-y-Gwyddon landfill, Wales (*Fielder et al.* **2000a, 1997,** *2000b*; *Mukerjee & Deacon 1999; Richardson 1999*)	household; industrial; commercial; difficult 1988 – present	landfill gas	community concerns that odours from site causing a variety of conditions	Fielder *et al.* 2000a, 1997 residents in 5 electoral wards within 3km of site 1981 - 1997	Mortality: all causes; respiratory disease; cancers Hospital admissions: general admissions; respiratory disease; asthma; cancer; sarcoidosis; spontaneous abortions Low birth weight Birth defects: all anomalies abdominal wall (gastroschisis) Drug prescription rates for gastrointestinal, respiratory and central nervous systems, skin and eyes	Non-significant Non-significant Non-significant Significant positive Significant positive Elevated
				Fielder *et al.* 2000b residents in 5 electoral wards within 3km of site 1998-2000	Time to pregnancy	Non-significant
				Mukerjee & Deacon 1999 residents within 1km, 1-2km, 2-3km and >3km from site 1998	Self reported symptoms: headache, sore throat, runny nose, feeling sick, diarrhoea Self reported symptoms: sore eyes, dizziness, skin rash Self-reported chronic diseases Frequency of GP consultations	Elevated Non-significant Non-significant Non-significant
				Richardson 1999 residents in 5 electoral wards within 3km of site 1991-1998	Sarcoidosis	Elevated

Table 3.17: Single-Site Epidemiological Studies of Potential Health Effects Associated with Landfill Sites (from Redfearn and Roberts, 2002) continued

Site	Type of Waste Received/Years of Operation/Other Site Details	Primary Exposure Route / Chemicals of Concern	Reason for Initiation of Study and/or Site Closure	Area or Population Treated As Being Exposed / Study Period	Health Effects Examined	Presence of Association With Exposure
Lipari landfill, New Jersey (**Berry & Bove 1997**)	municipal; household; liquid and semi-solid chemical; other industrial 1958 - 1971 ranked no. 1 on US EPA's National Priority List liquid wastes emptied from containers prior to disposal hazardous leachate migrated into nearby streams and a lake immediately adjacent to community with homes, schools and playgrounds	Inhalation of volatilised chemicals emitted from landfill and from contaminated waters	public complaints regarding odour, respiratory problems, headaches, nausea and dying vegetation	radius of 1km from perimeter of site, including high exposure group adjacent and downwind of site 1961 – 1985	Average birth weight Proportion low birth weight Proportion premature births	Significant positive Significant positive Significant positive
Miron Quarry, Quebec; (**Goldberg *et al.* 1995a, 1995b, 1999**)	domestic; industrial; commercial 1968 - present 3rd largest municipal solid waste landfill site in North America 100,000 people live within 2km has not been capped biogas collection system installed in 1980, and operated at low efficiency	release of landfill gas into ambient air and soil	health concerns expressed by local residents; frequent odour complaints registered	Goldberg *et al.* 1995a postal code areas containing and bordering site (up to 4km from perimeter of site) 1979 – 1989	Low birth weight Very low birth weight Small for gestational age Preterm births	Significant positive Non-significant Significant positive Non-significant
				Goldberg *et al.* 1995b postal code areas containing and bordering site (up to 4km from perimeter of site) 1981 - 1988	Males: cancers of stomach; liver & intrahepatic bile duct; trachea, bronchus & lung; prostate Females: cancer of stomach; cervix uteri Females, breast 13 other cancer sites in males; 17 other cancer sites in females	Significant or nearly significant positive Significant or nearly significant positive Significant negative No association
				Goldberg *et al.* 1999 postal code areas containing and bordering site (up to 4km from perimeter of site) 1979 – 1985	Males: cancer of liver; kidney; pancreas; prostate; and non-Hodgkin's lymphomas 8 other cancer sites in males	Significant or nearly significant positive No association

Table 3.17: Single-Site Epidemiological Studies of Potential Health Effects Associated with Landfill Sites (from Redfearn and Roberts, 2002) continued

Site	Type of Waste Received/Years of Operation/Other Site Details	Primary Exposure Route / Chemicals of Concern	Reason for Initiation of Study and/or Site Closure	Area or Population Treated As Being Exposed / Study Period	Health Effects Examined	Presence of Association With Exposure
BKK landfill, California (**Kharrazi *et al.* 1997**)	hazardous waste of all types; municipal 1963 – 1989 received nearly 4 million tons of hazardous waste residential developments in close proximity numerous complaints of odour, surface water runoff onto nearby streets, hazardous waste spills from HGVs, and dust releases	airborne exposures	concerns over public health and welfare following complaints of odours, surface water runoff, hazardous waste spills from trucks and dust releases	residence in areas with high rates of odour complaints (high odour area up to 0.6 miles from landfill) 1978 – 1986	Reduction in gestational age Low mean birth weight Fetal and infant mortality	Significant positive Significant positive No association
Montchanin landfill, France (**Zmirou *et al.* 1994, Deloraine *et al.* 1995**)	liquid and solid toxic industrial, including wastewater treatment sludge, dehydrated hydroxide sludge and solvent-containing wastes 1979 – 1988 received 400,000 tons of industrial wastes located adjacent to town of 6000 inhabitants - 100m from nearest houses	VOCs in ambient air	community health concerns triggered by offensive odours, suspected increase in certain health complaints, and elevated levels of VOCs in ambient air	Zmirou *et al.* 1994 estimated exposures using air dispersion model 1987 – 1989	Drug consumption rates for respiratory, opthalmological, dermatological, gastro-intestinal and neurological conditions	No significant association
				Deloraine *et al.* 1995 estimated exposures using air dispersion model 1990	Psychiatric disorders Respiratory symptoms Isolated biological abnormalities Skin diseases Eye diseases Ear, nose and throat conditions Miscellaneous conditions	Significant positive Significant positive No association No association No association No association No association
Upper Ottawa Street landfill, Ontario (**Hertzman *et al.* 1987**)	solid and liquid industrial; commercial; domestic 1950s - 1980 volumes of industrial waste received increased throughout 1970s, such that approx. 8 to 12 million gallons of liquid waste disposed of during 1978 capped in 1980/81	airborne exposures to vapours, fumes, dust or ash, as well as direct skin contact	public concerns regarding health effects	residence within 750m from edge of tipping face approx. 1984	Self-reported respiratory, skin, mood, narcotic and eye conditions Self-reported muscle weakness Self-reported adverse birth outcomes: low birth weight stillbirth miscarriage/spontaneous abortion birth defects	Significant positive No association No association No association No association No association
Waste disposal site, Northwestern Illinois (**Mallin 1990**)	municipal; industrial, including solvents, plating wastes and heavy metals late 1950s – 1972	Drinking water from wells contaminated with VOCs	several areas of elevated mortality from bladder cancer identified in region	residence in town using water from contaminated wells 1977-1985	Bladder incidence	Significant positive

Table 3.18: Multiple Site Epidemiological Studies of Potential Health Effects Associated with Waste Disposal Sites (from Redfearn and Roberts, 2002)

Author (s)	Study Parameters	Type of Sites Evaluated/ Years of Operation	Area or Population Treated As Being Exposed/ Study Period	Health Effects Examined	Presence of Association With Exposure
Dolk *et al.* 1998	21 landfill sites in 5 European Countries	landfill sites handling hazardous chemical wastes majority either opened before mid-1970s or closed before mid- to late- 1980s	maternal residence within 3 km of landfill site mid/late 1980s – 1993 in most cases	Non-chromosomal birth defects: all anomalies; neural tube; cardiac septa; great arteries and veins Non-chromosomal birth defects: tracheo-oesophageal; hypospadias; gastroschisis 19 other specified types of non-chromosomal birth defects	Significant positive Nearly significant positive No association
Vrijheid *et al.* 2002	23 landfill sites in 5 European Countries	landfill sites handling hazardous chemical wastes majority either opened before mid-1970s or closed before mid- to late- 1980s	maternal residence within 3 km of landfill site mid/late 1980s – 1993 in most cases	Chromosomal birth defects	Significant positive
Elliott *et al.* 2001a, 2001b	9,565 landfill sites in England, Wales and Scotland	774 special waste landfills, 7,803 non-special waste landfills, and 988 classified as unknown sites operational between 1982 and 1997	residence within 2 km of landfill site 1983 – 1998	Birth defects: all anomalies; neural tube; hypospadias/epispadias; abdominal wall; gastroschisis/exomphalos Birth defects: cardiovascular Low and very low birth weight Still births Cancer registrations: bladder; brain; hepatobiliary; childhood and adult leukaemia	Excess risks Depressed risks Excess risks No association No association
Lewis-Michl *et al.* 1998	38 landfill sites in New York State, USA	municipal landfills with soil-gas migration conditions; selected from the New York State Inactive Hazardous Waste Site Registry; sites in NY City excluded majority of landfills opened prior to 1970, closed prior to end of 1980s majority not capped or lined	residence within 250 ft of landfill site boundary (or greater distance if further gas migration shown) 1980 – 1989	Male cancer incidence: liver; lung; bladder; kidney; brain; non-Hodgkin's lymphoma; leukaemia Female cancer incidence: liver; lung; kidney; brain; non-Hodgkin's lymphoma Female cancer incidence: bladder; leukaemia	No association No association Significant positive

Table 3.19 Summary of Findings of Epidemiological Studies at Landfill Sites (from **Redfearn and Roberts, 2002)**

Health Outcome	Number of Studies Indicating Excess Risks	Number of Studies Indicating No Excess Risk
Birth Defects:		
All chromosomal anomalies	1	0
All non-chromosomal anomalies	3.6 (before site opened in 2 of these)	1
Central nervous system	0	1
Neural tube defects	2	0
Cleft lip/palate	0	1
Heart and circulatory	1	1
Hypospadias/epispadias	2 (borderline in 1; before site opened in 1)	0
Limb reductions	0	1
Abdominal/Gastroschisis	3.7 (borderline in 1; before site opened in 1)	0
Skin and other integument	0	1
Tracheo-oesophageal	1 (borderline)	0
Renal	0	1
Urinary tract	0	1
Other Pregnancy Outcomes:		
Low birth weight/prematurity	4	2
Still births	0	3
Infant mortality	0	1
Spontaneous abortions	0	2
Time to pregnancy	0	1
Cancer:		
All types	0	1
Oesophagus	0	1
Stomach	1	1
Liver	2	2
Trachea/bronchus/lung	1	2
Prostate	2	0
Cervix uteri	1	0
Breast	0	1
Colorectum	0	2
Brain	0	3
Pancreas	1	1
Kidney	1	2
Bladder	2	3
Leukaemia	1	2
Non-Hodgkin's lymphoma	1	2
Skin melanoma	0	1
Respiratory		
All respiratory diseases	1	1
Asthma	0	1
Sarcoidosis	1 (before industrial tipping commenced)	1

Table 3.19 Summary of Findings of Epidemiological Studies at Landfill Sites (from **Redfearn and Roberts, 2002)**

Health Outcome	Number of Studies Indicating Excess Risks	Number of Studies Indicating No Excess Risk
Psychiatric disorders	1	0
Miscellaneous self-reported symptoms	2	0
Drug prescription rates, miscellaneous symptoms	1	1
Unspecified:		
Hospital admissions, all diseases	0	1
Mortality, all causes	0	1

Table 3.20 Risks of Congenital Anomalies, Stillbirths, and Low and Very Low Birth Weight in Populations Living Within 2 km of a Landfill Site (all waste types) During Operation or After Closure Compared with those in the Reference Area (> 2 km from any site) (from **Elliott *et al.*, 2001a)**

Birth outcome	Near landfill (<2km)		Reference area		Relative risk (99% CI)		
	No. of cases	Rate (per 100,000 births)	No. of cases	Rate (per 100,000 births)	Unadjusted	Adjusted (but not for deprivation)	Adjusted (and for deprivation)
Congenital anomalies (register and terminations data*)							
All congenital anomalies	90 272	1 550	34 325	1 694	0.92 (0.907 to 0.923)	1.01 (1.00 to 1.02)	1.01 (1.005 to 1.023)
Neural tube defects	3 508	60	1 140	56	1.07 (1.02 to 1.12)	1.08 (1.03 to 1.12)	1.05 (1.01 to 1.10)
Cardiovascular defects	6 723	115	2 716	134	0.86 (0.83 to 0.89)	0.95 (0.92 to 0.98)	0.96 (0.93 to 0.99)
Hypospadias and epispadias†	7 363	247	2 485	240	1.03 (1.00 to 1.06)	1.07 (1.04 to 1.10)	1.07 (1.04 to 1.10)
Abdominal wall defects	1 488	26	448	22	1.16 (1.08 to 1.23)	1.14 (1.06 to 1.22)	1.08 (1.01 to 1.15)
Congenital anomalies (hospital admissions)							
Hypospadias and epispadias‡	1 503	257	536	268	0.96 (0.90 to 1.02)	-	0.96 (0.90 to 1.02)
Abdominal wall defects	755	40	227	35	1.13 (1.03 to 1.24)	-	1.07 (0.98 to 1.18)
Gastroschisis and exomphalos‡	467	25	126	19	1.26 (1.12 to 1.42)	-	1.19 (1.05 to 1.34)
Stillbirths and birth weight							
Stillbirths	32 271	532	11 200	514	1.04 (1.02 to 1.05)	1.05 (1.03 to 1.06)	1.00 (0.99 to 1.02)
Low birth weight	422 149	7 000	137 958	6 367	1.10 (1.095 to 1.104)	1.11 (1.102 to 1.111)	1.05 (1.047 to 1.055)
Very low birth weight	62 191	1 031	20 858	963	1.07 (1.06 to 1.08)	1.08 (1.07 to 1.09)	1.04 (1.03 to 1.05)

* Terminations included for England and Wales 1992-8, Scotland 1988-94

† Excludes terminations (3 cases)

‡ Surgical corrections. Surgical correction of gastroschisis and exomphalos was included in the study of Elliot et al. as a cross-check on the data for abdominal wall defects. The cases in this category are also included in the wider category of abdominal wall defects.

Table 3.21 Estimated Relative Risks (99% confidence Intervals) of Birth Outcomes for Populations Living Within 2 km of a Landfill Site, Adjusted for Deprivation and Other Variables* According to Waste Type and to Operating Status for those Sites that Opened During the Study Period (from **Elliott *et al.*, 2001a)**

	All operating and closed sites, by waste type			Sites that opened during study period (all waste types), by operating status†	
Birth outcome	**All wastes**	**Special waste**	**Non-special waste**	**Before opening**	**During operation or after closure**
Congenital anomalies (register and terminations data‡)					
All congenital anomalies	1.01 (1.005 to 1.023)	1.07 (1.04 to 1.09)	1.02 (1.01 to 1.03)	1.02 (0.99 to 1.05)	1.00 (0.99 to 1.01)
Neural tube defects	1.05 (1.01 to 1.10)	1.07 (0.95 to 1.20)	1.06 (1.01 to 1.12)	0.98 (0.82 to 1.16)	1.05 (0.99 to 1.10)
Cardiovascular defects	0.96 (0.93 to 0.99)	1.11 (1.03 to 1.21)	0.95 (0.91 to 0.98)	0.92 (0.80 to 1.04)	0.92 (0.88 to 0.95)
Hypospadias and episadias§	1.07 (1.04 to 1.10)	1.11 (1.03 to 1.21)	1.07 (1.04 to 1.11)	1.08 (0.98 to 1.19)	1.05 (1.02 to 1.09)
Abdominal wall defects	1.08 (1.01 to 1.15)	1.03 (0.86 to 1.25)	1.07 (0.99 to 1.16)	1.24 (0.97 to 1.60)	1.06 (0.98 to 1.14)
Congenital anomalies (hospital admissions)					
Hypospadias and epispadias¶	0.96 (0.90 to 1.02)	0.98 (0.81 to 1.19)	0.96 (0.90 to 1.04)	1.42 (0.94 to 2.16)	0.93 (0.86 to 1.00)
Abdominal wall defects	1.07 (0.98 to 1.18)	1.08 (0.82 to 1.42)	1.05 (0.94 to 1.16)	2.26 (1.23 to 4.15)	1.12 (1.01 to 1.25)
Gastroschisis and exomphalos¶	1.19 (1.05 to 1.34)	1.10 (0.77 to 1.58)	1.18 (1.03 to 1.34)	1.33 (0.46 to 3.81)	1.24 (1.09 to 1.42)
Stillbirths and birth weight					
Stillbirths	1.00 (0.99 to 1.02)	0.99 (0.95 to 1.03)	1.00 (0.99 to 1.02)	1.01 (0.96 to 1.06)	1.02 (1.00 to 1.03)
Low birth weight	1.05 (1.047 to 1.055)	1.05 (1.04 to 1.06)	1.06 (1.052 to 1.062)	1.01 (0.99 to 1.02)	1.07 (1.062 to 1.072)
Very low birth weight	1.04 (1.03 to 1.05)	1.03 (1.00 to 1.06)	1.04 (1.03 to 1.06)	0.98 (0.94 to 1.02)	1.04 (1.03 to 1.05)

† 522 landfill sites with available data for hospital admissions
‡ Terminations included for England and Wales 1992-8, Scotland 1988-94
§ Excludes terminations (3 cases)
¶ Surgical corrections. Note 3: Surgical correction of gastroschisis and exomphalos was included in the study of Elliot et al. as a cross-check on the data for abdominal wall defects. The cases in this category are also included in the wider category of abdominal wall defects.

Appendix 2 : Method statement for identifying detection limits

A2.1 This method statement was developed and used at the outset of the project. At that stage, the key issue was to ensure that the monitoring study provides data of suitable resolution to provide a useful input to the health risk assessment.

A2.2 In order to determine suitable detection limits for the measurement programme, we have worked backwards from benchmarks for a minimal level of risk. This enables us to estimate the levels of air pollutants that would not pose a significant health risk, based on current scientific knowledge. We aim to measure levels of air pollutants at a resolution 3-5 times lower than this critical level, where possible.

A2.3 For a small number of substances, it may not ultimately prove possible to achieve this resolution. There are inherent limitations on the resolution that can be achieved due to issues such as sample times, and the accuracy of laboratory analysis techniques. However, the measurements will nevertheless provide useful information, for two reasons. Firstly, atmospheric dilution means that concentrations at the site boundary will be higher than those experienced by local populations. This means that a higher concentration measurement at the site boundary is likely to correspond to a lower concentration experienced by at more distant locations where populations are located.

A2.4 Secondly, if a concentration above the detection limit is recorded, then the detection limit itself is much less relevant. For example, if the critical level for a substance is 1 $\mu g/m^3$, a detection limit of 2 $\mu g/m^3$ would not cause a significant issue for the progress of the study if the measured concentration is 5 $\mu g/m^3$. The detection limit would in this case only be important insofar as the detection limit of the measurement technique affects the reliability of the measured value of 5 $\mu g/m^3$. The possibility of inconclusive results would remain if the measured concentration is below the detection limit, but results in an estimated exposure which could give rise to significant health effects.

A2.5 Our benchmarks for a minimal or insignificant risk are as follows:

- For substances with statutory air quality standards, we have used these levels as representing an insignificant risk to health [nitrogen dioxide (NO_2), sulphur dioxide (SO_2), fine particulate matter (referred to as PM_{10}), lead, benzene, 1,3-butadiene]. A statutory air quality standard also exists for carbon monoxide, but we have excluded this from the scope of our study as levels of carbon monoxide are well below this standard throughout the UK, including in the vicinity of landfill sites. All monitored levels of carbon monoxide at UK air monitoring sites are well within the air quality standard, and landfill sites are not significant sources of carbon monoxide.
- For substances for which “no adverse effect levels” have been determined, we have used these levels as benchmarks for the monitoring survey.
- For substances for which tolerable daily intake (TDI) values have been determined, we have derived an air concentration that would give rise to 10% of the TDI value.

- For some substances, indirect exposure routes are significant. This class of substances are those which have relatively slow removal pathways in the environment. This may be due to a combination of factors, such as insolubility, and/or not being rapidly broken down in soils by microbial action. These substances may be deposited onto farmland, allotments or gardens, and subsequently be consumed directly (e.g. by children or gardeners), or be taken up in arable produce or livestock. A lower detection threshold would be appropriate for assessment against TDI benchmarks for these substances. The substances of concern with regard to indirect exposure pathways are:
    - Dioxins and furans
    - Polychlorinated biphenyls
    - Polycyclic aromatic hydrocarbons
    - Metals
- For other substances, we have derived a suitable exposure level by dividing the occupational exposure standard by factors proposed by the Environment Agency (Best Practicable Environmental Option for Integrated Pollution Control, Environment Agency Technical Guidance Note E1, 1997).
    - Annual mean guideline = long term exposure limit/100
    - Hourly mean guideline = short term exposure limit/10

    Technical Guidance Note E1 recommends the use of a further factor of 5 for substances with maximum exposure limits.

This is a crude approach to determining safe levels of air pollutants which we are adopting to assist in setting suitable detection levels. We believe that it is likely to yield levels which err on the side of caution for most of the parameters considered. We have reviewed each substance in this category to check whether there is any more recent information or other reasons to believe that the simple approach set out in the E1 document is not sufficiently conservative.

In the main study, we will conduct a more complete review, which may result in the identification of less stringent benchmarks for some substances.

[NB: This approach was specified in the methodology, but was not used in practice]

For other substances where suitable toxicological data exist we have used a benchmark for significance of an increased annual risk of 1 in 1,000,000. This benchmark derives from the Royal Commission on Environmental Pollution Seventeenth Report, “Incineration of Waste”, Cm2181, 1993. We have used this benchmark for all the health outcomes considered in the study.

As more than one emission from a landfill site could potentially affect health, we propose to reduce this benchmark by a further factor of 10. Hence, our benchmark is an incremental annual risk of 1 in 10^7 (equivalent to an incremental lifetime risk of 1 in 140,000 over a 70 year lifetime). We have

then determined the level of each substance that would be expected to give rise to this incremental risk.

A2.6 Many of the measurements are being carried out using the most precise techniques available. For these substances, there is no opportunity to improve the measurement resolution. The greatest flexibility in the measurement survey surrounds substances with no inherent limits on sampling times – metals and micro pollutants. For these substances, it would be possible to improve the detection limit at the expense of the temporal resolution and number of measurements by extending the sampling period.

Exposure Model

A2.7 The proposed overall exposure model is shown in Figure 2.5 (Main report). The key exposure routes for determination of detection limit for most substances are those by direct inhalation. As discussed above, for some substances, indirect pathways may be significant. An additional allowance will be made to ensure that air detection limits are adequate for evaluating indirect as well as direct exposure to these substances.

A2.8 For example, if an air concentration of 0.1 pg TEQ /m^3 of a toxic micropollutant is identified, this would result in a daily intake via inhalation of 0.03 picograms Toxic Equivalent per kilogram body weight per day (pg TEQ/kg BW – day)

[1 pg = 10^{-12} g; 1 ng = 10^{-9} g; 1 µg = 10^{-6} g; 1 mg = 10^{-3} g; based on an inhalation rate of 20 m3/day and body weight of 60 kg).

Technical Guidance Note E1 identifies deposition velocities which err on the side of caution, and can be used in screening studies such as this. Using the deposition velocity of 0.03 m/s recommended in Technical Guidance Note E1, this air concentration would result in a deposition rate to an adjacent field of a maximum of 0.003 pg TEQ/m^2-s, equivalent to 0.0001 mg TEQ/m^2-year. This would result in a concentration in fodder of 0.00001 mg per kg dry weight (HMIP, "Risk Assessment of Dioxin Releases from Municipal Waste Incineration Processes", 1996, quoting Lorber et al, "Development of an air-to-beef food chain model for dioxin-like compounds," Science of the Total Environment, 1994). This would result in a concentration in beef tissue of 0.000001 mg TEQ per kg.

An adult individual might consume up to 10 kg per year of beef products farmed in fields adjacent to the landfill site. This would result in an individual being exposed to 10 ng TEQ of toxic micropollutant over the course of a year, equivalent to a daily intake of 0.5 pg TEQ/kg BW – day. This is approximately 15 times higher than the daily intake via inhalation.

To ensure that detection limits in air are adequate for evaluating indirect exposure pathways, we will apply an additional factor of 50 to substances listed in paragraph A2.5 bullet 3 above.

Health-based Benchmarks

A2.9 The emissions of greatest concern from a health risk point of view have been identified and are listed in Table A2.1.

A2.10 The health risk assessment will take the available data for air, soil, and water intake of the identified contaminants and relate these to toxicological data from various sources. These include JEFCA /ILSI/ CLR data on TDIs and tolerable air intakes. WHO Criteria for Atmospheric Pollutants, United States Environmental Protection Agency data, UK Ambient Air Quality Standards, and HSE Occupational Exposure Limits (EH40) and associated criteria documents (EH64 and EH65).

A2.11 Where Occupational Exposure Limits are advised by HSE the risk assessment will be based on these limit values divided by a suitable factor as described in paragraph 8 (bullet 5). The risk assessment will ultimately be moderated by the most recent original research data on the toxicology of the substance and any epidemiological work linking the substance with an adverse health outcome. The approach to risk assessment will to some extent follow the DETR Guidelines for Environmental Risk Assessment and Management (July 2000) and take account of the EPA Guidelines for Ecological Risk Assessment. (US Environmental Protection Agency 1998). These guidelines, however do not deal specifically with health risk assessment. The requirement in these guidelines to take account of the societal aspects of risk and public risk perception cannot be applied as the study will not be able to generate data on individual perceptions. However, the quantification scheme provided in the DETR guidelines was adapted to human health outcomes for use in this study.

Negligible	Landfill contributes <1% of total exposure. Substance below any of the reference exposure guidelines and / or evidence suggests that at level of exposure identified there are no acute or chronic effects.
Mild – Moderate	Landfill contributes between 1% and 5% of total exposure. Substance marginally exceeds one or more of the reference exposure guidelines and / or evidence suggests that at levels identified, the adverse effects constitute only a minor threat to health and / or wellbeing.
Severe	Landfill contributes between 5% and 20% of total exposure. Substance exceeds one or more of the reference guidelines by a substantial margin and evidence exists for a significant risk of disease or other adverse health outcome from short term or long term exposure.
Very Severe	Landfill contribution to total exposure exceeds 20%. Extensive exceedance of reference values and a strong likelihood of serious health outcomes including likely increased risk of mortality.

NB. The DETR guidelines contain an “extremely severe” category which serves little purpose in this scheme and will not be included.

A2.12 The matrix against which this assessment was undertaken is developed below.

Table A2.1 : Initial Detection Limit Matrix Note: Used for initial study design only

Substance	EH40 STEL / 10 or 50 µg/m^3	EH40 LTEL / 100 or 500 µg/m^3	TDI (PMTDI) (µg/kg-week)	Derived tolerable air concentration Adult µg.m^{-3}	Derived tolerable air concentration Child µg.m^{-3}	UK/European AQS µg.m^{-3} unless otherwise given	WHO AQ Guideline µg.m^{-3}	Notes	Expected Detection limit	Achieved Detection limit	Typical rural level
Toxic Organic Micropollutants											
Dioxins, Furans and PCB's (TEQ)				5 x 10^{-8} (50 fg/m^3)	2 x 10^{-8} (20 fg/m^3)	*2 pg. Kg Daily intake (recommended)*	1 – 4 pg. Kg Daily intake	Includes dioxin-like PCBs	5 fg/m^3	5 fg/m^3	10 fg/m^3 [b]
PCBs		200,000,000 fg/m^3								5 fg/m^3	32 fg/m^3 [c]
Benz[a]pyrene		"no safe level"				*0.25 ng/m^3 (proposed)*			0.1 ng/m^3	0.1 ng/m^3	0.06 ng/m^3 [b]
METALS											
Mercury		0.25	5	0.04	*0.02*		1	WHO: annual average	0.5 / 0.0025	/ 0.001	0.0001 [d]
Arsenic		0.2	15	0.12	*0.04*			WHO unit risk 0.0015 [µg/m^3]$^{-1}$	1 / 0.005	/ 0.001	0.0015 [e]
Cadmium		0.05	7	0.05	0.02		*0.005*	WHO: annual average	0.5 / 0.0025	/ 0.001	0.00025 [e]
Nickel		*10*						WHO unit risk 0.00038 [µg/m^3]$^{-1}$	1 / 0.005	/ 0.001	0.0017 [e]
Lead			25	0.19	0.07	*0.25*			2 / 0.01	/ 0.001	0.020 [e]
Antimony		1							4 / 0.02	/ 0.001	0.0015 [d]
Cobalt		*0.2*							1 / 0.005	/ 0.001	
Chromium		*0.1*						WHO unit risk 0.011 - 0.13 [µg/m^3]$^{-1}$	1 / 0.005	/ 0.001	0.0019 [e]

Table A2.1 : Initial Detection Limit Matrix Note: Used for initial study design only

Substance	EH40 STEL / 10 or 50 µg/m^3	EH40 LTEL / 100 or 500 µg/m^3	TDI (PMTDI) (µg/kg-week)	Derived tolerable air concentration Adult µg.m^{-3}	Derived tolerable air concentration Child µg.m^{-3}	UK/European AQS µg.m^{-3} unless otherwise given	WHO AQ Guideline µg.m^{-3}	Notes	Expected Detection limit	Achieved Detection limit	Typical rural level
Copper	200	10	50 (daily TDI)	2.7	*1.0*				1 / 0.005	/ 0.001	0.0042 [e]
Manganese		50					*0.15*	WHO: annual average	1 / 0.005	/ 0.001	0.0064 [d]
Tin	400	*20*	14000	109	40			EH40 as inorganic tin	1 / 0.005	/ 0.001	
Thallium		*1*							2 / 0.01	/ 0.001	
Vanadium							*1*	WHO: 24 hour average	2 / 0.01	/ 0.001	0.0061 [d]
VOCs											
GROUP 1: Likely teratogens											
Benzene		32				16.25 µg m^{-3} / *3.25 µg m^{-3}*	"no safe level"	UK AAQS is a running annual mean	1	1	0.53 [a]
1,3-butadiene		44				*2.25 µg m^{-3}* (1ppb)		UK AAQS is a running annual mean	4	8	0.087 [a]
Chloroform		99	15 (daily TDI)	0.06	*0.02*			TDI specified by WHO WHO unit risk 4.2 x 10^{-7} [µg/m^3]$^{-1}$	1 - 4 screen 0.02 targeted	1	
1,2 Dichloroethene	101000	*8060*							1 - 4 screen 0.02	1	

Table A2.1 : Initial Detection Limit Matrix Note: Used for initial study design only

Substance	EH40 STEL / 10 or 50 µg/m^3	EH40 LTEL / 100 or 500 µg/m^3	TDI (PMTDI) (µg/kg-week)	Derived tolerable air concentration Adult µg.m^{-3}	Derived tolerable air concentration Child µg.m^{-3}	UK/European AQS µg.m^{-3} unless otherwise given	WHO AQ Guideline µg.m^{-3}	Notes	Expected Detection limit	Achieved Detection limit	Typical rural level
									targeted		
Ethyl Benzene	55200	*4410*					22000	WHO: annual average	1 - 4 screen 0.02 targeted	1	0.19 [a]
Formaldehyde[1]	50	*5*					100	WHO: 30 minute average (irritation)	1 - 4 screen 0.02 targeted	400	1.4 [f]
Tetrachloro ethene	68900	3450					*250*	WHO: 24 hour	1 - 4 screen 0.02 targeted	1	
Trichloroethene	16400	1100						WHO unit risk 4.3 x 10^{-7} [µg/m^3]$^{-1}$	1 - 4 screen 0.02 targeted	1	
Chloroethene		*0.04*						WHO unit risk 10^{-6} [µg/m^3]$^{-1}$	1 - 4 screen 0.02 targeted	2	
GROUP 2 : possible teratogens											
Alpha Terpinene										1	
Dichlorobenzene	30600	1530					*1000*	WHO: annual average	1 - 4 screen 0.02 targeted	1	
2- ethyl- 1-hexanol										1	

1 Note: IUPAC name for formaldehyde is “methanal”; however, as the term “formaldehyde” is in common usage, this has been used in this report.

Table A2.1 : Initial Detection Limit Matrix Note: Used for initial study design only

Substance	EH40 STEL / 10 or 50 µg/m^3	EH40 LTEL / 100 or 500 µg/m^3	TDI (PMTDI) (µg/kg-week)	Derived tolerable air concentration Adult µg.m^{-3}	Derived tolerable air concentration Child µg.m^{-3}	UK/European AQS µg.m^{-3} unless otherwise given	WHO AQ Guideline µg.m^{-3}	Notes	Expected Detection limit	Achieved Detection limit	Typical rural level
Hydrogen sulphide	2100	*140*					150	WHO: 24 hour mean	1	1	
Chloromethane	21000	*1050*							1 - 4 screen 0.02 targeted	2	
2-butanol										1	0.55 [f]
Toluene	57400	1910					*260* 1000	WHO: 1 week WHO: 30 minutes	1 - 4 screen 0.02 targeted	1	1.4 [a]
Xylenes	66200	4410					4800 *870*	WHO: 24 hours WHO: annual	1 - 4 screen 0.02 targeted	1	0.7 [a]
GROUP 3 : Unlikely to be teratogens											
Acetone	362000	*18100*							1 - 4 screen 0.02 targeted		1.5 [f]
2- Butanol	46200	*3080*							1 - 4 screen 0.02 targeted		
Ethanol		*19200*							1 - 4 screen 0.02 targeted		
Limonene											
1-Propanol	62500	*5000*							1 - 4 screen		

Table A2.1 : Initial Detection Limit Matrix Note: Used for initial study design only

Substance	EH40 STEL / 10 or 50 µg/m^3	EH40 LTEL / 100 or 500 µg/m^3	TDI (PMTDI) (µg/kg-week)	Derived tolerable air concentration Adult µg.m^{-3}	Derived tolerable air concentration Child µg.m^{-3}	UK/European AQS µg.m^{-3} unless otherwise given	WHO AQ Guideline µg.m^{-3}	Notes	Expected Detection limit	Achieved Detection limit	Typical rural level
									0.02 targeted		
Styrene	21600	860					*260*	WHO: 1 week average	1 - 4 screen 0.02 targeted	1	
Vinyl acetate	7200	*360*							1 - 4 screen 0.02 targeted		
GROUP 4 : Unknown teratogenicity											
1,1 Dichloroethane	*165000*	823000							1 - 4 screen 0.02 targeted	1	
Dichlorofluoro methane		*430*							1 - 4 screen 0.02 targeted	2	
Dichloromethane	21200	*700*					3000	WHO: 24 hour average	1 - 4 screen 0.02 targeted	Indeterm-inate	
Ethanethiol								1-5 µg/m^3 typical odour threshold	4	2	
Methanethiol									4	2	
2- Methyl furan										1	
Nitromethane	38100	*2540*							1 - 4 screen 0.02	1	

Table A2.1 : Initial Detection Limit Matrix Note: Used for initial study design only

Substance	EH40 STEL / 10 or 50 µg/m^3	EH40 LTEL / 100 or 500 µg/m^3	TDI (PMTDI) (µg/kg-week)	Derived tolerable air concentration Adult µg.m^{-3}	Derived tolerable air concentration Child µg.m^{-3}	UK/European AQS µg.m^{-3} unless otherwise given	WHO AQ Guideline µg.m^{-3}	Notes	Expected Detection limit	Achieved Detection limit	Typical rural level
									targeted		
OTHERS											
NO_2						200 *40*		1 hour mean Annual mean	1	1	12
SO_2						266 350 *125*		15 minute mean 1 hour mean 24 hour mean	1.5	1.5	3.6
PM_{10}						50 *20*-40		24 hour mean Annual mean	0.5	0.5	9.5 [g]
Organic sulphur compounds								1-5 µg/m^3 typical odour threshold	4	2	
Endotoxins								*50* EU/m^3 (4 ng/m^3)			
Bioaerosols									*10* (yeasts and moulds) *10* (E.coli)		

Blue: Detection limit below all criteria by factor of 5 or more
Purple: Detection limit below all criteria, but by factor of less than 5 in one or more cases
Red: Detection limit above one or more criteria
Italic value is used to assess significance
a: Average measurement from Harwell, 2000
b: Measurement from Hazelrigg, 2000
c: Measurement from Hazelrigg, 1999
d: Average measurement from Harwell, 1982 - 1991
e: Average measurement from Chilton (Oxfordshire), Styrrup (Nottinghamshire), and Wraymires (Cumbria), 1999
f: Measurement from Harwell, 1993
g: Measurement from Lough Navar, 2000

Appendix 3 : Monitoring methods

A3.1 Monitoring methodology

A3.1.1 Summary

The survey was designed to cover any substances which were identified as potentially being emitted to air in significant quantities from landfill sites. The survey design provides data over the relevant periods of interest as set out in Table A3.1.

Table A3.1 : Determinands and Averaging times

Substance	Critical period for health impacts	Study averaging period	Overall study sample duration
Nitrogen dioxide	One hour (acute respiratory effects) Annual (chronic effects)	One hour (continuous analyser) One month (diffusion tubes)	One year
VOCs	Few seconds (Odour) One hour (acute irritation effects) Annual (chronic effects - e.g. carcinogenicity)	15 minutes to one hour (continuous analyser) 2 – 6 hours (pumped samples)	One year
Sulphur containing VOCs	Few seconds (Odour) One hour (acute irritation effects)	15 minutes to one hour (continuous analyser) 2 – 6 hours (pumped samples)	Two months
Sulphur dioxide	15 minutes (acute respiratory effects) Annual (chronic effects)	15 minutes (continuous analyser) One month (diffusion tubes)	Two months
Hydrogen sulphide	Few seconds (odour) 15 minutes (acute respiratory effects)	15 minutes (continuous analyser)	Two months
PM_{10}	24 hours (acute respiratory effects) Annual (chronic morbidity)	1 to 24 hours (continuous analyser) 72 hours (pumped samples)	Two months
Dioxins and furans; PCBs, PAHs	Annual	72 hours	Two months
Metals	Annual	72 hours	Two months
Bioaerosols	Not known	2 – 6 hours	Two months
Deposited dust	Daily (nuisance) Annual (metal contaminant toxicity	One month	Two months

The study was carried out according to the programme outlined in Table A3.2. The key features were:

- Two one-month boundary fence monitoring campaigns at each of two landfill sites (winter 2000-2001 and summer 2001). Eight weeks of intensive monitoring during winter and summer provided measurements over a sufficient time period to include a wide variety of atmospheric conditions and process operations.

- Limited continuous boundary fence monitoring was carried out at each of two landfill sites for a period of over a year (December 2001 to September 2003, with some periods when monitoring was not undertaken).

- Continuous monitoring was carried out at two points on each site: south west site boundary and north east site boundary

- Continuous monitoring was specified to characterise levels of substances which may have acute effects on health (NO_2; SO_2; H_2S, PM_{10}, VOCs)

- Pumped sample monitoring was carried out at the two site boundary locations at each site. Samples of dusts, organic sulphur compounds and bioaerosols were also taken at a third location close to the active tipping face. Samplers were attached to the excavation/compaction plant.

- The boundary fence measurement survey was supplemented by monitoring of emissions from combustion sources.

The scope of the monitoring survey was developed taking account of guidance in Environment Agency guidance note M8. Chapter 6 of this document covers the choice of target species, and chapter 7 discusses considerations of sample durations. Sample locations are discussed in Chapter 10. The survey was consistent with these considerations, having regard to the objectives of the Environment Agency to undertake a comprehensive survey of landfill site emissions for the first time.

A3.1.2 Monitoring Methods

In this section, the monitoring methods are briefly described. These were specified with reference to the Environment Agency's Technical Guidance Note M9 "Monitoring methods for Ambient Air." In summary, measurements were carried out for the following substances:

- Particulate matter, in particular the PM_{10} fraction and dust deposition.

- Suspended Particulate Matter/Heavy Metals

- Toxic organic micro-pollutants, including dioxins and furans, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

- Volatile organic compounds (VOCs) including BTEX, CFCs, organosulphur compounds (e.g. mercaptans) and other likely volatile releases.

- Sulphur dioxide (SO_2).

- Nitrogen dioxide (NO_2).

- Hydrogen sulphide (H_2S).

- Bio-aerosols.

$PM_{10}/SO_2/NO_x//H_2S/VOCs$

Sampling for all of the above parameters was undertaken using continuous analysers housed in lockable cabins at two locations at each site.

PM_{10} was monitored using a TEOM and continuous analysers also provided for SO_2 (using converter and UV fluorescence) H_2S (UV fluorescence), NO_x (chemiluminescence) and VOCs (Flame Ionisation Detector including hydrogen generator, pure air supply). These methods of measurement are recommended in Technical Guidance Note M9 for the relevant determinations.

Dust Deposition

Dust deposition gauges in accordance with BS 1747 were used to determine dust deposition rates at two locations at each site, upwind and downwind. This measurement method is recommended in Technical Guidance Note M9 for dust deposition.

Monitoring methods are set out in Table A3.2

Table A3.2 : Monitoring methods

Parameter	Test Method	Certification	Calibration	Test Method	Referred to in TG9?	Detection limit	Air quality standard/ guideline
Initial VOC trial sampling	Adsorption tubes – GC/MS	UKAS	Lab SOPs	US EPA Method TO-1	Yes	50 µg/m^3	16 µg/m^3 minimum
NO_x	Chemiluminescence 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	40 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	16 µg/m^3
PM_{10}	Tapered Element Oscillating Microbalance (TEOM)	None available	Lab SOPs	Manufacturer's instructions/UK Automatic Network Site Operators Manual (where appropriate)	Yes	1 µg/m^3	40 µg/m^3
SO_2, H_2S	Photoionisation 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	125 µg/m^3
Dust deposition	Gauges to BS 1747	UKAS	Lab SOPs	BS1747	Yes	2 mg/m^2-day	80 mg/m^2-day
PCDDs/PCDFs and PAHs/PCBs	High Vol. Samplers / GC/MS	UKAS	Lab SOPs	USEPA Method TO9	Yes	10 fg/m^3 max	None
Particulates/Metals	High Vol. Samplers / AAS	UKAS	Lab SOPs	USEPA Method TO9 (adapted)	Yes	0.01 µg/m^3	0.1 - 60 µg/m^3
Parameter	Test Method	Certification	Calibration	Test Method	Referred to in TG9?	Detection limit	Air quality standard/ guideline
Speciated target VOCs, in particular chlorinated VOCs such as Chloroethene	Charcoal adsorption tubes - GC/MS	UKAS	Lab SOPs	US EPA Method TO-1	Yes	10 µg/m3	18 µg/m3 minimum

Parameter	Test Method	Certification	Calibration	Test Method	Referred to in TG9?	Detection limit	Air quality standard/ guideline
Organosulphur compounds	Mol. Sieve adsorption tubes -GC/MS	None available	Lab SOPS based on Analytical Chemistry 1984, 56, 1432-1436	US EPA Method TO-1	Yes	10 µg/m3	5 µg/m3 (odour threshold)
Bio-aerosols	Sterile filter /bubbler	None available	Lab SOPs	Internal SOP	No	100 cfu/m3 typical	600 cfu/m3 (typical environ-mental level)
Particulates/metals	Battery operated pumps / AAS	UKAS	Lab SOPs	MDHS 14/3	Yes	1.0 µg/m3	0.1 - 60 µg/m3

A3.1.3 Sampling/Analytical Method Statement

Scope of the Monitoring Survey

The following summarises the non-continuous monitoring carried out at the landfill sites at the upwind, downwind and tip face sites:

Upwind & Downwind Sites	***Tip Face***
Dioxins & Furans	Total Inhalable Dust
PCBs and PAHs	Heavy Metals from Dust
Suspended Particulate Matter	Bioaerosols
Heavy Metals from Suspended Particulate Matter	
Target VOCs	
VOC Screen	
1,3 Butadiene	
Formaldehyde	
Bioaerosols	
Stibene	
Arsine	
Fibre count	
SO_2 (diffusion tube)	
NO_2 (diffusion tube)	
Dust Deposition	

Sample collection was undertaken by REC Ltd personnel and equipment. The majority of the sample analysis was carried out by SAL Ltd, Manchester, a UKAS and GLP accredited contract laboratory. REC Ltd undertook filter weighing/re-weighing analysis in accordance with UKAS ISO 17025 procedures. Bioaerosol analysis was sub-contracted to the Health & Safety Laboratory, Sheffield.

Sampling & Analytical Methodology - Tip Face Samples

Total Inhalable Dust & Heavy Metals

Sampling was undertaken in accordance with the requirements of Methods for the Determination of Hazardous Substances (MDHS) Method 14/3. Air was drawn through a pre-weighed 25mm quartz fibre filter contained in a 7 hole sampling head. A battery operated sampling pump capable of maintaining a flowrate of 2 to 4 litres per minute was used to sample the air and the flowrate through the filter calibrated prior to and on completion of sampling using a rotameter. The filter

was conditioned and weighed in accordance with REC UKAS procedures.

Following re-weighing the filter was acid digested and analysed for a suite of heavy metals by inductively coupled plasma – optical emission spectrophotometry (ICP-OES). The metals suite comprised the following: antimony, arsenic, thallium, chromium, cobalt, copper, lead, manganese, nickel, tin, vanadium, cadmium and mercury. Full standardisations with multi-level mixtures of the metals of interest were performed prior to sample analysis.

Bioaerosols

Sampling was again undertaken in accordance with the requirements of Methods for the Determination of Hazardous Substances (MDHS) Method 14/3. Air was drawn through a sterile polytetrafluoroethylene (PTFE) filter contained in an IOM sampling head.

The sampling heads were pre-cleaned with alcohol to ensure they were sterile. A battery operated sampling pump capable of maintaining a flowrate of 2 litres per minute was used to sample the air and the flowrate through the filter calibrated prior to and on completion of sampling using a rotameter.

The samples were analysed for a Bioaerosol suite by the Health & Safety Laboratory Sheffield. Sample filters were returned to the laboratory within 24 hrs of collection by courier and a blank supplied with each set of filters. The suite included analysis for the following parameters: total bacteria, gram negative bacteria, E Coli, Salmonella, total Fungi and yeasts, Aspergillus fumigatus, and endotoxins.

Sampling & Analytical Methodology – Upwind & Downwind Samples

Dioxins and Furans, Polycyclic Biphenyls (PCBs) and Polycyclic Aromatic Hydrocarbons (PAHs)

Sampling was carried out in accordance with the requirements of United States Environmental Protection Agency (US EPA) methodology. The method was taken from the Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air (TO series). Method TO-9A describes a method for the sampling of dioxins and furans in ambient air using high resolution gas chromatography/mass spectrometry and a high volume sampler.

Sampling of the ambient air was achieved using high volume air samplers based upon General Metal Works Model PS-1 and manufactured by Graseby Anderson. Air is drawn through a fine porosity quartz filter and adsorbent cartridge containing polyurethane foam (PUF) to trap the particulate and volatile fractions respectively.

The samplers are capable of operating at a flowrate of up to 200 litre/minute and calibrated prior to and during the tests using a standard orifice and manometer.

The combined filter/PUF samples were spiked with a mixture of labelled internal standards (^{13}C labelled dioxins, furans and PCBs; deuterated

PAHs) and extracted by soxhlet for in excess of 16 hours with toluene. 10% of the raw extract was set aside for PAH analysis. The remainder of the extract was passed through a series of clean up and isolation stages to produce final extracts amenable to analysis by gas chromatography – mass spectrometry.

All analyses were performed using high resolution selected ion recording (3000 for PAHs, 5000 for PCBs and 10000 for dioxins). Quantitation was by isotope dilution or internal standard techniques as appropriate. Full multi-level calibrations were performed for all determinands to allow exact retention times and response factors to be established. At least one method blank was analysed for each batch of samples.

Suspended Particulate Matter and Heavy Metals

Sampling for Suspended Particulate Matter (SPM) was carried out in accordance with the requirements of US EPA methodology. The method was taken from the Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air (IO series). Method IO-2.1 describes a method for the sampling of SPM using a High Volume Sampler.

Sampling of the ambient air was achieved using high volume air samplers manufactured by Graseby Anderson. Air was drawn through a fine porosity quartz filter (203 x 254mm) used to trap the SPM.

The High Volume sampler was assembled with a pre-weighed quartz fibre filter clamped into the sampling head. Quartz filters were utilised as they have low background heavy metal concentrations. The filter used in the tests had a pore size capable of attaining a >99.95 percent efficiency of capture of smoke particles as determined by a smoke test.

The flowrate through the sampler was continually recorded on a pen chart over each sampling period.

Following re-weighing the filter was acid digested and analysed for a suite of heavy metals by inductively coupled plasma – optical emission spectrophotometry (ICP-OES). The metals suite comprised antimony, arsenic, thallium, chromium, cobalt, copper, lead, manganese, nickel, tin, vanadium, cadmium and mercury. Full standardisation with multi-level mixtures of the metals of interest were performed prior to sample analysis.

VOC Targets and Screens on Tenax and Mol. Sieve Adsorption Tubes

Tenax and Molecular Sieve adsorption tubes were used to sample for a suite of target volatile organic compounds (VOCs) potentially present in the ambient air around landfill sites. The sampling methodology was based upon US EPA Methods TO1 and TO2 covering the Tenax and Mol. Sieve tubes respectively.

Ambient air was sampled through the tubes using low flow (20 to 200 ml/min) battery operated sampling pumps. The flowrate through the

sampling pumps was calibrated prior to and on completion of sampling using a calibrated dry flow meter.

In order to screen for VOCs in the ambient air a Tenax tube sample was collected and analysed by the GC/MS system operating in the screening mode where the largest peaks are identified by the instruments vast spectral library and "semi-quantified" against a deuterated internal standard. In each case tentative library identifications were confirmed by the operator.

The target VOCs were analysed by thermal desorption HRGC-HRMS with the high resolution GC/MS system operating in the selective ion recording mode at 3000 resolution. The specific VOCs targeted on the Tenax and Molecular Sieve tubes are listed below:

Authentic standards of the targets were obtained and used to produce standard atmospheres that were then sampled onto the appropriate tube using similar techniques to those used in the field. These standards were then analysed to allow retention times and response factors to be determined. Quantitation was by external standard techniques.

Blank tubes were analysed with each batch of samples.

Other VOC Targets

A number of other target VOCs were sampled for using methodology based upon occupational hygiene methodology using low flow sampling pumps (20 to 200ml/min) and various adsorption tubes. The flowrates through the sampling systems were checked prior to and on completion of sampling using a calibrated dry flow meter. All adsorption tubes were obtained from a commercial supplier, SKC Ltd.

1,3 Butadiene: Sampling was carried out in accordance with the requirements of US occupational sampling methodology, in particular OSHA Method 56 using treated charcoal adsorption tubes. The tubes are treated with 4-tert-butylcatechol which is a polymerisation inhibitor for 1,3 Butadiene. The tubes were then solvent desorbed using carbon disulphide and analysed by selected ion recording GC/MS. Standards of butadiene were prepared using the tubes to allow determination of retention times and response factors. Butadiene was determined by external standard techniques. Blank tubes were desorbed and analysed with each batch of samples.

Formaldehyde: Sampling was originally carried out in accordance with accordance with US occupational hygiene method NIOSH 2541 using adsorption tubes containing XAD-2 resin with 10% 2-(hydroxymethyl)piperidine. This forms as stable oxazolidine derivative of formaldehyde which is then analysed for by GC/MS. The oxazolidine derivative is solvent desorbed from the tube prior to injection of 1/1000th of the sample extract into the GC/MS system. Formaldehyde standards were prepared on similar tubes and desorbed in the same manner. Analysis of these allowed retention times and response factors to be determined. In view of the relatively high limit of detection provided by this methodology compared to the HCV, these measurements were not used in the risk assessment.

The methodology for the summer 2003 sampling was changed in order to try to lower the limit of detection. For this work sampling was conducted using a method taken from the Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air (TO series).

Method TO5 describes a method for the sampling of formaldehyde in ambient air using 2,4 dinitrophenyl hydrazine (DNPH) to absorb the formaldehyde and form a stable DNPH derivative. Air is sampled through midget impingers containing the absorbing solution using battery operated sampling pumps set at a flowrate of 1.0 litres per minute. Analysis was performed using high performance liquid chromatography (HPLC) with UV detection. Standards of the derivative were prepared and analysed to allow retention time and response factors to be determined. Quantitation was by external standard techniques. Blanks were analysed with each batch of samples.

Stibene (SbH_3): Sampling was carried out using adsorption tubes containing mercuric chloride coated silica gel. The tubes were desorbed using dilute hydrochloric acid and antimony determined on the extract by ICP-OES rather than the ultraviolet/visible method quoted in the standard. Full calibration was performed by using external standards. Blank tubes were prepared in a similar manner with each batch of samples.

Arsine (AsH_3): Sampling was carried out using adsorption tubes containing charcoal media. The tubes were desorbed using dilute nitric acid and the extract analysed for arsenic by hydride atomic absorption spectrophotometry. Standardisation was via the use of matrix matched external standards. Blank tubes were prepared in a similar manner with each batch of samples.

Bioaerosols

As for Tip Face sampling.

Fibre Counts

Air was sampled through 25mm diameter, fine porosity, gridded, mixed cellulose ester filters housed in asbestos sampling heads in accordance with the requirements of HSE publication, Methods for the Determination of Hazardous Substances (MDHS) No. 59.

The filter holders were attached to intrinsically safe, battery operated sampling pumps with a pre-set flowrates of 2.0 litre/min. The flowrate through each pump was calibrated prior to and on completion of sampling using a calibrated rotameter.

The fibre count was undertaken in accordance with the method specified in MDHS 59 and EH 46 using a high resolution polarised light microscope.

Diffusion Tubes for NO_2 and SO_2

The NO_2 tubes consist of two stainless steel frits spiked with an aliquot of 10% triethanolamine in water to which a small amount of surfactant

is added. The surfactant ensures the frits are completely wetted. The sampler is held vertically with the open end downwards for a period of up to one month. The tube was mounted at least 5cm from the adjacent surface. On completion of sampling the tube is capped to stop further exposure.

The tube is then extracted using de-ionised water and determined as nitrite using an automated colorimetric reaction based upon the formation of an azo dye. The instrument is calibrated daily using a series of calibration standards and a standard check sample analysed after every fifty samples to ensure the calibration is still valid. A QC check is run after every 10 samples and assessed against warning and action levels described in the method. A travelling blank is also analysed at the same time as the samples.

The SO_2 tubes consist of two stainless steel frits spiked with an aliquot of sodium carbonate solution. The tube is assembled and a membrane placed over the open end to prevent the entry of particulate sulphate and dirt particles.

The tubes are exposed as for NO_2 tubes. The SO_2 is extracted using de-ionised water and subsequently determined as sulphate by ion chromatography (IC). The instrument is calibrated with standards and the performance checked with quality control samples in a similar manner to the NO2 analysis described above.

Dust Deposition

In order to assess dust deposition rates Frisbee type deposit gauges were utilised. These Frisbee type gauges are found to have superior collection efficiencies and aerodynamic characteristics to the original British standard deposit Gauge (BS 1747 Part 1). The inverted Frisbee (diameter 235mm) is mounted horizontally on a pole 1.75m above ground level. A hole at the centre of the Frisbee allows rainwater to drain trough a spacer tube into a 1 litre capacity polythene bottle. The Frisbee is also fitted with a dust trap to reduce contamination from fallen leaves etc. and plastic wire lines to minimise potential interference from birds.

At the end of the sampling period the Frisbee and collection bottle are transported to the laboratory and the deposited matter on the collection surface, dust trap and the insoluble matter in the bottle quantitatively removed and separated by vacuum filtration through a pre-weighed filter.

After drying the filter is re-weighed and from the exposure time and area of the Frisbee a dust deposition rate determined, expressed in terms of milligram of dust per square metre per day ($mgm^{-2}\ d^{-1}$).

This sampling methodology is recommended in Environment Agency publication, Technical Guidance Note M9 "Monitoring Methods for Ambient Air", published in 2000.

Flare/engine emissions measurements

The substances monitored in emissions from landfill gas engines and flares were determined on the basis of current and emerging 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.

Concentrations of dioxins and furans were measured using isokinetic stack sampling equipment satisfying the requirements of United States Environmental Protection Agency (US EPA) Method 5. The equipment was modified by the incorporation of a condenser and an XAD-2 resin trap for the determination of dioxins and furans in accordance with the requirements of US EPA Method 23.

Concentrations of combustion gases and total VOCs were measured using a Monitor Labs mobile emission monitoring laboratory. The system uses a heated probe (190°C) connected to a Baldwin Environmental Chiller to provide an in-line pre-filter made of non-absorbing materials and a flow meter with pre-set flow. The system will deliver between 1 and 5 l/min of conditioned gas to a suitably inert transport line. The unit is contained in an all-weather enclosure and is designed to meet the requirements of US EPA Congressional Federal Register (CFR)40, Part 60, Appendix A, Instrumental Analyser Test Procedure.

The unit is equipped with inert heat exchangers to ensure that gas absorption (bias losses) are the lowest achievable of any conditioners, the heat exchanges being made from Kynar (Teflon/Polyvinylidene Fluoride). The unit is designed to provide dry gases to analysers with a dewpoint of -5°C or better. Calibrations are performed via the probe or direct to instruments. It is general practice, as part of our UKAS procedures, to calibrate via the probe and only via the instrumentation to investigate bias of the gas transport unit. The VOCs are tapped off a heated line from the probe to a stand alone heated VOC process analyser (Signal 3030PM).

The gases having been dried to a dew point of less than 4°C are then pumped down the sample line (¼" PFA sample tube in a 30m section) to the sample module. The sample module is a Baldwin Environmental Flow Control Drawer designed to control, sample and calibration gases for up to 5 continuous gas analysers. The unit is controlled by a portable computer, which will direct calibration gases to the probe or to the analyser diluter unit. The sample gases are then passed either direct to the Servomex oxygen or carbon dioxide analysers or to a sample orifice and eductor to dilute the gases from 12:1 to 200:1, as

required, and the diluted gases diverted to Monitor Labs oxides of nitrogen, sulphur dioxide and carbon monoxide analysers. The data is fed back to the portable computer via an Analog to Digital Converter (ADC) unit to provide calibrated data logging facilities.

The stack temperature was measured using a thermocouple and digital thermometer. The stack velocity was measured using a pitot static probe (to BS 1042) and a digital manometer.

Sampling Protocol for dioxins and furans

A sample of the stack gas was removed and passed, via a glass-lined probe and nozzle, through a heated quartz filter contained in an oven compartment. Sampling was undertaken under isokinetic conditions i.e. the flowrate through the sampling nozzle was adjusted to match the flowrate in the stack. The filter had a pore size of 0.45 microns, capable of attaining a > 99.5 percent efficiency of capture of 0.3 micron smoke particles as stipulated in EPA Method 5. The filtered hot gas stream then passed through the condenser and a resin trap into an impinger train.

The condenser and resin trap were cooled with iced water to maintain emissions at low temperatures. The impinger train was seated in an iced water bath to cool the gas stream and condense out less volatile gases and water vapour. The first two impingers encountered by the gas stream contained distilled water. The third impinger was left empty to condense out any excess moisture in the gas stream.

The fourth impinger contained anhydrous silica gel which was used to dry the gas stream before passing through the dry gas meter (DGM), which measured the volume of gas sampled.

All the impingers were weighed before and after the sampling run in order to determine the mass of water trapped by the impinger train. This was used to calculate the moisture content of the gas stream in the duct. The resin trap employed was spiked with isotopic marker dioxins and furans, which enabled a surrogate standard recovery experiment to be performed.

All the impingers and associated glassware were cleaned prior to the survey according to the requirements of Section 3A of the ‘Manual of Analytical Methods for the Analysis of Pesticides in Human and Environmental Samples’.

Sampling was undertaken over a minimum three hour period to take into account possible process fluctuations and to ensure a reasonable detection limit was achieved. Sampling was undertaken at five points in the stack via the single access fitment provided. Upon completion of dioxin sampling, the filter was removed to a sealed container. The impinger solutions were re-weighed. The resin trap ends were sealed with PTFE tape and the trap stored in a cooler box prior to transfer to a refrigerator. The probe and all glassware were brushed and rinsed with acetone, dichloromethane and toluene and all the washings collected.

The samples were labelled and details logged onto a Laboratory Submission Sheet prior to transport from the site to ensure a chain of custody from sample collection to laboratory receipt.

Laboratory analysis for dioxins and furans

Samples were submitted to Scientific Analysis Laboratories (SAL) Ltd for subsequent analysis. SAL are UKAS accredited for the analysis of dioxins and furans.

Analysis for dioxins and furans was undertaken on a composite sample consisting of the particulate filter, spiked resin trap, and the equipment washings (acetone/dichloromethane and toluene). High resolution gas chromatography/mass spectrometry (GC/MS) was employed to accurately identify and quantify the PCDD and PCDF isomers. Extraction, clean-up and analysis procedures followed US EPA protocols and the full quality assurance and quality control regime set out in EPA Method 1613 was followed.

Surface emissions measurements

Survey design

The survey was carried out according to guidance given by the Environment Agency (Environment Agency, 2003b).

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

Based on the findings of the desk study and subsequent site walkover, the number of monitoring locations was determined following guidance given by the Environment Agency. In principle, the number of monitoring locations is a function of the zone size, with the size categorised into two distinct groups:

> Zone area greater than 5000 m^2: number of required flux measurements is: $N = 6 + 0.15 \sqrt{(\text{Zone area})}$
>
> Zone area less than 5000 m^2: number of monitoring locations is: $N = (\text{Zone area}/5000) \times 16$

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.

Monitoring techniques

A Research Engineering Autofim FID was used to measure volatile organic compounds (VOC's) to a detection limit of 0.1ppm. It is intrinsically safe and portable. This instrument is factory serviced and calibrated every six months with a certificate of calibration provided by the manufacturer. In addition, it was checked using a control gas of concentration 200ppm at the beginning

and end of each day. The sample concentration range for the Autofim FID was 0.1 – 10,000ppm carbon.

The flux box is of a standard design as recommended by the Environment Agency Protocol (Ref. 2001c). It incorporates a methane gas tap on the top of the box to connect the FID, an internally mounted perforated T-bar to ensure representative gas readings from within the flux box, and an activated carbon filter connected to the inlet used to equalise the internal pressure to prevent any background methane from entering the box during the monitoring.

Measurement method

The flux box measurements were taken as follows:

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 (0ppm) control gas, and the meter zeroed to ensure correct relative background concentration of methane.

Background readings near to the monitoring location were taken.

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

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.

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

Data interpretation

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

Concentrations (C) were converted from ppm to mg/m^3:

$$C_{mg/m^3} = C_{ppm} \times \frac{formula \quad mass_{CH_4}}{molar \quad volume}$$

Where: $$C_{ppm} = C \frac{m^3{}_{CH_4}}{m^3{}_{air}} \times 10^6$$

Formula mass $_{CH4}$ = 16 g/mol

Molar volume = 0.0224 m^3/mol

$$Density = \frac{16 \times 1000}{0.0244} mg/m^3$$

$$C_{mg/m^3} = \frac{C_{ppm}}{10^6} \times \frac{16 \times 1000}{0.0244}$$

The flux for each monitoring location was calculated using the formula:

$$Q = \frac{V}{A} \times \frac{dC}{dt}$$

Where: Q is the flux density of the gas ($g.m^{-2}.s^{-1}$)

V is the volume of air within the flux box (0.24 m^3)

A is the area of soil surface enclosed by the flux box (0.42 m^2)

dC/dt is the rate of change of gas concentration in the flux box ($g.m^{-2}.s^{-1}$)

The rate of change of the gas concentration (dC/dt) is determined by plotting CH_4 concentration ($mg.m^{-3}$) against time (seconds) and calculating the slope of the initial rise in concentration. The gradient of the slope is calculated by the spreadsheet al.ong with the correlation coefficient, r^2, which is a measure of how representative the trend line is of the measured value.

Data from a measurement location is considered acceptable if the value for r^2 is greater than 0.8, there are at least five data points used in the correlation and the change in concentration is greater than zero. Where these criteria are not satisfied, the data cannot be used to determine the methane flux and the result must, therefore, be reported as being at the lower detection limit of the method. This lower limit is 5 x 10^{5} $mg.m.s^{-1}$.

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.

A3.2 Project working plan (intensive surveys)

[Not included, as provides details which would enable sites to be identified]

A3.3 Project working plan (continuous analysers)

MONITORING STATION CALIBRATION PROCEDURE

During all Span Check/Calibration Procedures, the door to the cabin should be kept shut.

1.0 Span Check/Calibration Procedure – Total Hydrocarbon/Methane Analyser

1.1 Summary

This procedure provides for **span checks** and **calibrations** of the M&A FID analyser used for measuring total hydrocarbon and methane concentrations. A "Span check" is a check on the instrument, with no actual adjustment to the instrument settings performed. A "Calibration" consists of an actual adjustment to the instrument configuration by the analyser itself, which will then require a further manual span check.

Following a span check, the operator must decide, from the results obtained, whether any re-calibration is needed. No re-calibration of the analyser should be made without a span check then being carried out. The exception to this is in the event of a system malfunction that does not permit a span check to be carried out.

The procedure is as follows:

Carry out span check, recording details on Span Check Form

Decide whether EMC needs to be contacted or a call-out initiated. If EMC are contacted and any adjustments made to the system, record any changes to the instrument set up advised by EMC.

If no adjustment is needed, confirm this on the Span Check Form.

If a re-calibration is required due to drift outside the tolerances quoted, or following a service visit from EMC, then these details must be recorded on Calibration Form

This procedure is to be followed during routine calibration visits. The procedure is also to be carried out by REC following a call-out visit by an EMC engineer.

1.2 Instrument Details

The M & A Total hydrocarbon/methane analysers, when operating normally, will show a green LED on the front panel labelled EIN/ON and the digital read-out will show measured concentrations for the two channels. If not, press MEAS button to return to measure mode. The instrument measures total hydrocarbon and methane on two channels. Measurements are made with/without a catalyst which oxidises all organic carbon except methane into CO_2 (with H_2O the main other by-product). The instrument cycles between channels (15 sec sample, 15 sec purge), with the channel where measurements are currently being recorded marked with a "$\rightarrow$" sign on the screen.

The instrument itself has a zero check facility where air is passed over a heated palladium catalyst. A zero check should also be performed using a cylinder of air with a low certified concentration of hydrocarbons, normally less than 0.1 parts per million (ppm). Span gas consists of a methane and propane mix at accurately known concentrations of the order of 50 ppm.

1.3 Error/Service Status

If the "Error" or "Caution" light is on there is a problem with the Total hydrocarbon/methane analyser which may require a service call-out. Press the SERVICE button to gain access to the error messages. "Flame out" or "low H_2 pressure" messages may indicate that the hydrogen cylinder is running low. If this is found to be the case, check and if necessary replace the cylinder.

If the "Service" light is on this normally means the instrument is in calibration or purge mode and is not recording actual measuring data.

1.4 Span Check Procedure

Span Checks should be carried out weekly, and also after any instrument service or calibration adjustment. A re-calibration and subsequent span check will need to be performed either when the analyser has been serviced or if the span check values are outside the acceptable range.

If the span gas or zero gas is within two months of its expiry date, arrange for a replacement cylinder to be ordered. If any of the certificates are out of date, carry out a span check but note clearly the gas out of date, and notify the REC project management team immediately (Mike Smith or Paul Furmston). If the zero or span gas differs from that used for the previous calibration (posted in the cabin), check with the REC project management team before proceeding with the calibration.

1. Prior to carrying out the span check, record the analyser parameters listed on the Span Check Form. In the event that the Error or Caution lights are illuminated, or the Service light is illuminated for a long period contact EMC and arrange for a call-out if required. If the rack temperature recorded by the thermometer in the cabin exceeds 30°C (also check data from Enview), contact EMC.

2. Change the instrument pre-filter (NB: this must be done prior to every span check) see REC Routine Service Plan

3. Fit appropriate regulators to span and zero cylinders. Regulators are fitted with a plastic T piece with one end connected to the regulator and one to a small rotameter 0 to 1000ml/min. Leak check cylinder joints using soap solution.

4. With the instrument operating normally in "Ein/On" mode, disconnect the line from the T piece on the sample manifold and connect this to the vacant join on the cylinder T piece.

5. Open the regulator slowly until the flowmeter starts to read an excess of around 500ml/min being released. This ensures an excess in the system and that sufficient span gas is drawn into the instrument.

6. Wait for 3 - 4 sample cycles until steady values have been achieved (this may take between 3 - 5 minutes). Record the measured span values for methane and total hydrocarbons on the Span Check Form along with the span gas certified value on the cylinder. Note: Ignore any alarm messages, which may be displayed as the span gas concentration rises above set alarm levels.

7. Turn off the regulator to stop the span gas flow, close and disconnect the span gas cylinder. Disconnect the span gas connection line from the T piece and connect the zero gas regulator connection line to the analyser/rotameter/cylinder T piece at the same point.

8. Repeat steps 5 and 6 above for the zero gas as opposed to the span gas. Record the measured zero values for the methane and total hydrocarbon channels on the Span Check Form.

9. Turn off the zero gas flow from the regulator, close and disconnect the zero gas cylinder and reconnect the instrument sample line to the sample manifold T piece.

10. Note the channel identified with the "→" character. Press the ZERO CHECK button to cause air to pulled in across the heated catalyst. Air will be drawn in for approximately 3 minutes.

11. When a steady value has been achieved (let it run between channel to stabilise), record this measured zero value on the Span Check Form.

12. The instrument will then purge and return to normal measurement, (i.e. service light out and green EIN/On light on).

13. Repeat steps 10 – 12 for the other channel.

14. Cross-check the zero and span values against the values recorded at the most recent calibration (NB, calibration, not span check). These will be posted in the instrument cabin, and are also available by contacting Paul Furmston or Mark Broomfield at Enviros (01939 262227). If the span value differs by more than 10%, or the zero value differs by more than 0.5 ppm from the value obtained at the last calibration, this triggers a service call-out.

If required, arrange for a 48-hour service call out immediately by fax to EMC.
If no system adjustment is needed, confirm this on the Span Check Form.
Copy the form to Enviros and EMC as indicated.

IMPORTANT NOTE: This procedure does not alter the calibration settings. Do not press the CAL button, as this will cause the zero/span readings to be automatically adjusted.

1.5 Calibration Procedure

Recalibration may occasionally be required if, for example, there is a significant drift away from the original settings or the instrument has been modified or serviced by EMC.

If required, this is carried out by the instrument using the ~50ppm methane span gas directly connected to the back of the instrument and zero air drawn over the catalyst. Pressing the CAL button on the front of the instrument causes the instrument to carry out a zero and span check, and adjust the instrument to match the expected values.

Once this has been done a manual zero and span check must be carried out, according to the Span Check Procedure outlined above. These zero and span values provide a new point of reference for future zero/span checks.

2.0 Calibration Procedure – Oxides of Nitrogen Analyser

2.1 Summary

The automatic calibration system for the Monitor Labs oxides of nitrogen analyser is controlled by the Enview data management system. A daily span and zero check are undertaken over a 30-minute period from 01:00 to 01:30. The span and zero checks are recorded but no actual adjustment is made to off set the drift by the system.

The system records the expected and observed zero and span calibration values, and calculates a zero and span correction value for oxides of nitrogen (NOx) and nitric oxide (NO). The system also records raw monitored levels of oxides of nitrogen and nitric oxide. The calibration correction values are then subsequently applied to the raw monitoring data for oxides of nitrogen and nitric oxide.

Levels of nitrogen dioxide are calculated by subtraction of the corrected nitric oxide concentration from the corrected oxides of nitrogen concentration.

2.2 Span Check Procedure

Because of the audit trail provided by the calibration records and raw recorded data, and the additional confidence provided by a daily calibration, automatic calibration will continue to be applied for the oxides of nitrogen analyser. A span check is nevertheless to be carried out during the weekly site visits, and after any system adjustment e.g. cylinder change, servicing visit.

If the span gas is within two months of its expiry date, arrange for a replacement cylinder to be ordered. If any of the certificates are out of date, carry out a span check but note clearly the gas out of date, and notify the REC project management team immediately (Mike Smith or Paul Furmston). If the zero or span gas differs from that used for the previous calibration (posted in the cabin), check with the REC project management team before proceeding with the calibration.

1. Record the parameters listed on the NOx Span Check Form. In the event of a malfunction being identified, or a parameter lying outside a specified tolerance, contact EMC to discuss and arrange for a call-out if required. If the rack temperature exceeds 30°C, contact EMC.

2. Change the instrument pre-filter (NB: this must be done prior to each span check). – see REC Routine Service Plan.

3. With the instrument operating normally, press the NOx SPAN button on the Envidas unit front panel. The system floods the sample manifold with span gas for 5 minutes. Following this, the instrument enters into span check mode for 5 minutes. The instrument then purges the manifold for 5 minutes.

4. Wait until a steady value has been achieved. Record the measured NO and NOx span values on the Span Check Form along with the span gas certified value on the cylinder.

5. With the instrument operating normally, press the NOx ZERO button on the Envidas unit front panel. The system floods the sample manifold with zero gas for 5 minutes. Following this, the instrument enters into zero check mode for 5 minutes. The instrument then purges the manifold for 5 minutes.

6. Wait until a steady value has been achieved. Record the measured NO and NOx zero values on the Span Check Form.

If required, arrange for a 48-hour service call out immediately by fax to EMC.
If no system adjustment is needed, confirm this on the Span Check form.

Copy the form to Enviros, REC and EMC as indicated.

Note: This procedure does not alter the calibration settings.

2.3 Calibration Procedure

Re-calibration may occasionally be required after a system adjustment, for example, if there is a significant drift away from the original settings or the span cylinder is changed. This would normally be carried out by a service engineer. Once this has been done, a manual zero and span check must be carried out, according to the Span Check procedure detailed in Section 2.2. These zero and span values provide a new point of reference for future zero/span checks.

1. Record the parameters listed on the NOx Calibration Form. In the event of a malfunction being identified, or a parameter lying outside a specified tolerance, contact EMC and arrange for a call-out if required. If the rack temperature exceeds 30C, contact EMC.

   If the span gas or zero gas is within two months of its expiry date, arrange for a replacement cylinder to be ordered. If any of the certificates are out of date, carry out a span check but note clearly the gas out of date, and notify the REC project management team immediately (Mike Smith or Paul Furmston).

   If the zero or span gas differs from that used for the previous calibration (posted in the cabin), check with the REC project management team before proceeding with the calibration.

2. If not already changed this week, change the instrument pre-filter (NB: this must be done prior to calibration).

3. Ensure the Enview NOx SPAN button is pressed to allow calibration gas to flood the manifold.

4. The system floods the sample manifold with span gas for 5 minutes. Following this, the instrument enters into span check mode for 5 minutes. The instrument then purges the manifold for 5 minutes. Wait until steady values are recorded.

5. The values on the instrument are then corrected to those on the certified span bottle using the cursor adjusting each of the digits in turn using the up and down arrow keys and then moving to the next digit using the select button.

6. With the instrument operating normally, access the CALIBRATION Menu of the analyser using the Up and Down scroll keys on the front panel. This will bring new text onto the screen “Start Manual Calibration – NO”. Use the up/down key to change to “Start Manual Calibration – YES. Press the ENTER button (far right of panel to initiate calibration.

7. When the reading corresponds to that of the certified reference value for each channel press ENTER to confirm the new set points and then EXIT to return to the Main Menu.

8. Press the NOx SAMPLE button on the Envidas panel to return to normal measurements.

9. Carry out a Span Check as per Section 2.2.

3.0 Calibration Procedure – PM10 analyser

3.1 Summary

No direct calibration is carried out on a daily or weekly basis for the PM10 analyser. The equipment was serviced and calibrated using a standard mass transducer verification kit on delivery by the

equipment supplier (EMC), and a further full service and calibration was carried out prior to the intensive summer survey.

The filter loading is checked via the Enview data logging system on a daily basis according to REC procedures. The filter is then changed if the filter loading is greater than 80% of maximum load as part of the REC Routine Servicing Plan based upon EMC procedures. The instrument temperature and alarm indicator lights are checked. The sampling head is removed and cleaned on a monthly basis. The parameters listed in the TEOM Check Form are also noted.

M&A FID SPAN CHECK RECORD

NOTE: THIS FORM IS TO BE USED FOR INITIAL WEEKLY SPAN CHECKS. IT SHOULD ALSO BE USED FOR SPAN CHECKS AFTER INSTRUMENT CALIBRATION FOLLOWING SERVICING, ADJUSTMENT TO RECTIFY DRIFT ETC.

