Public Health and Landfill Sites

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Executive summary

Landfill management is a complex discipline, requiring very high levels of organisation, and considerable investment. Until the early 1990's most Irish landfill sites were not managed to modern standards. Illegal landfill sites are, of course, usually not managed at all.

Landfills are very active. The traditional idea of 'put it in the ground and forget about it' is entirely misleading. There is a lot of chemical and biological activity underground. This produces complex changes in the chemistry of the landfill, and of the emissions from the site.

The main emissions of concern are landfill gases and contaminated water (which is known as leachate). Both of these emissions have complex and changing chemical compositions, and both depend critically on what has been put into the landfill. The gases spread mainly through the atmosphere, but also through the soil, while the leachate (the water) spreads through surface waters and the local groundwater.

Essentially all unmanaged landfills will discharge large volumes of leachate into the local groundwater. In sites where the waste accepted has been properly regulated, and where no hazardous wastes are present, there is a lot known about the likely composition of this leachate and there is some knowledge of its likely biological and health effects. This is not the case for poorly regulated sites, where the composition of the waste accepted is unknown.

It is possible to monitor the emissions from landfills, and to reduce some of the adverse health and environmental effects of these. These emissions, and hence the possible health effects, depend greatly on the content of the landfill, and on the details of the local geology and landscape.

There is insufficient evidence to demonstrate a clear link between cancers and exposure to landfill, however, it is noted that there may be an association with adverse birth outcomes such as low birth weight and birth defects. It should be noted, however, that modern landfills, run in strict accordance with standard operation procedures, would have much less impact on the health of residents living in proximity to the site.

Introduction

In recent times waste management is an issue of increasing public debate. There has also been some concern about possible health effects of landfill. This research was commissioned by The Department of Public Health, ERHA, and completed by The Department of Epidemiology and Public Health, UCD, to document the procedures in relation to the management of landfill sites and to examine any scientific evidence in relation to the possible health effects of such forma of waste disposal.

Aim

There are two main questions to be addressed in this research:

1. Can landfill sites cause a potential public health problem?
2. What action should be taken in relation to landfills to monitor possible health effects?

Format Of The Report

This report is in four sections:

Part 1 examines the possible effect of exposure to landfill sites.

Part 2 examines landfill waste and human health.

Part 3 discusses evaluation and monitoring techniques of possible public health problems arising from landfill sites

Part 4 outlines control measures for reducing the impact on human health of emissions from the operation of landfill sites.

Contents

PART 1: LANDFILL SITES, POSSIBLE EFFECTS OF EXPOSURE

1. Introduction

This section describes landfill sites in general and the potential health effects related to them.

The objectives of this section are to:

- To describe the types of landfill sites in existence and the types of waste found in landfills
- To descibe 'leachate' and the factors that influence the production of leachate from landfill sites
- To outline and categorise by time (i.e. short term and long term) the routes of exposure that could give rise to possible public health problems from landfill sites and the documented health problems related to same
- To determine the potential public health problems from landfill sites categorising them into those, which arise from landfill sites in general, and those, which are determined by the type of waste, disposed in the landfill sites.

1.2 Mechanism Of Production Of Hazardous Chemicals In Landfills

A Landfill in which waste is decomposing produces both gaseous (called landfill gas) and liquid effluents (called leachate), which are potentially harmful to humans. To assess the risk requires knowledge of (i) their chemical composition, (ii) the rate at which they are produced, (iii) the potential pathways along which they may travel to come in contact with humans and (v) any chemical reactions or physical effects which may occur during transport that changes the nature or concentrations of the harmful chemicals.

1.2.1 Chemical Composition

The chemical composition of both leachate and landfill gas has been studied and some details are given later in this report. More detail is available from the HRB report (Crowley, Staines et al. 2003) and the EPA's Landfill Manuals (Carey, Carty et al. 2002).

The actual composition at any particular landfill depends mainly on the composition of the waste and its age. The waste composition is of obvious importance both because of its biodegradable components, but also because other non-biodegradable components, such as metals, may dissolve in the leachate. In the case of metals, for instance, their dissolution may be pH dependent.

The age of the waste is important because it influences both the rate of production of the landfill gas and leachate and also their composition. Much of the decomposition of the biodegradable part of the waste occurs in the first third of the landfill's life and reaction rates decrease thereafter.

The main types of reactions (and thus the by-products generated) change from aerobic to anaerobic as the supply of oxygen within the waste body is exhausted. In a lined landfill this happens very early in the life of the landfill, but in an unlined, uncovered and perhaps un-compacted landfill where oxygen may enter, the transition may be delayed.

1.3 Types of waste and types of landfill site

1.3.1 Definition and Categories of waste

The Waste Management Acts of 1996 and 2000 define waste as:

> ***'any substance or object belonging to a category of waste specified in the First Schedule or for the time being included in the European Waste Catalogue which the holder discards or intends or is required to discard, and anything which is discarded or otherwise dealt with as waste shall be presumed to be waste until the contrary is proved.'***

The first level of waste classification used in the European Union Waste Catalogues (Anonymous 1996; Anonymous 2002) includes 20 categories. Municipal waste is the last classification on this list and is the primary subject of interest here. Interestingly, as well as non-hazardous components (Table 1), municipal waste includes some components classed as hazardous (Table 2).

Table 1 Non-Hazardous components of Municipal Waste

Code	Category
20 01 01	Paper and cardboard
20 01 02	Glass
20 01 08	Biodegradable kitchen and canteen waste
20 01 10	Clothes
20 01 11	Textiles
20 01 25	Edible oils and fat
20 01 28	Paint, inks adhesives and resins other than those included in 20 01 27*
20 01 30	Detergents other than those mentioned in 20 01 29*

20 01 32	Medicines other than those mentioned in 20 01 31*
20 01 34	Batteries and accumulators other than those mentioned in 20 01 33*
20 01 36	Discarded electrical and electronic equipment other than those mentioned in 20 01 21, 23 or 35*
20 01 38	Wood other than that mentioned in 20 01 37*
20 01 39	Plastics
20 01 40	Metals
20 01 41	Wastes from chimney sweeping
20 01 99	Other fractions not mentioned
	Garden and park (incl. Cemetery) wastes
20 02 01	Biodegradable waste
20 02 02	Soil and stones
20 02 03	Other non-biodegradable wastes
	Other municipal wastes
20 03 01	Mixed municipal waste
20 03 02	Waste from markets
20 03 03	Street cleaning residues
20 03 04	Septic tank sludges
20 03 06	Waste from sewage cleaning
20 03 07	Bulky waste
20 03 99	Municipal wastes not otherwise specified

Table 2 Hazardous components of Municipal Waste

Code	Category
20 01 13	Solvents
20 01 14	Acids
20 01 15	Alkalis
20 01 17	Photochemicals
20 01 19	Pesticides
20 01 21	Fluorescent tubes and other mercury-containing waste
20 01 23	Discarded equipment containing chlorofluorocarbons
20 01 26	Oil and fat other than edible oil and fat
20 01 27	Paint, inks, adhesives and resins containing dangerous substances
20 01 29	Detergents containing dangerous substances
20 01 31	Cytotoxic and cytostatic medicines
20 01 33	Batteries and accumulators
20 01 35	Discarded electrical and electronic equipment other than those covered by 20 01 21 and 20 01 23 containing hazardous components
20 01 37	Wood containing dangerous substances

1.3.2 Waste flows in Ireland

Waste arising in Ireland for 1998 was estimated as approximately 80 million tonnes (Crowe, Fanning et al. 2000). Of this, approximately 64.6 million tonnes (80.7%) originated from agricultural sources, mainly animal manure. The municipal and industrial sectors are estimated to have produced over 15 million tonnes (19.3%) of waste in 1998. Municipal waste alone accounted for 2 million tonnes. This is a small increase in this category of waste since 1995, which had 1.8 million tonnes of municipal waste arisings (Carey, Carty et al. 1996) (Table 3).

Table 3 Comparison of amounts and types of waste arising in Ireland in 1995 and 1998

Waste Category	1998		1995	
	(Tonnes/annum)	(%)	(Tonnes/annum)	(%)
Agricultural	64,578,724	80.7	31,000,000	73.4
Manufacturing	4,876,406	6.1	3,540,226	8.4
Energy, Gas, & Water Supply	448,674	0.6	351,849	0.8
Mining & Quarrying	3,510,778	4.4	2,200,002	5.2
Hazardous Waste	370,328	0.5	243,754	0.6
Municipal Waste	2,056,652	2.6	1,848,232	4.4
End-of-Life Vehicles/Scrap Metal	187,484	0.2	52,154	0.1
Construction & Demolition Waste	2,704,958	3.4	1,318,908	3.1
Urban Wastewater Sludges	505,686	0.6	851,380	2.0
Drinking Water Sludges	38,988	0.0	58,095	0.1
Dredge Spoils	734,000	0.9	784,600	1.9
Total	80,012,678	100.0	42,249,200	100.0

The composition of household and commercial waste in Ireland, by weight, in 1998 is shown in Table 4. Note that paper (34.7%) and organics (24.9%) are the largest fractions. This is in sharp contrast to the situation fifty years earlier when ash (mostly from heating systems) formed by far the largest fraction.

Table 4 Composition of household and commercial waste in Ireland in 1998 (Source: Crowe et al. 2000)

Material	Amount	Percentage of total
	(Tonnes/ annum)	(%)
Paper	642,151	34.7
Glass	116,757	6.3
Plastic	200,403	10.8
Ferrous	32,559	1.8
Aluminium	15,455	0.8
Other Metals	6,236	0.3
Textiles	39,388	2.1
Organic	460,869	24.9
Others	338,630	18.3
Total	1,852,448	100.0

Table 5 compares the amounts and final destination of municipal waste in Ireland from 1995 to 2001. This table shows a steady and substantial increase in the amount of municipal waste arising, with an increase in the amount being recovered, which, however, does not suffice to reduce the amount being disposed of to landfill.

Table 5 Production and disposal of municipal waste in Ireland 1995-2001. Source (Anonymous 2002)

Category	1995 (tonnes)	1998 (tonnes)	2000 (tonnes)	2001 (tonnes)
Generated	1,848,232	2,056,652	2,278,695	2,704,035
Landfilled	1,385,439	1,685,766	1,971,355	1,992,050
Recovered	117,732	166,684	270,937	305,554

Note – the three rows of this table come from three different data collection systems, and are not mutually consistent.

1.3.3 Variability of municipal solid waste (MSW) flow and composition with time and space

There is no information on spatial and temporal variation in the waste arising in Ireland. Some indication of possible variability can be gauged from a study conducted by Porcel et al. (Porcel, Aguilar et al. 1997) on the physical and chemical characteristics of MSW in the city of Cordoba in Spain and its variability with space and time. This study revealed that the physical and chemical characteristics of waste vary with time (days of the week or seasons of the year) and in space depending on the socio-economic factors.

1.3.4 Composition of municipal solid waste

Some idea of the expected composition of MSW can be inferred from the municipal waste sub-categories in Tables 2.2 and 2.3. There is considerable variation from country to country and from waste stream to waste stream. For example, in the study from Cordoba described previously, municipal solid waste composition varied with season and with location within the city. However, the organic carbon composition is sufficient to contribute to leachate in the short term (Johnson, Kaeppeli et al. 1999). A study of over 60 landfills in Finland showed a large variation in metal content of waste between different landfills (Assmuth 1992). No comparable Irish data are to hand.

1.3.5 Methods of solid waste treatment in Ireland

The composition and amount of MSW (mainly household and commercial wastes) treated (landfilled) or recovered in Ireland annually is shown in Table 6.

Table 6 Disposal and recovery rates in the household and commercial waste streams in Ireland in 1998.

Material	Landfilled	Recovered	Total	Landfill Rate	Recovery Rate
	(Tonnes/ annum)	(Tonnes/ annum)	(Tonnes/ annum)	(%)	(%)
Paper	547,849	94,302	642,151	85.3	14.7
Glass	80,757	36,000	116,757	69.2	30.8
Plastic	192,927	7,476	200,403	96.3	3.7
Ferrous	28,491	4,069	32,559	87.5	12.5
Aluminium	14,724	731	15,455	95.3	4.7
Other Metals	6,209	28	6,236	99.6	0.4

Textiles	36,142	3,247	39,388	91.8	8.2
Organic	455,204	5,665	460,869	98.8	1.2
Other	323,463	15,167	338,630	95.5	4.5
Total	1,685,766	166,684	1,852,450	91.0	9.0

In 1998, there were 117 active known landfill sites (Crowe, Fanning et al. 2000). This was the position at the time of the last comprehensive survey in 1999. A considerable number of licences have been issued since then. The current position (as of 12/02/2002) is that 104 landfill licences and 16 draft licences have been issued. Eleven applications have been withdrawn or rejected and one application failed compliance. Fifty-five applications were under consideration (EPA, pers. comm.).