SITE VISIT DETAILS

OPERATOR NAME:

SITE:

Date Start time Finish time

TIME/DATE OF SPAN CHECK:

REASON FOR SPAN CHECK: Weekly Visit ?
Following Instrument Calibration ?
Other ?

IF FOLLOWING CALIBRATION PLEASE RECORD:

TIME/DATE OF CALIBRATION:

REASON FOR CALIBRATION:

CERTIFIED CALIBRATION GAS DETAILS FOR CALIBRATION

Calibration Gas	Cylinder Ref. No.	Certificate Expiry Date, Within (Y/N) ?	Certified Value (ppm)
Methane			
Propane			
Zero Gas			

CALIBRATION SUCCESSFUL (Y/N): _____Now repeat Span Check Procedure

Calibration form completed?

Note: automatic calibration via the “CAL” button adjusts the instrument to read span gas value and zero to read zero using catalyst purified air.

M&A FID SPAN CHECK RECORD (CONTD)

INSTRUMENT STATUS PRIOR TO CHECKS

	Y/N
Error LED lit?	
Service LED lit?	
Caution LED lit?	

Last 3 alarm entries in history file	Date/Time

Parameter	Units	Instrument value	Typical value	Comment (within tolerance?)
Detector Temp	°C		140	
Cat Temp	°C		400	
Sonde Temp	°C		250	
Burner pump value	Mbar		-400	
Burner pump capacity	%		50-60	
Sample pressure	Mbar		< -170	
Sample pump value	Mbar		-330	
Sample pump capacity	%		50-60	
Aer press	Bar		3.7	
Span gas pressure	Bar		2	
Flame Temperature	°C		415	
Suction voltage	V		-398	
H_2 Control value	Mbar		-310	
H_2 Control capacity	%		50-60	
Ambient methane	ppm			
Ambient Total HC	ppm			
Rack temperature (from cabin thermometer)	°C		5 - 30	Record and reset Max./Min Max.: Min:

2.1.1 NOTE: IF RACK TEMPERATURE EXCEEDED 30°C SERVICE CALL-OUT REQUIRED

2.1.2 STANDARD GAS DETAILS FOR SPAN/ZERO CHECKS

Calibration Gas	Cylinder Ref. No.	Certificate Expiry Date, Within (Y/N)?	Certified Value (ppm)
Methane			
Propane			
Zero Gas			

M&A FID SPAN CHECK RECORD (CONTD)

SPAN/ZERO CHECK RESULTS
PRE-FILTER CHANGED PRIOR TO TEST? (OBLIGATORY FOR WEEKLY CHECK): ____?

2.2 Calibration Parameter	**Concentration (ppm)**	**Value from last Span Check (ppm)**	**Tolerance**
Measured span value (Total hydrocarbon channel)			±10%
Measured span value (Methane channel)			±10%
Measured zero value using zero gas cylinder (Total hydrocarbon channel)			±0.5 ppm
Measured zero value using zero gas cylinder (Methane channel)			±0.5 ppm
Measured zero value using catalyst (Total hydrocarbon channel)			±0.5 ppm
Measured zero value using catalyst (Methane channel)			±0.5 ppm

Are all values within tolerances specified (Y/N) :

Does instrument require calibration (Y/N) :

Ambient Total HC POST test	ppm	
Ambient methane POST test	ppm	

Other Comments

Copy this form to Mark Broomfield at Enviros, Mike Smith at REC and Alan Batho at EMC. Leave a copy on file in the cabin.

NOx ANALYSER SPAN CHECK RECORD

NOTE: THIS FORM IS TO BE USED FOR INITIAL WEEKLY SPAN CHECKS. IT SHOULD ALSO BE USED FOR SPAN CHECKS AFTER INSTRUMENT CALIBRATION FOLLOWING SERVICING, CYLINDER CHANGE, ADJUSTMENT TO RECTIFY DRIFT ETC.

SITE VISIT DETAILS

OPERATOR NAME:

SITE:

	Date	Start time	Finish time
TIME/DATE OF SPAN CHECK:			

REASON FOR SPAN CHECK: Weekly visit ?
Following Instrument Calibration ?
Other ?

IF FOLLOWING CALIBRATION PLEASE RECORD:

TIME/DATE OF CALIBRATION:

REASON FOR CALIBRATION:

CERTIFIED CALIBRATION GAS DETAILS FOR CALIBRATION

Calibration Gas	Cylinder Ref. No.	Certificate Expiry Date, Within (Y/N)?	Certified Value (ppb)
NO_x			
NO			

CALIBRATION SUCCESSFUL (Y/N): ____If so repeat Span Check Procedure

Note: automatic calibration adjusts the instrument to read the certified span gas values.

NOx ANALYSER SPAN CHECK RECORD (Contd.)

INSTRUMENT STATUS

Parameter	Instrument Value	Range	Comment
Instrument Gain:		1.937- 4.287	
Gas Flow (SLPM)		0.45 to 0.70	
Gas Pressure (TORR)		75 to 300	
Ambient Press (TORR):		450 to 800	
Conc. Voltage (V)		0.1 to 4.5	
Analog Supply (V)		1.6 to 12.2	
Digital Supply (V)		4.8 to 5.2	
Ground Offset		200 to 320	
High Voltage (V)		600 to 700	
Firmware Ver:		B1.25.2	
Ambient NO (ppm)			
Ambient NO_2 (ppm)			
Ambient NO_x (ppm)			

Are all values within tolerances specified (Y/N)? :

Any Fault messages displayed (Y/N)? :

If Y list:

NOx ANALYSER SPAN CHECK RECORD (Contd.)

STANDARD GAS DETAILS FOR SPAN/ZERO CHECKS

Calibration Gas	Cylinder Ref. No.	Certificate Expiry Date, Within (Y/N)?	Certified Value (ppb)
NO			
NO_x			

SPAN/ZERO CHECK RESULTS

CONFIRM PRE-FILTER CHANGED PRIOR TO TEST: ____?

Calibration Parameter	Concentration (ppm)	Value from last Span Check (ppm)	Within tolerance? (yes/no)
Measured zero value using catalyst (NO channel)			±5 ppb
Measured zero value using zero gas cylinder (NO_x channel)			±5 ppb
Measured span value (NO channel)			±10%
Measured span value (NO_x channel)			±10%

Are all values within tolerances specified (Y/N) :

Does instrument require calibration (Y/N) :

Ambient NO POST Test (ppm)	
Ambient NO_2 POST Test (ppm)	
Ambient NO_x POST Test (ppm)	

Other comments

Copy this form to Mark Broomfield at Enviros, Mike Smith at REC and Alan Batho at EMC. Leave a copy on file in the cabin.

PM10 STATUS CHECK RECORD

SITE VISIT DETAILS

OPERATOR NAME:

SITE:

Date Start time Finish time

TIME/DATE OF STATUS CHECK:

REASON FOR STATUS CHECK: Weekly Visit ?
Other _____ ?

TEOM FILTER CHANGED PRIOR TO CHECK (Y/N):
(CHANGE PAST 80% FILTER LOADING ONLY)

INSTRUMENT STATUS

Parameter	Instrument Value	Typical Value	Comments
Status Code:		OK	
Operating Mode:			
Filter %:			
Mass Conc.:			
30 min MC:			
01hr MC:			
08hr MC:			
24hr MC:			
Total Mass:			
Case Temp:		50.00	
Air Temp:		50.00	
Cap Temp:		50.00	
Main Flow:		3.00	
Aux. Flow:		13.6	
Noise:			
Frequency:		234 (± 2)	

NOTE: FOR A NOISE VALUE EXCEEDING 0.100 SERVICE CALL-OUT REQUIRED

Other comments

Copy this form to Mark Broomfield at Enviros, Mike Smith at REC and Alan Batho at EMC. Leave a copy on file in the cabin.

A3.4 Data rectification/validation procedure

Instrumentation

A3.4.1 The air monitoring instruments were located in three units. Instruments in the permanent installations were located on site between November 2001 and August 2003, except where indicated:

- Site A permanent installation
  - NOx chemiluminescence analyser (ML9800 series)
  - PM10 TEOM[2] (ML9800 Series)
  - Methane/Total hydrocarbon analyser (ML9800 Series)
  - Sulphur dioxide analyser (ML9800 Series) (December 2001 – January 2002; July – August 2003)
  - Hydrogen sulphide analyser (ML9800 Series) (December 2001 – January 2002; July – August 2003)
- Site B permanent installation
  - NOx chemiluminescence analyser (ML9800 Series)
  - PM10 TEOM (ML9800 Series)
  - Methane/Total hydrocarbon analyser (ML9800 Series)
  - Sulphur dioxide analyser (ML9800 Series) (January – April 2002; June-July 2003)
  - Hydrogen sulphide analyser (ML9800 Series) (January – April 2002; June- July 2003)
- Mobile unit
  Site A: December 2001 to January 2002; July to August 2003
  Site B: January 2002 and April 2002; June to July 2003
  - NOx chemiluminescence analyser (ML9800 Series)
  - PM10 TEOM (ML9800 Series)
  - BTEX analyser (ML9800 Series) and Methane/Total hydrocarbon analyser (ML9800 Series)
  - Sulphur dioxide analyser (ML9800 Series)
  - Hydrogen sulphide analyser (ML9800 Series)

A3.4.2 Instruments were installed and serviced, and data logging commenced following satisfactory performance tests.

2 Tapered Element Oscillating Microbalance

Data acquisition

A3.4.3 Instrumental data was downloaded daily via modem links at 07:00am from all instruments in all three units using the EnView system. 15 minute average concentrations were stored. Each value is labelled with a time record corresponding to the start of the 15 minute period.

A3.4.4 Data was stored and backed up on computer in REC offices at Reading. Data was sent from REC to Enviros at periodic intervals, providing a further back-up.

Calibration

A3.4.5 The following instruments were calibrated daily at 01:00am using an automatic system. Zero drift was checked using zero gas. Span drift was measured using traceable span gases.

- Site A permanent installation :
  - NOx chemiluminescence analyser
  - Methane/total hydrocarbon analyser
- Site B permanent installation :
  - NOx chemiluminescence analyser
  - Methane/total hydrocarbon analyser

A3.4.6 Daily calibration data is stored within the EnView system. The calibration values are printed out and sent manually to Enviros for data processing and checking.

A3.4.7 The following instruments are calibrated at approximately monthly intervals.

Site A permanent installation	Sulphur dioxide analyser (Dec 2001 – Jan 2002)
	Hydrogen sulphide analyser (Dec 2001 – Jan 2002)
Site B permanent installation	Sulphur dioxide analyser (Jan – April 2002)
	Hydrogen sulphide analyser (Jan – April 2002)
Mobile unit	NOx chemiluminescence analyser
	Sulphur dioxide analyser
	Hydrogen sulphide analyser

A3.4.8 Monthly calibration data is stored by REC and sent manually to Enviros.

A3.4.9 The following instruments do not require calibration because of the nature of the instrumentation. It is serviced and the response checked at six-monthly intervals.

Site A permanent installation	PM10 TEOM
Site B permanent installation	PM10 TEOM
Mobile laboratory	PM10 TEOM
	BTEX analyser; Methane/total hydrocarbon analyser

A3.4.10 Calibration data consists of two values for each calibration event:

Zero value: The value *z* that the instrument reads when provided with a sample of gas with zero or non-detectable concentration of determinand

Span value: The value *s* that the instrument reads when provided with a sample of gas with a known concentration *k* of determinand

A3.4.11 Daily calibration values were assumed to apply throughout the day on which they were obtained. Monthly calibration values were assumed to apply to the day on which they were obtained. Values for intermediate days were calculated by assuming a linear drift between calibration events, in accordance with procedures normally adopted at temporary installations by bodies including the Environment Agency.

$z_d = z_a + (z_b - z_a) \times d/(b-a)$

Where z_n is the zero value on day number *n*

a is the day number of the initial calibration event

b is the day number of the subsequent calibration event

d is the day number of an intermediate day

$s_d = s_a + (s_b - s_a) \times d/(b-a)$

Where s_n is the span value on day number *n*

a is the day number of the initial calibration event

b is the day number of the subsequent calibration event

d is the day number of an intermediate day

Rectification procedure

A3.4.12 The response of all environmental monitoring instruments will drift over a period of time. The calibration procedures provide the method for deriving a reliable estimate of actual concentrations, on the basis of the measured values, and the calibration values. Data were rectified by converting the instrument reading to a calculated best estimate of the true concentration value.

When presented with zero gas of concentration 0, the instrument will read a value which may not be exactly zero because of the drift in instrument response. The instrument reading when presented with zero gas on day *n* is denoted z_n.

Similarly, when presented with span gas of known concentration k, the instrument will read a value which may not be exactly k because of the drift in instrument response. The instrument reading when presented with span gas of known concentration k on day n is denoted s_n.

A3.4.13 The following formula was applied to calculate the best estimate of the true concentration:

$$c_{hn} = (r_{hn} - z_n) \times k/s_n$$

Where c_{hn} is the best estimate concentration of determinand at hour number h on day number n

r_{hn} is the instrument reading at hour number h on day number n

z_n is the zero value on day number n

s_n is the span value on day number n

k is the known concentration of determinand in the span gas

A3.4.14 These calibration values were applied to the data using a spreadsheet. Calibration formulae and data were entered by a member of Enviros staff. The formula was then checked by an independent member of Enviros staff. The calibration data were verified by reporting the values applied back to REC for cross-checking against the original records.

A3.4.15 For the period up to March 2002, the methane/total hydrocarbon analyser was set up to apply this correction automatically, and no manual adjustment was required. Following this, the analyser was rectified as set out above. The methane/total hydrocarbon analyser requires two further forms of rectification. Firstly, the instrument only permits an analogue output. This precludes the reporting of specific error status. The instrument reports a signal of "-12.5 ppm" under fault conditions (this represents a signal of 0 milliamps on a 4-20 milliamp output, where the full scale value is 50 ppm). 15 minute mean data with a value of -12.5 therefore need to be removed from the data set.

A3.4.16 Some 15-minute mean data values are negative, but with a clearly identifiable signal. In this case, data can be recovered by eliminating the proportion of the signal which is caused by a -12.5 value. In this case, the signal is made up of -12.5 for an instrument downtime of 8 minutes (the 8 minute period is caused by a flame out event, followed by a restart and calibration). The remainder of the 15 minute period is a valid signal. Hence, to restore the signal, the following formula is applied:

$$c_{hn} = (15/t_v) \times [r_{hn} + \{12.5 \times (t_d/15)\}]$$

Where c_{hn} is the best estimate concentration of determinand at hour number h on day number n

r_{hn} is the instrument reading at hour number h on day number n

t_d is the downtime period in minutes (8 minutes)

t_v is the valid time period in minutes (equal to $15 - t_d = 7$ minutes)

A3.4.16 There is an element of judgement involved in identifying data values which need to be corrected for the mixed "-12.5 ppm" signal. The data values requiring correction were

identified from an inspection of the uncorrected and corrected data. If the uncorrected data appear to be measurements which are close to zero or negative, these are

A3.4.17 This correction was applied to the methane/total hydrocarbon data using a spreadsheet. The formulae were entered by a member of staff. The formula was then checked by an independent member of staff. The periods of application were verified by reporting the periods back to REC and EMC for cross-checking. Once this aspect of the instrumental operation became clear, the system was adapted to avoid the need for correction in this way.

A3.4.17 Secondly, the methane/ total hydrocarbon analyser can be operated with an offset applied by the installation/maintenance engineer. This acts as a further zero offset, added to the zero drift which occurs as the instrument operates. These offset values are confirmed by the equipment supplier (EMC Environment Ltd). The offset values were applied as follows:

$c_{hn} = (r_{hn} - e_n)$

Where c_{hn} is the best estimate concentration of determinand at hour number h on day number n

r_{hn} is the instrument reading at hour number h on day number n

e_n is the engineer-applied offset value on day number n

Data validation procedure

A3.4.18 The rectified dataset was then validated by eliminating data considered likely to be invalid

A3.4.19 ***Negative data:*** In some cases, the data rectification procedure results in concentrations which are below zero. This is a consequence of the assumption of linear zero/span drift, and constant zero/span drift throughout each day. If this occurs, and the magnitude of the negative value is less than the estimated uncertainty in the signal, the zero value is presented, but noted that it is below the limit of detection. If the magnitude of the negative value is more than the uncertainty in the signal, the data point is deemed to be invalid.

A3.4.20 ***Instrument performance out of spec:*** Instrument malfunctions (e.g. temperatures or gas flows outside normal operating ranges) resulted in error messages and data being flagged as invalid. Invalid calibrations due to instrument faults were also flagged as invalid by the system, and this data was not used in the rectification process.

A3.4.21 ***Site issues:*** The monitoring cabins were potentially subject to time-outs due to power outages which require the systems to be re-set vis the RCD protection switches provided. Once re-set the instruments were required to reach their normal operating parameters re temperatures and flows before valid data can be collected. This process took around 60 minutes and during this warm up time no valid data was collected.

A3.4.22 REC carried out regular routine maintenance including cleaning of the TEOM filter head and changing the of TEOM filter before the loading approaches the maximum value for satisfactory instrument performance. Other pre filters for the instruments were also changed on a monthly basis. During these procedures the instruments are set from “logging” to “in service” and data flagged as invalid. After changing the TEOM filter the system remained out of service for a period of 60 minutes to ensure that all operating temperatures and flows were within instrument specifications.

A3.4.23 The data downloading was carried out via modem links and occasionally periods of bad reception or problems with the service provider resulted in downloads not being made, although the data is still stored. This data was downloaded when communication with the site is restored.

A3.4.24 ***Timing of calibrations:*** The NOx and VOC analysers were calibrated over a period of 30 minutes from 01:00am every morning. During this period the data was flagged as invalid.

A3.4.25 ***Insufficient data:*** The resolution of data storage is 15 minutes. These values need to be converted to concentrations averaged over 1 hour or 24 hour periods for comparison with air quality standards and guidelines. A valid 1 hour mean concentration was only calculated if three or four of the 15-minute mean concentrations are available. A valid 24 hour mean concentration was only calculated if 75% or more of the 15-minute mean concentrations are available - i.e. if 72 or more values are available in a 24 hour day (data recorded from 00:00 to 23:45 on that day). This exceeds the requirements of the Air Quality Limit Values Regulations (2003) Statutory Instrument 2121, which requires 50% data capture for a valid 24 hour mean calculation to be performed.

A3.4.26 ***Visual inspection of data:*** The data set was graphed and inspected visually. Values which follow an unexpected pattern (e.g. constant value over an extended period; data below zero for an extended period) were investigated as follows:

- If the instrument performance at the time of the measurement was not within specification, the reading was rejected
- If the value was known to be an instrument output indicating an error, the reading was rejected
- Raw data flagged as “No Data” by the system indicates a problem either with one particular instrument or if noticed across all outputs was indicative of a power outage requiring a system re-set. Calibration data flagged as “Not Valid” was inspected as this may also indicate instrument problems (eg low calibration gas pressure).
- Data following an unexpected pattern occurring immediately before or immediately after a period of invalid data for some other reason were excluded.
- If there are no other indications that the value was invalid, it was accepted

Calculation of derived concentrations

A3.4.28 The concentration of nitrogen dioxide was obtained by subtracting the concentration of nitric oxide from the concentration of oxides of nitrogen. This step was only carried out if valid measurements were available for both nitric oxide and oxides of nitrogen. The resultant values were passed through the validation procedure.

Appendix 4 : Method for estimating emissions and exposure to air pollutants

This method statement sets out the methods used for the analysis of air monitoring data obtained during the course of R&D Project P1-396, “Exposure Assessment of Landfill Sites.”

Although estimates of population exposure were developed using this method, it was found that these were not sufficiently reliable to use in the study. Consequently, the information presented in Volume 1 does not use the methods described in this Appendix.

INTRODUCTION

The monitoring programme produces three kinds of data:

- Continuous monitoring data
- Discrete sampling/lab analysis data
- Meteorological data

The project aim was to evaluate exposure to emissions from the landfill sites being studied. These are referred to as Sites A and B. To do this, five steps were needed:

- Step 1 : Verification/rectification of data

  This provides a reliable dataset for use in the study, and is a standard step in processing data from continuous analysis equipment.

- Step 2 : Evaluation of site contribution to measured levels of pollutants
- Step 3 : Dispersion modelling

  This provides an assessment of the contribution of the site to airborne and deposited levels of pollutants in the local environment

- Step 4 : Exposure assessment

  This provides an assessment of the exposure of the local population to the modelled levels of pollutants due to emissions from the landfill sites.

- Step 5 : Health risk assessment

  This provides an evaluation of the significance of these emissions for the health of the local population

The method statement for steps 2 to 4 is provided in this appendix. The method statement for Step 1 is provided in Appendix 3 above. The method statement for Step 5 is provided in Appendix 11.

A4.1 STEP 2 : EVALUATION OF SITE CONTRIBUTION TO MEASURED LEVELS OF POLLUTANTS

Although estimates of population exposure were developed using this method, it was found that these were not sufficiently reliable to use in the study. Consequently, the information presented in Volume 1 does not use the methods described in this section.

A4.1.1 The monitoring phase of the project produced continuous monitoring data; discrete monitoring data, and meteorological data. This section describes how the discrete monitoring data from the monitoring phase were analysed to identify evidence for a contribution from the site to levels of air pollutants. Section 4 describes the method by which public exposure to emissions from the landfill sites was estimated from the measured site increments.

A4.1.2 Meteorological data to assist in carrying out this analysis were taken from the on-site monitoring station. These data were supplemented by measurements of cloud cover and atmospheric pressure taken from a nearby Meteorological Office weather station.

Site A: [Not identified to protect site confidentiality]

Site B: [Not identified to protect site confidentiality]

A4.1.3 The majority of measurements were taken in pairs. One sample was taken at the monitoring station to the north east of the site; the other sample was taken at the monitoring station to the south-west of the site.

Landfill Source Term

A4.1.4 The dispersion model was used to establish a source term for each measured substance. From this source term, an estimated environmental level of each substance due to emissions from the landfill site can be derived (see section 4 below). In summary, the source term was estimated by modelling emissions from the likely source(s) of each determinand during each period for which data was available. Comparing the measured increase in concentration at the monitoring station with the modelled concentration at this point for a given release rate enables an estimate of the release rate of the determinand from the site sources during the period to be made. A statistical evaluation of the estimated release rates provides an indication of the variability in release rates from the site over the study period.

A4.1.5 The source term estimation steps are set out in Table A4.1.1, and described in more detail below.

Table A4.1.1 : Estimation of Source term: Overall Method

Step	Description
1	Identify source for each measurement (Combustion [Flare or Engine], Fugitive or Tipping)
2	Assign release rate of 1 g/s
3	Use atmospheric dispersion model to give concentrations of released substance at upwind and downwind monitoring station based on assumed 1 g/s release rate
4	Classify measurement pair: **Class A:** One modelled concentration = 0; one modelled concentration > 0 **Class B:** Both modelled concentrations > 0 **Class C:** Both modelled concentrations equal or close to 0
5	If this measurement is in Class C, proceed to next measurement
6	If measurement in Class A or B, estimate actual release rate giving rise to measured concentration; and estimated background level for measurement period. $rr = 1g/s \times \frac{m_1 - m_2}{p_1 - p_2}$ (see below) $bgd = \frac{p_1 m_2 - p_2 m_1}{p_1 - p_2}$ (see below)
7	If a negative value obtained for release rate, this suggests that the main effect on levels of the substance at the site was the dilution of concentrations due to emissions from a separate upwind source. The site itself had a negligible or zero impact on environmental concentrations. In this case, assume a site contribution of zero.
8	Scale estimated release rates by consideration of continuous monitoring data
9	Cross-check estimated release rates using data obtained from other sources Note if the derived value is an upper limit based on instrumental detection limit

Identify sources

A4.1.6 The most likely source of the substance was identified. This allows the nature and location of the source which will be used in the dispersion modelling component of the study to be specified.

Table A4.1.2 : Assumed substance source types

Combustion source (engines and/or flare)	Fugitive landfill gas source	Tipping source
Dust/Metals [1] Dioxins and furans PCBs PAHs	Dust/Metals [1] VOCs	Dust/Metals [1] Mineral fibres Micro-organisms

Note 1: Dusts and metals were evaluated on the basis of emissions from all three source types. The source description providing the least variability in modelled dust/metal emission rates was adopted as the best representation of dust and metal emissions

A4.1.7 The sources operating at the landfill sites during the intensive monitoring surveys were as follows (note that NGR co-ordinates are not given in full, to protect site confidentiality):

Table A4.1.3 : Sources operating during intensive monitoring surveys

Site	Intensive survey dates	Combustion source	Tipping source	Fugitive landfill gas source[1]
Site A	27 November – 24 December 2001	Engines (*ax*0128, *ay*7681) (*ax*0136, *ay*7682)	(ax0450, ay7690)	(ax0420, ay7740) (ax0500, ay7700) (ax0460, ay7640) (ax0380, ay7670)
Site A	21 July – 22 August 2003	Engines (*ax*0128, *ay*7681) (*ax*0136, *ay*7682)	Phase 3 (ax0196, ay7666)	(ax0145, ay7687) (ax0208, ay7721) (ax0245, ay7647) (ax0182, ay7616)
Site B	23 January 2002 – 18 February 2002	Flare (*bx*0811, *by*9998)	(bx0960, by9620)	(bx0860, by9660) (bx1060, by9660) (bx1070, by9550) (bx0850, by9560)
Site B	9 June 2003 – 11 July 2003	Engines (bx0665, (by+1)0117) (bx0665, (by+1)0120) Flare (bx0665, (by+1)0105)	(bx0890, by9780)	Model area 1 (bx1030, by9760) (bx0980, by9740) (bx0960, by9800) (bx1005, by9805) Model area 2 (bx0980, by9740) (bx0805, by9740) (bx0770, by9820)

Site	Intensive survey dates	Combustion source	Tipping source	Fugitive landfill gas source[1]
				(bx0930, by9850)

Note 1: These areas were identified as the key sources of gas emissions in the surface emissions monitoring campaign.

Assign release rate

A4.1.8 A release rate of 1 gram per second was assigned to each source. The other model parameters used for each source were as follows. Release temperature, velocity and diameter information was taken from the emissions monitoring surveys carried out as part of this project:

Table A4.1.4 : Model parameters (Site A)

Parameter	Engine exhausts	Fugitive landfill gas source	Tipping source
Co-ordinates of north-east monitoring station	(*ax*0271, *ay*7848)		
Co-ordinates of south-west monitoring station	(*ax*0109, *ay*7625)		
Release temperature	550 ^{o}C	25 ^{o}C	10 ^{o}C
Release velocity (metres per second)	22.7 m/s	Nil	Nil
Release diameter (metres)	0.4 metres	Not applicable	Not applicable
Equivalent release rate in grams per square metre per second	Not applicable	2.75×10^{-4} g/m^2-s (Nov-Dec 2001) 1.67×10^{-4} g/m^2-s (Jul - Aug 2003)	Not applicable
Surface roughness (metres)	0.25 metres (agricultural area)		

Table A4.1.5 : Model parameters (Site B)

Parameter	Flare	Engine	Fugitive landfill gas source	Tipping source
Co-ordinates of north-east monitoring station	(*bx*0929, *(by+1)*0020)			
Co-ordinates of south-west monitoring station	(*bx*0577, *by*9707)			
Release temperature	1000 ^{o}C	550 ^{o}C	25 ^{o}C	10 ^{o}C
Release velocity (metres per second)	3.0	22.7	Nil	Nil
Release diameter (metres)	1.0 metres	0.4 metres	Not applicable	Not applicable
Equivalent release rate in grams per square centimetre per second	Not applicable	Not applicable	5.2×10^{-5} g/m^2-s (Jan-Feb 2001) 5.4×10^{-5} g/m^2-s (Jun-Jul 2003)	Not applicable
Surface roughness (metres)	0.25 metres (agricultural area)			

Note: The equivalent release rate is calculated to provide a release rate of 1 gram per second from the area source

Model emissions

A4.1.9 The atmospheric dispersion of emissions from the relevant source type were modelled over the sample period for each measurement. This varied from 3-6 hours for the VOC samples to 72 hours for the dioxin and furan, PCB and PAH measurements. Concentrations were modelled at the north-east and south-west monitoring stations. The atmospheric dispersion model UK-ADMS was used for the modelling study.

Classification of measured values

A4.1.10 The next stage was to classify each pair of measured values as follows.

- A: Modelled contribution from site greater than zero at one monitoring station, and zero at the other monitoring station
  Can be used to evaluate landfill contribution

- B: Modelled contribution from the site greater than zero at both monitoring stations
  Can be used to evaluate landfill contribution

- C: Modelled contribution from site equal or close to zero at both monitoring stations. "Close to" zero was defined as being less than 5% of the average modelled contribution. This constraint was introduced to eliminate estimates based on measurements which are on the edge of the modelled plume of emissions from the site. These will give estimated exposure levels which are subject to greatest uncertainty when this method is applied, and are likely to artificially increase the estimated exposure due to emissions from the site
  Cannot be used to evaluate landfill contribution

A4.1.11 It was also noted whether the measured values at the monitoring stations are "positive detections" (that is, measurements above the limit of detection of the sampling/analytical technique), or "upper limit values" (that is, theoretical values derived from the detection limit of the sampling and analytical procedures)

Identify contribution from site

A4.1.12 For measurements in Classes A and B, the actual release rate giving rise to the measured concentrations was estimated as follows. It is assumed that the actual process contribution from the site to measured levels at each monitoring station is in the same ratio as the modelled contribution. It is also assumed that the background level at each monitoring station is the same. That is,

$$\frac{\text{Contribution from the landfill site at station 1}}{\text{Contribution from the landfill site at station 2}} = \frac{\text{Predicted concentration at station 1}}{\text{Predicted concentration at station 2}}$$

A4.1.13 The contribution from the landfill site is equivalent to the measured concentration minus the background concentration. That is,

$$\frac{m_1 - b}{m_2 - b} = \frac{p_1}{p_2}$$

$$m_1 - b = \frac{p_1}{p_2}(m_2 - b) \qquad \text{Solving for b:} \qquad b(\frac{p_1}{p_2} - 1) = \frac{p_1}{p_2} m_2 - m_1$$

$$b = \frac{p_1 m_2 - p_2 m_1}{p_1 - p_2}$$

where

b: background concentration (µg/m^3)

m_1: measured concentration at monitoring station 1 (µg/m^3)

m_2: measured concentration at monitoring station 2 (µg/m^3)

p_1: predicted [modelled] concentration at monitoring station 1 (µg/m^3) based on 1 g/s release rate

p_2: predicted [modelled] concentration at monitoring station 2 (µg/m^3) based on 1 g/s release rate

A4.1.14 The contribution from the landfill site to measured levels at monitoring stations 1 and 2 is given by the predicted concentration based on 1 g/s release rate multiplied by the actual release rate. That is,

$$m_1 - b = rp_1 \qquad m_2 - b = rp_2 \quad \text{Eliminating b gives}$$

$$r = 1g/s \times \frac{m_1 - m_2}{p_1 - p_2}$$

where

r: release rate (g/s)

b: background concentration (µg/m^3)

m_1: measured concentration at monitoring station 1 (µg/m^3)

m_2: measured concentration at monitoring station 2 (µg/m^3)

p_1: predicted [modelled] concentration at monitoring station 1 (µg/m^3) based on 1 g/s release rate

p_2: predicted [modelled] concentration at monitoring station 2 (µg/m^3) based on 1 g/s release rate

A4.1.14 For measurements in Class A, p_2 is equal to zero. In this case, the estimated release rates and background levels reduce to:

$$r(ClassA) = 1g/s \times \frac{m_1 - m_2}{p_1}$$

$$b(ClassA) = m_2$$

No detectable increment from site

A4.1.15 If a negative value was obtained for release rate, this suggests that the main effect on levels of the substance at the site was the dilution of concentrations due to emissions from a separate upwind source. The site itself had a negligible or zero impact on environmental concentrations. In this case, it was assumed that the site contribution to levels of air pollutants was zero.

Estimate and scale release rate for study period

A4.1.16 The procedure outlined above provides a number of estimated release rates for each component. The number of these release rates varies from substance to substance because of differences in the detected levels of different substances. In some cases, a zero value is reported, as set out above.

A4.1.17 During the measurement campaigns, levels of emissions may have been higher or lower than those occurring during the year as a whole. An allowance was made for this by considering the measured concentrations of non-methane hydrocarbons, oxides of nitrogen and PM_{10} during the measurement campaigns compared to the levels recorded during the year as a whole. The estimated emissions rates of substances emitted from combustion sources were scaled by the ratio of measured levels of NO_x during the measurement campaign to measured levels of NO_x during the study as a whole. Similarly, measured levels of total hydrocarbons were used to scale estimated release rates of substances emitted in fugitive gas, and measured levels of PM_{10} were used to scale estimated release rates of substances emitted from tipping operations.

A4.1.18 The mean, 25th percentile, median (50th percentile), 75th percentile 95th percentile and maximum (100th percentile) of estimated release rates for each substance was reported. Subsequent analysis was based on the median, mean and 95th percentile values. A comment was also provided as to the number of estimated values, and a qualitative review of the data, including a comment on the prevalence of data in classes A, B, C and F and any consequences for confidence in the values. Any unusually high or low values were noted. The application of the forecast values for the intensive survey periods to the annual pattern of measurements around the sites was evaluated by considering the continuous monitoring data. Estimated emissions of combustion products were scaled by the ratio of measured annual NOx levels to measured NOx levels for the intensive survey period. Similarly, forecast emissions of substances associated with fugitive gas emissions were scaled by considering measured levels of total hydrocarbons. Forecast

emissions of substances associated with tipping operations were scaled by considering measured levels of PM_{10}.

A4.1.19 For some measurements, it was possible to provide a cross-check using estimates of release rates obtained in other ways. Measurements of flare and engine emissions were carried out during February 200A4.1. Measurements of the constituents of landfill gas were carried out in December 2001/January 2002 and February/March 200A4.1. These can be combined with calculated release rates of landfill gas using the Gas-sim model and information on the volume of gas collected and burnt to provide an estimated release rate of volatile organic compounds. The estimated release rates were compared with these measured values.

A4.2 STEP 3 AND STEP 4 : EVALUATION OF LANDFILL SITE CONTRIBUTION TO PUBLIC EXPOSURE

Although estimates of population exposure were developed using this method, it was found that these were not sufficiently reliable to use in the study. Consequently, the information presented in Volume 1 does not use the methods described in this section.

A4.2.1 The outcome of the analysis in Chapter 3 was an estimated release rate of the substances under consideration due to emissions from the landfill site. While this is of interest in itself, the overall objective of the project is to estimate public exposure to released substances. The source term data was therefore used in a further modelling study to evaluate the dispersion of released substances over the area surrounding the landfill site.

A4.2.2 The ADMS version 3.1 atmospheric dispersion model was used as in the evaluation of release rates set out in chapter 3. The study inputs were as follows:

Table A4.2.1 : Atmospheric dispersion model for exposure assessment: input parameters

Parameter	Site A	Site B
Flare, engine and area source parameters	As Table 3.3 and 3.4	As Table 3.3 and 3.5
Release rates	Mean, median and 95th percentile estimated values calculated previously	
Meteorological data	Site specific measurements supplemented by data from Meteorological Office for one 12 month period	
Surface roughness (metres)	0.25 metres (agricultural area)	0.25 metres (agricultural area)
Receptor locations	Grid of receptors extending 2 km in each cardinal direction from centre of site (*ax*0240,*ay*7737) Grid of receptors extending 7 km in each cardinal direction from centre of site (*ax*0240,*ay*7737) Specific local receptors	Grid of receptors extending 2 km in each cardinal direction from centre of site (*bx*0753,*by*9864) Grid of receptors extending 7 km in each cardinal direction from centre of site (*bx*0753,*by*9864) Specific local receptors
Complex terrain	64 x 64 terrain grids extending 3 km and 10 km from the site, obtained from OS data	Flat site, no terrain data needed
Deposition calculations	Long-term mean deposition rates calculated for particulate bound substances (metals and micro-pollutants), using ADMS module to calculate dry	

Parameter	Site A	Site B
	deposition velocities based on a particle size of 10 μm.	
Model averaging times	Long-term mean, 95th percentile hourly mean, maximum hourly mean, maximum 24 hour mean	
Reported values	Maximum value in 0 - 2 km grid zone, maximum value in 2 – 7 km grid zone, values at nearby properties All averaging times, all substances, all release rates.	

A4.2.3 The study outcome was a set of airborne concentrations and deposition rates in the vicinity of the two sites under consideration. These concentrations were used in the health impact assessment, described separately. The concentrations used in the health impact assessment are those based on the median estimated release rate. The health impact assessment also refers to the possible health consequences of releases at the 95th percentile estimated release rate.

A4.2.4 The approach adopted in this study resulted in the highest estimated concentrations being greater than the incremental concentrations measured at the site boundary. This was because the monitoring station may not be directly downwind of the site, nor at the distance where highest concentrations were forecast. Under these circumstances, the highest estimated concentrations would be expected to be higher than the measured incremental concentration. At other locations, in particular locations further from the site or those not lying downwind of the prevailing wind direction, estimated exposure due to emissions from the site is much lower than at locations close to and downwind of the site.

A4.2.5 As a cross-check on the model results, the maximum modelled airborne concentration levels were compared with measurements made at the tipping face and the additional boundary fence measurements made in February/March 2003. These points represent the maximum conceivable exposure levels that could arise, to members of the site workforce.

Uncertainty

A4.2.6 This approach to estimating exposure to emissions from the landfill site is subject to uncertainty, and necessarily makes a number of inherent assumptions. The use of a two-stage monitoring procedure (from the monitoring station to the source; and from the source to environmental exposures) means that some of the uncertainties of atmospheric dispersion modelling will cancel out. If the model over-estimates the source term required to give rise to an observed incremental concentration, it is likely to give a corresponding underestimate of the concentrations that would arise from that source term at other receptors. This situation will result in an estimated source term which is higher than the true value, but estimated environmental concentrations which are a good estimate of the true value.

A4.2.7 The key assumptions were:

- It was assumed that the substances are released from the sources specified in Table A4.2.2 in Appendix A4.1.

- It was assumed that the descriptive parameters for the sources specified in Tables A4.2.3, A4.2.4 and A4.2.5 are a good representation of these sources.

- It was assumed that the atmospheric dispersion model provides a reliable representation of dispersion of emissions from the landfill sites. The approach adopted in this study of working back from measured data to give a source term, and then working forward from the source term to give estimated environmental concentrations reduces the possible influence of model uncertainties, as these will tend to cancel out during the modelling procedures.

A4.2.8 The key uncertainties are as follows:

- Uncertainty in modelling

- Uncertainty in measurement

- Variability in different estimates of landfill emission rate, and variability in the actual emission rate over time

A4.2.9 These uncertainties are reflected in the forecast model exposure values. Each final result is provided with an uncertainty estimate, and an evaluation of the data pedigree. This is an indication of the confidence of the data estimates based on a consideration of:

- 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?

A4.2.10 The formulae set out above indicate that uncertainty in estimated contribution from the site will be greatest when the modelled concentrations at the north-east and south-west monitoring stations are similar. Under these circumstances, relatively small inaccuracies in these values could result in relatively large uncertainties in the estimated concentrations due to emissions from the site, and also in estimated background concentrations. This is most likely to arise when the modelled concentration at one monitoring station is a small value, and at the other monitoring station is zero. These values were excluded from the data analysis, on the basis that it is not possible to reliably identify a site contribution from the measured and modelled values.

Appendix 5 : Groundwater Risk Assessment

A5.1 Groundwater Risk Assessment: Site A

1. Introduction

The base of Site A is above ground water 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. All water which enters the wastes will become leachate and need to be managed to ensure no significant adverse impacts arise.

Any liquid wastes which may have entered the landfill would also contribute to the generation of landfill leachate.

Water borne emissions are normally controlled by:

- routeing 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
- Treatment of leachate followed by consented discharge.

Wastes will degrade and produce gas and leachate over many decades. Leachate generation is a combination of degradation, and flushing through water circulation. Wastes will biodegrade and dissolve in water over many decades. The less water that enters the site the longer this period will be but emissions will be more dilute. In addition, while travel times to potential receptors are rapid for surface water runoff, movement into and through the geosphere may be slow depending upon the specific landfill construction and geology and hydrogeology of the site.

1.1 Approach

A human health risk assessment requires that a conceptual model of the site is derived identifying the nature of the source for water borne emission, the potential receptors and pathways to these receptors. This requires collection of existing information from the landfill operator and regulator. Where this is not available or incomplete there will be a requirement to collect direct information or adopt a rationale for estimating the exposure of humans to direct or indirect water borne emissions from landfill. This information is formulated into a conceptual model of the site to understand the exposure pathways of humans to water borne emissions.

The conceptual model was used as the basis for quantifying the human exposure to water borne emissions from the landfill, either direct such as surface or groundwater abstraction for potable supply, or indirect through the food chain. Indirect exposure could occur if, for example, potentially contaminated water were to be used for irrigation of vegetables or as drinking water for farm animals. The loading of contaminants reaching identified receptors was assessed as part of this study.

1.2 Methodology

The methodology is based on:

- collection of information for each site and development of conceptual model;
- quantification of the likely exposure;
- assessment of the significance of this exposure.

1.3 Information Sources

Information has been obtained for the following items from the sources indicated:

1.3.1 Information on sources/hazards

- Site history and practices
- Waste types
- Surface water management
- Engineering barrier system (EBS)
- Leachate quality (site specific or UK database)
- Leachate control
- Leachate treatment/disposal

} Site operator

1.3.2 Information on pathways

◆ Leakage through EBS	Site operator
◆ Geology	Published maps and site operator
◆ Hydrogeology	Published maps and site operator
◆ Aquifer status	EA web site
◆ Licensed abstractions	Site operator
◆ Unlicensed abstractions	Farm studies report
◆ Location of springs	Published maps
◆ Hydrology	Published maps and EA
◆ Water level and quality monitoring data	Site operator

1.3.3 Information on receptors

- Groundwater abstraction, treatment and use (particularly private supplies)
- Surface water abstraction, treatment and use

} Site operator

- Via food where water used for stock drinking/irrigation. Farm survey report

Much of this information for Site A was available in public domain within permit application documents for part of the site although this provided processed rather than raw data.

A site walk-over was also undertaken to gain a better understanding of the area and how the landfill interacts with the hydrological regime.

1.4 Quantification of Exposure

The extent of any exposure of human receptors to water borne emissions from the landfill have been quantified or estimated to the extent that the data allowed. This has required assessment of, for instance the quality of leachate entering groundwater, the affects of retardation, attenuation and degradation within the geosphere, concentrations at the receptor and the potential for intake at each receptor.

The concentration of the receptors were either measured concentrations or estimated concentrations based on presumed concentrations in leachate and calculated dilution rates. Models to estimate leakage of leachate and fate and transport in the geosphere can be used to further quantify exposure, if appropriate. At Site A, the results and the data made available to Enviros did not support the use of models in this way.

1.5 Comparison with Other UK Landfill Sites

Health based assessments of other UK landfill sites are extremely limited. However we have used our knowledge of landfill site settings to indicate whether the sources, pathways and receptors are representative of UK landfill sites.

2. Site sensitivity

The key features of Site A which affect sensitivity to potential releases via groundwater are discussed in this section.

2.1 Topography

Site A is located at the top of a large hill, with a valley to the east and steep slopes downward to the north. The land to the west slopes more gently downwards with no appreciable surface water feature. To the south is a broad valley.

The central part of the hill has been quarried, leaving a void in the centre which is completely surrounded by inwards facing cliff faces. Part of this area is being used as the landfill.

A river runs south west to north east in the broad valley to the south of the site before changing course to run south to north along the valley to the east of the site.

There are considerable changes in relief across the landfill and surrounding area. Between the landfill and the valley to the east is a steep slope with rocky outcrops. Slopes to the south and west are more gentle.

The topography to the north of the site has been affected by quarrying activities. This has resulted in a steep sided quarry immediately to the north of the landfill, with a lagoon in the base. The land then slopes gently down to the north. Between this void and the landfill is a narrow ridge of rock which was part of the original hill.

2.2 Geology

Areas surrounding the site are partially overlain by drift deposits. These comprise Boulder Clay to the east and north east of the site (Ref. 2) in the base and on the sides of the river valley. These have been removed from the landfill area by the former quarrying activities. In the river valley, river gravels and alluvium are also present.

The underlying solid geology comprises limestone. In the quarry, a number of units within the limestone are exposed. These have partially been obscured by the landfill operations within the northern part of the quarry.

Limestone is a dual porosity stratum where both intergranular flow can occur between the grains forming the rock and fracture flow occurs in the joints that develop along the bedding planes and other lines of weakness. In the Carboniferous Limestone, much of the intergranular permeability has been reduced over time such the majority of flow occurs through the joints. This can occur very rapidly with little capacity for attenuation through interaction with the rock matrix.

The limestone beds dip locally at approximately 15^{o} towards the north-north-east. There are four faults located within the vicinity of the site, which have been taken into account in carrying out this risk assessment. Faults can act as enhanced fractures with associated reduced groundwater travel times. Conversely, fault gouge (a rock flour developed as faults slip) can be formed which significantly reduces the permeability of the fault.

Fault 1 is considered to have the greatest influence on the site and is considered a preferential flow path as the natural extension intersects the valley close to a surface water feature (Ref. 3). In view of this, landfilling operations are restricted above the fault.

2.3 Hydrogeology

The native strata are classified as a “major aquifer” (Ref. 4) which is typically highly permeable strata with significant fracturing and which may be highly productive and able to support large abstractions for public and other purposes.

Available evidence indicates that fracture flow is the dominant flow mechanism within the strata. Preferential flow paths, for example along faults or joints, have been confirmed by tracer tests carried out on-site. These are discussed in more detail below.

Despite the Limestone being classified as a Major Aquifer, the Environment Agency has confirmed that there are no licensed groundwater abstractions, or Source Protection Zones, within the vicinity of the site. However, registered private abstractions are located 400m to the north east and 750m to the south east of the Landfill.

2.3.1 Groundwater Flow

Leachate seeping through the liner in the base and sides of the landfill will firstly flow through unsaturated zone above the water table. The direction of flow will be affected by preferential flowpaths in the strata including the fracture network. Consequently, at Site A the unsaturated flow has a lateral component as well as a component downwards.

Groundwater levels have been monitored at a number of locations since the start of landfilling operations. Groundwater level data indicates that the depth to groundwater is in excess of 120m from the top of the landfill. On the lower ground to the north east of the landfill, groundwater levels are close to the

surface (less than 1m in some areas) and groundwater emerges at the spring in the valley side to the east of the landfill. Analysis of this groundwater level data has concluded that:

- from the southern area of site, the general groundwater flow direction is towards the river valley to the east and the sea to the north. Groundwater flows under the northern part of the site are more specifically towards the north east
- a wide range of groundwater levels have been recorded at the site. The highest recorded range of groundwater levels is over 50 m is considered due to its proximity to a preferential flow path;
- other boreholes show less seasonal variation, which could be due to their being located within poorly connected diffuse zones; and
- the landfill lies above the natural water table and so no groundwater management systems are required for this site.

2.4 Hydrology

The main surface watercourse within the vicinity of landfill is located approximately 500m to the east of the site, and flows from south to north. An unnamed tributary of the river, which flows in a north easterly direction, is located over 1 km to the south of the site

Flow within the river is not regularly gauged, however Reference 3 reports that the Environment Agency have estimated the mean flow of the river as 0.68 m^3/s.

Indicative maps, presented within the Environment Agency's website, suggest that the indicative floodplain associated with the river is extremely limited and that the landfill does not lie within this.

2.4.1 Surface Water Quality

Between 2000 and 2002, the Environment Agency classified the river downstream of the site as having "fair" water quality. The reasons for this classification were that the biological oxygen demand (BOD) was not complaint with the river quality objective and compliance for ammonia concentrations was marginal. The concentration of nitrate in the river during this period was classified as moderate or moderately low and the phosphate concentration was low.

3. Landfill Operation

Quarrying at the site began over 100 years ago, with mineral extraction moving progressively southwards. The first phase of the landfill is located in the north eastern corner and tipping commenced during 1983 and was completed during 1994. Further over-tipping operations occurred in this area during the latter part of 2001 and early part of 2002, in order to create the appropriate restoration contours. The lining comprised a 1m thick engineered seal constructed from silt obtained from the quarry lagoons. This was augmented with an overlying geomembrane for the later tipping operations. The seals were extended up the quarry walls as tipping proceeded. Works associated with the over-tipping allowed previously unrestored areas of this phase to be capped and restored with the works managed in accordance with Construction Quality Assurance (CQA) procedures.

The next phase of the landfill is located further to the south. Tipping began in 1994 in three cells and has recently been completed. The basal liner comprises

1m of engineered clay beneath a geomembrane. The geomembrane is terminated part way up the quarry walls. The lining system for the walls beneath this point comprises the engineered clay and geomembrane system described above constructed on 1:1.5 batters. Above the point where the geomembrane terminates, the sidewalls are lined with clay to a thickness of 1 metre. The sidewall liner was constructed of engineered clay, emplaced in 2m lifts. These engineering works have been undertaken in accordance with CQA procedures. This phase is currently being capped.

The third phase commenced during the latter half of 2002 and waste disposal operations are currently ongoing. The basal lining system is similar to that described for the second phase and this extends up the sidewalls of this Phase of the landfill. These works have again been undertaken in accordance with CQA procedures.

Leachate abstraction points have been included in all the phases. In the post-1994 cells, leachate drainage blankets have been installed. The current licence states that the leachate head should be limited to 1m or less in the first and third phases, and 2m or less in the second phase. This is managed by pumping excess leachate to a leachate treatment plant on the site. After treatment, leachate is discharged to sewer under a trade effluent discharge consent.

Annex 1 contains further details about the landfill construction.

At the time of the study, the site was licensed to receive municipal and commercial wastes together with some Difficult and Special Wastes, such as contaminated soils, incinerator residues and sewage sludge. During 2002, the annual waste input was approximately 160,000 tonnes of which 35,000 tonnes was inert waste. Small quantities (ie <1%) of hazardous waste (asbestos) have been accepted. The management of asbestos and other hazardous materials is governed by the terms of the waste management licence for the site.

4. Leachate, groundwater and surface water quality data

4.1 Data

Information on groundwater, surface water and leachate quality was provided by the landfill operator. This was collected from a number of points since 1995. The data was supplied as electronic files created from the operator's database.

4.1.1 Leachate

Leachate has regularly been sampled for chemical testing from a number of sample locations. Leachate quality is summarised in Annex 2. The chemical measurements are reasonably comprehensive and include limited analysis of some organic contaminants. The data was summarised to indicate the range of concentrations measured and the median and mean concentrations. Annex 2 also includes leachate quality data from the database in Reference 6 which includes analyses from up to 67 landfill sites for 27 substances.

4.1.2 Groundwater

Groundwater quality data has also been measured from a number of points, both upstream and downstream of the Site. This data is summarised in Annex 3. At one point, groundwater comes close enough to the surface for there to be a potential human exposure route. This could occur if individuals carry out private abstraction of water for consumption, or if groundwater feeds into surface watercourses which are then used for fishing or other recreation. The measured chemical levels in groundwater at this point were used as representative of downstream groundwater quality, although this represents a simplification of the

complex groundwater flows in the local area. At this location, two boreholes are adjacent to each other and their data has been combined to form one data set.

A number of boreholes are also located on the upstream (south) side of the landfill. Water quality data from one borehole is more comprehensive than for the others. This has been used as an indicator of the upstream groundwater quality.

4.1.3 Surface water

Surface water quality has been measured at locations in surface water features to the east of the Site. This data is summarised in Annex 4.

4.2 Identification of significant contaminants

The groundwater and surface water data has been screened to assess whether the concentrations of parameters measured are significant with respect to toxicological effects on humans. In the first instance, the Drinking Water Standards (Ref. 7) have been used for those parameters where a permitted level is specified. Where not available, knowledge of similar systems has been used to identify elevated concentrations. Gross indicators (eg Biological Oxygen Demand, conductivity etc) have not been included in this assessment as more specific data are available. It should also be noted that an extensive suite of organics was measured but none of the parameters were present above their detection level with the exception of phenol which is included in Table 4. Exceedences / elevated levels are shown in Tables 3 and 4 and are discussed in more detail below.

4.2.1 Leachate

A direct comparison of the concentration of determinands in the leachate with leachate quality or drinking water standards would not provide useful information on likely human exposures. In the following two sections discussing the chemical quality of both the groundwater and surface water, where concentrations of determinands in groundwater have found to be indicative of a possible contribution from the site, the measured levels have been evaluated to determine whether a possible link between site emissions and groundwater could exist.

4.2.2 Groundwater

Ammoniacal nitrogen was present in both the upstream and downstream boreholes at concentrations above the Drinking Water Standard. The elevated concentration in the upstream borehole indicates that there is a source of ammoniacal nitrogen upstream of the landfill. This could be contributing ammoniacal nitrogen directly to the groundwater or the ammoniacal nitrogen may be the result of reducing conditions in the aquifer reducing nitrate to ammoniacal nitrogen. Nitrate concentrations in the upstream borehole do vary from 2.8 mg/l as N to 9.7 mg/l as N, with a median concentration of 6.0 mg/l as N. The lower levels may indicate that some localised nitrate reduction is occurring.

Median concentrations of ammoniacal nitrogen in the downstream borehole are slightly higher than those in the upstream borehole. Leachate from the landfill contains high levels of ammoniacal nitrogen and may be contributing to the elevated concentrations observed in the downstream boreholes. However, this could also be due to other sources around the area or changes in the oxidation / reduction state of the aquifer which could affect the state of nitrogen compounds (ammoniacal nitrogen, nitrate etc). Nitrate concentrations varied from less than the detection limit to 6.2mg/l as N with a median concentration of 0.8 mg/l as N. The lower minimum and median concentrations indicate that some of the

ammoniacal nitrogen is derived from the reduction of nitrate. The reducing conditions could be the result of the leachate entering the groundwater as leachate typically has a significant oxygen demand.

Iron and manganese were present in the downstream borehole at higher concentrations than upstream. The median concentrations of iron and manganese found in the downstream boreholes were similar to those measured in the leachate. Considering that some dilution is likely between the leachate generation point and the downstream borehole, the concentrations found in the downstream groundwater are unlikely to be solely derived from the leachate. The Carboniferous Limestone is often mineralised with iron and manganese bearing minerals and these are likely to be providing a second source of these determinands as this aquifer. Furthermore, metals tend to be more mobile in acidic conditions and are not particularly mobile in the alkaline conditions which prevail in limestone. Metals in the leachate are therefore likely to be partially precipitated during transport through the limestone and the elevated iron and manganese results observed in the downstream boreholes are therefore likely to be derived from both the leachate and the aquifer itself.

The other metals present in the groundwater sample are unlikely to be derived from the landfill. Median concentrations are similar between the upstream and downstream boreholes and in some instances are higher in the upstream borehole. As discussed above, the metals could also be derived from minerals commonly found in limestone and alkaline conditions in the aquifer are not conducive to transport from beneath the landfill to the measurement point.

4.2.3 Surface water

In the river water samples, the maximum concentrations of the determinands listed in Table A5.3 are mostly greater in the downstream sample than in the upstream. However, the median concentrations are similar and in some cases (eg nickel) greater in the upstream samples.

The median concentrations of sodium, alkalinity, potassium and ammoniacal nitrogen were greater or similar in the spring water than the upstream water samples. The concentrations in the spring water are also greater than in the upstream groundwater samples.

Metal concentrations in the spring water were generally lower than the upstream surface water. This latter observation is another indication that conditions are not conducive to metal transportation within the aquifer.

The data shows that whilst the levels of some substances found in landfill leachate are higher at the spring than at locations upstream of Site A, other substances are lower in the spring. In any case, the dilution of spring water afforded by the river is sufficient to result in increased concentrations in the spring water being undetectable in the river.

Table A5.2 : DWS Exceedences – Groundwater

	Units	Downstream boreholes						Upstream borehole						DWS
		max	min	median	mean	n	no. > DL	max	Min	median	mean	n	no. > DL	
Ammoniacal Nitrogen	mg/l N	3.3	<DL	0.9	-	33	30	3.8	<DL	0.7	-	24	14	0.39
Iron	mg/l	21.5	0.07	3.5	6.7	5	5	0.19	<DL	0.1	-	8	4	0.2
Iron (Dissolved)	mg/l	39.86	<DL	0.8	-	29	22	0.21	<DL	0.1	-	16	5	0.2
Manganese	mg/l	7.33	0.72	3.4	3.7	4	4	0.21	0.05	0.1	0.1	7	7	0.05
Manganese (Dissolved)	mg/l	5.5	0.39	1.0	1.3	29	29	0.094	<DL	0.036	-	16	15	0.05
Cadmium	mg/l	<DL	<DL	-	-	4	0	0.008	<DL	0.008	-	8	1	0.005
Lead	mg/l	0.03	<DL	0.02	-	5	2	0.12	<DL	0.02	-	9	7	0.01*
Lead (Dissolved)	mg/l	1.21	<DL	0.016	-	29	8	0.051	0.006	0.0085	0.0138	16	16	0.01*
Nickel	mg/l	0.024	<DL	0.02	-	5	1	0.077	<DL	0.007	-	8	1	0.02
Nickel (Dissolved)	mg/l	0.024	<DL	0.0085	-	29	8	<DL	<DL	-	-	15	0	0.02
Chromium	mg/l	<DL	<DL	-	-	2	0	0.074	<DL	0.07	-	4	1	0.05

Grey = exceed DWS
Hatched = elevated concentration
* - DWS from 2003 – 2013
** - compared to the DWS for mineral oil
italic – 1989 DWS

Table A5.3 : DWS Exceedences – Surface water

	Units	Downstream						Spring						Upstream						DWS
		max	min	mean	Median*	n	no. > DL	max	min	mean	Median*	n	no. > DL	max	min	mean	Median*	n	no. > DL	
Sodium	mg/l	29	12	20.0	19.0	21	21	1330	20.4	105.8	29.6	20	20	27	11	19.1	18.4	21	21	*150*
Potassium	mg/l	16	<DL	-	4.5	21	20	530	<DL	-	4.1	21	20	15	<DL	-	4.3	21	20	*12*
Alkalinity	mg/l CaCO3	140	9	77.4	76.0	21	21	3440	18.5	348.7	221.0	23	23	125	6.5	67.9	64.5	21	21	Not used
Ammoniacal Nitrogen	mg/l N	10.8	<DL	-	0.2	156	102	32.3	<DL	-	0.6	367	220	9.9	<DL	-	0.2	185	115	0.39
Iron	mg/l	7.6	<DL	-	0.39	51	24	6.18	<DL	-	0.09	60	29	6.3	<DL	-	0.35	50	23	0.2
Manganese	mg/l	0.55	<DL	-	0.03	19	8	0.54	<DL	-	0.01	20	7	0.39	<DL	-	0.03	19	8	0.05
Zinc	mg/l	0.11	<DL	-	0.0	51	17	20	<DL	-	0.0	61	16	0.05	<DL	-	0.0	50	10	*5*
Cadmium	mg/l	0.005	<DL	-	0.0045	18	2	0.5	<DL	-	0.006	20	3	0.5	<DL	-	0.2505	17	2	0.005
Lead	mg/l	0.18	<DL	-	0.01	19	4	0.07	<DL	-	0.01	20	3	0.08	<DL	-	0.01	18	3	0.01*
Mercury	mg/l	0.01	<DL	-	0.01	14	4	0.05	<DL	-	0.02	16	4	0.03	<DL	-	0.02	14	4	0.001
Nickel	mg/l	0.04	<DL	-	0.005	19	4	0.007	<DL	-	0.005	19	2	0.06	<DL	-	0.010	18	3	0.02
Chromium	mg/l	0.006	<DL	-	0.01	18	2	1.02	<DL	-	0.01	19	3	10.38	<DL	-	5.19	18	2	0.05
Phenol(monohydric)	mg/l	0.1	<DL	-	0.1	4	1	0.1	<DL	-	0	10	3	0.1	<DL	-	0.1	4	1	*0.0005*

Grey = exceed DWS
Hatched = elevated concentration
* - DWS from 2003 – 2013
italic – 1989 DWS

5. Conceptual model and risk assessment

5.1 Conceptual Model

Landfill risk assessment is based on development of a conceptual model for the site in question. This is a representation of the relationship between contaminant sources, pathways and receptors developed on the basis of hazard identification.

5.1.1 Sources, Pathways & Receptors

This study is limited to the potential effect of landfills on human health and only considers pathways via the groundwater. This limits the sources and receptors discussed to:

Source	Landfill leachate	Determinands identified as of concern from analysis of concentrations at receptors (ammoniacal nitrogen and metals) and other substances for which there is no data from the receptors (ie most of those identified in Ref. 6).
Receptors		Local inhabitants

There are a number of potential exposure routes which include groundwater. These are via:

- The spring emerging from groundwater within the Carboniferous Limestone aquifer to the east of the site;
- Contact with groundwater just below the ground surface. This occurs 650m NNE of the Site, within the local village;
- Surface water partially fed by groundwater in the river to the east;
- Products from livestock who may come into contact with the surface water.

5.2 Qualitative Risk Assessment

A qualitative risk assessment has been undertaken for these potential source-pathway-receptor linkages based on DEFRA (Ref.) and CIRIA guidance (Ref.). This is based on consideration of both:

- the likelihood of an event (probability – takes into account both the presence of the hazard and receptor and the integrity of the pathway);
- the severity of the potential consequence (takes into account both the potential severity of the hazard and the sensitivity of the receptor).

Further information on the risk assessment methodology used is given in Annex 5.

Table A5.4 Qualitative Risk Assessment

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]	Unikely. Elevated concentrations observed. Linkage proved by previous studies, but consumption unlikely to occur	Low
			Migration via groundwater to surface followed by consumption of water	Effect on human health [Mild]	Unlikely. 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]	Low likelihood. Median concentrations in the stream similar downstream to upstream of the point where the spring discharges.	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]	Low Likelihood. Concentrations of metals in the spring are low.	Low
			Migration via groundwater to surface followed by consumption of water	Effect on human health [Mild]	Likely. Elevated concentrations observed but conditions in the aquifer may be contributing pollutant from other sources	Moderate / Low
			Surface water receiving groundwater discharge followed by fishing or consumption of surface waters	Effect on human health [Mild]	Low likelihood. Concentrations of metals in the spring are low. Concentrations in river are similar upstream and downstream.	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

Source	Pollutant	Receptors	Pathways to Receptor	Associated Hazard [Severity]	Likelihood of Occurrence	Potential Risk
	Organics and other determinands listed in Ref. 6	Local inhabitants	Migration via groundwater to the Spring followed by consumption of spring water	Effect on human health [Mild – Medium]	Low Likelihood. Little data but none noted to date	Moderate / Low - Low
			Migration via groundwater to surface followed by consumption of water	Effect on human health [Mild – Medium]	Low likelihood. No data but dilution with regional groundwater flow likely.	Moderate / Low - 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

5.3 Quantitative Risk Assessment

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 (Annex 6) which also considers the background concentration in the local groundwater. As a conservative estimate, chloride has been used as this is a conservative parameter generally unaffected by retardation within the aquifer:

Table A5.5 Dilution factors

Measured concentration	mg/l	Dilution factor
Leachate	3805	
Downstream borehole	79	100
Spring	44	1250

These dilution factors have been used to calculate the concentration of the 27 compounds listed in Reference 6 which have not been measured at the receptors. These are the anticipated contributions from leachate which are additional to the existing background concentrations. They are conservative estimates and do not consider attenuating factors such as adsorption within the landfill liner, unsaturated and saturated zone of the aquifer. The concentrations have been compared to drinking water standards to assess their significance.

Table A5.6 Calculated receptor concentrations

Selected substances (Ref. 6)	Leachate Quality from Database or real data		Downstream borehole		Spring		DWS[1]/ WHO[2]/ other[3]
	Median	Mean	Median	Mean	Median	Mean	
Dilution factor			**100**	**100**	**1250**	**1250**	
Aniline (µg/l)	<1	<1.46	<0.01	<0.0146	<0.0008	<0.001168	1[3]
Methyl tertiary butyl ether (µg/l)	<1	<1.38	<0.01	<0.0138	<0.0008	<0.001104	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 (µg/l)	<1	4.25	<0.01	0.0425	<0.0008	0.0034	8[2]
Fluoride (mg/l)	0.65	0.86	0.0065	0.0086	0.00052	0.000688	1.5[1]
Methyl chlorophenoxy acetic acid (µg/l)	<0.1	0.69	<0.001	0.0069	<0.00008	0.000552	0.1[1,4]
Dichloromethane (µg/l)	<1	42.8	<0.01	0.428	<0.0008	0.03424	20[2]
Organo-tin (µg/l)	0.2	0.3	0.002	0.003	0.00016	0.00024	Not available
Phosphorus (mg/l)	3	3.9	0.03	0.039	0.0024	0.00312	2.2[1]
Polycyclic aromatic hydrocarbons (µg/l)	<5.25	<5.60	<0.0525	<0.0560	<0.0042	<0.00448	0.1[1]
Nonyl phenol (µg/l)	1	4.9	0.01	0.049	0.0008	0.00392	Not available
Biphenyl (µg/l)	0.1	0.46	0.001	0.0046	0.00008	0.000368	Not available
Pentachlorophenol and compounds (µg/l)	<0.1	0.32	<0.001	0.0032	<0.00008	0.000256	1[3]
Arsenic (µg/l)	8	16	0.08	0.16	0.0064	0.0128	10[1]

1 = DWS 2000 or 1989
2 = WHO Guidelines v2
3 = other guidelines (Refs 10, 11, 12)
4 = Value for pesticides used

The predicted concentrations do not exceed drinking water standards where these exist. In most cases, the predicted concentrations are below the analytical level of detection.

6. Comparison with other UK landfill sites

The site was selected according to a number of specific criteria set out by the Environment Agency for the whole study, as set out in Table A5.7.

Table A5.7 Specification of landfill sites

Description	Criterion	Site A
Operational status	Open preferred	Open, with some restored areas
Throughput	>100,000 tonnes per annum	121,000 tonnes per annum
Waste description	Predominantly domestic	Predominantly domestic + 30% commercial/ industrial
Local area description	Populated areas preferred	Residential areas within 30 metres of site boundary
Proximity of groundwater table	Within 10 metres preferred	Depth to groundwater 20m+
Proximity of surface water	Within 50 metres preferred	Surface water features located 300 – 500 metres east of the site

Atypical aspects of Site A are summarised below:

(a) The site is elevated above the surrounding land.

The site is located in the top of a steep hill with steep slopes particularly to the east. This will affect the groundwater flow pattern and the groundwater catchment area.

(b) The site is unusually deep.

The ratio of the volume of waste to surface area is greater, hence the leachate generation capacity and strength atypical. However, leachate levels are controlled hence leakage rates are likely to be comparable with other sites.

(c) Phase 1 is not lined to current standards.

The method of lining of Phase 1 was less rigorous than the latter two stages and is likely to be less effective at containing leachate.

(d) Complex groundwater flows

As discussed above, the site is underlain by limestone which is characterised by rapid fissure flow with little attenuation of pollutants. The faults in the area exacerbate this flow regime particularly Fault 1 which emerges as a spring to the east of the site.

(e) Depth to groundwater

The groundwater is deeper than is typical of landfills and groundwater management is not required. However, the increased depth to groundwater will be somewhat negated by the fissure flow nature of the aquifer which will reduce the travel time from the base of the landfill to the water table.

(f) Surface water at some distance from the site

The distance to the nearest surface water course is more than many sites in the UK. Again however, the fissure flow nature of the aquifer will reduce the travel time to the surface water course to less than that in a landfill located on a granular aquifer.

7. Conclusions

Site A complies with the most of the criteria specified by the Environment Agency for the study.

Because of the wide variety of geological/hydrogeological regimes encountered in the UK, the location and hydrogeological setting are inevitably atypical of most other landfill sites. The fissured limestone geology at Site A will be a feature of some landfill sites, but not the majority of sites.

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 leak 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 (downstream boreholes were located in such a location in the village to the north east); and in a spring influenced by fault patterns to the east of the site.

The monitoring network for the site includes upstream boreholes, down stream boreholes, leachate collection points and surface water monitoring (spring and upstream and downstream of this in the river).

Monitoring data has indicated elevated concentrations of some determinands in the groundwater:

- Ammoniacal nitrogen was elevated in both the upstream and downstream boreholes. However, although there is likely to be a second source of ammoniacal nitrogen in the area, the concentrations were greater in the downstream borehole indicating that the landfill is probably 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 conditions in the aquifer are not conducive to transport of metals, these are likely to be partly naturally derived.

In the surface water, elevated concentrations of some determinands were also detected:

- The median concentration of sodium, alkalinity, potassium and ammoniacal nitrogen was elevated in the spring water. Concentrations in the river were similar upstream and downstream of where the spring discharged;

- Metal concentrations in the spring water were generally low, also indicating that conditions in the aquifer a re not conducive to the transport of metals;

The spring does appear to contain some contaminants from the leachate but the river dilution negates any impact.

The impact of other contaminants typically found in leachate, but that 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.

8. References

1. Ordnance Survey map, Scale 1:25,000

2. British Geological Survey map, Solid and Drift Edition. Scale 1:50,000

3. NRA Groundwater Vulnerability Map, Scale 1:100,000

4. Data supplied in a report from the landfill operator.

5. Pers. Comm.. from Site Manager to Enviros, November 2003.

6. Review of Environmental and Health Effects of Waste Management, Enviros report to DEFRA, 2004

7. Water Supply (Water Quality) Regulations 2000 & 1989, HMSO

8. Department of Environment Transport and the Regions, Environment Agency and Institute for Environment and Health. Guidelines for Environmental Risk Assessment and Management. HMSO, July 2000

9. Construction Industry Research and Information Association (CIRIA). Contaminated Land Risk Assessment. A Guide to Good Practice. CIRIA C552 2001

10. MTBE -http://www.epa.gov/waterscience/drinking/mtbefact.pdf

11. Aniline - http://bordeaux.uwaterloo.ca/biology447/modules/module1/drinkingwatera-c.htm

12. Pentachlorophenol - http://www.epa.gov/safewater/mcl.html#mcls

ANNEXES TO GROUNDWATER RISK ASSESSMENT (SITE A)

A5.A.1 LANDFILL CONSTRUCTION DETAILS

Site Detail	Phases		
	Older	Intermediate	Newer
Stage of Development	Restored to the crest of the waste batters	Waste disposal operations have been temporarily covered (on the western batter) with a geomembrane to reduce infiltration and gas emissions. Capping and partial restoration to ground level has been completed. Full restoration would be tied to the progressive development and restoration of other parts of the landfill	Infilling begun at the start of 2002.
Extent and Depth	Developed in three separate cells Pre-tipping plans for the site indicate that waste is in place to a depth of approximately 25 metres	Developed in three separate cells There is currently approximately 55 to 65 m depth of waste deposited within these cells, and it is currently being capped.	Waste disposal operations are ongoing within this phase.
Containment Details	Basal Liner The basal liner comprises a 1 m thick engineered seal constructed from silt obtained from the quarry lagoons located within the Lower Quarry unit. For Phase 1C, the mineral seal is augmented by an overlying geomembrane. Sidewall Liner It is understood that a sidewall seal was installed, comprising materials (silt from quarry lagoons) of low permeability being placed against the quarry face as disposal operations proceeded. A 1987 technical report3 refers to the presence of a sidewall lining system being installed within this phase. Construction Quality Assurance (CQA) The phase was developed without CQA	Basal Liner Composite liner comprising 1 m of engineered clay beneath geomembrane. Engineered clay needed to be placed at a maximum permeability of 1 x10-9 ms-1 however, actual permeabilities were much lower than this (<1x10-10 ms-1). Sidewall Liner The geomembrane is terminated in an anchor trench. The lining system below this point is constructed on 1:1.5 slope batters. A vertical engineered clay seal has been emplaced above this elevation. This seal is raised in 2 m lifts with no specified minimum lateral thickness. A 5 m high engineered bund is constructed at the toe of the western waste face of Phase 2. Construction Quality Assurance (CQA)	Basal Liner Basal liner consists of a composite liner comprising 1 m of engineered clay beneath geomembrane. Engineered clay placed at a maximum permeability of 1 x10-9 ms-1. Sidewall Liner Clay/geomembrane composite as per basal lining system Construction Quality Assurance (CQA) The phase was developed with CQA

Site Detail	Phases		
	Older	Intermediate	Newer
		The phase was developed with CQA	
Additional Engineering Detail	-	A cut-off trench, with associated engineered bund, has been installed along the toe of the western waste slope. This was constructed in order to intercept leachate from the toe of this slope. The collected leachate is collected within a collection lagoon and then subsequently abstracted. Additional engineering works, including the construction of an engineered cut-off seal, along the northern edge in order to prevent the leakage of leachate	
Leachate Management	Leachate abstraction occurs from defined leachate well, and leachate level/quality is monitored at two defined leachate wells. The current licence specifies a 1 m compliance level for leachate head. Abstracted leachate is pumped to an on-site treatment works with ultimate disposal via foul sewer. Since 1995, leachate head has varied from 2 to 13m.	Leachate abstraction points are placed adjacent to the inter-cell bunds along the western margins of each cell. Each abstraction point comprises a basal sump and a basal drainage blanket. Leachate drainage facilitated by drainage pipes, surrounded by gravel, laid on the top of the liner at a gradient of 1 in 50. The current licence specifies a 2 m compliance level for leachate head. Abstracted leachate is pumped to the leachate treatment plant. Leachate level and quality monitoring occurs at three specific Leachate Wells from which leachate is also abstracted. Prior to 2000, leachate levels generally increased within all of the wells. Since 2000 levels have remained relatively static, and there is no longer a rising trend in levels. Current (early 2003) leachate heads are generally less than 2 m.	Leachate abstraction point is placed adjacent to the inter-cell bunds along the western margin. The abstraction point comprises a basal sump and a basal drainage blanket. Leachate drainage facilitated by drainage pipes, surrounded by gravel, laid on the top of the liner at a gradient of 1 in 50. Leachate will drain across base at a gradient of 1:25 towards the Leachate Collection Point. The current licence specifies a 1 m compliance level for leachate head. Abstracted leachate is pumped to the leachate treatment plant. Leachate level and quality monitoring occurs at the abstraction point from which leachate would also be abstracted.

A.5.A.2 LEACHATE DATA

Measurement	Units	Maximum	Minimum	Median	Mean	N	Leachate Quality Database Ref. 6	
							Median value	Mean Value
pH (Field)		8.5	1.14	7.4	7.11	347		
Conductivity (Field)	µS/cm	44000	970	18600	19905.8	289		
Conductivity	µS/cm	719900	567	19900	23792.3	211		
Dissolved Oxygen (Field)	mg/l	5.6	0.5	0.5	1.1	115		
Dissolved Oxygen (Lab)	mg/l	5	0	1.8	1.72	197		
Suspended Solids	mg/l	784	360	572	572	2		
BOD	mg/l	6900	8.1	215	448.8	219		
COD	mg/l	14800	73	3470	3901.2	188		
Total Organic Carbon	mg/l	4800	0.8	1070	1121.6	223		
Calcium	mg/l	828	16	44.95	59.8	84		
Calcium (Dissolved)	mg/l	459	21	33	52.8	57		
Magnesium	mg/l	554	9.73	77.25	97.6	84		
Magnesium (Dissolved)	mg/l	110	35	67	65.2	57		
Sodium	mg/l	8420	9.8	2940	2909.2	98		
Sodium (Dissolved)	mg/l	4530	825	2970	3011.6	57		
Potassium	mg/l	2960	4.6	1250	1228.5	101		
Potassium (Dissolved)	mg/l	2220	357	1230	1254	57		
Alkalinity	mg/l $CaCO_3$	29500	110	8940	8825.6	139		
Total Sulphur	mg/l SO_4	1830	5	16.95	75.2	92		
Total Sulphur (Dissolved)	mg/l $S0_4$	475	23.4	166	174.8	38		
Sulphide	mg/l	27.5	0.06	0.45	3.196	10		
Chloride	mg/l	6210	5.51	3805	3513.9	326	1145	1425
Nitrate	mg/l NO_3	1.13	0	0.49	0.566	30		
Nitrate	mg/l N	1.6	0.3	0.3	0.52	55		
Nitrite	mg/l NO_2	0.566	0	0.3405	0.327	30		
Nitrite	mg/l N	0.6	0.1	0.1	0.12	55		
Total Oxidised Nitrogen	mg/l N	46	30	36	36.4	5	364	629
Total Oxidised Nitrogen	mg/l	13.4	0.22	0.3	0.83	96		
Ammoniacal Nitrogen	mg/l N	2930	0.03	1210	1172	329		
Total Organic Nitrogen	mg/l	3.76	0	0.955	0.96	34		
Phosphate	mg/l	91	0.09	3.47	14.79	23		
Iron	mg/l	163	0.6	1.8	5.97	155		
Iron (Dissolved)	mg/l	46.2	0.49	1.7	4.01	53		
Manganese	mg/l	37.6	0.04	0.16	1.159	85		
Manganese (Dissolved)	mg/l	3.66	0.049	0.15	0.251	53		
Zinc	mg/l	1330	0.03	0.18	10.748	155	135	1246

Measurement	Units	Maximum	Minimum	Median	Mean	N	Leachate Quality Database Ref. 6	
							Median value	Mean Value
Zinc (Dissolved)	mg/l	1.22	0.04	0.21	0.279	53		
Cadmium	mg/l	0.6	0.001	0.005	0.03	88		
Cadmium (Dissolved)	mg/l	0.013	0.001	0.003	0.003	49		
Copper	mg/l	10.6	0.01	0.04	0.257	87	11	26
Copper (Dissolved)	mg/l	0.72	0.002	0.072	0.125	53		
Lead	mg/l	70	0.008	0.04	1.533	93	<50	60
Lead (Dissolved)	mg/l	0.059	0.005	0.016	0.021	53		
Mercury	mg/l	1.1	0.00001	0.0001	0.028	144		
Nickel	mg/l	76	0.02	0.16	1.924	60	60	159
Nickel (Dissolved)	mg/l	0.37	0.11	0.23	0.219	7		
Chromium	mg/l	330	0.001	0.1	9.402	59	50	92
Chromium (Dissolved)	mg/l	0.26	0.034	0.2	0.187	11		
Titanium (Dissolved)	µg/l	309	132	220.5	220.5	2		
Thallium (Dissolved)	µg/l	1840	1180	1100	938.3	6		
Vanadium (Dissolved)	mg/l	0.13	0.1	0.115	0.115	2		
Colbalt (Dissolved)	mg/l	0.055	0.042	0.0485	0.049	2		
Barium (Dissolved)	mg/l	1.2	0.74	0.97	0.97	2		
NVM Light Petroleum Extract	mg/l	209	4	30	46.408	49		
Mineral Oil	mg/l	20	0.306	15	12.858	18		
Oil & Grease	mg/l	173	0.3	4.05	14.424	88		
Phenol(monohydric)	mg/l	16.6	0.022	0.2	0.596	78	0.03	0.35
Methane (Dissolved)	mg/l	4.8	2.1	4	3.63	3		
TCLVOC	µg/l	0.141	0.05	0.119	0.107	4		
1,3,5-trimethylbenzene	µg/l	5.7	5.7	5.7	5.7	1		
1,2,4-Drichlorobenzene	µg/l	0.175	0.104	0.1395	0.14	2		
1,2,4-trimethylbenzene	µg/l	12.8	9	10.9	10.9	2		
Toluene	µg/l	31.5	24.3	27.9	27.9	2	21	87
p-isopropyltoluene	µg/l	39.4	21.1	30.25	30.25	2		
Ethyl Benzene	µg/l	24.2	13.1	18.65	18.65	2	<10	19
m,p-xylene	µg/l	29.6	28.4	29	29	2	35	59
o-xylene	µg/l	20.7	13.1	16.9	16.9	2		
TPH >C6-C40	µg/l	2360	1740	2050	2050	2		
TPH >C6-C8	µg/l	64	40	52	52	2		
TPH >C8-C10	µg/l	160	108	134	134	2		
TPH >C10-C16	µg/l	1020	818	919	919	2		
TPH >C16-C24	µg/l	656	376	516	516	2		
TPH >C24-C40	µg/l	463	437	450	450	2		
Cis-1,2-dichloroethene	µg/l	33.9	8.2	21.05	21.05	2		
Naphthalene	µg/l	12.7	11.1	11.9	11.9	2	0.46	3.04
MCPP (Mecoprop)	µg/l	79.9	76.4	78.15	78.15	2	11	21.8

Measurement	Units	Maximum	Minimum	Median	Mean	N	Leachate Quality Database Ref. 6	
							Median value	Mean Value
Dichlorprop	µg/l	3.2	3.2	3.2	3.2	2		
Arsenic	µg/l						8	16
Biphenyl	µg/l						0.1	0.46
Pentachlorophenol and compounds	µg/l						<0.1	0.32
Nonyl phenol	µg/l						1	4.9
Polycyclic aromatic hydrocarbons	µg/l						<5.25	<5.60
Phosphorus	mg/l						3	3.9
Organo-tin	µg/l						0.2	0.3
Dichloromethane	µg/l						<1	42.8
Methyl chlorophenoxy acetic acid	µg/l						<0.1	0.69
Fluoride	mg/l						0.65	0.86
Di (2ethyl hexyl) phthalate	µg/l						<1	4.25
Cyanide	mg/l as CN						<0.05	<0.05
Methyl tertiary butyl ether	µg/l						<1	<1.38
Aniline	µg/l						<1	<1.46

A.5.A.3 GROUNDWATER QUALITY DATA

	Units	Perimeter borehole A				Perimeter borehole B				Perimeter borehole C				Perimeter borehole D			
		max	Min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n
Total Depth	m	135	12	40.34	21	34	12.92	31.93	13	33.45	9	14.06	16	22.8	21.55	21.92	16
Dip to Water	m	106.62	0.92	13.10636	22	33.58	0	3.426	10	0.91	0	0.52	16	7.22	4.26	5.9325	16
Turbidity	NTU	950	1.4	252.570	23	3650	4.5	274.113	15	2400	0.3	461.165	17	757	3.5	174.761	18
Air Temperature	Deg C	18	18	18	1												
Water Temperature	Deg C	14.5	11.4	12.99	7	14.4	11.4	13.47	6	16.5	12.9	14.6	7	16	11.7	14.11429	7
pH (Field)		8.11	6.54	7.52	22	7.95	6.24	7.33	12	8.29	6.26	7.38	16	9.03	6.78	7.53	15
pH (Lab)		8.5	7	7.70	23	8.6	7	7.68	15	8.1	6.9	7.33	18	8.4	7.1	7.72	18
Conductivity (Field)	uS/cm	1049	561	803.5	23	2270	778	1024.8	13	2070	700	1029.9	17	1540	618	840.0	15
Conductivity	uS/cm	1010	657	821.1	22	1130	688	849.7	15	1150	736	868.9	17	952	607	746.1	17
Dissolved Oxygen (Lab)	mg/l	12.7	<0.5	7.7	20	15.6	0.9	4.5	14	4.8	<0.5	1.3	16	9.3	<0.5	5.8	16
BOD	mg/l	97	<1	8.5	23	30	<1	4.7	15	276	3	72.9	17	3	<1	1.3	18
COD	mg/l	718	<20	133.6	23	770	<20	73.3	15	725	<20	237.9	18	116	17	44.6	18
Total Organic Carbon	mg/l	19.4	1.5	4.2	23	16.6	1.1	3.5	14	50	2	8.1	16	13	1.2	3.117647	17
Calcium	mg/l	290	131	157.8	8	138	138	138.0	1	198	153	177.5	4	119	89	110.0	4
Calcium (Diss)	mg/l	152	80	126.4	16	158	134	146.4	14	194	134	147.8	15	131	100	118.1	15
Magnesium	mg/l	11	9	9.4	8	17	17	17.0	1	20	12	17.0	4	18	9.8	15.5	4
Magnesium (Diss)	mg/l	23	6.8	10.91	16	22	17	17.93	14	27	17	22.13	15	20	11	17.47	15
Sodium	mg/l	66	50	57.4	8	36	36	36.0	1	68	37	49.3	4	55	42	47.5	4
Sodium (Diss)	mg/l	79	46	54.1	16	47	35	39.5	14	60	37	46.3	15	58	39	44.6	15
Potassium	mg/l	5	3	3.90	8	2	2	2.00	1	6	1.8	3.88	4	3	2	2.68	4
Potassium (Diss)	mg/l	8	2.5	3.89	16	3.3	1.6	2.06	14	4	1.6	2.72	15	3.6	2	2.86	15
Alkalinity	mg/l $CaCO_3$	382	194	263.7	23	338	271	302.5	15	585	301	388.8	18	320	203	273.9	18
Total Sulphur	mg/l SO_4	101	17.4	60.70	22	82	51	72.87	15	79	4.4	35.41	18	51	12.1	38.06	18
Sulphide	mg/l	0.08	0.07	0.08	2					1.05	1.05	1.05	1	0.08	0.08	0.08	1
Chloride	mg/l	154	65	87.9	22	85	78	81.3	15	85	45	70.2	17	78	58	64.8	17
Total Oxidised Nitrogen	mg/l	6.4	0	4.08	23	6.2	<0.3	0.91	15	1.2	<0.3	0.60	18	7	5.1	6.13	18

	Units	Perimeter borehole A				Perimeter borehole B				Perimeter borehole C				Perimeter borehole D			
		max	Min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n
Ammoniacal Nitrogen	mg/l N	9.9	<0.04	1.27	23	1.43	<0.04	0.29	15	3.3	0.11	1.53	18	0.46	0.04	0.19	18
Iron	mg/l	2.64	<0.05	0.486	8	0.07	0.07	0.070	1	21.5	0.79	8.370	4	0.18	<0.05	0.083	4
Iron (Diss)	mg/l	0.57	0	0.115	16	0.52	<0.05	0.177	14	39.86	<0.05	5.267	15	1.54	<0.05	0.393	15
Manganese	mg/l	0.64	0.05	0.172	7	0.72	0.72	0.720	1	7.33	1.21	4.680	3	3.21	0.05	1.104	3
Manganese (Diss)	mg/l	1.6	0.031	0.170	16	2.51	0.39	0.836	14	5.5	0.68	1.679	15	3.21	0.033	0.292	15
Zinc	mg/l	0.15	0.005	0.0590	7	0.03	0.03	0.0300	1	0.03	0.005	0.0133	3	0.03	0.006	0.0147	3
Zinc (Diss)	mg/l	0.18	0	0.0408	16	0.074	<0.005	0.0331	14	0.14	<0.005	0.0219	15	0.046	<0.005	0.0191	15
Cadmium	mg/l	0.001	<0.0005	0.00086	7	0.001	0.001	0.00100	1	0.001	<0.0005	0.00067	3	0.001	0.0005	0.00067	3
Cadmium (Diss)	mg/l	0.001	0	0.0006	16	0.001	<0.0005	0.0006	14	0.001	<0.0005	0.0007	15	0.001	<0.0005	0.0006	15
Copper	mg/l	0.07	<0.005	0.0271	7	0.02	0.02	0.0200	1	0.02	<0.005	0.0100	3	0.02	0.005	0.0100	3
Copper (Diss)	mg/l	0.052	0	0.009	16	0.02	0.005	0.006	14	0.042	<0.005	0.008	15	0.02	0.005	0.006	15
Lead	mg/l	0.41	<0.005	0.068571	7	0.01	0.01	0.01	1	0.03	<0.005	0.0125	4	0.01	0.005	0.006667	3
Lead (Diss)	mg/l	0.01	0	0.005	16	0.01	<0.005	0.005	14	1.21	<0.005	0.091	15	0.01	0.005	0.005	15
Nickel	mg/l	0.013	<0.005	0.008	7	0.007	0.007	0.007	1	0.024	<0.005	0.010	4	0.007	0.005	0.006	3
Nickel (Diss)	mg/l	0.009	0.005	0.0054	16	0.016	0.005	0.0060	14	0.024	0.005	0.0077	15	0.02	0.005	0.0067	15
Chromium	mg/l	0.008	<0.005	0.00575	4					0.005	0.005	0.005	2	0.005	0.005	0.005	2
Chromium (Diss)	mg/l	0.005	0.005	0.005	4	0.005	0.005	0.005	4	0.005	0.005	0.005	5	0.005	0.005	0.005	4
Mineral Oil	mg/l	100	50	66.66667	3												
Methane (Diss)	mg/l	<0.01	<0.01	<0.01	5	10	<0.01	2.5075	4	14	<0.01	6.362	5	0.019	<0.01	0.0135	4

	Units	Perimeter Borehole E				Perimeter Borehole F				Perimeter Borehole G				Perimeter Borehole H				Perimeter Borehole I			
		max	min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n
Total Depth	m	117.85	8.95	60.20	10	141.9	0	89.32	5	144.3	0	92.33	7	136	3.54	75.66	15	129	11.9	68.58	14
Dip to Water	m	100.59	0.5	71.53	23	109.7	2	64.69	22	129.88	11.5	80.88	22	136	3.54	69.08	21	124	4.26	72.95	20
Turbidity	NTU	1150	0.65	127.88	24	2040	0.33	127.4	24	1620	0.36	285.6	24	2590	0.38	315.812	15	550	0.45	102.697	17
Air Temperature	Deg C	15	15	15	1									15	15	15	1				
Water Temperature	Deg C	17.9	10.9	12.85	6	12.5	11.2	11.8	7	14	11.2	12.57	7	13	12.3	12.65	2	12.2	11.8	12	2
pH (Field)		9.24	6.76	7.58	26	8.8	0	7.43	27	8.66	0	7.18	28	9.23	6.79	7.73	17	69.9	6.73	10.74	19
pH (Lab)		8.1	7	7.55	24	8.6	7	7.74	24	8.5	6.9	7.55	24	8.5	7.3	7.89	15	8.4	7.2	7.59	17
Conductivity (Field)	uS/cm	2100	581	920.0	27	1533	509	687.5	27	2170	388	862.4	28	1020	350	630.7	17	1596	740	1023.9	19
Conductivity	uS/cm	15700	514	1416.4	23	859	388	612.9	23	1080	495	747.3	23	936	439	637.6	14	1987	594	975	16
Dissolved Oxygen (Lab)	mg/l	11.9	1.4	4.6	22	13.3	5.3	9.5	21	15.2	1.6	5.9	22	15.8	1.9	6.3	11	11.7	1.6	4.9	12
BOD	mg/l	13	<1	4.5	24	4	<1	1.4	24	10	<1	2.0	24	14	<1	2.4	15	5	<1	1.8	17
COD	mg/l	120	<20	49.5	24	598	0	51.3	24	185	0	48.4	24	2986	0	247.4	15	808	<20	114	17
Total Organic Carbon	mg/l	16.6	2.8	5.0	24	5.6	1.1	2.5	24	9	2	5.3	24	7.6	2.7	4.04	15	7.8	2.9	4.7	17
Calcium	mg/l	220	111	129.8	9	149	103	120.3	9	184	100	149.7	9	128	60	83.6	9	212	155	188.4	9
Calcium (Diss)	mg/l	220	114	133.4	16	131	101	117.3	16	197	110	177.4	16	128	58	84.0	7	207	32	151.1	9
Magnesium	mg/l	34	29	31.0	9	7	3.9	4.9	9	38	8.5	17.8	9	26	13	17.2	9	32	12	18.7	9
Magnesium (Diss)	mg/l	36	30	33.44	16	7	4	4.83	16	26	7.9	10.66	16	27	13	20.14	7	13	7.4	10.93	9
Sodium	mg/l	30	26	28.3	9	26	21	23.7	9	93	15	30.3	9	58	20	32.3	9	65	31	46.2	9
Sodium (Diss)	mg/l	30	23	26.4	16	27	21	23.3	16	36	16	22.4	16	59	27	45.1	7	249	23	62.1	9
Potassium	mg/l	4	3	3.53	9	5	3	3.97	9	7	2.9	4.23	9	4	2	3.07	9	8	1.4	3.93	9
Potassium (Diss)	mg/l	4.2	2.8	3.38	16	5	2.1	3.86	16	4.2	2.9	3.54	16	4.5	2.8	3.53	7	6	1.1	2.79	9
Alkalinity	mg/l $CaCO_3$	706	133	373.3	24	345	191	239.3	24	540	100	340.5	24	371	168	230.9	15	941	105	400.5	17
Total Sulphur	mg/l SO_4	244	11.7	37.03	24	35	<5	22.95	23	51	6.8	21.82	23	91	18.7	48.76	14	80	18.1	49.87	15
Sulphide	mg/l	0.08	0.08	0.08	1	0.09	0.08	0.09	2	0.09	0.08	0.09	2	0.08	0.07	0.08	2	0.1	0.08	0.09	3
Chloride	mg/l	45	35	39.5	23	51	30	41.2	23	61	19	28.3	23	58	23	40.8	14	158	37	57.6	16
Nitrate	mg/l N					6.6	6.6	6.6	1												
Total Oxidised Nitrogen	mg/l	1.8	<0.3	0.65	24	9.7	2.8	6.02	24	14	<0.3	10.42	24	7.4	<0.3	2.15	15	12.3	0	8.96	17

	Units	Perimeter Borehole E				Perimeter Borehole F				Perimeter Borehole G				Perimeter Borehole H				Perimeter Borehole I			
		max	min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n
Ammoniacal Nitrogen	mg/l N	7.4	0.04	1.03	24	3.8	<0.04	0.54	24	1.6	0	0.42	24	2.2	0	0.52	15	2.5	0	0.55	17
Iron	mg/l	0.24	<0.05	0.116	9	0.19	<0.05	0.094	8	0.13	<0.05	0.068	9	0.56	<0.05	0.169	9	9.56	<0.05	1.212	9
Iron (Diss)	mg/l	0.52	<0.05	0.158	16	0.21	0	0.063	16	0.7	0.05	0.124	16	0.29	<0.05	0.129	7	0.83	0	0.231	9
Manganese	mg/l	0.67	0.32	0.536	8	0.21	0.05	0.121	7	0.44	0.11	0.281	8	0.36	0.07	0.159	8	2.08	0.11	0.730	8
Manganese (Diss)	mg/l	0.76	0.53	0.659	16	0.094	0	0.040	16	0.19	0.058	0.113	16	1.12	0.022	0.205	7	1.23	0	0.210	9
Zinc	mg/l	0.34	<0.005	0.0668	9	0.62	<0.005	0.1113	8	0.38	<0.005	0.0781	8	0.56	0.007	0.1003	8	0.85	0.013	0.1279	9
Zinc (Diss)	mg/l	0.36	<0.005	0.0385	16	0.046	<0.005	0.0169	16	0.08	0	0.0229	16	0.079	0	0.0206	7	0.068	0	0.0148	9
Cadmium	mg/l	0.001	<0.0005	0.00089	9	0.008	<0.005	0.00175	8	0.001	<0.0005	0.00088	8	0.001	<0.005	0.00094	8	0.001	<0.0005	0.00089	9
Cadmium (Diss)	mg/l	0.001	<0.0005	0.0006	16	0.001	<0.005	0.0006	16	0.001	<0.0005	0.0007	16	0.001	<0.005	0.0007	7	0.001	0	0.0006	9
Copper	mg/l	<0.02	<0.005	0.0163	8	0.09	<0.005	0.0250	8	<0.02	<0.005	0.0163	8	<0.02	<0.005	0.0163	8	<0.02	<0.005	0.0163	8
Copper (Diss)	mg/l	0.02	<0.005	0.006	16	0.02	0	0.006	16	0.02	0	0.006	16	0.02	0	0.006	7	0.02	0	0.006	9
Lead	mg/l	0.04	<0.005	0.02	9	0.12	<0.005	0.026667	9	0.017	<0.005	0.01025	8	0.01	<0.005	0.00925	8	0.03	<0.005	0.0125	8
Lead (Diss)	mg/l	0.03	<0.005	0.007	16	0.051	0.006	0.014	16	0.02	<0.005	0.010	16	0.01	<0.005	0.007	7	0.02	0	0.007	9
Mercury	mg/l					0.0001	<0.0001	<0.0001	1												
Nickel	mg/l	<0.007	<0.005	0.007	8	0.077	<0.005	0.015	8	<0.007	<0.005	0.007	8	<0.007	<0.005	0.007	8	0.02	<0.005	0.008	8
Nickel (Diss)	mg/l	0.007	0.005	0.0054	16	<0.007	0	0.0048	16	0.01	0	0.0051	16	0.007	0	0.0047	7	0.009	0	0.0047	9
Chromium	mg/l	0.005	0.005	0.005	4	0.074	<0.005	0.02225	4	0.005	0.005	0.005	4	0.005	0.005	0.005	4	0.005	0.005	0.005	4
Chromium (Diss)	mg/l	0.22	<0.005	0.048	5	<0.005	<0.005	0.005	5	<0.005	<0.005	0.005	4	<0.005	<0.005	0.005	1	<0.005	<0.005	0.005	1
Titanium (Diss)	µg/l					<5	5	5	1												
Thallium (Diss)	µg/l					<100	100	100	1												
Vanadium (Diss)	mg/l					<0.005	0.005	0.005	1												
Colbalt (Diss)	mg/l					<0.005	0.005	0.005	1												

	Units	Perimeter Borehole E				Perimeter Borehole F				Perimeter Borehole G				Perimeter Borehole H				Perimeter Borehole I			
		max	min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n
Barium (Diss)	mg/l					0.033	0.033	0.033	1												
Antimony	mg/l					<0.001	0.001	0.001	1												
Arsenic (Diss)	mg/l					<0.001	0.001	0.001	1												
Beryllium	mg/l					<0.005	0.005	0.005	1												
Mercury (Diss)	µg/l					0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
Molybdenum	mg/l					<0.005	0.005	0.005	1												
Selenium (diss)	µg/l					1	1	1	1												
Silver (Diss)	mg/l					<0.015	0.015	0.015	1												
Tin (Diss)	mg/l					<0.1	0.1	0.1	1												
Tributyl Tin	mg/l					<0.04	0.04	0.04	1												
Cyanide (Total)	mg/l					<0.1	0.1	0.1	1												
Mineral Oil	mg/l	100	50	81.25	8	100	50	57.1	7	100	100	100	8	100	0	37.5	8	100	100	100	7
Phenol(monohydric)	mg/l					0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
Methane (Diss)	mg/l	0.053	<0.01	0.0335	6	0.01	0.01	0.01	5	0.01	0.01	0.01	5	0.01	0.01	0.01	2	0.01	0.01	0.01	2
1,2,4-Drichlorobenzene	µg/l					<0.005	0.005	0.005	1												
TPH >C6-C40	µg/l					624	624	624	1												
TPH >C6-C8	µg/l					<10	<10	<10	1												
TPH >C8-C10	µg/l					<10	<10	<10	1												
TPH >C10-C16	µg/l					<20	<20	<20	1												
TPH >C16-C24	µg/l					99	99	99	1												
TPH >C24-C40	µg/l					525	525	525	1												
MCPP (Mecoprop)	µg/l					<0.1	<0.1	<0.1	1												
Dichlorprop	µg/l					<0.1	<0.1	<0.1	1												
2,3,6-TBA	µg/l					<0.1	<0.1	<0.1	1												
2,4,5-T	µg/l					<0.1	<0.1	<0.1	1												
2,4-D	µg/l					<0.1	<0.1	<0.1	1												
2,4-DB	µg/l					<0.1	<0.1	<0.1	1												
Aldrin	ng/l					<5	<5	<5	1												
Azinphos-methyl	µg/l					<0.05	<0.05	<0.05	1												
Bromoxynil	µg/l					<0.1	<0.1	<0.1	1												

	Units	Perimeter Borehole E				Perimeter Borehole F				Perimeter Borehole G				Perimeter Borehole H				Perimeter Borehole I			
		max	min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n
Carbophenothion	µg/l					<0.05	<0.05	<0.05	1												
Chlordane-alpha	ng/l					<5	<5	<5	1												
Chlordane-gamma	ng/l					<5	<5	<5	1												
Chlorfenvinphos	µg/l					<0.05	<0.05	<0.05	1												
Chlortoluron	µg/l					<0.2	<0.2	<0.2	1												
Demeton-s-methyl	µg/l					<0.05	<0.05	<0.05	1												
Diazinon	µg/l					<0.05	<0.05	<0.05	1												
Dicamba	µg/l					<0.1	<0.1	<0.1	1												
Dichlobenil	ng/l					<5	<5	<5	1												
Dichlorvos	µg/l					<0.05	<0.05	<0.05	1												
Dieldrin	ng/l					<5	<5	<5	1												
Dimethoate	µg/l					<0.05	<0.05	<0.05	1												
Disulphoton	µg/l					<0.05	<0.05	<0.05	1												
Diuron	µg/l					<0.2	<0.2	<0.2	1												
Endosulphan-alpha	µg/l					<5	<5	<5	1												
Endrin	ng/l					<5	<5	<5	1												
Fenitrothion	µg/l					<0.05	<0.05	<0.05	1												
Fenthion	µg/l					<0.05	<0.05	<0.05	1												
HCH-alpha	ng/l					<5	<5	<5	1												
HCH-beta	ng/l					<5	<5	<5	1												
HCH-gamma	ng/l					<5	<5	<5	1												
Heptachlor Epoxide	ng/l					<5	<5	<5	1												
Hexachlorobenzene	µg/l					<0.005	<0.005	<0.005	1												
Hexachlorobutadiene	ng/l					<5	<5	<5	1												
Ioxynil	µg/l					<0.1	<0.1	<0.1	1												
Isoproturon	µg/l					<0.2	<0.2	<0.2	1												
Linuron	µg/l					<0.2	<0.2	<0.2	1												
lsodrin	ng/l					<5	<5	<5	1												
Malathion	µg/l					<0.05	<0.05	<0.05	1												
MCPA	µg/l					<0.1	<0.1	<0.1	1												

	Units	Perimeter Borehole E				Perimeter Borehole F				Perimeter Borehole G				Perimeter Borehole H				Perimeter Borehole I			
		max	min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n	max	min	mean	n
MCPB	µg/l					<0.1	<0.1	<0.1	1												
Mevinphos	µg/l					<0.05	<0.05	<0.05	1												
Monuron	µg/l					<0.2	<0.2	<0.2	1												
o,p-DDE	ng/l					<5	<5	<5	1												
o,p-DDT	ng/l					<5	<5	<5	1												
o,p-TDE	ng/l					<5	<5	<5	1												
p,p-DDE	ng/l					<5	<5	<5	1												
p,p-DDT	ng/l					<5	<5	<5	1												
p,p-TDE	ng/l					<5	<5	<5	1												
Parathion ethyl	µg/l					<0.05	<0.05	<0.05	1												
Parathion-methyl	µg/l					<0.05	<0.05	<0.05	1												
Phorate	µg/l					<0.05	<0.05	<0.05	1												
Pirimiphos-methyl	µg/l					<0.05	<0.05	<0.05	1												
Propetamphos	µg/l					<0.05	<0.05	<0.05	1												
Tecnazene	ng/l					<5	<5	<5	1												
Triallate	ng/l					<5	<5	<5	1												
Triazophos	µg/l					<0.05	<0.05	<0.05	1												
Trifluralin	µg/l					<5	<5	<5	1												
Triphenyltin	µg/l					<0.04	<0.04	<0.04	1												

	Units	Downstream						Upstream					
		max	min	mean	median	n	no. > DL	max	min	mean	median	n	no. > DL
Total Depth	m	34	9	22.07	13.71	29	29	141.9	0	89.32	132.52	5	5
Dip to Water	m	33.58	0	1.64	0.47	26	26	109.7	2	64.70	102.22	22	22
Turbidity	NTU	3650	0.3	373.5	59.0	32	32	2040	0.33	127.4	22.7	24	24
Air Temperature	Deg C	0	0			0	0	0	0			0	0
Water Temperature	Deg C	16.5	11.4	14.1	14.3	13	13	12.5	11.2	11.8	11.7	7	7
pH (Field)		8.29	6.24	7.4	7.3	28	28	8.8	0	7.4	7.7	27	27
pH (Lab)		8.6	6.9	7.5	7.4	33	33	8.6	7	7.7	7.8	24	24
Conductivity (Field)	uS/cm	2270	700	1027.7	936.5	30	30	1533	509	687.5	670.0	27	27
Conductivity	uS/cm	1150	688	859.9	842.5	32	32	859	388	612.9	606.0	23	23

	Units	Downstream						Upstream					
		max	min	mean	median	n	no. > DL	max	min	mean	median	n	no. > DL
Dissolved Oxygen (Lab)	mg/l	15.6	<DL	-	3.3	30	18	13.3	5.3	9.5	10.1	21	21
BOD	mg/l	276	<DL	-	30.0	32	27	4	<DL	-	2.0	24	11
COD	mg/l	770	<DL	-	179.5	33	24	598	<DL	-	27.0	24	9
Total Organic Carbon	mg/l	50	1.1	5.9	2.7	30	30	5.6	1.1	2.5	2.2	24	24
Calcium	mg/l	198	138	169.6	165.0	5	5	149	103	120.3	118.0	9	9
Calcium (Diss)	mg/l	194	134	147.1	144.0	29	29	131	101	117.3	118.5	16	16
Magnesium	mg/l	20	12	17.0	17.0	5	5	7	3.9	4.9	4.3	9	9
Magnesium (Diss)	mg/l	27	17	20.1	19.0	29	29	7	4	4.8	4.9	16	16
Sodium	mg/l	68	36	46.6	46.0	5	5	26	21	23.7	24.0	9	9
Sodium (Diss)	mg/l	60	35	43.0	40.0	29	29	27	21	23.3	23.0	16	16
Potassium	mg/l	6	<DL	-	3.9	5	4	5	3	4.0	4.0	9	9
Potassium (Diss)	mg/l	4	<DL	-	2.4	29	28	5	2.1	3.9	3.8	16	16
Alkalinity	mg/l $CaCO_3$	585	271	349.5	324.0	33	33	345	191	239.3	239.0	24	24
Total Sulphur	mg/l SO_4	82	<DL	-	64.0	33	30	35	<DL	-	24.5	23	22
Sulphide	mg/l	1.05	1.05	1.1	1.1	1	1	0.09	0.08	0.1	0.1	2	2
Chloride	mg/l	85	45	75.4	79.0	32	32	51	30	41.2	41.0	23	23
Nitrate	mg/l N	0	0			0	0	0	0			0	0
Total Oxidised Nitrogen	mg/l	6.2	<DL	-	0.8	33	20	9.7	2.8	6.0	6.0	24	24
Ammoniacal Nitrogen	mg/l N	3.3	<DL	-	0.9	33	30	3.8	<DL	-	0.7	24	14
Iron	mg/l	21.5	0.07	6.7	3.5	5	5	0.19	<DL	-	0.1	8	4
Iron (Diss)	mg/l	39.86	<DL	-	0.8	29	22	0.21	<DL	-	0.1	16	5
Manganese	mg/l	7.33	0.72	3.7	3.4	4	4	0.21	0.05	0.1	0.1	7	7
Manganese (Diss)	mg/l	5.5	0.39	1.3	1.0	29	29	0.094	<DL	-	0.0	16	15
Zinc	mg/l	0.005	<DL	-	0.01	4	1	0.62	<DL	-	0.38	8	2
Zinc (Diss)	mg/l	0.14	<DL	-	0.02	29	23	0.046	<DL	-	0.01	16	12
Cadmium	mg/l	<DL	<DL	-		4	0	0.008	<DL	-	0.008	8	1
Cadmium (Diss)	mg/l	0.001	<DL	-	0.00	29	8	0.001	<DL	-	0.00	16	2
Copper	mg/l	<DL	<DL	-		4	0	0.09	<DL	-	0.0	8	2
Copper (Diss)	mg/l	0.042	<DL	-	0.0	29	1	0	<DL	-	0.0	16	1
Lead	mg/l	0.03	<DL	-	0.02	5	2	0.12	<DL	-	0.02	9	7
Lead (Diss)	mg/l	1.21	<DL	-	0.016	29	8	0.051	0.006	0.0138125	0.0085	16	16
Mercury	mg/l	0	0			0	0	<DL	<DL	-		1	0
Nickel	mg/l	0.024	<DL	-	0.02	5	1	0.077	<DL	-	0.08	8	1

	Units	Downstream						Upstream					
		max	min	mean	median	n	no. > DL	max	min	mean	median	n	no. > DL
Nickel (Diss)	mg/l	0.024	<DL	-	0.0085	29	8	0	<DL	-	0	16	1
Chromium	mg/l	<DL	<DL	-		2	0	0.074	<DL	-	0.07	4	1
Chromium (Diss)	mg/l	<DL	<DL	-		9	0	<DL	<DL	-		5	0
Titanium (Diss)	µg/l	0	0			0	0	<DL	<DL	-		1	0
Thallium (Diss)	µg/l	0	0			0	0	<DL	<DL	-		1	0
Vanadium (Diss)	mg/l	0	0			0	0	<DL	<DL	-		1	0
Colbalt (Diss)	mg/l	0	0			0	0	<DL	<DL	-		1	0
Barium (Diss)	mg/l	0	0			0	0	0.033	0.033	0.033	0.033	1	1
Antimony	mg/l	0	0			0	0	0.001	0.001	0.001	0.001	1	1
Arsenic (Diss)	mg/l	0	0			0	0	<DL	<DL	-		1	0
Beryllium	mg/l	0	0			0	0	<DL	<DL	-		1	0
Mercury (Diss)	µg/l	0	0			0	0	0	0	0	0	1	1
Molybdenum	mg/l	0	0			0	0	<DL	<DL	-		1	0
Selenium (diss)	µg/l	0	0			0	0	<DL	<DL	-		1	0
Silver (Diss)	mg/l	0	0			0	0	<DL	<DL	-		1	0
Tin (Diss)	mg/l	0	0			0	0	<DL	<DL	-		1	0
Tributyl Tin	mg/l	0	0			0	0	<DL	<DL	-		1	0
Cyanide (Total)	mg/l	0	0			0	0	<DL	<DL	-		1	0
Mineral Oil	mg/l	0	0			0	0	100	50	57.142857	50	7	7
Phenol(monohydric)	mg/l	0	0			0	0	0	0	0	0	1	1
Methane (Diss)	mg/l	14	<DL	-	9.2	9	5	<DL	<DL	-		5	0
1,2,4-Drichlorobenzene	µg/l	0	0			0	0	<DL	<DL	-		1	0
TPH >C6-C40	µg/l	0	0			0	0	624	624	624	624	1	1
TPH >C6-C8	µg/l	0	0			0	0	<DL	<DL	-		1	0
TPH >C8-C10	µg/l	0	0			0	0	<DL	<DL	-		1	0
TPH >C10-C16	µg/l	0	0			0	0	<DL	<DL	-		1	0
TPH >C16-C24	µg/l	0	0			0	0	99	99	99	99	1	1
TPH >C24-C40	µg/l	0	0			0	0	525	525	525	525	1	1
MCPP (Mecoprop)	µg/l	0	0			0	0	<DL	<DL	-		1	0
Dichlorprop	µg/l	0	0			0	0	<DL	<DL	-		1	0
2,3,6-TBA	µg/l	0	0			0	0	<DL	<DL	-		1	0
2,4,5-T	µg/l	0	0			0	0	<DL	<DL	-		1	0
2,4-D	µg/l	0	0			0	0	<DL	<DL	-		1	0
2,4-DB	µg/l	0	0			0	0	<DL	<DL	-		1	0
Aldrin	ng/l	0	0			0	0	<DL	<DL	-		1	0
Azinphos-methyl	µg/l	0	0			0	0	<DL	<DL	-		1	0

	Units	Downstream						Upstream					
		max	min	mean	median	n	no. > DL	max	min	mean	median	n	no. > DL
Bromoxynil	µg/l	0	0			0	0	<DL	<DL	-		1	0
Carbophenothion	µg/l	0	0			0	0	<DL	<DL	-		1	0
Chlordane-alpha	ng/l	0	0			0	0	<DL	<DL	-		1	0
Chlordane-gamma	ng/l	0	0			0	0	<DL	<DL	-		1	0
Chlorfenvinphos	µg/l	0	0			0	0	<DL	<DL	-		1	0
Chlortoluron	µg/l	0	0			0	0	<DL	<DL	-		1	0
Demeton-s-methyl	µg/l	0	0			0	0	<DL	<DL	-		1	0
Diazinon	µg/l	0	0			0	0	<DL	<DL	-		1	0
Dicamba	µg/l	0	0			0	0	<DL	<DL	-		1	0
Dichlobenil	ng/l	0	0			0	0	<DL	<DL	-		1	0
Dichlorvos	µg/l	0	0			0	0	<DL	<DL	-		1	0
Dieldrin	ng/l	0	0			0	0	<DL	<DL	-		1	0
Dimethoate	µg/l	0	0			0	0	<DL	<DL	-		1	0
Disulphoton	µg/l	0	0			0	0	<DL	<DL	-		1	0
Diuron	µg/l	0	0			0	0	<DL	<DL	-		1	0
Endosulphan-alpha	µg/l	0	0			0	0	<DL	<DL	-		1	0
Endrin	ng/l	0	0			0	0	<DL	<DL	-		1	0
Fenitrothion	µg/l	0	0			0	0	<DL	<DL	-		1	0
Fenthion	µg/l	0	0			0	0	<DL	<DL	-		1	0
HCH-alpha	ng/l	0	0			0	0	<DL	<DL	-		1	0
HCH-beta	ng/l	0	0			0	0	<DL	<DL	-		1	0
HCH-gamma	ng/l	0	0			0	0	<DL	<DL	-		1	0
Heptachlor Epoxide	ng/l	0	0			0	0	<DL	<DL	-		1	0
Hexachlorobenzene	µg/l	0	0			0	0	<DL	<DL	-		1	0
Hexachlorobutadiene	ng/l	0	0			0	0	<DL	<DL	-		1	0
Ioxynil	µg/l	0	0			0	0	<DL	<DL	-		1	0
Isoproturon	µg/l	0	0			0	0	<DL	<DL	-		1	0
Linuron	µg/l	0	0			0	0	<DL	<DL	-		1	0
lsodrin	ng/l	0	0			0	0	<DL	<DL	-		1	0
Malathion	µg/l	0	0			0	0	<DL	<DL	-		1	0
MCPA	µg/l	0	0			0	0	<DL	<DL	-		1	0
MCPB	µg/l	0	0			0	0	<DL	<DL	-		1	0
Mevinphos	µg/l	0	0			0	0	<DL	<DL	-		1	0
Monuron	µg/l	0	0			0	0	<DL	<DL	-		1	0
o,p-DDE	ng/l	0	0			0	0	<DL	<DL	-		1	0
o,p-DDT	ng/l	0	0			0	0	<DL	<DL	-		1	0

	Units	Downstream						Upstream					
		max	min	mean	median	n	no. > DL	max	min	mean	median	n	no. > DL
o,p-TDE	ng/l	0	0			0	0	<DL	<DL	-		1	0
p,p-DDE	ng/l	0	0			0	0	<DL	<DL	-		1	0
p,p-DDT	ng/l	0	0			0	0	<DL	<DL	-		1	0
p,p-TDE	ng/l	0	0			0	0	<DL	<DL	-		1	0
Parathion ethyl	µg/l	0	0			0	0	<DL	<DL	-		1	0
Parathion-methyl	µg/l	0	0			0	0	<DL	<DL	-		1	0
Phorate	µg/l	0	0			0	0	<DL	<DL	-		1	0
Pirimiphos-methyl	µg/l	0	0			0	0	<DL	<DL	-		1	0
Propetamphos	µg/l	0	0			0	0	<DL	<DL	-		1	0
Tecnazene	ng/l	0	0			0	0	<DL	<DL	-		1	0
Triallate	ng/l	0	0			0	0	<DL	<DL	-		1	0
Triazophos	µg/l	0	0			0	0	<DL	<DL	-		1	0
Trifluralin	µg/l	0	0			0	0	<DL	<DL	-		1	0
Triphenyltin	µg/l	0	0			0	0	<DL	<DL	-		1	0
Chloroform		0	0			0	0	0	0			0	0

A.5.A.4 Surface water quality data

	Units	Downstream						Spring						Upstream					
		max	min	mean	Median*	N	no. > DL	max	min	mean	Median*	n	no. > DL	max	min	mean	Median*	n	no. > DL
Total Depth	m							0.22	0.09	0.11	0.10	8	8						
Dip to Water	m							0.03	0.03	0.03	0.03	1	1						
Spring Flow	l/min							225	0	48.8	21.0	77	77						
Turbidity	NTU							6.5	6	6.3	6.3	2	2						
Air Temperature	Deg C							18	15	16.5	16.5	2	2						
Water Temperature	Deg C	17	3.8	10.4	10.3	70	70	14.8	5.6	10.4	10.3	87	87	22.6	3.6	11.4	11.3	96	96
pH (Field)		9.8	5.2	7.7	7.8	84	84	8.8	5.6	7.4	7.4	99	99	9.74	5.43	7.6	7.8	115	115
pH (Lab)		8.7	6	7.6	7.6	149	149	8.7	6.2	7.4	7.3	356	356	8.9	6.2	7.6	7.7	176	176
Conductivity (Field)	µS/cm	880	37	310.3	295.0	84	84	891	120	595.7	620.0	111	111	3019	30	346.9	290.0	111	111
Conductivity	µS/cm	9310	3.25	394.9	307.0	156	156	9770	185	718.2	628.0	355	355	3020	12	312.4	291.0	185	185
Dissolved Oxygen (Field)	mg/l	105	5.1	11.2	9.6	57	57	95	2.2	8.5	6.3	81	81	105	3.7	11.3	9.5	56	56

	Units	Downstream						Spring						Upstream					
		max	min	mean	Median*	N	no. > DL	max	min	mean	Median*	n	no. > DL	max	min	mean	Median*	n	no. > DL
Dissolved Oxygen (Lab)	mg/l	15	1.3	8.4	7.0	73	73	13.4	0.1	5.4	5.2	100	100	15.6	<DL	-	8.8	98	97
BOD	mg/l	16.2	<DL	-	2.0	63	30	150	<DL	-	1.2	70	37	22	<DL	-	2.0	62	32
COD	mg/l	166	<DL	-	28.0	86	43	1900	<DL	-	25.0	99	51	466	<DL	-	30.0	93	43
Total Organic Carbon	mg/l	16	<DL	-	4.2	60	56	510	<DL	-	4.8	72	62	20	<DL	-	4.0	60	56
Calcium	mg/l	60.7	12	35.0	33.0	19	19	134	62	102.2	105.0	21	21	56	9	31.0	29.0	21	21
Calcium (Diss)	mg/l							120	117	118.5	118.5	2	2						
Magnesium	mg/l	8.71	<DL	-	6.5	21	15	39	<DL	-	5.8	21	17	8.96	<DL	-	6.0	21	15
Magnesium (Diss)	mg/l							7	7	7.0	7.0	2	2						
Sodium	mg/l	29	12	20.0	19.0	21	21	1330	20.4	105.8	29.6	20	20	27	11	19.1	18.4	21	21
Sodium (Diss)	mg/l							26	26	26.0	26.0	2	2						
Potassium	mg/l	16	<DL	-	4.5	21	20	530	<DL	-	4.1	21	20	15	<DL	-	4.3	21	20
Potassium (Diss)	mg/l							5	5	5.0	5.0	2	2						
Alkalinity	mg/l $CaCO_3$	140	9	77.4	76.0	21	21	3440	18.5	348.7	221.0	23	23	125	6.5	67.9	64.5	21	21
Total Sulphur	mg/l SO_4	28	5	17.5	17.0	19	19	48	21	33.1	33.0	19	19	31	5	16.9	17.0	19	19
Sulphide	mg/l	0.08	<DL	-	0.08	2	1	0.09	<DL	-	0.06	4	3	0.02	0.01	0.02	0.02	2	2
Chloride	mg/l	79	<DL	-	28.6	155	154	300	20	52.4	44.0	375	375	66	<DL	-	28.0	185	183
Total Oxidised Nitrogen	mg/l	9	2.27	5.0	4.8	18	18	20.6	0.7	9.7	9.5	20	20	8.8	1.61	4.8	4.6	18	18
Ammoniacal Nitrogen	mg/l N	10.8	<DL	-	0.2	156	102	32.3	<DL	-	0.6	367	220	9.9	<DL	-	0.2	185	115
Phosphate	mg/l	0.02	<DL	-	0.01	11	2	0.02	<DL	-	0.02	11	2	0.05	<DL	-	0.01	11	3
Iron	mg/l	7.6	<DL	-	0.39	51	24	6.18	<DL	-	0.09	60	29	6.3	<DL	-	0.35	50	23
Iron (Diss)	mg/l							0	0	0	0	2	2						
Manganese	mg/l	0.55	<DL	-	0.03	19	8	0.54	<DL	-	0.01	20	7	0.39	<DL	-	0.03	19	8
Manganese (Diss)	mg/l							0	0	0.0	0.0	2	2						
Zinc	mg/l	0.11	<DL	-	0.0	51	17	20	<DL	-	0.0	61	16	0.05	<DL	-	0.0	50	10
Zinc (Diss)	mg/l							0	<DL	-	0.0	3	2						
Cadmium	mg/l	0.005	<DL	-	0.0045	18	2	0.5	<DL	-	0.006	20	3	0.5	<DL	-	0.2505	17	2
Cadmium (Diss)	mg/l							0.001	<DL	-	0.001	3	2						
Copper	mg/l	0.04	<DL	-	0.02	19	5	0.05	<DL	-	0.02	20	3	0.03	<DL	-	0.01	19	4

	Units	Downstream						Spring						Upstream					
		max	min	mean	Median*	N	no. > DL	max	min	mean	Median*	n	no. > DL	max	min	mean	Median*	n	no. > DL
Copper (Diss)	mg/l							0	<DL	-	0	3	2						
Lead	mg/l	0.18	<DL	-	0.01	19	4	0.07	<DL	-	0.01	20	3	0.08	<DL	-	0.01	18	3
Lead (Diss)	mg/l							0.01	<DL	-	0.01	3	2						
Mercury	mg/l	0.01	<DL	-	0.01	14	4	0.05	<DL	-	0.02	16	4	0.03	<DL	-	0.02	14	4
Nickel	mg/l	0.04	<DL	-	0.005	19	4	0.007	<DL	-	0.005	19	2	0.06	<DL	-	0.010	18	3
Nickel (Diss)	mg/l							0	<DL	-	0	3	2						
Chromium	mg/l	0.006	<DL	-	0.01	18	2	1.02	<DL	-	0.01	19	3	10.38	<DL	-	5.19	18	2
Chromium (Diss)	mg/l							<DL	<DL	-	-	1	0						
Titanium (Diss)	µg/l							<DL	<DL	-	-	1	0						
Thallium (Diss)	µg/l							<DL	<DL	-	-	1	0						
Vanadium (Diss)	mg/l							0.005	0.005	0.005	0.005	1	1						
Colbalt (Diss)	mg/l							<DL	<DL	-	-	1	0						
Barium (Diss)	mg/l							0.067	0.067	0.067	0.067	1	1						
Antimony	mg/l							0.001	0.001	0.001	0.001	1	1						
Arsenic (Diss)	mg/l							<DL	<DL	-	-	1	0						
Beryllium	mg/l							<DL	<DL	-	-	1	0						
Molybdenum	mg/l							<DL	<DL	-	-	1	0						
Selenium (diss) ug/l	µg/l							1	1	1	1	1	1						
Silver (Diss)	mg/l							<DL	<DL	-	-	1	0						
Tin (Diss)	mg/l							<DL	<DL	-	-	1	0						
Tributyl Tin	mg/l							<DL	<DL	-	-	1	0						
Cyanide (Total)	mg/l							<DL	<DL	-	-	1	0						
Phenol(monohydric)	mg/l	0.1	<DL	-	0.1	4	1	0.1	<DL	-	0	10	3	0.1	<DL	-	0.1	4	1
Methane (Diss)	mg/l	<DL	<DL	-	-	1	0	<DL	<DL	-	-	1	0						
1,2,4-Drichlorobenzene	µg/l							<DL	<DL	-	-	1	0						
TPH >C6-C40	µg/l							<DL	<DL	-	-	1	0						
TPH >C6-C8	µg/l							<DL	<DL	-	-	1	0						
TPH >C8-C10	µg/l							<DL	<DL	-	-	1	0						
TPH >C10-C16	µg/l							<DL	<DL	-	-	1	0						

	Units	Downstream						Spring						Upstream					
		max	min	mean	Median*	N	no. > DL	max	min	mean	Median*	n	no. > DL	max	min	mean	Median*	n	no. > DL
TPH >C16-C24	µg/l							<DL	<DL	-	-	1	0						
TPH >C24-C40	µg/l							<DL	<DL	-	-	1	0						
MCPP (Mecoprop)	µg/l							<DL	<DL	-	-	1	0						
Dichlorprop	µg/l							<DL	<DL	-	-	1	0						
2,3,6-TBA	µg/l							<DL	<DL	-	-	1	0						
2,4,5-T	µg/l							<DL	<DL	-	-	1	0						
2,4-D	µg/l							<DL	<DL	-	-	1	0						
2,4-DB	µg/l							<DL	<DL	-	-	1	0						
Aldrin	ng/l							<DL	<DL	-	-	1	0						
Azinphos-methyl	µg/l							<DL	<DL	-	-	1	0						
Bromoxynil	µg/l							<DL	<DL	-	-	1	0						
Carbophenothion	µg/l							<DL	<DL	-	-	1	0						
Chlordane-alpha	ng/l							<DL	<DL	-	-	1	0						
Chlordane-gamma	ng/l							<DL	<DL	-	-	1	0						
Chlorfenvinphos	µg/l							<DL	<DL	-	-	1	0						
Chlortoluron	µg/l							<DL	<DL	-	-	1	0						
Demeton-s-methyl	µg/l							<DL	<DL	-	-	1	0						
Diazinon	µg/l							<DL	<DL	-	-	1	0						
Dicamba	µg/l							<DL	<DL	-	-	1	0						
Dichlobenil	ng/l							<DL	<DL	-	-	1	0						
Dichlorvos	µg/l							<DL	<DL	-	-	1	0						
Dieldrin	ng/l							<DL	<DL	-	-	1	0						
Dimethoate	µg/l							<DL	<DL	-	-	1	0						
Disulphoton	µg/l							<DL	<DL	-	-	1	0						
Diuron	µg/l							<DL	<DL	-	-	1	0						
Endosulphan-alpha	µg/l							<DL	<DL	-	-	1	0						
Endrin	ng/l							<DL	<DL	-	-	1	0						
Fenitrothion	µg/l							<DL	<DL	-	-	1	0						
Fenthion	µg/l							<DL	<DL	-	-	1	0						

	Units	Downstream						Spring						Upstream					
		max	min	mean	Median*	N	no. > DL	max	min	mean	Median*	n	no. > DL	max	min	mean	Median*	n	no. > DL
HCH-alpha	ng/l							<DL	<DL	-	-	1	0						
HCH-beta	ng/l							<DL	<DL	-	-	1	0						
HCH-gamma	ng/l							<DL	<DL	-	-	1	0						
Heptachlor Epoxide	ng/l							<DL	<DL	-	-	1	0						
Hexachlorobenzene	µg/l							<DL	<DL	-	-	1	0						
Hexachlorobutadiene	ng/l							<DL	<DL	-	-	1	0						
Ioxynil	µg/l							<DL	<DL	-	-	1	0						
Isoproturon	µg/l							<DL	<DL	-	-	1	0						
Linuron	µg/l							<DL	<DL	-	-	1	0						
lsodrin	ng/l							<DL	<DL	-	-	1	0						
Malathion	µg/l							<DL	<DL	-	-	1	0						
MCPA	µg/l							<DL	<DL	-	-	1	0						
MCPB	µg/l							<DL	<DL	-	-	1	0						
Mevinphos	µg/l							<DL	<DL	-	-	1	0						
Monuron	µg/l							<DL	<DL	-	-	1	0						
o,p-DDE	ng/l							<DL	<DL	-	-	1	0						
o,p-DDT	ng/l							<DL	<DL	-	-	1	0						
o,p-TDE	ng/l							<DL	<DL	-	-	1	0						
p,p-DDE	ng/l							<DL	<DL	-	-	1	0						
p,p-DDT	ng/l							<DL	<DL	-	-	1	0						
p,p-TDE	ng/l							<DL	<DL	-	-	1	0						
Parathion ethyl	µg/l							<DL	<DL	-	-	1	0						
Parathion-methyl	µg/l							<DL	<DL	-	-	1	0						
Phorate	µg/l							<DL	<DL	-	-	1	0						
Pirimiphos-methyl	µg/l							<DL	<DL	-	-	1	0						
Propetamphos	µg/l							<DL	<DL	-	-	1	0						
Tecnazene	ng/l							<DL	<DL	-	-	1	0						
Triallate	ng/l							<DL	<DL	-	-	1	0						
Triazophos	µg/l							<DL	<DL	-	-	1	0						

	Units	Downstream						Spring						Upstream					
		max	min	mean	Median*	N	no. > DL	max	min	mean	Median*	n	no. > DL	max	min	mean	Median*	n	no. > DL
Trifluralin	ng/l							<DL	<DL	-	-	1	0						
Triphenyltin	µg/l							<DL	<DL	-	-	1	0						
Chloroform	µg/l							2.8	2.8	2.8	2.8	1	1						

DL = Detection limit.

* Median calculation excludes values less than detection limit.

Note – Detection limits changed during the course of monitoring for most determinands.

A.5.A.5 RISK ASSESSMENT METHODOLOGY

Risk assessment is the process of collating known information on a hazard or set of hazards in order to estimate actual or potential risks to receptors. The receptor may be human health, a water resource, a sensitive local ecosystem or even future construction materials. Receptors can be connected with the hazard under consideration via one or several exposure pathways (e.g. the pathway of direct contact). Risks are generally managed by isolating or removing the hazard, isolating the receptor, or by intercepting the exposure pathway. Without the three essential components of a source (hazard), pathway and receptor, there can be no risk. Thus, the mere presence of a hazard at a site does not mean that there will necessarily be attendant risks. The following risk assessment thus focuses on those parts of the site where hazards or potential hazards have been identified and is not general to the whole site.

Hazards

Potential sources of contamination are identified for the site, based on a review of the current and previous site uses. Not only the nature but also the likely extent of any contamination is considered, e.g. whether such contamination is likely to be localised or widespread.

Receptors

The varying effects of a hazard on individual receptors depend largely on the sensitivity of the target. Receptors include any people, animal or plant population, or natural or economic resources within the range of the source which are connected to the source by the transport pathway. Receptors can, in addition, extend to remediation processes and future construction materials that may be adversely affected by on-site contamination. In general, however, receptors can be divided into a number of groups depending on the final use of the site.

Pathways

The mere presence of contamination does not infer a risk. The exposure pathway determines the dose delivered to the receptor and the effective dose determines the extent of the adverse effect on the receptor. The pathway which transports the contaminants to the receptor or target generally involves conveyance via soil, water or air.

Exposure Assessment

By considering the source, pathway and receptor, an assessment is made for each contaminant on a receptor by receptor basis with reference to the significance and degree of the risk. In assessing this information, a measure is made of whether the source contamination can reach a receptor, determining whether it is of a major or minor significance. The exposure risks are assessed against the present site conditions.

The assessment of risk presented here has been based upon the procedure outlined in DETR Circular 02/2000. In addition DETR, with the Environment Agency and the Institute of Environment & Health, has published guidance on risk assessment (Guidelines for Environmental Risk Assessment and Management).

This guidance from DEFRA and CIRIA states that the designation of risk is based upon a consideration of both:

The likelihood of an event (probability); [takes into account both the presence of the hazard and receptor and the integrity of the pathway].

The severity of the potential consequence [takes into account both the potential severity of the hazard and the sensitivity of the receptor].

Under such a classification system the following categorisation of risk has been developed and the terminology adopted as follows:

Term	Description
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.

Dilution calculation

$Q_1.C_1 + Q_2.C_2 = Q_t.C_t$

$Q_t = Q_1 + Q_2$

Where:

Q_1 Rate at which leachate enters groundwater

Q_2 Groundwater flow

C_1 Concentration of Chloride in leachate

C_2 Background concentration of Chloride in groundwater

C_t Concentration of chloride in groundwater at receptor

Formula:

$Q_1.C_1 + Q_2.C_2 = Q_t.C_t$

$\therefore Q_1.C_1 + Q_2.C_2 = (Q_1+Q_2).C_t$

$\therefore Q_1.C_1 + Q_2.C_2 = C_t.Q_{1+} C_t.Q_1$

$\therefore Q_1.C_1 - Ct.Q1 = C_t.Q_2 - Q_2.C_2$

$\therefore Q_1.(C_1 - Ct) = Q2.(C_t. - C_2)$

$\therefore (C_1 - Ct)/(Ct. - C_2) = Q_2/Q_1$

Receptor	C_1	C_2	C_t	Q_2/Q_1
Spring 3805	41	44	1253.7	
Downstream borehole	3805	41	79	98.1

APPENDIX A5.2 GROUNDWATER RISK ASSESSMENT : SITE B

1. Introduction

The base of Site B is above ground water 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. All water which enters the wastes will become leachate and need to be managed to ensure no significant adverse impacts arise.

Any liquid wastes which may have entered the landfill would also contribute to the generation of landfill leachate.

Water borne emissions are normally controlled by:

- routeing 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
- Treatment of leachate followed by consented discharge.

Wastes will degrade and produce gas and leachate over many decades. Leachate generation is a combination of degradation, and flushing through water circulation. Wastes will biodegrade and dissolve in water over many decades. The less water that enters the site the longer this period will be but emissions will be more dilute. In addition, while travel times to potential receptors are rapid for surface water runoff, movement into and through the geosphere may be slow depending upon the specific landfill construction and geology and hydrogeology of the site.

1.1 Approach

A human health risk assessment requires that a conceptual model of the site is derived identifying the nature of the source for water borne emission, the potential receptors and pathways to these receptors. This requires collection of existing information from the landfill operator and regulator. Where this is not available or incomplete there will be a requirement to collect direct information or adopt a rationale for estimating the exposure of humans to direct or indirect water borne emissions from landfill.

The conceptual model was used as the basis for quantifying the human exposure to water borne emissions from the landfill, either direct exposure such as surface or groundwater abstraction for potable supply, or indirect exposure through the food chain. Indirect exposure could occur if, for example, potentially contaminated water were to be used for irrigation of vegetables or as drinking water for farm animals. The loading of contaminants reaching identified receptors was assessed as part of this study.

1.2 Methodology

The methodology is based on:

- collection of information for the site and development of conceptual model;
- quantification of the likely exposure;

- assessment of the significance of this exposure.

1.3 Information Sources

Information has been obtained for the following items from the sources indicated:

1.3.1 Information on sources/hazards

- Site history and practices
- Waste types
- Surface water management
- Engineering barrier system (EBS)
- Leachate quality (site specific or UK database)
- Leachate control
- Leachate treatment/disposal

} Site operator

1.3.2 Information on pathways

◆ Leakage through EBS	Site operator
◆ Geology	Published maps and site operator
◆ Hydrogeology	Published maps and site operator
◆ Aquifer status	EA web site
◆ Licensed abstractions	Site operator
◆ Unlicensed abstractions	Farm studies report
◆ Location of springs	Published maps
◆ Hydrology	Published maps and EA
◆ Water level and quality monitoring data	Site operator

1.3.3 Information on receptors

- Groundwater abstraction, treatment and use (particularly private supplies)
- Surface water abstraction, treatment and use

} Site operator

- Via food where water used for stock drinking/irrigation. Farm survey report

Some of the information on geology and hydrogeology of the site was contained within a consultants site investigation report produced before the start of the landfilling operation. Other information was provided as raw data. No further information on groundwater risk assessment was available from the operator.

A site walkover was also undertaken to gain a better understanding of the area and how the landfill interacts with the hydrological regime.

1.4 Quantification of Exposure

The extent of any exposure of human receptors to water borne emissions from the landfill have been quantified or estimated to the extent that the data allowed. This has required assessment of, for instance the quality of leachate entering groundwater, the affects of retardation, attenuation and degradation within the geosphere, concentrations at the receptor and the potential for intake at each receptor.

The concentrations at the receptors to which humans could be exposed were based on either measured concentrations or concentrations estimated using presumed concentrations in leachate and calculated dilution rates. Models can be used to estimate leakage of leachate and fate and transport in the geosphere and therefore to further quantify exposure. However at Site B, the results and the data made available to Enviros did not support their use.

1.5 Comparison with Other UK Landfill Sites

Health based assessments of other UK landfill sites are extremely limited. However we have used our knowledge of landfill site settings to indicate whether the sources, pathways and receptors are representative of UK landfill sites.

2. site sensitivity

2.1 Topography

Site B is located at the site of a mineral excavation quarry. The surrounding land is gently undulating (Ref 1)

The site has been quarried, leaving a partially filled void in the centre part of this area which is being used as the landfill.

2.2 Geology

The geology of the mineral excavation site comprises variable drift underlain by sandstone (Ref 2 and 4). The drift is variable with permeable drift (sand and gravel) directly overlying the major aquifer along a north south axis in the centre of the site. Elsewhere low permeability drift is present between the aquifer and the permeable drift. The permeable drift is overlain by lower permeability till. The thickness of the permeable drift ranges from 5.2m to 15.4m.

The underlying sandstone is approximately 30m in thickness. The sandstone is a soft red weathered sandstone which becomes stronger with depth. The sandstone is underlain by 20m marl and beneath that limestone.

2.3 Hydrogeology

The sandstone is classified as a “major aquifer” with significant groundwater movement in fractures and the potential for high bulk permeability.

Groundwater is abstracted in the north of the site for mineral washing. The borehole is licensed to abstract up to 220,000 m3/a, although the actual volumes abstracted are not known.

Two other licensed groundwater abstractions are present within 1km of the site. An abstraction close to the fishing ponds to the south of the site is licensed to abstract 16366 m3/a between March and October. An abstraction approximately 400m east of the site is licensed to abstract for spray irrigation between March and October, although the volume of this abstraction is not known. Further abstractions for agricultural and domestic uses are located between 1 and 2 km

to the south-east, north-east and west of the site. There are no unlicensed abstractions in use within 2km of the site.

Two abstraction boreholes are located greater than 2km to the north-east of the site. The Environment Agency has produced groundwater protection zones for these abstractions. This defines the parts of the local area from which groundwater will flow to the abstractions. The landfill area falls within the total groundwater protection zone and it is therefore likely that groundwater beneath the site will flow to the abstractions.

2.3.1 Groundwater Flow

A series of boreholes were drilled before landfilling commenced, including an abstraction well in the north of the site and five monitoring wells around the site.

The monitoring boreholes were drilled through the drift into the major aquifer and demonstrated that groundwater flow was from the north to the south-east with a gradient of approximately of 0.0022 m/m. Groundwater levels were approximately 13 to 16.5m below the local ground level. Groundwater in the permeable drift and in the sandstone are considered likely to be in continuity.

Pumping tests of the 76m abstraction well indicated transmissitivities of approximately 700m^2/day for the two major aquifers. The borehole record states that it was cased through the 3m thick sand and gravel and also cased through the marl (a deeper non-aquifer). It is therefore assumed that the borehole includes a response zone in both the sandstone and the deeper limestone.

The previous boreholes are still routinely monitored and recent data confirms a flow from north to south. Levels in the north of the site (BH2 and BH3) were typically 3m higher than other boreholes suggesting an increased gradient across the centre of the site.

The landfill lies above the natural water table and so leachate from the site can percolate downwards to groundwater. However because the groundwater level is below the waste there is no potential for groundwater to flow into the waste. Groundwater management systems are therefore not required for this site.

2.4 Hydrology

A settling lagoon is present in the north of the site. Although this was not lined on construction, many years of settling may have lead to siltation of the base of the lagoon, which could limit water leaking downwards. The depth of the lagoon is not known.

A stream is present along the eastern boundary of the site which currently discharges to land. Potentially this could also connect to a second stream which flows to the east in a wooded area adjacent to the east of the site, although this does not at present occur.

A series of man-made fishing ponds are present to the south of the site, with the closest 30m from the southern boundary of the site. These are fed by a series of drains on field boundaries close to lakes, and in the summer groundwater is pumped to help maintain levels from a borehole adjacent to the pond approximately 300m south of the site.

These streams and lakes have water levels considerably higher than those in the aquifer and are located on the lower permeability till. Aside from groundwater abstraction to top up levels these water bodies are not considered to be in hydraulic connectivity with the aquifer.

3. Landfill Operation

The site has been accepting waste for 10 years. Most of the received waste is municipal waste, and although trade waste is taken this generally relates to local tourism industry and is therefore similar to municipal waste. Some bonded asbestos is accepted. The management of asbestos and other hazardous materials is governed by the terms of the waste management licence for the site.

Six phases have been filled in the northeast and central eastern areas of the site. However the oldest phases completed by 1996 are to be raised and re-capped with HDPE in the coming years.

The mineral excavation site was excavated to the water levels and in places to levels below this using dewatering. Before filling overburden has been replaced to a level of 4m above the water table. All cells are then lined with 1m of clay of permeability 10^{-9} m/s or less.

Leachate heads are maintained at a level not exceeding 1m head, using two extraction points in each cell. Leachate is removed by tanker for treatment at an off-site sewage treatment works.

4. Leachate, groundwater and surface water quality data

4.1 Data

Information on groundwater, surface water and leachate quality was provided by the landfill operator. This comprised electronic files of data since 2000 from the operator's database.

4.2 Identification of significant contaminants

The available data has been screened to assess whether the concentrations of parameters measured are significant with respect to toxicological effects on humans. In the first instance, the Drinking Water Standards (Ref. 7) have been used for those parameters where a permitted level is specified. Where not available, knowledge of similar systems has been used to identify elevated concentrations. Gross indicators (e.g. Biological Oxygen Demand, conductivity etc) have not been included in this assessment as more specific data are available.

4.3 Leachate

Leachate quality has regularly been sampled for chemical analysis from a number of locations. The dataset is reasonably comprehensive but does not include organic contaminants. Information on leachate quality is summarised in Annex 2, which also includes leachate quality data from the database in Ref 6 which includes analyses from up to 67 landfill sites for the 27 substances.

A direct comparison of the concentration of determinands in the leachate with leachate quality or drinking water standards would not provide useful information on likely human exposures. In the following two sections discussing the chemical quality of both the groundwater and surface water, where concentrations of determinands in groundwater have found to be indicative of a possible contribution from the site, the measured levels have been evaluated to determine whether a possible link between site emissions and groundwater could exist.

4.4 Groundwater Quality

Groundwater quality data has also been measured from a number of points, this data is summarised in Table 1.

The groundwater quality data obtained before landfilling commenced indicated a relatively low level of key determinants. Maximum concentrations were ammonia 0.09 mg/l, Chemical Oxygen Demand (COD) 28 mg/l, Biological Oxygen Demand (BOD) 1.5 mg/l, Chloride up to 110 mg/l, and electrical conductivity up to 920 µS/cm.

Current concentrations of chloride in groundwater are generally within the range of the concentrations measured before landfilling, although sporadic results from BH1, BH5 and BH5A are outside of this range. At BH5 elevated chloride concentrations in the range 259 mg/l to 689 mg/l have been detected on six of the thirty nine sampling rounds since January 2000.

Electrical conductivity results are also generally within or slightly in excess of the range from before landfilling. Sporadic elevated levels up to 2880 have been detected at BH1, BH5 and BH5A.

Concentrations of ammonia in groundwater are more variable than those measured before landfilling, with concentrations typically in the range from below the detection limit to 1mg/l. Sporadically higher concentrations between 1 and 5 mg/l have been detected in most boreholes.

Aside from the ammonia results these concentrations suggest that groundwater has not been consistently impacted by leachate. Even the elevated concentrations of ammonia are significantly lower than the concentrations in leachate, but may indicate an influence of diluted leachate on groundwater.

The general groundwater concentrations suggest that significant dilution and attenuation occurs beneath the site. From the available data it is not clear why the sporadically elevated concentrations of chloride and ammonia, and high electrical conductivity, have been detected, although this could relate to changes in sampling methods or to sampling from different levels.

Concentrations of other anion and cations have typically been analysed less frequently. Concentrations of metals in groundwater are more variable than those measured before landfilling, with mean or median concentrations greater than or equal to the maximum concentrations recorded before infilling. No data is available on organic compounds.

4.5 Surface water Quality

Surface water quality has been measured from a number of points. This data is summarised in Table A5.9.

Surface water concentrations in the fishpond and the stream along the eastern boundary are more difficult to interpret without access to data from before landfilling. Concentrations of electrical conductivity, ammonia and chloride are generally similar to groundwater with sporadically elevated concentrations. At the fish pond concentrations of chloride may be slightly elevated (typical range 100 – 120 mg/l) compared to those in groundwater.

Table A5.8 Groundwater data

Selected substances	Pre infilling			Groundwater Quality Site B 2000 – 2003					DWS
	Minimum	Maximum	Number	Minimum	Maximum	Median concentration	Mean Concentration	Number	
Chloride (mg/l)	26	110	4	8	689	49	72.76	235	250
Arsenic (µg/l)	<5	12.04	4	<1	<1			6	10
Chromium (µg/l)	<2	<2	4	<5	1010	5	45.88	83	50
Copper (µg/l)	-	-	-	5	40	20	16.10	71	2000
Lead (µg/l)	<5	<5	4	5	40	10	13.54	83	25*
Nickel (µg/l)	<5	<5	4	<5	580	7	33.34	83	20
Zinc (µg/l)	<10	31	4	<4	1150	30	47.33	83	
pH (Field)	6.9	7.1	4	6.3	14	7.435	7.593	246	
BOD (mg/l)	<1	1.5	4	<2	2	2	2	26	
COD (mg/l)	3	28	4	<20	288	20	32.465	114	
Conductivity (Field) (uS / cm)	750	920	4	120	2480	803	839.01	227	2500
Ammoniacal Nitrogen (N:mg/l)	<0.04	0.097	4	<0.04	5.5	0.175	0.397	218	0.39

Grey = exceed DWS

* - DWS from 2003 – 2013

** - compared to the DWS for mineral oil

Table A5.9 Surface water data

Selected substances)	Surface water Quality Site B 2000 – 2003					DWS
	Minimum	Maximum	Median concentration	Mean Concentration	Number	
Chloride (mg/l)	16	493	74	82.35	75	250
Arsenic (µg/l)	1	1	1	1	1	10
Chromium (µg/l)	<5	45	5	11.76	17	50
Copper (µg/l)	<5	30	20	15.64	14	2000
Lead (µg/l)	<5	50	10	14.41	17	25*
Nickel (µg/l)	<5	30	7	13.18	17	20
Zinc (µg/l)	<8	40	30	26.29	17	
pH (Field)	5	14	7.8	7.82	80	
BOD (mg/l)	<1	21	2	3.17	29	
COD (mg/l)	20	334	27	43.65	75	
Conductivity (Field) (uS / cm)	317	1750	600	650.20	74	2500
Ammoniacal Nitrogen (N:mg/l)	<0.04	3.94	0.41	0.55	70	0.39

Grey = exceed DWS

* - DWS from 2003 – 2013

** - compared to the DWS for mineral oil

5. conceptual model & risk assessment

5.1 Conceptual Model

Landfill risk assessment is based on development of a conceptual model for the site in question. This is a representation of the relationship between contaminant sources, pathways and receptors developed on the basis of hazard identification.

This study is limited to effect of landfills on human health and only considers pathways via emissions to waters, which for this site relates to pathways via the groundwater. This limits the sources and receptors discussed to:

5.1.1 Source

The source of potential emissions to waters is landfill leachate. Determinands which have been identified as of concern from the site are ammoniacal nitrogen and metals. Other pollutants such as those identified in Ref. 6 could be also present for however there is no site specific data for these.

5.1.2 Receptors - Groundwater

Groundwater flow within the aquifer is from the north to the south. Based on the depth to groundwater local inhabitants are considered unlikely to come into contact with in-situ groundwater, however some local residents use water taken from the groundwater abstractions.

Due to the presence of a number of groundwater abstractions in the local area, if there are significant releases of contaminants to groundwater these could affect;

- Farm workers who handle abstracted water,
- Livestock (e.g. pigs given abstraction water),
- Crops irrigated using abstracted water and agricultural workers
- Users of the fishing ponds as the levels of these surface water bodies are increased using abstracted water as described below.

5.1.3 Receptor - Surface water

Due to the depth of the cells used, the requirement to keep leachate head at 1m above the base, and the presence of low permeability till in the area around the site, leachate emission are unlikely to directly impact surface waters.

However as the levels in fishing ponds are increased using abstracted water these ponds could receive impacted groundwater. The frequency of the abstraction and discharge to the lakes is not known.

If contamination reaches the fishing lakes both the fish and amenity users could be exposed.

5.2 Qualitative Risk Assessment

A qualitative risk assessment has been undertaken for these potential source-pathway-receptor linkages based on DEFRA (Ref. 8) and CIRIA guidance (Ref. 9). This is based on consideration of both:

- the likelihood of an event (probability – takes into account both the presence of the hazard and receptor and the integrity of the pathway);
- the severity of the potential consequence (takes into account both the potential severity of the hazard and the sensitivity of the receptor).

Further information on the risk assessment methodology used is given in Annex 5.

Table A5.10 Qualitative Risk Assessment

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 levels in fishing 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 fishing 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
		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

Source	Pollutant	Receptors	Pathways to Receptor	Associated Hazard [Severity]	Likelihood of Occurrence	Potential Risk
Landfill leachate	Organics and other determinands listed in Ref. 6	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 levels in fishing 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 fishing 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

5.3 Quantitative Risk Assessment

For the risks assessed as moderate / low identified by the qualitative risk assessment, and for those risks where actual data is not available for the site, further analysis has been undertaken to quantify the concentration of the contaminants at the receptor.

Using the limited data available, a dilution factor can be calculated using a simple mass balance calculation (Appendix 3). The lack of consistent measurable impacts to existing groundwater quality means that that the dilution of leachate in groundwater cannot be estimated from changes in groundwater quality. However dilution factors can be estimated by comparison of flows in the aquifer with volumes of leachate which could reach the unsaturated zone beneath the landfill liner.

5.3.1 Volume of Leachate

The volume of leachate which could reach the unsaturated zone beneath the landfill liner has been estimated using an estimate of 3mm/a for vertical leakage, and the area of the phases filled to date.

The volume of leachate is therefore estimated as

Leachate flow (L) = vertical leakage x area

= 3 mm/a x 131000m^2

= 0.003 m/a / 365 d/a x 131000 m^2

= 0.003 m/a / 365 d/a x 131000 m^2

= 1.077 m^3/d

5.3.2 Impact to groundwater

Leachate emitted from the landfill will need to pass through the 4m unsaturated zone beneath the landfill. During this unsaturated flow, concentrations of contaminants will be attenuated, however for the purposes of this assessment the effect of this attenuation on lowering concentrations has not been considered.

Leachate will then enter the shallow groundwater and be diluted into this groundwater. The extent of this dilution will depend on the mixing zones in the aquifer. However as the abstractions extend significantly into the sandstone, a dilution factor has been estimated based on the full thickness of the aquifer

The volume of groundwater flow can be estimated using Darcy's Law. The flow per day can be estimated using the transmissivity (500m^2/d) multiplied by the gradient (0.0022) multiplied by the width of the site perpendicular to flow (approx 300m)

Darcys Law

Groundwater flow (Q) = permeability (K) x Area (A) x gradient(i)

or Q = transmissivity (T) x Width (W) x gradient(i)

Q = 500 m^2/d x 300m x 0.0022

= 330 m^3/d

These estimates suggest leachate may be diluted by a factor of approximately;

DF = 1.077 / 330

= 1 : 306

The groundwater abstracted from downstream of the site would therefore be expected to contain concentrations approximately 300 times lower than the leachate concentration shown in Appendix 1. Table A5.11 below shows the effect of a dilution of 1: 306.

Further attenuation will occur as the groundwater migrates downstream, however there is unlikely to be any significant further dilution. The impact of attenuation on the quality at the boreholes further downstream has not been taken into account, so as to ensure the assessment is conservative.