1.4 Landfill design and characteristics

The most commonly used method of management of solid waste in Ireland is landfilling. About 91% of all household and commercial waste collected in 1998 in Ireland was landfilled (Crowe, Fanning et al. 2000).

A landfill is where waste is deposited in a series of compacted layers in specially constructed cells either on the land surface or in holes created on the land surface by excavation. Cells are filled sequentially, and when full the landfill is sealed with a cap, prior to eventual site remediation.

The design of a landfill must take account of the ground conditions, the geology and hydrogeology of the site, the potential environmental impacts and the location of the landfill. The investigations for a landfill should provide sufficient information to enable the formulation of a site-specific design.

A major goal of landfill design and construction is to control the ingress of water to the site, and to restrict and monitor the egress of leachate from the site.

1.4.1 Past Design characteristics

In the not too distant past, landfills were called ‘dumps’ and were located in areas of cheap, poor-quality land. They included disused quarries and low-lying marshy ground. Landfill gas was allowed enter the atmosphere to be dispersed and the policy of ‘dilute and disperse’ applied to the contaminated liquid, called leachate, which seeped from the waste.

This practice presumed that contaminants in leachate would be attenuated by passage through the soil and diluted by the receiving water, that is, groundwater, surface water or marine water, to the extent that its impact would be minimal. The environmental hazards posed to groundwater by ‘dumps’ have been recognised and efforts to close (and sometimes remediate) these facilities have been undertaken in the EU and elsewhere.

Currently, natural attenuation is rarely considered as the sole method of leachate management. Some ‘monitored natural attenuation’ protocols are mentioned by (Rifai, Bedient et al. 2000) in relation to hazardous waste sites in the US. With a far greater range of potential contaminants in modern leachates, the risks to health of its direct release to the environment are correspondingly greater.

1.4.2 Current design characteristics

Current practice in landfill design must consider the construction, operation, closure, restoration and aftercare of the facility. The landfill designer should consider all of its potential environmental impacts and the factors influencing them, including those itemised below.

- Nature and quantity of waste deposited
- Water control on site
- Protection of soil and water
- Leachate management
- Gas control
- Environmental nuisances
- Slope stability of both waste and containment cells
- Visual appearance and landscaping
- Operational and restoration requirements
- Monitoring requirements
- Estimated cost of the facility
- Construction
- After use and aftercare

The Irish Environmental Protection Agency (EPA) has produced a set of Manuals for use in landfill design (Environmental Protection Agency 1995; Environmental Protection Agency 1995; Environmental Protection Agency 1997; Environmental Protection Agency 1999; Environmental Protection Agency 2000). The UK Department of the Environment has also produced guidelines (Department of the Environment (UK) 1995).

The Department of the Environment and Local Government (DoELG), the Environmental Protection Agency (EPA) and the Geological Survey of Ireland (GSI) have produced guidelines for groundwater protection, which have an important input into the selection of suitable sites for landfills (Department of the Environment and Local Government and Geological Survey Ireland 1999).

Groundwater protection during the design of a landfill site is more specifically addressed in an Irish report on groundwater protection responses for landfills (Geological Survey of Ireland 1991).

1.5 Processes of degradation

Landfills are highly chemically and biologically active bioreactors. The details of landfill chemistry vary greatly depending on the composition of the waste stream, and the amount of water permitted to enter the landfill. The waste is degraded by a complex range of reactions, which include the following general categories:

Hydrolysis, in which large organic molecules such as lipids and proteins are broken down into their monomeric components, which can then be ingested by micro-organisms.

Acidogenesis, by which micro-organisms break down the products of hydrolysis into smaller molecules such as small organic acids (known as volatile fatty acids), accompanied by the liberation of carbon dioxide and dihydrogen.

Fermentation, by which different micro-organisms convert the small organic acids into methane and carbon dioxide. This is also called the methanogenic phase.

1.6 Types of Leachate from Landfill Sites and Factors that Influence its Production

1.6.1 Nature and composition of Landfill Leachate

Leachate is defined as any liquid (for instance, precipitation or ingress groundwater) percolating through the deposited waste and emitted from or contained within a landfill. As it percolates through the waste it picks up suspended and soluble materials that originate from, or are products of, the degradation of the waste.

The principal organic contents of leachate are formed during the breakdown process described above and its organic 'strength' is normally measured in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD), or total organic carbon (TOC). The composition of leachate generated from a municipal landfill changes with time as the degradation of the waste continues inside the landfill. Table 7 shows typical constituents of leachate formed at different stages of the waste degradation of municipal waste.

Table 7 Comparison of leachate from landfills early in their course, and later on. Data is from studies of large landfills, with high waste input rates. All values are in mg/l except pH value and conductivity (μS/cm). (Source UK DoE, quoted in (Environmental Protection Agency 2000))

Analyte	Early phase	Late phase
	(Median)	**(Median)**
pH-value	6	7.35
Conductivity (mS/cm)	13195	10000
Alkalinity (as CaCO3)	5155	5000
COD	23600	1770
BOD20	14900	391
BOD5	14600	253
TOC	7800	555
Fatty acids (as C)	5144	5
Ammoniacal-N	582	902
Nitrate-N	0.7	0.7
Nitrite-N	0.1	0.09
Sulphate (as SO4)	608	35
Phosphate (as P)	3.3	2.7
Chloride	1490	1950
Sodium	1270	1400
Magnesium	400	166
Potassium	900	791
Calcium	1600	117
Chromium	0.12	0.07
Manganese	22.95	0.3
Iron	475	15.3
Nickel	0.23	0.14
Copper	0.075	0.07
Zinc	6.85	0.78
Arsenic	0.01	0.009
Cadmium	0.01	<0.01
Mercury	0.0003	<0.0001
Lead	0.3	0.13

Early landfill leachate is more biologically and chemically active (higher BOD and COD), more acidic (lower pH), has higher concentrations of most, but mot all. chemical species (e.g. calcium, manganese, iron and zinc, but not ammoniacal nitrogen, sodium and chloride) than later leachate. It is important to appreciate that these figures are very dependent on the exact composition of the waste stream, and on the amount of water allowed into the waste. Some of the inorganic trace elements may be used as indicators of leachate contamination of groundwater (Looser, Parriaux et al. 1999).

Due to the potential threat of leachate to both the environment, particularly groundwater, and human health, indirect discharges (leachate) from waste disposal are expressly mentioned in Article 10 of the Groundwater Directive (CEC 1980). It is therefore important to control and manage it. Properly designed leachate management systems will accomplish the following objectives:

- To reduce the potential for seepage out of the landfill through the sides or the base either by exploiting weaknesses in the liner or by flow through its matrix.
- To prevent liquid levels rising to such an extent that they can spill over and cause uncontrolled pollution to ditches, drains, watercourses, etc.
- To influence the reaction rates of the processes leading to the formation of landfill gas and leachate. This will also change the time required for chemical and biological stabilisation of the landfill.
- To minimise the interaction between the leachate and the liner.
- In the case of above-ground landfill, to ensure the stability of the waste.

1.6.2 Leachate Volumes

Knowledge of the likely leachate generation of a landfill is a prerequisite of a leachate management strategy. Water balances are used to assess likely leachate generation volumes. The calculated leachate quantity is used in designing leachate collection and treatment systems and in the design of different landfill cells.

1.6.3 Leachate Collection and Removal Systems

An effective leachate collection and removal system is a prerequisite for all non-hazardous and hazardous landfill sites (Environmental Protection Agency 2000). It is a component of the landfill liner system and its purpose is to allow the removal of leachate from the landfill and to control the depth of the leachate above the liner. The leachate collection system must function over the landfill's design lifetime irrespective of the liquids management strategy being used.

Therefore, any leachate management system should include the following components:

- A drainage layer (blanket) constructed of natural granular material (sand, gravel) or synthetic drainage material (e.g. geonet or geocomposite);
- Perforated leachate collection pipes within the drainage blanket to collect leachate and carry it to a sump or collection header pipe;
- A protective filter layer over the drainage blanket, if necessary, to prevent physical clogging of the material by fine-grained material;

- Leachate monitoring points;
- Leachate collection sumps or a header pipe system by which leachate can be removed.

A landfill liner is used as a barrier to prevent leachate leaving the bottom and sides of a landfill and can also prevent groundwater entering. Note, however, if groundwater levels are such that it would enter the landfill naturally, then groundwater should be managed in some other way to reduce uplift pressures on the liner.

1.7 Landfill Liners

1.7.1 Liner Leakage

Certain plastics used in liners, such as crystalline polyethylene, polypropylene and polybutylene, were not found to be affected after one year of contact with leachate, but some thermoplastics, such as chlorinated polyethylene, chlorosulfonated polyethylene and polyvinyl chloride, showed some swelling (Buss, Butler et al. 1995).

Liners may leak because of tears or faults during manufacture, transport, laying, infilling with waste, interaction with leachate or by diffusion. Leakage rates are related to the depth of leachate accumulating on the liner. There is a broad range of quoted synthetic liner leakage rates in the USA. A typical value of 200 litre/hectare/day is claimed to be equivalent to a 2 mm diameter hole with a hydrostatic head of 30 mm. Diffusion through the liner material may also be a significant source of groundwater contamination.

In the double liner design specified by the Irish Environmental Protection Agency (Environmental Protection Agency 2000), leakage through the liner would be retarded by the lower second barrier and collected by the intermediate drainage layer. This not only gives a second level of protection for groundwater but also provides a warning of leakage through the top liner. Some studies have been made of the attenuating effects on leachate constituents of specific clays (see, for instance, (Mimides and Perraki 2000), but it is difficult to generalise the results.

1.7.2 Leachate Toxicity

Leachate can be highly toxic (Clément, Persoone et al. 1996). Methods have been developed for rapid toxicity tests of leachate prior to release into sewage treatment plants (Ward, Bitton et al. 2000). A cancer risk analysis conducted in the US which focused mainly on leachate indicated that 60% of Municipal Solid Waste landfills posed a cancer risk of less than one in 10 billion, another 6% posed a risk of less than one in a billion and 17% presented a risk of less than one in a million (Chilton and Chilton 1992). (Assmuth 1996) furnishes a detailed consideration of the difficulties in developing risk indices.

Lead and zinc are the metals most easily leached from old landfills (Assmuth 1992), with concentration distributions skewed towards small values and irregular spatial distributions but with some maximum concentrations exceeding drinking water standards.

Toxicity depends mainly on the content of the waste in the landfill. At one extreme builder's rubble and clay pose little more hazard than an equivalent volume of soil and rock, while at the other extreme hazardous chemical wastes could pose an immediate and serious threat to the health or well being of those living around the site.

1.7.3 Important Factors in Exposure Modelling

If a leak does occur from a landfill, or when considering older, unlined landfills which invariably leak, human and environmental exposure depends on local groundwater conditions. The most important groundwater flow variables influencing exposure through water abstraction in wells have been determined by (Mills, Lew et al. 1999) as follows:

Net recharge to groundwater,

Source width,

Hydraulic gradient,

Hydraulic conductivity of waste materials,

Longitudinal dispersivity coefficient,

Distance to groundwater receptor,

Source length.

These all reflect the exact nature of the local groundwater flow, the shape, size and position of the landfill, and local rock or soil conditions. Clearly when selecting a site for a landfill these would be considered as part of the site assessment. An illegal landfill would presumably be sited without regard to such considerations.

A substantial body of literature exists on the transport of contaminants by groundwater. There are many different mechanisms of transport thorough groundwater, which can affect greatly the timing of exposures to groundwater-borne contaminants. Different substances can be carried at very different rates, and in different parts of the groundwater stream.

As a result the modelling of leachate transport is complicated. There are a large number of components with different transport mechanisms, some floating on the groundwater, some dissolved in it and some more dense components tending to sink downwards through the aquifer. Each may also have its own biological and geochemical reaction mechanisms and rates.

A widely used computer model is MT3DMS (Zheng and Wang 1999; Zheng, Hill et al. 2001), which can support the modelling of biological and geochemical processes as well as advective transport (transport of water-borne particulates), diffusion and dispersion.

In Ireland, modelling difficulties are also compounded by the high degree of spatial variability and inhomogeneity in groundwater systems, which require special care in characterising the flow system and in calibrating and verifying the model. Again this reflects the local geology. Difficulties arise with preferential flow paths, fracture and karstic (limestone) flow systems, which, if not adequately modelled, can result in overly optimistic predictions of contaminant travel times, concentrations and exposure risks.