Table A5.11 Calculated receptor concentrations

Selected substances (Ref. 6)	Leachate Quality from Database or site data		Groundwater beneath the site (based on 1:306 dilution factor)		DWS[1]/ WHO[2]/ other[3]
	Median	Mean	Median	Mean	
Aniline (µg/l)	<1	<1.46	<0.0033	<0.0048	13
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	0.0139	82
Ethylbenzene (µg/l)	<10	19	<0.033	0.0621	Not available
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	0.1399	202
Nitrogen (Total) (mg/l)	364	629	1.1895	2.0556	Not available
Organo-tin (µg/l)	0.2	0.3	0.0007	0.0010	Not available
Phenols (mg/l)	0.03	0.35	0.0001	0.0011	0.005
Phosphorus (mg/l)	3	3.9	0.0098	0.0127	2.21
Polycyclic aromatic hydrocarbons (µg/l)	<5.25	<5.60	<0.0172	<0.0183	0.11
Nonyl phenol (µg/l)	1	4.9	0.0033	0.0160	Not available
Biphenyl (µg/l)	0.1	0.46	0.0003	0.0015	Not available
Mecoprop (µg/l)	11	21.8	0.0359	0.0712	0.1
Naphthalene (µg/l)	0.46	3.04	0.0015	0.0099	Not available
Pentachlorophenol and compounds (µg/l)	<0.1	0.32	<0.00033	0.0010	13
Toluene (µg/l)	21	87	0.0686	0.2843	Not available
Xylenes (µg/l)	35	59	0.1144	0.1928	Not available

Selected substances (Ref. 6)	Leachate Quality from Database or site data		Groundwater beneath the site (based on 1:306 dilution factor)		DWS[1]/ WHO[2]/ other[3]
	Median	Mean	Median	Mean	
Arsenic (µg/l)	8	16	0.0261	0.0523	10
Chloride (mg/l)	1160	1123	3.7908	3.6699	250
Chromium (µg/l)	29	57	0.0948	0.1863	50
Copper (µg/l)	20	57	0.0654	0.1863	2000
Lead (µg/l)	30	50	<0.1634	0.1634	25
Nickel (µg/l)	112	115	0.3660	0.3758	20
Zinc (µg/l)	270	563	0.8824	1.8399	Not available
Ammoniacal Nitrogen (N:mg/l)	520	549	1.6993	1.7941	0.39

1 = DWS 2000 or 1989

2 = WHO Guidelines v2

3 = other guidelines (Refs 10, 11, 12)

4 = Value for pesticides used

With the exception of ammoniacal nitrogen the predicted concentrations do not exceed drinking water standards where these exist. In most cases, the predicted concentrations are below the analytical level of detection.

Predicted concentrations of ammoniacal nitrogen are predicted to exceed drinking water standards beneath the site, and although median concentrations in groundwater are currently less than those predicted, these also exceed drinking water standards. The actual concentrations beneath the site, and further down the flow path may be reduced due to the effects of retardation and degradation.

At many times the fishing ponds will receive uncontaminated surface water draining from the adjacent fields, however during drier periods a greater volume of the water could be derived from groundwater. To be conservative it has therefore been assumed that fish and site users could be exposed to concentrations similar to those in groundwater.

6. Comparison with other UK landfill sites

The site was selected according to a number of specific criteria set out by the Environment Agency for the whole study, as set out in Table A5.12.

Table A5.12 Calculated Specification of landfill sites

Description	Criterion	Site B
Operational status	Open preferred	Open, with some earlier phases being raised.
Throughput	>100,000 tonnes per annum	132,000 tonnes per annum
Waste description	Predominantly domestic	Predominantly domestic
Local area description	Populated areas preferred	A number of farms close by,

		but no town or villages close to the site
Proximity of groundwater table	Within 10 metres preferred	Depth to groundwater 13 - 16.5m. Minimum of 4m of overburden between waste and water table.
Proximity of surface water	Within 50 metres preferred	Stream adjacent to landfill boundary, unlikely to be in continuity with groundwater. Other lagoons and ponds partially lined.

Atypical aspects of Site B are summarised below:

(a) Surface water features unlikely to be in continuity with groundwater

A stream, a settling lagoon and a series of man-made fishing ponds are present close to the site. However these streams and ponds have water levels considerably higher than those in the aquifer and are located on the lower permeability till. Aside from groundwater abstraction to top up levels these water bodies are not considered to be in hydraulic connectivity with the aquifer. The site therefore does not pose a direct risk to surface water, whereas direct risks do occur at other landfill sites.

7. Conclusions

Site B complies with the most of the criteria specified by the Environment Agency for the study.

It is atypical of many landfills in the UK in that the presence of low permeability drift prevents continuity between surface 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 sporadically elevated concentrations of Chloride, EC, ammonia and metals have also been detected. This could relate to changes in sampling methods or to sampling from different levels. Concentrations of ammonia predicted using a mass balance approach also exceeded drinking water standards.

The impact of other contaminants typically found in leachate, but which 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.

8. References

1. Ordnance Survey map, Scale 1:25,000

2. British Geological Survey map, Solid and Drift Edition. Scale 1:50,000

3. NRA Groundwater Vulnerability Map, Scale 1:100,000

4. Data supplied in a report from the landfill operator.

5. Pers. Comm.. from Site Manager to Enviros, November 2003.

6. Review of Environmental and Health Effects of Waste Management, Enviros report to DEFRA, 2004 (draft)

7. Water Supply (Water Quality) Regulations 2000 & 1989, HMSO

8. Department of Environment Transport and the Regions, Environment Agency and Institute for Environment and Health. Guidelines for Environmental Risk Assessment and Management. HMSO, July 2000

9. Construction Industry Research and Information Association (CIRIA). Contaminated Land Risk Assessment. A Guide to Good Practice. CIRIA C552 2001

10. MTBE -http://www.epa.gov/waterscience/drinking/mtbefact.pdf

11. Aniline - http://bordeaux.uwaterloo.ca/biology447/modules/module1/drinkingwatera-c.htm

12. Pentachlorophenol - http://www.epa.gov/safewater/mcl.html#mcls

ANNEXES TO GROUNDWATER RISK ASSESSMENT: SITE B

A.5.B.1 Leachate data

Selected substances	Leachate Quality Database Ref		Leachate Quality Site B			
	Median concentration	Mean Concentration	Minimum	Maximum	Median concentration	Mean Concentration
Aniline (µg/l)	<1	<1.46	-	-	-	-
Methyl tertiary butyl ether (µg/l)	<1	<1.38	-	-	-	-
Chloride (mg/l)	1145	1425	9	2430	1160	1123
Cyanide (as CN) (mg/l)	<0.05	<0.05	-	-	-	-
Di(2ethyl hexyl)phthalate (µg/l)	<1	4.25	-	-	-	-
Ethylbenzene (µg/l)	<10	19	-	-	-	-
Fluoride (mg/l)	0.65	0.86	-	-	-	-
Methyl chlorophenoxy acetic acid (µg/l)	<0.1	0.69	-	-	-	-
Dichloromethane (µg/l)	<1	42.8	-	-	-	-
Nitrogen (Total) (mg/l)	364	629	-	-	-	-
Organo-tin (µg/l)	0.2	0.3	-	-	-	-
Phenols (mg/l)	0.03	0.35	-	-	-	-
Phosphorus (mg/l)	3	3.9	-	-	-	-
Polycyclic aromatic hydrocarbons (µg/l)	<5.25	<5.60	-	-	-	-
Nonyl phenol (µg/l)	1	4.9	-	-	-	-
Biphenyl (µg/l)	0.1	0.46	-	-	-	-
Mecoprop (µg/l)	11	21.8	-	-	-	-
Naphthalene (µg/l)	0.46	3.04	-	-	-	-
Pentachlorophenol and compounds (µg/l)	<0.1	0.32	-	-	-	-
Toluene (µg/l)	21	87	-	-	-	-
Xylenes (µg/l)	35	59	-	-	-	-
Arsenic (µg/l)	8	16	-	-	-	-
Chromium (µg/l)	50	92	<5	490	29	57
Copper (µg/l)	11	26	6	680	20	57
Lead (µg/l)	<50	60	<10	330	30	50
Nickel (µg/l)	60	159	13	234	112	115
Zinc (µg/l)	135	1246	<30	2510	270	563
pH (Field)	-	-	6.5	8.4	7.4	7.40
BOD (mg/l)	-	-	<1	3330	102	165
COD (mg/l)	-	-	<20	11800	1430	1515
Conductivity (Field) (uS / cm)	-	-	392	21480	9870	9778
Ammoniacal Nitrogen (N:mg/l)	-	-	<0.3	1370	520	549

A.5.B.2 RISK ASSESSMENT METHODOLOGY

Risk assessment is the process of collating known information on a hazard or set of hazards in order to estimate actual or potential risks to receptors. The receptor may be human health, a water resource, a sensitive local ecosystem or even future construction materials. Receptors can be connected with the hazard under consideration via one or several exposure pathways (e.g. the pathway of direct contact). Risks are generally managed by isolating or removing the hazard, isolating the receptor, or by intercepting the exposure pathway. Without the three essential components of a source (hazard), pathway and receptor, there can be no risk. Thus, the mere presence of a hazard at a site does not mean that there will necessarily be attendant risks. The following risk assessment thus focuses on those parts of the site where hazards or potential hazards have been identified and is not general to the whole site.

Hazards

Potential sources of contamination are identified for the site, based on a review of the current and previous site uses. Not only the nature but also the likely extent of any contamination is considered, e.g. whether such contamination is likely to be localised or widespread.

Receptors

The varying effects of a hazard on individual receptors depend largely on the sensitivity of the target. Receptors include any people, animal or plant population, or natural or economic resources within the range of the source which are connected to the source by the transport pathway. Receptors can, in addition, extend to remediation processes and future construction materials that may be adversely affected by on-site contamination. In general, however, receptors can be divided into a number of groups depending on the final use of the site.

Pathways

The mere presence of contamination does not infer a risk. The exposure pathway determines the dose delivered to the receptor and the effective dose determines the extent of the adverse effect on the receptor. The pathway which transports the contaminants to the receptor or target generally involves conveyance via soil, water or air.

Exposure Assessment

By considering the source, pathway and receptor, an assessment is made for each contaminant on a receptor by receptor basis with reference to the significance and degree of the risk. In assessing this information, a measure is made of whether the source contamination can reach a receptor, determining whether it is of a major or minor significance. The exposure risks are assessed against the present site conditions.

The assessment of risk presented here has been based upon the procedure outlined in DETR Circular 02/2000. In addition DETR, with the Environment Agency and the Institute of Environment & Health, has published guidance on risk assessment (Guidelines for Environmental Risk Assessment and Management).

This guidance from DEFRA and CIRIA states that the designation of risk is based upon a consideration of both:

- The likelihood of an event (probability); [takes into account both the presence of the hazard and receptor and the integrity of the pathway].

- The severity of the potential consequence [takes into account both the potential severity of the hazard and the sensitivity of the receptor].

Under such a classification system the following categorisation of risk has been developed and the terminology adopted as follows:

Term	Description
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.

Appendix 6 : Farm survey report

1. INTRODUCTION

1.1 This report has been prepared by CPM Environmental Planning and Design on the instruction of the Environment Agency, through their lead consultant Enviros. It addresses agricultural issues for use within an exposure assessment of landfill sites being conducted by Enviros.

1.2 The research project aims to provide the Environment Agency and DEFRA with independent advice on the potential exposures which could arise from landfill site emissions.

1.3 Research into the activities of farm businesses within this area aims to identify any management practices that may be modifying the pathways of any population exposure to landfill emissions.

1.4 The assessment was 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.

2. METHODOLOGY

2.1 For the purposes of this assessment, the area surrounding the studied landfill sites was split into two zones. The first is within a two kilometre radius of the landfill centre point. The second is between two and seven kilometre radius. A number of farm businesses within these zones were identified using the Yellow Pages. Of those that 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.

2.2 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.

2.3 Prior to each interview it was agreed that the identity of the farm business would not be explicitly identified within the report, to the Environment Agency, DEFRA, the landfill operator or any regulatory body. While findings of the agricultural assessment are presented in this report, details of each interview will remain confidential to CPM and Enviros.

2.4 Following the visits to each farm holding and the farmer interviews, CPM consultants have made their own assessment of potential pathways for landfill emissions to be transmitted to local populations offered by the farm business. This assessment has not been communicated to the farmer.

2.5 At landfill site A landfill gas from capped cells is recovered for power generation. Landfill gas generated from completed cells at landfill site B is flared.

3. INTERVIEW SUMMARIES

Landfill Site A

Farm Business 1

3.1 Farm Business 1 is a small dairy unit that lies within the 2 – 7 km zone, centred approximately 5 km south south east of the landfill centre. The land has soils that are typically thin and stony, and drought stress is the principal limitation on cropping.

3.2 The farm occupies approximately 40 hectares of land held on a secure tenancy agreement. Approximately one third of this land is in arable rotation and has Integrated Administrative Control System (IACS) registration enabling the farm to claim area payments for cereal crops. The remaining land is all permanent pasture. Feed barley is grown on the arable land approximately one year in three. For the remainder of the rotation the land is in setaside or under ley pasture, cut for silage. The silage and feed barley is consumed by the farm's livestock.

3.3 The farm normally supports a herd of 40 – 50 dairy cows. As a result of FMD restrictions over the past year, the milking herd is down to 37 with a further 13 cows in calf, 14 heifers and 3 calves. The farm has a Limosan bull, the crossed calves (12 in January) being sold for fattening after 20 months. In addition to its own livestock, the farm land is used to graze over winter 250 ewe lambs from a hill farm 25 miles away.

3.4 Dairy cows are housed with a slurry based system. There is an underground tank for the slurry that also receives silage effluent. This tank has a capacity for five to six weeks, limiting the farmers choice on when slurry should be spread on the land. Any additional farmyard manure from the beef stores can be held in a field midden prior to spreading.

3.5 There are no surface watercourses within the farm's land. A spring is intercepted and piped away along with the farm yard storm water. All livestock troughs are mains fed. This could potentially result in a baseload of contamination on the watercourse, on which any contribution of emissions from the nearby landfill site would be superimposed.

3.6 The farm business consumes all of the barley and silage produced. It has no part in the sale of the ewe lambs that overwinter on its land. Livestock are normally sold through the local auction. FMD restrictions have closed this market but the farmer intends to return once it reopens.

3.7 The farm has a milk quota of 213,000 litres, two thirds of which is sold to Zenith. The remaining milk is pasteurised on farm for sale direct to local customers, including some retail outlets. The farmer's own family also consume this milk.

3.8 The farmer does not consider his farm operations interact with, or are limited by, the landfill site in any way. He is not aware of any incidence of landfill emissions affecting his farm or any adjoining land. The presence of the landfill site has no influence upon how the land or livestock are managed.

Farm Business 2

3.9 Farm Business 2 is a small sheep and beef enterprise, centred approximately 1.5 km east north east of the landfill site. The majority of the farmland lies within the 2 km zone. In addition to Landfill Site A, the farm lies close to a small inert waste site (recently capped).

3.10 The farm covers an area of approximately 49 hectares on a 12 month contract. Half of this land is IACS registered through which approximately 6 hectares of feed barley is grown per year, the remainder of the rotation being under setaside or pasture cut for silage. The non registered land is all under permanent pasture. Most of the land has medium textured

soils. The land on the western bank of a river flowing along the east side of the farm is clayey, and there are patches of stony material across the farm land.

3.11 The farm has a flock of 500 breeding ewes with 200 of the last year's lambs still on the farm. In addition the farm buys in calves for fattening and normally has 50 to 60. Owing to FMD restrictions these were down to 20 in January 2002. The farm also keeps two suckler cows and a few horses.

3.12 When housed, livestock are on straw. The farmyard manure is held in a field midden then spread on the available land. Silage is stored in bags rather than a clamp so there is no silage effluent to dispose of.

3.13 Livestock can access and drink from the adjacent river when in the fields along its western bank. Field troughs are mains fed. Rainwater is collected from the roofs of farm buildings for use by the housed livestock.

3.14 The unit's own livestock consume the silage and barley produced. Normally all livestock are sold through the local auction. Following FMD restrictions, the farmer has sent livestock direct to slaughter houses, sometimes in collaboration with other local livestock farmers. The farmer intends to return to using the local auction as soon as it reopens.

3.15 The farm does receive some windblown litter from the landfill site, obliging the farmer to collect it, particularly prior to operations such as sowing or silage making. However the farmer describes a nearby trunk road as a larger source of litter than the landfill site. Aside from the litter, the farmer is unaware of any interaction between the landfill site and his land, or of any incidence of landfill emissions affecting his farm business. The presence of some litter does not affect the choice of crop grown or the fields grazed by livestock.

Farm Business 3

3.16 Farm Business 3 is a sheep farm, the centre of which lies approximately 1.5 km south-south-west from the landfill centre point. The farmland adjoins the southern edge of the landfill site where soils are shallow and stony. It extends down the hill to the south where the soil changes to thicker red clay.

3.17 The farm occupies approximately 97 hectares of land, three quarters of which are owner occupied (bought in 1978). The remainder, including an outlying parcel of 6.5 hectares is held on a farm business tenancy. The outlying land lies outside of the 7 km zone, and the remainder is within the 2 km zone. Hay and silage cuts are taken from approximately 24 hectares of suitable land. The farmer does not consider the proximity of the landfill to affect the suitability of the land for hay and silage.

3.18 The farm currently has a herd of 700 ewes. Under normal (non-FMD) circumstances the farmer would have a herd of 800 to 900. In addition the farm also has 170 replacement ewe lambs and 12 rams. Four suckler cows that had remained unsold because of foot and mouth disease are now worthless, and the farm business will now terminate the suckler cow enterprise.

3.19 Housed livestock are held on straw, the resulting farmyard manure being held in field middens prior to being spread. All silage is bagged and so there is no need to dispose of silage effluent.

3.20 All livestock drinking troughs are mains fed. Stock may also drink from one spring. The farmer commented that high lead levels have been recorded in spring water in the surrounding area. If elevated lead levels have been recorded, this may be related to historical lead mining activities.

3.21 The farm has ongoing problems with vermin that in the farmer's opinion are made more acute by the presence of the landfill site. In the farmer's view, rat, bird and fox populations are all supported by the landfill site and this limits the farmer's ability to utilise the adjoining pasture land. Without the increased vermin population the farmer would make greater use

of this dry and sheltered land as it can carry stock year round and has sufficient shelter for young lambs.

3.22 In 2001 the farmer was unable to move ewes from the adjacent pasture land prior to lambing because of FMD restrictions. The farmer estimates that approximately 100 lambs were lost to foxes as a result. Large numbers of crows and gulls are supported by the landfill. The farmer estimates that approximately 30 ewes lose eyes to crows per year. The farmer's ability to control crow numbers is hampered by the presence of a Site of Special Scientific Interest (SSSI). Rats appear to come onto the land from the landfill in sudden occasional flushes, and are therefore difficult to control.

3.23 Prior to the landfill, the landowner had assisted local farmers by allowing shooting on the site now occupied by the landfill. The farmer believes that this would be difficult for the landfill operator because of the larger numbers of vermin and safety concerns in an active site.

3.24 Livestock are normally sold through the local auction. While this has remained closed the farmer has sent lambs to a number of slaughterhouses across the country, often in conjunction with other local farmers. Some lambs have been sold direct to a butcher in a nearby town. When the auction reopens the farmer intends to return, but may continue selling a small number of lambs direct to the butcher.

3.25 The farmer is concerned about the vermin problem attributed to the landfill site. He is also concerned that the landfill gas collection system is a potential explosion hazard. Very little litter comes onto the land as the farm is upwind of the site. The farmer is not aware of any landfill emissions affecting his land and, aside from the lead which may have been found in local spring water (see above), is unaware of any incidence of contamination in this area.

Landfill Site B

Farm Business 4

3.26 Farm Business 4 is a large arable unit based approximately 4.5 km north west of the landfill centre. It has no livestock enterprise, the fattening of sheep and cattle along with the pig enterprise having been scaled down progressively then terminated two years ago. The farmer pointed out that a nearby disused railway cutting has been filled using inert waste and that this lies closer to the farm than Landfill Site B.

3.27 The farm occupies approximately 350 hectares of land. 182 hectares of this land is a separate parcel, detached from the main unit, which lies within the 2 km zone, west of the landfill site. The remaining land all lies within the 2 to 7 km zone. All of the land within the 2 km zone is held on a farm business tenancy; the land in the outer zone is held on a mix of farm business tenancies and a more secure full agricultural tenancy.

3.28 9 hectares in the outer zone and 14 hectares in the inner zone are under permanent pasture. All of this land is sublet for grazing. All remaining land is in arable rotation and is registered for IACS. A typical rotation for this land comprises sugar beet, three wheat crops, beans and a further three wheat crops. This rotation is common to land in both the inner and outer zones, and the proximity of the landfill site has no influence upon rotation.

3.29 Soils across the land tend to be loamy and reasonably well drained. The outer zone does contain some less well drained clayey land and an area of peat.

3.30 Several watercourses, including surface water drainage ditches, cross the farm land. The farm does not use any irrigation. Livestock drinking troughs in the pasture fields are mains fed.

3.31 Some of the farmland is shot with patches of game cover crops grown. There have also been instances of trespassers hare coursing on the land.

3.32 A trunk road lies between the landfill site and the farmland within the inner zone. This provides an effective barrier reducing the potential for rats to come onto the farm from the landfill. The road verge itself does however act as a small reservoir for the rat population. The farmer considers that the presence of the landfill does raise the numbers of gulls in the area but these are only a minor nuisance to the farmer in both the inner and outer zones.

3.33 Sugar beet all goes to a sugar production plant. The combinable crops are all farm assured and are sold for the best available price nationwide.

3.34 The land closest to the landfill site does receive more wind blown litter than the remainder of the farmland, but not enough to be more than an irritation to the farmer. This land is also the closest to the trunk road and the farmer regards this as the primary source of the litter.

3.35 The presence of the landfill site does not constrain the farmer's management of any of his land. The farmer is unaware of any landfill emissions (other than visible litter) coming onto his land, or any pollution incidence on or around his farm.

Farm Business 5

3.36 Farm Business 5 is a small livestock enterprise that breeds sheep and fattens cattle. It lies approximately 1 km north of the landfill centre point and does not have any agricultural land that directly abuts the landfill site. A relatively consistent loamy soil cover is found across the holding.

3.37 The farm occupies approximately 28 hectares of land on a secure tenancy from the local authority. Approximately 8 hectares of this land is under permanent pasture, the remainder is in arable rotation and is IACS registered. Feed barley is rotated through this land once every four to five years. For the remaining time the land is under ley pasture (cut for hay) or in setaside. Proximity of the fields to the landfill site has no influence upon the arable rotation or whether the land is under permanent pasture.

3.38 The hay and most of the feed barley are consumed by the farm livestock. Approximately 10% of the barley is surplus and is sold on a price basis around the country. Approximately 15 years ago the farm business terminated its sugar beet enterprise. There have been no significant changes to the enterprise for the last 10 years.

3.39 The farm has a herd of 70 ewes with two rams. The ewes lamb in February with the lambs sold on for fattening. Calves are bought in for fattening with a herd of 50 to 60 calves. Four ponies are also kept on the farm.

3.40 All livestock drinking troughs are mains fed and there are no surface water courses crossing the farms land.

3.41 Farmyard manure from housed livestock is held in a field midden and spread ahead of the barley rotation. No silage cuts are taken so there is no need to dispose of silage effluent. Were the farm to start producing silage, bags would be used.

3.42 Prior to the FMD restrictions, all livestock were bought and sold through the local auction. Following the FMD restrictions, finished cattle are sold direct to a local butcher in a nearby town. The farmer is pleased with this arrangement and intends to continue selling cattle in this way after the auction reopens.

3.43 In the farmer's opinion, there is no interaction between his farm business and the landfill site as the neighbouring farm's fields buffer his land from it. He is not aware of any landfill emissions affecting his or the surrounding farmland and is not aware of any local incidence of pollution.

Farm Business 6

3.44 Farm Business 6 is a large agricultural estate that adjoins the landfill site to the south and east, The farm buildings and the majority of the land lie within the 2 km zone; some

farmland extends south into the 2 to 7 km zone. Soils across this area are a relatively constant moderately well drained material.

3.45 The estate is managed on behalf of the owner by a land agent, with land work undertaken by an agricultural contractor. The estate includes approximately 437 hectares of agricultural land, virtually all of which lies in a single block. Approximately 60 hectares is under permanent pasture and is sublet on a grazing licence to a local sheep farmer.

3.46 The remaining agricultural land is IACS registered. The cropping for 2002 is 148 ha wheat, 111 ha barley, 59 ha potatoes, 19 ha sugar beet and 40 ha under setaside. Both the potato and sugar beet crops are grown by other farm businesses, occupying the estate land under contract.

3.47 Farm buildings are sublet to another farm business for a 150 sow pig enterprise. The estate has no livestock of its own.

3.48 The pig unit is slurry based and the estate accepts all the waste generated. This waste is easily accepted by the available arable land.

3.49 Several surface water courses cross the estate land and include a small chain of fish ponds. Fishing rights are let to a local angling group, and are to shortly be transferred to another angling group. All livestock troughs in fields are mains fed. The estate has four bore holes. The pig unit draws water from one of these, the remaining three are used to irrigate the potato crop.

3.50 In addition to the agricultural land the farm also has approximately 100 hectares of commercial woodland including Christmas trees. Estate land is also used for commercial shooting.

3.51 The estate takes no part in the marketing of the pigs, sheep, potatoes and sugar beet raised by other farm businesses on its land. However it is known that the sugar beet goes to a sugar production plant. The wheat and barley crops are all produced under a farm assured scheme and are marketed through a pool. Fish and game leave the estate via the angling and shooting participants.

3.52 Litter can be seen in the hedgerows closest to the landfill site. Following windy weather the landfill operators organise collection of the litter. The presence of the litter constitutes a minor inconvenience to the running of the arable enterprise. The land agent is not aware of any landfill emissions reaching the estate land and does not know of any incidents of contamination on or around the estate.

3.53 Some agricultural land is accessed by crossing the landfill haul roads, requiring dedicated crossing facilities. However, in the land agent's opinion, the presence of the landfill site does not constrain the management of the estate's agricultural land.

3.54 When visited, the haul roads were heavily puddled in places with a deep pool of mud at one crossing. Sediment from the haul roads will therefore be carried onto the farm by vehicle wheels. Sediment may also flow from these roads into surface water courses, particularly following heavy rain.

4. RESEARCHER'S INTERPRETATION

4.1 All 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.

4.2 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.

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

4.4 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.

4.5 For each of the six farms studied, CPM has attempted to identify any activity that may affect the way in which produce could act as a vector for landfill emissions to the human population.

Landfill Site A

Farm Business 1

4.6 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

4.7 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

4.8 Farm Business 3 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 is sold to a butcher in a nearby town and will be consumed locally as a result.

Landfill Site B

Farm Business 4

4.9 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 ground water.

Farm Business 5

4.10 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 are sold through a butcher in a nearby town. The farmer intends 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

4.11 Farm Business 6 occupies agricultural land adjoining landfill site B. This estate operates four bore holes, abstracting ground water. 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.

4.12 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.

5. CONCLUSIONS

5.1 CPM has investigated the farming operations of six farm businesses based around two landfill sites. This research has been undertaken to assist in a population exposure to landfill emissions assessment being carried out by Enviros on behalf of the Environment Agency.

5.2 CPM has highlighted any practices or circumstances found at these farm businesses that may be influencing the role of agriculture as a vector between the landfill site and the surrounding population.

5.3 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 be affected by any landfill emissions rather than the mains, and abstracting groundwater for irrigating crops.

5.6 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.

5.7 No farmer interviewed was aware of any air or water borne landfill emissions (other than litter) affecting their farm business in any way. Farm visits by CPM found no evidence of such emissions affecting farm land or farming practices.

Appendix 7 : Landfill gas modelling records

The Environment Agency Gas-Sim v1.03 model was used to estimate the rate of production of landfill gas within each landfill site.

Table A7.1 : Site A Gas-sim input data

Phases	Liner	Cap	Start year	End year	Annual tonnage	Total tonnage
					T/yr	Tonnes
1	Single	Single clay	1983	1994	48,170	578,040
2	Single	Single clay	1995	2001	120,000	720,000
3a	Single	Composite	2002	Ongoing	150,000	-

Other study inputs used Gas-Sim default settings

Table A7.2 : Site B Waste input data (tonnes)

Year	Domestic	Commercial	Industrial	Inert	Chemical Sludge	Total
1996	63,600		16,256	62,732		142,588
1997	70,376		37,401	40,356		148,133
1998	65,464	9,266	9,553	52,430	1,428	138,141
1999	72,608	8,626	11,820	49,675	2,239	144,968
2000	75,715		17,235	45,785	1,794	140,529
2001	70,643	9,547	36,181	32,136	1,324	149,831
2002	16,991	2,714	10,595	7,839	233	38,372

Other study inputs used Gas-Sim default settings

Table A7.3 : Site A Landfill Gas Model results

Year	Volume of landfill gas generated (m3/hour)			
	Phase 1	Phase 2	Phase 3a	Total
2002 (50th percentile)	299	1298	-	1597
2002 (95th percentile)	322	1420	-	1742

Table A7.4 : Site B Landfill Gas Model results

Year	Volume of landfill gas generated (m3/hour)							
	Phase 1	Phase 2E	Phase 2W	Phase 3W	Phase 3E	Phase 4W	Phase 4E	Total
2002 (50th percentile)	38	41	55	48	72	152	222	627
2002 (95th percentile)	41	44	59	51	77	162	236	667

Appendix 8 : monitoring information database

A8.1 : Descriptive statistics for continuous monitoring stations

Site A – Annual data

Table A8.1.1 Site A: North-east Station - 2002

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2[1]	Total HC	PM10	H2S[1]
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		10.6	6.6	6.7	0.7	3.2	13.8	3.8
15 minute mean	5	-0.3	-0.2	-0.1	0.3	1.6	2.6	0.5
	10	0.1	0.1	0.4	0.4	1.9	4.3	1.1
	25	1.4	1.2	1.6	0.7	2.3	7.4	2.0
	50	4.8	3.7	4.3	1.2	2.6	11.5	3.1
	75	12.9	9.0	9.6	2.4	3.4	16.8	5.2
	90	29.8	17.6	17.0	4.8	5.0	23.3	7.8
	100	257.9	76.0	57.2	23.0	32.5	751	53.1
1 hour mean	99.8			37.55				
24 hourly mean	90.4						22.2	
24 hourly mean	98.1						38.6	
15 minute mean	99.9				22.3			
1 hour mean	99.7				16.7			
24 hourly mean	99.2				4.8			
24 hourly mean	100							28.9

1: Measurements made between 12-12-01 to 16-1-02

Table A8.1.2 Site A: North-east Station –2003

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2[1]	Total HC	PM10	H2S[1]
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		3.7	4.5	4.6	1.3	0.7	14.3	1.7
15 minute mean	5	-6.3	-1.5	-1.3	0.3	-1.3	0	0.4
	10	-4.6	-0.6	-0.5	0.4	-1.2	0	0.6
	25	-1.6	0.5	0.7	0.7	-0.9	5.1	1.1
	50	1.2	3.1	3.4	1.0	-0.8	10.9	1.5
	75	6.2	6.6	6.8	1.6	2.2	17.2	2.1
	90	15.2	12.0	11.5	2.5	3.3	26.9	2.9
	100	77.6	46.0	33.0	9.5	34.0	598.6	13.3
1 hour mean	99.8			29.9				
24 hourly mean	90.4						27.7	
24 hourly mean	98.1						59.3	
15 minute mean	99.9				8.3			
1 hour mean	99.7				5.4			
24 hourly mean	99.2				2.6			
24 hourly mean	100							3.1

1: Measurements made between 25-7-03 to 1-9-03

Site A Intensive Survey 27 November – 24 December 2001

Table A8.1.3 Site A: North-east Station – Winter Survey 2001/02

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2	Total HC	PM10	H2S
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		10.6	7.6	7.6	3.2	7.2	10.2	5.9
15 minute mean	5	0.3	0.4	0.5	0.8	2.0	1.82	1.8
	10	0.7	0.8	0.9	0.9	2.4	3.2	2.3
	25	2.2	2.1	2.3	1.1	2.9	5.7	3.9
	50	5.6	4.9	5.2	1.8	3.9	9.2	5.9
	75	12.1	9.8	9.8	4.5	7.1	14.3	7.7
	90	28.1	19.4	19.0	7.6	17.6	18.3	9.2
	100	203.6	42.5	33.4	23.0	86.8	40.8	53.1
1 hour mean	99.8			33.1				
24 hourly mean	90.4						14.6	
24 hourly mean	98.1						18.3	
15 minute mean	99.9				22.9			
1 hour mean	99.7				16.3			
24 hourly mean	99.2				5.6			
24 hourly mean	100							9.5

Table A8.1.4 Site A: South-west Station – Winter Survey 2001/02

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2	Total HC	PM10	H2S
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		18.9	11.5	11.5	1.8	No data	10.6	1.7
15 minute mean	5	3.2	1.5	1.7	-2.1		1.8	-0.9
	10	3.6	2.2	2.3	-1.8		3.6	-0.1
	25	4.6	3.2	3.2	-0.7		6.225	1.2
	50	7.1	5.8	5.9	0.9		9.7	1.7
	75	15.0	12.1	12.2	2.5		14.3	2.1
	90	37.8	26.9	25.9	5.9		18.7	2.6
	100	260.0	107.1	90.4	304.1		98.2	277.9
1 hour mean	99.8			89.6				
24 hourly mean	90.4						15.8	
24 hourly mean	98.1						19.2	
15 minute mean	99.9				22.8			
1 hour mean	99.7				33.6			
24 hourly mean	99.2				6.1			
24 hourly mean	100							7.1

Site A Intensive Survey 21 July – 18 August 2003

Table A8.1.5 Site A: North-east Station – Summer Survey 2003

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2	Total HC	PM10	H2S
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		4.4	5.1	5.2	1.2	3.1	22.7	1.4
15 minute mean	5	-4.6	-1.4	-1.2	0.3	1.7	4.3	0.4
	10	-3.2	-0.4	-0.2	0.4	1.8	6.1	0.5
	25	-0.8	0.9	1.3	0.6	1.8	9.7	0.9
	50	1.6	3.7	4.1	1.0	2.0	15.4	1.3
	75	5.8	6.8	7.5	1.6	2.9	24.6	1.8
	90	15.9	12.5	12.4	2.4	5.4	38.6	2.4
	100	75.7	46.0	33.0	9.5	32.1	311.8	5.9
1 hour mean	99.8			30.7				
24 hourly mean	90.4						52.7	
24 hourly mean	98.1						68.2	
15 minute mean	99.9				7.0			
1 hour mean	99.7				4.4			
24 hourly mean	99.2				2.2			
24 hourly mean	100							2.2

Table A8.1.6 Site A: South-west Station – Summer Survey 2003

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2	Total HC	PM10	H2S
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		7.1	5.0	5.0	1.9	1.7	15.1	2.8
15 minute mean	5	2.0	1.0	1.1	0.5	1.5	1.1	1.4
	10	2.1	1.1	1.2	0.8	1.5	2.3	1.6
	25	2.6	1.6	1.6	1.1	1.5	4.8	2.0
	50	4.1	3.0	3.1	1.6	1.6	8.9	2.4
	75	7.8	6.0	6.0	2.3	1.7	18.8	2.9
	90	14.3	11.7	11.9	3.5	1.8	33.3	3.7
	100	95.2	47.8	36.5	9.1	24.7	432.9	13.7
1 hour mean	99.8			33.2				
24 hourly mean	90.4						33.2	
24 hourly mean	98.1						53.5	
15 minute mean	99.9				8.2			
1 hour mean	99.7				7.0			
24 hourly mean	99.2				4.2			
24 hourly mean	100							6.4

Site B – Annual data

Table A8.1.7 Site B: North-east Station - 2002

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2[1]	Total HC	PM10	H2S[1]
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		13.4	8.2	8.2	1.6	3.0	15.8	3.6
15 minute mean	5	-0.4	-0.8	-0.7	0.0	1.5	3.065	0.2
	10	0.4	0.0	0.1	0.1	1.6	5.2	0.6
	25	2.6	1.9	2.1	0.4	1.8	8.9	1.7
	50	8.2	6.1	6.3	0.9	2.2	13.4	3.3
	75	17.2	12.7	12.7	1.6	2.7	19.6	5.1
	90	32.7	19.9	19.5	2.7	4.2	28.6	7.1
	100	222.0	61.3	47.2	182.1	49.7	521.2	335.5
1 hour mean	99.8			33.9				
24 hourly mean	90.4						25.4	
24 hourly mean	98.1						35.1	
15 minute mean	99.9				62.2			
1 hour mean	99.7				42.1			
24 hourly mean	99.2				14.7			
24 hourly mean	100							10.4

1: Measurements made between 18-1-02 to 18-3-02

Table A8.1.8 Site B: North-east Station – 2003

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2[1]	Total HC	PM10	H2S[1]
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		8.4	4.6	4.6	1.3	3.0	15.4	0.9
15 minute mean	5	-3.7	-3.9	-3.9	0.5	1.7	0	0.4
	10	-2.9	-3.2	-3.2	0.5	1.9	4.1	0.5
	25	-0.1	-0.6	-0.4	0.9	2.1	7.9	0.7
	50	5.2	3.5	3.9	1.1	2.3	12.4	0.8
	75	12.0	8.6	8.5	1.2	2.8	19.4	0.9
	90	22.6	14.2	13.4	1.8	4.2	28.6	1.4
	100	102.3	40.0	26.9	28.3	20.8	326.2	3.9
1 hour mean	99.8			26.2				
24 hourly mean	90.4						26.7	
24 hourly mean	98.1						33.4	
15 minute mean	99.9				18.5			
1 hour mean	99.7				11.5			
24 hourly mean	99.2				4.1			
24 hourly mean	100							1.1

1: Measurements made between 12-6-03 to 22-7-03

Site B Intensive Survey 23 January – 28 February 2002

Table A8.1.9 Site B: North-east Station – Winter Survey 2001/02

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2	Total HC	PM10	H2S
		ppb	ppb	Ppb	ppb	ppm	ug/m3	ppb
Annual Mean		13.5	9.0	9.1	1.4	2.8	12.4	4.8
15 minute mean	5	1.3	-0.4	-0.2	0.4	1.6	2.54	0.7
	10	2.0	0.5	0.9	0.5	1.9	4.2	1.3
	25	4.1	2.9	3.1	0.8	2.2	7.5	2.6
	50	9.3	6.8	7.2	1.3	2.5	11.9	4.3
	75	17.7	12.9	12.8	1.6	3.1	16.5	6.3
	90	31.6	21.3	21.1	2.3	3.8	21.2	8.7
	100	95.1	45.8	35.6	8.8	26.9	41.4	30.3
1 hour mean	99.8			34.9				
24 hourly mean	90.4						18.2	
24 hourly mean	98.1						20.5	
15 minute mean	99.9				8.0			
1 hour mean	99.7				5.3			
24 hourly mean	99.2				2.8			
24 hourly mean	100							10.4

Table A8.1.10 Site B: South-west Station – Winter Survey 2001/02

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2	Total HC	PM10	H2S
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		17.2	11.3	11.3	0.6	2.5	11.7	3.7
15 minute mean	5	3.3	1.7	1.9	-1.0	2.1	3.3	1.0
	10	3.9	2.4	2.5	-0.7	2.1	4.8	1.6
	25	6.2	3.9	4.1	-0.2	2.2	7.8	2.7
	50	11.1	7.8	8.0	0.4	2.2	11.3	3.6
	75	23.4	16.6	16.9	1.0	2.3	15.0	4.8
	90	38.1	25.7	25.4	1.9	2.7	19.2	5.7
	100	189.0	54.1	43.8	34.3	19.7	32.9	7.7
1 hour mean	99.8			42.2				
24 hourly mean	90.4						15.8	
24 hourly mean	98.1						18.0	
15 minute mean	99.9				10.8			
1 hour mean	99.7				8.7			
24 hourly mean	99.2				3.9			
24 hourly mean	100							5.7

Site B Intensive Survey 9 June - 11 July 2003

Table A8.1.11 Site B: North-east Station – Summer Survey 2003

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2	Total HC	PM10	H2S
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		8.4	4.5	4.5	1.1	3.6	18.3	0.8
15 minute mean	5	-3.80	-4.0	-3.9	0.5	2.1	1.6	0.3
	10	-2.9	-3.3	-3.2	0.5	2.2	4.8	0.5
	25	-0.4	-0.8	-0.6	0.8	2.3	9	0.7
	50	5.0	3.3	3.6	1.0	2.5	13.9	0.8
	75	12.1	8.5	8.5	1.1	3.2	22.5	0.9
	90	22.7	14.5	13.1	1.5	6.0	35.2	1.3
	100	102.3	40.0	26.9	8.5	20.6	326.2	2.5
1 hour mean	99.8			25.8				
24 hourly mean	90.4						31.7	
24 hourly mean	98.1						38.9	
15 minute mean	99.9				7.9			
1 hour mean	99.7				6.1			
24 hourly mean	99.2				1.9			
24 hourly mean	100							1.1

Table A8.1.12 Site B: South-west Station – Summer Survey 2003

Averaging period	Percentile	NOx	NO2	NO2 (hourly mean)	SO2	Total HC	PM10	H2S
		ppb	ppb	ppb	ppb	ppm	ug/m3	ppb
Annual Mean		20.6	11.2	11.2	2.2	2.6	74.6	3.1
15 minute mean	5	3.8	2.5	2.9	0.3	1.7	4.6	0.7
	10	5.5	3.7	4.0	0.5	1.7	6.8	1.0
	25	9.9	6.4	6.8	0.9	1.8	9.8	1.6
	50	16.2	9.8	10.2	1.5	1.8	14.6	2.3
	75	26.9	14.5	14.3	2.6	2.1	37.1	3.6
	90	40.4	20.3	19.4	4.4	4.6	225.5	6.0
	100	113.0	45.7	36.1	25.3	14.1	1029.0	15.6
1 hour mean	99.8			36.1				
24 hourly mean	90.4						150.0	
24 hourly mean	98.1						207.1	
15 minute mean	99.9				24.2			
1 hour mean	99.7				18.6			
24 hourly mean	99.2				6.4			
24 hourly mean	100							5.9

A8.2 : Intensive survey measurements

Appendix 9 : Draft quantitative exposure assessment

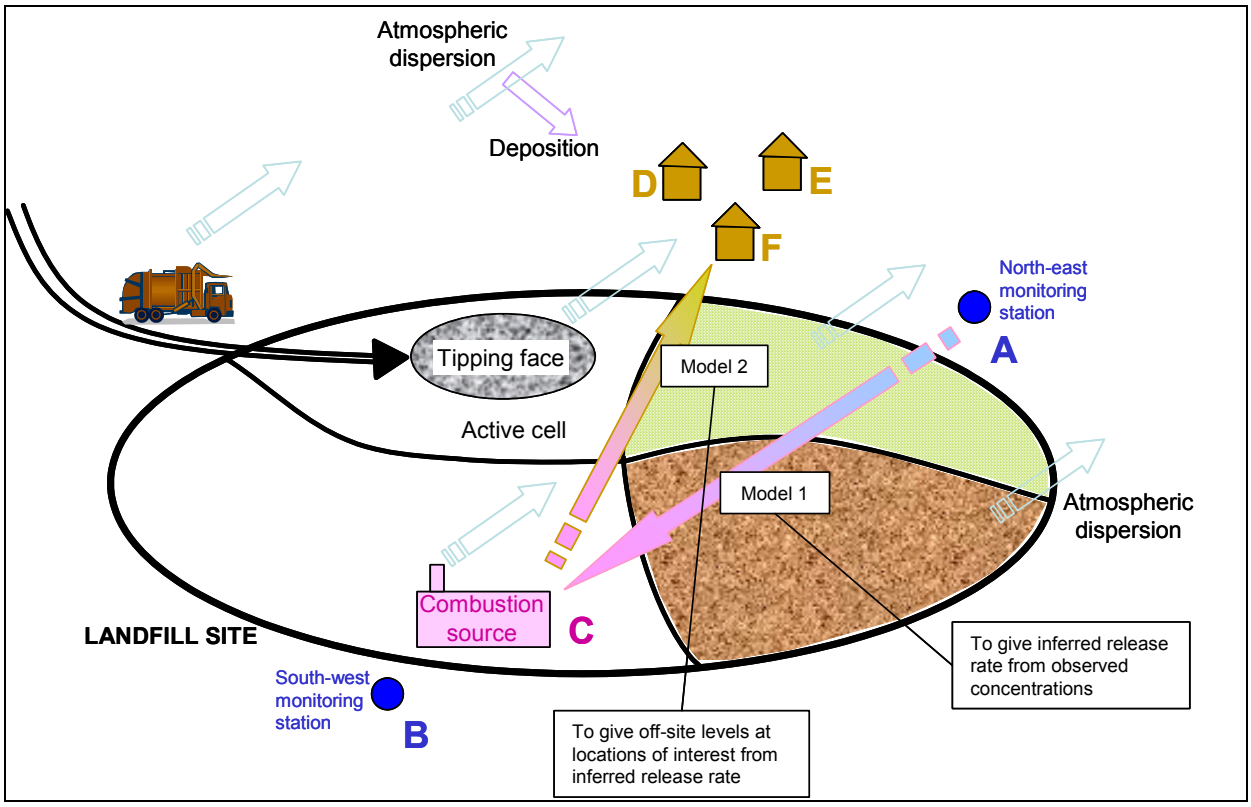
A9.1 Introduction

This section sets out the quantitative exposure assessment carried out for this project. **It was found that the approach did not give reliable results, and was not used in drawing conclusions from the measurement database derived as the major part of this study. The quantitative assessment is provided in this volume as a record of the work carried out.**

A9.2 Summary of quantitative assessment method

Quantitative assessments were carried out for a limited range of substances where it was considered that the data permitted an investigation of emission rates from the landfill, and an estimation of possible off-site levels. This was carried out using a dispersion modelling technique, undertaken in two steps. Firstly, a modelling study was carried out to derive the emissions that could give rise to observed increases in environmental concentrations of released substances between the upwind side and the downwind side of the sites. Secondly, the model was used to estimate, from the derived emissions, the concentrations of released substances that could arise at particular locations off-site (Figure A9.1).

Figure A9.1 Approach to estimating off-site exposures



A9.2.1 Calculation method

The site contribution is provided by the concentration measured at the downwind station minus the concentration measured at the upwind station (**A** – **B**). This is used to derive an estimated release rate from the source at the landfill site (**C**). The estimated release rate is used to estimate population exposure at off-site locations (**D, E** and **F**). The method for estimating the source term and assessing exposure of local people in this way is set out in Appendix 4. The steps involved in estimating the release rate of substances were as follows:

(i) Measure the concentration of each substance at the monitoring stations located north-east and south-west of the landfill site.
(ii) Characterise the source of each substance. Substances are released from one or more of three different types of source at the site – emissions from the active working area (for example, micro-organisms); emissions from landfill gas (for example, volatile organic compounds); and/or emissions from landfill gas combustion (for example, dioxins and furans). Information such as the location and temperature of emissions was needed to characterise each source.
(iii) Identify meteorological data for each site. Meteorological measurements made at each site were used, supported by further observations made at a nearby station operated by the UK Meteorological Office;
(iv) Run the dispersion model for each source of emissions, for each period when monitoring was carried out.
(v) Using the dispersion model results, sort each pair of measurements (north-east and south-west site boundary) to identify which of the measurements should be considered "upwind" and which should be considered "downwind" – or identify if the measurements cannot be sorted in this way.
(vi) For each pair of measurements, evaluate the release rate needed to cause the observed increase in pollution concentrations between the "upwind" and "downwind" measurements.
(vii) Analyse the estimated release rates for each substance to give an average, 50th percentile and 95th percentile release estimate.

The outcome of this analysis is an estimated release rate of the substances under consideration due to emissions from the landfill site. While this was of interest in itself, the overall objective of the project is to estimate exposure of local people to released substances. The estimated source term was therefore used to evaluate the dispersion of released substances over the area surrounding the site. An atmospheric dispersion model was used to model the dispersion of emissions from the landfill sites. The starting point was the estimated release rates of substances from the site set out in Section A9.6. The dispersion model was used to estimate the concentrations of released substances likely to arise at properties in the vicinity of the landfill sites under consideration and to estimate the average concentrations of substances released from the site in an area within 2 km of the sites, and in an area between 2 km and 7 km from the sites.

This approach to estimating the contribution of the landfill sites to concentrations of substances at locations near each site meant that the highest estimated concentrations at locations very close to the sites were in some cases greater than the concentrations measured at the site boundary. This occurs because the monitoring stations were not always located directly downwind of the site, nor at the distance where the highest concentrations due to emissions from the site were forecast to occur. When this was the case, the highest off-site concentrations would be higher than the measured concentrations. At other locations, in particular locations further from the site or those not lying downwind of the prevailing wind direction, estimated exposure due to emissions from the site is much lower than at locations close to and downwind of the site.

A9.2.2 Assumptions used in exposure modelling

The main assumptions inherent in the exposure modelling method are:

- that the substances are released from the sources identified in Table A9.1 below. However, the investigations and cross-checks indicated that the model of site emissions summarised in Table A9.1 is not a satisfactory representation of site emissions;
- that the values used in the dispersion model to describe the location and other characteristics of these sources are a good representation of the sources (see Appendix 4). The ADMS dispersion model was used for this assessment.
- that the atmospheric dispersion model provides a reliable representation of dispersion of emissions from the landfill sites.

Table A9.1 Assumed source types

Combustion source (engines and/or flare)	Fugitive landfill gas source	Tipping source
Dust/Metals [1]	Dust/Metals [1]	Dust/Metals [1]
Dioxins and furans	VOCs	Mineral fibres
PCBs		Micro-organisms
PAHs		

Note 1: Dusts and metals were evaluated on the basis of emissions from all three source types. The source description providing the least variability in modelled dust/metal emission rates was adopted as the best representation of dust and metal emissions

Applying the methodology above allows estimates of exposure of local people to emissions from the two sites under consideration to be obtained. Full information on exposure of individuals to substances emitted from the landfill sites is set out in Appendix 10.

A9.2.3 Excerpt from measurement database to illustrate data analysis

The measured values set out in Chapter 4 and in Appendix 8 provide useful information on site boundary concentrations at the two sites. However, the measured concentrations do not reflect site contribution to air quality, or population exposure. They include a potentially significant background component from other sources of pollution which may be local and/or remote. This chapter sets out how the database was investigated with the aim of understanding the effect of the landfill site itself on local air quality, and hence to estimate the exposure of local residents to substances emitted to air from the facility.

This chapter provides an example of the calculations carried out for three substances. The measured levels of these substances are set out in Table A9.2 below.

Table A9.2 : Selected measurements to illustrate data analysis

Substance and site	Date	Measured concentration	
		North-east	South-west
Dioxins/furans/PCBs Site A Winter	27/11/2001 – 30/11/2001	25 fg/m^3	25.7 fg/m^3
	30/11/2001 – 04/12/2001	18.7 fg/m^3	19.4 fg/m^3
	04/12/2001 - 07/12/2001	43.6 fg/m^3	30.2 fg/m^3
	07/12/2001 - 11/12/2001	23.2 fg/m^3	22.3 fg/m^3
	11/12/2001 - 14/12/2001	42.2 fg/m^3	47.4 fg/m^3
	14/12/2001 - 17/12/2001	92 fg/m^3	67.2 fg/m^3
	17/12/2001 - 21/12/2001	34.8 fg/m^3	26.5 fg/m^3
	21/12/2001 – 24/12/2001	23.6 fg/m^3	25.5 fg/m^3
Nickel Site A Summer	24/07/2003	0.41 ng/m^3	0.97 ng/m^3
	25/07/2003	0.20 ng/m^3	0.32 ng/m^3
	28/07/2003	0.72 ng/m^3	0.99 ng/m^3
	31/07/2003	0.24 ng/m^3	0.41 ng/m^3
	04/08/2003	1.75 ng/m^3	1.37 ng/m^3
	07/08/2003	1.37 ng/m^3	1.58 ng/m^3
	11/08/2003	0.26 ng/m^3	0.27 ng/m^3
	13/08/2003	0.21 ng/m^3	0.44 ng/m^3
Benzene Site B Winter	09/06/2003	0.19 µg/m^3	0.19 µg/m^3
	12/06/2003	0.15 µg/m^3	0.31 µg/m^3
	16/06/2003	0.10 µg/m^3	0.15 µg/m^3

	17/06/2003	0.09 µg/m^3	0.05 µg/m^3
	18/06/2003	0.38 µg/m^3	0.07 µg/m^3
	19/06/2003	0.04 µg/m^3	0.04 µg/m^3
	20/06/2003	0.05 µg/m^3	0.03 µg/m^3
	23/06/2003	0.32 µg/m^3	0.31 µg/m^3
	24/06/2003	0.25 µg/m^3	0.40 µg/m^3
	25/06/2003	0.29 µg/m^3	0.36 µg/m^3
	26/06/2003	0.10 µg/m^3	**4.11 µg/m^3**

A9.3 Estimated inhalation exposures

A9.3.1 Background

Inhalation is a direct exposure pathway meaning that inhaled air containing substances of concern is delivered directly to the receptor. The processes that act to reduce such exposures are those associated with dispersion and dilution in the air before the substances of concern reach the individual(s). The objectives of the inhalation exposure assessment then were to assess the site-specific exposure of receptors to the measured and forecast concentrations of pollutants released from two example landfill sites.

The analysis draws on modelled background airborne concentrations of pollutants and modelled concentrations due to site emissions, where the data permitted these to be established with confidence. Modelled exposure data for approximately 80 chemical and microbiological substances were derived. Two zones around each site were considered. The inner zone was a circular area extending up to 2 km from the site. The outer zone was an annular area extending from 2 km to 7 km from the site. Modelled concentrations for each substance, at each site, at each location, were estimated for the winter and summer monitoring periods. Typically, for VOCs, fourteen sets of modelled values were provided at each site and location for the summer and winter periods; for dioxins and furans, typically eight values were provided. The mean and 95th percentile values of these data sets were used in the assessment. In addition, the maximum mean and 95th percentile modelled concentrations at any nearby receptor were also considered.

The project-specific HCVs for each compound were compared directly to the exposure data for each landfill site (summer and winter) in order to determine which substances exceeded their HCV. For the majority of the compounds, this was achieved by dividing the mean 'average' seasonal exposure at 0–2 km, 2–7 km and maximum at any receptor by the HCV. This calculation was expressed as a percentage of the HCV. The assessment for carcinogenic PAHs was conducted using a similar method except that the relative potencies of individual PAHs were calculated relative to benzo[*a*]pyrene. Individual and total carcinogenic PAHs were expressed as an overall percentage of the HCV for benzo[*a*]pyrene (0.25 ng/m3). PCBs were expressed as toxic equivalent (TEQ) and dioxin-like PCBs were reported with dioxins.

The assessments were based on modelled seasonal 'long-term' airborne exposures and HCVs that, based on current knowledge, represent intakes that are of minimal risk to health over a lifetime and are protective of the whole population, including the unborn child. A specific assessment of the potential for congenital anomalies due to exposure of pregnant women to maximum, short-term (hourly), modelled exposures was made for those substances considered to have potentially teratogenic effects. Estimated exposure levels were assessed in the light of current evidence for teratogenicity (Department of Health, 2001).

The following factors should be borne in mind and may have impacted on this assessment:

- the estimated site contribution values are based on modelled data. For a number of substances, it was not possible to provide quantitative modelled data. In these cases, a semi-quantitative risk assessment was carried out; and

- the use of zero concentrations for 'non detects' rather than 'detection limits' (or other conventions) is the least precautionary approach and may have resulted in underestimation of exposure and thus the health impact of some substances (IGHRC, 2004).

In the event, it was concluded that the data did not support the assessment of exposure at off-site locations (Receptor (iv) above). A semi-quantitative assessment was therefore carried out by considering the highest measured fenceline concentration against the HCV. This is described in Chapter 5.

A9.3.2 Estimated emission rates

The outcome of the first stage of quantitative modelling is a range of estimated emission rates for the substances measured in this project (see Section A9.6). The mean estimated release rates for each substance are set out in Table A9.3, and the full data for three example substances are set out in Table A9.4

Table A9.3 Mean estimated emission rates

Substance	Site A Winter	Site B Winter	Substance	Site A Summer	Site B Summer
Antimony			Antimony		
Arsenic	0	0	Arsenic	0.000043	0.0000018
Cadmium	0	0	Cadmium	0	0.00012
Chromium	0	0.0014	Chromium	0.00022	0.000014
Cobalt	0	0.0028	Cobalt	0.000017	0
Copper	0	0	Copper	0	0
Lead	0	0.0012	Lead	0.0012	0.000020
Manganese	0.0023	0	Manganese	0.0011	0
Mercury			Mercury		
Nickel	0	0	Nickel	0.000017	0.00021
Thallium			Thallium		
Tin			Tin		
Vanadium			Vanadium		
Dioxin (g TEQ / s)	6.52×10^{-10}	1.86×10^{-9}	Dioxin (g TEQ / s)	9.26×10^{-9}	7.48×10^{-8}
Dioxin/furan/PCB	6.52×10^{-10}	2.65×10^{-9}	Dioxin/furan/PCB (g TEQ / s)	1.28×10^{-8}	7.67×10^{-8}
Naphthalene			Naphthalene		
Acenaphthylene	0	0.0000567	Acenaphthylene	0	0
Acenaphthene			Acenaphthene		
Fluorene	0.000178	0.000706	Fluorene	0.0000100	0.00000668
Phenanthrene	0.00000142	0.00139	Phenanthrene	0.00330	0.000197
Anthracene			Anthracene		
Fluoranthene			Fluoranthene		
Pyrene			Pyrene		
Benzo (a) anthracene			Benzo (a) anthracene		
Chrysene			Chrysene		
Benzo (b/k) fluoranthene	4.54×10^{-7}	0.0000492	Benzo (b/k) fluoranthene	0.00000107	0.0000365
Benzo (a) pyrene			Benzo (a) pyrene		
Indeno (123-cd) pyrene	0		Indeno (123-cd) pyrene	0	
Benzo (ghi) perylene	0		Benzo (ghi) perylene	0	
Dibenzo (ah) anthracene			Dibenzo (ah) anthracene		
Dichloromethane	0		1,1,1-Trichloroethane		
1,2-Dichloroethene			1,1-Dichloroethane		

Substance	Site A Winter	Site B Winter	Substance	Site A Summer	Site B Summer
2-Methylfuran	0		Benzene	0.130	
Nitromethane	0		1,2-Dichloroethane		
2-butanone			Chlorobenzene		
Chloroform			Chloroethane		
Benzene	0.00339		Chloroform		
1,2-Dichloroethane	0.00258		Dichloromethane	0.0316	
Trichloroethene	0.00344		Tetrachloroethene	0.0301	
Toluene			Toluene	0.112	
Tetrachloroethene	0.000196		Ethylbenzene		
Ethylbenzene			m+p Xylene		
Trimethylbenzene			o Xylene		
alpha-Terpinene	0.00464		1,2-Dichloroethene		
Dichlorobenzene			Styrene	0.0469	
2-Ethyl-1-hexanol	0.0013		Formaldehyde	0	
Formaldehyde	0		1,3-butadiene [1]	0	
1,3-butadiene	0		Methanethiol		
Chloromethane			Ethanethiol	0	
Carbon disulphide	0		Chloroethene	0	
Dimethyl disulphide	0		Chlorodifluoromethane		
Dimethyl sulphide	0		Dichlorodifluoromethane		
Methanethiol	0		Chloromethane		
Ethanethiol	0		Carbon disulphide	0.451	
Chloroethene	0		Dimethyl sulphide	0	
Dichlorofluoromethane	0		Dimethyl disulphide	0.00125	
Fibres	0	0	Fibres	10900000	0
Mesophilic Aerobes (cfu/s)	165000		Arsine [1]	0	0
Moulds (cfu/s)	331000		Stibene [1]	0	0
Yeasts (cfu/s)	0		Total Bacteria Nutrient 25 °C (cfu/s)	76400000	150000
Entrobacteriaceae (cfu/s)	0		Total Bacteria Nutrient 37 °C (cfu/s)	0	300000
Endotoxins (EU/s	0		Total fungi and yeasts Malt 25 °C (cfu/s)	2150000	3490000
Total Bacteria Nutrient 25 °C (cfu/s)		0	Total fungi and yeasts Malt 40 °C (cfu/s)	0	0
Total Bacteria Nutrient 37 °C (cfu/s)		0	Total fungi and yeasts DG18 25 °C (cfu/s)	4280000	585000
Total fungi and yeasts Malt 25 °C (cfu/s)		0	Gram -ve bacteria VRBG (cfu/s)	0	0
Total fungi and yeasts Malt 40 °C (cfu/s)		0	Endotoxins (EU/s)	0	0
Total fungi and yeasts DG18 25 °C (cfu/s)		0			
Gram -ve bacteria VRBG (cfu/s)		0			
Endotoxins (EU/s)		0			

Grey cell: not measured Hatched cell: screened out
Blank cell: conceptual model not reliable; assessed via semi-quantitative risk assessment

Table A9.4 Estimated emission rates for three example substances

Substance	Dioxins/furans/PCBs	Nickel	Benzene
	Site A Winter	**Site A Summer**	**Site B Summer**
Estimated release rate values for each pair of measurements (g/s)	***Eight pairs of measurements:*** 5.6×10^{-11} 9.9×10^{-11} 0 0 No estimate possible 0 0 4.41×10^{-9}	***Eight pairs of measurements:*** 0.000037 0.0000113 0.000024 0.000054 0 0 0.0000058 0	***Eleven pairs of measurements:*** 0 0.0127 0.00130 No estimate possible No estimate possible 0 No estimate possible No estimate possible 0.033 0.0182 0
Mean estimated release rate (g/s)	6.5×10^{-10}	0.000017	0.0070
50th percentile estimated release rate (g/s)	Zero	0.0000086	0.00130
95th percentile estimated release rate (g/s)	3.11×10^{-9}	0.000048	0.027
Estimated baseline concentration (µg/m^3)	3.7×10^{-8}	0.00078	0.161

Note: Release rates and baseline concentrations calculated using method set out in Appendix 4.

The estimated emission rates set out in Table A9.3 and Section A9.6 provide a best estimate of release rates of the measured substances from the landfill sites under consideration. The benchmarking analysis set out below indicates that these release rates are likely if anything to be over-estimates of the true value of release rates from the sites. The "pedigree" of these values was evaluated to provide an indication of confidence in the quality of these data values. Because they were derived indirectly from measured concentrations rather than being directly measured, the confidence in the values is lower than the confidence in the measured fenceline concentrations.

The pedigree of the estimated release rates was ranked between 0 to 16. A score of 0 – 4 was described as "poor", 5 – 8 "moderate"; 9 – 12 "good" and 13 – 16 "very good". The following confidence concentrations in estimated emission rates were identified:

Metals — Poor (4)
The low level of confidence relative to the very good confidence level in the measured values is largely due to uncertainty in the source of metal emissions. They could emanate from flare emissions, landfill gas emissions and/or tipping of waste.

Dioxins and furans/PAHs/PCBs — Moderate (5)

VOCs — Poor (4)

Micro-organisms — Poor (4)

Fibres — Moderate (5)

Arsine/stibene — Poor (4)

The estimated release rate of dioxins and furans from Site B in the summer survey was dominated by a single high value. This value arose from a single relatively high measured concentration of dioxins and furans of 1.8×10^{-6} µg/m^3 recorded between 9 and 12 June 2003 at the north-east side of Site B. The wind was blowing from the site towards the monitoring

location for the majority of this period. This concentration was more than 20 times higher than any of the other 64 values recorded at Site A or Site B.

Laboratory procedures and analyses have been checked to ensure that this measured value was not subject to error. The sample was taken with clean glassware which was subsequently re-used for measurements at Site B. The absence of high concentrations following this sample suggests that the high value was not caused by cross-contamination from the experimental equipment. The landfill site manager reported that there were no unusual activities ongoing at the site or reported in the site diary for the period of the measurement. The site received a consignment of contaminated soil over a period of three weeks, covering the period between 9 and 12 June 2003. However, if this were giving rise to unusually high emissions of dioxins and furans, this would be expected to show up in high measured concentrations in subsequent samples at the site which did not occur.

Including this unusually high value in the analysis results in a relatively high estimated release rate for dioxins and furans from Site B during the summer survey of 7.5×10^{-8} grams per second. If the unusually high value is excluded from the analysis, the estimated release rate is 5.0×10^{-10} grams per second. Comparison with the value estimated from emissions measurements suggests that the lower value is likely to be closer to the true value for emissions from the site. Also, the absence of detectable concentrations of dioxins and furans in soils on the north-east side of Site B also suggests that a lower release rate (e.g. one similar to or lower than that estimated for Site A) is likely to be closer to the true value.

A9.3.3 Estimated off-site concentrations

The long-term mean concentrations at off-site receptors based on the average estimated release rate are provided in Tables A9.5 (winter survey) and A9.6 (summer survey). Additionally, the full estimated concentration data for the three example substances at off-site locations are set out in Table A9.7.

Table A9.5 Estimated long-term mean exposure concentrations (winter survey)

All values in µg/m3 Substance	Site A Baseline	Maximum at any receptor based on mean emission rate Site A Winter	Site B Baseline	Maximum at any receptor based on mean emission rate Site B Winter
Antimony				
Arsenic		0		0
Cadmium				0
Chromium	0.00100	0	0.00245	0.0039
Cobalt	0.0115	0	0.0277	0.0068
Copper				
Lead	0.00278	0.000048	0.00175	0.0015
Manganese	0.00395	0.0022		
Mercury				
Nickel	0.00203	0.000048	0.00100	0
Thallium				
Tin				
Vanadium				
Dioxin	2.4×10^{-8}	1.8×10^{-9}	2.3×10^{-8}	4.0×10^{-9}
Dioxins/furancs/PCBs (TEQ) - upper limit	3.7×10^{-8}	1.8×10^{-9}	3.3×10^{-8}	5.8×10^{-9}
Naphthalene				
Acenaphthylene	0.000394	0	0.000125	0.00012
Acenaphthene				
Fluorene				
Phenanthrene	0.00354	0.0000040	0.00322	0.0030
Anthracene				
Fluoranthene				
Pyrene				

All values in µg/m3 Substance	Site A Baseline	Maximum at any receptor based on mean emission rate Site A Winter	Site B Baseline	Maximum at any receptor based on mean emission rate Site B Winter
Benzo (a) anthracene			0.000333	0.00062
Chrysene				
Benzo (b/k) fluoranthene	0.000434	0.0000013	0.000546	0.00011
Benzo (a) pyrene				
Indeno (123-cd) pyrene	0.000173	0		
Benzo (ghi) perylene	0.000228	0		
Dibenzo (ah) anthracene				
Dichloromethane	0	0		
1,2-Dichloroethene	0	0		
2-Methylfuran	0	0		
Nitromethane	0	0		
Methylethylketone				
Chloroform				
Benzene	0.883	0.092		
1,2-Dichloroethane				
Trichloroethene	0.605	0.093		
Toluene				
Tetrachloroethene	1.20	0.0053		
Ethylbenzene				
Trimethylbenzene				
alpha-Terpinene	0.608	0.13		
Dichlorobenzene	1.78	0		
2-Ethyl-1-hexanol	0.769	0.035		
Formaldehyde		0		
1,3-butadiene		0		
Chloromethane				
Carbon disulphide		0		
Dimethyl disulphide		0		
Dimethyl sulphide		0		
Methanethiol				
Ethanethiol		0		
Chloroethene		0		
Dichlorofluoromethane		0		
Fibres	0	0	0	0
Mesophilic Aerobes (cfu/m3)	5.98×10^7	96000		
Moulds (cfu/m3)	4.32×10^7	1900000		
Yeasts (cfu/m3)		0		
Entrobacteriaceae (cfu/m3)		0		
Endotoxins (IU/filter)	6070	0		
total bacteria			2.0×10^9	0
total bacteria			1.05×10^9	0
Gram -ve bacteria			0	0
total fungi + yeasts			0	0
total fungi + yeasts			0	0
Thermophilic fungi			0	0
Penicillia			0	0
A. fumigatus			0	0

Grey cell: not measured Hatched cell: screened out
Blank cell: conceptual model not reliable; assessed via semi-quantitative risk assessment

Table A9.6 Estimated long-term mean exposure concentrations (summer survey)

All values in µg/m3 Substance	Site A Baseline	Maximum at any receptor based on mean emission rate Site A Summer	Site B Baseline	Maximum at any receptor based on mean emission rate Site B Summer
Antimony				
Arsenic	0.000215	0.00013	0.000277	0.0000057
Cadmium			0.000233	0.00053
Chromium	0.00136	0.00022	0.00118	0.000073
Cobalt	0.000152	0.000012	0.000300	0
Copper				
Lead	0.00155	0.0017	0.00265	0.000078
Manganese	0.00319	0.0028		
Mercury				
Nickel	0.000781	0.000094	0.000932	0.0029
Thallium				
Tin				
Vanadium				
Dioxin	4.51×10^{-8}	2.1×10^{-8}	2.29×10^{-8}	5.4×10^{-7}
Dioxins/furancs/PCBs (TEQ) - upper limit	4.01×10^{-8}	2.9×10^{-8}	8.30×10^{-8}	5.5×10^{-7}
Naphthalene				
Acenaphthylene	0.000425	0	0.0000950	0
Acenaphthene				
Fluorene				
Phenanthrene	0.00147	0.0075	0.00454	0.0014
Anthracene				
Fluoranthene				
Pyrene				
Benzo (a) anthracene				
Chrysene				
Benzo (b/k) fluoranthene	0.000195	2.4×10^{-6}	0.000567	0.00026
Benzo (a) pyrene				
Indeno (123-cd) pyrene	0.0000899	0		
Benzo (ghi) perylene		0		
Dibenzo (ah) anthracene				
1,1,1-Trichloroethane				
1,1-Dichloroethane				
Benzene	0.144	1.1		
1,2-Dichloroethane	0.0245	0		
Chlorobenzene				
Chloroethane				
Chloroform				
Dichloromethane	2.67	0.27		
Tetrachloroethene	0.279	0.26		
Toluene				
Ethylbenzene				
m+p Xylene				
o Xylene				
1,2-Dichloroethene				
Styrene	0.815	0.41		
Formaldehyde	0	0		
1,3-butadiene		0		
Methanethiol				
Ethanethiol	0.155	0		

All values in µg/m3 Substance	Site A Baseline	Maximum at any receptor based on mean emission rate Site A Summer	Site B Baseline	Maximum at any receptor based on mean emission rate Site B Summer
Chloroethene	0.252	0		
Chlorodifluoromethane				
Dichlorodifluoromethane				
Chloromethane				
Carbon disulphide	6.99	3.9		
Dimethyl sulphide	11.6	0		
Dimethyl disulphide		0.011		
Fibres	1.37×10^{9}	6.3×10^{7}	3.00×10^{9}	0
Arsine		0		
Stibene	34.6	0		
Total Bacteria Nutrient 25 oC	9.11×10^{7}	4.4×10^{8}	6.78×10^{8}	2.9×10^{6}
Total Bacteria Nutrient 37 oC	1.68×10^{6}	0	1.61×10^{8}	5.7×10^{6}
Total fungi and yeasts Malt 25 oC	1.81×10^{7}	1.2×10^{7}	3.80×10^{7}	6.7×10^{7}
Total fungi and yeasts Malt 40 oC	1.04×10^{6}	0	6.00×10^{7}	0
Total fungi and yeasts DG18 25 oC	2.44×10^{8}	2.5×10^{7}	1.02×10^{8}	1.1×10^{7}
Gram -ve bacteria VRBG	0	0		0
Endotoxins	1.01×10^{6}	0	2.98×10^{6}	0

Hatched cell: screened out
Blank cell: conceptual model not reliable; assessed via semi-quantitative risk assessment

Table A9.7 Estimated off-site concentrations of three example substances

Substance		Dioxins/furans/PCBs	Nickel	Benzene
Site/period		Site A Winter	Site A Summer	Site B Summer
Number of values used in analysis		7 values from 8 pairs of measurements	8 values from 8 pairs of measurements	7 values from 11 pairs of measurements
Estimated baseline concentration (µg/m^3)		3.7×10^{-8}	0.00078	0.16
Estimated long-term mean concentration (µg/m^3)	Maximum at any potentially sensitive receptor	1.8×10^{-9}	0.000094	0.18
	Average value between 0 and 2 km of the site.	4.1×10^{-10}	0.000047	0.054
	Average value between 2 and 7 km of the site	2.0×10^{-11}	0.0000015	0.0017
Estimated maximum hourly mean concentration (µg/m^3)	Maximum at any potentially sensitive receptor	3.7×10^{-9}	0.0094	9.4
	Average value between 0 and 2 km of the site.	1.1×10^{-9}	0.0062	3.9
	Average value between 2 and 7 km of the site	2.0×10^{-9}	0.00029	0.18

The inhalation exposure assessment was based on the assumption that substances not detected are not present at significant concentrations. An alternative approach would have been to assume that substances not detected could be present at concentrations up to the limit of detection of the measurement and analytical techniques used. This second approach will increase the tendency to over-estimate exposure of local residents to substances released from the landfill sites.

In most cases, making the assumption that substances not detected are present at concentrations at the limit of detection resulted in no more than a minor increase in estimated exposure concentrations. Table A9.8 below sets out the substances for which this assumption could be important. These are substances for which assuming that substances not detected are present at the limits of detection results in an increase of more than 50% in the estimated exposure concentrations.

Table A9.8 Substances sensitive to assumptions used to assess non-detections

Site A Winter	Site A Summer	Site B Winter	Site B Summer
Benzene	Tin		**Arsenic**
Tetrachloroethene	**Naphthalene**		**Naphthalene**
Trimethylbenzene	Acenaphthene		Acenaphthene
2-Ethyl-1-hexanol	**Fluorene**		
Moulds (cfu/m3)	**Fluoranthene**		
	Pyrene		
	Benzo (b/k) fluoranthene		
	Chlorobenzene		
	Dimethyl disulphide		

Note: substances listed in this table are those for which assuming that substances not detected are present at the limits of detection results in an increase of more than 50% in the estimated exposure concentrations. Substances in bold were detected in landfill gas, and/or in most field measurements

Most substances listed in Table A9.8 were detected in landfill gas or in most of the field measurements. This suggests that the substance could conceivably have been present in the sample(s) in which it was not detected, albeit at concentrations below the detection limit.

A9.3.4 Quantitative assessment

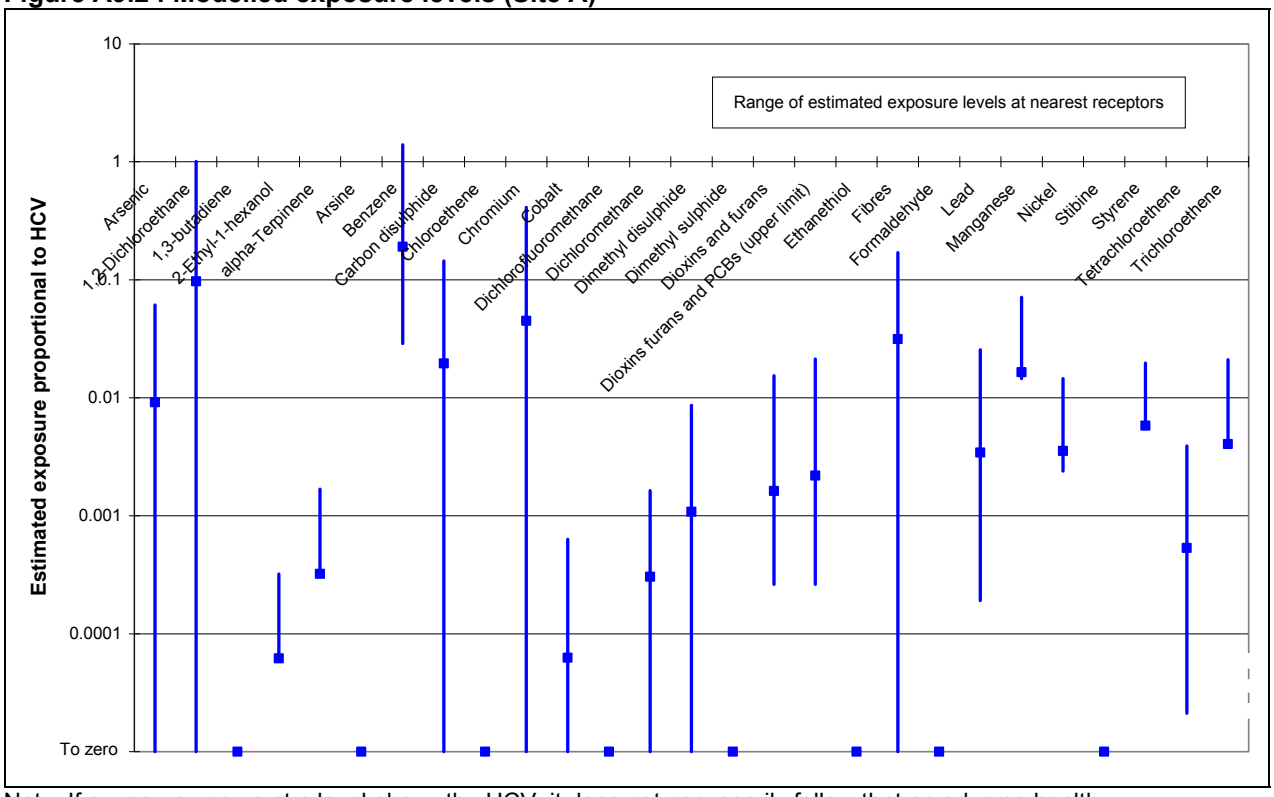
The quantitative exposure assessment calculations provided a number of estimated site emission rates for each of the substances under concern. These corresponded to the pairs of measurements carried out at upwind and downwind locations. These site emission rates were analysed statistically to identify the mean release rate, the 50th percentile release rate, and the 95th percentile release rate. These release rates were used to estimate off-site concentrations of the measured substances. These datasets were referred to as "mean concentrations," "50th percentile concentrations," and 95th percentile concentrations" respectively.

Because of the skewed distribution of data, the 50th percentile modelled concentrations were typically less than the mean concentrations, and were often zero. Thus, the 50th percentile might represent an underestimation of potential exposure and it was therefore appropriate to discount these data for the purposes of this discussion. In contrast, the 95th percentile concentrations can give useful 'upper limits' to any possible health risks, with the "95th percentile of the maximum mean concentration measured at any receptor" reflecting the level below which 95% of exposure measurements are estimated to fall, at the single most exposed receptor.

This latter level can therefore be used as a 'worst case' level. It is also important to consider concentrations above the site-specific Health Criteria Value (HCV) in terms of the criteria upon which the HCV is based, and to acknowledge the uncertainty factors used in their derivation as in many cases, there are substantial safety factors built in to the HCVs.

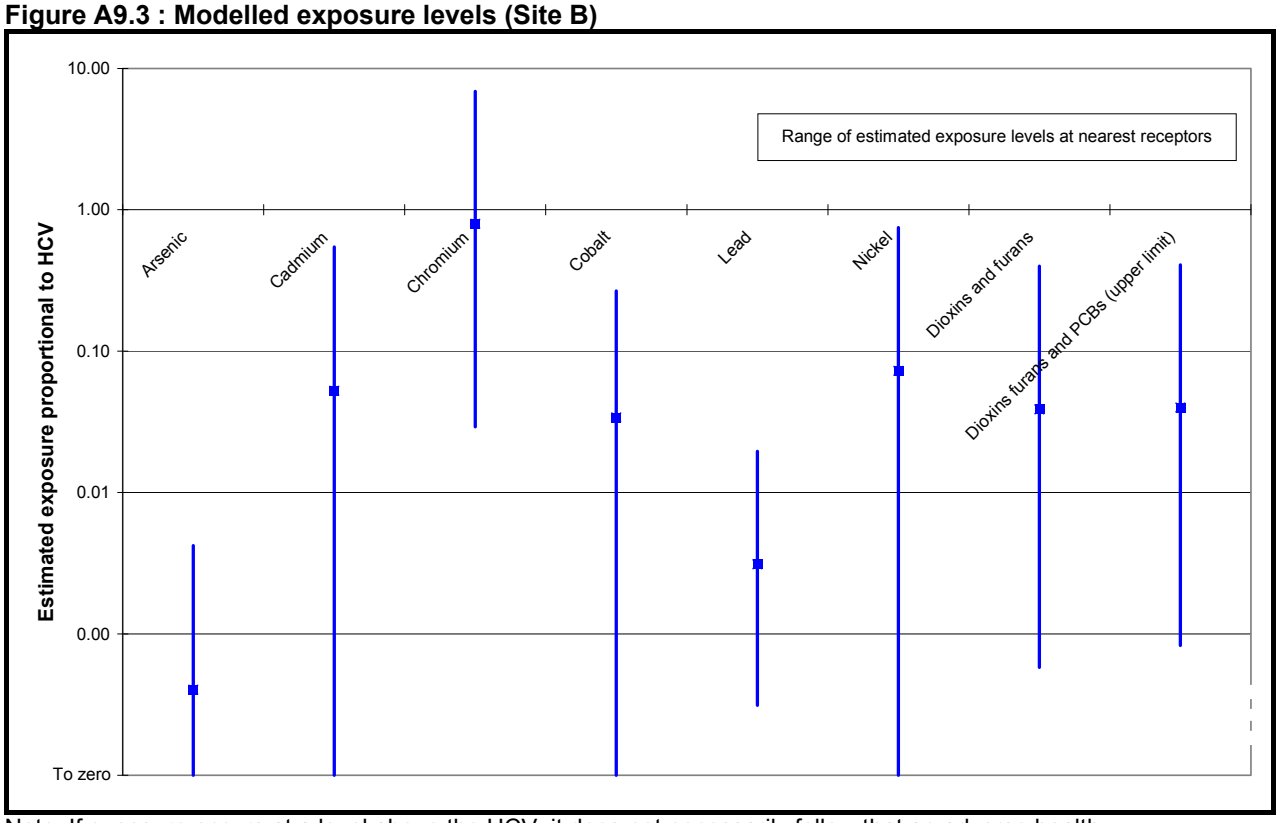
The modelled exposure levels are set out in Figures A9.2 and A9.3. These figures show the best estimate of exposure, together with the range of exposure estimates, for Sites A and B respectively. The upper end of the range reflects the 95th percentile exposure estimate.

Figure A9.2 : Modelled exposure levels (Site A)



Note: 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.

Figure A9.3 : Modelled exposure levels (Site B)



Note: 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.

The substances for which the estimated 95th percentile concentration was above the HCV were as follows:

- Site A: 1,2-dichloroethane, benzene and dioxins/furans
- Site B: chromium and dioxins/furans.
  The assessment of chromium was based on the assumption that all chromium is present in the most toxic form, chromium VI. In fact, the majority is likely to be present in the less toxic form chromium III.

The following discussion considers only those substances for which the 95th percentile of estimated exposures was above the HCV, together with dioxins and furans. A high percentile was chosen because the assessment model appeared to be a relatively poor representation of emissions from the landfill sites. Using a higher percentile for exposure introduced an additional margin of safety. In view of the only moderate confidence in data quality of the estimated exposure concentrations of these substances, it is considered appropriate to discuss any potential health risks in relation to HCVs in broad qualitative terms, and to avoid quantitative comparisons, which might suggest a level of precision which is not supported by the data. The contribution of the landfill to total exposure is considered in the interpretation of the exposure concentrations.

Chromium

In order to discuss any possible health risks of these estimates, it is important to establish speciation of chromium emissions. The selected HCV is based on chromium VI, which is associated with an increased incidence of lung cancer, rather than the less hazardous chromium III, which is an essential nutrient and only toxic in large doses. Although site-specific information on the proportions of chromium VI and chromium III are not available, chromium VI typically accounts for 3-8% of the total chromium concentration in air. In this study, it was assumed that all chromium was present as chromium VI.

Site B: Background and site contributions were negligible in the summer. In the winter months, background estimates and modelled mean site contributions combined were up to 50% of the HCV. However, the 95th percentile exposure estimate was above the HCV. Since chromium(VI)

is a carcinogen (lung cancer) there could be a potential risk if individuals are exposed to the concentrations that were modelled as the worst case. Taking account of the likely proportion of chromium present as chromium VI, present in air indicates that levels of chromium VI are likely to comply with the HCV, although the proportion present as chromium VI at Site B has not been specifically investigated. On this basis, the forecast exposure to chromium VI is not considered likely to pose a significant risk to health. As discussed above, a number of factors were incorporated in the derivation of the HCV, which make this a still more conservative assessment.

Benzene

Site A: Background concentrations and total background plus site contributions were below the HCV in summer and winter. At the 95th percentile level for the most exposed receptor, the modelled exposure level was above the HCV, but was nevertheless within the current national air quality objective. The modelled exposure level was several hundred times lower than the level at which no detectable risk of leukaemia was observed in occupational epidemiological studies. This reflects the approach to setting the air quality objective and HCV at levels which pose a negligible risk to health. It is therefore considered that there are negligible health risks associated with benzene emissions from this site.

1,2-Dichloroethane

Site A: At the most conservative 'worst case' estimate (95th percentile at the most exposed receptor), the level of 1,2-dichloroethane was double the inhalation HCV, due almost equally to the estimated site and background contributions. The HCV was set at a level 25,000 times lower than the inhalation dose equivalent to an oral dose which was found to cause a 5% increase in tumours in animals. This was considered to be a level posing a negligible risk to health. If the dose-response relationship at low exposures is linear, or if there is a threshold for these effects, it is considered that negligible health impacts are likely to be associated with exposure to 1,2-dichloroethane emanating from this site. This study indicates that there are unlikely to be any significant health effects associated with dichloroethane, but that this substance should be included in the assessment and control of the trace components of landfill gas.

Dioxins and dioxin-like polychlorinated biphenyls

The dietary intakes of dioxins were considered for toddlers, school age children and adults. Inclusion of an outlying measured site boundary value caused exposure concentrations for Site B (summer only) to significantly exceed the Tolerable Daily Intake (TDI) of 2pg WHO-TEQ/kg bw/day. However, when this data point was excluded, the concentrations, including the worst case concentrations, were significantly lower than the TDI. For Site A (summer and winter) and Site B in the winter, the site contribution did not exceed the TDI.

The dietary intake data indicate that both sites contribute only a small fraction of the total dietary intakes for the age groups 1.5-2.5 years, 2.5-3.5 years, 3.5-4.5 years, school age children and adults, at 0-2 and 2-7km from the sites. In all cases the Tolerable Daily Intake (TDI) of 2 picograms toxic equivalent per kilogram body weight per day (2 pg WHO-TEQ/kg bw/day) was not exceeded. At Site A in the summer worst case exposure concentrations were highest with exposures reaching between 72-96% of the TDI, for toddlers.

When total dietary exposure (all sources, including the landfill sites) to dioxins is considered a different conclusion is reached. The TDI is not exceeded for adults and school children for either site. However, for toddlers, particularly the youngest age group (1.5-2.5 years), the mean and worst case exposures are approximately equal to the TDI for Site A and B in the winter and Site B in the summer, but are 150-300% of the TDI at Site A in the summer.

The Site B summer data were very strongly influenced by one of the eight pairs of measurements. When this data point was included in the site contribution exposure data, the mean exposures for the youngest age group of children within 0-2km of the site were 170-230% of the TDI, and the worst case exposure concentrations up to 29 times the TDI. Inclusion of the outlying data point for Site B (summer only) leads to exposure concentrations that warrant further investigation. The estimated exposure values at Site A in the summer also warrant further investigation.

The COT (2001) concluded that because of the long half-life, short-term exceedances of the TDI are not expected to result in adverse effects. Nevertheless it is not possible to identify a duration and degree of exceedance at which adverse effects might occur. It is the intake averaged over a prolonged period that should be kept within the TDI, so that the body burden of dioxins is kept below the level thought to cause health effects, including developmental toxicity.

On the basis of the forecast exposure levels, it is concluded that the total dietary intake of dioxins and furans in populations living close to landfill sites warrants further consideration.

A9.4 Checks on estimated exposure levels

As well as the checks described in Section 4.5, a number of cross-checks on the quality of data produced in the course of the project were built into the study. These checks allow the measured values and subsequent derived data values to be evaluated to establish their validity. Based on this evaluation, the conceptual model can be revised if appropriate to improve the representation of potential exposures to substances emitted from landfill sites.

The following cross-checks were carried out:

1. Measured surface emissions were evaluated against estimated total hydrocarbon emissions. A correspondence between these two data sets would be expected.

2. Substances which were measured in the source gas and for which a significant contribution to emissions was estimated were investigated to see if any were identified as being emitted, but not measured in the source gas. This could indicate an alternative local source of these substances. Conversely, substances could be detected only in the landfill but not identified as being emitted if they are attenuated when passing through the landfill and soils to the open air, or if they had been diluted to below the fenceline instrumental detection limit.

3. Estimated emissions of dioxins and furans were evaluated against the measured emissions from landfill gas engines/flares

4. The modelled contribution of emissions from the site was compared to the measured contribution of emissions to establish whether the model study was providing a reasonable forecast of population exposure.

5. Estimated background concentrations of substances measured at the sites were benchmarked against national records of concentrations of these substances at rural locations. If the estimated background level at the site was found to be significantly higher than the concentrations measured at rural locations away from specific sources, this could indicate that substances emitted from the site are being wrongly attributed to background.

6. Concentrations of trace components of landfill gas measured during the site walkover survey were evaluated against the fenceline measurements and estimated maximum exposure concentrations. This gave an indication of whether the fenceline data and/or estimated maximum exposure concentrations were giving reasonable information on maximum likely exposure to the trace components of landfill gas.

7. Estimated background concentrations of released substances were evaluated against national air monitoring records

8. The levels of trace components of landfill gas obtained from the site walkover survey, the fenceline measurements and the estimated exposures were compared.

A9.4.1 Comparison of estimated emissions and source gas measurements

Figures A9.4 to A9.7 provide a comparison of estimated emissions based on fenceline measurements and measured landfill gas concentrations. Any substance associated with landfill gas emissions with a non-zero estimated site contribution would be expected to be

detected in the landfill gas. The values plotted for estimated release rate and measured concentration in landfill gas are not directly comparable.

Figure A9.4 Comparison of estimated emissions and source gas concentrations (Site A, Winter)

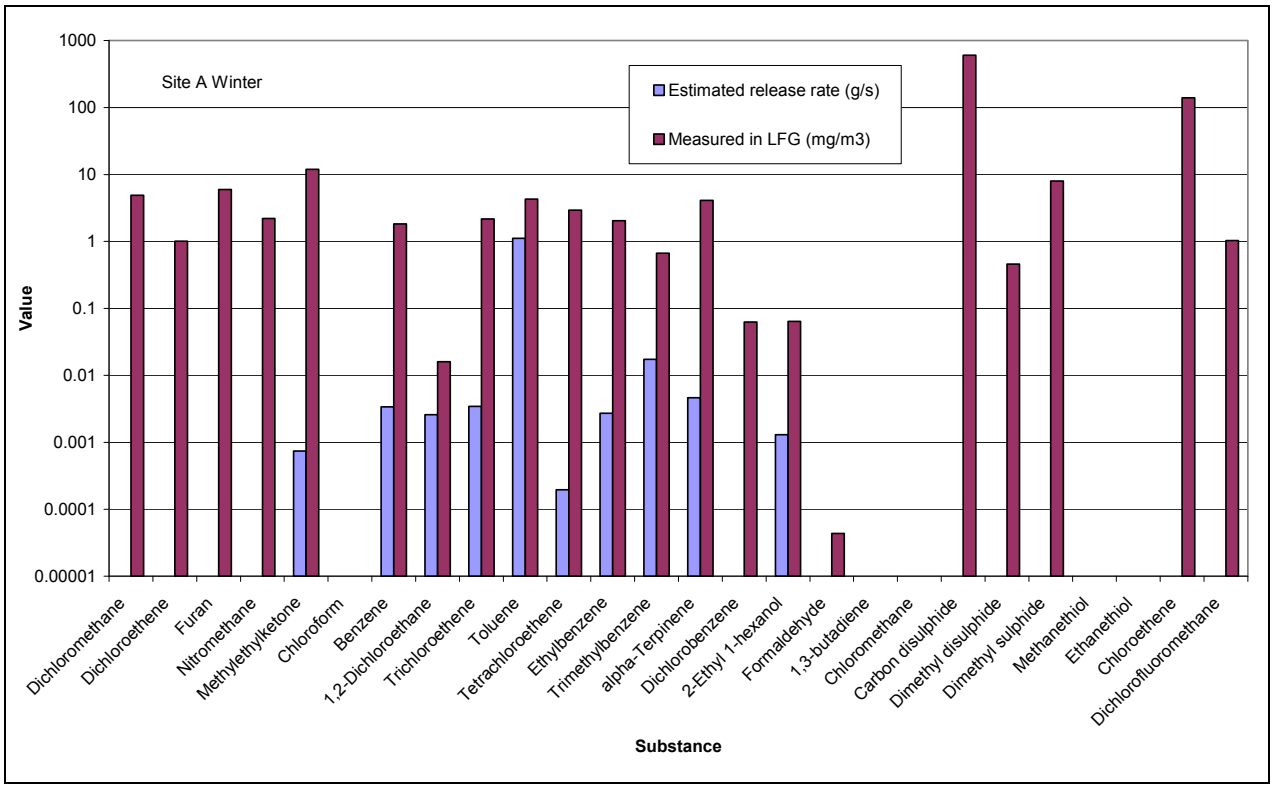


Figure A9.5 Comparison of estimated emissions and source gas concentrations (Site A, Summer)

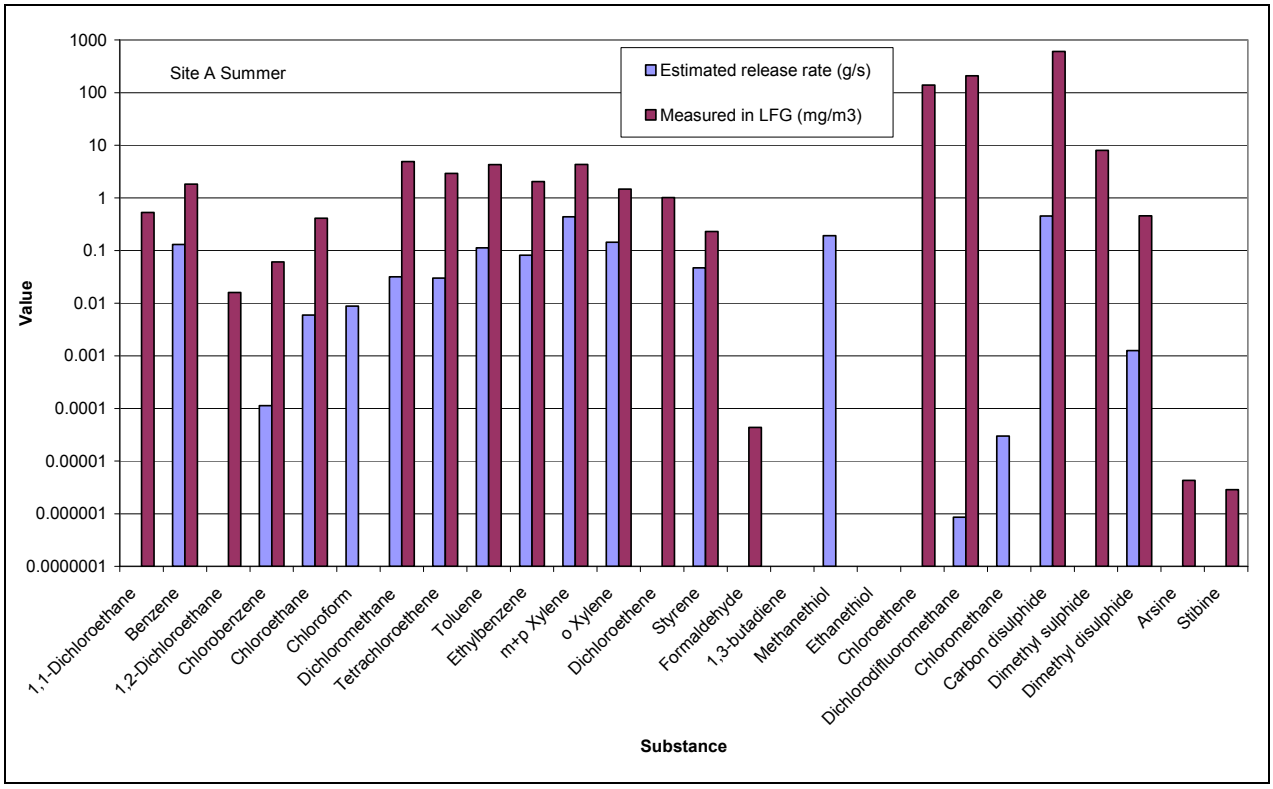


Figure A9.6 Comparison of estimated emissions and source gas concentrations (Site B, Winter)

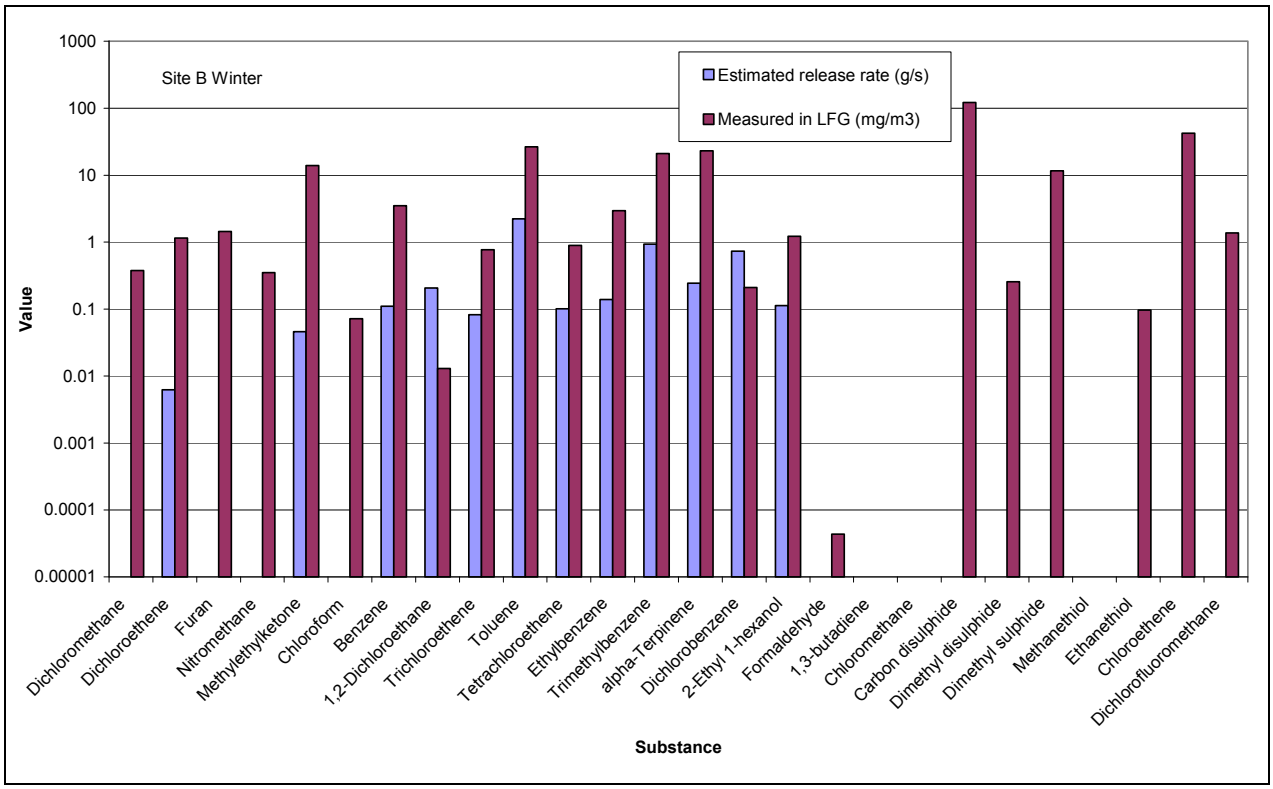
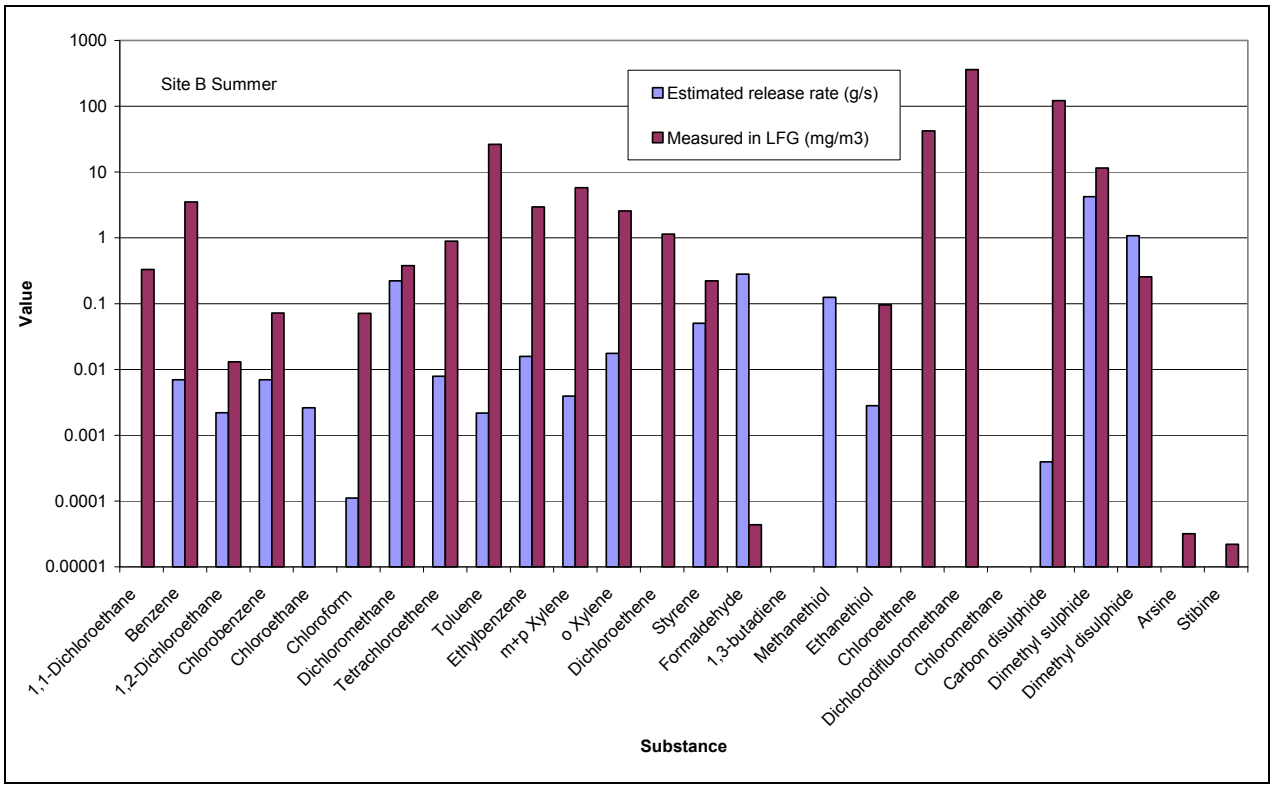


Figure A9.7 Comparison of estimated emissions and source gas concentrations (Site B, Summer)



The information in Figures 4.9 – 4.12 indicates that the only substances for which a site increment was identified but which were not found in landfill gas were chloroform, chloromethane and methanethiol (Site A, Summer), and methanethiol (Site B, Summer). The

estimated release rate for chloromethane was two to three orders of magnitude below the other estimated release rates, and so the site increment may be consistent with not detecting the substance in landfill gas. The lack of observed site increment of sulphur-containing compounds during the winter survey was due to the relatively high detection limit of these measurements. The detection limit was improved for the summer survey, and a site increment was detected.

A much wider range of substances were detected in the landfill gas, but no site increment was identified. As indicated above, this could have been due to attenuation when passing through the body of the landfill and soils to the open air, or if they had been diluted to below the fenceline instrumental detection limit.

It is concluded that the range of substances identified at the boundary fence is consistent with the range of substances identified in the source gas measurements. This provides confidence that the measured fenceline concentrations are reliable. Other sources of emissions may be responsible for the concentrations of chloroform, chloromethane and methanethiol detected at Site A, and methanethiol detected at Site B. These substances were therefore assessed using a qualitative risk assessment approach, rather than the quantitative methods used in the study as a whole.

A9.4.2 Estimated total hydrocarbon/individual VOC emissions

Estimated release rate of VOCs compared to measured surface emissions

Measured surface emissions during the summer and winter surveys are set out in Table A9.9 below, together with the average estimated emission rate of individual VOCs. 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 A9.9 : Measured total hydrocarbon concentrations and surface emissions

Period	Total surface emissions from flux box measurements	Average estimated release rate of VOCs
Site A Winter	76 mg carbon/s	44 mg/s
Site A Summer	7090 mg carbon /s	66 mg/s
Site B Winter	630 mg carbon /s	190 mg/s
Site B Summer	794 mg carbon /s	234 mg/s

The average estimated release rate of VOCs is a higher proportion of the measured total surface emissions than would be expected. This indicates that either the surface emissions measurements are under-estimating the true site emissions, and/or the estimated release rates are over-estimates of the actual release rates. Over-estimates of the release rates of individual VOCs could arise if the actual source of emissions was different to that assumed in the modelling study.

Estimated release rates of VOCs compared to theoretical forecasts

The estimated release rates of trace components of landfill gas were also cross-checked by considering theoretical forecasts of the quantity of landfill gas generated at each landfill. Checking in this way is limited because the estimated release rates based on source measurements are themselves not fully reliable estimates of emissions. This is because emissions may vary from time to time; substances may be subject to further change during release from the site; and the emissions estimates based on landfill gas emissions depend on theoretical estimates of the volume of landfill gas generated at the site.

The cross-check was carried out by estimating the release rate of landfill gas by multiplying the estimated volume of landfill gas released without combustion by the measured concentration of trace components in the landfill gas. This was compared with the overall site release rate estimated from the fenceline measurements. Neither method is a direct measurement of overall emissions from the site, but they would in principle be expected to give similar values. The comparison is set out in Table A9.10 and graphically in Figures A9.8 and A9.9.

Table A9.10 Cross-check of estimated emission rates from fugitive gas against measured/modelled emission rates

Substance	Site A Estimated release rate (g/s)			Site B Estimated release rate (g/s)		
	Based on measurement in source gas	Based on site boundary measurement (Winter 2001)	Based on site boundary measurement (Summer 2003)	Based on measurement in source gas	Based on site boundary measurement (Winter 2002)	Based on site boundary measurement (Summer 2003)
Dichlorodifluoromethane	0.023	-	8.64E-07	0.029	-	0
Chloromethane	No detections	0	0.000030	No detections	0	0
Chloroethene	0.015	0	0	0.0034	0	0
Chloroethane	0.000045	-	0.059	No detections	-	0.0026
Ethanethiol	No detections	0	0	7.8E-06	0	0.0028
Dimethyl sulphide	0.00089	0	0	0.0009	0	4.2
Dichloromethane	0.00054	0	0.032	3.0E-05	0	0.22
Carbon disulphide	0.067	0	0.451	0.010	0	0.00039
trans-1,2-Dichloroethene	0.000015	-	-	1.5E-05	0.0062	0
1,1-Dichloroethane	0.000059	-	0	2.7E-05	-	0
Methylethylketone	0.00132	0.00074	-	0.0011	0.046	-
cis-1,2-Dichloroethene	0.00013	-	-	0.00023	0.0062	0
Chloroform	No detections	0	0.0087	5.776E-06	0	0.00011
Benzene	0.00020	0.0034	0.13	0.00028	0.11	0.0070
Dimethyl disulphide	0.000051	0	0.0012	2.1E-05	0	1.1
Toluene	0.00048	1.12	0.11	0.0021	2.2	0.0022
Tetrachloroethene	0.00032	-	0.030	7.2E-05	-	0.0079
Chlorobenzene	0.0000067	-	0.00011	5.8E-06	-	0.0070
EthylBenzene	0.00023	0.0027	0.081	0.00024	0.14	0.016
m+p Xylene	0.00048	-	0.44	0.00047	-	0.0039
Styrene	0.000025	-	0.047	1.8E-05	-	0.051
o Xylene	0.00016	-	0.14	0.00021	-	0.018
Methanethiol 1	No detections	0	0.19	No detections	0	0.12
1,3-butadiene	No detections	0	0	No detections	0	0
Formaldehyde	4.8E-09	0	0	3.5E-09	0	0.28
Nitromethane	0.00024	0	-	2.8E-05	0	-
1,2-Dichloroethane	0.0000018	0.0026	0	1.052E-06	0.21	0.0022
Alpha-terpinene	0.00045	0.0046	-	0.0019	0.24	-
Dimethyl sulphide	No detections	0	0	0.00038	0	4.2

Figure A9.8 Cross-check of estimated emission rates from fugitive gas against measured/modelled emission rates (Site A)

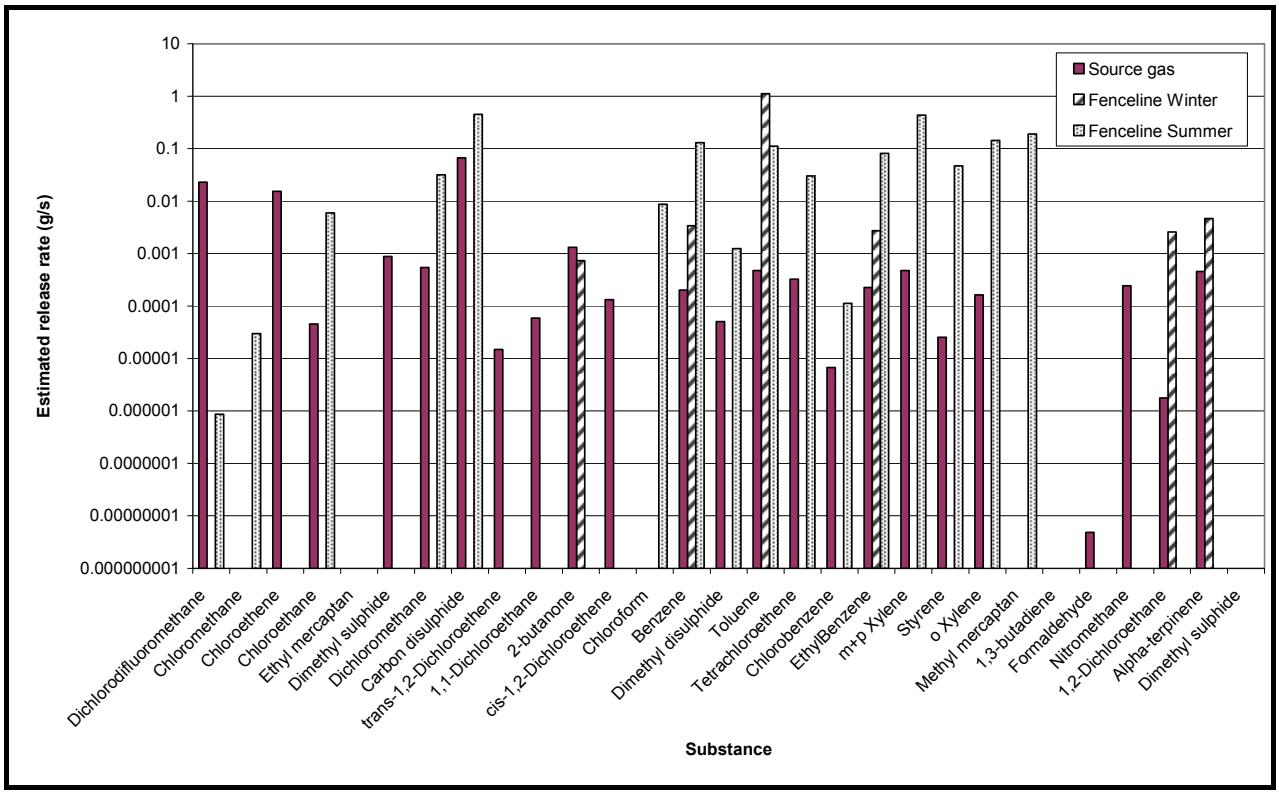
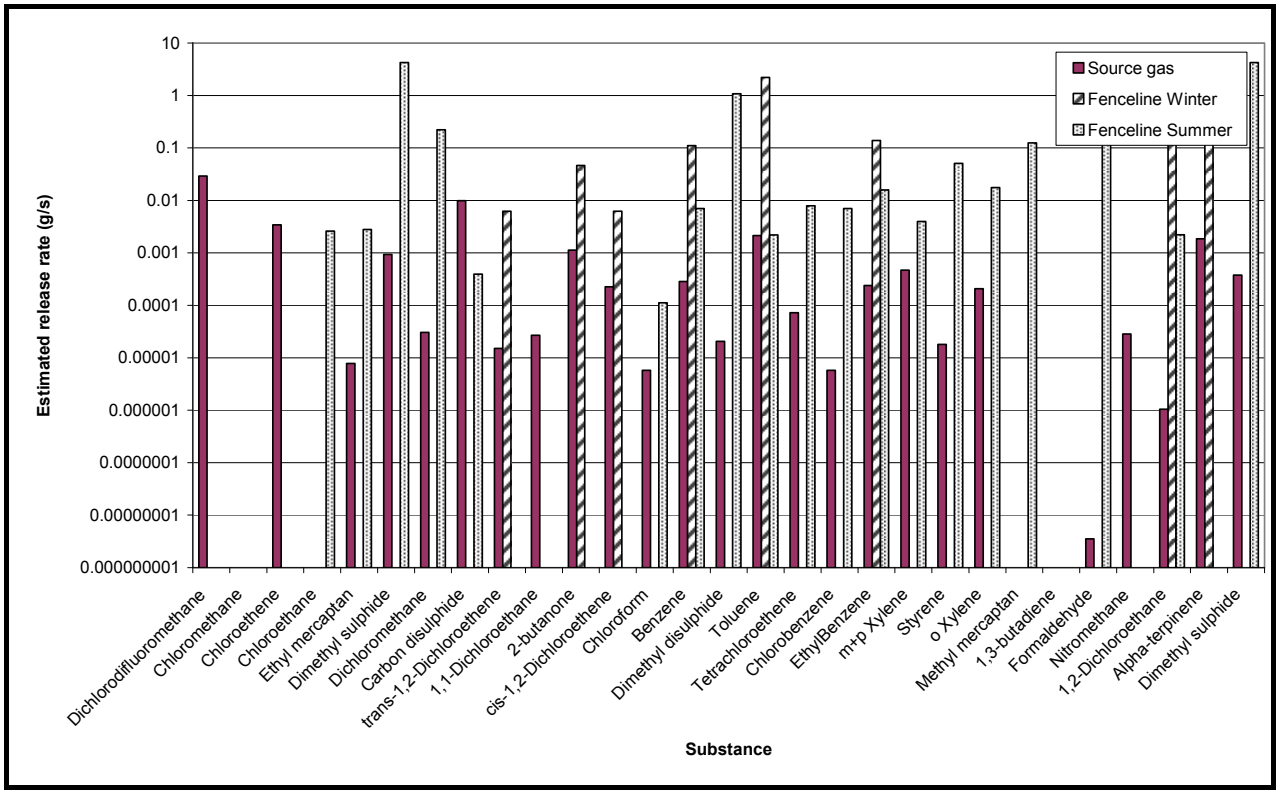


Figure A9.9 Cross-check of estimated emission rates from fugitive gas against measured/modelled emission rates (Site B)



The estimated emission rates based on landfill gas modelling used to check the analysis based on boundary fence measurements are subject to additional uncertainty associated with landfill gas modelling and surface oxidation. It was found that the volumes of gas generated at Site B estimated using the GasSim model were less than the volumes of gas known to be collected and combusted in the landfill gas flare/engines. The metered gas generation rate during March – May 2002 was 1200 m^3 per hour, approximately 70% higher than the GasSim forecast. This may be due to a departure from the normal procedure of calibrating the GasSim model against metered oxygen flows, with the aim of developing a model which can be used to forecast future gas production. For this study, prior calibration was not possible, but also was not required as future forecasting of gas yields did not form part of this study. The measured landfill gas volumes were used in the study without further refinement of the GasSim models.

The volume of gas released as a fugitive emission from Site B was estimated for the purposes of the cross-check data on the assumption that the volume of gas collected and passed to the engines amounted to 80% of the gas generated at the site. The remaining 20% was assumed to be released directly to the atmosphere. In practice, some of the components of landfill gas will be oxidised on passing through the surface of the landfill.

In general, the method used in this study gives higher estimated release rates than the values obtained using the method based on landfill gas modelling and source gas concentrations. At Site A, the estimates based on boundary fence measurements were typically 20 times higher than the estimates based on modelled source gas production. At Site B, the estimates based on boundary fence measurements were typically 200 times higher than the estimates based on modelled source gas production. In view of the conservative assumptions built into the estimating of release rates, the values based on boundary fence measurements would be expected to be an over-estimation of the true emission rates. This is consistent with the higher emission rates obtained using the boundary fence data. The wider disparity at Site B may reflect the uncertainty in gas yield at the site, with the GasSim model giving a lower estimated gas yield than the rate of gas collection at the site.

The higher values derived from the method based on boundary fence measurements mean that it would tend, if anything, to over-estimate release rates of trace components of landfill gas, thereby erring on the side of caution. This means that, if anything, the approach adopted to estimating site release rates in the study represents a conservative approach.

A9.4.3 Comparison of estimated emissions of dioxins and furans against measured engine/flare emissions

The estimated release rate of dioxins and furans was cross-checked to a limited extent by comparing measured emission rates from landfill gas engines against the values estimated from boundary fence measurements. Checking in this way is limited because neither method is a direct measurement of overall emissions from the site. The estimated release rates based on source measurements are themselves not fully reliable because emissions may vary from time to time, and there may be other sources of dioxins and furans either on-site or off-site. However, the two methods would be expected to give comparable values.

Table A9.11 Comparison of estimated and measured emission rates of dioxins and furans

Substance and source	Estimated emission rate (gTEQ/s)				Measured emission rate (gTEQ/s)
	25th %ile	Mean	75th %ile	95th %ile	
Site A Winter 2001/02 Dioxins and furans	0	6.5×10^{-10}	7.8×10^{-11}	3.1×10^{-9}	2.8×10^{-11}
Site A Summer 2003 Dioxins and furans	0	9.3×10^{-9}	4.7×10^{-10}	4.8×10^{-8}	2.8×10^{-11}
Site B Summer 2003 Dioxins and furans (including single high value)	0	7.5×10^{-8}	1.6×10^{-9}	3.9×10^{-7}	2.8×10^{-11}

Site B Summer 2003 Dioxins and furans (excluding single high value)	0	5.0×10^{-10}	8.0×10^{-10}	1.7×10^{-9}	2.8×10^{-11}

The mean estimated release rate of dioxins and furans obtained from the fenceline measurement is greater than the measured release rate from the landfill gas engines. The mean value is due to a relatively small number of measurements which indicate a potential source of dioxins at the site, and a larger number of measurements which indicate no detectable increase in dioxins due to emissions from the site. The higher mean estimated release rates than the measured values may reflect the fact that the model representation of sources is not a true reflection of the sources of dioxins at the site. ources other than the engines may be contributing to emissions of dioxins and furans – for example, emissions from diesel engine vehicles. This would tend to reduce confidence in the estimated release rates and derived off-site levels of dioxins and furans based on the site boundary measurements. The boundary measurements themselves remain a valid source of data.

A9.4.4 Comparison of modelled and observed site contribution

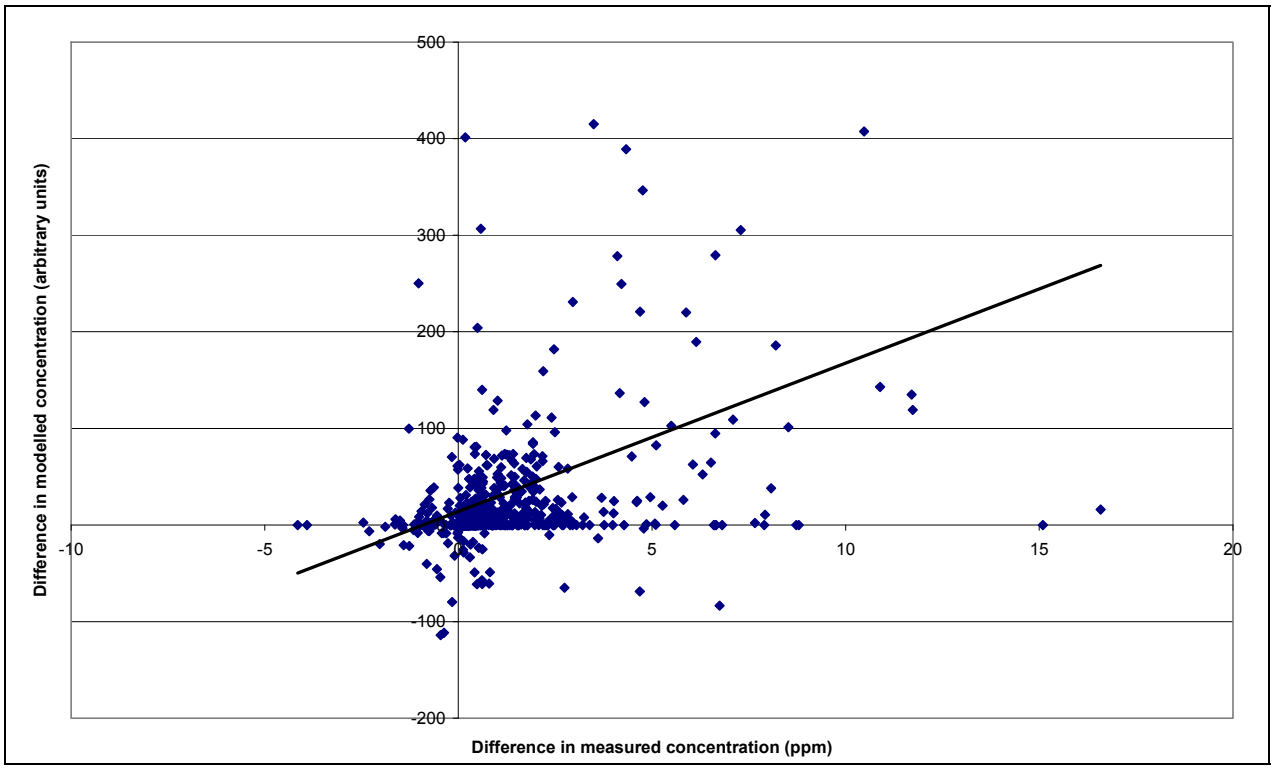
The analysis method used in this project means that there is a risk of a site contribution being incorrectly assigned to the local baseline. There is also a risk of the reverse process occurring, whereby substances present in the air arriving at the landfill site are incorrectly assigned to emissions from the landfill site. However, this would be less of a concern for the purposes of this data analysis, as it would, if anything, result in an over-estimation of the effect of the landfill.

Even if there has been a mis-allocation between baseline concentrations and site contribution, the highest overall exposure is likely to be well represented by the total concentration due to baseline concentrations plus the site contribution. As a worst case, it might be that the contribution from background concentrations is very small compared to the site contribution, and virtually all the exposure at receptors downwind of the monitoring stations is due to the landfill site. This gives two possible extremes: assigning too much of the exposure concentrations to baseline on the one hand, and assigning all of the observed exposure to landfill emissions on the other hand. The true picture is likely to be between these two extremes:

The exposure data were investigated to identify whether there was evidence for mixing of a contribution from the site into the component of the measured concentration which was identified as the local baseline. This was investigated by plotting the difference in modelled concentration of fugitive landfill gas emissions between the two monitoring stations against the difference in measured concentration of total hydrocarbons at the two monitoring stations for the summer sampling periods. Ideally, the points should lie on a straight line. Points lying off the line indicate that there may be some contribution from the site to baseline concentrations of substances under consideration. The data show that, there is little correlation between the measured and modelled values, indicating that the assessment technique is not a realistic representation of emissions from the site. The variations away from a linear correlation suggest that there is a risk that baseline concentrations have a contribution from the site, or that the site contribution includes a contribution from baseline levels.

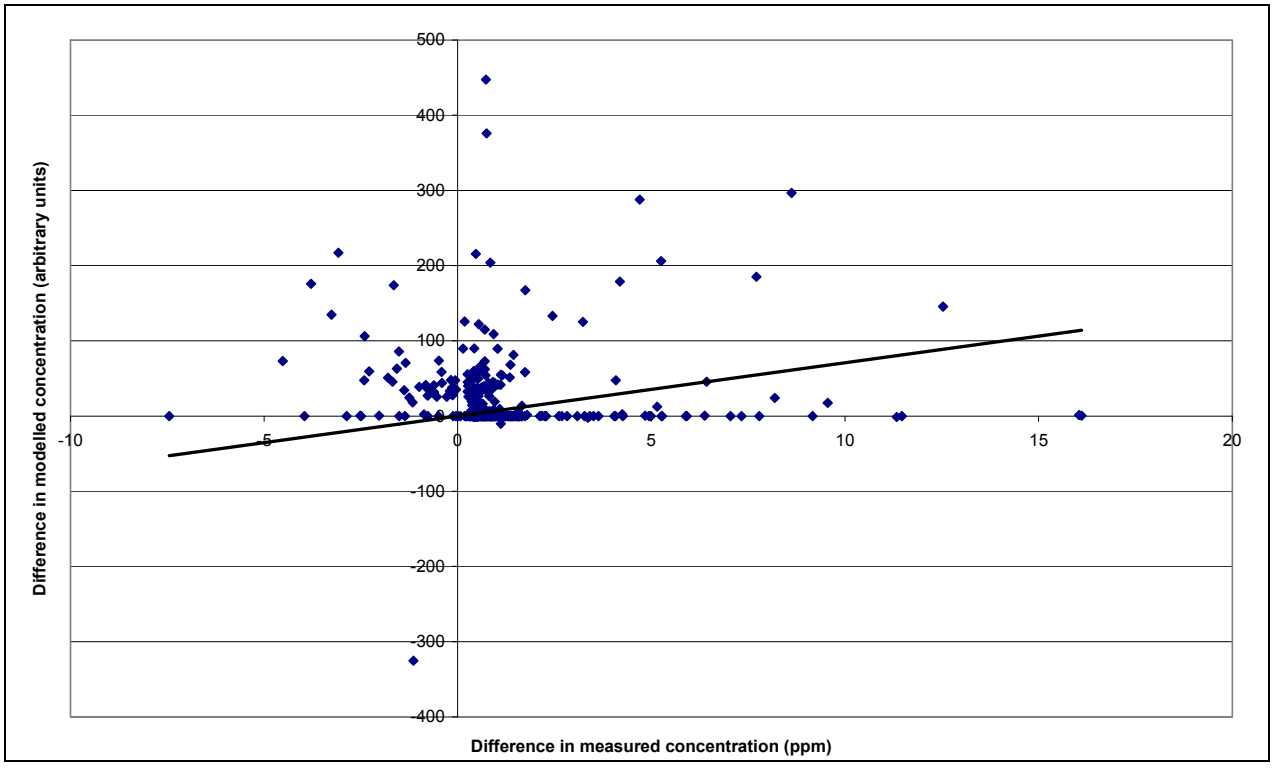
A plot of these parameters is shown in Figure A9.10 for data recorded during the summer survey at Site A, and in Figure A9.11 for data recorded during the summer survey at Site B.

Figure A9.10 Measured versus modelled concentrations of substances associated with fugitive gas emissions, Site A



Horizontal axis: difference between measured concentration at the north-east and south-west monitoring station of trace substance
Vertical axis: difference between modelled concentration at the north-east and south-west monitoring station of a substance released in landfill gas at a unit release rate during the measurement period

Figure A9.11 Measured versus modelled concentrations of substances associated with fugitive gas emissions, Site B



Horizontal axis: difference between measured concentration at the north-east and south-west monitoring station of trace substance
Vertical axis: difference between modelled concentration at the north-east and south-west monitoring station of a substance released in landfill gas at a unit release rate during the measurement period

The charts show that the model forecasts are not well correlated with the measured concentrations of total hydrocarbons at Site A or Site B.

This could be caused by differences between the meteorological conditions at the site and those used in the modelling study (some parameters were taken from nearby Meteorological Office weather stations); discrepancies between the modelled and actual source characteristics for hydrocarbons; or a significant influence of other sources on the measured concentrations of methane and total hydrocarbons. The most likely cause of the lack of correlation is considered to be discrepancies between the modelled and actual source characteristics for hydrocarbons.

In view of this, it was concluded that little weight was placed on the quantitative evaluation of exposure to substances associated with landfill gas.

A9.4.5 Comparison of estimated background concentrations with national records

A second approach to evaluating the allocation of measured concentrations of substances to site or background sources was based on consideration of records of air monitoring data from rural and urban sites elsewhere in the UK, where data are available. In some cases, the baseline level derived from analysis of the boundary fence monitoring data in this project was above concentrations measured in urban areas in the UK. This provided a further indication that the model for exposure to these substances was in some respects flawed.

Table A9.12 Comparison of estimated site baseline and UK rural and urban baseline concentrations

Substance	Measured baseline concentration[1]		Estimated baseline concen-tration	Estimated project baseline as proportion of rural baseline	Above urban baseline ?	Estimated baseline concen-tration	Estimated project baseline as proportion of rural baseline	Above urban baseline ?
	Rural	Urban	Site A	Site A	Site A	Site B	Site B	Site B
Arsenic	0.003		0.00022	7%		0.00028	9%	
Cadmium	0.0001	0.0004	0.00035	363%	**Yes**	0.00023	239%	No
Chromium	0.0046	0.0052	0.0012	26%	No	0.0018	39%	No
Copper	0.0017	0.0070	0.19	10890%	**Yes**	0.025	1494%	**Yes**
Manganese	0.0008	0.0041	0.0040	466%	No	0.0094	1109%	**Yes**
Nickel	0.0006	0.0013	0.0011	179%	No	0.0010	160%	No
Vanadium	0.0007	0.0012	0.00071	105%	No	0.0024	357%	**Yes**
Dioxin and furan	1.0×10^{-8}	4.0×10^{-8}	3.4×10^{-8}	345%	No	2.3×10^{-8}	228%	No
Acenaphthylene		0.00043	0.00041		No	0.00011		No
Acenaphthene	0.00063	0.00075	0.00043	69%	No	0.00015	24%	No
Fluorene	0.0038	0.0034	0.0012	31%	No	0.0006	16%	No
Phenanthrene	0.093	0.015	0.0025	3%	No	0.0039	4%	No
Anthracene	0.0050	0.00058	0.00077	15%	**Yes**	0.00065	13%	**Yes**
Pyrene	0.0075	0.0026	0.00068	9%	No	0.00113	15%	No
Benzo (a) anthracene	0.00039	0.00017	0.00099	254%	**Yes**	0.00031	81%	**Yes**
Chrysene	0.00073	0.00047	0.00065	88%	**Yes**	0.00047	64%	**Yes**

Benzo (a) pyrene	4.8×10^{-5}	0.00013	0.00022	460%	**Yes**	0.00030	623%	**Yes**
Indeno (123-cd) pyrene	9.3×10^{-5}	0.00032	0.00013	142%	No	0.00040	432%	**Yes**
Benzo (ghi) perylene	0.000070	0.00033	0.00023	326%	No	0.00041	581%	**Yes**
Dibenzo (ah) anthracene		2.7×10^{-5}	0.00029		**Yes**	0.00029		**Yes**
Benzene	0.58	3.3	0.51	89%	No	0.77	133%	No
Ethylbenzene		2.6	11.5		**Yes**	0.92		No
m+p Xylene		9.3	108		**Yes**	4.6		No
o Xylene		3.2	55		**Yes**	3.2		No
Styrene	1.30		0.82	63%		0.73	56%	
Methylethylketone	0.55		0.83	152%		0.76	139%	
Toluene	1.4	13.6	39	2843%	**Yes**	7.3	530%	No
Trimethylbenzene		4.6	1.18		No	2.4		No
Formaldehyde	1.4		0	0%		89	6255%	
Chloromethane	1.2		7.5	621%				

Note 1 : Data taken from Air quality archive, 2004

The data in Table A9.12 does not indicate any clear pattern of mis-allocation to baseline concentrations for any group of substances, or for one site more than the other.

Where national monitoring records indicated that the exposure model was not performing adequately, the substances concerned were assessed using a qualitative risk assessment approach, rather than the quantitative methods used in the study as a whole. These substances were defined as those where the estimated baseline level was above the national urban background level, or (in the absence of an urban background measurement) more than twice the rural background level. The substances identified in this way were:

Site A
Cadmium
Copper
Anthracene
Benzo (a) anthracene
Chrysene
Benzo (a) pyrene
Dibenzo (ah) anthracene
Ethylbenzene
m+p Xylene
o Xylene
Toluene
Chloromethane

Site B
Copper
Manganese
Vanadium
Anthracene
Benzo (a) anthracene
Chrysene
Benzo (a) pyrene
Indeno (123-cd) pyrene
Benzo (ghi) perylene
Dibenzo (ah) anthracene
Formaldehyde

A9.4.6 Comparison of trace components of landfill gas from site walkover, fenceline measurements and estimated exposures

The highest concentrations of trace components of landfill gas in ambient air estimated or measured in different ways would be expected to be broadly similar. These maximum concentrations can be estimated in three ways using data obtained in this project:

- Measurements of the trace components of landfill gas during a site walkover survey at the points where the highest concentrations of hydrocarbons were observed.
- The highest concentrations of trace components measured at the boundary fence monitoring stations

- The highest forecast concentrations of trace components at receptors in the vicinity of the landfill sites, derived on the basis of the site boundary measurements.

The highest concentrations of trace components forecast in these ways are shown in Tables A9.13 and A9.14.

Table A9.12 Highest estimated concentrations of trace components of landfill gas (Site A)

Substance	Site Walkover [µg/m^3]	Boundary fence measurement [µg/m^3]		Highest forecast value at any property [µg/m^3]	
		Winter	Summer	Winter	Summer
Hydrogen Sulphide	0.63	8.6	4.1	Not assessed	Not assessed
Methanethiol	Not detected	3.0	21.6	0	1.66
Ethanethiol	0.16	Not detected	0.8	0	0
Chloroethene	0.04	Not detected	0.46	0	0
Chlorodifluoromethane	Not detected	Not measured	3.0	Not measured	0.35
Dichlorodifluoromethane	4.21	Not measured	0.01	Not measured	7.5E-06
1,1,1-trichloroethane	0.21	Not measured	0.27	Not measured	0.12
Dichloroethane	0.00	2.0	0.01	0.070	0
1,3-Butadiene	3.02	Not detected	Not detected	0	0
Chlorobenzene	0.14	Not measured	0.09	Not measured	0.0010
Choroethane	0.04	Not measured	0.12	Not measured	0.051
Chloroform	0.10	Not detected	0.83	0	0.076
Dichloromethane	0.51	Not detected	7.4	0	0.27
Trichloroethene	3.45	3.0	Not measured	0.093	Not measured
Arsine	Not detected	Not measured	Not detected	Not measured	0
Stibine	157	Not measured	222	Not measured	0
Formaldehyde	34	Not detected	213	0	0

Table A9.13 Highest estimated concentrations of trace components of landfill gas (Site B)

Substance	Site Walkover [µg/m^3]	Boundary fence measurement [µg/m^3]		Highest forecast value at any property [µg/m^3]	
		Winter	Summer	Winter	Summer
Hydrogen Sulphide	0.69	7.0	4.5	Not assessed	Not assessed
Methanethiol	0.43	Not detected	7.5	0	1.66
Ethanethiol	1.91	Not detected	2.1	0	0
Chloroethene	0.03	Not detected	4.9	0	0
Chlorodifluoromethane	0.12	Not measured	0.7	Not measured	0.35
Dichlorodifluoromethane	1.75	Not measured	Not detected	Not measured	7.5E-06
1,1,1-trichloroethane	0.85	Not measured	0.1	Not measured	0.12
Dichloroethane	Not detected	1.5	0.03	4.2	0
1,3-Butadiene	3.71		Not detected	0	0
Chlorobenzene	0.69	Not measured	0.44	Not measured	0.0010
Choroethane	0.02	Not measured	0.09	Not measured	0.051
Chloroform	1.01	1.5	0.45	0	0.08
Dichloromethane	1.16	Not detected	2.09	0	0.27
Trichloroethene	1.32	2.1	Not measured	1.67	Not measured
Arsine	Not detected	Not measured	0.53	Not measured	0
Stibine	539	Not measured	Not detected	Not measured	0
Formaldehyde	85	Not detected	487	0	0

Estimated maximum concentrations of trace landfill gas components using these three methods gave results of similar magnitude. In general, the forecast concentrations of trace components at nearby properties are lower than those measured at the boundary fence or detected during the site walkover survey. This pattern would be expected in practice, and provides a degree of confidence that the exposure assessment provides a realistic estimate of the order of magnitude of exposure.

A9.4.7 VOCs at Site B

One reason for the poor representation of concentrations of VOCs at Site B by the conceptual model could be a significant influence of other sources of VOCs. Three possible sources of VOCs at the site were identified:

- A trunk road running to the west of site B. Although the road is sufficiently far from the site to have no significant effects on normal air quality studies, it could have influenced concentrations of VOCs sufficiently to reduce confidence in the conceptual model. However, the measured concentrations of most individual VOCs were higher at the north-east side of the site (further from the road) than the south-west side (closer to the road), including VOCs associated with road traffic (benzene, toluene, xylenes and ethyl benzene). This indicates that the road is having a less significant influence on concentrations of VOCs at the site than other sources of VOCs, supporting the assumption that the landfill (possibly together with other sources) is the principal source of VOCs at the site. This is consistent with the observed pattern of wind flows during the course of the study, with a relatively high prevalence of winds from the south-east. These would take emissions from the trunk road away from the site.

- An airfield is located approximately 12 kilometres north of site B. This airfield is used for training purposes by light aircraft. However, the relatively low level of usage at the

airfield and its distance from the site mean that it is unlikely to make a significant contribution to concentrations of VOCs at the site.

- A process manufacturing isocyanates and chlorinated VOCs is located 13 km south-east of the site. A preliminary dispersion modelling analysis indicated that emissions of chlorinated VOCs from this process could give rise to individual VOCs at Site B at concentrations up to 0.03 µg/m^3. The average concentrations of all but four VOCs at Site B were four or more times this level (the exceptions were 1,1,1-trichloroethane, chloromethane, 1,1-dichloroethane and chloroethane). It is concluded that emissions from this process are unlikely to have had a significant influence on concentrations of VOCs at the site.

An alternative reason for the poor representation of concentrations of VOCs at the site could be the poor performance of the dispersion modelling study, which could arise if the weather data were not representative of local conditions or because of the local topography. The weather data recorded at the site did not show the expected pattern of dominant wind bearing from the south-west.

This was investigated by comparing the wind bearing measured at Site B with the wind bearing measured at a nearby Meteorological Office station, as shown in Figure A9.12 (winter monitoring period) and Figure A9.13 (summer monitoring period). This showed that the wind bearings measured at Site B and the nearby Meteorological Office station were similar, suggesting that the site-specific measurements are likely to be reliable.

The observed pattern of wind directions and speeds was taken into account in the quantitative assessment study. However, the predominant wind bearings observed at the site mean that the monitoring stations were directly upwind and downwind of the site relatively infrequently. This reduces the reliability of the monitoring data for estimating the site contribution to levels of released substances.

Figure A9.12 Comparison of wind direction measured at Site B and a nearby Met Office station (winter survey)

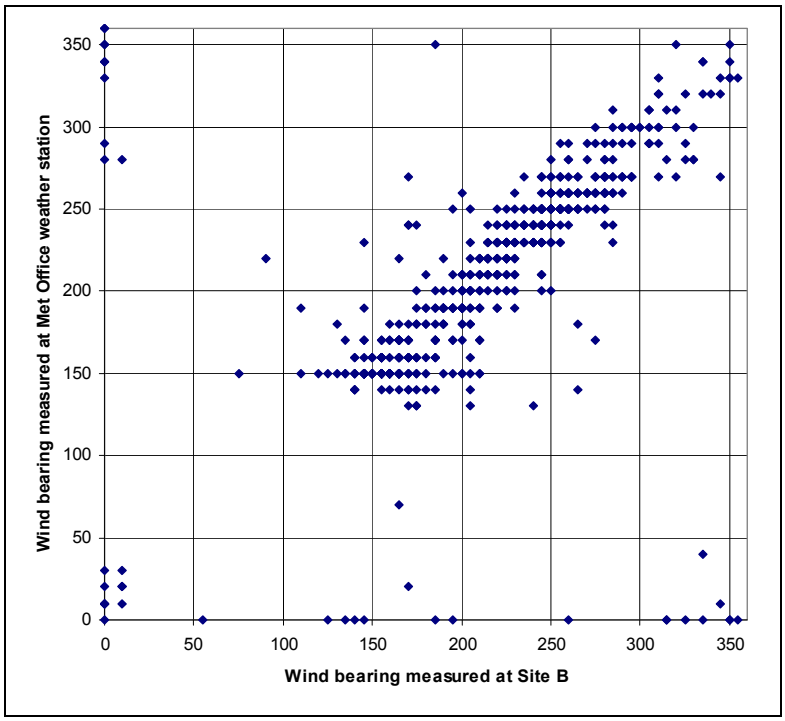
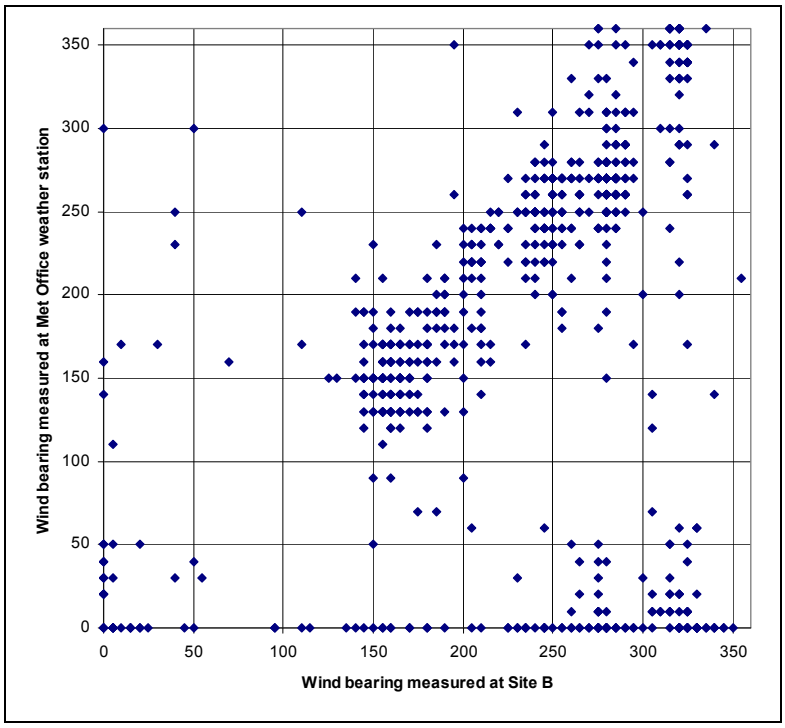


Figure A9.13 Comparison of wind direction measured at Site B and a nearby Met Office station (summer survey)



As outside sources of VOCs at Site B do not appear to be significant, it is appropriate to review the conceptual model used as the basis for investigating emissions from Site B. Reviewing the Risk Screening part of the project (Chapter 3) indicates that all the sources of airborne VOCs identified as potentially significant were assessed in this study. It is possible that additional sources and/or pathways for release of VOCs may exist which have not been considered, or that the sources are not well represented in the quantitative assessment model. For example, the locations of VOC sources could change over time, or could fluctuate significantly within a sampling period, whereas the quantitative assessment model assumed that sources were constant during a sampling period.

A9.4.8 Conclusions

A dispersion modelling approach was used in an attempt to estimate emission rates of airborne pollutants from the two sites, and hence to estimate possible public exposure. The estimated release rates obtained using the modelling approach were in general significant over-estimates of the true release rates, by one to two orders of magnitude.

For some substances, it was possible to compare a measurement of the emission rate of the substance with the modelled emission rate. When the measured and modelled emission rates were compared, the modelled values were found generally to be one to two orders of magnitude higher than those that had been measured. Other cross-checks also indicated that the modelling method was not satisfactory. In view of this, potential exposures were assessed using a semi-quantitative approach, as described in Chapter 5.

A9.5 Data quality

The data quality of the measured concentrations, estimated release rates and estimated exposure concentrations is set out in Tables A9.14 to A9.16.

Table A9.14 Data quality of measured concentrations

Substance	Proxy	Empirical	Methodological rigour	Validation	Pedigree
Metals	4	3	4	2	Very Good (13)
Dioxins and furans/PAHs/PCBs	4	3	4	2	Very Good (13)
VOCs (Site A)	2	3	3	2	Good (10)
1,3-butadiene and formaldehyde	2	3	3	2	Good (10)
Micro-organisms	2	3	2	1	Moderate (8)
Fibres	4	3	3	2	Good (12)
Arsine/Stibene	2	2	2	1	Moderate (7)
PM_{10} (continuous analyser)	4	4	4	3	Very Good (15)
Oxides of nitrogen (continuous analyser)	4	4	4	3	Very Good (15)
Sulphur dioxide (continuous analyser)	4	4	3	2	Very Good (13)
Hydrogen sulphide (continuous analyser)	3	4	3	2	Good (12)
Methane/total hydrocarbons (continuous analyser)	2	4	2	1	Good (9)
Non-methane hydrocarbons (continuous analyser)	1	2	2	1	Moderate (6)

Table A9.15 : Data quality of estimated release rates

Substance	Proxy	Empirical	Methodological rigour	Validation	Pedigree
Metals	2	2	0	0	Poor (4)
Dioxins and furans/PAHs/PCBs	2	2	1	0	Moderate (5)
VOCs (Site A)	1	2	1	0	Poor (4)
1,3-butadiene and formaldehyde	1	2	1	0	Poor (4)
Micro-organisms	1	2	1	0	Poor (4)
Fibres	2	2	1	0	Moderate (5)
Arsine/stibene	1	2	1	0	Poor (4)

Table A9.16 : Data quality of estimated exposure concentrations

Substance	Proxy	Empirical	Methodological rigour	Validation	Pedigree
Metals	2	2	0	1	Moderate (5)
Dioxins and furans/PAHs/PCBs	2	2	1	1	Moderate (6)
VOCs (Site A)	1	2	1	1	Moderate (5)
1,3-butadiene and formaldehyde	1	2	1	1	Moderate (5)
Micro-organisms	1	2	1	1	Moderate (5)
Fibres	2	2	1	1	Moderate (6)
Arsine/Stibene	1	2	1	1	Moderate (5)
PM_{10} (continuous analyser)	3	4	2	2	Good (11)
Oxides of nitrogen (continuous analyser)	3	4	2	2	Good (11)
Sulphur dioxide (continuous analyser)	3	4	2	2	Good (11)
Hydrogen sulphide (continuous analyser)	2	4	2	2	Good (10)

The data quality is necessarily less good than would be ideal – in particular, for the estimated release rates. In view of this, it is recommended that the estimated exposure concentrations are not used to obtain quantitative numerical forecasts of the health effects of landfill sites.

A9.6 : SITE EMISSION RATES

Although estimates of population exposure were developed as set out in this section, it was found that these were not sufficiently reliable to use in the study. Consequently, the information presented in Volume 1 does not use the data set out in this section.