The effect of this is that certain groundwater flows, and the associated contaminants can travel with far higher speeds than simple models might predict. Actual groundwater flow is highly variable in Ireland, with flow rates ranging from hours to centuries per kilometre.

1.7.4 Leachate Treatment

The main constituents of leachate requiring treatment are the ammoniacal content and the organic constituents of the leachates. Treatment methods may be divided into four categories:

1. Physical/chemical pre-treatment (e.g. air stripping of methane or ammonia and precipitation or flocculation).
2. Biological treatment (e.g. activated sludge, sequencing batch reactors, rotating biological contactors, combined leachate and urban wastewater treatment, anaerobic treatment, and biological nitrogen removal).
3. Combination of physical-chemical and biological treatment (e.g. membrane bioreactor, powdered activated carbon, or filtration).
4. Advanced treatment (activated carbon adsorption, reverse osmosis, chemical oxidation, evaporation, and reed bed treatment).

1.7.5 Protection of Groundwater and Surface Water

Good landfill design includes provisions for the management and protection of both groundwater and surface water.

A groundwater management system is required to minimise or prevent:

- Interference with the groundwater regime during the landfill construction period;
- Damage to the liner (by uplift, that is rising of the underlying soil);
- Transport of contaminants from the landfill;
- Leachate generation by preventing groundwater infiltration.

Hydrology and groundwater protection issues are first dealt with at the site selection phase. These have been addressed in a set of guidelines for groundwater protection, issued jointly by the Geological Survey of Ireland and the Environmental Protection Agency (Department of the Environment and Local Government and Geological Survey Ireland 1999).

Modern design requires monitoring systems to detect the movement through the ground of either leachate or landfill gas (Environmental Protection Agency 2000). Because of the relatively slow speed of movement of water through the ground, there may be a significant time lag between the occurrence of a leak and the detection of contamination at a monitoring point. However, the slow movement also means it is likely the contaminant plume, that is the part of the groundwater contaminated by leachate, will not have a wide extent when detected.

A surface water management system is required:

- To minimise leachate generation, by providing for surface water runoff, preventing surface ponding and the infiltration of water into the fill;
- To transport contaminants from the landfill;
- For the degradation of the liner or cover material.

Modern landfill design, with its double liner and capping systems, aims to minimise emissions of leachate and landfill gas from a landfill. This is in contrast with the ‘dilute and disperse’ policies applied previously. As a consequence, care is needed when inferring effects from observations of emissions at older landfills.

1.8 Future Directions for Landfills

1.8.1 Landfill as a reactor

At present the active life of a MSW landfill, during which the waste is being decomposed, is estimated as over fifty years. There is considerable interest in techniques for shortening this time because it has the potential of reducing overall costs and risks.

To do this, the landfill is considered as a bio-reactor in which the degradation processes must be accelerated. I other words, rather than relying on the natural processes of decay to break down biologically active elements in the waste, the conditions within the landfill are adjusted so as to optimise biological breakdown. A substantial quantity of water must be added to a landfill cell if methane production is to be optimised. The temperature should be maintained at approximately 40 ^{o}C.

Rates of water addition of 1 to 2 m (i.e. 1 to 2 cubic meters per square meter of landfill area) per year have been suggested as a suitable compromise between the required moisture and the negative effect of lowering the temperature (Rees 1980;

Rees and Granger 1982). However, the raising of the moisture content will increase leachate leakage if the liner has been damaged.

1.8.2 Sustainable landfill

Walker (1997) distinguishes between environmental pollution and contamination. He points out that prevention of pollution from landfill cannot be guaranteed and, from the viewpoint of sustainable landfill, urges (i) a risk-based approach to site selection, design and operation and (ii) further research into proposed management options, such as the bio-reactor mentioned above.

1.9 Routes of Human Exposure to Environmental Contaminants from Landfill Sites

1.9.1 Leachate

Landfills which are not properly designed are likely to be unlined, uncapped and may or may not have had mechanical compaction of the waste. Each day's additional waste may or may not have been covered with a clay layer. The likely implications of this deviation from good design practice are discussed below.

The increased amounts of rainfall passing through the top of an uncapped landfill means that considerably more leachate is generated than in a properly capped landfill although it may be more dilute. Possible movement of groundwater through the unlined sides and bottom can also contribute to the volume of leachate.

The movement of leachate from an unlined landfill depends on the exact details of the local hydrogeologic setting:

- the nature and condition of the subsurface geological conditions
- the depth of the watertable,
- the background groundwater flow field (the amount of local groundwater flow)
- the difference in hydraulic head between the leachate and the ambient groundwater (essentially the vertical distance between the leachate and the local groundwater).

The matter is further complicated because some components of the leachate will dissolve in the groundwater and be carried by it, some lower density immiscible components will "float" on top of the groundwater table and may spread out on it in all horizontal directions. Other more dense immiscible components may sink through the groundwater to the base of the aquifer and move in a direction dictated by its slope, i.e. in a direction that may be different to that of the background groundwater flow. Thus, considerable care is need in designing systems to detect and/or monitoring the occurrence and movement of leachate contamination.

However, depending on the type of subsurface material the movement and dispersion of the leachate plume may be slow, e.g. typically in clays and silts. Movement can be somewhat faster in sands and gravels and quicker still in fractured rock. Karst systems, (the sort of limestone in which caves usually form) which are common throughout the island of Ireland, provide the potential for the fastest movement.

Whether or not the leachate is a threat to human health depends on whether it enters the capture zone of a water supply, either a well or spring. The Groundwater Section of the Geological Survey of Ireland, may be able to advise of this, as they have been involved in the preparation of aquifer protection plans for many counties in Ireland and, for these counties, have collected a considerable amount of the geologic and subsurface information required for a risk analysis.

While leachate is the main hazardous emission from landfills there are several other important emissions from operating and closed landfills. These are :

- Landfill gas
- Transport hazards
- Wind-blown dust and litter
- Vermin and insects.

1.9.2 Landfill Gas (LFG)

Landfill gas (LFG) results from the biodegradation of waste. Gas production within the landfill takes place at elevated temperature and the gas is usually saturated with water. Undiluted landfill gas can be expected to have a calorific value of 15 – 21 MJ/m^3 (Environmental Protection Agency 2000), which is approximately half that of natural gas.

The major components of landfill gas are methane (CH_4) and carbon dioxide (CO_2) (typically in a 3:2 ratio), with a large number of other constituents at low concentrations. Methane is flammable and can be asphyxiant. Carbon dioxide is asphyxiant. However, from a human health perspective, some of the constituents found in low concentrations may be as important as the major components. This is because it is unusual for landfill gases to be present in levels that give rise to risks of either fire or asphyxiation, but odour associated with the gases is a problem, and some of the gases released are highly irritant. Again, it is important to emphasise that landfill gas emissions depend critically on what has been put into the landfill. The values reported below (Table 8) are typical of municipal waste landfills.

Table 8 Typical Landfill Gas Composition (% volume)

Component	Comment	UK - Typical Value (EPA 2000)	UK-Observed Maximum (EPA 2000)	US typical (Ham 1979)*	Palos Verdes, CA, USA (Brosseau and Heitz 1994)
Methane	Flammable	63.8	88	47.4	53.28
Carbon dioxide		33.6	89.3	47	45.59
Oxygen		0.16	20.9	0.8	0.07
Nitrogen		2.4	87	3.7	0.27
Hydrogen	Flammable	0.05	21.1	0.1	0.06
Carbon monoxide	Toxic	0.001	0.09		
Ethane		0.005	0.0139		
Ethene		0.018	-		
Acetaldehyde	Smelly	0.005	-		
Propane	Flammable	0.002	0.0171		
Butanes	Flammable	0.003	0.023		
Helium		0.00005	-		
Higher alkanes		< 0.05	0.07		
Unsaturated hydrocarbons		0.009	0.048		
Halogenated compounds		0.00002	0.032		
Hydrogen sulphide	Irritant	0.00002	35	0.01	0.002
Organosulphur compounds	Irritant and smelly	0.00001	0.028		
Alcohol		0.00001	0.127		
Others		0.00005	0.023		
Paraffin Hydrocarbons				0.1	
Aromatic hydrocarbons				0.2	
Trace				0.5	

Farquhar and Rovers (1973) describe four phases in the production of landfill gas.

Aerobic decomposition: of short duration (few weeks) depletion of O_2 and production of CO_2 and H_2O.

Anaerobic, non-methanogenic: CO_2 production peaks and volatile fatty acids and H_2 production begins. Methane (CH_4) is not produced.

Anaerobic methanogenic phase: Methane (CH_4) production starts and increases to a relatively substantial constant rate; H_2 is rapidly used up and CO_2 production falls to a relatively constant rate; N_2 is produced.

In the final phase, gas production rates vary only slowly until the nutrient is depleted or sufficient amounts of inhibitory substances build up.

Gas production shows considerable variation with depth in the landfill, with a dramatic increase in the vicinity of a water (or leachate) table (if one exists in the waste) as explained by Rees and Granger (1982).

Fires and explosions in the landfill can occur when a flammable gas, or vapour from a flammable liquid mix with air and ignite. This can only happen within certain concentration limits. The concentration limits are known as the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL). For example, the LEL and UEL of methane are approximately 5% and 15% (v/v).

Some of the non-methane organic compounds found include benzene, heptane, nonane, acetaldehyde, acetone, and ethylmercaptan (Gandola, Grabner et al. 1982). Toluene, xylenes, propylbenzenes, vinyl chloride, tetrachloroethylene, methanethiol and methanol have been reported from landfills that received both municipal and industrial wastes (O'Leary and Tansel 1986). The US EPA (1991) listed 94 non-methane organic compounds found in air emissions from municipal solid waste landfills, which included benzene, toluene, chloroform, vinyl chloride, carbon tetrachloride, and 1,1,1 trichloroethane. Forty-one are halogenated compounds. One of the limitations of gas composition surveys is the practical one of selecting in advance those compounds to seek by analysis. Of all the surveys found in this review, the survey of landfill gas from the Fresh Kills landfill investigated the most compounds, namely 202 (Environmental Protection Agency (US) 1999).

Volatile Organic Compounds (VOCs) can migrate from a landfill or from an associated contaminated groundwater plume through the soil in the form of vapour or can be carried with other gases, such as methane, over considerable distances (Foster and Beck 1996). Once landfill gas enters a house it tends to accumulate in basements. The greatest threat to humans is by inhalation.

There has been the suggestion that the VOCs in landfill gas, together with nitrogen oxides from other sources, could lead to the formation of ozone, a lung irritant (Brosseau and Heitz 1994). Foster and Beck (1996) have estimated human health risk from inhalation of a number of components of landfill gas and differentiate between cancer and non-cancer risks and between the risks to children and to adults.

1.9.3 Routes of human exposure to landfill gas

Landfill gas may leave the landfill through the surface, if uncapped, and through its sides or bottom, if unlined. The gas leaving though the surface is likely to be mixed and considerably diluted in a plume extending in a direction dictated by the wind and meteorological conditions.

Landfill gas travelling through the ground will tend to take the paths of least resistance, e.g. fissures in rock, or loose backfill in trenches. Such trenches tend to be associated with water supply or drainage systems (including road drainage), electricity or phone cables, and if landfill gas moves through these trenches it can collect in the foundations or basements of the houses they service.

This can be a significant local health hazard. It provides a direct route from landfill emissions to human exposures, and it may lead to high levels of exposure, albeit to small number of people.

1.9.4 Quantity of Landfill Gas Generated

The rate of gas generation at a landfill site varies throughout the life of the landfill and is dependent on factors such as waste type, organic matter content, depth, moisture content, degree of compaction, landfill pH, temperature, soil type, bacterial content and length of time since the waste was deposited.

1.9.5 Landfill Gas Control

Landfill gas should be controlled and managed in order to avoid any potential risk or damage to human health and the environment. Normally, landfill gas management systems are installed with the following objectives:

- Minimise the risk of migration of LFG beyond the perimeter of the site.
- Minimise the risk of migration of LFG into services building on site.
- Avoid unnecessary ingress of air into the landfill and thereby minimise the risk of landfill fires.
- Minimise the damage to soils and vegetation within the restored landfill area.
- Permit effective control of gas emission.
- Where practicable, permit energy recovery.
- Minimise the impact on air quality and the effect of greenhouse gases on the global climate.

Landfill gas may migrate from the landfill by diffusion, convection or transportation by water or leachate. These modes of transport of gases are independent of each other but may occur simultaneously so that some migration control measures may mitigate one without removing the risk presented by others.