Table A9.6.1 : Estimated emission rates; Site A Winter 2001/02 (g/s)

Substance	Mean	25%ile	50%ile	75 %ile	95%ile	100%ile
Antimony	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Arsenic	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cadmium						
Chromium	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cobalt	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Copper						
Lead	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Manganese	2.3E-03	0.0E+00	0.0E+00	0.0E+00	1.1E-02	1.6E-02
Mercury	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nickel	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Thallium	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Vanadium	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dioxin	6.52E-10	0.00E+00	0.00E+00	7.78E-11	3.11E-09	4.41E-09
D,F,PCB (TEQ) - upper limit	6.52E-10	0.00E+00	0.00E+00	7.78E-11	3.11E-09	4.41E-09
Naphthalene	1.62E-08	0.00E+00	0.00E+00	0.00E+00	7.95E-08	1.14E-07
Acenaphthylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Acenaphthene	2.70E-04	0.00E+00	0.00E+00	0.00E+00	1.32E-03	1.89E-03
Fluorene	1.78E-04	0.00E+00	0.00E+00	2.28E-06	8.71E-04	1.24E-03
Phenanthrene	1.42E-06	0.00E+00	0.00E+00	0.00E+00	6.97E-06	9.96E-06
Anthracene						
Fluoranthene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pyrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Benzo (a) anthracene						
Chrysene						
Benzo (b/k) fluoranthene	4.54E-07	0.00E+00	0.00E+00	0.00E+00	2.23E-06	3.18E-06
Benzo (a) pyrene						
Indeno (123-cd) pyrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Benzo (ghi) perylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dibenzo (ah) anthracene						
Dichloromethane	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,2-Dichloroethene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2-Methylfuran	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nitromethane	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Methylethylketone	7.40E-04	0.00E+00	0.00E+00	0.00E+00	3.85E-03	5.92E-03
Chloroform						
Benzene	3.39E-03	0.00E+00	0.00E+00	6.98E-04	1.68E-02	2.44E-02
1,2-Dichloroethane	2.58E-03	0.00E+00	0.00E+00	0.00E+00	1.34E-02	2.07E-02
Trichloroethene	3.44E-03	0.00E+00	0.00E+00	0.00E+00	1.79E-02	2.75E-02
Toluene						

Substance	Mean	25%ile	50%ile	75 %ile	95%ile	100%ile
Tetrachloroethene	1.96E-04	0.00E+00	0.00E+00	0.00E+00	1.02E-03	1.57E-03
Ethylbenzene						
Trimethylbenzene	1.74E-02	0.00E+00	0.00E+00	7.04E-03	8.24E-02	1.15E-01
alpha-Terpinene	4.64E-03	0.00E+00	0.00E+00	0.00E+00	2.41E-02	3.71E-02
Dichlorobenzene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2-Ethyl-1-hexanol	1.30E-03	0.00E+00	0.00E+00	0.00E+00	6.75E-03	1.04E-02
Formaldehyde	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,3-butadiene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chloromethane						
Carbon disulphide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dimethyl disulphide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dimethyl sulphide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Methanethiol						
Ethanethiol	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chloroethene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dichlorofluoromethane	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fibres	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mesophilic Aerobes (cfu/s)	1.65E+05	0.00E+00	0.00E+00	0.00E+00	8.59E+05	1.32E+06
Moulds (cfu/s)	3.31E+05	0.00E+00	0.00E+00	1.73E+03	1.72E+06	2.64E+06
Yeasts (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Enterobacteriaceae (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Endotoxins (EU/s	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table A9.6.2 : Estimated emission rates; Site A, summer 2003 (g/s)

Substance	Mean	25%ile	50%ile	75 %ile	95%ile	100%ile
Antimony	1.6E-05	0.0E+00	1.4E-06	2.0E-05	5.9E-05	7.8E-05
Arsenic	4.3E-05	1.2E-05	3.4E-05	7.8E-05	9.7E-05	1.1E-04
Cadmium						
Chromium	2.2E-04	0.0E+00	4.4E-06	3.7E-05	1.1E-03	1.6E-03
Cobalt	1.7E-05	0.0E+00	0.0E+00	1.9E-06	8.4E-05	1.2E-04
Copper						
Lead	1.2E-03	6.3E-05	3.0E-04	5.5E-04	5.4E-03	8.0E-03
Manganese	1.1E-03	3.5E-04	6.2E-04	1.4E-03	3.3E-03	4.1E-03
Mercury	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nickel	1.7E-05	0.0E+00	8.6E-06	2.8E-05	4.8E-05	5.3E-05
Thallium	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	5.3E-06	0.0E+00	0.0E+00	4.4E-06	2.2E-05	2.6E-05
Vanadium	9.8E-04	0.0E+00	0.0E+00	0.0E+00	5.1E-03	7.8E-03
Dioxin (g TEQ / s)	9.26E-09	0.00E+00	0.00E+00	4.74E-10	4.76E-08	7.22E-08
PCBs (g TEQ / s)	1.28E-08	0.00E+00	0.00E+00	4.88E-10	6.58E-08	1.00E-07
Naphthalene	1.43E-04	0.00E+00	6.95E-06	2.17E-04	5.19E-04	6.30E-04
Acenaphthylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Acenaphthene	2.71E-06	0.00E+00	0.00E+00	1.96E-06	1.18E-05	1.39E-05
Fluorene	1.00E-05	0.00E+00	0.00E+00	4.27E-06	4.69E-05	6.29E-05
Phenanthrene	3.30E-03	6.17E-05	1.59E-04	9.77E-04	1.59E-02	2.33E-02
Anthracene						
Fluoranthene	1.36E-04	0.00E+00	4.66E-05	1.93E-04	4.64E-04	5.96E-04
Pyrene	4.28E-05	0.00E+00	1.18E-06	6.42E-05	1.60E-04	2.09E-04
Benzo (a) anthracene						
Chrysene						
Benzo (b/k) fluoranthene	1.07E-06	0.00E+00	0.00E+00	0.00E+00	5.56E-06	8.55E-06
Benzo (a) pyrene						
Indeno (123-cd) pyrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Benzo (ghi) perylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dibenzo (ah) anthracene						
1,1,1-Trichloroethane	1.34E-02	0.00E+00	6.24E-04	1.54E-03	5.24E-02	6.51E-02
1,1-Dichloroethane [1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Benzene	1.30E-01	0.00E+00	1.98E-03	6.88E-03	5.16E-01	6.43E-01
1,2-Dichloroethane	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chlorobenzene	1.13E-04	0.00E+00	0.00E+00	1.75E-04	3.47E-04	3.90E-04
Chloroethane	5.94E-03	0.00E+00	0.00E+00	7.67E-04	2.33E-02	2.89E-02
Chloroform						
Dichloromethane	3.16E-02	0.00E+00	8.58E-03	5.80E-02	8.49E-02	9.16E-02
Tetrachloroethene	3.01E-02	0.00E+00	4.81E-04	1.27E-02	1.13E-01	1.38E-01
Toluene						
Ethylbenzene						
m+p Xylene						
o Xylene						
1,2-Dichloroethene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Styrene	4.69E-02	0.00E+00	3.84E-03	4.21E-02	1.59E-01	1.89E-01

Substance	Mean	25%ile	50%ile	75 %ile	95%ile	100%ile
Formaldehyde	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,3-butadiene [1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Methanethiol						
Ethanethiol	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chloroethene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chlorodifluoromethane	4.02E-02	0.00E+00	0.00E+00	8.21E-05	1.61E-01	2.01E-01
Dichlorodifluoromethane	8.64E-07	0.00E+00	0.00E+00	0.00E+00	3.46E-06	4.32E-06
Chloromethane						
Carbon disulphide	4.51E-01	0.00E+00	7.54E-03	2.10E-01	1.67E+00	2.04E+00
Dimethyl sulphide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dimethyl disulphide	1.25E-03	0.00E+00	0.00E+00	0.00E+00	4.99E-03	6.24E-03
Fibres	1.09E+07	0.00E+00	0.00E+00	1.64E+07	2.94E+07	3.27E+07
Arsine [1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Stibene [1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total Bacteria Nutrient 25 ^{o}C (cfu/s)	7.64E+07	0.00E+00	5.74E+04	1.09E+07	2.99E+08	3.71E+08
Total Bacteria Nutrient 37 ^{o}C (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total fungi and yeasts Malt 25 ^{o}C (cfu/s)	2.15E+06	0.00E+00	0.00E+00	3.38E+06	6.59E+06	7.39E+06
Total fungi and yeasts Malt 40 ^{o}C (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total fungi and yeasts DG18 25 ^{o}C (cfu/s)	4.28E+06	0.00E+00	0.00E+00	0.00E+00	1.71E+07	2.14E+07
Gram -ve bacteria VRBG (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Endotoxins (EU/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Note 1 : Substance detected, but at lower concentrations downwind of site than upwind

Table A9.6.3 : Estimated emission rates; Site B Winter 2001/02 (g/s)

Substance	Mean	25%ile	50%ile	75 %ile	95%ile	100%ile
Antimony	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Arsenic	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cadmium	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chromium	1.4E-03	0.0E+00	0.0E+00	1.7E-04	7.1E-03	1.1E-02
Cobalt	2.8E-03	0.0E+00	3.0E-04	6.4E-03	7.9E-03	7.9E-03
Copper						
Lead	1.2E-03	0.0E+00	3.3E-04	2.0E-03	3.7E-03	3.9E-03
Manganese						
Mercury	7.2E-04	0.0E+00	0.0E+00	3.8E-04	3.3E-03	4.7E-03
Nickel	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Thallium	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Vanadium						
Dioxin	1.86E-09	0.00E+00	1.51E-10	1.03E-09	8.45E-09	1.22E-08
D,F,PCB (TEQ) - upper limit	2.65E-09	0.00E+00	4.21E-10	2.09E-09	1.13E-08	1.61E-08
Naphthalene	2.01E-04	0.00E+00	0.00E+00	3.83E-04	6.76E-04	7.87E-04
Acenaphthylene	5.67E-05	0.00E+00	0.00E+00	1.51E-05	2.77E-04	3.93E-04
Acenaphthene	1.62E-04	0.00E+00	0.00E+00	1.87E-04	6.48E-04	7.85E-04
Fluorene	7.06E-04	0.00E+00	0.00E+00	3.64E-04	3.25E-03	4.33E-03
Phenanthrene	1.39E-03	0.00E+00	6.08E-05	8.46E-04	6.20E-03	8.26E-03
Anthracene						
Fluoranthene	3.05E-04	0.00E+00	3.65E-05	1.43E-04	1.39E-03	1.97E-03
Pyrene	1.78E-04	0.00E+00	1.22E-05	8.44E-05	8.22E-04	1.18E-03
Benzo (a) anthracene						
Chrysene						
Benzo (b/k) fluoranthene	4.92E-05	0.00E+00	0.00E+00	0.00E+00	2.56E-04	3.93E-04
Benzo (a) pyrene						
Indeno (123-cd) pyrene						
Benzo (ghi) perylene						
Dibenzo (ah) anthracene						
Dichloromethane						
1,2-Dichloroethene						
2-Methylfuran						
Nitromethane						
Methylethylketone						
Chloroform						
Benzene						
1,2-Dichloroethane						
Trichloroethene						
Toluene						
Tetrachloroethene						
Ethylbenzene						
Trimethylbenzene						
alpha-Terpinene						
Dichlorobenzene						
2-Ethyl-1-hexanol						

Substance	Mean	25%ile	50%ile	75 %ile	95%ile	100%ile
Formaldehyde						
1,3-butadiene						
Chloromethane						
Carbon disulphide						
Dimethyl disulphide						
Dimethyl sulphide						
Methanethiol						
Ethanethiol						
Chloroethene						
Dichlorofluoromethane						
Fibres	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total Bacteria Nutrient 25 ^{o}C (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total Bacteria Nutrient 37 ^{o}C (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total fungi and yeasts Malt 25 ^{o}C (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total fungi and yeasts Malt 40 ^{o}C (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total fungi and yeasts DG18 25 ^{o}C (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Gram -ve bacteria VRBG (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Endotoxins (EU/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total Bacteria Nutrient 25 ^{o}C (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table A9.6.4 : Estimated emission rates; Site B, summer 2003 (g/s)

Substance	Mean	25%ile	50%ile	75 %ile	95%ile	100%ile
Antimony	3.5E-06	0.0E+00	0.0E+00	0.0E+00	1.8E-05	2.8E-05
Arsenic	1.8E-06	0.0E+00	0.0E+00	0.0E+00	9.2E-06	1.4E-05
Cadmium	1.2E-04	0.0E+00	0.0E+00	0.0E+00	6.3E-04	9.7E-04
Chromium	1.4E-05	0.0E+00	0.0E+00	2.9E-06	6.7E-05	9.7E-05
Cobalt	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Copper						
Lead	2.0E-05	0.0E+00	0.0E+00	0.0E+00	1.0E-04	1.6E-04
Manganese						
Mercury	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nickel	2.1E-04	0.0E+00	0.0E+00	3.3E-05	1.1E-03	1.6E-03
Thallium	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	2.0E-05	0.0E+00	0.0E+00	3.5E-06	1.0E-04	1.5E-04
Vanadium						
Dioxin (g TEQ / s)	7.48E-08	0.00E+00	3.32E-10	1.64E-09	3.87E-07	5.95E-07
PCBs (g TEQ / s)	7.67E-08	0.00E+00	8.72E-10	2.49E-09	3.95E-07	6.07E-07
Naphthalene	2.02E-05	0.00E+00	4.03E-06	1.33E-05	8.61E-05	1.20E-04
Acenaphthylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Acenaphthene	2.17E-07	0.00E+00	0.00E+00	0.00E+00	1.13E-06	1.73E-06
Fluorene	6.68E-06	0.00E+00	0.00E+00	1.06E-06	3.35E-05	4.92E-05
Phenanthrene	1.97E-04	0.00E+00	0.00E+00	0.00E+00	1.02E-03	1.57E-03
Anthracene						
Fluoranthene	5.45E-05	0.00E+00	0.00E+00	0.00E+00	2.84E-04	4.36E-04
Pyrene	5.41E-05	0.00E+00	0.00E+00	0.00E+00	2.81E-04	4.33E-04
Benzo (a) anthracene						
Chrysene						
Benzo (b/k) fluoranthene	3.65E-05	0.00E+00	0.00E+00	0.00E+00	1.90E-04	2.92E-04
Benzo (a) pyrene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Indeno (123-cd) pyrene	4.31E-07	0.00E+00	0.00E+00	0.00E+00	2.24E-06	3.45E-06
Benzo (ghi) perylene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dibenzo (ah) anthracene	1.72E-06	0.00E+00	0.00E+00	0.00E+00	8.96E-06	1.38E-05
1,1,1-Trichloroethane						
1,1-Dichloroethane [1]						
Benzene						
1,2-Dichloroethane						
Chlorobenzene						
Chloroethane						
Chloroform						
Dichloromethane						
Tetrachloroethene						
Toluene						
Ethylbenzene						
m+p Xylene						
o Xylene						
1,2-Dichloroethene						
Styrene						

Substance	Mean	25%ile	50%ile	75 %ile	95%ile	100%ile
Formaldehyde						
1,3-butadiene [1]						
Methanethiol						
Ethanethiol						
Chloroethene						
Chlorodifluoromethane						
Dichlorodifluoromethane						
Chloromethane						
Carbon disulphide						
Dimethyl sulphide						
Dimethyl disulphide						
Fibres	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsine [1]						
Stibene [1]						
Total Bacteria Nutrient 25 ^{o}C (cfu/s)	1.50E+05	0.00E+00	0.00E+00	0.00E+00	7.36E+05	1.05E+06
Total Bacteria Nutrient 37 ^{o}C (cfu/s)	3.00E+05	0.00E+00	0.00E+00	0.00E+00	1.47E+06	2.10E+06
Total fungi and yeasts Malt 25 ^{o}C (cfu/s)	3.49E+06	0.00E+00	0.00E+00	0.00E+00	1.71E+07	2.44E+07
Total fungi and yeasts Malt 40 ^{o}C (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total fungi and yeasts DG18 25 ^{o}C (cfu/s)	5.85E+05	0.00E+00	0.00E+00	0.00E+00	2.87E+06	4.10E+06
Gram -ve bacteria VRBG (cfu/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Endotoxins (EU/s)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Note 1 : Substance detected, but at lower concentrations downwind of site than upwind

Table A9.6.5 : Estimated population exposure levels; Site A Winter 2001/02 : long term exposure

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Antimony		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Arsenic		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cadmium										
Chromium	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cobalt	1.15E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Copper										
Lead	2.78E-03	4.8E-05	0.0E+00	2.3E-04	1.3E-05	0.0E+00	6.1E-05	2.5E-07	0.0E+00	1.2E-06
Manganese	3.95E-03	2.2E-03	0.0E+00	1.1E-02	4.9E-04	0.0E+00	2.4E-03	2.4E-05	0.0E+00	1.2E-04
Mercury		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nickel	2.03E-03	4.8E-05	0.0E+00	2.3E-04	1.3E-05	0.0E+00	6.1E-05	2.5E-07	0.0E+00	1.2E-06
Thallium		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	2.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Vanadium	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dioxin	2.38E-08	1.8E-09	0.0E+00	8.8E-09	4.1E-10	0.0E+00	2.0E-09	2.0E-11	0.0E+00	9.8E-11
D,F,PCB (TEQ) - upper limit	3.71E-08	1.8E-09	0.0E+00	8.8E-09	4.1E-10	0.0E+00	2.0E-09	2.0E-11	0.0E+00	9.8E-11
Naphthalene	4.52E-04	4.6E-08	0.0E+00	2.2E-07	1.0E-08	0.0E+00	5.0E-08	5.1E-10	0.0E+00	2.5E-09
Acenaphthylene	3.94E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Acenaphthene	2.96E-04	7.6E-04	0.0E+00	3.7E-03	1.7E-04	0.0E+00	8.3E-04	8.5E-06	0.0E+00	4.2E-05
Fluorene	9.39E-04	5.0E-04	0.0E+00	2.5E-03	1.1E-04	0.0E+00	5.5E-04	5.6E-06	0.0E+00	2.7E-05
Phenanthrene	3.54E-03	4.0E-06	0.0E+00	2.0E-05	9.0E-07	0.0E+00	4.4E-06	4.5E-08	0.0E+00	2.2E-07
Anthracene										
Fluoranthene	9.18E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Pyrene	8.29E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Benzo (a) anthracene										
Chrysene										
Benzo (b/k) fluoranthene	4.34E-04	1.3E-06	0.0E+00	6.3E-06	2.9E-07	0.0E+00	1.4E-06	1.4E-08	0.0E+00	7.0E-08
Benzo (a) pyrene										
Indeno (123-cd) pyrene	1.73E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Benzo (ghi) perylene	2.28E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dibenzo (ah) anthracene										
Dichloromethane	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1,2-Dichloroethene	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2-Methylfuran	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nitromethane	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Methylethylketone	8.31E-01	2.0E-02	0.0E+00	1.0E-01	4.0E-03	0.0E+00	2.1E-02	5.2E-05	0.0E+00	2.7E-04
Chloroform										
Benzene	8.83E-01	9.2E-02	0.0E+00	4.6E-01	1.8E-02	0.0E+00	9.1E-02	2.4E-04	0.0E+00	1.2E-03
1,2-Dichloroethane	3.59E-01	7.0E-02	0.0E+00	3.6E-01	1.4E-02	0.0E+00	7.3E-02	1.8E-04	0.0E+00	9.5E-04
Trichloroethene	6.05E-01	9.3E-02	0.0E+00	4.8E-01	1.9E-02	0.0E+00	9.7E-02	2.4E-04	0.0E+00	1.3E-03
Toluene										
Tetrachloroethene	1.20E+00	5.3E-03	0.0E+00	2.8E-02	1.1E-03	0.0E+00	5.5E-03	1.4E-05	0.0E+00	7.2E-05
Ethylbenzene										
Trimethylbenzene	1.18E+00	4.7E-01	0.0E+00	2.2E+00	9.4E-02	0.0E+00	4.5E-01	1.2E-03	0.0E+00	5.8E-03
alpha-Terpinene	6.08E-01	1.3E-01	0.0E+00	6.5E-01	2.5E-02	0.0E+00	1.3E-01	3.3E-04	0.0E+00	1.7E-03
Dichlorobenzene	1.78E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2-Ethyl-1-hexanol	7.69E-01	3.5E-02	0.0E+00	1.8E-01	7.0E-03	0.0E+00	3.7E-02	9.2E-05	0.0E+00	4.8E-04
Formaldehyde		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1,3-butadiene		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chloromethane										

Substance All values in µg/m3	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Carbon disulphide		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dimethyl disulphide		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dimethyl sulphide		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Methanethiol										
Ethanethiol		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chloroethene		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dichlorofluoromethane 2		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Fibres	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Mesophilic Aerobes (cfu/m3)	5.98E+07	9.6E+05	0.0E+00	5.0E+06	4.1E+05	0.0E+00	2.1E+06	1.2E+04	0.0E+00	6.1E+04
Moulds (cfu/m3)	4.32E+07	1.9E+06	0.0E+00	1.0E+07	8.2E+05	0.0E+00	4.2E+06	2.4E+04	0.0E+00	1.2E+05
Yeasts (cfu/m3)		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Entrobacteriaceae (cfu/m3)		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Endotoxins (IU/filter)	6.07E+04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Table A9.6.6 : Estimated population exposure levels; Site A Winter 2001/02 : short term exposure

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Antimony		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Arsenic		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cadmium										
Chromium	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cobalt	1.15E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Copper										
Lead	2.78E-03	3.1E-03	0.0E+00	1.5E-02	1.7E-03	0.0E+00	8.5E-03	7.5E-05	0.0E+00	3.7E-04
Manganese	3.95E-03	4.4E-02	0.0E+00	2.2E-01	1.3E-02	0.0E+00	6.2E-02	2.4E-03	0.0E+00	1.2E-02
Mercury		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nickel	2.03E-03	3.1E-03	0.0E+00	1.5E-02	1.7E-03	0.0E+00	8.5E-03	7.5E-05	0.0E+00	3.7E-04
Thallium		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	2.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Vanadium	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dioxin	2.38E-08	3.7E-08	0.0E+00	1.8E-07	1.1E-08	0.0E+00	5.1E-08	2.0E-09	0.0E+00	9.7E-09
D,F,PCB (TEQ) - upper limit	3.71E-08	3.7E-08	0.0E+00	1.8E-07	1.1E-08	0.0E+00	5.1E-08	2.0E-09	0.0E+00	9.7E-09
Naphthalene	4.52E-04	9.3E-07	0.0E+00	4.5E-06	2.7E-07	0.0E+00	1.3E-06	5.1E-08	0.0E+00	2.5E-07
Acenaphthylene	3.94E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Acenaphthene	2.96E-04	1.5E-02	0.0E+00	7.6E-02	4.4E-03	0.0E+00	2.2E-02	8.4E-04	0.0E+00	4.1E-03
Fluorene	9.39E-04	1.0E-02	0.0E+00	5.0E-02	2.9E-03	0.0E+00	1.4E-02	5.6E-04	0.0E+00	2.7E-03
Phenanthrene	3.54E-03	8.1E-05	0.0E+00	4.0E-04	2.3E-05	0.0E+00	1.1E-04	4.4E-06	0.0E+00	2.2E-05
Anthracene										
Fluoranthene	9.18E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Pyrene	8.29E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Benzo (a) anthracene										
Chrysene										
Benzo (b/k) fluoranthene	4.34E-04	2.6E-05	0.0E+00	1.3E-04	7.5E-06	0.0E+00	3.7E-05	1.4E-06	0.0E+00	6.9E-06
Benzo (a) pyrene										
Indeno (123-cd) pyrene	1.73E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Benzo (ghi) perylene	2.28E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dibenzo (ah) anthracene										
Dichloromethane	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1,2-Dichloroethene	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2-Methylfuran	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nitromethane	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Methylethylketone	8.31E-01	1.1E+00	0.0E+00	5.8E+00	4.0E-01	0.0E+00	2.1E+00	1.6E-02	0.0E+00	8.2E-02
Chloroform										
Benzene	8.83E-01	5.1E+00	0.0E+00	2.5E+01	1.8E+00	0.0E+00	9.0E+00	7.2E-02	0.0E+00	3.6E-01
1,2-Dichloroethane	3.59E-01	3.9E+00	0.0E+00	2.0E+01	1.4E+00	0.0E+00	7.2E+00	5.5E-02	0.0E+00	2.9E-01
Trichloroethene	6.05E-01	5.2E+00	0.0E+00	2.7E+01	1.8E+00	0.0E+00	9.6E+00	7.3E-02	0.0E+00	3.8E-01
Toluene										
Tetrachloroethene	1.20E+00	2.9E-01	0.0E+00	1.5E+00	1.0E-01	0.0E+00	5.4E-01	4.2E-03	0.0E+00	2.2E-02
Ethylbenzene										
Trimethylbenzene	1.18E+00	2.6E+01	0.0E+00	1.2E+02	9.3E+00	0.0E+00	4.4E+01	3.7E-01	0.0E+00	1.7E+00
alpha-Terpinene	6.08E-01	7.0E+00	0.0E+00	3.6E+01	2.5E+00	0.0E+00	1.3E+01	9.9E-02	0.0E+00	5.1E-01
Dichlorobenzene	1.78E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2-Ethyl-1-hexanol	7.69E-01	1.9E+00	0.0E+00	1.0E+01	6.9E-01	0.0E+00	3.6E+00	2.8E-02	0.0E+00	1.4E-01
Formaldehyde		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1,3-butadiene		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chloromethane										

Substance All values in µg/m3	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Carbon disulphide		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dimethyl disulphide		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dimethyl sulphide		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Methanethiol										
Ethanethiol		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chloroethene		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dichlorofluoromethane		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Fibres	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Mesophilic Aerobes (cfu/m3)	5.98E+07	8.8E+07	0.0E+00	4.6E+08	7.8E+07	0.0E+00	4.0E+08	3.5E+06	0.0E+00	1.8E+07
Moulds (cfu/m3)	4.32E+07	1.8E+08	0.0E+00	9.2E+08	1.6E+08	0.0E+00	8.1E+08	7.1E+06	0.0E+00	3.7E+07
Yeasts (cfu/m3)		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Enterobacteriaceae (cfu/m3)		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Endotoxins (IU/filter)	6.07E+04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Table A9.6.7 : Estimated population exposure levels; Site B Winter 2001/02: long term exposure

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Antimony	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Arsenic		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cadmium		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chromium	2.45E-03	3.9E-03	0.0E+00	1.7E-02	3.2E-03	0.0E+00	1.4E-02	7.1E-05	0.0E+00	3.2E-04
Cobalt	2.77E-02	6.8E-03	2.2E-04	2.7E-02	5.7E-03	5.9E-05	2.2E-02	1.3E-04	4.5E-06	4.6E-04
Copper										
Lead	1.75E-03	1.5E-03	2.4E-04	4.9E-03	1.2E-03	6.5E-05	4.1E-03	3.3E-05	4.9E-06	1.1E-04
Manganese										
Mercury	2.13E-03	7.0E-04	0.0E+00	3.2E-03	4.1E-04	0.0E+00	1.9E-03	1.5E-05	0.0E+00	7.0E-05
Nickel	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Thallium	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Vanadium										
Dioxin	2.27E-08	4.0E-09	3.3E-10	1.8E-08	1.1E-09	8.8E-11	4.9E-09	8.2E-11	6.7E-12	3.8E-10
D,F,PCB (TEQ) - upper limit	3.29E-08	5.8E-09	9.2E-10	2.5E-08	1.6E-09	2.5E-10	6.6E-09	1.2E-10	1.9E-11	5.0E-10
Naphthalene	2.50E-04	4.4E-04	0.0E+00	1.5E-03	1.2E-04	0.0E+00	3.9E-04	8.9E-06	0.0E+00	3.0E-05
Acenaphthylene	1.25E-04	1.2E-04	0.0E+00	6.0E-04	3.3E-05	0.0E+00	1.6E-04	2.5E-06	0.0E+00	1.2E-05
Acenaphthene	1.77E-04	3.5E-04	0.0E+00	1.4E-03	9.5E-05	0.0E+00	3.8E-04	7.2E-06	0.0E+00	2.9E-05
Fluorene	6.36E-04	1.5E-03	0.0E+00	7.1E-03	4.1E-04	0.0E+00	1.9E-03	3.1E-05	0.0E+00	1.4E-04
Phenanthrene	3.22E-03	3.0E-03	1.3E-04	1.4E-02	8.1E-04	3.6E-05	3.6E-03	6.1E-05	2.7E-06	2.7E-04
Anthracene										
Fluoranthene	9.49E-04	6.6E-04	8.0E-05	3.0E-03	1.8E-04	2.1E-05	8.1E-04	1.4E-05	1.6E-06	6.2E-05
Pyrene	6.43E-04	3.9E-04	2.7E-05	1.8E-03	1.0E-04	7.1E-06	4.8E-04	7.9E-06	5.4E-07	3.6E-05
Benzo (a) anthracene										
Chrysene										
Benzo (b/k) fluoranthene	5.46E-04	1.1E-04	0.0E+00	5.6E-04	2.9E-05	0.0E+00	1.5E-04	2.2E-06	0.0E+00	1.1E-05
Benzo (a) pyrene										
Indeno (123-cd) pyrene										
Benzo (ghi) perylene										
Dibenzo (ah) anthracene										
Dichloromethane										
1,2-Dichloroethene										
2-Methylfuran										
Nitromethane										
Methylethylketone										
Chloroform										
Benzene										
1,2-Dichloroethane										
Trichloroethene										
Toluene										
Tetrachloroethene										
Ethylbenzene										
Trimethylbenzene										
alpha-Terpinene										
Dichlorobenzene										
2-Ethyl-1-hexanol										
Formaldehyde										
1,3-butadiene										
Chloromethane										

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Carbon disulphide										
Dimethyl disulphide										
Dimethyl sulphide										
Methanethiol										
Ethanethiol										
Chloroethene										
Dichlorofluoromethane 2										
Fibres	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
total bacteria	2.00E+09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
total bacteria	1.05E+09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Gram -ve bacteria	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
total fungi + yeasts	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
total fungi + yeasts	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
thermophilic fungi	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Penicillia	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
A. fumigatus	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Table A9.6.8 : Estimated population exposure levels; Site B Winter 2001/02: short term exposure

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Antimony	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Arsenic		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cadmium		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chromium	2.45E-03	3.9E-03	0.0E+00	1.7E-02	3.2E-03	0.0E+00	1.4E-02	7.1E-05	0.0E+00	3.2E-04
Cobalt	2.77E-02	6.8E-03	2.2E-04	2.7E-02	5.7E-03	5.9E-05	2.2E-02	1.3E-04	4.5E-06	4.6E-04
Copper										
Lead	1.75E-03	1.5E-03	2.4E-04	4.9E-03	1.2E-03	6.5E-05	4.1E-03	3.3E-05	4.9E-06	1.1E-04
Manganese										
Mercury	2.13E-03	7.0E-04	0.0E+00	3.2E-03	4.1E-04	0.0E+00	1.9E-03	1.5E-05	0.0E+00	7.0E-05
Nickel	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Thallium	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	1.00E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Vanadium										
Dioxin	2.27E-08	4.0E-09	3.3E-10	1.8E-08	1.1E-09	8.8E-11	4.9E-09	8.2E-11	6.7E-12	3.8E-10
D,F,PCB (TEQ) - upper limit	3.29E-08	5.8E-09	9.2E-10	2.5E-08	1.6E-09	2.5E-10	6.6E-09	1.2E-10	1.9E-11	5.0E-10
Naphthalene	2.50E-04	4.4E-04	0.0E+00	1.5E-03	1.2E-04	0.0E+00	3.9E-04	8.9E-06	0.0E+00	3.0E-05
Acenaphthylene	1.25E-04	1.2E-04	0.0E+00	6.0E-04	3.3E-05	0.0E+00	1.6E-04	2.5E-06	0.0E+00	1.2E-05
Acenaphthene	1.77E-04	3.5E-04	0.0E+00	1.4E-03	9.5E-05	0.0E+00	3.8E-04	7.2E-06	0.0E+00	2.9E-05
Fluorene	6.36E-04	1.5E-03	0.0E+00	7.1E-03	4.1E-04	0.0E+00	1.9E-03	3.1E-05	0.0E+00	1.4E-04
Phenanthrene	3.22E-03	3.0E-03	1.3E-04	1.4E-02	8.1E-04	3.6E-05	3.6E-03	6.1E-05	2.7E-06	2.7E-04
Anthracene										
Fluoranthene	9.49E-04	6.6E-04	8.0E-05	3.0E-03	1.8E-04	2.1E-05	8.1E-04	1.4E-05	1.6E-06	6.2E-05
Pyrene	6.43E-04	3.9E-04	2.7E-05	1.8E-03	1.0E-04	7.1E-06	4.8E-04	7.9E-06	5.4E-07	3.6E-05
Benzo (a) anthracene										
Chrysene										
Benzo (b/k) fluoranthene	5.46E-04	1.1E-04	0.0E+00	5.6E-04	2.9E-05	0.0E+00	1.5E-04	2.2E-06	0.0E+00	1.1E-05
Benzo (a) pyrene										
Indeno (123-cd) pyrene										
Benzo (ghi) perylene										
Dibenzo (ah) anthracene										
Dichloromethane										
1,2-Dichloroethene										
2-Methylfuran										
Nitromethane										
Methylethylketone										
Chloroform										
Benzene										
1,2-Dichloroethane										
Trichloroethene										
Toluene										
Tetrachloroethene										
Ethylbenzene										
Trimethylbenzene										
alpha-Terpinene										
Dichlorobenzene										
2-Ethyl-1-hexanol										
Formaldehyde										
1,3-butadiene										
Chloromethane										

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Carbon disulphide										
Dimethyl disulphide										
Dimethyl sulphide										
Methanethiol										
Ethanethiol										
Chloroethene										
Dichlorofluoromethane										
Fibres	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
total bacteria	2.00E+09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
total bacteria	1.05E+09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Gram -ve bacteria	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Total fungi + yeasts	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Total fungi + yeasts	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
thermophilic fungi	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Penicillia	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
A. fumigatus	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Table A9.6.9 : Estimated population exposure levels; Site A Summer 2003: long term exposure

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Antimony	5.42E-04	8.9E-05	3.4E-05	3.4E-04	4.6E-05	1.7E-05	1.7E-04	1.5E-06	5.1E-07	5.6E-06
Arsenic	2.15E-04	1.3E-04	4.5E-05	4.3E-04	6.5E-05	2.2E-05	2.1E-04	2.1E-06	8.2E-07	6.8E-06
Cadmium										
Chromium	1.36E-03	2.2E-04	4.1E-05	1.0E-03	1.0E-04	2.2E-05	4.3E-04	4.1E-06	7.0E-07	1.8E-05
Cobalt	1.52E-04	1.2E-05	0.0E+00	6.3E-05	3.9E-06	0.0E+00	2.0E-05	1.9E-07	0.0E+00	9.7E-07
Copper										
Lead	1.55E-03	1.7E-03	5.3E-04	6.4E-03	7.7E-04	2.8E-04	2.7E-03	2.9E-05	9.8E-06	1.1E-04
Manganese	3.19E-03	2.8E-03	1.5E-03	7.7E-03	1.4E-03	7.5E-04	4.1E-03	4.9E-05	2.5E-05	1.4E-04
Mercury		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nickel	7.81E-04	9.4E-05	4.5E-05	2.9E-04	4.7E-05	2.4E-05	1.4E-04	1.5E-06	7.6E-07	4.5E-06
Thallium		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	1.80E-04	2.1E-05	1.1E-07	1.0E-04	9.7E-06	6.7E-08	4.8E-05	3.1E-07	2.1E-09	1.5E-06
Vanadium	4.22E-04	7.4E-04	0.0E+00	3.9E-03	2.4E-04	0.0E+00	1.3E-03	1.2E-05	0.0E+00	6.0E-05
Dioxin	4.51E-08	2.1E-08	0.0E+00	1.1E-07	6.6E-09	0.0E+00	3.4E-08	3.2E-10	0.0E+00	1.7E-09
D,F,PCB (TEQ) - upper limit	4.01E-08	2.9E-08	0.0E+00	1.5E-07	9.1E-09	0.0E+00	4.7E-08	4.4E-10	0.0E+00	2.3E-09
Naphthalene	1.00E-03	3.2E-04	1.6E-05	1.2E-03	1.0E-04	4.9E-06	3.7E-04	5.0E-06	2.4E-07	1.8E-05
Acenaphthylene	4.25E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Acenaphthene	5.66E-04	6.1E-06	0.0E+00	2.7E-05	1.9E-06	0.0E+00	8.4E-06	9.4E-08	0.0E+00	4.1E-07
Fluorene	1.39E-03	2.3E-05	0.0E+00	1.1E-04	7.1E-06	0.0E+00	3.3E-05	3.5E-07	0.0E+00	1.6E-06
Phenanthrene	1.47E-03	7.5E-03	3.6E-04	3.6E-02	2.3E-03	1.1E-04	1.1E-02	1.1E-04	5.5E-06	5.5E-04
Anthracene										
Fluoranthene	8.74E-04	3.1E-04	1.1E-04	1.0E-03	9.7E-05	3.3E-05	3.3E-04	4.7E-06	1.6E-06	1.6E-05
Pyrene	5.37E-04	9.7E-05	2.7E-06	3.6E-04	3.0E-05	8.4E-07	1.1E-04	1.5E-06	4.1E-08	5.6E-06
Benzo (a) anthracene										
Chrysene										
Benzo (b/k) fluoranthene	1.95E-04	2.4E-06	0.0E+00	1.3E-05	7.6E-07	0.0E+00	4.0E-06	3.7E-08	0.0E+00	1.9E-07
Benzo (a) pyrene										
Indeno (123-cd) pyrene	8.99E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Benzo (ghi) perylene		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dibenzo (ah) anthracene										
1,1,1-Trichloroethane	1.23E-02	1.2E-01	5.4E-03	4.5E-01	5.1E-02	2.4E-03	2.0E-01	1.5E-03	7.0E-05	5.9E-03
1,1-Dichloroethane	1.00E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Benzene	1.44E-01	1.1E+00	1.7E-02	4.5E+00	5.0E-01	7.6E-03	2.0E+00	1.5E-02	2.2E-04	5.8E-02
1,2-Dichloroethane	2.45E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chlorobenzene	2.43E-02	9.8E-04	0.0E+00	3.0E-03	4.3E-04	0.0E+00	1.3E-03	1.3E-05	0.0E+00	3.9E-05
Chloroethane	2.25E-02	5.1E-02	0.0E+00	2.0E-01	2.3E-02	0.0E+00	8.9E-02	6.7E-04	0.0E+00	2.6E-03
Chloroform										
Dichloromethane	2.67E+00	2.7E-01	7.4E-02	7.3E-01	1.2E-01	3.3E-02	3.2E-01	3.6E-03	9.6E-04	9.5E-03
Tetrachloroethene	2.79E-01	2.6E-01	4.2E-03	9.7E-01	1.2E-01	1.8E-03	4.3E-01	3.4E-03	5.4E-05	1.3E-02
Toluene										
Ethylbenzene										
m+p Xylene										
o Xylene										
1,2-Dichloroethene	1.00E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Styrene	8.15E-01	4.1E-01	3.3E-02	1.4E+00	1.8E-01	1.5E-02	6.1E-01	5.3E-03	4.3E-04	1.8E-02
Formaldehyde	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1,3-butadiene		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Methanethiol										

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Ethanethiol	1.55E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chloroethene	2.52E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chlorodifluoromethane	9.70E-03	3.5E-01	0.0E+00	1.4E+00	1.5E-01	0.0E+00	6.2E-01	4.5E-03	0.0E+00	1.8E-02
Dichlorodifluoromethane	1.03E-02	7.5E-06	0.0E+00	3.0E-05	3.3E-06	0.0E+00	1.3E-05	9.7E-08	0.0E+00	3.9E-07
Chloromethane										
Carbon disulphide	6.99E+00	3.9E+00	6.5E-02	1.4E+01	1.7E+00	2.9E-02	6.4E+00	5.1E-02	8.5E-04	1.9E-01
Dimethyl sulphide	1.16E+01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dimethyl disulphide		1.1E-02	0.0E+00	4.3E-02	4.8E-03	0.0E+00	1.9E-02	1.4E-04	0.0E+00	5.6E-04
Fibres	1.37E+09	6.3E+07	0.0E+00	1.7E+08	3.8E+07	0.0E+00	1.0E+08	1.2E+06	0.0E+00	3.3E+06
Arsine		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Stibene	3.46E+01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Total Bacteria Nutrient 25 oC	9.11E+07	4.4E+08	3.3E+05	1.7E+09	2.7E+08	2.0E+05	1.1E+09	8.5E+06	6.4E+03	3.3E+07
Total Bacteria Nutrient 37 oC	1.68E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Total fungi and yeasts Malt 25 oC	1.81E+07	1.2E+07	0.0E+00	3.8E+07	7.6E+06	0.0E+00	2.3E+07	2.4E+05	0.0E+00	7.4E+05
Total fungi and yeasts Malt 40 oC	1.04E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Total fungi and yeasts DG18 25 oC	2.44E+08	2.5E+07	0.0E+00	9.9E+07	1.5E+07	0.0E+00	6.0E+07	4.8E+05	0.0E+00	1.9E+06
Gram -ve bacteria VRBG	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Endotoxins	1.01E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Table A9.6.10 : Estimated population exposure levels; Site A Summer 2003 : short term exposure

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Antimony	5.42E-04	8.3E-03	3.9E-03	3.1E-02	6.1E-03	2.3E-03	2.3E-02	2.8E-04	1.0E-04	1.1E-03
Arsenic	2.15E-04	1.3E-02	3.0E-03	4.6E-02	7.8E-03	2.2E-03	2.7E-02	3.8E-04	1.2E-04	1.3E-03
Cadmium										
Chromium	1.36E-03	1.1E-02	3.8E-03	4.4E-02	8.6E-03	3.1E-03	3.1E-02	5.4E-04	1.4E-04	2.2E-03
Cobalt	1.52E-04	3.4E-04	0.0E+00	1.7E-03	8.5E-05	0.0E+00	4.3E-04	1.7E-05	0.0E+00	8.4E-05
Copper										
Lead	1.55E-03	1.2E-01	4.4E-02	4.1E-01	7.3E-02	3.1E-02	2.3E-01	4.2E-03	1.6E-03	1.4E-02
Manganese	3.19E-03	2.5E-01	1.5E-01	6.6E-01	1.7E-01	8.7E-02	4.9E-01	8.5E-03	4.4E-03	2.4E-02
Mercury		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nickel	7.81E-04	9.4E-03	4.1E-03	3.2E-02	6.2E-03	3.2E-03	1.9E-02	2.9E-04	1.4E-04	8.7E-04
Thallium		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	1.80E-04	2.6E-03	1.0E-05	1.3E-02	1.2E-03	1.0E-05	5.8E-03	5.7E-05	4.4E-07	2.8E-04
Vanadium	4.22E-04	2.0E-02	0.0E+00	1.0E-01	6.3E-03	0.0E+00	3.3E-02	1.0E-03	0.0E+00	5.3E-03
Dioxin	4.51E-08	5.7E-07	0.0E+00	2.9E-06	1.4E-07	0.0E+00	7.2E-07	2.8E-08	0.0E+00	1.4E-07
D,F,PCB (TEQ) - upper limit	4.01E-08	7.8E-07	0.0E+00	4.0E-06	1.9E-07	0.0E+00	1.0E-06	3.8E-08	0.0E+00	2.0E-07
Naphthalene	1.00E-03	8.7E-03	4.3E-04	3.2E-02	2.2E-03	1.1E-04	7.9E-03	4.3E-04	2.1E-05	1.5E-03
Acenaphthylene	4.25E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Acenaphthene	5.66E-04	1.7E-04	0.0E+00	7.2E-04	4.1E-05	0.0E+00	1.8E-04	8.1E-06	0.0E+00	3.5E-05
Fluorene	1.39E-03	6.1E-04	0.0E+00	2.9E-03	1.5E-04	0.0E+00	7.1E-04	3.0E-05	0.0E+00	1.4E-04
Phenanthrene	1.47E-03	2.0E-01	9.7E-03	9.7E-01	5.0E-02	2.4E-03	2.4E-01	9.8E-03	4.8E-04	4.7E-02
Anthracene										
Fluoranthene	8.74E-04	8.4E-03	2.9E-03	2.8E-02	2.1E-03	7.1E-04	7.1E-03	4.1E-04	1.4E-04	1.4E-03
Pyrene	5.37E-04	2.6E-03	7.2E-05	9.8E-03	6.5E-04	1.8E-05	2.4E-03	1.3E-04	3.5E-06	4.8E-04
Benzo (a) anthracene										
Chrysene										
Benzo (b/k) fluoranthene	1.95E-04	6.5E-05	0.0E+00	3.4E-04	1.6E-05	0.0E+00	8.5E-05	3.2E-06	0.0E+00	1.7E-05
Benzo (a) pyrene										
Indeno (123-cd) pyrene	8.99E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Benzo (ghi) perylene		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dibenzo (ah) anthracene										
1,1,1-Trichloroethane	1.23E-02	1.7E+01	7.9E-01	6.6E+01	6.7E+00	3.1E-01	2.6E+01	3.1E-01	1.4E-02	1.2E+00
1,1-Dichloroethane	1.00E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Benzene	1.44E-01	1.7E+02	2.5E+00	6.5E+02	6.5E+01	9.9E-01	2.6E+02	3.0E+00	4.6E-02	1.2E+01
1,2-Dichloroethane	2.45E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chlorobenzene	2.43E-02	1.4E-01	0.0E+00	4.4E-01	5.7E-02	0.0E+00	1.7E-01	2.6E-03	0.0E+00	8.0E-03
Chloroethane	2.25E-02	7.5E+00	0.0E+00	2.9E+01	3.0E+00	0.0E+00	1.2E+01	1.4E-01	0.0E+00	5.4E-01
Chloroform										
Dichloromethane	2.67E+00	4.0E+01	1.1E+01	1.1E+02	1.6E+01	4.3E+00	4.3E+01	7.3E-01	2.0E-01	2.0E+00
Tetrachloroethene	2.79E-01	3.8E+01	6.1E-01	1.4E+02	1.5E+01	2.4E-01	5.6E+01	7.0E-01	1.1E-02	2.6E+00
Toluene										
Ethylbenzene										
m+p Xylene										
o Xylene										
1,2-Dichloroethene	1.00E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Styrene	8.15E-01	5.9E+01	4.9E+00	2.0E+02	2.4E+01	1.9E+00	8.0E+01	1.1E+00	8.9E-02	3.7E+00
Formaldehyde	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1,3-butadiene		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Methanethiol										

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Ethanethiol	1.55E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chloroethene	2.52E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Chlorodifluoromethane	9.70E-03	5.1E+01	0.0E+00	2.0E+02	2.0E+01	0.0E+00	8.1E+01	9.3E-01	0.0E+00	3.7E+00
Dichlorodifluoromethane	1.03E-02	1.1E-03	0.0E+00	4.4E-03	4.3E-04	0.0E+00	1.7E-03	2.0E-05	0.0E+00	8.0E-05
Chloromethane										
Carbon disulphide	6.99E+00	5.7E+02	9.5E+00	2.1E+03	2.3E+02	3.8E+00	8.4E+02	1.0E+01	1.7E-01	3.9E+01
Dimethyl sulphide	1.16E+01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Dimethyl disulphide		1.6E+00	0.0E+00	6.3E+00	6.3E-01	0.0E+00	2.5E+00	2.9E-02	0.0E+00	1.2E-01
Fibres	1.37E+09	5.8E+09	0.0E+00	1.6E+10	6.0E+09	0.0E+00	1.6E+10	2.5E+08	0.0E+00	6.8E+08
Arsine		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Stibene	3.46E+01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Total Bacteria Nutrient 25 oC	9.11E+07	4.1E+10	3.1E+07	1.6E+11	4.2E+10	3.1E+07	1.6E+11	1.8E+09	1.3E+06	6.9E+09
Total Bacteria Nutrient 37 oC	1.68E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Total fungi and yeasts Malt 25 oC	1.81E+07	1.1E+09	0.0E+00	3.5E+09	1.2E+09	0.0E+00	3.6E+09	5.0E+07	0.0E+00	1.5E+08
Total fungi and yeasts Malt 40 oC	1.04E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Total fungi and yeasts DG18 25 oC	2.44E+08	2.3E+09	0.0E+00	9.1E+09	2.3E+09	0.0E+00	9.4E+09	9.8E+07	0.0E+00	3.9E+08
Gram -ve bacteria VRBG	0.00E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Endotoxins	1.01E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Table A9.6.11 : Estimated population exposure levels; Site B Summer 2003: long term exposure

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Antimony	5.77E-04	1.1E-05	0.0E+00	5.9E-05	2.3E-06	0.0E+00	1.2E-05	1.1E-07	0.0E+00	5.6E-07
Arsenic	2.77E-04	5.7E-06	0.0E+00	2.9E-05	1.1E-06	0.0E+00	6.0E-06	5.3E-08	0.0E+00	2.8E-07
Cadmium	2.33E-04	5.3E-04	0.0E+00	2.7E-03	1.5E-04	0.0E+00	8.0E-04	6.4E-06	0.0E+00	3.3E-05
Chromium	1.18E-03	7.3E-05	0.0E+00	3.7E-04	2.4E-05	0.0E+00	1.2E-04	9.7E-07	0.0E+00	4.9E-06
Cobalt	3.00E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Copper										
Lead	2.65E-03	7.8E-05	0.0E+00	4.1E-04	2.0E-05	0.0E+00	1.1E-04	8.8E-07	0.0E+00	4.6E-06
Manganese										
Mercury	4.00E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nickel	9.32E-04	2.9E-03	0.0E+00	1.5E-02	9.1E-04	0.0E+00	4.7E-03	3.3E-05	0.0E+00	1.7E-04
Thallium		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	3.17E-04	2.6E-04	0.0E+00	1.4E-03	8.3E-05	0.0E+00	4.3E-04	3.0E-06	0.0E+00	1.5E-05
Vanadium										
Dioxin	2.29E-08	5.4E-07	2.4E-09	2.8E-06	4.3E-08	1.9E-10	2.2E-07	3.2E-09	1.4E-11	1.7E-08
D,F,PCB (TEQ) - upper limit	8.30E-08	5.5E-07	6.3E-09	2.8E-06	4.4E-08	5.0E-10	2.3E-07	3.3E-09	3.8E-11	1.7E-08
Naphthalene	5.05E-04	1.5E-04	2.9E-05	6.2E-04	1.2E-05	2.3E-06	5.0E-05	8.7E-07	1.7E-07	3.7E-06
Acenaphthylene	9.50E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Acenaphthene	1.20E-04	1.6E-06	0.0E+00	8.1E-06	1.2E-07	0.0E+00	6.5E-07	9.3E-09	0.0E+00	4.9E-08
Fluorene	5.61E-04	4.8E-05	0.0E+00	2.4E-04	3.8E-06	0.0E+00	1.9E-05	2.9E-07	0.0E+00	1.4E-06
Phenanthrene	4.54E-03	1.4E-03	0.0E+00	7.4E-03	1.1E-04	0.0E+00	5.9E-04	8.5E-06	0.0E+00	4.4E-05
Anthracene										
Fluoranthene	2.59E-03	3.9E-04	0.0E+00	2.0E-03	3.1E-05	0.0E+00	1.6E-04	2.3E-06	0.0E+00	1.2E-05
Pyrene	1.61E-03	3.9E-04	0.0E+00	2.0E-03	3.1E-05	0.0E+00	1.6E-04	2.3E-06	0.0E+00	1.2E-05
Benzo (a) anthracene										
Chrysene										
Benzo (b/k) fluoranthene	5.67E-04	2.6E-04	0.0E+00	1.4E-03	2.1E-05	0.0E+00	1.1E-04	1.6E-06	0.0E+00	8.2E-06
Benzo (a) pyrene										
Indeno (123-cd) pyrene										
Benzo (ghi) perylene										
Dibenzo (ah) anthracene										
1,1,1-Trichloroethane										
1,1-Dichloroethane										
Benzene										
1,2-Dichloroethane										
Chlorobenzene										
Chloroethane										
Chloroform										
Dichloromethane										
Tetrachloroethene										
Toluene										
Ethylbenzene										
m+p Xylene										
o Xylene										
1,2-Dichloroethene										
Styrene										
Formaldehyde										
1,3-butadiene										
Methanethiol										

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Ethanethiol										
Chloroethene										
Chlorodifluoromethane										
Dichlorodifluoromethane										
Chloromethane										
Carbon disulphide										
Dimethyl sulphide										
Dimethyl disulphide										
Fibres	3.00E+09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Arsine										
Stibene										
Total Bacteria Nutrient 25 oC	6.78E+08	2.9E+06	0.0E+00	1.4E+07	9.7E+05	0.0E+00	4.8E+06	3.8E+04	0.0E+00	1.8E+05
Total Bacteria Nutrient 37 oC	1.61E+08	5.7E+06	0.0E+00	2.8E+07	1.9E+06	0.0E+00	9.5E+06	7.5E+04	0.0E+00	3.7E+05
Total fungi and yeasts Malt 25 oC	3.80E+07	6.7E+07	0.0E+00	3.3E+08	2.3E+07	0.0E+00	1.1E+08	8.7E+05	0.0E+00	4.3E+06
Total fungi and yeasts Malt 40 oC	6.00E+07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Total fungi and yeasts DG18 25 oC	1.02E+08	1.1E+07	0.0E+00	5.5E+07	3.8E+06	0.0E+00	1.9E+07	1.5E+05	0.0E+00	7.2E+05
Gram -ve bacteria VRBG		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Endotoxins	2.98E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Table A9.6.12 : Estimated population exposure levels; Site B Summer 2003: short term exposure

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Antimony	5.77E-04	2.9E-04	0.0E+00	1.5E-03	1.4E-04	0.0E+00	7.1E-04	8.8E-06	0.0E+00	4.6E-05
Arsenic	2.77E-04	1.5E-04	0.0E+00	7.7E-04	6.8E-05	0.0E+00	3.5E-04	4.4E-06	0.0E+00	2.3E-05
Cadmium	2.33E-04	2.3E-02	0.0E+00	1.2E-01	1.0E-02	0.0E+00	5.4E-02	5.7E-04	0.0E+00	3.0E-03
Chromium	1.18E-03	3.7E-03	0.0E+00	1.9E-02	1.7E-03	0.0E+00	8.7E-03	9.1E-05	0.0E+00	4.6E-04
Cobalt	3.00E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Copper										
Lead	2.65E-03	2.9E-03	0.0E+00	1.5E-02	1.3E-03	0.0E+00	7.0E-03	7.7E-05	0.0E+00	4.0E-04
Manganese										
Mercury	4.00E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nickel	9.32E-04	1.5E-01	0.0E+00	7.9E-01	6.6E-02	0.0E+00	3.4E-01	3.2E-03	0.0E+00	1.7E-02
Thallium		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Tin	3.17E-04	1.4E-02	0.0E+00	7.2E-02	6.0E-03	0.0E+00	3.1E-02	2.9E-04	0.0E+00	1.5E-03
Vanadium										
Dioxin	2.29E-08	4.8E-06	2.1E-08	2.5E-05	9.3E-07	4.1E-09	4.8E-06	2.0E-07	8.9E-10	1.0E-06
D,F,PCB (TEQ) - upper limit	8.30E-08	4.9E-06	5.5E-08	2.5E-05	9.5E-07	1.1E-08	4.9E-06	2.0E-07	2.3E-09	1.1E-06
Naphthalene	5.05E-04	1.3E-03	2.6E-04	5.5E-03	2.5E-04	5.0E-05	1.1E-03	5.4E-05	1.1E-05	2.3E-04
Acenaphthylene	9.50E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Acenaphthene	1.20E-04	1.4E-05	0.0E+00	7.2E-05	2.7E-06	0.0E+00	1.4E-05	5.8E-07	0.0E+00	3.0E-06
Fluorene	5.61E-04	4.2E-04	0.0E+00	2.1E-03	8.3E-05	0.0E+00	4.2E-04	1.8E-05	0.0E+00	8.9E-05
Phenanthrene	4.54E-03	1.3E-02	0.0E+00	6.5E-02	2.4E-03	0.0E+00	1.3E-02	5.3E-04	0.0E+00	2.7E-03
Anthracene										
Fluoranthene	2.59E-03	3.5E-03	0.0E+00	1.8E-02	6.8E-04	0.0E+00	3.5E-03	1.5E-04	0.0E+00	7.6E-04
Pyrene	1.61E-03	3.4E-03	0.0E+00	1.8E-02	6.7E-04	0.0E+00	3.5E-03	1.4E-04	0.0E+00	7.5E-04
Benzo (a) anthracene										
Chrysene										
Benzo (b/k) fluoranthene	5.67E-04	2.3E-03	0.0E+00	1.2E-02	4.5E-04	0.0E+00	2.4E-03	9.7E-05	0.0E+00	5.1E-04
Benzo (a) pyrene										
Indeno (123-cd) pyrene										
Benzo (ghi) perylene										
Dibenzo (ah) anthracene										
1,1,1-Trichloroethane										
1,1-Dichloroethane										
Benzene										
1,2-Dichloroethane										
Chlorobenzene										
Chloroethane										
Chloroform										
Dichloromethane										
Tetrachloroethene										
Toluene										
Ethylbenzene										
m+p Xylene										
o Xylene										
1,2-Dichloroethene										
Styrene										
Formaldehyde										
1,3-butadiene										
Methanethiol										

Substance	Baseline	Maximum at any receptor based on			Average 0 - 2 km based on			Average 2 - 7 km based on		
All values in µg/m3		Mean	50%ile	95%ile	Mean	50%ile	95%ile	Mean	50%ile	95%ile
Ethanethiol										
Chloroethene										
Chlorodifluoromethane										
Dichlorodifluoromethane										
Chloromethane										
Carbon disulphide										
Dimethyl sulphide										
Dimethyl disulphide										
Fibres	3.00E+09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Arsine										
Stibene										
Total Bacteria Nutrient 25 oC	6.78E+08	1.7E+08	0.0E+00	8.3E+08	7.9E+07	0.0E+00	3.9E+08	3.8E+06	0.0E+00	1.8E+07
Total Bacteria Nutrient 37 oC	1.61E+08	3.4E+08	0.0E+00	1.6E+09	1.6E+08	0.0E+00	7.8E+08	7.5E+06	0.0E+00	3.7E+07
Total fungi and yeasts Malt 25 oC	3.80E+07	3.9E+09	0.0E+00	1.9E+10	1.8E+09	0.0E+00	9.0E+09	8.8E+07	0.0E+00	4.3E+08
Total fungi and yeasts Malt 40 oC	6.00E+07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Total fungi and yeasts DG18 25 oC	1.02E+08	6.6E+08	0.0E+00	3.2E+09	3.1E+08	0.0E+00	1.5E+09	1.5E+07	0.0E+00	7.2E+07
Gram -ve bacteria VRBG		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Endotoxins	2.98E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Appendix 10 : Health criteria values

Preamble

This briefing note details an approach to deriving health criteria values that has been developing during the course of the project.

There has been general consensus between the Project Board and Contractors that, because of the potentially large number of chemicals that may be emitted from landfill sites, there is a need to prioritise the contaminants of concern. This may be done through the development of a 'Decision tree' including a prioritisation framework (see Fig.1). This framework, which highlights the steps taken to prioritise these contaminants, involves information on both the toxicity of compounds and their presence in a landfill waste scenario The approach for the identification of health criteria values (HCVs) for these chemicals adopted here, is broadly consistent with the principles summarised in CLR 9, taking into consideration that the CLR document is specifically concerned with selecting health criteria in the context of contaminated soils.

The study built in part upon a study commissioned by the Department of Health, to review the potential teratogenicity of substances emanating from landfill sites. This study comprised a review of the data and literature on chemicals and other substances which were known to be released from landfill sites, to assess whether any have teratogenic potential. The review was carried out by independent consultants and a representative of the National Teratology Information Service). The review can be accessed at http://www.advisorybodies.doh.gov.uk/landup.htm.

Principles

The establishment of HCVs is based on the following principles:

- Priority will be given to substances which were positively detected during the monitoring programme. There will also be a 'second tier' of compounds (Group 3) which were not detected but about which there may be significant toxicological concerns

- Where additional research is required, priority will be given to establishing HCVs for compounds with a measured contribution from the landfill site and to non-threshold (e.g. genotoxic carcinogens) and reproductive/developmental toxicants (including teratogens). The assignment of non-genotoxic agents with evidence of carcinogenic potential in animals will be considered on a case-by-case basis.

- In establishing the most appropriate HCV, it is important that this value is protective of all health endpoints, based on current knowledge. The use of uncertainty factors to account for data gaps is appropriate. Advice in this area will be taken from the Interdepartmental Group on Health Risks for Chemicals report entitled "From risk assessment to risk management: dealing with uncertainty" (www.le.ac.uk/ieh/ighrc/igpublications.html).

- Inherent in the derivation of HCVs (i.e. daily intakes such as TDIs and IDs, as specified in CLR 9) 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, where sufficient data exist to allow this to be evaluated.

- HCVs set on the basis of non-threshold effects will follow the approach outlined in CLR9.4, whereby an Index Dose is identified. In this context an Index Dose is defined as:

  > *The dose which can be considered to present a minimal human health risk from a single source of exposure to that contaminant. 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 will be given to ensure that Index Doses are appropriate to the route of exposure for the substances under consideration.

- HCVs for threshold substances will also be 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). A TDI 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.*

- Health criteria will be expressed in the most appropriate terms. Thus, 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).

Decision tree

Step 1 : Brief toxicological assessment and identification of available HCVs

The Defra/Environment Agency publication CLR 9 details a framework for the identification of the most appropriate sources of HCVs. Initially, a literature review would be undertaken for all chemicals of concern (see list presented in Table 1 at the end of this document) to identify the findings and recommendations of key authoritative bodies. Where available, this information is used to come to a conclusion as to the critical toxicological endpoint and the most appropriate TDI or Index Dose in the context of standards that are protective of human health for the relevant route of exposure. The principal source documents to be used as reference sources of health criteria for use in this study are set out below in descending order of priority. Expert scientific judgement will be employed in assessing the recommendations of the various authoritative bodies, with particular attention being paid to more recent assessments/recommendations.

Source S_1: Soil guideline values in CLEA toxicological reports[5]. There are also a number of these reports which have been agreed and finalised for publication and these may also be used as a source of HCVs, although reference will be made to the actual source of the initial recommendation used for the HCV.

4 DEFRA / Environment Agency (2002) *Contaminants in soil: collation of toxicological data and intake values for humans, CLR Report No. 9 (CLR9*).
5 DEFRA/Environment Agency (2002) *Contaminants in Soil: Collation of Toxicological Data and Intake Values for Humans* R&D Publications. TOX series 1–10.

Source S_2: Recommendations produced by authoritative bodies in the UK such as the Committee on Toxicity (COT), Committee on Mutagenicity and Carcinogenicity of Chemicals in Food (COM), Committee on Consumer Products and the Environment (COC), Committee on the Medical Effects of Air Pollutants (COMEAP), the Expert Panel on Air Quality Standards (EPAQS), the Health and Safety Commissions' Advisory Committee on Toxic Substances (ACTS), the Advisory Committee on Pesticides (ACP), the Working Group on Assessment of Toxic Chemicals (WATCH)

Source S_3: Toxicological criteria documents and summaries produced by the Health and Safety Executive (HSE). Where occupational levels are used as HCVs, detected exposure greater than 1% of these values will trigger further consideration of the data.

Source S_4: Recommendations made by the European Commission Scientific Committee on Food (SCF), or the Scientific Committee for Toxicity, Ecotoxicity and the Environment

Source S_5: 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.

Source S_6: 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)

Source S_7: Health criteria may be derived from health criteria/recommendations produced by authoritative organisations for different purposes (e.g. a health criteria applicable to an alternative exposure pathway)

Source S_8: Health criteria may be derived from standards/guidelines for occupational exposure on a case-by-case basis

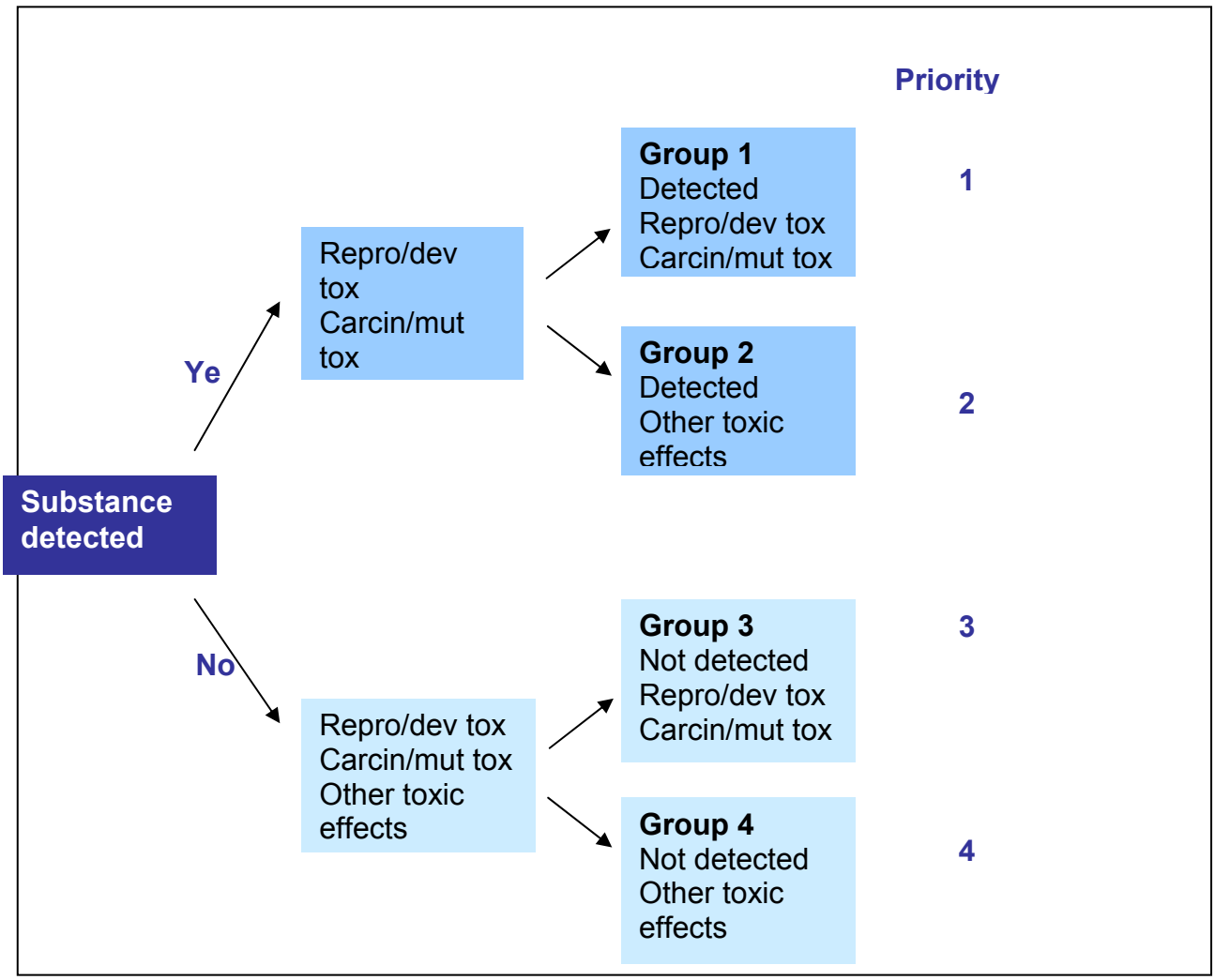
Step 2: Prioritisation framework to highlight chemicals of concern for which it may be necessary to derive project-specific health criteria values

Information on available health criteria and presence in the environment will be used to group the contaminants into four categories (see Fig. A10.1):

Group 1.	Chemicals detected with a contribution from the landfill site. Evidence of reproductive/development toxicity (including teratogenicity); carcinogenic/mutagenic toxicity
Group 2.	Chemicals detected with a contribution from the landfill site. Evidence of other toxic effects
Group 3.	Chemicals not detected with a contribution from the landfill site, at the site boundary or in landfill gas. Evidence of reproductive/development toxicity (including teratogenicity); carcinogenic/mutagenic toxicity

Group 4.	Chemicals not detected with a contribution from the landfill site, at the site boundary or in landfill gas Evidence of other toxic effects.

Figure A10.1: Prioritisation framework of chemicals for the derivation of HCVs



This framework was used to prioritise the chemicals for which HCVs will be adopted or derived. This tiering will identify a group of chemicals (Group 3) which may be of high toxic concern but for which there is no detection in this project.

Step 3 : Derive project-specific health criteria

For some substances, there are no published health criteria values. These substances were considered using a prioritisation framework to rank the substances according to their potential for adverse health effects and their presence at landfill sites. De-novo HCVs were derived for the substances identified in discussion with the project board as being of greatest concern. Information on available health criteria and presence in the environment were used to group the contaminants into four categories (Figure A10.1):

Group 1 Chemicals that have been detected at the landfill site and/or site boundary and for which there is evidence of reproductive/development toxicity (including teratogenicity) and/or carcinogenic/mutagenic toxicity

Group 2 Chemicals that have been detected at the landfill site and/or site boundary and for which there is evidence of toxic effects other than

reproductive/development toxicity (including teratogenicity) and/or carcinogenic/mutagenic toxicity etc.

Group 3 Chemicals not detected with a contribution from the landfill site or at the site boundary.
Evidence of reproductive/development toxicity (including teratogenicity); carcinogenic/mutagenic toxicity

Group 4 Chemicals not detected with a contribution from the landfill site, at the site boundary or in landfill gas
Evidence of other toxic effects.

There were 12 chemicals for which HCVs could not be derived from published data. Applying the prioritisation scheme highlighted above allowed de-novo HCVs to be derived for seven substances (see Table A10.1).

Table A10.1 List of compounds for de novo HCV derivation

Compound	Chemical Abstracts Service (CAS) Registry Number
alpha terpinene	99-86-5
2-ethyl 1-hexanol	104-76-7
Stibene	7803-52-3
trimethyl benzene	25551-13-7 for mixed isomers, also 95-63-6, 526-73-8 & 108-67-8 for individual isomers
Methanethiol	74-93-1
dimethyl sulphide	75-18-3
dimethyl disulphide	624-92-0

Health Criteria Values

Table A10.2 below set out the chemicals identified and the information required for the prioritisation framework and the derivation of HCVs. The Comments column includes details of the data upon which the HCV is set including the toxicological/health effect.

Table A10.2 : Health Criteria Values identified in this project

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
1,1-Dichloroethane CAS 75-34-3			x	x		x	x	x	x	□	4.12 mg m^{-3}	1% of HSE OES 8-h RP, 100 ppm (412 mg m^{-3}) (HSE EH40/2002)	HSE has recently adopted the EC IOELV for 1,1-DCE; no toxicological basis is provided for this in the HSC consultation document cd156. HSE EH40 states that an OEL summary is given in EH65/4 – this document only deals with 1,2-DCE. CLR Tox report is specific to 1,2-dichloroethane	NC	Heart and kidney toxicity. Conflicting evidence of genotoxicity Some cancers in rats and mice but inconclusive. Evidence of mutagenicity. Not classifiable for cancer by IARC but USEPA gives classification C - probable human carcinogen based on limited evidence of carcinogenicity in animals. Found to be slightly embryotoxic but not teratogenic. Some retarded foetal development but no toxic effects. Thought unlikely to cause developmental toxicity.
1,1,1-Trichloroethane CAS 71-55-6	D		x	x		x	x	□			4820 µg m^{-3}	Dutch Maximum Permissible Concentration (RIVM, 2001; detailed in addendum to Rademaker & van de Plassche, 1993)	Dutch HCV is based on a duration corrected NOAEL of 482 mg m^{-3} for increased body weigth and slight hepatic effects in rats exposed for 2 years (addendum to Rademaker & van de Plassche, 1993)	3	General toxicity; large oral doses produce nausea, vomiting and diarrhoea while inhalation can cause dizziness and inco-ordination at high levels. No dose-related reproductive or teratogenic effects observed in a multigenerational study on mice. CLR Tox evaluation published during course of study indicating a lower HCV of 2100 µg/m^3

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
1,2 Dichloroethane CAS 75-09-2	D		x[1]	x		x	□				0.36 µg m^{-3}	IPCS (1998) CICAD: 0.36 µg/m^3 (after Draft CLR TOX Report). WHO (2003) draft drinking water guidelines: 4 µg L^{-1}; based on 0.12 µg kg^{-1} bw being 50 000-fold less than the estimated carcinogenic potency	HCV for inhalation and oral exposure based on carcinogenic potency expressed as the dose causing a 5% increase in tumours from studies of animals exposed by gavage.	2B	Based on available data, 1,2-dichloroethane is considered to be a probable human carcinogen (IARC Group 2B); consistently demonstrated to be genotoxic in numerous *in vitro* and in *vivo studies* for a wide range of end points. No observed reproductive toxicity or teratogenicity.
1,2 Dichloroethene (NB. Cis and trans isomers) CAS 540-59-0	D		x	x		x	x	x	□		60 µg m^{-3}	Extrapolation from oral HCV. WHO (1996) Drinking Water Guidelines. TDI, 17 µg kg^{-1} bw day^{-1} for cis – and trans-1,2-dichloroethene.	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).	NC	Long term exposure to both cis- and trans-1,2-DCE has the potential to cause liver, circulatory and nervous system damage. Trans form is twice as potent as the cis form in ability to depress CNS. WHO (1996) state that there is limited data to suggest that both isomers may possess some genotoxic activity but there is no information on carcinogenicity. Group 1 classification for developmental/reproductive toxicity according to Sullivan/Barlow but on single study in which non-dose-related effects observed.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
1,3 butadiene CAS 106-99-0	D		x	□							2.21 µg m^{-3}	EPAQS (1994): 1 ppb (= 2.21* µg m^{-3}) as 'running annual average' *conversion factor from CICAD (IPCS, 2001)	EPAQS (1994) 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.	2A	1,3-Butadiene is a genotoxic carcinogen; effect of most concern is induction of cancers of lymphoid system and blood-forming tissues, lymphomas and leukemias. Group 1 classification for developmental/reproductive toxicity according to Sullivan/Barlow but IEH believe that should be group 2.
2-Butanone (methyl ethyl ketone) CAS 78-93-3	(D) D, C		x	x		x	x	□			5 mg m^{-3}	USEPA (2003) inhalation RfC: 5 mg m^{-3} with low confidence	USEPA RfC is based on an adjusted LEC of 1,517 mg/m^3 for developmental toxicity (skeletal variations).	NC	Neurotoxic effects, eye and skin irritation and CNS effects. Not genotoxic. Not classifiable as to cancer.. Sullivan/Barlow group 2 for reproductive/developmental toxicity, based on teratogenicity at high doses, and minor anomalies at non-maternal doses in animals. The presence of 2-butanone can potentiate the toxicity of some other solvents (EHC 143).
2-ethyl-1-hexanol aka iso-octanol CAS 26952-21-6	D		x	x		x	x	x	x	□	*De novo* HCV to be derived			NC	Irritant, CNS depressant. Group 2 classification for developmental/reproductive toxicity according to Sullivan/Barlow.
2-methyl furan CAS 534-22-5	D	2	x	x		x	x	x	x	x	No HCV			NC	No data
2-Octanone CAS 111-13-7	(D)	4	x	x		x	x	x	x	x	No data or HCV No ADI set by JECFA, current levels in food deemed 'acceptable'.			NC	Skin, eye and respiratory irritant. Recognition threshold 250 ppm. Possible CNS effects. Ketones have little or no repro effects.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Acetic acid CAS 64-19-7	(D)		x	x		x	x	x	x	□	0.25 mg m^{-3}	1% of HSE OES 8-h RP, 25 mg m^{-3} (HSE EH40/2002).	No OEL Summary available.	NC	Severe irritant.
Acetone CAS 67-64-1	(D)		x	x		x	x	□			31 mg m^{-3}	ATSDR (1995) chronic duration MRL of 13 ppm.	MRL is based on a LOAEL of 1,250 ppm for neurological effects in human volunteers.	NC	Nephropathy, irritancy. Non-genotoxic, not carcinogenic. Some potential for developmental/reproductive toxicity – sl skeletal malformations in rats, decreased fetal weight and sl developmental effects. Odour threshold is 240 mg/m^3 (WHO 2000b).
Alpha terpinene CAS 99-86-5	D	1	x	x		x	x	x	x	x	*De novo* HCV to be derived			NC	Sl minor skeletal abnormalities. Sullivan/Barlow classified as group 2 for repro/developmental toxicity based on minor anomalies at maternally toxic doses in animals. Moderate irritant.
Antimony CAS 7440-36-0	D		x	x		x	x	x	□	x	0.003 mg m^{-3}	Extrapolation from oral HCV WHO (1996) Drinking Water Guidelines, oral TDI 0.86 µg kg^{-1} bw day^{-1}.	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.	2B for trioxide; 3 for trisulfide	Chronic respiration of Sb-containing dusts leads to respiratory tract irritation and myocardial and liver damage. General toxicity from oral exposure (WHO, 2003). Positive results for carcinogenicity in animal studies but inconclusive evidence for carcinogenicity in humans. One incomplete study reported that respired Sb-compounds could trigger premature births and spontaneous abortions. (WHO, 2003).

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Arsenic CAS 7440-38-0	D		□								0.007 µg m^{-3} ID_{oral} 0.3 µg kg^{-1} bw day^{-1}	CLR Tox 1 (Defra/EA, 2002), ID_{inh} 0.002 µg kg^{-1} bw day^{-1}	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.	1	Inorganic arsenic is a genotoxic carcinogen by oral or inhalation exposure. WHO (2000a) air quality guidelines: 6.6 ng m^{-3}; associated with lifetime lung cancer risk of 10^{-5}.
Arsine CAS 7784-42-1	D		x	x		x	□				0.007 µg m^{-3}	See above for Arsenic. IPCS (2002) CICAD: 0.05 µg m^{-3} for non-cancer endpoints USEPA RfC: 0.05 µg m^{-3}. More stringent value for arsenic used	NOAEL of 0.08 mg m^{-3} for increased haemolysis, abnormal RBC morphology and increased spleen weight from 13 week rat and mouse study.	1	Arsine is a potent haemolytic agent; this can progress to oliguric renal failure. Haemolytic anaemia is the most consistent clinical finding in humans following exposure to arsine. No information on carcinogenicity or reproductive toxicity. If metabolism to arsenic compounds is considered then human carcinogenicity is proven and there is some evidence for reproductive and developmental toxicity, although this is not conclusive. IARC consider that arsenic and arsenic compounds are *carcinogenic to humans (Group 1).*
Benzaldehyde CAS 100-52-7	D		x	x		x	x	x	□		0.35 mg m^{-3}	Extrapolation from oral HCV, USEPA RfD: 0.1 mg kg^{-1} bw day^{-1}	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).	NC	Animal toxicity in brain, forestomach, liver and kidneys. Not mutagenic. Forestomach tumours in mice, not in rats. No airborne occupational guideline located. JECFA (1996) ADI, 0-5 mg kg^{-1} bw, maintained in 2001.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Benzene CAS 71-43-2	D, C		□	x							3.2 µg m^3	CLR Tox 11 (Defra/EA, 2002), ID_{inh} 0.91 µg kg^{-1} bw day^{-1} (EPAQS 1994: 3.2 µg m^3 as 'running annual average').	EPAQS (1994) 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}).	1	Key health hazard is ability to induce leukaemia. Benzene has been demonstrated to be a genotoxic carcinogen. No studies in animals have detected teratogenic potential, even at exposure levels that produce maternal and foetal toxicity. However, based on occupational data Group 1 classification for developmental/reproductive toxicity according to Sullivan/Barlow
Cadmium CAS oxide 1306-19-0 sulphide 1306-23-6			□								0.005 µg m^{-3} TDI_{oral} 1 µg kg^{-1} bw day^{-1}	CLR Tox 3 (Defra/EA, 2002), ID_{inh} 0.001 µg kg^{-1} bw day^{-1}	WHO set level of Cd in air (5 ng m^3) to prevent further increases of Cd levels in the kidney. JECFA set level for safe oral intake of Cd to prevent accumulation in the renal cortex.	1	Inhalation exposure to cadmium can produce lung cancer and kidney toxicity. Genotoxic carcinogen. Cadmium causes nephrotoxicity, specifically proteinuria. Data on reproductive and developmental effects are inconclusive – indication of effects on neurobehavioural development in rodents. WHO (2000a) Air Quality: 5 ng m^{-3}.
Carbon Disulphide CAS 75-15-0	D, C		x	x		x	□				100 µg m^{-3}	WHO (2000a) Air Quality: 100 µg m^{-3}, with a 24 hr averaging time	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.	NC	Effects on CNS; can also produce effects on blood vessels in various organs and tissues, especially cerebral and renal arteries (producing encephalopathy and nephropathy). Effects on endocrine system. Some studies have reported disturbance of the menstrual cycle in women and a slight increase in miscarriages. Some evidence for embryotox (but not teratogenicity) and reprotox (group 1 classification by Sullivan/Barlow). Not genotoxic and not evaluated for carcinogenicity

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Chlorobenzene CAS 108-90-7	D		x	x		x	□				0.5 mg m^{-3}	WHO (2000b) Guidelines for Air Quality – 'tolerance conc', 1 yr averaging period	LOAEL of 341 mg m^{-3} for decreased food intake, increased organ weight, lesions and changes in blood parameters.	NC	MCB causes CNS disturbances in humans. SI skeletal dev delay at maternal tox level. No repro/dev tox (WHO 2003). The WHO water guideline is based on neoplastic liver nodules in male rats but the weight of evidence suggests that MCB is not genotoxic (WHO 1996).
Chlorodifluoro-methane CAS 75-45-6	D		x	x		x	x	□			50 mg m^{-3}	USEPA IRIS RfC: 50 mg m^{-3}	USEPA RfC is based on an adjusted NOAEL of 5260 mg m^{-3} for increased kidney, adrenal and pituitary weights in rats.	NC	Very low toxicity. No repro/dev toxicity.
Chloroethane CAS 75-00-3	D		x	x		x	x	□			10 mg m^{-3}	USEPA IRIS RfC: 10 mg m^{-3}	USEPA RfC is based on a NOAEL of 4000 mg m^{-3} for delayed foetal ossification in mice.	3	General anaesthetic and CV effects at high dose. Slight developmental effects and minimal evidence of foetotox. Some evidence of animal carcinogenicity. Alkylating agent, mutagenic in vitro but not in vivo.
Chloroform CAS 67-66-3	D		x	x		x	□				52.5 µg m^{-3}	Inhalation HCV based on a TDI of 15 µg kg^{-1} bw day^{-1} from WHO (2000b) Guidelines for Air Quality. TDI for 24 h averaging over lifetime.	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}.	2B	Liver fatty degeneration. No teratogenicity, but Group 1 classification for developmental/reproductive toxicity according to Sullivan/Barlow based on growth anomalies. Evidence suggests principal effects mediated via non-genotoxic pathways. Liver and kidney tumours in animals at doses where there is regenerative hyperplasia and cytotoxicity.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Chloromethane CAS 74-87-3			x	x		x	□				0.018 mg m^{3}	CICAD (IPCS, 2000) guidance value for indirect inhalation exposure via the environment for the general population.	LOAEL of 103 mg m^{3} derived from 2-year study for effects on the nervous system, corrected for continous exposure.	3	General toxicity, particularly nervous system . Genotoxicity in vitro. Renal tumours in animals. Testicular lesions and developmental heart defects. Group 1 classification for reproductive/developmental toxicity according to Sullivan/Barlow based on teratogenicity.
Chromium CAS 7440-47-3	D		□								0.0025 µg m^{-3} TDI_{oral} 3 µg kg^{-1} bw day^{-1}	CLR Tox 4 (Defra/EA, 2002), ID_{inh} 0.001 µg kg^{-1} bw day^{-1}. (Based on WHO 2000a Air Quality Guidelines)	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. TDI_{oral}, which is based on USEPA RfD, is derived from a drinking water study in rats which did not identify any adverse effects at the highest tested dose of 2.5 mg Cr (VI) kg^{-1} bw.	1 (VI); 3 (III)	Cr(VI) is considerably more toxic than Cr(III). Cr (VI) is a carcinogen in humans exposed via inhalation (IARC Group 1). Foeto- and embryotoxicity have been reported for Cr(VI)
Cobalt CAS 7440-48-4			x	x		x	x	□			0.1 µg m^{-3}	ATSDR (1993) chronic inhalation MRL.	ATSDR MRL is based on a NOAEL of 5.3 µg m^{-3} for respiratory effects in diamond workers.	2B	Toxicity - CV, hepatic respiratory and sensitisation. Developmental/Reproductive effects in animals. Fibrosarcomas in animals (when injected); no evidence in humans.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Copper CAS 7440-50-8	D		x	x		x	x	x	x	□	0.002 mg m^{-3} TDI_{oral} 0.5 mg kg^{-1} bw day^{-1}	1% of HSE OES 8-h RP, 0.2 mg m^{-3} (HSE EH40/2002) WHO (1996) Drinking Water Guidelines: 2 mg L^{-1}, after JECFA (1982) PMTDI of 0.5 mg kg^{-1} bw day^{-1}	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} JECFA PMTDI is based on a NOAEL of 5 mg kg^{-1} bw for the end-point of liver toxicity in dogs.	NC	Toxicity - Liver, GI, anaemia, Immunotox. No reprotox but evidence for developmental tox. Some evidence for human carcinogenicity but negative in animals. Neg in mutagenic tests but positive for DNA damage. Inhalation of copper fume (particularly the oxide) causes respiratory tract irritation.
Decane CAS 124-18-5 In combination with nonane.	(D)		x	x		x	x	□			0.2 mg m^{-3}	See entry for nonane and decane; to be considered in combination as C_9-C_{18} aliphatic hydrocarbons.		NC	Eye, skin and respiratory irritant. Possible CN effects.
Dichlorobenzene CAS ortho 95-50-1 meta 541-73-1 para 106-46-7	D		x	x		x	□				1 mg m^{-3} (1,4-) This HCV is used for all isomers as 1,4-DCB is the most toxic (i.e. a pre-cautionary approach)	WHO (2000b) Guidelines for Air Quality; 1 yr averaging	NOEL of 450 mg/m^3 for increase in organ weight and urinary proteins.	Para (2B); ortho & meta (3)	General toxicity in humans. Oral exposure to high doses of 1,2-DCB affects mainly the liver and kidneys. IARC has classified 1,4-DCB as Group 2B, possibly carcinogenic to humans due to evidence that it increases the incidence of renal tumours in rats and liver tumours in mice but it is not considered to be genotoxic. 1,4-DCB - Repro/developmental: increase in skeletal variations at high dose level and dose-related increase in extra ribs (WHO, 1996). Group 2 classification according to Sullivan/Barlow. 1,2 and 1,3 DCB are classified as Group 3 by IARC
Dichlorodifluoro-methane CAS 75-71-8	D		x	x		x	x	x	x	□	50.3 mg m^{-3}	1% of HSE OES 8-h RP, 5030 mg m^{-3} (HSE EH40/2002).	No OEL Summary available.	NC	Animals studies showed no indication of carcinogenicity or reproductive effects.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Dichlorofluoro-methane CAS 75-43-4			x	x		x	x	x	x	□	0.43 mg m^{-3}	1% of HSE OES 8-h RP, 43 mg m^{-3} (HSE EH40/2002).	No OEL Summary available.	NC	Low toxicity – CNS, liver, CV, respiratory system. Some evidence for reproductive effects. No mutagenicity or carcinogenicity data.
Dichloromethane CAS 75-09-2	D, C		x	x		x	□				0.45 mg m^{-3}	WHO (2000a) Air Quality Guidelines: 3 mg m^{-3} for 24 hr exposure & 0.45 mg m^{-3} as weekly average	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.	2B	Critical effects of DCM include effects on the CNS, the production of COHb and carcinogenicity. Some evidence of genotoxicity in vitro but genotoxic metabolites not considered to form in vivo. Not indicated to be teratogenic in animal studies via oral exposure. Minor skeletal variants (WHO 1996) at high inhalation exposure conc.
Dimethyl disulphide CAS 624-92-0		2	x	x		x	x	x	x	x	*De novo* HCV to be derived			NC	Primarily those of hydrogen sulphide. Irritant. Respiratory paralysis at high inhalation exposures. Hepatic toxicity. No data on repro tox. Not genotoxic.
Dimethyl sulphide CAS 75-18-3		2	x	x		x	x	x	x	x	*De novo* HCV to be derived			NC	Primarily those of hydrogen sulphide. Less toxic than dimethyl disulphide. Respiratory paralysis at high inhalation exposures. Severe eye irritant No data on repro tox. Not genotoxic. Current levels in food deemed acceptable by JECFA (1999).

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Dioxins CAS 1746-01-6	D, C		□	x		x	x	x	□		No air quality HCV used: assessed via exposure to all pathways TDI 2 pg kg^{-1} bw day^{-1}	Extrapolation from oral HCV. CLR Tox 12 (Defra/EA, 2003), TDI 2 pg kg^{-1} bw day^{-1} *WHO do not propose an air quality guideline for PCDDs and PCDFs because direct inhalation exposures constitute only a small proportion of the total exposure, generally <5% of intake from food.*	TDI_{oral} 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.	TCDD (1); others (3)	TCDD has been demonstrated to be a reproductive toxicant and teratogen; effects on sperm production and morphology in the offspring of dosed animals are most sensitive indicators of toxicity. TDI_{oral} is based on data for TCDD but is applicable to other dioxins, dibenzofurans and dioxin-like, co-planar PCBs using TEF methodology.
Dust	D		x	□							See PM_{10}				
Ethyl benzene CAS 100-41-4	D		x	x		x	x	□			595 µg m^{-3}	NTP(1999):170 µg kg^{-1} bw day^{-1}	NTP (1999) regarded the NOAEL as 325 mg m^{-3}, based on hyperplasia of the pituitary gland in female mice.	2B	CNS toxicity is the primary human health concern. Group 1 classification for developmental/reproductive toxicity according to Sullivan/Barlow, based on minor growth anomalies below the maternally toxic dose. For rats exposed during gestation, principal finding was an increased incidence of supernumerary and rudimentary ribs in the high exposure group.
Ethyl mercaptan CAS 75-08-1	D		x	x		x	x	x	x	□	0.01 mg m^{-3}	1% of ACGIH (2001) TLV TWA, 1 mg m^{-3}.	TLV-TWA is recommended in order to minimise the potential of irritation.	NC	Irritant

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Formaldehyde CAS 50-00-0	D		x	x		x	x	x			10 µg m^{-3} (long-term exposure)	ATSDR chronic duration inhalation exposure MRL of 8 ppb.	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.	2A	Formaldehyde is a nasal carcinogen (IARC Group 2A) perhaps by hyperproliferative response; evidence of genotoxicity. Likely to be a threshold for these effects. Nasopharyngeal cancer observed in humans; irritation of nose, eyes and throat from short-term exposure. Not teratogenic, some evidence of effects on testes and sperm (WHO 1996). Sullivan/Barlow classification Group 1 possible embyotoxicity in occupationally exposed women, even at relatively low levels. NB. USEPA unit risk for inhalation: 1.3 x 10-5 (ug m^{-3})$^{-1}$
Fibres (Assuming asbestos)			x	x		x	x				1000 F m^{-3} (or 0.0005 F* ml^{-1} or 500 F* ml^{-1})	WHO (2000a) Air Quality Guidelines	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}.	1	Asbestos is a proven carcinogen; endpoint of concern is lung cancer (mesothelioma).
Formic acid CAS 64-18-6	(D)		x	x		x	x	x	x	□	0.37 mg m^{-3}	1% of HSE OES 8-h RP, 37 mg m^{-3} (HSE EH40/2002).	No OEL Summary available.	NC	Corrosive R35. Non-genotoxic. No reproductive toxicity
Heptanone CAS 110-43-0 (2-one 106-35-4 (3-one)	(D)		x	x		x	x	x	x	□	1.66 mg m^{-3}	1% of HSE OES 8-h RP, 166 mg m^{-3} (HSE EH40/2002) Lower value for the two isomers used (3-one).	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.	NC	Harmful irritant R10. Some neurotoxic potemtial. Unlikely to be genotoxic/carcinogenic. Mild devel tox at maternal toxic levels. Toxicity data indicates that the two heptanone isomers have a similar toxicity profile and can be grouped together for consideration (HSE EH 64/1994).

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Hydrogen sulphide CAS 7783-06-4	D		x	x		x	□				150 µg m^{-3}	WHO (2000a) Air Quality Guidelines: 0.15 mg m^{-3} with an averaging time of 24 hr.	HCV is based on a LOAEL of 15 mg m^{-3} for eye irritation.	NC	Changes of haem synthesis have been reported at low exposure levels. Eye irritation. Effects on CNS and respiratory system leading to collapse and death at high concentrations. Not mutagenic. No definitive data on carcinogenicity. No significant reproductive toxicological effects observed. Group 2 classification by Sullivan/Barlow
Lead CAS 7439-92-1	D		□	□							0.25 µg m^{-3} [Blood lead concentration: 10 µg dL^{-1}] HCV_{oral} 25 µg kg^{-1} bw $week^{-1}$	EPAQS (1998): 0.25 µg m^{-3} as an annual average CLEA Tox 6 (Defra/EA, 2002) JECFA: 25 µg kg^{-1} bw $week^{-1}$	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.	2B	Health effects of lead include anaemia and effects on the nervous system, e.g. cognitive impairment in children. An increased risk of miscarriage and stillbirth has been attributed to lead. Inorganic lead compounds are classified by IARC as possibly carcinogenic to humans (Group 2B).
Limonene CAS 5989-27-5	D		x	x		x	x	x	□		0.35 mg m^{-3} TDI_{oral} for d-limonene 0.1 mg kg^{-1} bw day^{-1}	Extrapolation from oral HCV, TDI for d-limonene, 0.1 mg kg^{-1} bw day^{-1}, from IPCS (1998) CICAD.	TDI_{oral} is based on a NOEL for increased liver weight of 10 mg kg^{-1} bw day^{-1} with uncertainty factor of 100.	3	Skin and eye irritant. Main toxic effects are on the liver. Non-genotoxic. Renal tumours in male rats with mechanism not considered relevant to humans (α2-microglobulin). No reprotoxic or teratogenic potential. Oral exposure considered most important pathway; IPCS CICAD did not produce an inhalation guideline for this reason. No airborne occupational guideline was located.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Manganese CAS 7439-96-5	D		x	x		x	□				0.15 µg m^{-3} TDI_{oral} 60 µg kg^{-1} bw day^{-1}	WHO (2000a) Air Quality Guidelines: 0.15 µg m^{-3} as an annual average. WHO (2003) draft drinking water guidelines: 0.4 mg L^{-1} as 'provisional guideline value'. UK drinking water standard: 50 µgMn L^{-1} (possibly based on aesthetic considerations – discolouration).	WHO air quality guideline is based on a an estimated NOAEL of 30 µg m^{-3} for neurotoxic effects observed in occupationally exposed workers. Oral TDI is based on a NOAEL of 11 mg day^{-1} for an increase in lymphocyte superoxide dismutase activity in women given daily supplements of manganese.	NC	Manganese is considerably more toxic by inhalation. Manganese is neurotoxic; 'manganism' is characterised by psychiatric and movement disorders. Respiratory effects are also reported. No strong evidence for carcinogenicity or repro/dev toxicity Manganese is an essential trace element and has relatively low toxicity by ingestion.
Mercury CAS 7439-97-6			□								1 µg m^{-3}, for elemental & inorganic mercury TDI_{oral} 0.3 µg kg^{-1} bw day^{-1} for inorganic mercury	CLR Tox 7 (Defra/EA, 2002) based on WHO (2000a) Air Quality Guidelines: 1 µg m^{-3} for elemental mercury, also applicable to inorganic compounds CLEA Tox 7 based on USEPA (1995): 0.3 µg kg^{-1} bw day^{-1}	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}. USEPA RfD based on autoimmune glomerulonephritis in rats – LOAEL of 0.3 mg kg^{-1} bw day^{-1}.	3	Elemental mercury is neurotoxic. The kidney is the critical organ for chronic exposure to inorganic mercury compounds Reproductive or developmental effects have been seen in rodents given single doses of mercuric chloride by the intraperiteneal or intravenous routes.
Methyl mercaptan CAS 74-93-1	D		x	x		x	x	x	x	□	*De novo* HCV to be derived			NC	Toxic effects on CNS, blood. No data on CMR. ACGIH (2001) TLV-TWA of 0.98 mg m^{-3} is recommended to minimise exposure to objectionable odour; higher levels lead to irritation and possible CNS effects.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Nickel CAS 7440-02-0	D		□								0.020 µg m^{-3}	CLR Tox 8 (Defra/EA, 2002) after CSTEE (2001): 20 ng m^{-3} TDI_{oral}, 5 µg kg^{-1} bw day^{-1}	CSTEE recommendation is based on a LOAEL of 0.6 mg m^{-3} for increased lung weight in rats. WHO (1996) oral TDI is based on a NOAEL of 5 mg kg^{-1} bw day^{-1} for reduced body weight in rats (females also had increased relative heart weight and decreased relative liver weight).	Ni compounds (1); Ni (2B)	Nickel (particularly as soluble salts) is a carcinogen in humans exposed via inhalation. Animal studies have demonstrated reproductive or foetotoxicity via the oral route. Sensitisation
Nitrogen dioxide CAS 10102-44-0	D		x	□	□						40 µg m^{-3} 200 µg m^{-3} (see Main Report Table 5.19)	EC Air Quality Daughter Directive 1999/30/EC. EPAQS (1996): 287 µg m^{-3} (150 ppb) as a 1 hour mean	Limit value for the protection of human health (as annual mean) 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.	NC	NO_2 causes irritation of the lungs/respiratory tract via damage to cell membranes and proteins
Nitromethane CAS 75-52-5	D		x	x		x	x	x	x	□	2.54 mg m^{-3}	1% of HSE OES 8-h RP, 254 mg m^{-3} (HSE EH40/2002)	No OEL Summary available.	2B	Irritation, skin, eye, liver, lung. Nitromethane has been confirmed as a carcinogen in animal studies but NTP study (1997) indicates non-genotoxic carcinogenicity. No data on repro/dev tox.
Nonane CAS 111-84-2	(D)		x	x		x	x	x	x	□	0.2 mg m^{-3}	See below.		NC	Respiratory irritation and narcosis. Not genotoxic

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Nonane + Decane			x	x		x	x	□			0.2 mg m^{-3}	MA DEP (2002) RfC for C_9-C_{18} aliphatics	Neurotoxicity in rats.	NC	MA DEP has derived HCVs for petroleum hydrocarbon fractions for the health risk assessment of complex petroleum hydrocarbon mixtures. The EA are proposing the adoption of a similar approach in the context of the assessment of health risks from petroleum–contaminated land.
PAHs				□							0.25 ng m^{-3} BAP as marker for PAH carcino-genicity.	EPAQS (1999) considered BaP as an appropriate marker/indicator compound for PAHs in urban air. Relative potencies (RPs) derived by EPAQs (1999) were used to assess the contribution to the carcinogenicity of the mixture from each PAH designated by IARC as being of carcinogenic concern.	Carcinogenic potencies of PAHs relative to BaP were derived by 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).		Studies on PAHs have demonstrated elevated incidence of lung tumours on inhalation and of skin tumours from skin contact. It is difficult to predict, with confidence, the contribution of individual PAHs.
Benzo (a) anthracene CAS 56-55-3	D		x	□							(RP = 0.1)	EPAQS (1999)	See above.	2A	High level of concern about carcinogenic hazard for humans (COM/COC Group A).
Chrysene CAS 218-01-9	*D*		x	□							(RP = 0.03)	EPAQS (1999)	See above.	3	Concern about carcinogenic hazard for humans (COM/COC Group B).

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Benzo (b/k) fluoranthene CAS 205-97-0	*D*		x	□							(RP = 0.1)	EPAQS (1999)	See above.	2B	Concern about carcinogenic hazard for humans (COM/COC Group B).
Benzo (a) pyrene CAS 50-32-8	*D*		□	□							(RP = 1) 0.25 ng m^{-3}	CLR Tox 2 (Defra/EA, 2002) & EPAQS(1999): 0.25 ngBaP 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.	2A	High level of concern about carcinogenic hazard for humans (COM/COC Group A). Evidence of genotoxic potential. Classified by IARC as a probable human carcinogen. Foetal malformations at a maternally toxic dose in mice.
Indeno (123-cd) pyrene CAS 193-39-5	*D*		x	□							(RP = 0.08)	EPAQS (1999)	See entries above.	2B	Concern about carcinogenic hazard for humans but data incomplete or mechanism is unclear (COM/COC Group B).
Dibenzo (ah) anthracene CAS 52-70-3	*D*		x	□							(RP = 1.91)	EPAQS (1999)	See entries above.	2A	High level of concern about carcinogenic hazard for humans (COM/COC Group A).
Naphthalene CAS 91-20-3	*D*		□								0.003 mg m^{-3}	CLR Tox 20 (Defra/EA, 2003) TDI_{inh}, 0.86 µg kg^{-1} bw day^{-1}.	HCV based on a LOAEL of 9.3 mg m^{-3} for benign lung tumour induction.	2B	Not genotoxic, some evidence of nasal tumours in animals Systemic toxicity
Acenaphthylene CAS 208-96-8	*D*	1	x	x		x	x	x	x	x	No HCV			NC	No classification of carcinogenicity. Inadequate carcinogenicity, genotoxicity data.
Acenaphthene CAS 83-32-9	*D*		x	x		x	x	x	□		0.21 mg m^{-3}	Extrapolation from oral HCV, USEPA IRIS RfD, 60 µg kg^{-1} bw day^{-1}.	RfD based on a NOAEL of 175 mg kg^{-1} day^{-1} for hepatotoxicity in mice.	NC	Data inadequate for assessment of carcinogenicity (COM/COC Group D). …

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Fluorene CAS 86-73-7	*D*		x	x		x	x	x	□		0.14 mg m^{-3}	Extrapolation from oral HCV USEPA IRIS RfD, 40 µg kg^{-1} bw day^{-}	Decreased RBC, packed cell volume and haemoglobin (NOAEL of 125 mg kg^{-1} day^{-1} in mice).	3	Data inadequate for assessment of carcinogenicity (COM/COC Group D). …
Phenanthrene CAS 85-01-8	D, C	*1*	x	x	x	x	x	x	x	x	No HCV			3	No concern about carcinogenic hazard (COM/COC Group E).
Anthracene CAS 120-12-7	*D*		x	x	x	x	x	x	□		1.05 mg m^{-3}	Extrapolation from oral HCV USEPA IRIS RfD, 0.3 mg kg^{-1} bw day^{-1}.	USEPA RfD is based on a NOAEL of 1000 mg kg^{-1} day^{-1} from a subchronic toxicity study in mice (no observed effects).	3	No concern about carcinogenic hazard (COM/COC Group E).
Fluoranthene CAS 206-44-0	*D*		x [1]	x	x	x	x	x	□		0.044 mg m^{-3}	Extrapolation from oral HCV USEPA IRIS RfD, 0.04 mg kg^{-1} bw day^{-1}.	USEPA RfD is based on a NOAEL of 125 mg kg^{-1} day^{-1} for nephropathy, increased liver weights and hematological alterations in mice.	3	No concern about carcinogenic hazard (COM/COC Group E). Renal and hepatic toxicity. Draft CLR Tox report recommends TDI of 12.5 µg/kg. This extrapolates to 44 µg/m^3.
Pyrene CAS 129-00-0	*D*		x	x	x	x	x	x	□		0.105 mg m^{-3}	Extrapolation from oral HCV USEPA IRIS RfD, 0.03 mg kg^{-1} bw day^{-1}.	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) .	3	No concern about carcinogenic hazard (COM/COC Group E).
Benzo (ghi) perylene CAS 191-24-2	D	*1*	x	x	x	x	x	x	x	x	No HCV			3	Concern about carcinogenic hazard for humans but data incomplete or mechanism is unclear (COM/COC Group B).

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
PCB's	D	1			x	x	x	x	□		7 pg m^{-3} TEQ (for dioxin-like PCBs, in combination with dioxins)	Extrapolation from oral HCV. CLR Tox 12 (Defra/EA, 2003), TDI_{oral} 2 pgTEQ kg^{-1} bw day^{-1} for co-planar, dioxin-like PCBs. See COT (2001).	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.	2A	PCBs produce a wide spectrum of adverse effects in experimental animals including reproductive toxicity, immunotoxcity and carcinogenicity (via a non-genotoxic mechanism). COM/COC state that it would be prudent that all PCB congeners are considered potential human carcinogens. WHO do not propose an air quality guideline for PCBs because direct inhalation exposures constitute only a small proportion of the total exposure, generally <1-2% of intake from food.
Pentane All isomers CAS 78-78-4; 109-66-0; 463-82-1			x	x		x	x	x	x	□	17.7 mg m^{-3} (All isomers)	1% of ACGIH (2001) TLV 8-h RP TWA, 1770 mg m^{-3}	TLV-TWA is recommended by ACGIH 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.	NC	Eye, nose irritation. Narcosis at high dose (neurobehavioural and neurotoxic effects). N-pentane - not mutagenic and there is no concern for cancer. No evidence of reproductive or developmental toxicity for n-pentane (CSTEE opinion on RAR).
PM_{10}	D		x	□							40 µg m^{-3} (see also main report Table 5.19)	EPAQS (2001) recommended 50 µg m^{-3} as a 24-hr average for PM_{10} in their 1995 report. EC Directive (1999/30/EC) sets an annual mean limit value of 40 µg /m^3.	EPAQS (1995) standard for PM_{10} 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.	NC	Health effect is a pulmonary inflammatory response. Precise mechanism of toxicity is unclear and probably related to composition of particles. Ultrafine particles (e.g. from diesel exhaust) indicated to be potentially carcinogenic.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Stibine CAS 7803-52-3	D		x	x		x	x	x	x	□	*De novo* HCV to be derived			NC	Antimony compounds are considered to be carcinogenic (although evidence is inconclusive for humans) and may be genotoxic (HSE EH65/23, 1996). Main toxicity is haemolytic. No specific data for stibine but the data may be comparable to that for antimony oxide (see antimony).
Styrene CAS 100-42-5	D, C		x	x		x	□				70 µg m^{-3}	WHO (2000a) Air Quality Guidelines: 0.26 mg m^{-3} as a weekly average (or 70 µg m^{-3} as a 30 min average if basing guideline on odour threshold)	WHO inhalation 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.	2B	Health effects of concern are carcinogenicity/genotoxicity and neurological effects, including effects on development. No teratogenic effects.
Sulphur dioxide CAS 7446-09-5	D		x	**x**		**x**	**x**				*125* µg m^{-3} 267 µg m^{-3} (15 min averaging time) (see also Main Report table 5.19)	EC Air Quality Daughter Directive 1999/30/EC EPAQS (1995): 267 µg m^{-3} (100 ppb) measured over a 15 minute averaging period	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.	3	SO_2 causes irritant effects to the respiratory tract (and also eyes) by stimulating nerves in the lining of the nose, throat and lung's airways. Sufferers of asthma are particularly sensitive to the effects of SO_2.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Tetrachloro-ethene CAS 127-18-4	D		x[1]	x		x	□				250 µg m^{-3}	WHO (2000a) Air Quality Guidelines: 0.25 mg m^{-3}	Inhalation HCV 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.	2A	Kidney effects (including proteinuria and haematuria) and CNS effects observed in dry cleaning workers. Non-genotoxic carcinogen; humans thought to be less sensitive than laboratory animals. Fetotoxicity and embryotoxicity at high dose levels but EU do not classify it as a 'substance toxic to reproduction'. There is some evidence though of increased spontaneous abortion in dry cleaning workers (COT 1997). Sullivan/Barlow classification for developmental/reproductive tox is group 1.
Thallium CAS 7440-28-0	D		x	x		x	x	x	□		0.25 µg m^{-3}	Extrapolation from oral HCV, TDI_{oral} 0.07 µgTl kg^{-1} bw day^{-1} based on USEPA oral RfD: 0.08 µg kg^{-1} bw day^{-1} for thallium carbonate, chloride & sulphate.	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.	NC	General toxicity. Some evidence for repro/dev tox – testicular effects and learning impairment. Not classifiable for carcinogenicity but evidence for genotoxicity. No animal studies for exposure via inhalation are available.
Tin CAS 7440-31-5	D		x	x		x	x	x	x	□	20 µg m^{-3} (inorganic tin). 1 µg m^{-3} (organic tin). TDI_{oral} 2 mg kg^{-1} bw day^{-1}	1% of HSE OES 8-h RP (HSE EH40/2002). 2 mg m^{-3} (inorganic tin) and 0.1 mg m^{-3} (organic tin). JECFA (1988, 33rd meeting) PTWI: 14 mg kg^{-1} bw day^{-1}	No OEL Summary available.	NC	General toxicity. No classification for carcinogenicity. Equivocal results for genotoxicity. Some evidence of devel. Toxicity No drinking water guideline developed for tin as it is not thought to represent a hazard to human health from this source (WHO, 1996).

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Toluene CAS 108-88-3	D		X	x		x	□				0.26 mg m^{-3}	WHO (2000a) Air Quality Guidelines: 0.26 mg m^{-3}	WHO's inhalation HCV is based on a LOAEL of 332 mg m^{-3} for effects on the CNS.	3	CNS toxicity is the primary human health concern. Some evidence that toluene can induce spontaneous abortion or congenital defects, but doses concerned were much higher than would normally be encountered from occupational or environmental exposure. Sullivan/Barlow repro/dev toxicity classification group 2.
Trichloroethene CAS 79-01-6	D		x^{1}	x		x	□				23 µg m^{-3}	WHO (2000a) Air Quality Guidelines: 23 µg m^{-3} for excess cancer risk of 10^{-5}. ID_{oral} is 6.6 µg kg^{-1} bw day^{-1} based on the assumption that there is the same risk for oral exposure as inhalation.	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.	2A	Trichloroethylene is classed as a probable human carcinogen (IARC Group 2A); also affects the liver and CNS. Feto- and embryotoxicity and adverse effects on reproductive performance were observed at very high doses. Clearly teratogenic below maternally toxic doses – Sullivan/Barlow class 1. Comparable guideline derived for CLR Tox paper
Trimethyl-benzene CAS 25551-13-7	D		x	x		x	x	x	x	□	*De novo* HCV to be derived	)		NC	Skin, eye and respiratory irritant. No studies or evaluation of carcinogenicity. Critical endpoint for setting OES is toxicity to reproduction HSE (EH64/D71, 1994) state that there are no differences in the toxicological profiles of the 3 individual isomers.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Vanadium CAS 7440-62-2	D		x	x		x	□				1 µg m^{-3} TDI_{oral} 5 µg kg^{-1} bw day^{-1}	WHO (2000a) Air Quality Guidelines: 1 µg/m^3 with 24 hr averaging time USEPA IRIS RfD, 9 µg kg^{-1} bw day^{-1} for vanadium pentoxide.	Inhalation HCV is based on a LOAEL of 20 µg m^{-3} for chronic upper respiratory tract symptoms observed in occupational studies.	NC	Vanadium dust (as pentoxide) is an irritant to the upper respiratory tract. General toxicity (e.g. retarded growth and hair loss) in oral studies. HSE (1999) has concluded that vanadium pentoxide has been demonstrated to be a somatic and presumed germ cell mutagen by "a mechanism which involves effects on the mitotic spindle rather than direct interaction with DNA."; they also considered that the mutagenic properties of vanadium compounds gave cause for concern over their possible carcinogenicity. NTP study (2002) indicates evidence of animal non-genotoxic carcinogenicity There is some evidence for reproductive and developmental toxicity although the interpretation is difficult due to other toxicity.
Vinyl chloride CAS 75-01-4	D		x[1]	x		x	□				1 µg m^{-3}	WHO (2000a) Air Quality Guidelines: 1 µg m^{-3}	Inhalation HCV is based on a unit risk estimate of 1 × 10^{-6} per µg m^{-3} for excess cancer risk.	1	CLR Tox collation has index dose equivalent to WHO risk estimate. Clear evidence that vinyl chloride is a genotoxic carcinogen; associated with hepatic angiosarcoma. Developmental toxicity in animals has been observed only at doses above those causing maternal toxicity. Sullivan/Barlow group 1.

Substance	Detected	Priority Class	S1	S2	S3	S4	S5	S6	S7	S8	HCV	Source of HCV	Basis for HCV	IARC Grp	Comments
Xylenes CAS 1330-20-7 for mixed isomers; 95-47-6 ortho 108-38-3 meta 106-42-3 para	D		x[1]				**x**				872 µg m^{-3}	WHO (1997): EHC: 0.2 ppm = 0.87 mg m^{3}	HCV 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}.	3	General toxicity, TDI_{oral} based on decreased body weight in rats. Embryotoxicity & teratogenicity (increased incidence of cleft palate) observed at highest doses tested, concurrent with maternal toxicity. . Group 2 classification by Sullivan/Barlow, but possibly should be Group 1 as effects observed below maternal toxicity. Draft CLR Tox report recommends a value of 220 µg m^{-3}

Note: D: Detected; (D): Detected in screening samples; C: Site contribution detected

x[1] – Draft TOX Reports and Environment Agency Project Manager consulted

Source Documents (and Committee websites) consulted:

S1 – TOX Reports 1-20 (including drafts, where available);
S2 – EPAQS Reports; websites (detailing reports and statements) of COM, COT, COC, COMEAP, ACTS & WATCH;
S4 – SCF & CSTEE website (including reports and 'outcome of discussions';
S5 – WHO Air Quality Guidelines (European and International versions); WHO EHCs; IPCS CICADs; WHO Guidelines for Drinking Water Quality; JECFA reports
S6 – Recommendations of selected national organisations: USEPA IRIS Database, ATSDR toxicological profiles, RIVM environmental quality standards
S7 – Recommendations for oral guidelines, e.g. TDIs, ADIs, RfDs etc. (sources consulted in order of hierarchy detailed above, i.e. S1-S6)
S8 – Occupational exposure standards/levels
Reference:

MA DEP (2002) UPDATED PETROLEUM HYDROCARBON FRACTION TOXICITY VALUES FOR THE VPH/EPH/APH METHODOLOGY
Massachusetts Department of Environmental Protection, Bureau of Waste Site Cleanup. Boston, MA, USA, 2002. Viewed online at:
http://www.state.ma.us/dep/ors/files/tphtox.htm January 2004.

Sullivan, Barlow & McElhatton Classifications:

Group 1 (*Chemicals of possible interest*) – Chemicals for which animal and/or human data demonstrate clear teratogenic potential (or potential for other important reproductive effects) at relatively low doses/exposures

Group 2 (*Chemicals of less likely interest*) – Chemicals for which animal and/or human data indicate that there may be teratogenic potential (or potential for other important reproductive effects) at higher doses exposures, usually in the presence of maternal toxicity

Group 3 (*Chemical of no/unlikely interest*) - Chemicals for which animal and/or human data demonstrate there is unlikely to be teratogenic potential (or potential for other important reproductive effects), or for which effects have only been demonstrated at very high dose levels

Unclassifiable (UC, *Chemicals with insufficient data*) – Chemicals for which it is not possible to assess teratogenic potential due to inadequate data

Toxicological evaluation of substances for which a *de-novo* project-specific benchmark was derived

De novo derivation of Health Criteria Value for:

2-ethyl-1-hexanol

JUNE 2004

Contents : 2-ethyl 1-hexanol

Executive Summary

2-Ethyl-1-hexanol (EH) is a colourless liquid with a mild odour reminiscent of the smell of roses. EH is used a food additive and industrial solvent and there is a fairly extensive database on ingested EH in a variety of animal species, and a more limited database on the effects of inhaled EH, including one recent human volunteer study. There are no major data gaps in the toxicity profile of EH, and sufficient inhalation data to identify a critical NOAEL in human volunteers (1.33 mg/m^3) and by extrapolation to derive a project-specific health criteria value (133 µg/m^3). This value compares well with HCVs derived solely from animal inhalation and oral data, and is 20-fold lower than a German building regulation 'lowest level of concern'.

A project-specific health criteria value (HCV) of 570 µg/m^3 (107 ppb) is proposed for 2-ethyl-1-hexanol.

1. Introduction

The general population is exposed to 2-ethyl-1-hexanol (EH) by ingestion (it occurs naturally in certain fruits in addition to its use as a flavouring agent) and by inhalation of its vapour (indoor air contains EH that has leached from plastics and carpets). The daily intake of EH ingested as a flavouring agent is approximately 0.65µg/kg bw/day (USA data). EH has been detected in expired air from normal healthy non-smoking urban residents with a geometric mean concentration of 4 µg/m^3 (Krotoszynski *et al*, 1979 cited in HSDB, 1996). In a study of West German homes in the 1980s, EH was found in concentrations ranging from <1 to 10 µg/m^3, with a mean of 2 µg/m^3 (Wallace *et al*., 1984 cited in HSDB, 1996).

2 Chemical and Physical Properties

The chemical 2-ethyl-1-hexanol (EH) is a colourless liquid with a mild odour reminiscent of the smell of roses. EH occurs naturally, or is prepared by petrochemical synthesis. It is used in the production of phthalates for rubber and PVC use, and is a metabolite of diethyl hexyl phthalate (DEHP). Data are summarised in Table 1.

Table 1: Physical and Chemical Properties of 2-ethyl-1-hexanol

Chemical name	2-ethyl-1-hexanol
CAS number	104-76-7
Synonyms	2-ethylhexyl alcohol; ethylhexanol; 2-ethylhexanol; [octyl alcohol]
Chemical formula	$C_8H_{18}O$
Molecular Weight	130.3
Boiling Point	184.34 deg C
Vapour Density	4.5 (AIR= 1)
Vapour Pressure	0.136 mm Hg @ 25 deg C
Conversion factor	1 ppm approx = 5.32 mg/m^3 @ 25 deg C, 760 mm HG 1 mmol/kg = 130 mg/kg

3 Toxicology

3.1 Toxicokinetics

3.1.1. Absorption, distribution and excretion

Rat studies indicate EH is well absorbed following oral administration. Elimination is rapid, occurring predominantly within the first 24 hours, with up to 98% of radiolabelled EH accounted for in expired carbon dioxide, urine and faeces within 96 hours (Deisinger *et al*., 1994). Approximately 5% of dermally applied EH is absorbed over the first 6 hours.

3.1.2. Metabolism

Rat studies indicate orally administered EH is principally metabolised to 2-ethylhexanoic acid and 2-ethylhexanoyl glucuronide, with subsequent rapid excretion in the urine (Deisinger *et al*., 1994).

3.2 Toxicity in experimental animals

Several studies were reported in the 1960s and 1970s on the toxic effects of EH orally administered to rats and mice. The majority of these studies administered EH by gavage, rather than in the feed. Other routes of administration included intraperitoneal and intravenous (rats and mice) and dermal (rabbit and guinea-pig). Acute short-term inhalation studies were also reported in mice, rats and guinea pigs, but no long-term studies of low-dose inhalation were located.

3.2.1 Acute exposure

An oral LD_{50} in the range 2.05–3.7 g/kg was reported in rats, and 2.0–6.4 g/kg in the mouse (Rowe & McCollister, 1982 cited in Astill *et al*., 1996a).

Of more relevance are the results of acute **inhalation** studies. Scala and Burris (1973, cited in Astill *et al*., 1996a) reported 8 hr exposures to 227 ppm (1200 mg/m^3) produced clinical signs of CNS depressions and moderate irritation of eyes, nose, throat and respiratory passages in mice, rats and guinea-pigs. All animals recovered within an hour of termination of exposure. Corneal injury with severe eye irritation and moderate skin irritation was reported in rabbits in acute exposure studies using undiluted EH (Smyth *et al*, 1969; Scala & Burris, 1973, both cited in JECFA, 1993).

3.2.2 Subacute exposure

Administration of EH by oral gavage for 11 days to rats and mice at doses of 1, 100, 330, 1000 and 1500 mg/kg/day had no effect at the lowest two doses (Astill *et al*, 1996a). Clinical signs were limited to the higher doses: 1000 mg/kg and above in rats and 1500 mg/kg in mice. These included ataxia and posturing; 4/10 female rats in the highest dose level became comatose and died. The lowest dose at which toxic effects were seen was 330 mg/kg, and included thymic atrophy and an increase in kidney weight in rats, and acanthosis with hyperkeratosis in mice. No effects were observed in rats administered 130 mg/kg/day for 14 days, although the number of animals in the study was low (Rhodes *et al*, 1984, cited in JECFA, 1993).

3.2.3 Subchronic exposure

Oral administration by gavage to mice and rats for 3 months showed toxic effects at doses of 250 mg/kg/day or above (Astill *et al*., 1996a). Toxic effects included increased liver and stomach-to-bodyweight ratios and serum enzyme changes.

Of direct relevance is a recent 90-day subchronic **inhalation** toxicity study in rats (Klimisch *et al*., 1998). Animals were exposed to EH at concentrations of 15, 40 and 120 ppm (equivalent to 80, 213 and 638 mg/m^3) for 6 h/day for 90 days. Animals were sacrificed after day 90. No adverse clinical effects were observed during the 90 days study period, including ocular effects. Post mortem pathology was unremarkable. Based on this study a NOAEL of inhaled EH of 120 ppm (638 mg/m^3) was established in rats.

3.2.4 Chronic exposure

A long-term oral gavage study in mice (18 months) and rats (24 months) reported a number of statistically significant adverse effects with a LOAEL of 50 mg/kg/day causing an increase in relative organ weights (Astill *et al.,* 1996b).

3.3 Toxicity in humans

3.3.1 Acute exposure

Male volunteers (n=24, mean age <30 years) were exposed to **inhaled** EH at concentrations ranging from 1.5 to 40 ppm (8 to 213 mg/m^3) for up to 4 hours (van Thriel *et al.* 2003). The study was a cross-over design with three exposure sessions with an interval of at least 2 days between sessions. The three exposure conditions were: 1.5 ppm (8 mg/m^3; constant for 4 h), 10 ppm (57 mg/m^3; hourly changing from 20 to 1.5 ppm) and 20 ppm (116 mg/m^3; hourly changing from 40 to 1.5 ppm). Exposure conditions were chosen to produce low, moderate and high sensory responses, and there was therefore no exposure dose equivalent to a no-observed effect level (NOEL). During exposure subjects rated symptoms (including nasal and ocular

irritation) on a severity scale from 0 ('not at all') to 5 ('very, very much'). Physiological effects (nasal airway resistance and substance P levels in nasal lavage) were recorded pre- and post-exposure. The purpose of the study was to look at correlations between self-reported and physiological effects, and EH was one of a number of solvents assessed.

Subjectively reported sensory irritation indicated a 'strong irritative potency of EH', although average ratings were only reported for sensory irritation for the medium (57 mg/m^3) and high (116 mg/m^3) dose levels, being scores of 0.69 and 0.99 respectively, on a scale of 0 to 5. Nasal airway resistance decreased after all exposures, but only reached statistical significance at the high exposure level (p=0.01), and dose-dependency could not be confirmed. Similarly, substance P secretion increased after each exposure, but only reached statistical significance at the highest exposure (p=0.01), and again dose-dependency could not be confirmed.

3.3.2 Subacute/subchronic exposure

No human studies were found.

3.3.3 Chronic exposure

A report on human exposure to unstated **inhaled** concentrations caused headaches, fatigue, intestinal disorders and dizziness (BIBRA, 1990 cited in Astill *et al*., 1996a).

3.4 Mutagenicity and carcinogenicity

EH in concentrations up to 1 µl/plate was found to be nonmutagenic in both the Salmonella/mammalian microsome mutagenicity (Ames) assay and the mouse lymphoma cell mutagenicity assay (Kirby *et al*., 1983).

EH was not found to be carcinogenic in a long-term rodent study at oral doses up to 750 mg/kg/day for 18 months in mice and 24 months in rats (Astill *et al*., 1996).

All studies identified by the Chemical Carcinogenesis Research Information System were negative for carcinogenicity (n=4) and mutagenicity (n=34; CCRIS, 2003).

3.5 Reproductive toxicity

No effect on rat testes germ cells was seen *in vivo* (male rats given oral doses of 2.7 mmol/kg/day for 5 days) or *in vitro* (incubation of germ cells with 0-1000 µM for 24 or 48 hr; Sjoberg *et al*., 1986 cited in JECFA, 1993).

3.6 Developmental toxicity

In the past there was concern that EH might be teratogenic for two reasons: (i) one of its metabolites, 2-ethylhexanoic acid, is an isomer of the teratogen valproic acid and (ii) EH is a major metabolite of DEHP in the rat, and DEHP is fetally toxic in the rat and teratogenic in the mouse. Studies on rodents exposed to EH have confirmed that EH is capable of teratogenic effects, but only when administered in high doses by the oral route. High concentrations administered as a vapour or dermally were not teratogenic to rats. Details of these studies are as follows:

Developmental toxicity following **inhalation** of EH was studied in rats (Nelson *et al*., 1989; Nelson *et al*., 1990). Pregnant dams were exposed to 850 mg/m^3 for 7 h/day during gestation days 1–19. This is the highest dose of EH that can be produced as a vapour. Dams were sacrificed on day 20. Mean feed consumption in the pregnant dams decreased significantly compared with controls ($p<0.05$), with a (non-significant) reduction in weight gain. There was no gross maternal toxicity, and no malformations observed in the fetuses. Of interest is a comparison made by these authors of their results with those of a developmental toxicity study in which EH was administered by oral gavage (Ritter *et al*., 1987 cited in Nelson *et al*., 1989). Oral administration of up to 500 mg/kg on gestation day 12 increased the number of malformed surviving offspring (1% at 250 mg/kg, 68% at 500 mg/kg), and these were similar to the number of malformations produced by approximately one-half the dose of valproic acid. Malformations included hydronephrosis, limb defects and tail defects, and were thought to be due to the metabolic breakdown product of EH, 2-ethylhexanoic acid (Ritter *et al*., 1986 & 1987, cited in JECFA, 1993). Nelson and colleagues estimated that their daily dose of 850 mg/m^3 would have been equivalent to an oral dose of 24 mg/kg i.e. EH is only capable of producing teratogenic effects at concentrations ten times higher than can be produced as a vapour.

Undiluted EH up to 3 ml/kg/day was administered by occluded dermal application for 6h/day to pregnant rats on days 6–15 of gestation. A dose of 3 ml/kg is equivalent to approximately 2520 mg/kg. The NOAEL for maternal toxicity was at least 2520 mg/kg/day, with no teratogenicity. Exfoliation and encrustation were seen at the dermal application site at doses of 840 mg/kg and above (Tyl *et al*., 1992).

Female mice administered 1525 mg/kg EH/day by gavage on days 6-13 of gestation experienced statistically significant reduced weight gain, and decreased numbers of viable litters; 30% of the dams died (Hardin *et al*., 1987, cited in JECFA and HSDB, 1996).

4 Existing Exposure Limits

TLV not established (ACGIH, 2003).

On the basis of a NOEL of 50 mg/kg/day from the long-term study in rats, and using a safety factor of 100, the Joint (WHO/FAO) Expert Committee on Food Additives established an Acceptable Daily Intake of 0–0.5 mg/kg (JECFA, 1993).

The German occupational MAK (maximum allowable concentration = 8 hr TWA) stands at 50 ppm (van Thriel *et al*., 2003). This is equivalent to 266 mg/m^3.

The (German) Committee for Health-related Evaluation of Building Products established the 'Lowest Concentration of Interest' (LCI) as 2700 µg/m^3. This was calculated as 1/100th the OEL, based on EH being non-carcinogenic. LCI values are 'considered as values to be used for the evaluation of certification of building products and not as indoor air limit values'. However, due to their derivation, LCI values 'represent an adequate expression of the criteria required in building regulations to safeguard against health risk caused by VOC/SVOC mixtures bearing in mind the amount of multi-compound mixtures emitted from building products into indoor air' (AgBB, 2002).

5 Discussion and derivation of health criteria value

The method used to derive a de novo Health Criteria Value (HCV) is based on the framework used for the derivation of soil contaminant intakes protective of human health (CLR9) published in 2002 (Defra & Environment Agency, 2002). Studies indicate that EH is a threshold chemical, and is not considered mutagenic or carcinogenic i.e. there is a finite dose below which adverse effects are not discernable (the NOAEL). For threshold chemicals it is considered reasonable to apply uncertainty factors to the NOAEL in order to extrapolate to the general population.

As the above report indicates, there are no major data gaps in the toxicological profile of EH. In particular, there is sufficient inhalation data to identify a critical $NOAEL_{INH}$ and to derive an inhalation Health Criteria Value for this substance based on these studies alone (summarized in Table 2).

Table 2. Inhalation studies on 2-ethyl-1-hexanol

Species	Exposure concentration	Duration	Adverse Effect

	mg/m3		
Human volunteers (male)	8, 57 and 116 mg/m^3	4 h	Sensory irritation at 53 mg/m^3 and above Decreased nasal airway resistance and increased substance P secretion at 8 mg/m^3 and above, but only reaching statistical significance at 116 mg/m^3
Mice, rats, guinea-pigs	1200	8 h	Reversible CNS depression and moderate sensory irritation
Pregnant rats	850	7h/day for 21 days	No maternal or foetal toxicity
Rats	80–638	6h/day for 90 days	NOAEL established of 638 mg/m^3 in rats

The human inhalation study carried out on healthy young male volunteers exposed to low (8 mg/m^3), moderate (57 mg/m^3) and high (116 mg/m^3) levels of EH reported statistically significant effects on nasal airway resistance and substance P secretion at the highest dose level only, and was unable to confirm dose-dependency. Subjective data on sensory irritation was only reported for the medium and high dose levels, mean scores being 0.69 and 0.99 respectively, on a scale of 0 to 5. Taking the moderate dose of 57 mg/m^3 as a lowest observed effect level (LOEL) and applying a factor of 10 to derive a NOAEL gives a concentration of 5.7 mg/m^3 for the critical sensory effect in healthy male volunteers. Applying an uncertainty factor of 10 to allow for the possibility of greater susceptibility to sensory irritation in other sectors of the population gives an exposure of 0.57 mg/m^3 below which it can reasonably be expected that no adverse health effects would occur on a short-term basis. This is equivalent to 570 µg/m^3.

Turning to the results of animal inhalation studies, a NOAEL of 638 mg/m^3 was established in rats exposed to EH for 6 h/day for 90 days (Table 2). Applying a factor of 4 to extrapolate to a 24-hour period gives a daily concentration of 160 mg/m^3. Applying an uncertainty factor of 10 to account for inter-species variability, and a further uncertainty factor of 10 to account for inter-individual variability results in an exposure of 1.6 mg/m^3 below which it could reasonably be expected that no adverse health effects would occur in humans. This is equivalent to 1600 µg/m^3. This 90-day study indicates that EH is not a cumulative toxin, and it is therefore reasonable to assume that the short-term tolerable exposure level derived from human volunteer studies (570 µg/m^3) would also be tolerable for exposures of a far longer time period.

It is of interest to look at oral data using the estimation given by Nelson *et al* (1989) for extrapolating oral to inhalation dosage (24 mg/kg equivalent to 850 mg/m^3). A LOAEL of 50 mg/kg/day was found in rats and mice, and applying an uncertainty factor of 10 to convert this to a NOAEL of 5 mg/kg/day and converting back to inhalation values gives a possible NOAEL of 177 mg/m^3. Again applying an uncertainty factor of 10 to account for inter-species

variability, and a further factor of 10 to account for inter-individual variability results in an exposure of 177 µg/m^3 below which it could reasonably be expected that no adverse health effects would occur in humans.

It should be noted that the HCV value derived from human volunteer studies (570 µg/m^3) is far more precautionary than the German Committee for Health-related Evaluation of Building Products 'Lowest Concentration of Concern' which currently stands at 2700 µg/m^3; this gives further confidence in the value being truly protective not just of young healthy males, but of the human population as a whole.

A de novo Health Criteria Value of 570 µg/m^3 (107 ppb) is proposed for 2-ethyl-1-hexanol.

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De novo derivation of Health Criteria Value for:

α-Terpinene

JUNE 2004

Contents : α-terpinene

Executive summary

Alpha-terpinene is a colourless liquid with the odour of lemons found in the essential oils of a number of plants and trees. It is used in a variety of fragrance products, and as a flavouring food additive. There is an extremely limited toxicological database on α-terpinene, and the current project-specific health criteria value (HCV) is derived from two studies: a human volunteer inhalation study, and a 9-day fetal toxicity study in the rat. In June 2004 JECFA will publish the results of a full evaluation of α-terpinine, and the proposed provisional HCV should be revisited in the light of this.

A project-specific Health Criteria Value of 390 µg/m^3 (70 ppb) is proposed for α-terpinene.

Introduction

α-Terpinene is a monoterpene found in the essential oils of a large number of plants, including cardamon, marjoram, coriander, the nutmeg family and the Australian tea tree. It has the odour of lemons and is a constituent of a variety of fragrance products. α-Terpinene is also used as a flavouring food additive.

α-Terpinene database

There is an extremely limited database on α-terpinene. Two peer-reviewed publications were located: a developmental toxicity study in the rat, and a human volunteer study on odour thresholds and nasal pungency. In addition, a few 'grey literature' reports (Material Safety Data Sheets etc) were located. Alpha-terpinene is a minor constituent (10%) of tea tree oil and there is a larger database on the toxicology of this oil. However, tea tree oil is made up of a mixture of 14 substances, of which the major constituent (40%) is terpinen-4-ol. For the purposes of the current evaluation, the tea tree oil database was not considered relevant. The Joint FAO/WHO Expert Committee on Food Additives recognise the very limited α-terpinene database, and list this substance for evaluation at its 63rd meeting in June 2004. Publication of their report will inform any future updates of this *de novo* Health Criteria Value derivation.

2 Chemical and Physical Properties

α-Terpinene is a colourless liquid with a pleasant odour of lemons.

Table 1: Physical and Chemical Properties of α-terpinene

Chemical name	ALPHA-TERPINENE
CAS number	99-86-5
Synonyms	1-Methyl-4-isopropyl-1,3-cyclohexadiene; terpilene; p-Mentha-1,3-diene
Chemical formula	$C_{10}H_{16}$
Molecular Weight	136.26
Boiling Point	173 to 175°C
Specific Gravity	0.840 @ 25°C
Vapour Density	4.7 (AIR=1)
Vapour Pressure	ca. 0.8 mmHg @ 20°C
Conversion factor	1 ppm = 5.56 mg/m^3

3 Toxicology

3.1 Toxicokinetics

No toxicokinetic data were located.

3.2 Toxicity in experimental animals

An unsubstantiated oral LD_{50} of 1680 mg/kg in the rat was given in a data safety sheet on α-terpinene[6]. It is possible this value is taken from a 3-page Toxicity Profile on alpha- and gamma-terpinene carried out by BIBRA in 1992. In a Toxline abstract of this profile[7], the following statement is given:

> The alpha- and gamma-terpinenes were moderately irritant to rabbit skin. Gamma-terpinene may have caused a skin sensitization reaction in one individual. Alpha-terpinene was of moderate acute oral toxicity in rats whilst gamma-terpinene was of low acute oral and dermal toxicity in rats and rabbits respectively. A brief unsubstantiated comment notes that alpha-terpinene has caused liver and blood effects.

There is one published study on the fetal toxicity of alpha-terpinene in the rat, and this is described in detail in Section 3.5 below.

3.3 Toxicity in humans

3.3.1 Acute exposure

A study on the differences between selected terpenes on odour threshold and nasal pungency was carried out in anosmics and normosmics (Cometto-Muniz *et al*., 1998). Study numbers were low. The normosmic group comprised four non-smoking individuals (two men, two women, age range 25–58 years). Odour and nasal pungency threshold was determined by a series of forced-choice procedures. Stimuli were presented via 270-ml squeeze bottles containing 30 ml of solution. Three dilution steps were included: undiluted chemical (100% v/v), 33%, 11% and 3.7%. The lowest concentration chosen five times in a row compared with a blank stimulus was taken as the threshold. The threshold for α-Terpinene-induced nasal pungency was reached at dilution step 0, i.e. undiluted chemical (approx 1500 ppm; 8.34 g/m^3), while the odour threshold was reached at 1.4 ppm (7.8 mg/m^3).

3.3.2 Subacute/subchronic/chronic exposure

No longer-term human studies were located.

6 Available [April 2004] at http://www.camd.lsu.edu/msds/a/alphaterpinene.htm
7 Available [April 2004] at http://www.toxnet.nlm.nih.gov/

3.4 Mutagenicity and carcinogenicity

No mutagenicity studies were located.

3.5 Reproductive/developmental toxicity

Araujo and colleagues (1996) evaluated the embryotoxicity of α-terpinene in the rat. Doses of 30, 60, 125 and 250 mg/kg were given by gavage on days 6 to 15 of gestation, and caesarian sections performed on day 21. The two highest doses tested were found to be maternally toxic (reduction in maternal weight gain). No other signs of maternal toxicity were found. There were concomitant effects on embryofoetal development at 125 and 250 mg/kg (reduced foetal body weight and delayed ossification). Delayed ossification was seen at 60 mg/kg, but there were no skeletal abnormalities at 30 mg/kg. The authors conclude that the oral NOAEL for α-terpinene-induced embryofoetotoxicity can be set at 30 mg/kg.

4 Existing Exposure Limits

None located.

5 Discussion and derivation of health criteria value

It must be stressed that a Health Criteria Value derived from data in only two short-term exposure studies is very provisional, and should be revisited once the outcome of the June 2004 JECFA evaluation is known.

The mono-terpinenes are natural constituents of essential oils and have been used as fragrance substances for many years (α-terpinene has a pleasant odour of lemons). It could be argued that the lack of a toxicity database reflects the fact that these essential oils have not shown any adverse health effects at exposure levels inhaled for their odour. Indeed, in healthy non-smoking adults, there is a 100-fold difference between the odour threshold (7.8 mg/m^3) and the threshold level required to detect nasal pungency (approx 8.34 g/m^3), giving further weight to the proposal that levels at the odour threshold are not harmful to health. Starting from the odour threshold level to derive a health criteria value, a safety factor of two can be included to protect against odour nuisance, with a further safety factor of 10 to account for individual variation. This gives a level of 390 µg/m^3 below which it could reasonably be assumed that there is minimal risk to health.

The route of exposure in the short-term rat study is oral, and α-terpinene may have different health end-points for different intake routes. In order to carry out route-to-route extrapolation from oral to inhalation exposure it is normal to have acute toxicity data by both routes (however limited) in order to make an initial comparison of relative potencies on a particular marker of toxicity. This is clearly not possible in the case of α-terpinene, and therefore any extrapolation from the NOAEL for embryotoxicity in the rat (30 mg/kg) to an equivalent inhalation intake makes the assumption that the target for α-terpinene toxicity is systemic, and is the same whatever the exposure route. A recent paper on validation of extrapolations from oral to inhalation route found a general unreliability in the methods used, and the authors urged route-specific studies only be considered for inhalation exposure risk evaluations (Rennen *et al*., 2004). Despite these reservations, it is of interest to extrapolate from the oral 30 mg/kg NOAEL in the rat to derive an equivalent inhalation dose in humans, as follows:

If the absorption ratio is 1 i.e. oral absorption is assumed to be equal to inhalation absorption, an oral NOAEL dose of 30 mg/kg in the rat would be equivalent to 30.2 mg/m^3 by inhalation in the rat (using correction factors for rat of bodyweight 0.348kg [taken from Araujo et al, 1996] and inhalation rate 0.35 m^3/day [inhalation volume 0.24 L/min] taken from Rennen *et al.,* 2004). Including a safety factor of 10 for interspecies, and 10 for intra-species variation reduces this value to 302 µg/m^3, which is not markedly different than the value derived from the odour threshold human volunteer study.

A *de novo* project-specific inhalation Health Criteria Value of 390 µg/m^3 (70 ppb) is proposed for α-terpinene.

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De novo derivation of health criteria value for dimethyl sulphide and dimethyl disulphide

JUNE 2004

Contents : Dimethyl sulphide and dimethyl disulphide

Executive Summary

Dimethyl sulphide (DMS) and dimethyl disulphide (DMDS) are similar substances, both chemically and biologically, therefore they have been considered together in the derivation of a health criteria value (HCV) for each. DMS and DMDS are unpleasant smelling liquids. The odour thresholds are 6.5 μg/m^3 and 15.2 μg/m^3, for DMS and DMDS, respectively. The data available to characterise the toxic effects of DMS and DMDS are extremely limited. There are only limited data for acute, sub-chronic, and genotoxic effects of exposure to these two substances, and none for carcinogenic, reproductive and developmental toxicity.

DMS is thought to be rapidly oxidised, once in the systemic circulation, to the sulfoxide and subsequently the sulfone, which are the major urinary metabolites. DMDS is thought to be reduced to a thiol, which then enters the same metabolic route as DMS. According to limited studies using experimental animals the majority of these substances is thought to be exhaled unchanged.

Acute toxicity following exposure, by inhalation, is thought to be qualitatively similar to that of hydrogen sulphide. The effects are coma and respiratory failure. The LC_{50}s for DMS and DMDS were 40250ppm (104 g/m^3) and 805ppm (3.14 g/m^3), respectively. In several studies the test substances were irritating to the eyes and mucous membranes.

No effects were observed in Wistar rats given doses of DMS up to 250 mg/kg bw/day by oral intubation for 14 weeks. In a six month inhalation study with rats the LOAEL was 5 mg/m^3. It is not clear from the limited report of the study what the effects at this exposure level were, but they are stated to be reversible. At 25 mg/m^3 significant effects on haemoglobin and blood chemistry were observed. A study of paper pulp workers revealed a possible association between exposure to sulphides and disruption of iron metabolism.

Based on a limited Ames test and a mouse lymphoma assay DMS and DMDS are not genotoxic. There are no data regarding the carcinogenicity of these substances.

There are no data regarding the reproductive or developmental toxicity potential of DMS or DMDS.

The HCV is based on a sub-chronic rat inhalation study of DMS. By taking the LOAEL of 5 mg/m^3 from this study and applying the standard uncertainty factor of 100 for interindividual and interspecies variation, as well as an additional factor of 10 to compensate for the use of a LOAEL, an exposure level of 5 μg/m^3 is derived. Due to the similar toxicity profiles of DMS

and DMDS this exposure level applies to both substances ,and total exposure to them should be considered against this level.

The limit of 5 μg/m^3 is below the odour thresholds and should be protective against the potential irritant effects of DMS and DMDS.

A *de novo* Health Criteria Value of 5μg/m^3 is proposed for dimethyl sulphide and dimethyl disulphide.

1 Introduction

A search for major reviews of data regarding the toxicity of dimethyl sulphide and dimethyl disulphide in humans and experimental animals was conducted. The most recent and comprehensive internationally peer-reviewed review, entitled 'Simple aliphatic and aromatic sulphides and thiols' conducted by the World Health Organization as part of its 'Food additives series' confirmed the limited data on DMS and DMDS (FAO/WHO, 2000)[8]. There were no Concise International Chemical Assessment Documents (CICADs), Environmental Health Criteria (EHC) monographs, International Agency for Research on Cancer (IARC) monographs or reviews by the Agency for Toxic Substances and Disease Registry (ATSDR) available. A small number of additional papers were identified from a search of the ToxNet[9] databases.

2. Chemical and physical properties

Dimethyl sulphide (DMS), CAS number 75-18-3, is a volatile, colourless liquid with an unpleasant smell. It is sparingly soluble in water and soluble in alcohol and ether. The odour threshold is reported to be 2.5ppb (6.5 μg/m^3[10])(Lundberg, 1987).

Dimethyl disulphide (DMDS), CAS number 624-92-0, is a liquid with an unpleasant smell. The odour threshold for this compound is 7.5ppb (15.2 μg/m^3[11])(Lundberg, 1987).

3 Toxicology

3.1 Toxicokinetics

The data on the toxicokinetics of DMS and DMDS are limited. Following subcutaneous injection in rabbits, 9% of a dose of DMS was excreted in urine in the form of dimethyl sulfoxide and 9% in the form of dimethyl sulfone, while the remainder was thought to have been exhaled unchanged. When DMDS was given to mice by intraperitoneal injection, DMDS, DMS and methyl mercaptan were identified in exhaled air (Lundberg, 1987). These results are supported by the limited review of DMS conducted by Opdyke (1979).

8 *FAO/WHO (2000) Safety evaluation of certain food additives and contaminants, WHO Food additives series 44.* *http://www.inchem.org/documents/jecfa/jecmono/v44jec09.htm* *at April 2004*
9 http://toxnet.nlm.nih.gov/ at April 2004
10 1ppm dimethyl sulphide = 2.582mg/m^3
11 1ppm dimethyl disulpide = 3.9mg/m^3

In a safety evaluation of 137 flavouring agents, JECFA (FAO/WHO, 2000)[12] sub-grouped agents according to the position of the sulphur atoms. They were able to summarise the metabolic pathways by subgroup. DMS was categorised as a 'simple sulphide' 'thioether', which was said to be rapidly oxidised, once in the systemic circulation, to the sulfoxide and subsequently the sulfone, which are the major urinary metabolites. The oxidation is catalysed by cytochrome P450 enzymes and flavin-containing monooxygenases. Sulfoxides can be metabolised back to the thioether by several enzymes and gut microflora. Whereas, conversion to the sulfone is an irreversible metabolic reaction in mammals.

FAO/WHO[1] includes DMDS in the subgroup of 'simple disulphides'. The reduction of disulphides is believed to be extensive, with catalysis by thioltransferases and chemical exchange with glutathione, thioredoxin, cysteine and other endogenous thiols. The reduction described would result in the formation of low molecular mass thiols, which would be metabolised by the pathways described for 'simple sulphides'.

3.2 Toxicity in experimental animals

3.2.1 Acute exposure

Tansy *et al*. (1981) investigated the LC_{50} of reduced-sulphur compounds, including DMS and DMDS. Groups of Sprague-Dawley rats (5 animals/sex/dose) were exposed (whole body) to either DMS (0, 800 to 48000ppm) or DMDS (0, 500 to 1581ppm) for four hours, then observed for a further 14 days. The LC_{50}s for DMS and DMDS were 40250ppm (104 g/m^3) and 805ppm (3.14 g/m^3), respectively. According to the authors these results were in agreement with the results of other studies. The cause of death and symptoms were not reported.

In an inhalation study in which rats were exposed to 0.1 to 5.5% (1,000-55,000 ppm; 2.58-1,420 g/m^3) DMS in air for up to 30 minutes. Slight irritation of the eyes and mucous membranes was observed at 0.5% (5,000 ppm; 13 g/m^3), and at 5.5% the rats died within 15 minutes (Lundberg, 1987).

However, in a study in which rats were exposed to DMDS in air at concentrations of 0.2 (2,000 ppm; 7.8 g/m^3) to 0.7% (7,000 ppm; 27.3 g/m^3) for 30 minutes, irritation was noted at the lowest dose. At 0.7% DMDS animals died within 25 minutes (Lundberg, 1987).

In a study that investigated the possibility of using DMS as an analogue of hydrogen sulphide, the LD_{50} following intraperitoneal injection was 537 mg/kg (30 times less than the LD_{50} for

12 FAO/WHO (2000) Safety evaluation of certain food additives and contaminants, WHO Food additives series 44. http://www.inchem.org/documents/jecfa/jecmono/v44jec09.htm at April 2004

hydrogen sulphide). Animals died of abrupt respiratory failure. DMS induced a reversible comatose state (ED_{50} 813 mg/kg)(Reiffenstein *et al.*, 1992).

3.2.2 Subchronic and chronic exposure

Selyuzhitskii (1972; reported in Opdyke, 1979) investigated the effects of exposing groups of rats (10 groups of 15 animals) to DMS over a range (not given) of concentrations in air. At exposure levels of 25 mg/m^3 for six hours/day for six months, several effects were noted: body weight gain was reduced, increase in heart weight, disorders of corticosteroid distribution in adrenal tissue, decreased oxygen consumption and carbon dioxide elimination, decreased catalase activity, decreased methaemaglobin and phospholipids levels in blood, increases in pyruvic acid, lactic acid and thiol groups in whole blood and in tissue homogenates, and increased cholesterol levels in blood serum. The statistical or toxicological significance of these effects were not reported or discussed. The exposure level of 5 mg/m^3 was the lowest dose to produce temporary changes in this study.

In a study in which Wistar rats (15 animals/sex/dose) were administered reasonably low levels (0 (control), 2.5, 25 and 250 mg/kg bw/day) of DMS by oral intubation for 14 weeks, no body weight changes or adverse effects were observed. In addition, organ weight, haematological and histopathological examination did not reveal any compound-related changes (Butterworth *et al.*, 1975). The NOAEL for this study was >250 mg/kg bw/day.

In a poorly reported, old study, no toxic effects were observed in rats that had been exposed to 100ppm DMDS (390 mg/m^3), 6 hours/day for 20 days (Lundberg, 1987). These results suggest that DMDS is considerably less toxic than DMS, which is surprising given the information on their acute toxicities. All of the inhalation studies are from secondary sources that have limited the study details reported to that shown above. Therefore it is difficult to determine which are the most reliable. Overall, it is believed that DMDS is more acutely toxic than DMS, and it would therefore follow that DMDS is also more toxic following prolonged exposure. However, there are insufficient data to verify this.

3.3 Toxicity in humans

In a study of 18 workers in a pulp and paper plant, the relationship between exposure to continuous, low levels of organic sulphides and disturbances of the synthesis of haem and erythrocytes was investigated (Klingberg *et al.*, 1988). Five of the workers were exposed to 'high' peak levels of sulphides, although information on the concentration was not available, nor was there any speciation with regard to the sulphides. A minor, but not statistically significant, decrease in the activities of the enzymes delta-aminolevulinic acid synthetase and haem synthase in reticulocytes was reported. However, the concentration of iron and transferrin

were elevated, and the concentration of ferritin was low in comparison to the referents. The authors stated that this combination of effects could not occur spontaneously, and concluded that exposure to low levels of sulphides could disturb iron metabolism, by inhibition of intracellular uptake of iron in the reticuloendothelial system (Klingberg *et al*., 1988). The concentrations of sulphides to which workers were exposed was not included in the report. In addition, there was no discussion regarding the speciation of the sulphides, or the likely contribution of different sulphide species to the effects observed.

In humans, DMS has been shown to lack allergenic properties in maximisation tests (Lundberg, 1987).

3.4 Mutagenicity and carcinogenicity

DMDS was not mutagenic in *Salmonella typhimurium* TA98, 100 and 102 with and without metabolic activation (Aeschbacher *et al*., 1989).

In a study reported in abstract form, DMS was not mutagenic in the mouse lymphoma assay (Dooley *et al.,* 1987).

No further studies on the genotoxic potential, or studies relating to the carcinogenic potential of DMS or DMDS are available.

3.5 Reproductive and developmental toxicity

No data on the reproductive hazards of DMS or DMDS are available.

4 Existing Exposure Limits

There are no existing exposure limits for DMS or DMDS. Lundberg (1987) concluded that there were no data on which to base a dose-response relationship to these two sulphides, and concluded that the critical effect was discomfort caused by odour. The odour thresholds are 6.5 μg/m^3 and 15.2 μg/m^3, for DMS and DMDS, respectively (Lundberg, 1987).

5 Discussion and derivation of the health criteria value

The critical effect of DMS and DMDS is discomfort caused by odour (Lundberg, 1987), and irritation to eyes and skin. There is also evidence, from a limited inhalation study in rats, of

possible effects following sub-chronic exposure to DMS (Selyuzhitskii, 1972; reported in Opdyke, 1979). There are no data regarding the carcinogenic potential of these sulphides; however, they do not appear to be genotoxic. There are also no data regarding the reproductive or developmental toxicity of these compounds.

Based on the available data, which is limited in quality and quantity, it is difficult to derive a robust exposure limit. The LOAEL in the sub-chronic rat inhalation study was 5 mg/m^3 DMS. It is not clear from the limited report of the study what the effects at this exposure level were, but they are stated to be reversible. At the next highest dose of 25 mg/m^3 several effects were observed, but unfortunately the consistency of these effects across the groups of animals tested, and the statistical significance of the effects was not discussed. This study, although not well reported, provides the best available basis for setting an exposure level to assess the potential for health effects following releases of DMS and DMDS from landfills. By taking the LOAEL of 5 mg/m^3 for DMS following six months repeated exposure and applying the standard uncertainty factor of 100 for interindividual and interspecies variation, as well as an additional factor of 10 to compensate for the use of a LOAEL. An exposure level of 5$\mu g/m^3$ is derived for DMS. The limit of 5 $\mu g/m^3$ is below the odour threshold and should be protective against the potential irritant effects of DMS.

It is more difficult to set a long-term exposure limit for DMDS as acute toxicity data suggest that this substance is more toxic than DMS, but there are no reliable repeated dose inhalation studies available, and that which is available, seems to contradict the acute inhalation toxicity findings. Thus, for the purposes of this assessment it has been deemed adequate to propose the same HCV for DMS as that for DMDS as the large uncertainty factor should allow for any real toxicological differences at low environmental levels.

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De novo derivation of Health Criteria Value for:

Methyl mercaptan

JUNE 2004

Contents : Methyl mercaptan

Executive Summary

Methyl mercaptan is a colourless gas with the smell of rotten cabbages. The acute toxic effects are similar to those of hydrogen sulphide – mucous membrane irritation, headache and vomiting. There is a limited database on subchronic exposure to methyl mercaptan,, no chronic data and no data on possible carcinogenic or developmental effects. The project-specific Health Criteria Value for methyl mercaptan (2 µg/m^3) has been derived from data from a subchronic exposure study in rats (serum enzyme changes with a LOEL of 4 mg/m^3) together with data on the odour threshold, and is more precautionary than the acceptable annual air concentration proposed by New York State (3.3 µg/m^3) and the maximum acceptable ambient level in North Dakota (10 µg/m^3).

A project-specific health criteria value (HCV) of 4 µg/m^3 (2 ppb) is proposed for methyl mercaptan.

1. Introduction

Methyl mercaptan is a colourless gas, with the smell of rotten cabbages. It occurs naturally in the body, where it is mainly formed by transamination of methionine. It is found in certain foods (nuts, cheese, onions) and is released from decaying organic matter, including decaying wood in pulp mills and waste matter at sewage plants. It is present in the breath of persons with liver damage, and is released by periodontal bacteria and is one of the gases responsible for halitosis (Ratcliff & Johnson, 1999). Ambient levels have been reported at 4 ppb (>8.2 $\mu g/m^3$), with a half-life of approximately 4 months (ATSDR, 1992). Levels in a primary school in Japan were reported to be 2.8 ppb (5.7 $\mu g/m^3$; Okita, 1970 cited in ATSDR, 1992). Workplace concentrations ranged from 0.02 to 15 ppm in Finnish pulpmills (0.04 to 29.4 mg/m^3; Kangas et al, 1984 cited in HSDB, 2001) and 0.55 to 1.06 ppm at a Japanese river lockgate (1 to 2 mg/m^3; Okita, 1970 cited in ATSDR, 1992).

1.1 Methyl mercaptan database

There is a limited toxicological database on inhaled methyl mercaptan in animal species, and little data in humans. There is one report of accidental death in a worker who had been cleaning tanks of methyl mercaptan for a week. In addition to original publications, this report draws on two documents: the Agency for Toxic Substances and Disease Registry toxicological profiles (ATSDR, 1992) and the National Library of Medicine's Hazardous Substances Databank on methyl mercaptan (HSDB, 2001).

2 Chemical and Physical Properties

Methyl mercaptan is a colourless gas with a characteristic odour of rotting cabbages. It is used in the manufacture of jet fuel, poultry feed and pesticides. The odour threshold in air is 3.14 $\mu g/m^3$ (0.0016 ppm; Amoore and Hautala, 1983, cited in ATSDR, 1992). Methyl mercaptan is used to add odour to some odourless hazardous gases. Data are summarised in Table 1.

Table 1: Physical and Chemical Properties of methyl mercaptan

Chemical name	Methyl mercaptan
CAS number	74-93-1
Synonyms	methanethiol; thiomethyl alcohol; methyl sulfhydrate;

	mercaptomethane; thiomethanol
Chemical formula	CH_3SH
Molecular Weight	48.1
Boiling Point	6°C
Vapour Density	1.66 (AIR=1)
Vapour Pressure	225 kPa at 20°C
Conversion factor	1 ppm = 1.96 mg/m^3 ; 1 mg/m^3 = 0.51 ppm

3 Toxicology

3.1 Toxicokinetics

3.1.1. Absorption, distribution and excretion

No studies were located on the absorption, distribution or excretion of methyl mercaptan following inhalation or dermal exposure, although it is said to be 'easily absorbed by the lungs, and is transported in the blood bound to protein, and in the erythrocytes' (Lundberg, 1987). Injection of radiolabelled methyl mercaptan into rats showed distribution to plasma proteins, liver, intestinal mucosa, lungs, kidneys, spleen and testes after 6 hours (Canellakis and Tarver, 1953 cited in ATSDR, 1992). Intraperitoneal administration of ^{35}S-methyl mercaptan to rats gave a half-life of 1.21 hr for the metabolism to sulphate, and 8.47 hr for the elimination of sulphate in urine (Derr & Draves, 1984).

3.1.2. Metabolism

Radiolabelled methyl mercaptan incubated in whole (human) blood was trapped within 30 minutes, and distributed between plasma and erythrocytes. It was concluded that methyl mercaptan is oxidised by erythrocytes to formic acid and sulphite or sulphate. One to two percent is incorporated into protein, and 1% metabolised to dimethyl sulphide by the enzyme methyltransferase (Blom & Tangerman, 1988). Following intraperitoneal injection, methyl mercaptan is metabolised to carbon dioxide and sulphate in rats (Derr & Draves, 1984).