The common LFG migration control systems are:

1. Barriers: properly designed modern landfills have liner systems on the sides and bottom to prevent escape of leachate and landfill gas. While the landfill is being filled, gas may escape to the atmosphere by migrating upwards. However, when a section (cell) of the landfill is full of waste, it is covered with a clay cap, which may include a synthetic barrier layer to control infiltration of rainwater and egress of landfill gas.

2. Venting: a system of pipes underneath the cap collects landfill gas. This can then be released for atmospheric dispersion.
3. Active control / flaring / energy recovery (see below for options): suction pumps are used to extract landfill gas, which may be used as a fuel in a turbine or internal combustion engine to generate electricity.

The available management options include:

- Allow LFG to escape to the atmosphere.
- Flare LFG.
- Combust to heat boilers (to produce usable heat).
- Use to fuel an internal combustion engine (to convert to mechanical energy, usually to generate electricity).
- Use to fuel a gas turbine, usually to generate electricity.
- Feed a fuel cell.
- Convert the methane to methanol.
- Deliver purified LFG to a national or regional gas supply.

Hodgson et al. Garbesi (1988; 1988) and Wood and Porter (1986) warn of the possibility of landfill gas migrating through the ground to nearby buildings and of the possible accumulation of some toxic gases (vinyl chloride) before odours are detected. Molton and colleagues (cited by Brosseau and Heitz (1994)) warn of the danger of increased migration due to the capping of the landfill. Presumably this applies where active gas extraction and combustion, for instance, does not take place.

1.9.6 Landfill Gas Combustion Products

Air pollutants from combustion of landfill gas depend on the type of equipment used. Emissions from a gas turbine are less significant than those from an internal combustion engine because of the greater amounts of air used and the higher combustion temperature of the turbine. Brosseau and Heitz (1994) quote earlier unpublished research, which suggests that trace gas destruction efficiencies are of the order of 95% to 99%.

Nevertheless, Keller (1988) recommends that trace gases be removed before combustion to reduce human health hazards in the emissions. Dent et al. (1986) report that (i) sulphur and chlorine can react with oxygen in the combustion process to produce corrosive acids which can damage a combustion system and (ii) concentrations of chlorine greater than 100 mg per m^3 may be found in the gas during early stages of a landfill.

1.9.7 Wind borne contaminants

Biological activity within the landfill can generate very high concentrations of micro-organisms and fungal spores; both are known to be capable of contributing to respiratory disease. Work on people occupationally exposed to high levels of these agents from waste handling has demonstrated some impact on their health, but the relevance of this to people living near landfills is not clear (Malmros, Sigsgaard et al. 1992; Sigsgaard, Abel et al. 1994; Sigsgaard, Malmros et al. 1994; Sigsgaard, Hansen et al. 1997).

These biological exposures have also been identified as a potential hazard of occupational exposure to composting (Meeker, Gephardt et al. 1991; Yoshida, Neda et al. 1993), but we were unable to identify relevant work on landfills. Exposure from composting declines rapidly with distance from the source, and this presumably applies to landfill also.

An obvious potential hazard from landfills, depending on the composition of the waste stream, is wind-blown dust. If, for example, asbestos contaminated waste were received at a dump, and not buried promptly, dust and fibres could be emitted from the facility. Similarly, large pieces of litter can be blown around by the wind, and look very ugly. This probably serves more as a marker for poor landfill practice, than representing an independent health hazard in its own right. This could also contribute to psychological stress.

1.9.8 Vermin and insects

Landfills may also attract vermin, such as rats and flies. Again this partly reflects the composition of the waste stream, but also the management of the site. These seem to be no published studies of this aspect of the health impact of landfills. Again, the possible contribution to psychological stress of these agents should not be neglected.

1.9.9 Risk assessment for human exposure

In general, human exposure to landfill emissions depends on proximity to the site, and on details of the local geology and topography. Clearly, exposure to vermin and larger wind-blown material will be minimal at any substantial distance from the site.

Exposure to landfill gas emissions, although affected by local topography and weather, will extend rather further. Active management of landfill gas, for example by energy recovery, will substantially reduce human exposure off-site.

Landfill gas exposure can also occur through soil, with the gas either moving directly, or in solution in groundwater. This was a major route of human exposure at the Love Canal site (Goldman and Paigen 1985).

The route of human exposure that has caused most public concern is groundwater contamination. There are several reasons for this. Many rural and some urban Irish communities draw the bulk of their water supplies from groundwater. Groundwater contamination is usually occult, and (obviously) hidden and remediation is difficult and takes considerable time. In several parts of Ireland there are no alternative water supplies available at reasonable cost. Finally, the risk of contamination of major reservoirs must be considered.

PART 2: LANDFILL WASTE AND HUMAN HEALTH

The first part of this report discussed landfill emissions. There is a significant literature, divided amongst the disciplines of health, engineering, hydrology, and environmental sciences, on what is emitted from landfills and what the consequences of these emissions might be. Far less is definitely known about the consequences of actual human exposure to real landfill emissions.

In part this reflects the simple difficulty of the topic. The recently published report from the Health Research Board (Crowley, Staines et al. 2003) describes the reasons for this at some length. Briefly, the likely effects are small, and hence difficult to detect with small epidemiological studies. There have been few large studies of landfill exposed populations. It is important not to equate an absence of evidence for major health effects of exposure, with evidence that these exposures are, in fact, safe.

2. Introduction

Most waste in Ireland is currently consigned to landfill. The constituents of landfill have changed over time in terms of waste that is deposited and also in terms of biological degradation in existing sites. Although modern landfill sites are superior in terms of containment and emission reduction, emissions from landfill continue to give rise to concerns about the health effects of living and working near these sites. Illegal landfill sites are more difficult to assess due to the large uncertainties associated with types of waste deposited and the duration of the landfill.

This section describes the scientific literature in relation to landfill and health. Most studies do not examine the health effects of living near landfill sites have been carried out in relation to specific single geographic sites. Several studies have also examined a number of different sites together. An advantage of these multi-site studies is a larger population base, which is particularly useful when studying health outcomes that occur infrequently in the general population. Congenital malformations and rare forms of cancer are examples of such outcomes.

A disadvantage of multi-site studies is that the waste sites being studied may vary according to the type of waste deposited, how the sites are managed and differences in pollutant transport and population exposure pathways (Vrijheid 2000). Exposure may be via direct contact, inhalation or ingestion of contaminated food or water. Drinking water contamination has been identified as the source of exposure to harmful substances in many studies (Griffith, Duncan et al. 1989; Agency for Toxic Substances and Disease Registry 1994; Agency for Toxic Substances and Disease Registry 1997; Berry and Bove 1997; Adami, Siviero et al. 2001). In addition a number of risk assessments have been undertaken to determine the public health risk attributable to drinking water contamination incidents. These risk assessments are discussed later in this section.

2.1 Studies of Health Effects

Specific health outcomes that have been examined in epidemiological studies of the health effects of landfill sites include (a) congenital malformations, (b) birth weight, prematurity and child growth, (c) cancers, (d) symptoms of illness. Identified studies will be discussed according to these categories.

Most of the studies of human health near landfill sites have used a very non-specific model of exposure. Usually proximity to the site has been used as a proxy for exposure, presumably working on a model of simple radial diffusion of unspecified contaminants from the site.

As the likely routes of exposure are more structured than this, such studies have fundamental weaknesses. There must be an exposure pathway from a source in order for an agent released into the environment to ultimately effect human health. The potential exposure pathways are water, air, soil and (locally produced) food and so exposures to the local population could be ingestion, inhalation or through the skin (trans-dermal). Some exposure of the wider population might occur through eating food produced near the landfill site.

A description of exposure for a particular route should include the concentration, and the duration of contact. For example, landfill leachate might enter local groundwater and surface water but people are only exposed if the waters are used for drinking, producing or preparing food or for recreational purposes.

2.1.1 Congenital malformations

Congenital malformations are a group of human disorders, whose aetiology is largely unknown. For several reasons they have been the focus of many studies of the consequences of exposure to environmental pollution. The underlying hypothesis in these studies is that the complex processes of cell differentiation, cell migration and cell death, during the phase of organogenesis in human embryos is likely to be a particularly sensitive marker of human exposure to biologically active chemical compounds or combinations of such chemicals.

A number of studies have examined the congenital abnormality, birth weight, prematurely and childhood growth, cancers and psychological impact of possible exposure to landfill.

2.2 Review Of Hazardous Waste Sites

2.2.1 Love Canal

One of the most publicised incidents of environmental pollution from landfill took place in New York State in the 1970s and 80s. The Love Canal landfill was comprised of a sixteen-acre area, which contained approximately 21,800 tons of chemical wastes that had been deposited over a twenty-year period from the mid-1940s. This land was subsequently developed for housing, and a school was built on the site.

Local residents were exposed to a variety of hazardous chemicals that migrated through the soil and into surface water and local ground water. Drinking water was not contaminated, and exposure was either through inhalation, direct skin exposure or through ingestion. Hazardous chemicals identified in high concentrations included chlorinated hydrocarbons, organic solvents, dioxin, toluene and tri-chloro- and tetra-chloroethylene (Stark 2000).

Among the earlier investigations of the Love Canal residents was a study of low birth weight, prematurity and birth defects (Goldman and Paigen 1985). Children born in the Love Canal area were reported to be at three times greater risk of low birth weight than children born in a different unexposed area. Birth defects were also reported to be increased. However, the information on birth defects was that reported by parents rather than data contained in a congenital malformation register. This result could have been subject to recall bias, with parents living in the study area more likely to remember minor defects than those parents living in the comparison area. This does not account for the association found for major birth defects.

2.2.2 New York State

In a later multi-site study of residents of New York State, a 12% increased risk of congenital malformations in children born to families within one mile of hazardous waste sites was reported (Geschwind, Stolwijk et al. 1992). Exposure risk was quantified using the US EPA scoring system of waste sites, in addition to information on off-site leaks.

Higher malformation rates were associated with a higher exposure risk. Higher risks were found for malformations of the nervous and musculo-skeletal systems and for malformations of skin, hair and nails. A dose-response relationship was reported with higher estimated hazard potential being associated with higher risk of malformation.

Selected toxic waste sites containing specific chemical groups were studied separately. Pesticides were associated with musculo-skeletal anomalies, metals and solvents with central nervous system anomalies, and plastics with chromosomal anomalies. Smoking and alcohol consumption, occupational factors (both maternal and paternal) and the effect of other sources of emissions were not taken into account in this study.

In addition, miscarriages and foetal deaths were not included. These factors may also be influenced by exposure to certain hazards in waste. However, a follow-up study found no relation between central nervous system and musculo-skeletal malformations and residential proximity to a hazardous waste site. The researchers examined specific types of hazards, and found an association between central nervous system defects and metal or solvent emitting industrial facilities (Marshall, Gensburg et al. 1997).

2.2.3 California

A case-control study conducted in California investigated whether maternal residential proximity to waste sites increased the risk of neural tube defects (NTDs), heart defects and oral cleft defects (Croen et al. 1997). Separate proximity measures were used, residence in a census tract containing a waste site and distance of residence from a site. No significant increases in risk were found with either measure of exposure. Risks for NTDs and heart defects were increased two- and four-fold, respectively, for maternal residence at a quarter of a mile from a site. The small number of cases and controls meant that these risks did not reach significance.

2.2.4 Pennsylvania

Budnick et al. (1984) examined birth defect incidence to investigate the effects of the Drake Superfund site in Pennsylvania. This site was contaminated with the carcinogens beta-naphthylamine, benzidene, and benzene. The authors reviewed type-specific birth defect incidence rates for the six-year period from 1973 to 1978. There were no statistically significant excesses in birth defects found.

2.2.5 Europe

A multi-site European study, called EUROHAZCON, was carried out in ten European regions(Dolk, Vrijheid et al. 1998). A 33% increase in non-chromosomal birth defects was reported for residents living within 3 km of the 21 hazardous waste landfill sites studied. The increased risk of neural tube defects and certain heart defects was small but statistically significant. This observed increase may have been a chance finding. This study examined very different types of hazardous waste sites. Some sites were uncontrolled dumps, whereas others were subject to modern control measures and management. The authors concluded that further work was required to investigate whether their reported associations are causal.

Chromosomal congenital anomalies were studied in a further report from the EUROHAZCON group (Vrijheid, Dolk et al. 2002). Vrijheid and her colleagues examined 245 cases of chromosomal anomalies and 2,412 controls living near one of 23 hazardous waste sites in 17 study areas in Europe. After adjusting for confounding by maternal age and socio-economic group, the investigators reported a higher risk of chromosomal anomalies in those who lived within 3 km of a hazardous waste site when compared to those in the study population who lived between 3 and 7 km from one of the study sites.

The risks for chromosomal anomalies were similar to those in the earlier EUROHAZCON study discussed above (Dolk, Vrijheid et al. 1998). As the influence of socio-economic factors on the risk of non-chromosomal and chromosomal anomalies is in opposite directions, it was surmised that residual confounding was not responsible for the increased risks reported.

2.3 Review of General Waste Sites

2.3.1 South Wales

Another recent study of birth defects, reported in 2000, compared health outcomes in a population living near a large landfill site in South Wales (Fielder, Poon-King et al. 2000). Populations in five electoral wards near the landfill site were compared with a similar population in 22 other wards in the same local authority for frequencies of deaths, hospital admissions, and indicators of reproductive health, such as low birth weight and congenital malformations. In addition, records of environmental monitoring of emissions were collected, where available.

Although there were no differences in deaths, hospital admission or low birth weight rates between the study and comparison areas, there was an increased risk of congenital malformations. This difference was found to be present before the site was opened as well as during operation.

Possible reasons for this observation may have been the effect of a nearby waste incinerator which was closed prior to opening of the landfill site. Other potential causes of both the pre-existing increase in risk of congenital malformations, and the observed risk since the landfill site was opened, include the existence of other alternative pollutant sources (Roberts, Redfearn et al. 2000).

2.3.2 United Kingdom

In response to the publication of the EUROHAZCON study, government departments in the UK commissioned a national epidemiological study of the health effects of landfill sites in the UK. The Small Area Health Statistics Unit (SAHSU) at Imperial College London conducted a study around 19,196 known, open or closed landfill sites in Great Britain (Elliott, Briggs et al. 2001).

It was found that approximately 80% of the population of Great Britain live within 2 km of a landfill site. Therefore the study population was much larger in size than the comparison population. The 9,565 sites that were eventually included in the study comprised hazardous waste, non-special waste sites and sites handling unknown wastes. Residents living within 2 km of one of these sites were compared to those who lived further away. Small increases in risk of neural tube defects, abdominal wall defects and low birth weight were reported.

2.3.3 Conclusions

There is reasonable evidence of a slight increase in the incidence of birth defects in populations living near hazardous waste landfill sites. There is however, rather less evidence for such an increase in populations living near general waste landfills. A difficulty with all of these studies is that it was not possible to relate risk to any other than the crudest measures of exposure. In particular the distance from a residence to the landfill was sued as the measurement of exposure in all of these studies.

As described above the emissions from a landfill are most unlikely to have a neat circular distribution around the centre of the site, yet this is the model on which all of these studies are based. The effect of this on the ability of these studies to identify small risks is uncertain, but overall it probably makes them more likely to underestimate than overestimate real risks.

2.4 Birth weight, prematurity and childhood growth

2.4.1 Love Canal

(Goldman and Paigen 1985) reported a three-fold increase in risk of low birth weight in children born in the Love Canal area over that in children living elsewhere. Homeowners and renters were examined separately and homeowners only were found to have a significantly increased risk. This factor could not be explained, as no known differences in exposure risk were identified for the two groups.

One of a number of studies carried out on the Love Canal reported a reduction in stature in children who had spent at least 75% of their lives in the Love Canal area (Paigen, Goldman et al. 1987). The observed differences could not be accounted for by factors such as parental height, socio-economic status, nutrition, birth weight or chronic illness.

2.4.2 Lipari landfill

The Lipari Landfill in New Jersey was the site of a study of the effects of environmental emissions on nearby residents (Berry and Bove 1997). Leachate, containing volatile organic chemicals, was reported to have contaminated water supplies in the area. Inhalation of volatile organic chemicals directly from the landfill and from water was considered to be the most significant environmental concern. Birth certificate information for the 25-year period, 1961 to 1985, was used to identify maternal residence.

For the period of highest potential exposure to environmental emissions, the number of low birth weight babies born to mothers living within a 1 km radius of the site was significantly increased. Although the investigators did not have information on other influencing factors, such as smoking, alcohol consumption and socio-economic status, birth certificate information showed that mothers born in the study area were more highly educated than those in the comparison area. As education is closely linked to socio-economic status, the study population was assumed to be less deprived than that of the comparison area. As a result, higher birth weights in the exposed population would be expected. This difference in birth weight was observed for babies born both before and after the periods of maximum pollution. This lends further weight to the study findings.

2.4.3 Los Angeles

Birth weight was also examined in a study of a large hazardous waste site in Los Angeles, California (Kharrazi, Von Behren et al. 1997). Frequency and location of odour complaints from the site were considered to be more reliable estimates of exposure than proximity to the site. Although there were no overall differences in birth weight between the study and comparison areas, the time of greatest dumping activity was associated with a significant but small decrease in birth weight.

2.4.4 Montreal – Miron Quarry

(Goldberg, Goulet et al. 1995) looked at the Miron quarry, a municipal waste site in Montreal containing domestic, commercial and industrial waste. Biogas emitted from the site was found to contain a number of hazardous chemicals, which were the main cause for concern. No reliable information was available to determine resident exposure to these gas emissions, but exposure zones were defined according to proximity to the site and prevailing wind direction. Using information on birth registration, the authors examined infants born to mothers living near the site, which, at the time of reporting, was the third largest in North America.

Babies born in the high-exposure zone had a greater than 20% increased risk of low birth weight. Babies born in this zone were also reported as being small for their gestational age, but this was not a statistically significant difference. Although education and maternal age were taken into account in the analysis, some other potentially important confounding factors, such as smoking, were not examined in this study.

2.4.5 Conclusions

There is much less relevant evidence about the possible effect of these exposures on growth in-utero. The Lipari landfill study (Berry and Bove 1997) provides the strongest evidence for an impact, but considerable further work would be needed to either confirm or refute these findings.

2.5 Cancers

2.5.1 Love Canal

Using information from the New York Cancer Registry, (Janerich, Burnett et al. 1981) investigated the risks of cancer in residents of the Love Canal area. Cancer rates associated with living near the Love Canal toxic waste burial site were no higher than those calculated for the entire state outside of New York City. Rates of liver cancer, lymphoma, and leukaemia, were not consistently elevated. Although a higher rate of respiratory cancer was noted, this was not consistent across age groups and appeared to be related to a high rate for the entire city of Niagara Falls. The authors reported that there was no evidence that the lung cancer rate was associated with the toxic wastes buried at the Love Canal site. Confounding factors such as socio-economic status and smoking were not examined.

2.5.2 New York State

In a further study of lung cancer in areas of New York State containing 12 toxic-waste disposal sites, (Polednak and Janerich 1989) examined death certificates of 339 lung cancer cases (decedents) and 676 controls who died of other causes. There was no association between death from lung cancer and residence in the selected census tracts. Analysis of mail questionnaires from relatives of 209 cases who died from lung cancer and 417 controls showed no significant association between lung cancer and a history of ever having resided in the selected areas (response rate approximately 60%). In addition, there was no significant association with cigarette smoking. Duration of residence in the selected census tracts did not differ between cases and controls.

2.5.3 Montreal - Miron Quarry

The Miron quarry, a municipal landfill site in Montreal, Quebec, was mentioned in the section on birth outcomes. Using data from the Quebec Tumour Registry, Goldberg et al. (1995) evaluated whether cancer incidence among persons who lived near the site was higher than expected. Proximity to the site was used to define exposure. Reference areas, with roughly similar sociodemographic characteristics, further from the site were selected for comparison. Among men living in the exposure zone closest to the site, elevated risks were observed for cancers of the stomach, liver and intrahepatic bile ducts and trachea, bronchus, and lung. Among women, rates of stomach cancer and cervix uteri cancer were elevated. Prostate cancer was also elevated in men living in one of the zones closest to the site.

In a further study of the Miron Quarry, (Goldberg, Siemiatycki et al. 1999) investigated whether men who lived near the landfill site were at higher risk of developing cancer than individuals who lived at a distance from the site. Subjects were selected from a previously completed population-based, interview, a cancer case-control study of men who lived in metropolitan Montreal. Thirteen sites of cancer (n = 2,928 subjects) and a population-based control group (n = 417) were analysed. Street address at the time of diagnosis was used to classify subjects by geographic zones and distance from the landfill site.

In the exposure zone nearest to the site, elevated risks were found for cancers of the pancreas, liver and prostate. A high risk was also found for pancreatic cancer and the non-Hodgkin's lymphomas in a sub-exposure zone approximately downwind from the site. When distance from the site was examined, higher than expected risks were found for pancreatic cancer liver cancer, kidney cancer and the non-Hodgkin's lymphomas. These increases in risk were weak and for most conditions were not statistically significant.

2.5.4 United States of America

Griffith et al. (1989) identified 593 waste sites in 339 US counties in 49 states with analytical evidence of contaminated ground drinking water providing a sole source water supply. Age-adjusted, specific cancer mortality rates in counties with one or more of these hazardous waste sites (HWS) were compared with those from counties not containing sites.

Significant associations between excess deaths and all the HWS counties were shown for cancers of the lung, bladder, oesophagus, stomach, large intestine, and rectum for white males; and for cancers of the lung, breast, bladder, stomach, large intestine, and rectum for white females when compared to all non-HWS counties.

Similarly to the earlier study by Janerich et al. (1981), this study did not adjust for confounding factors such as smoking and socio-economic status. Results are therefore difficult to interpret.

2.5.5 New York State

An ATSDR study of cancer incidence surrounding 38 municipal waste landfills in New York State (State of New York Department of Health 1989) specifically targeted sites where landfill gas exposure may have occurred. The New York Cancer Registry was used to identify cases among nearby residents. These were compared with controls, taken from a random selection of deaths from causes other than cancer, and matched for age and sex. Cancers which were thought to be sensitive to the effects of chemical exposures were selected. These included lung, liver, brain and bladder cancers, leukaemia and non-Hodgkin’s lymphoma. Significant results reported were an increase, in women, of bladder cancer and leukaemia. No information was available on smoking status and duration of residence near landfill sites.

2.5.6 Pennsylvania - Drake Superfund Site

The Drake Superfund site in Pennsylvania was the site of a study of cancer incidence. This site had been contaminated by a number of carcinogenic chemicals, including beta-naphthylamine, benzidene, and benzene (Budnick, Logue et al. 1984). In addition to the data on birth defects mentioned above, county-wide, age-adjusted, sex-, race-, and site-specific cancer mortality rates for three decades (50s, 60s, 70s) were examined. During the 1970s, a significantly increased number of bladder cancer deaths occurred among white males in the county, and a significantly increased number of other cancer deaths occurred in the general population of Clinton and three surrounding counties.

2.5.7 Conclusions

The evidence limiting residence near landfills, whether hazardous waste sites or other sites, to cancer is tenuous. The studies, that have been reported are difficult to interpret, usually because of a lack of information on other known major causes of cancer. While, a great deal of further work needs to be done to establish the true risks, it is not likely that the excess risk of cancer for residents living near a waste site is high.

2.6 Symptoms of illness

Many studies of symptoms conducted in communities living near landfill sites rely on self-reported symptoms. The knowledge of and concern about possible exposure to hazards present in the landfill may introduce some bias into the results of these studies. When compared to populations living further away from such sites, individuals in proximity to landfills may be more likely to recall minor complaints and symptoms, which they may attribute to landfill exposures.

2.6.1 Pennsylvania - Drake Superfund Site

The Drake Superfund site was the subject of another study in relation to exposures of the local population (Logue and Fox 1986). This study was carried out in response to public concerns about adverse health effects possibly related to the site. A questionnaire survey was carried out on a cross-section of residents who had lived in the area for ten years or more. A control group of residents was selected randomly from a surrounding area.

No serious chronic health conditions in the exposed group of residents were found. Significantly more individuals in the exposed group complained of skin problems and sleepiness for at least one month prior to the survey, indicative of a possible association between direct human exposure to toxic chemicals from the site and the manifestation of symptoms. The authors acknowledged that the observed increased in prevalence of the two symptoms might also have been caused by factors other than contaminants at the Drake site, such as stress, occupational exposure, or other etiologic agents. This association may also have been a chance finding, or due to differences in recall of symptoms in the two groups.

2.6.2 France - Montchanin

A study of morbidity to assess the short-term health impacts of a hazardous waste landfill was conducted in Montchanin, France by Zmirou et al. (1994). The site released volatile organic compounds (VOCs) into the air and provoked intense health concern in the community. The landfill was closed in 1988. Subjects were 694 inhabitants residing in three different parts of town. Individual exposure was estimated using a dispersion model of volatile air pollutants and information on the daily activity patterns of each individual within the area under investigation. Instead of self-reported symptoms and illness as used in the Drake Superfund study, the investigators used information on the consumption of medications prescribed for specific ailments over a three-year period (18 months before and 18 months after the site was closed).

Although differences were not statistically significant, the most exposed subjects had been prescribed more medications, for diseases possibly linked to emissions from the site before it closed, than had the least exposed individuals. There was a suggestion of a slight trend in the consumption of medications for ear, nose, and throat and pulmonary ailments with individual exposure levels.

In a case control study of the residents of Montchanin, France, conducted during the same period, (Deloraine, Zmirou et al. 1995) used the same exposure information as that reported in the above study. The study was designed to reduce bias introduced by the high degree of public concern locally. Seven participating GPs selected patients according to two categories of ailments thought to be associated with landfill emissions. Controls were patients who consulted their doctor for conditions not associated with these emissions. Associations were reported between exposure and frequency of respiratory illnesses and also frequency of psychological disorders. The bias may not have been fully controlled for, as GP consultation may be associated with increased concern about the effects of the landfill emissions.

2.6.3 New York – Fresh Kills

Levels of morbidity were more recently examined in a telephone survey in New York. Berger et al. (2000) examined the levels of respiratory symptoms and illness among Staten Island residents living adjacent to the Fresh Kills landfill. These were compared to symptoms of residents living on the other side of Staten Island. An increase in respiratory symptoms was reported among residents living near the landfill site. An association was also reported between the odour emitted from the landfill site and the occurrence of eye nose and throat irritation.

2.6.4 Poland

A study of a Polish population living near a large mixed (hazardous and municipal) waste site near Warsaw was reported by Zejda et al. (2000). A self-administered questionnaire survey was conducted in tandem with a physician-administered questionnaire. Exposure was estimated by three measures: distance from the waste site; area of residence; and intensity of transport traffic to the waste site in the vicinity of the subject’s house. No control group was identified. The response rate was very poor (11% overall), with the highest rate among residents living nearest to the site. Although the investigators reported an increase in psychological complaints, respiratory and gastrointestinal disorders, and in allergic symptoms, the results are unreliable due to the methodological problems with the study.

2.6.5 Conclusions

These studies are generally methodologically weak, apart from that of Berger et al. (2000). It seems reasonable that residence near landfills might be associated with an excess of minor symptoms, but this remains to be established.

2.7 Other health impacts

There are certain other categories of possible health effects of living near landfill sites that have been less closely examined. These include psychological effects, hazards related to transport, and the impact of noise and disturbance on human health.

2.7.1 Psychological impacts

A recent unpublished review of psychological effects by Hollie Thomas from the University of Wales identified eight studies, mostly relating to hazardous chemical landfill sites addressing these impacts namely -(Bachrach, Zautra et al. 1989; Dunne, Burnett et al. 1990; Foulks and McLellen 1992; Zmirou, Deloraine et al. 1994; Deloraine, Zmirou et al. 1995; Kilburn and Warshaw 1995; Miller and McGeehin 1997; McCarron, Harvey et al. 2000). These studies, which covered 7 sites, as two -(Zmirou, Deloraine et al. 1994; Deloraine, Zmirou et al. 1995) cover the same site, used different methods of assessment, and different measuring instruments.

2.7.1(a) Positive studies

Three of these studies reported a significant difference in scores on a standardised scale of psychiatric morbidity between exposed and unexposed residents. Dunnet et al. (1990) studied residents on the site of two old mines in New Zealand, which had been used as a hazardous waste dump and a municipal dump, and they reported that exposed residents scored approximately six points higher on the GHQ-28 on average than unexposed residents. Foulks and McLellen (1992) studied residents living near a chemical waste dump in the United States, and reported that exposed residents scored 0.37 points higher on average on the SCL-90. Kilburn and Warshaw (1995) studied residents at a Superfund site in the United States and reported an average increase in 33 points on the POMS score in exposed residents.

2.7.1(b) Negative studies

However, McCarron et al. (2000) found no significant difference in mean SF-36 score between residents exposed to a chromium waste landfill site and those not exposed, whilst Miller and McGeehin (1997) found a significant association between diagnoses of anxiety, nervousness or depression and exposure to an oil processor site only amongst individuals who were current drinkers.

2.7.1(c) Irish studies

Irish studies in Askeaton Co. Limerick, where a large study of environmental concerns was carried out in an area where there were concerns about environmental toxicity amongst animals, found no difference between residents in the area which was the focus of public concern, and people living in other comparable areas (Kelleher, Birbeck et al. 2001; Staines, Houghton et al. 2001).

2.7.1(d) Conclusions

Interpretation of these results is difficult. There are very few studies, in very different communities, with very different exposures. It seems probable that marked concern about living near a potentially hazardous site might contribute to psychiatric morbidity, but the evidence remains inconclusive.

2.7.2 Traffic related hazards

Another category of plausible hazards to resident near a landfill site is traffic. Landfills are usually located in rural area, and often served by small country roads. These roads must bear a heavy burden of traffic, and local residents will almost surely have an increased risk of road traffic accidents, and higher levels of air pollution than would otherwise be the case.

The impact of landfill use on wider traffic burdens does not seem to have received much attention in the health literature. EIS's for landfills reviewed by us (Staines et al, unpublished) usually consider only local traffic burden, and never seem to include air pollution from the operation of diesel fuelled lorries in their impact estimates.

2.7.3 Other possible hazards

Landfill operations, especially those of poorly run sites, can lead to the emission of unpleasant odours. The health effects of this do not seem to be well established. In the literature odour is commonly referred to as a 'nuisance', with the implication that it is not a serious issue, and hence, not a priority for amelioration.

Noise from traffic from site operations is another potential health issue. A great deal of published work on airport noise exists, but like odour, this issue has not been well explored in the waste management and health literature.

2.7.4 Emissions from waste management sites

Emissions from landfills do not always lead to human exposure. Exposure can only arise if individuals come into contact with the harmful agents in emissions. Contact can be by breathing, skin contact or eating or drinking food or water contaminated with the substance. If there is no contact there can be no toxicity.

Another important factor to take into account is the fact that a person may be exposed to levels of the compound from other sources. If a person is exposed to a harmful substance, a number of factors will determine whether a harmful or toxic effect is likely to occur. These factors will include the dose (how much), the duration (how long) and the route of exposure. Other factors to be considered include age, gender, diet, family traits (possible genetic susceptibility), lifestyle, state of health and consideration of other chemicals to which the person may be exposed.

Landfill sites contain many different potentially toxic substances. Potential and actual hazardous emissions from these sites have caused concern to both local populations and regulatory bodies. This has resulted in numerous studies examining different potential adverse effects. These studies indicate that residence near certain specific sites is associated with risks to health.

Although a great number of studies have been carried out, evidence of a causal relationship between specific health outcomes and landfill exposures is still inconclusive. Methodological difficulties make determination of cause and effect very difficult. Difficulties in assessing and categorising exposure, and difficulties in controlling for other confounding factors, limit the ability of such studies to detect these adverse effects.

2.8 Health effects of landfilling

At present there is insufficient evidence to demonstrate a clear link between cancer and exposure to landfill. Excesses of bladder, lung, leukaemia and stomach cancer have been reported in some studies and not in others. The association between adverse birth outcomes such as low birth weight and birth defects is more compelling, but as yet cannot be described as causal. Further studies are required. In particular, examination of specific types of defects, which may be related to exposure to specific environmental agents may serve to clarify these questions.

Reports of increased risk of respiratory, skin and gastrointestinal illnesses are based mainly on self-reported symptoms. Although this evidence must not be dismissed, consideration should be given to the strong possibility of bias and the influence of fears and worry related to the waste sites.

Much of the existing work relates to older landfills, which would have been managed poorly by modern standards, or specifically to hazardous waste landfills. It seems likely that the health impact of residence near modern landfills, run in strict accordance with standard operating procedures, would be smaller.

PART 3: EVALUATION AND MONITORING OF POSSIBLE PUBLIC HEALTH PROBLEMS ARISING FROM LANDFILL SITES

3. Objectives

- To outline the tests that can be done to evaluate and monitor possible public health problems from landfill sites for e.g. the tests that can be done to measure the levels of leachate from landfill sites
- To outline the control measures that can be put in place to reduce public health effects of landfill sites and of leachate in particular?
- To describe any further current relevant issues e.g. “Drinking water standards and quality”.

3.1 Environmental contamination

The primary route by which environmental contaminants from landfill sites affect the environment is probably through discharge of leachate into surface water or, more usually, ground water. Other routes which may be important are the diffusion of gas through soil, direct gaseous, vapour and dust emissions to air, vector carriage of contaminants, especially bacteria, from the site, and bulk airborne dispersion of larger pieces of contaminated rubbish.

A mode of environmental contamination which has been relatively understudied is the airborne emission of bacterial and fungal spores, toxins and antigens. Emissions of microbial and fungal spores from composting are known to reach levels which could be associated with health effects, and which are far higher than background levels (Lacey and Crook 1988; Danneberg, Gruneklee et al. 1997; Reinthaler, Haas et al. 1999; Mullins 2001). We were unable to identify any comparable studies of landfills. It is worth emphasising that these could conceivably be the main emissions from a well-run modern landfill site.

3.2 Human health impacts

For human health effects of landfill emissions to occur it is not sufficient for landfill emission to the environment to occur, there must also be human exposure to the emissions, and absorption of hazardous compounds in sufficient quantity to produce health effects.

It can be very difficult to detect small health impacts, especially in small populations, and for this reason direct evidence of health impacts in the local population is neither a sensible nor feasible monitoring tool. This is one of the reasons that epidemiological studies of populations living near landfill sites are not more conclusive. Direct measures of environmental contamination are likely to be much more sensitive.

3.3 Congenital malformations

Congenital malformations are the health outcome related to landfill exposure for which there is most evidence. Several studies, as discussed earlier, have provided good evidence for a small increase in the risk of congenital malformations in residents near landfill sites. The best evidence, from the EuroHazCon study (Dolk, Vrijheid et al. 1998; Vrijheid, Dolk et al. 2002), relates to hazardous waste landfills, but the SAHSU study, which covered all types of landfills also showed a small increase in risk (Elliott, Briggs et al. 2001).

At present, there is no national surveillance scheme for congenital anomalies. In the absence of such a scheme, it is not easy to assess possible effects of landfills. It would be impossible, for example, to replicate the SAHSU study in Ireland outside Dublin and Galway. However, surveillance for congenital anomalies is unlikely to be sensitive enough to suffice as a monitoring system for health effects around landfills.

We are currently awaiting the results of an Irish study of congenital malformations and proximity to landfill sites.

3.3.1 Birth weight, prematurity and child growth

Evidence relating landfill exposure to birth outcomes apart from congenital anomalies is less convincing. Existing birth registration systems cover all Irish births, but do not provide results on a fine enough geography to be of any use for this purpose. ERHA currently have small area birth data, but most of the rest of the country does not.

3.4 Cancer

Unlike the other health outcomes discussed here, there is an excellent national system of cancer registration. It is far from certain that landfills are associated with an increased incidence of cancer. However, any increase in cancer risk amongst residents in the vicinity of a landfill site is likely to be very small, even if the site is very poorly managed. Again, cancer incidence is not likely to be a useful tool for health monitoring around landfill sites.

3.5 Symptoms of illness

There is currently no routinely collected information on prevalence of symptoms in Ireland. Standardised self-reported health assessment tools can be used for this purpose, primarily in ad hoc studies. Slán is a recent large scale Irish health study, and the questions used by the Slán group are likely to be useful for local investigations.

Primary care attendance and hospital admission and A+E attendance can be used to identify and monitor the health effects of large scale releases of chemicals, but this will seldom be of use in monitoring the health effects of landfill emissions. This could be particularly useful in the study of vulnerable or sentinel groups.

Continuous and insidious releases are more difficult to detect using these data sources due to the many other factors influencing health care uptake.

3.6 Other impacts

Other impacts of landfill site operation are likely to be harder to detect.

3.6.1 Psychological impacts

Rather like monitoring symptoms of disease around sites, these are not available from any routine sources. Slán and the Askeaton studies have used a number of instruments to monitor psychological distress in Irish populations, and these could be used as part of specific health studies around exposed sites. Little is known about the sensitivity of these instruments in identifying psychological impacts.

3.6.2 Traffic

The health impact of traffic in relation to landfill site operation is hard to specifically identify. Existing data sources do not record what vehicles involved in road traffic accidents were doing when the accident occurred. Injuries close to landfill sites are identifiable, but those remote from the site are usually not. Greater attention needs to be paid to road transport issues in the design of landfills.

Air pollution from vehicle exhausts probably represents a significant proportion of the total emissions from landfill operations, and such emissions are known to have significant health effects. Issues of landfill location, use of alternative modes of transport, for example, rail, and alternative fuels for trucks, all need careful assessment. Existing models can estimate the impact of operations on air pollution and health, given basic traffic data.

3.7 Other possible hazards

A hazard which should be remembered in assessing landfill impacts is the hazard to people working on the landfill site. Landfills are potentially very dangerous places to work, with many opportunities for exposure of employees to hazardous substances, and a significant risk of accidental injury. Meticulous adherence to occupational health and safety practices will be required.

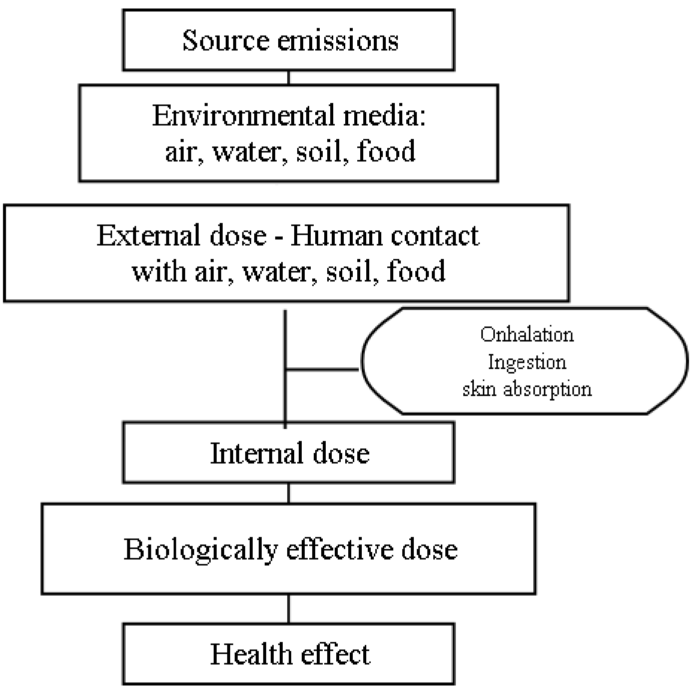
3.8 Biomonitoring

Human exposure to pollutants is normally monitored by measurement of potentially harmful chemicals in the environment. However biomarkers are a valuable means of detecting environmental exposure to pollutants as they can measure possible biological effects before overt disease develops.

The concepts and principles of application of biomarkers to health risk assessment and criteria for selection and validation were reviewed by a WHO Task Group on Biomarkers and Risk Assessment (World Health Organisation 1993). In the assessment of risk, biomarkers may be used in hazard identification, exposure assessment and to associate a response with the probability of a disease outcome (Anonymous 2000; Wakefield 2000). By examining the interactions between human host and chemical exposure, and comparable data for experimental studies of mammalian species, criteria for the selection of biomarkers indicative of exposure, effects, susceptibility and toxic response(s) to chemicals may be established. The reaction to exposure to a chemical depends on inherited and acquired characteristics and the life-style of the individual, the properties and form of the chemical, and the circumstances of the contact.

Human health is affected by all the activities of an individual, who is subject to a continuum of chemical exposures in the external environment, including air, water, soil and food. The important considerations for assessment of risk are the dose rate, route, duration and frequency of exposure (Figure 1.).

Figure 1 – Conceptual model of exposure assessment using biomarkers.



The application of biomarkers, linked to toxic processes or mechanisms, to the risk assessment process, and particularly to quantitative risk assessment, has the potential to provide a more rational and less judgmental process, particularly when compared with methods that arbitrarily attach protection factors to doses assessed to minimize or avoid adverse health effects.

A major advantage of using biomarkers is that the measurement of internal exposure is more likely to be directly related to adverse health effects than the measurement of external exposure. Measurements of concentrations of potentially harmful agents in a critical organ or site of action (the most sensitive organ or site, where adverse effects are seen at the lowest concentrations) such as the brain, liver, kidneys or skeleton is rarely possible unless an autopsy or surgery is carried out.

In contrast, a biomarker that mirrors the result of the exposure may be measured in human tissues or body fluids. Ideally, biological monitoring mirrors the concentration of the hazardous agent in the body organ of concern. Biological monitoring has proved to be particularly useful for assessing exposure to metals (Elinder, Friberg et al. 1994) as well as for more than 50 organic substances (Lauwerys and Hoet 1993).

The usefulness and application of biomonitoring in assessing health effects in populations living in the vicinity of waste dump sites has been examined in recent reports from the WHO (Anonymous 2000). They have the advantage that they take into account inter-individual differences in absorption, metabolism, bioavailability, excretion and distribution (Bond, Wallace et al. 1992).

Although it also has limitations, biological monitoring is complementary to environmental monitoring because it takes into consideration the biokinetics or toxicokinetic factors of a compound. In addition, biological monitoring may reflect different patterns of exposures over time that might not have be detected in sporadic environmental measurements, and integrates exposure occurring shortly before the sampling (some hours) with exposure occurring some days previously.

However, a measured internal dose may reflect the accumulation of repeated exposures. A prerequisite for biological monitoring is knowledge of the physio-chemical properties, kinetics and stability of the compound and the sensitivity and specificity of the monitoring methods. Examples of substances which may be of concern related to waste sites and for which biomarkers have been developed to assess exposure include the following (Table 9) :-

Table 9 Examples of selected substances for which biomarkers of exposure are readily available.

Substances	Biomarker
Lead	Blood lead
Cadmium	Urinary cadmium
Chromium	DNA-protein cross-links
Mercury	Urine mercury
Polychlorinated biphenyls (PCB)	Serum PCB
Volatile organic compounds (VOC)	Blood VOC
Chlorinated pesticides	Breastmilk chlorinated pesticide
Polycyclic aromatic hydrocarbons	DNA adducts

Biomarkers of exposure (dose) may be used in a similar way as personal monitoring. Appropriate biomarkers are only available for a limited number of substances, and should only be used when there are clear indications of exposure (e.g. from stationary monitors in houses).

3.8.1 Biomarkers of health effects.

Biological markers of health effect have been defined by the US National Research Council as "indicators of an endogenous component of the biological system, or an altered state of the system that is recognised as impairment or disease" (National Research Council 1991). They can be used in three main ways:

(i) to screen for preclinical signs of a disease,

(ii) to facilitate conventional epidemiological studies of disease aetiology, and

(iii) to monitor variations in health risk (Vainio 1999).

In terms of measurable health effects, biological markers may be used as indicators of (i) an alteration in a tissue or organ; (ii) an early event in a biological process that is predictive of a development of a health impairment; (iii) a health impairment or clinically recognized disease; (iv) a response peripheral or parallel to a disease process but correlated with it and thus usable in predicting the development of a health impairment (Committee on Biological Markers of the National Research Council 1987). The application of well established biomarkers for a specific endpoint or health outcome linked to exposure and toxic mechanism has the potential to enhance the reliability of predictions of risk.

However, there are large inter-individual variations in responses to equivalent doses of chemicals and such biomarkers may not be specific for a single toxic chemical as a causative agent. Many biomarkers of effect have been established and used in occupational and environmental epidemiology as tools for detecting early and reversible clinical effects in target tissues and organs.

In studies on health effects of effluents from waste landfills, the priority in selecting biomarkers of effects should be given to those which are available for detecting early signs of health effects most frequently found in association with exposures from waste landfills (Indulski and Lutz 1995). Examples of health effects for which biomarkers have been developed include the following (Table 10):

Table 10 Health effects of chemical and other environmental exposures which can be identified using biomarkers.

Health effect	Selected biomarker
Hepatotoxicity	Serum aspartate and alanine transaminase enzymes
Nephrotoxicity	Functional markers - serum creatinine, albumin, alpha 2 - microglobulin
(Cytotoxicity)	Markers - tubular antigens, urine enzymes Biochemical markers - sialic acid, glycosaminoglycans Tubular proteinuria - beta-2-microglobulin, NAG, RBP
Immunotoxicity	Lymphocyte changes - T cells, IgE antibodies
Pulmonary toxicity	Neutrophils, cytokines
Neurotoxicity	Plasma and erythrocyte acetylcholine esterase inhibition
Genotoxic carcinogenesis	Chromosome aberrations, micronuclei, sister chromatid exchanges.

Biomarkers must be validated before application in the risk assessment process by establishing the relationship between the biomarker, the exposure and the health outcome.

In conclusion, using biomarkers for assessing health risks related to exposure to toxic effluents from landfills may provide an alternative to the use of traditional health outcome measures. The use of biological markers in epidemiological research should be a means, not an end (McMichael 1994). Before initiating field studies in which biomarkers are to be used, it is cost-effective to make a critical evaluation of the suitability of the biomarkers selected for the study. Such an evaluation should be based on the statistical sensitivities of the specific tissue or function biomarkers and health endpoints for detecting changes. Identification of the compounds present in landfill emissions helps to decide on when and if biomonitoring is appropriate.

PART 4: CONTROL MEASURES FOR REDUCING THE IMPACT ON HUMAN HEALTH OF EMISSIONS FROM THE OPERATION OF LANDFILL SITES

4. Introduction

As discussed above, landfills contain many hazardous substances. A primary objective of landfill design and practice is to ensure containment of these substances and to provide early warning of unexpected or excessive release of landfill contents into the wider environment.

4.1 Detection and Monitoring of Groundwater contamination

In general, there are a number of different types of monitoring, including

- Ambient e.g. National sampling programmes
- Baseline i.e. before a facility starts operations
- Compliance i.e. routine monitoring of a facility during operation
- Detection i.e. during normal operation of a facility to identify a problem
- Assessment i.e. having identified a problem to determine the extent and severity of the problem
- Research

Since the purpose and objectives of each of these are different so must the approach and the design of the respective monitoring systems.

The purpose of monitoring at a modern, properly designed landfill, is to detect leaks of leachate through the liner systems. It can be assumed that landfills without liners or caps will leak leachate to the environment and that a plume of leachate extends from the landfill. The main purpose of monitoring is to determine where the leachate is going and how fast.

Leachate detection and monitoring systems must take account of all the factors mentioned earlier. For modern landfill operations, the Irish EPA has produced a series of manuals on design, operation and monitoring (Environmental Protection Agency 1995; Environmental Protection Agency 1995; Environmental Protection Agency 1997; Environmental Protection Agency 1999; Environmental Protection Agency 2000). A thorough knowledge of the hydrogeological setting is required, *prior to designing a monitoring strategy*. Standard monitoring protocols for modern lined landfills may not be appropriate for illegal landfills. These protocols are designed to maximise the probability of detection of a relatively narrow leakage plume if it occurs. Also, modern landfills will have systems in place to monitor leakage of leachate though the first layer of liner, something which doesn't apply to unlined landfills.

The first task is to understand the local hydrogeology, the soils and bedrock (types of material and thickness), and to identify recharge areas, springs and existing wells. If these do not provide sufficient information about the background groundwater flow field then some trial boreholes may be required. Water levels are measured in these and from comparison with other boreholes and wells a general hydraulic gradient direction can be estimated. From this the wells, springs or rivers most at risk from the leachate can be identified.

In the circumstances being considered here, an unlined landfill in a comparatively wet Irish climate is certain to generate leachate so the purpose of monitoring is to map its extent and movement so that its threat to existing water resources can be assessed. The plume from an unlined landfill is likely to be larger than from a leak in a lined landfill.

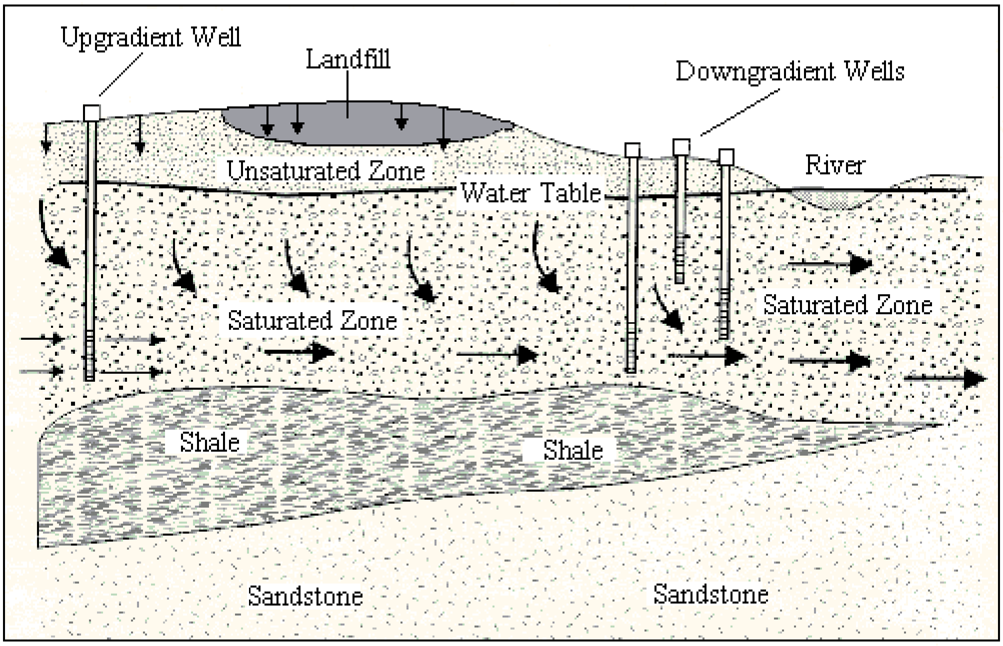
Once the background groundwater movement is known, the general direct of plume movement can be estimated. What is difficult to predict is the velocity of the movement and the extent of plume dispersion (spreading out in a direction perpendicular to the general movement). These depends greatly on the type of aquifer permeability i.e., intergranular, fissure or karst (roughly low, medium and high rates of flow). Monitoring boreholes, where water level is measured and from which water samples are taken for analysis are required, but these require careful placing, not only terms of locations but also depth of screen. For example, in Figure 2, three monitoring wells are located close together, but each extends to a different depth to increase the probability of detecting leachate if it reaches the location.

The programme will include monitoring of existing water sources as well as purpose built and sited monitoring wells, e.g. Figure 2. High total organic carbon or chloride concentrations in groundwater may signal leachate contamination, but much depends on the character of the ambient groundwater.

In addition to monitoring boreholes, there are a number of surface geophysical techniques that may be able to detect a plume of leachate in the groundwater. These methods use instruments on the surface of the ground to measure some characteristics of the subsoil, such as electrical conductivity, which is changed by contamination with leachate. A drawback of the groundwater detection methods is that, for recently placed wastes, the leachate plume may not yet have reached the water table and it will not be detected until it reaches a monitoring well, which may take considerable time Thus it is beneficial to have at least some of the monitoring wells close to the landfill.

Monitoring frequency will depend on many factors, including the type and purpose of monitoring the number and nature of vulnerable locations and the hydrogeology. For compliance monitoring, monthly sampling during landfill operation and quarterly sampling after closure is often specified

Figure 2 : Typical schematic of monitoring wells (Source: US GAO, 1995)



In an investigation, in the UK, to assess of the impact of old landfills on groundwater quality, two domestic waste sites in sand and gravel workings above the Middle Chalk were investigated. The authors reported that (Williams, Noy et al. 2001)

> "Initial drilling and a 2-D resistivity survey failed to detect a significant pollution plume in the Chalk. However, water level monitoring in more closely spaced boreholes has revealed a high degree of seasonal variability in groundwater flow direction, while a 3-D resistivity tomography survey has identified the spatial variability in leachate drainage below the waste. The pulsed release of leachate from specific areas of the landfill has been modelled whilst changing hydraulic heads at the flow boundaries. The results illustrate how the tortuous migration pathway enhances lateral dispersion and dilution of the plume. The study highlights the need for a detailed and accurately surveyed network of boreholes for continuous water level and groundwater quality monitoring in high transmissivity fractured aquifers."

This is confirmation of the practical importance of the factors raised above. It serves to emphasise the need for detailed site-specific design for monitoring programmes.

4.2 Remediation Options

Remediation actions can be categorised as those applied at the waste site, at water abstraction points or in between.

4.2.1 Actions at the landfill

a) Cap the landfill with an impermeable cover, as in the closure of a modern landfill. This will prevent or reduce the ingress of rainwater and the generation of leachate. One consequence is that waste degradation processes within the waste will slow down considerably, but the total duration of the decay and thus the duration of the threat to groundwater will be prolonged.

b) Remove the waste. If this option is chosen then all of the waste must be removed (the reduction in leachate plume volume or concentration of contaminants is not pro rata with percentage of waste removal). The waste must then be segregated and the hazardous (if any) and non-hazardous fractions managed appropriately. As this may involve transport to another site, there are health risks involved in the handling and transport.

c) Containment of leachate at site. Provide structural barriers to prevent leachate leaving the vicinity of site. For example, vertical barriers (walls) usually combined with hydraulic control measures, e.g. inward hydraulic gradient created by pumping the groundwater (which must then be treated and discharged elsewhere). In the latter case, the wall reduces considerably the rate at which water must be pumped from the vicinity of the landfill to maintain an inward hydraulic gradient) Funnel and gate arrangements can be constructed to manage contaminant plumes. These channel the leachate into areas where they may be treated. Barrier materials should have a low permeability ($< 10^{-10}$ m/s) and diffusivity and should be corrosion resistant with a long service life. Slurry walls will be thin because of cost.

Quality Control and Assurance are both very important because of the complexity of the methods. There are a number of possible techniques:

a) Excavation of soil and placement of wall (e.g. slurry (soil-bentonite or cement-bentonite) wall, composite wall, interlocking bored pile wall, HDPE liner wall)

b) Displacement of soil and placement of wall (e.g. sheet pile wall)

c) Reduction of soil permeability in place (e.g. injection wall, jet grouting, frozen wall)

d) Reactive walls (e.g. permeable reactive wall, funnel and gate)

e) Other barrier types include :- Grout barrier; Deep Soil Mixed Barrier; Soil Bentonite slurry cutoff wall; Capillary barriers; Combined systems; Permeable reactive barriers.

4.2.2 Actions at a water supply source

- Find an alternative source of water and discontinue use of the contaminated source. This may involve constructing a new well in a different location, or deepening the existing well to tap into a deeper possibly uncontaminated source. Alternatively, it may involve providing a connection to a treated water supply. Care must be taken to ensure that utilising a deeper source does not draw the plume downwards into the deeper aquifer.

- Treat the water abstracted from the source to make it safe before using it.

4.2.3 Actions to remediate the groundwater and plume

- Bio or phyto-remediation. Insert specially chosen bacteria into the ground in the path of the leachate which can digest components of leachate.
- Air sparging. Pump air into the ground to accelerate oxidation/degradation of material in plume.
- Plume capture. Install a pumping well which draws in the contaminated plume. The landfill site must be in the capture zone of this well. The volume of pumped water will likely be considerable and will require treatment.
- Rely on "monitored natural attenuation". It may be that the natural attenuation and dilution of the plume in the aquifer may reduce contaminant concentrations to acceptable levels. If so then a monitoring network to measure and verify this will be required.

4.3 Irish resources for further information

a) Geological Survey of Ireland,(GSI) Groundwater Section, Beggars Bush, Dublin 4. They have undertaken an aquifer protection study for a large number of Local Authorities (including Wicklow County Council) and have up-to-date aquifer and soil maps, which are an essential prerequisite for predicting the fate of the leachate plume.

b) Environmental Protection Agency, Waste Section, Head Office, Johnstown Castle, Ardcavan, Co. Wexford. They have produced a comprehensive set of landfill manuals which describe the design, construction and operation of a modern landfill so will be aware of "best practice" in this area.

4.4 Monitoring and Control

4.4.1 Landfill Gas Monitoring

Because of the possibility of landfill gas travelling through preferential paths of least resistance, the most important places to take samples of soil gas are (i) close to the buildings or open spaces where the public may gather (e.g. football pitches, playgrounds etc.) which are nearest the landfill and (ii) close to the landfill itself. The former is to provide a warning of an immediate threat to the buildings occupants and the latter is to check if landfill gas is migrating horizontally from the landfill (and not up into the atmosphere). Small diameter Landfill Gas Probes are installed in the soil away from any source of negative pressure (suction). A combustible Gas Indicator capable of detecting methane at from 5% to 10% concentration range is required and a soil gas vapour probe and a pump if the probe is very deep. The EPA Landfill Monitoring manual (Environmental Protection Agency 1995) has a list of suitable instruments together with the advantages and disadvantages of each.

4.4.2 Control of leachate and landfill gas

The optimum place for the application of leachate and gas control measures is at the time of construction of the landfill. Much of modern landfill design, including the use of cells, double liners, and capping are intended precisely to minimise the risk of accidental emissions during routine operation and afterwards.

Adherence to good engineering and construction practices, and the EPA design manuals is necessary. Landfill design has already been covered in some detail earlier in this report, and we will not discuss it further here. Application of modern design features, and good operating practice can reduce off-site hazards significantly.

4.4.3 Control of dust and windblown rubbish

Like much else in landfill operation, control of dust and windblown rubbish should be designed into a modern landfill. Devices such as fences and netting to catch larger items of escaped rubbish may be effective in minimising obvious nuisance, but careful adherence to standard operating procedures will be more effective. Correct handling of waste on-site, with proper covering will be effective. For minimising dust borne hazards specific control over the categories of waste accepted at a facility will remain important.

4.4.4 Vermin control

Vermin control requires adherence to good operating practice. The principal vermin species associated with landfill are flies, wild birds (especially gulls and members of the crow family) and rodents, but other scavenging mammals such as foxes and badgers can also cause problems. Although flies tend to stay near the food source from which they emerge, they have been known to travel up to 8 km a day, given favourable winds. A study of fly species in the vicinity of a landfill site in Wicklow found 14 different types, all from the order Diptera (Murray 1996). The resident insect population is liable to be augmented by incoming refuse material. UK estimates for a facility serving 10,000 houses are that some 20,000 fly maggots would be dumped into refuse each week (Busvine 1980).

Vermin have the ability to carry disease vectors (bacteria, viruses, fungi) and chemical contaminants out of the site, either directly or through the spread of litter. Distributed litter can cause its own visual and physical hazards (e.g. fire hazard, choking of domestic animals, blockage of drains and watercourses). In all cases, the impacts from vermin can be minimised through chemical control with insecticides/rodenticides (which have their own impact on contaminant levels in the site) and by appropriate containment and regular sealing of the landfilled material. Bird populations can be reduced by visual or audible scaring techniques, or through the use of falconry, but birds become acclimatised to these tactics.

4.4.6 Traffic control

Traffic management is a major factor in relation to landfill operations. Two issues arise, first a global issue of the location, and size of waste disposal sites, and secondly a local issue about traffic handling for each individual site.

The global issue is harder to address, but may be more important in terms of the impact on human health. Landfills are costly to establish and quite expensive to run. There is at least some incentive to have fewer, but larger, landfills. The price for this is that every item disposed of in the landfill must travel further before disposal. The human health impact depends on the amount of travel, and on the mode of travel. In Ireland, the vast majority of landfill waste travels in diesel-fuelled lorries on public roads. Diesel exhaust emissions have well characterised effects on human health, and road transport is associated with well-known risks of injury.

A systematic national study of the locations of landfills and other waste disposal sites, together with a thorough evaluation of ways of transporting waste should be considered.

Local traffic management is also an issue. Most older landfill sites are in rural areas, often poorly served by road. The impact of a large number of heavy lorry movements on small roads can be very severe. Appropriate design of road links to new and existing landfill sites should consider both protection from hazard and abatement of nuisance to local residents.

4.5 Illegal landfills

A major source of recent public concern has been the discovery of illegal landfill sites operating in various parts of the country. These sites raise many legal and regulatory issues that are beyond our remit, but it seems appropriate to consider possible health hazards that might arise from the location and operation of such sites.

Illegal landfill sites are locations where significant volumes of assorted wastes have been dumped. Those identified so far seem to have used existing excavations, such as quarries for their dumping. Unlike older municipal waste dumps, where the location was selected with a view to protecting local water supplies, quarries are built wherever the appropriate material can be found. Quarries are often deep, and may extend below local groundwater levels. Issues of hazard to local residents and local water supplies are not a major factor in the choice of sites for illegal dumping.

Illegal landfills do not operate according to the Waste Management regulations. This has two implications. First, such sites may have received wastes of types that would not ordinarily be permitted in landfill. Examples include hazardous chemical wastes, biologically contaminated hospital wastes and poorly characterized wastes such as contaminated soil, sludge and the like. Secondly such sites will not have liners, or monitoring systems in place. Therefore, unless the illegal dump is in an unusually favourable location, all such facilities will leak leachate in to the local soil, and in due course into the local groundwater.

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