3.2 Toxicity in experimental animals

3.2.1 Acute exposure

Rats were exposed to increasing levels of methyl mercaptan gas for 4-h periods to determine the inhalatory LD_{50} (Tansy *et al*., 1981). The LD_{50} was established at 1.32 g/m^3 (675 ppm).

Mice were exposed 7 hours/day, 5 days/week for 3 months to methyl mercaptan by nose-only inhalation at 114, 258 or 512 ppm and sacrificed 24, 48 or 72 hours later. These doses are equivalent to 225, 500 and 1000 mg/m^3 respectively. Adverse effects included shallow

breathing and hypoactivity at 500 mg/m^3, and 5/15 mice died before sacrifice at the highest dose level. Mice treated at the lowest concentration (223 mg/m^3) 'appeared normal throughout the experiment' (EPA 2001 study, cited in HSDB, 2001).

Inhalation LC_{50} in mice ranged from 3.33 ppm over 2 hours (6.53 mg/m^3) to 1664 ppm over 4 hours (3.26 g/m^3; Lewis, 1996 and Bingham et al., 2001 both cited in HSDB, 2001). [Note: It is likely that the wide discrepancy is a typographical error, and the Lewis data should have been 6.53 g/m^3 not 6.53 mg/m^3].

3.2.2 Subacute exposure

No information in animals was located.

3.2.3 Subchronic exposure

Rats were exposed to 2, 17 and 57 ppm methyl mercaptan gas for 7 hr/day, 5d/week for 3 months (Tansy et al., 1981). These exposures are equivalent to 4, 33 and 112 mg/m^3 respectively. Final body weights were reduced in all exposure groups compared with controls, reaching statistical significance at the highest concentration. Total serum bilirubin was raised, and serum lactate dehydrogenase reduced, at all exposures. There was evidence of pathological changes in the liver at all three dose levels. These results are consistent with hepatitis and liver damage, although none of the serum changes were dose-related at the 95% confidence level (HSDB, 2001).

Mice experienced severe toxicity when exposed to 588 mg/m^3 (300 ppm) 2 hr/day, 3days/week for 2 months. 6/11 animals died after 15 exposures, and all animals had died after 25 exposures (Sandmeyer, 1981 cited in Lundberg, 1987).

3.2.4 Chronic exposure

No information in animals was located.

3.3 Toxicity in humans

3.3.1 Acute exposure

The acute toxic effects of methyl mercaptan are believed to be similar to those of hydrogen sulphide – mucous membrane irritation, headache and vomiting. A group of students accidentally exposed to approximately 4 ppm (7.6 mg/m^3) for several hours reported headaches and vomiting, which disappeared 24 hours after cessation of exposure (Sandmeyer, 1981 cited in Lundberg, 1987). In a case report of a 53-year old man who emptied tanks of methyl mercaptan for a week, irreversible coma was followed by respiratory arrest and death (Shults et al., 1970 cited in ATSDR, 1992).

3.3.2 Subacute/subchronic exposure

No information in humans was located.

3.3.3 Chronic exposure

Two studies of occupational exposure at paper pulp mills were located. Workers complained of headaches, eye and nasal irritation, and had a greater number of sick leaves than controls; however it is not possible to separate out adverse effects due to methyl mercaptan from those due to co-exposure to hydrogen sulphide and dimethyl sulphides (HSDB, 2001).

A case study was reported of a 59-year old plumber's assistant exposed to 'high' methyl mercaptan levels when pumping out school kitchen grease traps for 15 years without the use of protective clothing or respirators. Symptoms included throbbing headache, nausea and vomiting, eye irritation, chest tightness, wheezing, dizziness and diplopia (double vision) (Garrettson & Warren, 1990).

3.4 Mutagenicity and carcinogenicity

Mice were exposed for 6 hours to methyl mercaptan by nose-only inhalation at 114, 258 or 512 ppm and sacrificed 24, 48 or 72 hours later, and rate of micronuclei formation in bone marrow erythrocytes measured (EPA 1983 study, cited in HSDB, 2001). These dose levels are equivalent to 225, 500 and 1000 mg/m^3 respectively. At all dose levels no statistically significant effects were found on micronuclei frequency, compared with controls.

In the 3-month exposure study in rats, nodular hyperplasia was detected in liver sections from 1/31 rats exposed to 2 ppm (4 mg/m^3) and 3/31 rats in the 57 ppm (112 mg/m^3) group, and a hepatic carcinoma was detected in a liver from a rat in the group of 31 rats exposed to 17 ppm (33 mg/m^3). However, hyperplastic nodules were also found in control rats, and the authors concluded that the hepatic carcinoma was a singular event and it was not possible to conclude that it was treatment-related (Tansy et al., 1981).

3.5 Reproductive and developmental toxicity

No information in humans or animals was located. When injected intraperitoneally into male rats, a small amount (8.5%) distributed to the testes (Canellakis and Tarver, 1953, cited in ATSDR, 1992).

4 Existing Exposure Limits

Because methyl mercaptan is known to cause adverse health effects in exposed people, there are a number of occupational regulations and guidelines. These are summarised in Table 2.

Table 2. Regulations for methyl mercaptan (ATSDR, 1992; HSDB, 2001).

Occupational permissible level	Countries
[a]TWA 0.5 ppm (1 mg/m^3)	Australia, Belgium, Denmark, Finland, France, Germany, Ireland, Netherlands, Poland, Switzerland, UK, USA
TWA 10 ppm (20 mg/m^3)	Philippines, Thailand, Turkey
AEGL(1)[b] not recommended due to insufficient data; AEGL(2) 59 ppm (up to 30 min), 47 ppm (1 hr), 30 ppm (4 h), 19 ppm (8 hr) AEGL(3) 120 ppm (10 min), 86 ppm (30 min), 68 ppm (1 h), 43 ppm (4 h), 22 ppm (8 h) ACGIH TLV 0.5 ppm (0.98 mg/m^3) DFG MAK TWA 0.5 ppm (1 mg/m^3)	USEPA website www.epa.gov [June 2004] Technical support document in preparation ACGIH, 2003
[c]REL 0.5 ppm (1 mg/m^3) 15 min ceiling	USA (NIOSH, 2001).
Acceptable ambient air concentration	
3.3 µg/m^3 over 1 year	New York State, USA 1989 [Ref in ATSDR, 1992, p50]
16.0 µg/m^3 over 24 hours	Virginia State, USA- 1989 [Ref in ATSDR, 1992, p50]
Maximum acceptable ambient level	
10 µg/m^3	North Dakota, USA 1990 [Ref in ATSDR, 1992, p50]

[a]TWA=8 hr Time Weighted Average; [b]AEGL(1) is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure. AEGL(2) is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape. AEGL(3) is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death; [c]REL=Recommended Exposure Limit.

5 Discussion and derivation of health criteria value

Although a number of animal studies were located on the adverse health effects of high doses of inhaled methyl mercaptan, there was no chronic toxicity data, and no data on possible carcinogenic or developmental effects. The following HCV derivation is therefore based on the 3-dose level subchronic exposure study in rats (Tansy et al., 1981). Although not statistically significant, there was evidence of a number of effects at the lowest dose tested: 4 mg/m^3 (2 ppm). These included a reduction in body weight, and alterations in serum enzymes. Since this is a "minimum LOAEL" level i.e. the effects were not dose-related, and did not reach statistical

significance, it would be very precautionary to use a safety factor of 10 to derive a NOAEL from this value. However, in light of the lack of long-term data it is reasonable to be very precautionary, and a NOAEL of 0.4 mg/m^3 (0.2 ppm) is therefore postulated. Applying the standard 100-fold safety factor to extrapolate to humans gives a value of 4 µg/m^3 (2 ppb) below which it could reasonably be expected that no adverse health effects would occur. This value is in the same range as the odour threshold for methyl mercaptan (3.2 µg/m^3) and the annual acceptable annual air concentration in New York State (3.3 µg/m^3).

It is noted that this value is lower than the approach we have adopted elsewhere of using 1% of the current UK OES value, which in this case would lead to a HCV of 5ppb. However, it is felt that on balance, the 4 µg/m^3 (2ppb) HCV value is preferred as it would provide further population protection against odour nuisance.

A project-specific de novo Health Criteria Value (HCV) of 4 µg/m^3 (2ppb) is proposed for methyl mercaptan.

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De novo derivation of health criteria value for stibine

JUNE 2004

Contents : Stibine

Executive Summary

Stibine (antimony trihydride) is a colourless gas with a disagreeable, hydrogen sulphide-like odour, and it is unclear whether the odour threshold is sufficiently low to act as a warning and thus to prevent adverse health effects.

Stibine exposure gives rise for concern as it appears to have a similar acute haemolytic toxicity to arsine. One of the early signs of stibine toxicity in man is haemoglobinuria. Effects on the morphology of erythrocytes appears to take place within minutes of exposure. The dataset on the toxicology of stibine is incomplete, with few studies, most of which are old and poorly described. There are no chronic, carcinogenicity, mutagenicity or reproductive toxicity studies. Among the few reasonably described studies there is a LOAEL for renal tubular dilation in guinea pigs and rats of 799 mg/m^3 (160 ppm). However, other studies find that concentrations lower than this LOAEL are lethal (in cats and dogs) and haematotoxic in guinea-pigs.

As the database is so poor, the best available basis for deriving a 24-hour TWA long-term limit is the current UK HSE OES, and US ACGIH TLV-TWA exposure value for an 8-hour working day of 0.51mg/m^3 (0.1ppm: see Table 4.1). An uncertainty factor of 100 is applied to take account of the wider community variability, the longer term environmental exposure duration versus the 40 year working lifetime, 8 hour/day, 5 day/week of the OES, and also the poor quality of the dataset. This leads to a HCV of 5$\mu g/m^3$ (0.001ppm).

A *de novo* Health Criteria Value of 5$\mu g/m^3$ (0.001ppm) is proposed for stibine.

1 Introduction

The toxicology of stibine (antimony trihydride) is reviewed with a view to deriving a health criteria value (HCV) for routine and occasional exposure by inhalation. A search for major reviews of data regarding the toxicity of stibine in humans and experimental animals was conducted. The most relevant, recent and comprehensive international reviews (ATSDR, 1992 and IARC, 1989) were retrieved.

2 Chemical and physical properties

Stibine, CAS Number 7803-52-3, antimony trihydride, SbH_3, is a colourless gas with a disagreeable, hydrogen sulphide-like odour. It is unclear whether the odour threshold is sufficiently low to provide a warning and thus to prevent adverse health effects. It is formed by the action of acids on metal antimonides, reduction of Sb compounds or the electrolysis of acidic or basic solutions where Sb is present in the cathode. Stibine slowly decomposes into metallic Sb and hydrogen. It is readily and sometimes violently oxidised by air to form Sb trioxide and water (ATSDR, 1992).

3 Toxicology

3.1 Toxicokinetics

The only data on the toxicokinetics of stibine comes from a study of workers involved in the production of lead batteries (Kentner *et al*., 1995). During this process three Sb compounds are used: Sb trioxide (in the casting of grids) and Sb oxide plus stibine (in the formation of the lead plates). Blood and urine Sb concentrations were measured in seven workers from the grid-casting area and 14 from the formation area at the beginning and end of the working week and at the beginning and end of a shift. At the end of a shift, the median exposure for the casting workers was 4.5 μgSb/m^3 and 12.4 μg/m^3 for the stibine-exposed formation workers. All exposures were more than 10 times lower than the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) 8-hour Time Weighted Average (TWA) of 0.51 mg/m^3 (0.1 ppm) for stibine.

The study concluded that the two Sb compounds displayed virtually equal absorption and renal elimination. The significant correlation between Sb air:blood concentrations and air:urine concentrations could form the basis for appropriate biological exposure limits for occupational Sb exposure (Kentner *et al*., 1995).

3.2 Toxicity in experimental animals

3.2.1 Acute exposure

Early studies in cats and dogs showed that single exposure to 200–225 mg/m^3 (40–45 ppm) stibine for 1 h was dangerous to life with death occurring within a few h to 1 day (Browning, 1969).

In guinea pigs, changes appeared in the morphology of erythrocytes within a few minutes of exposure, the characteristic appearance resembling crenation (Webster, 1946). These cells appear to precede the haemoglobinuria seen in most animals exposed to 325 mg/m^3 (65 ppm) for 1 h. This was followed in a few days by profound anaemia. At concentrations of 460 mg/m^3 (92 ppm), animals died after 2–6 days with crystals and casts in renal tubules (Browning, 1969).

Acute 30-min exposure of rats and guinea pigs to stibine led to serious effects including increased mortality and pulmonary oedema with a lowest observed adverse effect level (LOAEL) of 1395 mg/m^3 (280 ppm), and a no observed adverse effect level (NOAEL) of 799 mg/m^3 (160 ppm). For less serious effects, there was a LOAEL for renal tubular dilation of 799 mg/m^3 (160 ppm). Eye irritation was also seen in these experiments (Price *et al*., 1979; ATSDR, 1992). There is no explanation for why rats are less sensitive than cats and dogs.

Death in mice occurred rapidly at 51000 mg/m^3 (10000 ppm), in a few hours at 510 mg/m^3 (100 ppm) and in 4 to 8 h after a 15 min exposure at 153–255 mg/m^3 (30–50 ppm)[13].

3.2.2 Subchronic and chronic exposure

There are no subchronic or chronic studies reported with stibine.

3.3 Toxicity in humans

The physiological action of stibine greatly resembles that of arsine. The early symptoms of acute exposure are headache, weakness, irregular pulse, nausea, lumbar pain, jaundice and haematuria. Like arsine, stibine is haemolytic and one of the early signs of overexposure to stibine in man may be haemoglobinuria (Clayton & Clayton, 1994).

No clear-cut case of fatal poisoning in man has been reported, perhaps because of the usual concomitant exposure with arsine, phosphine, hydrogen sulphide or lead (Clayton & Clayton, 1994).

Chronic occupational exposure to Sb (generally Sb oxide) is most commonly associated with 'Sb pneumoconiosis', which is characterised by the presence of dust in the lungs and correlates with time of exposure to Sb (ATSDR, 1992).

3.4 Mutagenicity and carcinogenicity

No mutagenicity data are currently available for stibine. There are no International Agency for Research on Cancer (IARC) or EPA classifications for stibine[14].

There are animal data indicating that exposure to Sb oxide leads to an increase in lung tumours in rats (IARC, 1989). Therefore Sb oxide is evaluated as *possibly carcinogenic to humans* (Group 2B) with *sufficient evidence for carcinogenicity in animals* but *inadequate evidence in humans* (IARC, 1989). There are no *in vivo* genotoxicity studies with Sb oxide and the single *in vitro* assay with *Bacillus subtilis* was positive for DNA damage. In general, Sb compounds are negative for gene mutation and positive for chromosomal damage.

13Hazardous Substances Databank (HSDB), S*tibine*, National Library of Medicine's TOXNET system available [March 2002] at http://toxnet.nlm.nih.gov

14 Overall Evaluations of Carcinogenicity to Humans as evaluated in IARC Monographs Vol. 1–79, available [March 2002] at http://193.51.164.11/monoeval/crthall.html

3.5 Reproductive and developmental toxicity

There are no available data on the reproductive or developmental effects of stibine.

4 Existing Exposure Limits

Table 4.1 US and UK Exposure guidelines and limits for stibine

Agency	Exposure guideline	Exposure limit
ACGIH, 1989 (ACGIH, 2000)	TLV 8-h TWA	0.51 mg/m^3 (0.1 ppm)
NIOSH, 1990 (ATSDR, 1992)	REL 10-h TWA	0.5 mg/m^3 (0.1 ppm)
	IDLH	25 mg/m^3 (5 ppm)
OSHA, 1989 (ATSDR, 1992)	PEL 8-h TWA	0.5 mg/m^3 (0.1 ppm)
HSE, 2002 (HSE, 2002)	OES Long-term exposure limit 8-h TWA RP	0.52 mg/m^3 (0.1 ppm)
	OES Short-term exposure limit 15-min RP	1.6 mg/m^3 (0.3 ppm)

TLV, Threshold limit value; TWA, Time weighted average; REL, Recommended Exposure Limit
IDLH, Immediate Danger to Life and Health; PEL, Permissible Exposure Limit; OES, Occupational Exposure Standard, Long-term exposure limit for an 8-h time waited average reference period (TWA RP); Occupational Exposure Standard (OES), Short-term exposure limit for a 15-min reference period (RP)

In addition, the USA AIHA has set two further occupational permissible levels, Emergency Response Planning Guidelines (ERPG; ATSDR, 1992):

ERPG (2) 2.5 mg/m^3 (0.5 ppm; without serious, adverse effects) for up to 1 hour

ERPG (3) 7.5 mg/m^3 (1.5 ppm; not life threatening) up to 1 hour exposure

5 Discussion and derivation of the health criteria value

Stibine appears to have a similar acute toxicity to arsine (haemolysis). The toxicological data for stibine are incomplete with no chronic, carcinogenicity, mutagenicity or reproductive toxicity studies. There are some acute animal data giving no effect levels but many of the other studies are quite old. The LOAEL for renal tubular dilation in guinea pigs and rats was 799 mg/m^3 (160 ppm). If this figure was used to set the present US and UK exposure limits, this would give an uncertainty factor of 1600 for the 8h TWA of 0.51 mg/m^3 (0.1 ppm). With factors of 10 for interspecies conversion, 10 to protect sensitive individuals and 10 to convert a LOAEL to a NOAEL then there is a factor of 1.6 for lack of complete toxicity data, which would be just adequate. However, it is more likely that the HSE value was based on the ACGIH figure and adopted at a time when the UK used the ACGIH TLV values as a primary source of guidance values for the control of airborne substances. The basis for the US ACGIH TLV is stated as irritation and blood effects, although which studies this decision was based on is unclear. The exposure guidelines, set in 1957, also appear to take into account a study from 1935, where stibine exposure in a telephone office of less than 5.1 mg/m^3 (1 ppm) was not considered to

constitute a health hazard (Haring & Compton, 1935). The scientific foundation for this statement is unclear.

As the database is so poor, the best available basis for deriving a 24-hour TWA long-term limit is the current UK HSE OES, and US ACGIH TLV-TWA exposure value for an 8-hour working day of 0.51mg/m^3 (0.1ppm: see Table 4.1). An uncertainty factor of 100 is applied to take account of the wider community variability, the longer term environmental exposure duration versus the 40 year working lifetime, 8 hour/day, 5 day/week of the OES, and also the poor quality of the dataset. This leads to a HCV of 5μg/m^3 (0.001ppm).

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De novo derivation of Health Criteria Value for :

Trimethylbenzenes

June 2004

Contents : Trimethylbenzenes

Executive Summary

Trimethylbenzenes (TMBs) are colourless liquids found in petroleum distillation products, and are readily absorbed through the lungs and distribute throughout the body with the potential for accumulation in adipose tissue. The main toxic effects of TMBs are thought to be central nervous system impairment, altered haematological profile, increased risk of asthma symptoms and irritation to the respiratory and gastrointestinal tracts and the skin.

There is a limited toxicological database on TMBs, and the current project-specific Health Criteria Value (HCV) is derived from a LOAEL for neurobehavioural effects in rats of 125 mg/m^3.

A *de novo* Health Criteria Value of 625 µg/m^3 (125 ppb) is proposed for three isomers of trimethylbenzene.

1 Introduction

Trimethylbenzenes (TMBs) are colourless liquids. They occur in petroleum distillation products such as white spirits, high flash naphthas, high aromatics and gasoline. The proportions of TMBs in these products vary from 5 to 50%. TMBs are also used as paint thinners and solvents and in the industrial manufacture of plasticisers, dyes, resins and other chemicals (Järnberg, 1996). General exposure to TMBs probably arises from vehicle emissions or fuel, while the use of traditional white spirit probably accounts for some occupational exposure (Järnberg, 1996).

1.1 Trimethylbenzenes database

The database for trimethylbenzenes (TMBs) is limited and incomplete, with no carcinogenicity studies. Studies on reproductive toxicity are on the C9-fraction of petroleum distillate, which contains mainly TMBs, or on the 1,2,4-TMB isomer. In addition to recent original papers on the neurotoxicity and toxicokinetics of TMBs, the current derivation draws on a set of authoritative reports from the US Hazardous Substances Data Bank (for trimethylbenzenes, 1,2,4-trimethylbenzene and mesitylene, last updated in May 2003, August 2002 and August 2002, respectively). Three structural isomers are considered in this review for the purposes of deriving a Health Criteria Value (1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene).

2 Chemical and Physical Properties

Trimethylbenzenes (TMBs) are colourless liquids. The physico-chemical properties of the three structural isomers considered in this review (1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene) are given in Table 2.1 (data from HSDB, 2003).

Table 2.1: Physical and Chemical Properties of trimethylbenzenes

Chemical names and synonyms; CAS numbers	1,2,4-trimethylbenzene (1,2,4-TMB, pseudocumene) CAS number 95-63-6 1,2,3-trimethylbenzene (1,2,3-TMB, hemimellitene) CAS number 526-73-8 1,3,5-trimethylbenzene (1,3,5-TMB, mesitylene) CAS number 108-67-8
Chemical formula	C_9H_{12}
Molecular Weight	120.19
Boiling Points	Range 164.7 to 176.1^{o}C.
Melting Points	Range -44.7 to –25.4 ^{o}C
Vapour Pressure	2.10 mmHg at 25^{o}C (for TMB)
Odour threshold	1.97 mg/m^3 (0.4 ppm) for 1,2,4-TMB.
Conversion factor	1 ppm = 4.92 mg/m^3 ; 1 mg/m^3 = 0.2 ppm

3 Toxicology

The three isomers of TMB exhibit quantitative and, in a few cases, qualitative differences in health effects (Ritchie, 2003). The reproductive toxicology data summarised in this report are from studies carried out on the C9-aromatic hydrocarbon fraction of petroleum distillation, which is formed primarily of the three TMB isomers and ethyltoluenes.

3.1 Toxicokinetics

3.1.1. Absorption and Distribution

In the occupational setting, absorption of TMB may occur after exposure through the inhalation or dermal routes; absorption occurs readily through the inhalation route and is much slower through intact skin (Kostrzewski, 1997). There is extensive accumulation in adipose tissues (Järnberg, 1996). TMB present in the blood stream is largely (85%) transported bound to red blood cells (US EPA, 1994).

3.1.2 Metabolism and excretion

Metabolism of TMBs occurs by side-chain oxidation to form alcohols and carboxylic acids; these are then conjugated with glucuronic acid, glycine or sulphates before excretion into the

urine. In an experimental study in rats, following a single oral dose of 1,2,4-TMB at 1200 mg/kg, urinary metabolites consisted of approximately 43.2% glycine, 6.6% glucuronic and 12.9% sulphuric acid conjugates while, in rabbits, oral dosing with 438 mg/kg/day for 5 days resulted in two principal urinary metabolites — 2,4-dimethylbenzoic acid (2,4-DMBA) and 3,4-dimethyl hippuric acid (3,4-DMHA; US EPA, 1994).

In a human volunteer inhalation study the main metabolic pathway was shown to be aliphatic hydroxylation of one of the methyl groups followed by further oxidation to dimethylbenzoic acids, which then underwent conjugation with glycine to form dimethylhippuric acid (Järnberg, 1997). In another study, in which nine male human volunteers were exposed to 11 mg/m^3 (2.2 ppm) of 1,2,4-TMB, alone or in combination with 300 mg/m^3 of white spirit vapour, there were indications that, under conditions of co-exposure, the metabolic elimination of TMB was reduced (Järnberg, 1997). In another study it was also shown that co-exposure to TMB as part of a hydrocarbon mixture may alter clearance rates in humans (Ritchie, 2001).

3.2 Toxicity in experimental animals

3.2.1 Acute exposure

Mice exposed to 40 000 or 45 000 mg/m^3 (8000–9000 ppm) of 1,2,4-TMB by inhalation (duration not recorded) showed loss of righting response and reflexes. In another study, rats and mice exposed by inhalation to a coal tar distillate containing about 70% of 1,3,5-TMB and 1,2,4-TMB showed no pathological change after exposure to 8856–9840 mg/m^3 for up to 48 h continuously (HSDB, 2002a).

Two studies investigated oral toxicity of 1,2,4-TMB in rats. One study reported an LD_{50} of 6.0 g/kg in male rats, while the other reported an LD_{50} of 3.55 g/kg in males and 3.28 g/kg in female rats (HSDB, 2002a). A minimal lethal dose of 1.5–2.0 g/kg was reported in rats following intraperitoneal injection of 1,3,5-TMB (HSDB, 2002b).

No studies were identified on the acute dermal toxicity of TMB.

In an acute inhalation study in rats, rotarod performance and pain sensitivity were tested immediately after a 4-h exposure to TMBs at concentrations of 1230–9840 mg/m^3 (250–2000 ppm). Exposure to each of the isomers resulted in dose-related disturbance in rotarod performance and a decrease in pain sensitivity: EC_{50} values for rotarod performance were as follows: for 1,2,4-TMB, 4693 mg/m^3 (95% CI, 3891–5493 mg/m^3; 954 ppm); for 1,3,5–TMB, 4738 mg/m^3 (CI, 3675–5453 mg/m^3; 963 ppm); and for 1,2,3-TMB, 3779 mg/m^3 (CI, 2832–4615 mg/m^3; 768 ppm). The EC_{50} values for pain sensitivity were higher than those noted for

rotarod performance but again demonstrated that the most pronounced functional disturbance occurred with the 1,2,3-isomer (Korzak, 1996).

3.2.2 Subchronic and chronic exposure

No effects were reported for rats exposed by inhalation to a mixture of TMBs at 8364 mg/m^3 (1700 ppm) for 10 to 21 days. However, rats exposed to this dosage of an isomeric mixture of TMB for 4 months showed decreased weight gain, lymphopenia and neutrophilia (HSDB, 2002a).

When rats were given 1,2,4-TMB orally at 0.5 or 2 g/kg/day, 5 days a week for 4 weeks, all rats exposed to the high dose died, as did one rat from the low dose group. No other effects were reported (HSDB, 2002a). In a study on 1,3,5-TMB, rats were orally dosed at 0, 50, 200 or 600 mg/kg/day, 5 days a week for 90 days (stated to be equivalent to 7 days/week dosing at 0, 36, 143 or 429 mg/kg/day). The lowest-observed-adverse-effect level (LOAEL) was 429 mg/kg/day, based on increased serum phosphorus level, and the no-observed-adverse-effect level (NOAEL) was 143 mg/kg/day (OEHHA, 2001).

In a subchronic experiment reported by Korzak and Rydzynski (1996), rats exposed by inhalation to 1,2,4- or 1,2,3-TMB, for 6 h a day, 5 days per week for 3 months, at levels of 123, 492 or 1230 mg/m^3 (25, 100 or 250 ppm), as in the acute experiment reported above, showed dose-related decreases in rotarod performance and pain sensitivity; the effects of 1,2,3-TMB, again, were more pronounced. Indeed, while pair-wise analysis showed no statistically significant difference between controls and rats exposed to 1,2,4-TMB at the lowest dose, a no-observed-effect level (NOEL) was not identified for the 1,2,3-isomer.

In a neurobehavioural study, rats were exposed by inhalation to 1,2,4-TMB at 123, 492 or 1230 mg/m^3 (6 h/day, 5 days/week) for 4 weeks and subjected to a bank of neurobehavioural tests 3 to 8 weeks after the last exposure (Gralewicz, 1997). Rats exhibited significant deficits in learning of passive and active avoidance, but these effects were not dose-related in that significant effects were seen at 123 and 492 mg/m^3, but not at the highest dose of 1230 mg/m^3. The authors believe their results were not an experimental artifact, but acknowledge that further studies are required to confirm or refute their findings.

3.3 Toxicity in humans

3.3.1 Acute effects

Direct contact with liquid 1,2,4-TMB is irritating to the skin and breathing the vapour is irritating to the respiratory tract, possibly leading to pneumonitis (US EPA, 1994). Ingestion may cause irritation of the oral mucous membranes and oesophagus, and nausea or vomiting

may occur. Similar findings have been reported for the 1,3,5-isomer (US EPA, 1994). However, according to ACGIH (ACGIH, 2001), levels of 172–246 mg/m^3 (35–50 ppm) were not associated with complaints of mucous membrane irritation.

Breathing high concentrations of 1,2,4-TMB vapour (24 600–44 280 mg/m^3; 5000–9000 ppm) causes headache, fatigue and drowsiness. A concentration of 5000 ppm is roughly equivalent to 221 mg/kg, assuming a 30 min exposure period. Nausea and anxiety may also develop (US EPA, 1994). Asthmatic bronchitis can be provoked by exposure to 1,2,4-TMB, and chemical pneumonitis or noncardiogenic pulmonary oedema may develop. Thrombocytopenia, leukopenia, mild anaemia and altered blood coagulation profile have also been reported following acute exposure. Both 1,3,5- and 1,2,4-TMB are established central nervous system depressants. Acute symptoms include central nervous system depression and headache (HSDB, 2002a, b).

Ten male human volunteers were exposed, in turn, to each of the three isomers of TMB for 2 h while undertaking light exercise (Järnberg, 1996). Subjects exposed on four occasions to 123 mg/m^3 (25 ppm) reported no discomfort (degree of irritation and CNS symptoms rated on a 100-mm visual analog scale). Similarly, in a study on eight male volunteers exposed for 8 h to TMB isomers at concentrations ranging from 5 to 150 mg/m^3 (1-30 ppm) subjects showed no abnormalities in routine clinical examinations (including neurological and haematological) after exposure and at 3-month intervals after the experiment (Kostrzewski, 1997).

3.3.2 Subchronic and chronic exposure

Occupational exposure to TMB has been associated with altered haematological profiles and increased risk of asthma-like symptoms and dermatological conditions, in addition to effects on the central nervous system (HSDB, 2002a, b).

Among painters working for several years with a solvent containing greater than 50% 1,2,4-TMB and 30% 1,3,5-TMB (as well as 1,2,3-TMB and various other methylbenzenes) at stated overall exposure levels of 49–295 mg/m^3 (10–60 ppm), higher incidences of chronic asthma-like bronchitis, anaemia and altered clotting times occurred, compared with non-exposed controls from the same factory, although a level of statistical significance was not attained. Although increased levels of hypochromatic anaemia and altered blood coagulation profiles were noted in these workers, these haematological effects could have been due to contamination of the solvent with benzene (ACGIH, 2001). The painters working with the solvent containing greater than 50% 1,2,4-TMB and 30% 1,3,5-TMB reported significantly

higher incidences of vertigo, headaches and drowsiness (OEHHA, 2001) and nervousness, tension and anxiety (HSDB, 2002a,b) than did controls.

Long-term exposure to 1,2,4- or 1,3,5-TMB is also associated with defatting of the skin, with consequent dermatological changes, such as irritation, dryness and cracking (HSDB, 2002a,b).

3.4 Mutagenicity and carcinogenicity

There is little information on the mutagenicity and no reliable human or experimental data on the carcinogenicity of TMBs; they have not been assessed for carcinogenicity by either the International Agency for Research on Cancer or the US Environmental Protection Agency.

Only the 1,2,3-isomer has shown a positive result in a gene mutation *Salmonella sp*. assay (Ames test) and then only in the absence of metabolic capacity (S9 liver extract). Induced sister chromatid exchanges have been noted for all three isomers (strongest response with 1,2,3-TMB) in mouse bone marrow cells (Ritchie, 2003).

In a study on rats given 1,2,4-TMB orally at 800 mg/kg/day, 4 days per week, for 104 weeks no effects on tumour profile were identified. However, the study had many methodological flaws and is considered unreliable (OEHHA, 2001).

3.5 Reproductive toxicity

No information on the potential reproductive toxicity of TMB in humans has been found.

No effect on fecundity or fertility was noted in rats treated dermally with up to 0.3 mℓ/rat/day of mixed isomers of TMB, 4–6 hours/day, 5 days/week for one generation (US EPA, 1994)

A three-generation study was conducted on CD rats exposed to C9-fraction by inhalation at doses of 0, 100, 500 or 1500 mg/kg/day (100 –1500 ppm), for 6 hours a day, 5 days per week (US EPA, 1994). There was evidence of both parental and reproductive toxicity in all treated groups. Parental effects included reduced body weight, increased salivation, hunched posture, aggressive behaviour and death. Indicators of adverse reproductive effects comprised reduced litter size and reduced pup body weight. Developmental toxicity (including possible developmental neurotoxicity) was also evident. The LOAEL, based on reproductive toxicity, was 100 mg/kg/day.

An associated developmental study was conducted on CD-1 mice exposed by inhalation to the C9-fraction at 0, 210, 1100 or 3200 mg/kg/day (100–1500 ppm) for 6 hours a day from days 6 to 15 of gestation (US EPA, 1994). There was evidence of developmental toxicity at all dose

levels. Indicators of adverse developmental effects included increased frequency of whole litter resorption, reduced pup viability and malformations (i.e. cleft palate, unossified sternum and reduced skull ossification). The LOAEL, based on developmental toxicity, was 210 mg/kg/day.

4 Existing Exposure Limits

A number of inhalation exposure limits have been recommended for the TMBs (Table 4.1); these relate to all isomers or mixtures of isomers.

Table 4.1 Exposure guidelines and limits for trimethylbenzenes

Agency	Exposure guideline	Exposure limit	References
ACGIH	TLV 8-h TWA	123 mg/m^3 (25 ppm)	ACGIH, 2001
EC	8-hr TWA for 1,2,4- and 1,2,3-TMB	100 mg/m^3 (20 ppm)	EC, 2000
HSE	IOELV 8-h TWA	125 mg/m^3 (25 ppm)	HSE, 2002
NIOSH	REL 10h-TWA	125 mg/m^3 (25 ppm)	US EPA, 1994
OSHA	PEL 10-h-TWA	125 mg/m^3 (25 ppm)	OSHA[15]
Polish MAC Values Commission (date unspecified)	OES MAC	100 mg/m^3 (20 ppm)	Kostrzewski *et al*., 1997

IOELV, Indicative Occupational Exposure Limit Value; MAC, Maximum Allowable Concentration; OES, Occupational Exposure Standard; REL, Recommended Exposure Limit; TLV, Threshold Limit Value;
TWA, Time-Weighted Average;

5 Discussion and derivation of HCV

Toxicological background

There are insufficient animal studies to establish an inhalation NOAEL for all three TMB isomers. Two animal studies established a LOAEL of 492 mg/m^3 (100 ppm) for reproductive effects in the rat, and developmental effects in mice. In a 4-week study in rats, impaired passive avoidance behaviour was noted with 1,2,4-TMB at 123 mg/m^3 (25 ppm). In a 3-month study in rats, although statistically significant effects on neurobehaviour were only seen in those exposed to 1,2,4-TMB at levels above 125 mg/m^3, statistically significant neurobehavioural impairment was noted with the 1,2,3-isomer at this exposure level. Given these findings, it would appear precautionary to regard a level of approximately 125 mg/m^3 (25 ppm) as the LOAEL in rats for TMB-induced neurotoxicity. Also, whilst acknowledging the limited nature of the data set, there is some evidence for the genotoxicity of the TMB isomers suggesting that it is appropriate to keep levels as low as reasonably possible.

Currently, all occupational exposure limits identified are set at approximately 125 mg/m^3 (25 ppm) as 8–10 h TLV-TWAs. Generally, the principle concern on which these have been based is the potential long-term neurotoxicity of TMB. This level is also considered protective

15 US OSHA *Chemical Sampling Information Trimethylbenzene* [December 2003] at http://www.osha.gov/dts/chemicalsampling/data/CH_273880.html

for other potential health effects of TMB, including exacerbation of asthma and the potential for induction of blood dyscrasias, which have been observed following short-term or repeated exposure.

Studies on human volunteers with exposures up to 150 mg/m^3 (30 ppm) indicate that approximately steady-state toxicokinetics are established within a working week, when exposure is for approximately 8 to 10 h per day, and a NOAEL of 150 mg/m^3 (30 ppm) was established for acute exposure in males. Chronic human data comes from an epidemiological study on painters which reported symptoms suggestive of central nervous system depression following long-term exposure to 49–295 mg/m^3 (10–60 ppm) of a solvent mixture containing over 80 % TMB. The haematological changes observed might be related to contamination of TMB with benzene, but this has not been firmly established.

Given these considerations, using the LOAEL from animal studies of approximately 125 mg/m^3 and applying a safety factor of 100 (10 for use of a LOAEL and 10 for interspecies variation) gives an exposure limit value of 1.25 mg/m^3 (0.25 ppm). The robustness of the available data on the toxicity and metabolism of this chemical in humans suggests that application of a further safety factor for human variability of 2 would be reasonable. This reduces the value to 625 µg/m^3 (125 ppb). This level is approximately 80-fold lower than the lowest long-term exposure level which may be responsible for symptoms suggestive of CNS depression in painters, and 240-fold lower than the NOAEL observed in acute (8 h) exposure studies in human volunteers. It is also 160-fold lower than the current most precautionary occupational guideline.

A *de novo* Health Criteria Value of 625 µg/m^3 (125 ppb) is proposed for three isomers of trimethylbenzene.

6 References

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Appendix 11 : Comparison of estimated exposure against health criteria values

Although estimates of population exposure were developed as set out in this section, it was found that these were not sufficiently reliable to use in the study. Consequently, the information presented in Volume 1 does not use the data set out in this section.

Table A11.1 : Site A: Substances for which estimated exposure is greater than 20% of HCV

WINTER SUMMER

Substance	CAS no.	HCV[A] (µg/m^3)	'Averaging time' 1% occupational or oral[B]	Baseline[C]		Modelled period mean concentration: Maximum at any receptor[D]		Modelled period mean concentration: Average 0 - 2 km[E]						Modelled period mean concentration: Average 2 - 7 km[F]					
				Conc. (µg/m^3)	Baseline as % of HCV	95%ile (µg/m^3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV
Benzene	71-43-2	3.2	Annual	8.83E-01	27.6%	4.6E-01	14.2%	1.8E-02	0.6%	0.0E+00	0.0%	9.1E-02	2.9%	2.4E-04	0.0%	0.0E+00	0.0%	1.2E-03	0.0%
Benzene	71-43-2	3.2	Annual	1.44E-01	4.5%	4.5E+00	139.6%	5.0E-01	15.6%	7.6E-03	0.2%	2.0E+00	61.7%	1.5E-02	0.5%	2.2E-04	0.0%	5.8E-02	1.8%
1,2 Dichloroethane	75-09-2	0.36	Long term/lifetime	3.59E-01	99.8%	3.6E-01	101.1%	1.4E-02	3.9%	0.0E+00	0.0%	7.3E-02	20.3%	1.8E-04	0.1%	0.0E+00	0.0%	9.5E-04	0.3%
Vinyl chloride	75-01-4	1	Long term/lifetime	2.52E-01	25.2%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Stibine	7803-52-3	17		3.46E+01	204%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Dimethyl sulphide	75-18-3	5		1.16E+01	232%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%

A = Health Criteria Value
B = Basis for deriving HCV
C = Estimated background level at site
D = Estimated period mean concentration based on maximum at any receptor
E = Estimated period mean concentration at distance 0-2 km from centre of site
F = Estimated period mean concentration at distance 2-7 km from centre of site

WINTER SUMMER

Table A11.2 Site B : Substances for which estimated exposure is greater than 20% of HCV

Substance	CAS no.	HCV[A] (µg/m^3)	'Averaging time', 1% occupational or oral[B]	Baseline[C]		Modelled period mean concentration: Maximum at any receptor[D]		Modelled period mean concentration: Average 0 - 2 km[E]						Modelled period mean concentration: Average 2 - 7 km[F]					
				Conc. (µg/m^3)	Baseline as % of HCV	95%ile (µg/m^3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV
Chromium (assuming 25%CrVI)	7440-47-3	0.0025	Long term/lifetime	6.13E-04	24.5%	4.3E-03	170%	8.0E-04	32.0%	0.0E+00	0.0%	3.5E-03	140%	1.8E-05	0.7%	0.0E+00	0.0%	8.0E-05	32%
Cadmium	7440-43-9	0.005	Long term/lifetime	2.33E-04	4.7%	2.7E-03	**54.7%**	1.5E-04	3.1%	0.0E+00	0.0%	8.0E-04	15.9%	6.4E-06	0.1%	0.0E+00	0.0%	3.3E-05	0.7%
Cobalt	7440-48-4	0.1	Long term/lifetime	2.77E-02	27.7%	2.7E-02	26.6%	5.7E-03	5.7%	5.9E-05	0.1%	2.2E-02	22.4%	1.3E-04	0.1%	4.5E-06	0.0%	4.6E-04	0.5%
Nickel	7440-02-0	0.02	Long term/lifetime	9.32E-04	4.7%	1.5E-02	75.0%	9.1E-04	4.6%	0.0E+00	0.0%	4.7E-03	23.6%	3.3E-05	0.2%	0.0E+00	0.0%	1.7E-04	0.8%
Dioxins	1746-01-6	0.000007	Oral extrap	2.29E-08	0.3%	2.8E-06	39.9%	4.3E-08	0.6%	1.9E-10	0.0%	2.2E-07	3.2%	3.2E-09	0.0%	1.4E-11	0.0%	1.7E-08	0.2%
PCBs as TEQ[G]		0.000007	Dioxin-like PCBs + dioxins	8.30E-08	1.2%	2.8E-06	40.7%	4.4E-08	0.6%	5.0E-10	0.0%	2.3E-07	3.3%	3.3E-09	0.0%	3.8E-11	0.0%	1.7E-08	0.2%
Carcinogenic PAHs (Winter)[H]		2.5E-04																	
Benzo (b/k) fluoranthene	205-97-0	RP = 0.1		5.46E-04	21.8%	5.6E-04	22.3%	2.9E-05	1.1%	0.0E+00	0.0%	1.5E-04	**6.0%**	2.2E-06	0.1%	0.0E+00	0.0%	1.1E-05	0.5%
Carcinogenic PAHs (Summer)		2.5E-04																	
Benzo (b/k) fluoranthene	205-97-0	RP = 0.1		5.67E-04	22.7%	1.4E-03	54.7%	2.1E-05	0.8%	0.0E+00	0.0%	1.1E-04	4.4%	1.6E-06	0.1%	0.0E+00	0.0%	8.2E-06	0.3%

A = Health Criteria Value
B = Basis for deriving HCV
C = Estimated background level at site
D = Estimated period mean concentration based on maximum at any receptor
E = Estimated mean concentration at distance 0–2 km from centre of site
F = Estimated mean concentration at distance 2–7 km from centre of site
G = PCBs (Polychlorinated biphenyls) as TEQ (Toxic Equivalency)
H = HCV is standard for benzo(a)pyrene, RP is relative potency of carcinogenicity in relation to benzo(a)pyrene

Table A11.3: Site A - All substances WINTER data

Substance	CAS no.	HCV (µg/m^3)	'Averaging time', 1% occupational or oral	Baseline		Modelled period mean concentration: Maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
				Conc (µg/m^3)	% HCV Baseline	95%ile (µg/m^3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV
Antimony	7440-36-0	3	Oral extrap		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Arsenic	7440-38-0	0.007	Long term/lifetime		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Chromium (assuming 25%CrVI)	7440-47-3	0.0025	Long term/lifetime	2.5E-04	10.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Cobalt	7440-48-4	0.1	Long term/lifetime	1.15E-02	11.5%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Lead	7439-92-1	0.25	Annual	2.78E-03	1.1%	2.3E-04	0.1%	1.3E-05	0.0%	0.0E+00	0.0%	6.1E-05	0.0%	2.5E-07	0.0%	0.0E+00	0.0%	1.2E-06	0.0%
Manganese	7439-96-5	0.15	Annual	3.95E-03	2.6%	1.1E-02	7.1%	4.9E-04	0.3%	0.0E+00	0.0%	2.4E-03	1.6%	2.4E-05	0.0%	0.0E+00	0.0%	1.2E-04	0.1%
Mercury	7439-97-6	1	Long term/lifetime		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Nickel	7440-02-0	0.02	Long term/lifetime	2.03E-03	10.1%	2.3E-04	1.2%	1.3E-05	0.1%	0.0E+00	0.0%	6.1E-05	0.3%	2.5E-07	0.0%	0.0E+00	0.0%	1.2E-06	0.0%
Thallium	7440-28-0	0.25	Oral extrap		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Tin	7440-31-5	20 (inorg); 1 (org)	1% Occupational	2.00E-03	0.2%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Vanadium	7440-62-2	1	24 h	1.00E-03	0.1%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Dioxins	1746-01-6	0.000007	Oral extrap	2.38E-08	0.3%	8.8E-09	0.1%	4.1E-10	0.0%	0.0E+00	0.0%	2.0E-09	0.0%	2.0E-11	0.0%	0.0E+00	0.0%	9.8E-11	0.0%
PCBs - TEQ		0.000007	Dioxin-like PCBs to be combined with dioxins	3.71E-08	0.5%	8.8E-09	0.1%	4.1E-10	0.0%	0.0E+00	0.0%	2.0E-09	0.0%	2.0E-11	0.0%	0.0E+00	0.0%	9.8E-11	0.0%
PAHs																			
Naphthalene	91-20-3	3	Long term/lifetime	4.52E-04	0.0%	2.2E-07	0.0%	1.0E-08	0.0%	0.0E+00	0.0%	5.0E-08	0.0%	5.1E-10	0.0%	0.0E+00	0.0%	2.5E-09	0.0%
Fluorene	86-73-7	140	Oral	9.39E-04	0.0%	2.5E-03	0.0%	1.1E-04	0.0%	0.0E+00	0.0%	5.5E-04	0.0%	5.6E-06	0.0%	0.0E+00	0.0%	2.7E-05	0.0%
Fluoranthene	206-44-0	140	Oral	9.18E-04	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Pyrene	129-00-0	105	Oral	8.29E-04	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Acenaphthene	83-32-9	210	Oral	2.96E-04	0.0%	3.7E-03	0.0%	1.7E-04	0.0%	0.0E+00	0.0%	8.3E-04	0.0%	8.5E-06	0.0%	0.0E+00	0.0%	4.2E-05	0.0%
Acenaphthylene	208-96-8	No HCV available		3.94E-04		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	

Substance	CAS no.	HCV ($\mu g/m^3$)	'Averaging time', 1% occupational or oral	Baseline		Modelled period mean concentration: Maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
				Conc ($\mu g/m^3$)	% HCV Baseline	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV
Benzo (ghi) perylene	191-24-2	No HCV available		2.28E-04		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Phenanthrene	85-01-8	No HCV available		3.54E-03		2.0E-05		9.0E-07		0.0E+00		4.4E-06		4.5E-08		0.0E+00		2.2E-07	
Carcinogenic PAHs		2.5E-04																	
Benzo (b/k) fluoranthene	205-97-0	RP = 0.1		4.34E-04	17.4%	6.3E-06	0.0%	2.9E-07	0.0%	0.0E+00	0.0%	1.4E-06	0.1%	1.4E-08	0.0%	0.0E+00	0.0%	7.0E-08	0.0%
Indeno (123-cd) pyrene	193-39-5	RP = 0.08		1.73E-04	5.5%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Dichloromethane	75-09-2	450	Weekly	0.00E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
1,2 Dichloroethene	540-59-0	60	Oral extrap	0.00E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
2-methyl furan	534-22-5	No HCV available		0.00E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Nitromethane	75-52-5	2540	1% Occupational	0.00E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
2-Butanone (MEK)	78-93-3	5000	Long term/lifetime	8.31E-01	0.0%	1.0E-01	0.0%	4.0E-03	0.0%	0.0E+00	0.0%	2.1E-02	0.0%	5.2E-05	0.0%	0.0E+00	0.0%	2.7E-04	0.0%
Benzene	71-43-2	3.2	Annual	8.83E-01	27.6%	4.6E-01	14.2%	1.8E-02	0.6%	0.0E+00	0.0%	9.1E-02	2.9%	2.4E-04	0.0%	0.0E+00	0.0%	1.2E-03	0.0%
1,2 Dichloroethane	75-09-2	0.36	Long term/lifetime	3.59E-01	99.8%	3.6E-01	101.1%	1.4E-02	3.9%	0.0E+00	0.0%	7.3E-02	20.3%	1.8E-04	0.1%	0.0E+00	0.0%	9.5E-04	0.3%
Trichloroethylene	79-01-6	23	Long term/lifetime	6.05E-01	2.6%	4.8E-01	2.1%	1.9E-02	0.1%	0.0E+00	0.0%	9.7E-02	0.4%	2.4E-04	0.0%	0.0E+00	0.0%	1.3E-03	0.0%
Tetrachloro-ethene	127-18-4	250	Long term/lifetime	1.20E+00	0.5%	2.8E-02	0.0%	1.1E-03	0.0%	0.0E+00	0.0%	5.5E-03	0.0%	1.4E-05	0.0%	0.0E+00	0.0%	7.2E-05	0.0%
Trimethyl-benzene	25551-13-7	625	De novo	1.18E+00	0.2%	2.2E+00	0.4%	9.4E-02	0.0%	0.0E+00	0.0%	4.5E-01	0.0%	1.2E-03	0.0%	0.0E+00	0.0%	5.8E-03	0.0%
Alpha terpinene	99-86-5	390	De novo	6.08E-01	2%	6.5E-01	2%	2.5E-02	0.0%	0.0E+00	0.0%	1.3E-01	0.0%	3.3E-04	0.0%	0.0E+00	0.0%	1.7E-03	0.0%
Dichlorobenzene	95-50-1(ortho)	1000	Annual (total for both isomers)	1.78E+00	0.2%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%

Substance	CAS no.	HCV ($\mu g/m^3$)	'Averaging time', 1% occupational or oral	Baseline		Modelled period mean concentration: Maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
				Conc ($\mu g/m^3$)	% HCV Baseline	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV
2-ethyl-1-hexanol	104-76-7	133	De novo	7.69E-01	0.6%	1.8E-01	0.1%	7.0E-03	0.0%	0.0E+00	0.0%	3.7E-02	0.0%	9.2E-05	0.0%	0.0E+00	0.0%	4.8E-04	0.0%
Formaldehyde	50-00-0	10	annual		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
1,3 butadiene	106-99-0	2.21	Annual		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Carbon Disulphide	75-15-0	100	24 h		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Dimethyl disulphide	624-92-0	0.5	De novo		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Dimethyl sulphide	75-18-3	5	De novo		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Ethyl mercaptan	75-08-1	10	1% Occupational		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Vinyl chloride	75-01-4	1	Long term/lifetime		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Dichlorofluoro-methane	75-43-4	430	1% Occupational		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Fibres				0.00E+00		0.0E+00		0.0E+00		0.0E+00	!	0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Arsine	7784-42-1	0.007	Long term/lifetime (using As HCV)		0.0%				0.0%		0.0%		0.0%		0.0%		0.0%		0.0%
Stibine	7803-52-3	17	De novo		0.0%														
Mesophilic Aerobes (cfu/m3)				5.98E+07		5.0E+06		4.1E+05		0.0E+00		2.1E+06		1.2E+04		0.0E+00		6.1E+04	
Moulds (cfu/m3)				4.32E+07		1.0E+07		8.2E+05		0.0E+00		4.2E+06		2.4E+04		0.0E+00		1.2E+05	
Yeasts (cfu/m3)						0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Entrobacteriaceae (cfu/m3)						0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Endotoxins (IU/filter)				6.07E+04		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	

Table A11.3: All substances SUMMER data, Site A

Substance	CAS no.	HCV ($\mu g/m^3$)	'Averaging time', 1% occupational or oral	Baseline		Modelled period mean concentration: Maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
				Conc. ($\mu g/m^3$)	% HCV Baseline	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV
Antimony	7440-36-0	3	Oral extrap	5.42E-04	0.0%	3.4E-04	0.0%	4.6E-05	0.0%	1.7E-05	0.0%	1.7E-04	0.0%	1.5E-06	0.0%	5.1E-07	0.0%	5.6E-06	0.0%
Arsenic	7440-38-0	0.007	Long term/lifetime	2.15E-04	3.1%	4.3E-04	6.1%	6.5E-05	0.9%	2.2E-05	0.3%	2.1E-04	3.0%	2.1E-06	0.0%	8.2E-07	0.0%	6.8E-06	0.1%
Chromium (assuming 25%CrVI)	7440-47-3	0.0025	Long term/lifetime	1.36E-03	13.6%	2.5E-04	10%	2.5E-05	1.0%	5.5E-06	0.2%	1.1E-04	4.3%	1.0E-06	0.0%	1.0E-07	0.0%	4.5E-06	0.2%
Cobalt	7440-48-4	0.1	Long term/lifetime	1.52E-04	0.2%	6.3E-05	0.1%	3.9E-06	0.0%	0.0E+00	0.0%	2.0E-05	0.0%	1.9E-07	0.0%	0.0E+00	0.0%	9.7E-07	0.0%
Lead	7439-92-1	0.25	Annual	1.55E-03	0.6%	6.4E-03	2.5%	7.7E-04	0.3%	2.8E-04	0.1%	2.7E-03	1.1%	2.9E-05	0.0%	9.8E-06	0.0%	1.1E-04	0.0%
Manganese	7439-96-5	0.15	Annual	3.19E-03	2.1%	7.7E-03	5.1%	1.4E-03	1.0%	7.5E-04	0.5%	4.1E-03	2.7%	4.9E-05	0.0%	2.5E-05	0.0%	1.4E-04	0.1%
Mercury	7439-97-6	1	Long term/lifetime		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Nickel	7440-02-0	0.02	Long term/lifetime	7.81E-04	3.9%	2.9E-04	1.5%	4.7E-05	0.2%	2.4E-05	0.1%	1.4E-04	0.7%	1.5E-06	0.0%	7.6E-07	0.0%	4.5E-06	0.0%
Thallium	7440-28-0	0.25	Oral extrap		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Tin	7440-31-5	20 (inorg); 1 (org)	1% Occupational	1.80E-04	0.0%	1.0E-04	0.0%	9.7E-06	0.0%	6.7E-08	0.0%	4.8E-05	0.0%	3.1E-07	0.0%	2.1E-09	0.0%	1.5E-06	0.0%
Vanadium	7440-62-2	1	24 h	4.22E-04	0.0%	3.9E-03	0.4%	2.4E-04	0.0%	0.0E+00	0.0%	1.3E-03	0.1%	1.2E-05	0.0%	0.0E+00	0.0%	6.0E-05	0.0%
Dioxins	1746-01-6	0.000007	Oral extrap	4.51E-08	0.6%	1.1E-07	1.5%	6.6E-09	0.1%	0.0E+00	0.0%	3.4E-08	0.5%	3.2E-10	0.0%	0.0E+00	0.0%	1.7E-09	0.0%
PCB's as TEQ		0.000007	Dioxin-like PCBs to be combined with dioxins	4.01E-08	0.6%	1.5E-07	2.1%	9.1E-09	0.1%	0.0E+00	0.0%	4.7E-08	0.7%	4.4E-10	0.0%	0.0E+00	0.0%	2.3E-09	0.0%
PAHs																			
Naphthalene	91-20-3	3	Long term/lifetime	1.00E-03	0.0%	1.2E-03	0.0%	1.0E-04	0.0%	4.9E-06	0.0%	3.7E-04	0.0%	5.0E-06	0.0%	2.4E-07	0.0%	1.8E-05	0.0%
Acenaphthene	83-32-9	210	Oral	5.66E-04	0.0%	2.7E-05	0.0%	1.9E-06	0.0%	0.0E+00	0.0%	8.4E-06	0.0%	9.4E-08	0.0%	0.0E+00	0.0%	4.1E-07	0.0%
Fluorene	86-73-7	140	Oral	1.39E-03	0.0%	1.1E-04	0.0%	7.1E-06	0.0%	0.0E+00	0.0%	3.3E-05	0.0%	3.5E-07	0.0%	0.0E+00	0.0%	1.6E-06	0.0%
Fluoranthene	206-44-0	140	Oral	8.74E-04	0.0%	1.0E-03	0.0%	9.7E-05	0.0%	3.3E-05	0.0%	3.3E-04	0.0%	4.7E-06	0.0%	1.6E-06	0.0%	1.6E-05	0.0%
Pyrene	129-00-0	105	Oral	5.37E-04	0.0%	3.6E-04	0.0%	3.0E-05	0.0%	8.4E-07	0.0%	1.1E-04	0.0%	1.5E-06	0.0%	4.1E-08	0.0%	5.6E-06	0.0%

Substance	CAS no.	HCV (µg/m^3)	'Averaging time', 1% occupational or oral	Baseline		Modelled period mean concentration: Maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
				Conc. (µg/m^3)	% HCV Baseline	95%ile (µg/m^3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV
Acenaphthylene	208-96-8	No HCV available		4.25E-04		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Benzo (ghi) perylene	191-24-2	No HCV available				0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Phenanthrene	85-01-8	No HCV available		1.47E-03		3.6E-02		2.3E-03		1.1E-04		1.1E-02		1.1E-04		5.5E-06		5.5E-04	
Carcinogenic PAHs		2.5E-04																	
Benzo (b/k) fluoranthene	205-97-0	RP = 0.1		1.95E-04	7.8%	1.3E-05	0.0%	7.6E-07	0.0%	0.0E+00	0.0%	4.0E-06	0.2%	3.7E-08	0.0%	0.0E+00	0.0%	1.9E-07	0.0%
Indeno (123-cd) pyrene	193-39-5	RP = 0.08		8.99E-05	2.9%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
1,1,1-Trichloroethane	71-55-6	2000	Annual	1.23E-02	0.0%	4.5E-01	0.0%	5.1E-02	0.0%	2.4E-03	0.0%	2.0E-01	0.0%	1.5E-03	0.0%	7.0E-05	0.0%	5.9E-03	0.0%
1,1-Dichloroethane	75-34-3	4120	1% Occupational	1.00E-02	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Benzene	71-43-2	3.2	Annual	1.44E-01	4.5%	4.5E+00	139.6%	5.0E-01	15.6%	7.6E-03	0.2%	2.0E+00	61.7%	1.5E-02	0.5%	2.2E-04	0.0%	5.8E-02	1.8%
1,2 Dichloroethane	75-09-2	0.36	Long term/lifetime	2.45E-02	6.8%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Chlorobenzene	108-90-7	500	Annual	2.43E-02	0.0%	3.0E-03	0.0%	4.3E-04	0.0%	0.0E+00	0.0%	1.3E-03	0.0%	1.3E-05	0.0%	0.0E+00	0.0%	3.9E-05	0.0%
Chloroethane	75-00-3	10000	Long term/lifetime	2.25E-02	0.0%	2.0E-01	0.0%	2.3E-02	0.0%	0.0E+00	0.0%	8.9E-02	0.0%	6.7E-04	0.0%	0.0E+00	0.0%	2.6E-03	0.0%
Dichloromethane	75-09-2	450	Weekly	2.67E+00	0.6%	7.3E-01	0.2%	1.2E-01	0.0%	3.3E-02	0.0%	3.2E-01	0.1%	3.6E-03	0.0%	9.6E-04	0.0%	9.5E-03	0.0%
Tetrachloro-ethene	127-18-4	250	Long term/lifetime	2.79E-01	0.1%	9.7E-01	0.4%	1.2E-01	0.0%	1.8E-03	0.0%	4.3E-01	0.2%	3.4E-03	0.0%	5.4E-05	0.0%	1.3E-02	0.0%
1,2 Dichloroethene	540-59-0	60	Oral extrap	1.00E-02		0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Styrene	100-42-5	70	Weekly	8.15E-01	1.2%	1.4E+00	2.0%	1.8E-01	0.3%	1.5E-02	0.0%	6.1E-01	0.9%	5.3E-03	0.0%	4.3E-04	0.0%	1.8E-02	0.0%
Formaldehyde	50-00-0	10	Annual	0.00E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%

Substance	CAS no.	HCV ($\mu g/m^3$)	'Averaging time', 1% occupational or oral	Baseline		Modelled period mean concentration: Maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
				Conc. ($\mu g/m^3$)	% HCV Baseline	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV
1,3 butadiene	106-99-0	2.21	Annual		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Ethyl mercaptan	75-08-1	10	1% Occupational	1.55E-01	1.5%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Vinyl chloride	75-01-4	1	Long term/lifetime	2.52E-01	25.2%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Chlorodifluoro-methane	75-45-6	50000	Long term/lifetime	9.70E-03	0.0%	1.4E+00	0.0%	1.5E-01	0.0%	0.0E+00	0.0%	6.2E-01	0.0%	4.5E-03	0.0%	0.0E+00	0.0%	1.8E-02	0.0%
Dichlorodifluoro-methane	75-71-8	50300	1% Occupational	1.03E-02	0.0%	3.0E-05	0.0%	3.3E-06	0.0%	0.0E+00	0.0%	1.3E-05	0.0%	9.7E-08	0.0%	0.0E+00	0.0%	3.9E-07	0.0%
Carbon Disulphide	75-15-0	100	24 h	6.99E+00	7.0%	1.4E+01	14.5%	1.7E+00	1.7%	2.9E-02	0.0%	6.4E+00	6.4%	5.1E-02	0.1%	8.5E-04	0.0%	1.9E-01	0.2%
Dimethyl sulphide	75-18-3	5	De novo	1.16E+01	232%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Dimethyl disulphide	624-92-0	0.5	De novo		0.0%	4.3E-02	8.6%	4.8E-03	1.0%	0.0E+00	0.0%	1.9E-02	3.8%	1.4E-04	0.0%	0.0E+00	0.0%	5.6E-04	0.0%
Fibres				1.37E+09		1.7E+08		3.8E+07		0.0E+00		1.0E+08		1.2E+06		0.0E+00		3.3E+06	
Arsine	7784-42-1	0.007	Long term/lifetime (using As HCV)		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Stibine	7803-52-3	17	De novo	3.46E+01	204%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Total Bacteria Nutrient 25 oC (cfu/m3)				9.11E+07				2.7E+08		2.0E+05		1.1E+09		8.5E+06		6.4E+03		3.3E+07	
Total Bacteria Nutrient 37 oC (cfu/m3)				1.68E+06				0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Total fungi and yeasts Malt 25 oC (cfu/m3)				1.81E+07				7.6E+06		0.0E+00		2.3E+07		2.4E+05		0.0E+00		7.4E+05	
Total fungi and yeasts Malt 40 oC (cfu/m3)				1.04E+06				0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	

Substance	CAS no.	HCV ($\mu g/m^3$)	'Averaging time', 1% occupational or oral	Baseline		Modelled period mean concentration: Maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
				Conc. ($\mu g/m^3$)	% HCV Baseline	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV
Total fungi and yeasts DG18 25 oC (cfu/m3)				2.44E+08				1.5E+07		0.0E+00		6.0E+07		4.8E+05		0.0E+00		1.9E+06	
Gram -ve bacteria VRBG (cfu/m3)				0.00E+00				0.0E+00		0.0E+00		0.0E+00	DIV/0!	0.0E+00		0.0E+00		0.0E+00	
Endotoxins (EU/m3)				1.01E+06				0.0E+00		0.0E+00		0.0E+00	DIV/0!	0.0E+00		0.0E+00		0.0E+00	

Table 1.4: Site B - All substances WINTER data

Substance	CAS no.	HCV (µg/m^3)	'Averaging time', 1% occupational or oral	Baseline (µg/m^3)	Baseline as % of HCV	Modelled period mean concentration: maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
						95%ile (mg/m3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV
Antimony	7440-36-0	3	Oral extrap	1.00E-03	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Arsenic	7440-38-0	0.007	Long term/lifetime		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Cadmium	7440-43-9	0.005	Long term/lifetime		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Chromium (assuming 25%CrVI)	7440-47-3	0.0025	Long term/lifetime	6.13E-04	24.5%	4.3E-03	170%	8.0E-04	32.0%	0.0E+00	0.0%	3.5E-03	140%	1.8E-05	0.7%	0.0E+00	0.0%	8.0E-05	3.2%
Cobalt	7440-48-4	0.1	Long term/lifetime	2.77E-02	27.7%	2.7E-02	26.6%	5.7E-03	5.7%	5.9E-05	0.1%	2.2E-02	22.4%	1.3E-04	0.1%	4.5E-06	0.0%	4.6E-04	0.5%
Lead	7439-92-1	0.25	Annual	1.75E-03	0.7%	4.9E-03	2.0%	1.2E-03	0.5%	6.5E-05	0.0%	4.1E-03	1.6%	3.3E-05	0.0%	4.9E-06	0.0%	1.1E-04	0.0%
Mercury	7439-97-6	1	Long term/lifetime	2.13E-03	0.2%	3.2E-03	0.3%	4.1E-04	0.0%	0.0E+00	0.0%	1.9E-03	0.2%	1.5E-05	0.0%	0.0E+00	0.0%	7.0E-05	0.0%
Nickel	7440-02-0	0.02	Long term/lifetime	1.00E-03	5.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Thallium	7440-28-0	0.25	Oral extrap	1.00E-03	0.4%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Tin	7440-31-5	20 (inorg); 1 (org)	1% Occupational	1.00E-03	0.1%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Dioxins	1746-01-6	7E-06	Oral extrap	2.27E-08	0.3%	1.8E-08	0.3%	1.1E-09	0.0%	8.8E-11	0.0%	4.9E-09	0.1%	8.2E-11	0.0%	6.7E-12	0.0%	3.8E-10	0.0%
PCBs		7E-06	Dioxin-like PCBs to be combined with dioxins	3.29E-08	0.5%	2.5E-08	0.4%	1.6E-09	0.0%	2.5E-10	0.0%	6.6E-09	0.1%	1.2E-10	0.0%	1.9E-11	0.0%	5.0E-10	0.0%
PAHs																			
Naphthalene	91-20-3	3	Long term/lifetime	2.50E-04	0.0%	1.5E-03	0.0%	1.2E-04	0.0%	0.0E+00	0.0%	3.9E-04	0.0%	8.9E-06	0.0%	0.0E+00	0.0%	3.0E-05	0.0%
Acenaphthene	83-32-9	210	Oral	1.77E-04	0.0%	1.4E-03	0.0%	9.5E-05	0.0%	0.0E+00	0.0%	3.8E-04	0.0%	7.2E-06	0.0%	0.0E+00	0.0%	2.9E-05	0.0%
Fluorene	86-73-7	140	Oral	6.36E-04	0.0%	7.1E-03	0.0%	4.1E-04	0.0%	0.0E+00	0.0%	1.9E-03	0.0%	3.1E-05	0.0%	0.0E+00	0.0%	1.4E-04	0.0%
Fluoranthene	206-44-0	140	Oral	9.49E-04	0.0%	3.0E-03	0.0%	1.8E-04	0.0%	2.1E-05	0.0%	8.1E-04	0.0%	1.4E-05	0.0%	1.6E-06	0.0%	6.2E-05	0.0%

Substance	CAS no.	HCV (µg/m^3)	'Averaging time', 1% occupational or oral	Baseline (µg/m^3)	Baseline as % of HCV	Modelled period mean concentration: maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
						95%ile (mg/m3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV	Mean (µg/m^3)	Mean as % HCV	50%ile (µg/m^3)	50%ile as % HCV	95%ile (µg/m^3)	95%ile as % HCV
Pyrene	129-00-0	105	Oral	6.43E-04	0.0%	1.8E-03	0.0%	1.0E-04	0.0%	7.1E-06	0.0%	4.8E-04	0.0%	7.9E-06	0.0%	5.4E-07	0.0%	3.6E-05	0.0%
Acenaphthylene	208-96-8	No HCV available		1.25E-04		6.0E-04		3.3E-05		0.0E+00		1.6E-04		2.5E-06		0.0E+00		1.2E-05	
Phenanthrene	85-01-8	No HCV available		3.22E-03		1.4E-02		8.1E-04		3.6E-05		3.6E-03		6.1E-05		2.7E-06		2.7E-04	
Carcinogenic PAHs		2.5E-04																	
Benzo (b/k) fluoranthene	205-97-0	RP = 0.1		5.46E-04	21.8%	5.6E-04	22.3%	2.9E-05	1.1%	0.0E+00	0.0%	1.5E-04	6.0%	2.2E-06	0.1%	0.0E+00	0.0%	1.1E-05	0.5%
Ethyl mercaptan	75-08-1	10	1% Occupational		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Fibres				0.00E+00				0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
total bacteria				2.00E+09		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
total bacteria				1.05E+09		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Gram -ve bacteria				0.00E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
total fungi + yeasts				0.00E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
total fungi + yeasts				0.00E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
thermophilic fungi				0.00E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Penicillia				0.00E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
A. fumigatus				0.00E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	

Table A11.4: All substances SUMMER data, Site B

Substance	CAS no.	HCV ($\mu g/m^3$)	'Averaging time', 1% occupational or oral	Baseline ($\mu g/m^3$)	Baseline as % of HCV	Modelled period mean concentration: maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
						95%ile (mg/m3)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV
Antimony	7440-36-0	3	Oral extrap	5.77E-04	0.0%	5.9E-05	0.0%	2.3E-06	0.0%	0.0E+00	0.0%	1.2E-05	0.0%	1.1E-07	0.0%	0.0E+00	0.0%	5.6E-07	0.0%
Arsenic	7440-38-0	0.007	Long term/lifetime	2.77E-04	4.0%	2.9E-05	0.4%	1.1E-06	0.0%	0.0E+00	0.0%	6.0E-06	0.1%	5.3E-08	0.0%	0.0E+00	0.0%	2.8E-07	0.0%
Cadmium	7440-43-9	0.005	Long term/lifetime	2.33E-04	4.7%	2.7E-03	54.7%	1.5E-04	3.1%	0.0E+00	0.0%	8.0E-04	15.9%	6.4E-06	0.1%	0.0E+00	0.0%	3.3E-05	0.7%
Chromium (assuming 25%CrVI)	7440-47-3	0.0025	Long term/lifetime	3.0E-04	11.8%	9.3E-05	3.7%	6.0E-06	0.2%	0.0E+00	0.0%	3.0E-05	1.2%	0.2E-07	0.0%	0.0E+00	0.0%	1.2E-06	0.0%
Cobalt	7440-48-4	0.1	Long term/lifetime	3.00E-04	0.3%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Lead	7439-92-1	0.25	Annual	2.65E-03	1.1%	4.1E-04	0.2%	2.0E-05	0.0%	0.0E+00	0.0%	1.1E-04	0.0%	8.8E-07	0.0%	0.0E+00	0.0%	4.6E-06	0.0%
Mercury	7439-97-6	1	Long term/lifetime	4.00E-04	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Nickel	7440-02-0	0.02	Long term/lifetime	9.32E-04	4.7%	1.5E-02	75.0%	9.1E-04	4.6%	0.0E+00	0.0%	4.7E-03	23.6%	3.3E-05	0.2%	0.0E+00	0.0%	1.7E-04	0.8%
Thallium	7440-28-0	0.25	Oral extrap		0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%	0.0E+00	0.0%
Tin	7440-31-5	20 (inorg); 1 (org)	1% Occupational	3.17E-04	0.0%	1.4E-03	0.1%	8.3E-05	0.0%	0.0E+00	0.0%	4.3E-04	0.0%	3.0E-06	0.0%	0.0E+00	0.0%	1.5E-05	0.0%
Dioxins	1746-01-6	7E-06	Oral extrap	2.29E-08	0.3%	2.8E-06	39.9%	4.3E-08	0.6%	1.9E-10	0.0%	2.2E-07	3.2%	3.2E-09	0.0%	1.4E-11	0.0%	1.7E-08	0.2%

Substance	CAS no.	HCV ($\mu g/m^3$)	'Averaging time', 1% occupational or oral	Baseline ($\mu g/m^3$)	Baseline as % of HCV	Modelled period mean concentration: maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
						95%ile (mg/m3)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV
PCBs as TEQ		7E-06	Dioxin-like PCBs to be combined with dioxins	8.30E-08	1.2%	2.8E-06	40.7%	4.4E-08	0.6%	5.0E-10	0.0%	2.3E-07	3.3%	3.3E-09	0.0%	3.8E-11	0.0%	1.7E-08	0.2%
PAHs																			
Naphthalene	91-20-3	3	Long term/lifetime	5.05E-04	0.0%	6.2E-04	0.0%	1.2E-05	0.0%	2.3E-06	0.0%	5.0E-05	0.0%	8.7E-07	0.0%	1.7E-07	0.0%	3.7E-06	0.0%
Acenaphthene	83-32-9	210	Oral	1.20E-04	0.0%	8.1E-06	0.0%	1.2E-07	0.0%	0.0E+00	0.0%	6.5E-07	0.0%	9.3E-09	0.0%	0.0E+00	0.0%	4.9E-08	0.0%
Fluorene	86-73-7	140	Oral	5.61E-04	0.0%	2.4E-04	0.0%	3.1E-05	0.0%	0.0E+00	0.0%	1.6E-04	0.0%	2.9E-07	0.0%	0.0E+00	0.0%	1.4E-06	0.0%
Fluoranthene	206-44-0	140	Oral	2.59E-03	0.0%	2.0E-03	0.0%	3.1E-05	0.0%	0.0E+00	0.0%	1.6E-04	0.0%	2.3E-06	0.0%	0.0E+00	0.0%	1.2E-05	0.0%
Pyrene	129-00-0	105	Oral	1.61E-03	0.0%	2.0E-03	0.0%	3.1E-05	0.0%	0.0E+00	0.0%	1.6E-04	0.0%	2.3E-06	0.0%	0.0E+00	0.0%	1.2E-05	0.0%
Acenaphthylene	208-96-8	No HCV available		9.50E-05		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Phenanthrene	85-01-8	No HCV available		4.54E-03		7.4E-03		1.1E-04		0.0E+00		5.9E-04		8.5E-06		0.0E+00		4.4E-05	
Carcinogenic PAHs		2.5E-04																	
Benzo (b/k) fluoranthene	205-97-0	RP = 0.1		5.67E-04	22.7%	1.4E-03	54.7%	2.1E-05	0.8%	0.0E+00	0.0%	1.1E-04	4.4%	1.6E-06	0.1%	0.0E+00	0.0%	8.2E-06	0.3%

Substance	CAS no.	HCV ($\mu g/m^3$)	'Averaging time', 1% occupational or oral	Baseline ($\mu g/m^3$)	Baseline as % of HCV	Modelled period mean concentration: maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
						95%ile (mg/m3)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV
Ethyl mercaptan	75-08-1	10	1% Occupational	4.21E-01	4.2%	4.1E-01	4.1%	2.2E-02	0.2%	0.0E+00	0.0%	1.2E-01	1.2%	7.0E-04	0.0%	0.0E+00	0.0%	3.9E-03	0.0%
Fibres				3.00E+09		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Total Bacteria Nutrient 25 oC (cfu/m3)				6.78E+08		1.4E+07		9.7E+05		0.0E+00		4.8E+06		3.8E+04		0.0E+00		1.8E+05	
Total Bacteria Nutrient 37 oC (cfu/m3)				1.61E+08		2.8E+07		1.9E+06		0.0E+00		9.5E+06		7.5E+04		0.0E+00		3.7E+05	
Total fungi and yeasts Malt 25 oC (cfu/m3)				3.80E+07		3.3E+08		2.3E+07		0.0E+00		1.1E+08		8.7E+05		0.0E+00		4.3E+06	
Total fungi and yeasts Malt 40 oC (cfu/m3)				6.00E+07		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Total fungi and yeasts DG18 25 oC (cfu/m3)				1.02E+08		5.5E+07		3.8E+06		0.0E+00		1.9E+07		1.5E+05		0.0E+00		7.2E+05	

Substance	CAS no.	HCV ($\mu g/m^3$)	'Averaging time', 1% occupational or oral	Baseline ($\mu g/m^3$)	Baseline as % of HCV	Modelled period mean concentration: maximum at any receptor		Modelled period mean concentration: Average 0 - 2 km						Modelled period mean concentration: Average 2 - 7 km					
						95%ile (mg/m3)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV	Mean ($\mu g/m^3$)	Mean as % HCV	50%ile ($\mu g/m^3$)	50%ile as % HCV	95%ile ($\mu g/m^3$)	95%ile as % HCV
Gram -ve bacteria VRBG (cfu/m3)						0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	
Endotoxins (EU/m3)				2.98E+06		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00		0.0E+00	

We are The Environment Agency. It's our job to look after your environment and make it **a better place** – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

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Environment Agency
Rio House
Waterside Drive, Aztec West
Almondsbury, Bristol BS32 4UD
Tel: 0870 8506506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk