Department of the Environment:
Contaminated Land Research Report

GUIDANCE ON PRELIMINARY SITE INSPECTION OF CONTAMINATED LAND

Prepared by Applied Environmental Research Centre Ltd

CLR No 2 Volume Two (of Two)

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REFERENCES

1. INTRODUCTION

This is the second volume of a two volume report providing guidance on the identification of visual and other sensory indicators of the possible presence of contamination on a site. Volume 2 provides a detailed review of the relevant literature on these indicators. Volume 1 is intended as a manual for use on site and includes a check list and assessment forms.

A range of abiotic and biotic indicators have been identified that are all detectable by sight or smell.

- Abiotic indicators include: debris and structures on site; anomalies in topography and soil between the site and adjacent land or within the site; the presence of characteristic colours and odours.

- Biotic indicators are related to the biological features of the site and include: the type of animal or plant species present; symptoms of effects of contamination in any species; the condition of the soil.

The review provides an introduction to the use of these indicators, followed by separate sections on the main types of contaminants and the indicators associated with them. These sections include tables summarising the information discussed and giving references.

The review is based on information drawn from:

- scientific literature;

- experience of AERC staff and associates;

- consultation with local authority staff with experience of assessment and redevelopment of contaminated land;

- consultation with major industries.

The review, and the manual which it complements, are intended primarily for use at the site inspection stage of investigation.

Both volumes concentrate on information directly relevant to visual and other sensory assessment during a short site visit. The review makes few references to ecotoxicological and other chemical data, except where these may assist in the interpretation of field observations. More emphasis has been given to field records of indicators, particularly in the UK, than to information obtained under laboratory conditions. Taxonomy generally follows that provided in the literature reviewed.

Much of the information in this review is based on papers and books which were written for purposes other than providing sensory indicators of contaminated land. The use of the material they contain for on-site investigations is to some extent speculative and will need to be tested thoroughly.

2 SUMMARY OF REVIEW

A range of abiotic and biotic indicators has been identified which, in combination, can provide useful clues concerning potential contamination in preliminary site inspections. Biotic indicators are rarely of use unless considered in the context of abiotic indicators and information on site history.

Useful abiotic indicators include: the presence of debris and structures on site; physical appearance of waste materials; discontinuities in topography, and/or soil type between the site and adjacent land or within the site; and the presence of characteristic odours and colours. Indicators related to biological features of the site include the presence of tolerant species; appearance of species; species diversity and poor soil structure and greater depth of litter layer which may be related to reduced soil microbial activity.

Biotic indicators are only useful on sites in which the concentrations of contaminants are sufficient to affect biota; they are of little use where contaminants do not affect biota even though their levels may be above normal background concentrations. Most of the indicator species identified also occur on uncontaminated sites; their usefulness lies in the information to be gained from the whole biotic community present, rather than individual species, in combination with other features of the site.

Plants are generally the most useful biotic indicators since they are static, they root directly into the medium, and discontinuities in plant communities and any individual symptoms attributable to contamination are readily visible. Limitations of their use as indicators arise from their seasonality and the fact that their distribution and abundance and any symptoms they display are also influenced by other ecological factors. Also shallow rooting species may not reflect contamination at depth. Nevertheless plants are generally the best documented group. Among animals, invertebrates are more useful indicators than higher animals, and aquatic invertebrates (where present) more useful than terrestrial invertebrates as they are more visible.

Biotic indicators have been identified for some contaminant groups but not others. For metals and for waste material of extreme pH or salinity there are a number of indicator plant species; for high Biochemical Oxygen Demand (BOD) organic discharges and seepages into water bodies on or adjacent to the site, aquatic macroinvertebrates are useful indicators. There are few reliable indicators (either tolerant species or visible symptoms) for most non-metals, synthetic organics or gases. However, there are some abiotic indicators which may provide evidence for these contaminants.

Metal indicator plant species are usually tolerant of several metals and their distribution and any symptoms they display may also reflect other environmental factors such as pH and soil texture. Therefore they tend to be indicative species rather than true indicators. Chlorosis of young leaves is a typical symptom of metal contamination, but it can also be caused by other environmental factors such as nutrient deficiency.

Extremes of pH are indicated not only by certain characteristic plant species, but frequently by overall plant diversity. As a rough guide a high pH soil is likely to support between 30 - 40 species, whereas a low pH soil is likely to support no more than 5 species.

Varying degrees of pollution by high BOD organics are indicated in fresh water by particular invertebrate groups, and also by overall invertebrate diversity: the lower the BOD the higher the diversity. The use of invertebrates as heavy metal indicators is less well documented, although some authors consider the percentage of chironomids in invertebrate samples to be a useful index: a high percentage of chironomids in a sample may indicate metal contamination. However the value of freshwater invertebrates as indicators is limited as not all contaminated sites have water bodies on or associated with them.

Where possible the interpretation of biota on land which may be contaminated should be compared with biota on adjacent land, both semi-natural and disturbed. Particular caution is required where no comparison is possible.

There are a number of relatively simple biotic indicators which can be used by inexperienced personnel. These include an assessment of vegetation cover, community discontinuities, the relative diversity of plants compared to similar uncontaminated sites; chlorosis of young leaves; stunting of root growth (where comparisons with healthy plants are available); relative diversity of invertebrates in water courses above and below the site, and absence of fauna from well established pools on the site.

This review has focused on sensory indicators. The uses of indicator species in the context of ecotoxicological studies may provide more information on the significance of contamination at a site, especially for those contaminants for which there are no sensory indicators.

SUMMARIES OF INFORMATION

Summary Sheets

Chapters 4 to 8 discuss different groups of contaminants that may be found on contaminated sites. At the end of each chapter there are summary sheets recapitulating the sources and the abiotic and biotic indicators of the contaminants dealt with in the chapter. Common names of animals and plants are used where they are available.

Where information is available the environmental factors influencing toxicity and non-toxic factors producing similar symptoms are included.

There are serious gaps in information: where no information is given under a heading it means that there is no literature on it, not that there is positively no effect.

The Appendix

The appendix at the end of the volume lists the UK species that are cited in the literature as being tolerant of metals, pH, salinity, fluoride, boron, waterlogging and ammonia. Plants and then animals are listed, in alphabetical order by their Latin names within each taxonomic group (where there are common names, they are also given).

3. USE OF VISUAL/SENSORY INDICATORS

3.1 ABIOTIC INDICATORS

While abiotic indicators occasionally point to the presence of particular contaminants, they are generally of more use in providing clues to previous uses of land. Information about previous land uses is invaluable in assessing the likelihood of particular contaminants being present.

Literature relating to particular industries should be consulted for detail of the processes they use and their likely visible effects (for example Figg *et al.* 1980). Many industries have characteristic buildings, infrastructure and machinery, vestiges of which may remain on site, for example sand and gravel plants (though under a range of planning conditions, Section 106 Agreements, Site Licence Conditions etc., relating to different industries, for example MPG 2 (DoE/Welsh Office, 1988) these should be removed when operations cease). Particular shapes such as the longitudinal banks of firing range butts, and the usually large spoil heaps associated with mining and smelting waste, are useful abiotic indicators. Mine shafts and mineral extraction pits whose sides display the type of mineral are obvious indicators of previous activity.

The colour of soil, or of deposits on the ground surface, can be characteristic of contamination, for example yellow coloration often, but not always, indicates chromium waste (Figg *et al.* 1980; Gemmell 1973); white powder can be one of a number of chemicals including calcium sulphate (Sury and Slingsby 1991). Features such as bare patches have many possible causes, including toxicity, made ground, or mechanical wear compaction by vehicles, as well as natural stresses such as drought and nutrient deficiency (IEHO 1988). Oils and tars are usually characteristic of a small range of previous uses, mostly associated with hydrocarbon processing and transport industries, including vehicle dismantling.

The usefulness of waste material as an abiotic indicator depends on how many previous activities it could indicate. Few abiotic indicators are as reliable as "blue billy" (a complex of spent oxides containing iron and cyanide compounds) with its characteristic colour and smell, indicative of waste from gasworks (Hidding 1986) and other industries using coal and coke. Hope and Herbert (1990) provide descriptions of the appearance and smell of slag from iron and steelworks. Piles of rubble can be indicative of buildings; a site with rubble distributed throughout may have been landfilled and inadequately restored.

Odours, difficult to describe in words, are best learnt on-site from experienced personnel, though there have been a few published descriptions (eg. Figg *et al.* 1980). On water bodies rainbow-coloured film on the surface resulting from bacterial action can be distinguished from oil film by the smell. While some intermittent bubbling of (odourless) methane and ("bad eggs" smelling) hydrogen sulphide occurs naturally from anaerobic mud, a continuous stream of bubbles from deeper sources is more likely to be associated with previous landfilling or the presence of hydrocarbon waste.

Some road and public house names, for example Sand Pit Lane, Gas Works Alley, Brickmakers Arms, can be indicators of a particular past industrial use within the vicinity.

3.2 BIOTIC INDICATORS

3.2.1 Use of Biotic Indicators

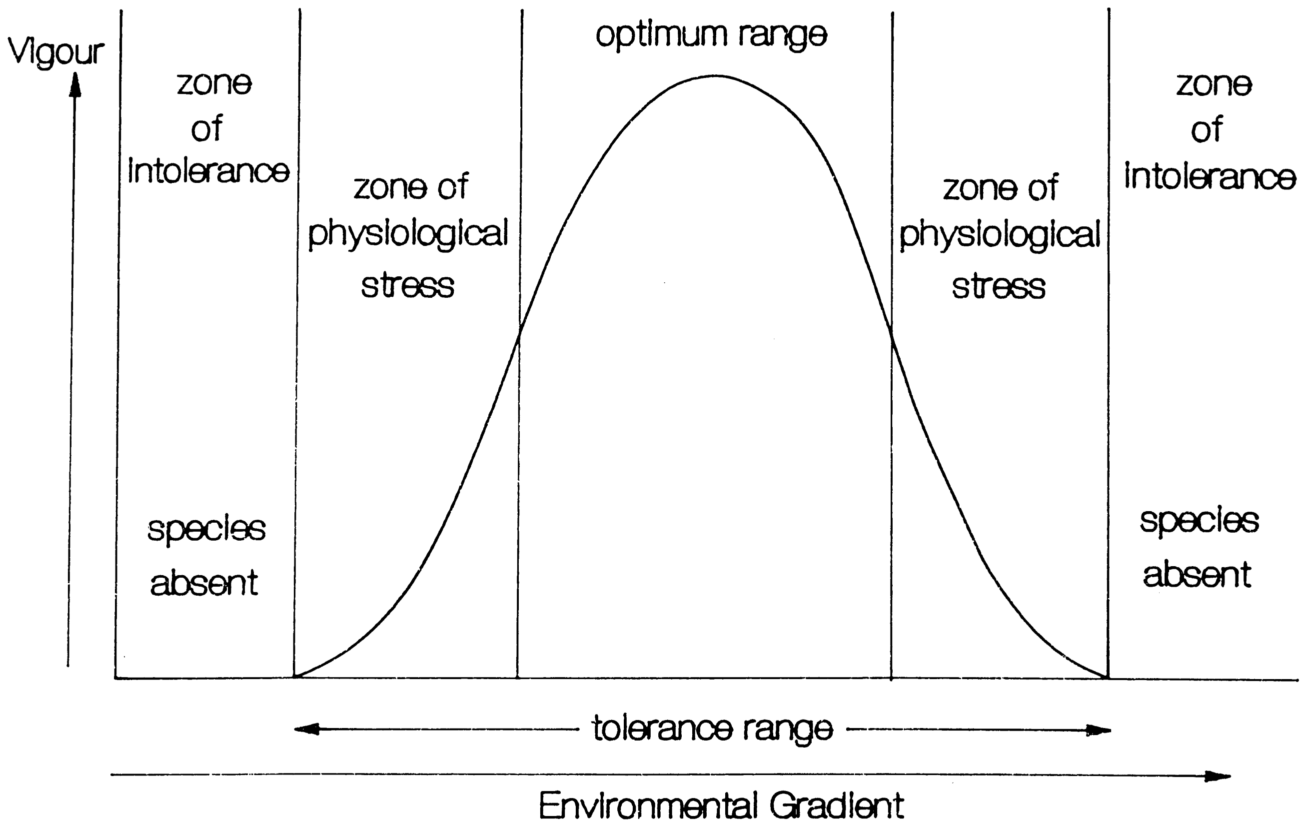
Biotic indicators, in the form of metal-tolerant plant species have been used for decades in mineral prospecting (biogeochemical prospecting) for example Cannon (1960). More recently, biological monitoring of macroinvertebrates and fish has been used by the National Rivers Authority (NRA 1991) to assist in classifying water quality.

Plants, animals and micro-organisms are used in preliminary site investigations in two ways:

i) Some species are more tolerant of particular contaminants than other species. The community occurring on a significantly contaminated site may be dominated by "tolerant" species, and have few or no intolerant or sensitive species.

   Very few species occur only where there are abnormally high levels of particular contaminants, but they are very useful and can be regarded as **universal indicator species**. However, for most species tolerance is a matter of degree, different species tolerating different ranges of contaminant levels. Some have a wide spectrum of tolerance, not only of contamination but also of physical or chemical conditions (Fig. 1).

Fig. 1 Relationship between performance or vigour of a plant species and environmental gradients in relation to tolerance to an environmental factor.



A number of species have evolved "tolerant ecotypes" (locally adapted populations with hereditary tolerance) in contaminated areas, while populations of the same species from uncontaminated areas are intolerant of such contaminants (Cook *et al.* 1972). Species which occur in areas with increased levels of a particular contaminant, but are also found in uncontaminated areas can be regarded as **local indicators** of that contaminant (Martin and Coughtrey 1982).

The presence of a species on a site will only be a certain indicator of a particular contaminant if it is one of the few **universal indicator** species, such as alpine pennycress (*Thlaspi caerulescens*). However, a community with a high proportion of local indicators provides a useful clue to the presence of contamination.

The presence of indicator species, which make up the majority of useful visual indicators, needs to be evaluated in conjunction with all the other visual indicators described in this document, both biotic and abiotic.

ii) Some contaminants cause particular visible symptoms in certain plants or animals, but the picture may be complicated by the symptom possibly being caused by a number of contaminants or other environmental factors.

3.2.2 Ecological Factors Influencing the Distribution of Plants and Animals

The distribution of plants and, to a lesser extent, animals is influenced by a large number of physical, chemical, and biotic factors including:

- pH: acidity or alkalinity

- nutrient availability: the nutrients required in relatively large quantities by most plants and animals are nitrogen, phosphorus and potassium. Trace elements that are required in minute quantities, include magnesium, iron, zinc, copper, and boron. Nutrient uptake in plants is usually related to water availability.

- water availability: each plant species can survive a range of water conditions, with some being particularly tolerant of waterlogging or drought.

- soil texture: coarser texture gives good drainage but may lead to water deficiency; fine texture provides good water retention properties, but there is an increased likelihood of soil waterlogging.

- soil structure: this factor influences drainage, degree of aeration, and root penetration. The depth and type of litter accumulation may also influence plant distribution.

- exposure/aspect: these factors can influence water availability

- temperature: increase in temperature results in increased evaporation from the surface and from any plants growing on it, possibly leading to drought stress.

- compaction/aeration: these factors may affect root growth and therefore general health of plants. Waterlogging can restrict aeration.

- season: this will influence the life cycle of a particular plant or animal and may affect its presence/absence and appearance. Discoloration of leaves occurring at particular times of year can be confused with the effects of toxicity.

- availability of colonisers from adjacent areas. Plants and animals disperse onto a site from surrounding habitats so the diversity of these habitats will determine the range of potential colonisers.

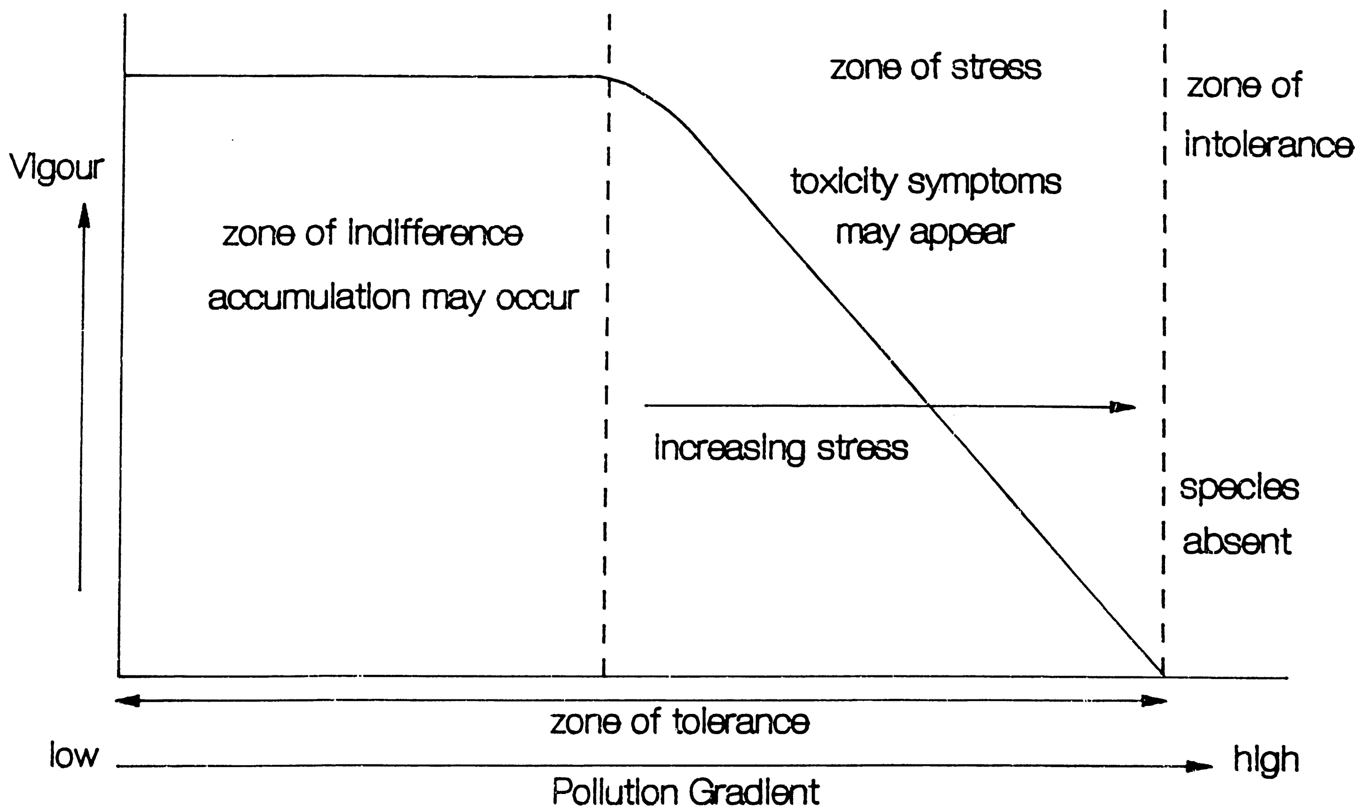
- age of the site: habitats undergo 'succession'. The greater the time since a site was disturbed the more opportunity there is for plants and animals to colonise it, and for any contaminants present to 'select' for tolerant species or cause particular symptoms. A litter layer may accumulate (especially if microbes are reduced by contamination) which can act as a barrier between shallow-rooting plants and any waste material that has been deposited, allowing a more diverse plant community to develop than when the material is exposed.

The response of a species to a particular factor is best illustrated by its vigour along a theoretical gradient of that factor. With some physical and chemical factors, including those contaminants which are nutrients, or trace elements, the species is only able to exist over a limited range of the gradient, and near the limits of this range it may show symptoms of stress (Fig. 1). For other types of contaminants there is a critical level at which stress symptoms appear and below which the organism exhibits greatest vigour (Fig. 2).

The toxicity of a contaminant to a particular species is influenced by the physical and chemical properties of the contaminant and the physico-chemical environment of the soil or water in which it occurs. Specifically, its impact on biota will be influenced by its solubility and, potentially, by a number of soil factors including pH, redox (oxidation-reduction) potential, the capacity of soil particles to attract and retain ions on their surfaces, texture, organic matter content, and temperature.

An overview of the physical and chemical properties of various types of waste material is provided by Bradshaw and Chadwick (1980).

Fig. 2 Relationship between performance and vigour of a plant species and the environmental gradient of a pollutant.



(After Coughtrey and Martin 1982)

3.2.3 Plants as Visual Indicators

Plants are generally better indicators of contamination than animals because of their lack of mobility, making them easier to locate and record, and because during most of their life cycle they are rooted or attached to their growth medium. As the first link in the food chain they absorb contaminants directly from the medium.

The use of tolerant plant species as indicators of contamination is comparatively well documented, particularly in relation to metal contamination and the influence of pH. Species diversity is also used as an indicator of environmental conditions (Cooke and Morrey 1981; Smith and Bradshaw 1979). Some plant species show visible symptoms of contamination such as chlorosis or yellowing of the younger leaves or inhibited root development.

However, the use of plants as indicators of contaminated land is also subject to a number of limitations. Some visible symptoms of contamination can be caused by other factors (3.2.7). In addition, the presence or absence of plant species on a site is influenced by many factors other than contamination (cf 3.2.2). Another disadvantage is that the response of the species to the contaminant will depend on the relationship between its rooting zone and the location and depth of the contaminant on site, so contamination which has been covered may have no impact on surface vegetation. Finally, there is limited documentation on the effects of organic contaminants upon plants.

3.2.4 Animals as Visual Indicators

As they are more mobile and less easily seen in the habitat, animals are generally less useful than plants as visual indicators of contamination. However, in particular parts of the habitat where they are easily visible, for example invertebrates in shallow pools, and to a lesser extent the larger invertebrates in soils, they can be useful in this respect.

As with plants, species (or family) diversity of invertebrates will usually reflect environmental conditions. A medium relatively uncontaminated and not subject to extreme conditions usually supports a high diversity. A significantly contaminated medium may be dominated by large numbers of tolerant species or groups, for example particular freshwater invertebrates tolerant of organic pollution or of heavy metals (for which case studies are less well documented).

In a small number of species there may be visible symptoms of contamination in a certain proportion of the population. For example, on exposure to elevated levels of mercury, nickel, copper and cobalt, some earthworms have been recorded as lacking a clitellum or "saddle". Limitations on using invertebrates as indicators include problems with identification; the seasonality of their life cycle; and the lack of documentation, except for freshwater invertebrates as indicators of organic pollution.

3.2.5 Micro-organisms

The chief use of micro-organisms as indicators of contamination is that their absence will usually result in lack of decomposition and, therefore, an increased accumulation of leaf litter on the ground surface. However, the level of accumulation of leaf litter is also influenced by other factors, for example the kind of plant species present, soil pH, moisture conditions, and presence or absence of invertebrates.

3.2.6 Comparative Use of Land and Water Biota as Indicators

Water in ditches, streams or pools on a contaminated site is likely to have the same characteristics as the ground water or any surface water. The biota occurring in them may be more sensitive to contaminants than those on land, depending on the solubility of the particular contaminants. Where they are present, this sensitivity combined with the relative visibility of biota in small water bodies can make them useful as indicators. However, the relative mobility of invertebrates, especially winged groups, and different stages in their life cycles, should be taken into account when using their presence or absence to indicate degree or type of contamination. At sites crossed by, or adjacent to, small watercourses, visual comparison of the aquatic biota upstream and downstream of the site can provide an initial indication of the effect of contamination. The use of freshwater invertebrates as indicators of environmental quality is reviewed by Lenat, Smock and Penrose (1980).

As the majority of contaminated sites consist mostly of land, and some have no water bodies at all, land biota, and plants in particular, are likely to have a much wider use in preliminary site investigations than water biota.

3.2.7 Factors Causing Similar Symptoms to those Caused by Contamination

Some visible symptoms in plants produced by contamination can also be caused by other ecological factors such as lime content of soils, nutrient deficiency and drought, extremes of temperature, invertebrate pests (eg. leaf hoppers, aphids, thrips, spiders, mites, nematodes, sawfly), fungi, viruses, herbicides, flooding, or salt spray. Examples of symptoms of micronutrient deficiency in common cultivars are shown in Table 1, adapted from Kabata-Pendias and Pendias (1992).

Visible symptoms caused by soil contamination may be similar to those associated with airborne emissions of the same contaminants, for example metallic dusts (Taylor *et al.* 1984). In certain cases, for example where the source of airborne contamination is known and the symptoms only occur on the side of trees nearest to this source, it is possible to distinguish between the two sources of toxicity (Linzon 1981).

3.2.8 Discontinuities Between Communities

Marked differences in major ecological factors influencing the distribution of plants and animals usually result in visible discontinuity between communities. Disturbance of a site, for example by earth movement for purposes such as agriculture or landscaping, or by deposition of inert or contaminated waste, alters the balance of ecological factors and can lead to visible discontinuity between communities on the site and those on adjacent land.

In order to distinguish the effects of contamination from those of disturbance, it is useful to compare the vegetation on the site with that of nearby disturbed but uncontaminated land, and so take into account the 'ruderal' (or disturbed ground) species typical of the locality. Undisturbed established plant communities in the vicinity will reflect the 'natural' background levels of ecological factors (especially pH, nutrient availability, soil texture and associated properties) typical of the locality.

Waste material giving rise to contamination may be of different pH, nutrient content and texture to the soil typical of the locality, and this difference will often be reflected in the vegetation present on the site. Within the site itself, deposition of different kinds of waste, for example of markedly different pH, can also result in quite distinct plant communities.

Some expertise is required to interpret the relationship between plant and animal communities and the ecological factors influencing them. However, the observation of discontinuities within a site and between a site under investigation and its surroundings, by those without such expertise, can provide a useful starting point in the identification of significantly contaminated land.

Table 1 **Symptoms of Micronutrient Deficiency in some Common Cultivars**

ELEMENT	SYMPTOMS	SENSITIVE CROP
Boron	Chlorosis and browning of young leaves; dead growing points; distorted blossom development; lesions in pith and roots, and multiplication of cell division	Legumes, *Brassica* (cabbage and relatives), beets, celery, grapes, and fruit trees (apples and pears)
Copper	Wilting, melanism (pigment accumulation); white twisted tips; reduction in flower formation; disturbance of woody tissue formation, and of development and fertility of pollen	Cereals (oats), sunflower, spinach, and lucerne (alfalfa)
Iron	Interveinal chlorosis of young organs	Fruit trees (citrus), grapes, and several clacifuge species
Manganese	Chlorotic spots; death of young leaves and wilting	Cereals (oats), legumes, and fruit trees (apples, cherries, and citrus)
Molybdenum	Chlorosis of leaf margins; "whiptail" of leaves and distorted curding of cauliflower; "fired" margin and deformation of leaves due to NO_3 excess, and destruction of embryonic tissues	*Brassica* (cabbage and relatives) and legumes
Zinc	Interveinal chlorosis (mainly of monocots); stunted growth; "little leaf" rosette of trees, and violet-red points on leaves	Cereals (corn), legumes, grasses, hops, flax, grapes, and fruit trees (citrus)

4. METALS AND SEMI-METALS

4.1 INTRODUCTION

This chapter deals with metals and semi-metals.

- **Metals** are chemical elements (or alloys) which are lustrous, ductile, have a high specific gravity, form positive ions, react with acids and non-metals, combine with oxygen to give bases, have a crystalline structure and are good conductors of heat and electricity;

- **Semi-metals (or metalloids),** for example arsenic and antimony, have the physical properties of metals but the chemical properties of non-metals. For the purposes of this chapter, metals and semi-metals are called metals.

Table 4 lists UK species cited in the literature as metal tolerant, with references and notes. Summary sheets are given in Table 5 at the end of the chapter.

Metal has been mined since ancient times. The industrial revolution increased the diversity and rate of release of metals into the environment. Sources of metals in the environment include surface and percolating drainage water and flood water from metal and other mines; airborne dispersal of dust particles from spoil tips; metal smelting; manufacturing processes using metals such as electroplating, battery, alloy and pigment production; fungicides and pesticides; power station ash, and sewage sludge (Gemmell 1977; Mason *et al.* 1982; Peterson and Girling 1981; Berrow and Burridge 1979).

Visual indicators for lead, copper, zinc and cadmium are relatively well documented, and for nickel they are moderately well documented. A few references are available for arsenic, chromium, and mercury, and for molybdenum, particularly in relation to effects on animals. For the remaining metals listed in the summaries there is relatively little information on visual indicators. Other metals known to occur on contaminated land, for example tin, are omitted owing to the lack of information.

4.2 ABIOTIC INDICATORS

General abiotic indicators of a number of metal contaminants include spoil heaps near mine shafts, sparse vegetation or bare patches. The presence of coloured deposits can occasionally indicate a particular metallic or semi-metallic contaminant. Some of the more common metal salts and colours are shown in Table 2. The conditions on the site may suggest that there is a greater likelihood of certain contaminants being present. For example, sulphides occur predominantly in water-logged soils while oxides are more likely to occur in freely draining situations.

4.3 BIOTIC INDICATORS

4.3.1 Background to Metal Tolerance

Metal mine spoil generally supports characteristic assemblages of metal-tolerant plants and animals owing to the increased metal content, low nutrient availability and, in many cases, poor water retention of the substance. Mine sites are therefore a good source for selecting species to use as visual indicators of elevated metal levels in other contaminated sites (Sellars and Baker unpublished). Many of these plants have been used for a long time in botanical prospecting for heavy metal ores (Cannon 1960; Antonovics *et al.* 1971).

The presence of a particular plant on a site cannot be used to indicate an individual metal, since most indicator-plants display multiple tolerance. (Baker and Walker 1989; Baker and Proctor 1990).

The term **"metallophyte"** has been applied to any plant which shows an association with, or restriction to, metalliferous substrates. **Absolute metallophytes** only occur on metalliferous soils over all their distribution. **Pseudometallophytes** are plants which occur on both contaminated and normal soils in the same region. Some of these have evolved locally-adapted populations (or ecotypes) resistant to heavy metals. **Accidentals**, usually ruderals and annuals, appear sporadically and are often stunted (Antonovics *et al.* 1971; Baker 1987; Sellars and Baker unpublished).

Table 2 Colours of Common Metal Compounds [1]

GREEN	BLUE	YELLOW	ORANGE
Most chromium salts	Chloride	Some antimony salts	Antimony sulphides
Some cobalt salts	Some copper salts	Arsenic sulphide	Cadmium sulphide
Some copper salts		Cadmium sulphide	Dichromates
Ferric sulphide		Chromates	Stannous iodide
Ferrous salts		Copper hydroxide	
Some gold salts		Some gold salts	
Some nickel salts		Lead iodide	
		Lead oxide	
		Some mercury salts	
		Anhydrous nickel salts	
		Some silver salts	
		Tin sulphide	
		Some vanadium salt	

REDDISH BROWN	DEEP PINK	PALE PINK	LILAC
Some ferric compounds	Most cobalt compounds	Most manganese salts	Some vanadium salts
Mercurous arsenate			
Mercurous sulphide			
Molybdenum sulphide			
Silver chromate			

BLACK	WHITE	BLUE-BLACK	RED
Cobalt hydroxide	Most aluminium salts	Thallium sulphide	Arsenic iodide
Cobalt sulphide	Most arsenic salts		Some cobalt salts
Copper, ferric, manganese and nickel oxides	Most cadmium salts		Cuprous oxide
Copper sulphide	Most lead salts		Red lead (oxide)
Ferrous sulphide	Most magnesium salts		Some mercury salts
Gold sulphide	Mercurous chloride		Some silver salts
Lead sulphide	Mercurous sulphate		
Mercurous sulphide	Most silver salts		
Nickel sulphide	Most zinc salts		
Silver sulphide			
Vanadium sulphide			

(After Clifford 1961, and King 1959)

1 Coloured deposits on a site may not necessarily be indicative of the presence of 'toxic' metal compounds. For example coal dust and soot (black); sodium chloride deposits (white) and de-icing salt/grit mixtures (brown).

Like all plant species, metallophytes show characteristic regional distribution. A few metallophyte species occur naturally in other habitats besides mine sites. For example, *Silene vulgaris* subsp. *maritima* With., has a largely coastal distribution, with its inland distribution being confined to base-rich rocks in mountain areas or metalliferous mine sites (Baker and Dalby 1980).

Some authors have suggested that the ability of metallophytes to survive on mine waste may be linked to tolerance of other factors such as low nutrient availability and drought, which are often features of mine waste (Antonovics *et al.* 1971; Baker and Walker 1989).

4.3.2 The Influence of Environmental Factors upon the Sensitivity of Biota to Metal Contaminants

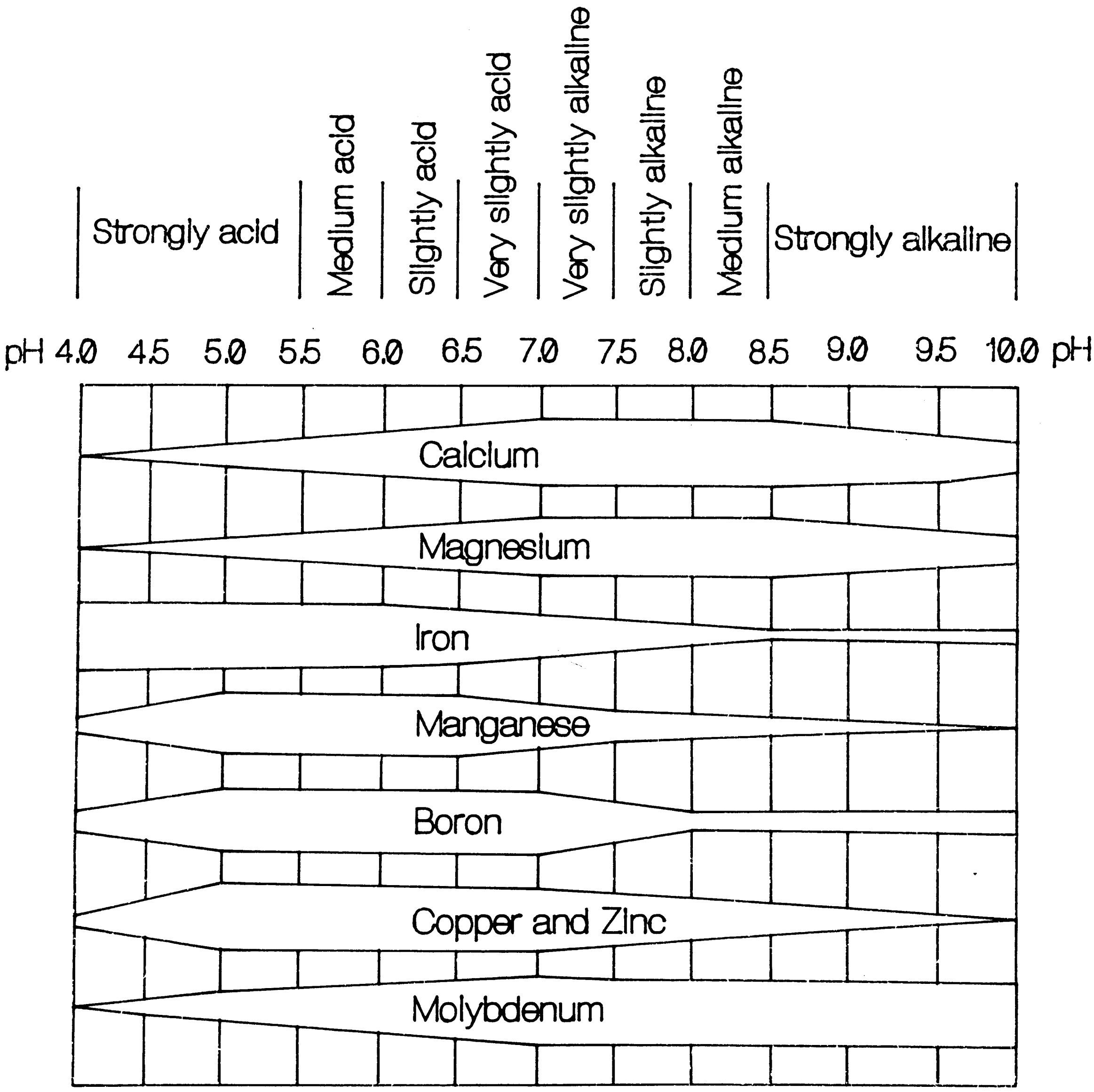
Soil pH is one of the most important environmental factors influencing the sensitivity of plants to metal contaminants. Different metal ions are soluble, and therefore more available to plants, over different pH ranges. These effects are believed to play a significant role in determining the overall toxicity of mixtures of different ions in solution (Gemmell 1977).

In general, acidity increases the level of metal cations in soil solution, and for this reason metal toxicity is often reduced by the addition of lime (Simon 1987; Baker 1987; Baker and Proctor 1990; Garland and Wilkins 1981). However, Gemmell (1973) found that the effect on vegetation of chomate in smelter waste of pH up to 12.6 was intensified by the presence of calcium hydroxide, and concluded that this effect was related to the presence of chromium (VI) in the anionic form. The mobility of a number of metals at different pH values is illustrated in Fig. 3.

While some metallophytes occur on both alkaline and acidic metalliferous sites, most are characteristic of alkaline sites, owing to the lower availability and therefore toxicity of metal cations. (Antonovics *et al.* 1971; Baker & Proctor 1990; Cooke and Morrey 1981).

Phosphate and other nutrient levels, organic status and water content of soils are also believed to be important in regulating metal toxicity (Simon 1978; Smith and Bradshaw 1979; Shaw *et al.* 1984; Baker and Proctor 1990). Mycorrhizal (root symbiotic) fungi are thought to be effective in binding and detoxifying metal ions around the roots of some metal tolerant species, such as ling (*Calluna vulgaris*)

Fig. 3 A schematic illustration of the relation between plant nutrient availability and soil reaction.



Maximum availability is indicated by the widest part of the bar

(After Thompson and Troeh 1957)

(Bradley *et al.* 1982). The degree of tolerance of metals by invertebrates varies with the stages of the life cycle (Clubb *et al.* 1975).

4.3.3 Relative Toxicity of Metals

Literature on the relative toxicities of different metals to different species is limited to a few, mostly species-specific studies. Examples are given in Table 3. These studies provide a very broad indication of the toxicity of different metals.

Table 3 Relative Toxicity of Metals - Some Examples from the Literature

Species	Order of Toxicity	Reference
Agrostis spp.	Cu>Ni>Zn>Pb	Jowett 1958
Azolla pinnata	Cd>Hg>Cu>As>Pb>Cr	Sarkar and Jana 1986
Citrus seedlings	Cu>Zn>Mn	Reuther and Smith 1954
Myriophyllum spicatum	Cu>Hg>As>Cd>Zn>Pb	Stanley 1974
Elodea canadensis	Cu>Hg>As>Cd>Zn,Pb	Brown and Rattigan 1979
Mollusca	Hg, Ag>Cu>Zn	Wurtz 1962
Ephemerella (mayfly)	Cu>Fe>Cd, Cr, Hg>Ni>Co	Warnick and Bell 1969
A range of species; based on published data.	Hg>Cu>Cd, Zn>Au?, Sn>Ag?, Al, Ni>Pt?, Fe^{3+}, Fe^{2+}>Ba>Mn, Co>Li, K>Ca>Sr, Mg>Na	Hellawell 1986

4.3.4 Plants as Visual Indicators of Metal Contamination

i) Indicator species

The majority of metal tolerant UK species occur in the families Poaceae (= Gramineae:Grasses), Caryophyllaceae (Pink family) and Brassicaceae (= Cruciferae:Cabbage family) (Tyler *et al.* 1989; Baker and Proctor 1990), and also in the bryophytes and lichens (Rao *et al.* 1977). Fitter and Peat (unpublished) have prepared an Ecological Flora Database in which heavy metal tolerance is one of a large number of categories covered.

Alpine pennycress (*Thlaspi caerulescens*) is probably the only absolute metallophyte or universal indicator of metalliferous soils to be found in the UK. This and four other species, vernal sandwort (*Minuartia verna)*, Pyrenaean scurvy-grass *(Cochlearia pyrenaica*), sea campion (*Silene vulgaris* subsp. *maritima*) and thrift (*Armeria maritima)* are considered by Sellars and Baker (unpublished) to be the most notable metallophytes on lead, zinc and copper contaminated soils. The first three species however, are relatively uncommon, and therefore are of little value as biological indicators of metal contamination in preliminary site investigations. Common species whose tolerance is well established in the literature are the most useful indicators in preliminary site investigations.

ii) Visual Symptoms

The most widely described effects of metal toxicity in plants are inhibited root growth, depressed shoot and leaf growth, and general chlorosis of the younger leaves (Baker and Walker 1989; Bradshaw and McNeilly 1981). Gemmell (1977) reports that root growth of plants in metalliferous media is inhibited both in solution culture and in the field, wtih roots often being coralloid and stumpy. The roots of legumes normally bear nodules containing nitrogen-fixing bacteria, but metal toxicity leads to poor root nodulation (Robinson 1976). Small white coloured nodules appear in contrast to larger pinker nodules in normal plants (Giller and McGrath 1989).

The general yellowing (chlorosis) of grasses adjacent to metalliferous mine waste has long been recognised. Leaf chlorosis is believed to be caused by interference with iron metabolism, and therefore chlorophyll formation (Koeppe 1977; Cannon 1960). Gemmell (1977) considers that each metal causes a characteristic type of leaf necrosis (dead tissue) or discoloration; however this is unlikely to be of use in site inspections as metal contaminants rarely occur singly. Linzon (1981) reported chlorosis, necrosis and leaf cupping in fruit trees near a nickel refinery.

Krause and Kaiser (1977) recorded various symptoms in plants exposed to metal oxide dust, including brown spotting in the interveinal area of the upper leaf surface, dark brown, black or white chlorotic lesions, the spreading of necrosis to the leaf apex (which becomes curled), and early senescence of leaves. Fabiszewski (1981) reported deformity of leaves and stems resulting from heavy metal contamination. Monocotyledonous leaves incurred more severe injury than dicotyledonous, and eventually became horizontally banded.

A number of other authors have recorded chlorosis and necrosis in a variety of plants subjected to elevated metal levels (Oertli and Kohl 1961; Millikan 1949; Hoagland 1945; Dekock 1956; Crooke *et al.* 1954; Berger and Gerloff 1947; Ahmed and Twyman 1953; Krause and Kaiser 1977; Peterson and Girling 1981; Baker and Dalby 1980; Collins 1981; Haghiri 1973; Little 1973; Lepp 1981; Dijkshoorn *et al.* 1974; Linzon 1981; Fabiszewski 1981).

Metallophyte higher plants often have an abnormally low growth form, and most are perennial herbs (Antonovics *et al.* 1971; Cook *et al.* 1972). Some authors have recorded various changes in flowers (Antonovics *et al.* 1971; Krause and Kaiser 1977), or leaf size (Baker and Dalby 1980) in metallophytes.

Many visible symptoms produced by metal toxicity can also be caused by other ecological factors. Excess lime in soils can cause iron-deficiency chlorosis. Standard biology textbooks describe symptoms of nutrient deficiency, many of which are similar to those caused by metal toxicity (also Chapheker 1978).

4.3.5 Mammals

Toxicity in herbivorous mammals usually results from their grazing in contaminated areas, including exposed or overgrazed wastes, re-spread wastes, land subjected to flooding by contaminated rivers and areas re-seeded with plant species which accumulate metals (Ineson 1981). Most of the literature on heavy metal toxicity in small mammals relates to rates of accumulation of metals within the body, the symptoms of which (for example, liver disorders and sub-cellular changes) are not visible in the field.

It may be that ruminants are more susceptible to metal poisoning than monogastric mammals (Bremner 1974). Pigs are generally more tolerant of metals, especially of copper, than cattle or sheep (Bremner 1974; Ineson 1981), and sheep are more tolerant than horses (Robinson 1976).

4.3.6 Invertebrates

i) Terrestrial

Terrestrial invertebrates that can be regarded as being visual indicators of metal toxicity are mostly species living in the soil. Investigating them requires digging. A number of authors have recorded earthworms of various species as being tolerant of elevated metal levels. Morgan and Morgan (1988) found that *Lumbricus rubellus* and *Dendrodrilus rubidus*, both acid-tolerant species, were capable of inhabiting shallow soils covering metalliferous spoil heaps especially where these were revegetated and there was adequate moisture. Ireland (1977) found evidence of tolerance by earthworms of lead and zinc in mine areas, and Bisessar (1982) of tolerance of arsenic, although the population density of earthworms increased with distance from the source of arsenic, a metal smelter.

In a study of the effects of metals from motor vehicle exhaust, Muskett and Jones (1980) reported that the numbers of isopods, hemiptera, hymenoptera and collembola declined as pollution levels reduced and the distance from the road increased. They suggested this unexpected result may be the consequence of increased numbers of predators not tolerant of metals such as carabid beetles associated with decline in metal levels. Hopkin (1986) found clubionid spiders in areas with exceptionally high metal concentrations, especially zinc, and woodlice and millipedes have been recorded as showing some tolerance to lead (Williamson and Evans 1973; Tyler *et al.* 1989). The isopod *Porcellio scaber* was found to be zinc-tolerant by Joose *et al.* (1981)

ii) Aquatic

Most of the literature on metal toxicity in freshwater invertebrates relates to rivers. The water bodies on contaminated land are not usually rivers but small streams, ditches or ponds, though they may be inundated by the flooding of contaminated rivers. A considerable number of studies on rivers contaminated with metal mine drainage in Wales, Cornwall, North America, Australia and elsewhere have shown that as metal levels decline with time, or with distance from the source, there tends to be an increase in diversity of freshwater invertebrate species (Carpenter 1924, Jones 1940, 1958; Jones and Howells 1969). Weatherly *et al.* (1980) reviewed some of these studies. In one example, the number of species in the River Rheidol recorded downstream of zinc and lead mines increased from 14 in 1919-22, to 29 in 1922-23, to 103 in 1931-32, and to 131 in 1965-66. There were no data on metal levels within the water, so the increase in species may reflect increased tolerance or decreasing concentration of metal with time, or a combination of the two.

Some authors have concluded that metal contamination cannot be reliably detected by indicator species (for example Weatherly *et al.* 1980 for zinc). However, other authors have recorded particular taxonomic groups as being relatively tolerant of metal toxicity, including: a few dipteran groups (flies), especially orthocladiinae and other midges (chironomidae); worms (oligochaetes); stoneflies (plecoptera); mayflies (ephemeroptera); bugs (hemiptera), and caddis (trichoptera). Brown (1976 and 1977) and Coughtrey *et al.* (1979) found a malacostracan crustacean (*Asellus meridianus*) particularly tolerant of lead and copper in mine drainage, and Fraser (1980) recorded *A. aquaticus* as being lead tolerant. Brown (1977) confirmed the findings of Jones (1940) that caseless caddis (trichoptera) are more tolerant of metal toxicity than case-bearing caddis. Wren and Stephenson (1991) recorded that crayfish *(Astacus pallipes)* is tolerant of cadmium. Wielgolaski (1975) recorded tolerance of heavy metals in oligochaetes, and Winner *et al.* (1980) proposed that the percentage of chironomids in samples can provide a useful index of trace metal contamination in streams. Mance and Yates (1984) recorded that insect larvae are more tolerant of zinc than other aquatic invertebrate taxa, and that *Tubifex tubifex*, caddis larvae and damselfly nymphs are relatively tolerant of increased levels of nickel. Most freshwater invertebrates are more tolerant than fish of increased levels of metals (Warnick and Bell 1969).

Groups recorded as being relatively sensitive to metal toxicity include: the freshwater shrimp *(Gammarus)*; molluscs; mites (hydracarina); annelids, platyhelminthes and non-malacostracan crustacea (Carpenter 1924; Brown 1977; Wurtz 1962; Brown *et al.* 1984; Mance *et al.* 1984).

As part of their proposals for Statutory Water Quality Objectives, the National Rivers Authority (NRA) has developed an Ecological Quality Index (EQI). While this index was designed to reflect the effects of sewage pollution rather than other types of pollution such as incresed metal concentrations, the NRA is currently analysing their 1990 survey biological database (upon which the EQI was based) with a view to developing a system which might include metal indicator groups (NRA 1991).

4.3.7 Micro-organisms

A number of authors have reported that microbial decomposition is reduced on sites with elevated levels of metals. Doelman and Haanstra (1979) recorded that lead inhibits decomposition and may result in accumulation of organic matter, although they also recorded that lead pollution can result in greater numbers of lead-tolerant bacteria. Williams *et al.* (1977) found that the accumulation of litter was greater on metal mine waste than on an uncontaminated control site. A reduction in the rate of leaf litter decomposition in the vicinity of metal smelters has been noted by a number of authors (Coughtrey *et al.* 1979; Van Hook *et al.* 1977; Martin and Coughtrey 1982; Strojan 1978). Bisessar (1982) found lower numbers of bacteria, fungi, nematodes and earthworms in these locations.

4.4 CONCLUSIONS

Sensory indicators of metals as a group are relatively well documented. Useful abiotic indicators include spoil heaps associated with metal mine shafts and smelting plants, sparse vegetation and bare batches, and the particular colours of certain metal compounds.

There is good evidence of metal tolerance in certain plant species and a few invertebrate groups. Most of these are tolerant of several metals, but since increased levels of metals rarely occur singly, this does not diminish their usefulness as indicators of contamination.

The influence of other environmental factors needs to be taken into account when interpreting visual indicators of metal contamination, including other contaminants, drought, nutrient deficiency and the influence of pH on metal toxicity.

Plants exhibit a number of visual symptoms of metal contamination including chlorosis of young leaves and stunting of various parts of the plant. In the soil metal contamination can lead to a build up of leaf litter owing to reduction in decomposition by soil micro-organisms.

Invertebrate diversity is often inversely proportional to the extent of metal contamination. Some tolerant groups are recorded, which may occur in abundance in contaminated conditions.

TABLE 4

UK SPECIES CITED IN LITERATURE AS METAL TOLERANT

Latin Name	Common Name	Metals	References	Context of Citation/Comments
PLANTS				
GRASSES, RUSHES AND REEDMACES				
Agrostis canina	Brown bent-grass	Pb	Craig 1977	Tolerant races demonstrated experimentally
		Zn	Gemmell 1977	Tolerant ecotypes from metal mine spoil
			Gregory & Bradshaw 1965	Tolerant races demonstrated experimentally
Agrostis gigantea	Common bent	Co,Cu,Ni,Zn	Hogan + Rauser 1979	Tolerant clones recorded
Agrostis stolonifera	Creeping bent-grass	Cu	Maschmeyer & Quinn 1976	Tolerance recorded on mine sites
		Pb	Jowett 1958	Tolerant races demonstrated experimentally
		Zn	Archer 1964 +	Tolerant races demonstrated experimentally
			Gregory & Bradshaw 1965;	Tolerant races demonstrated experimentally
			Harding 1981	Recorded as capable of genetic adaptation to high metal levels
			Maschmeyer & Quinn 1976	Tolerant races
		Cu,Ni,Pb,Zn	Gemmell 1977	Tolerant ecotypes in metal mine spoil
		Metals	Antonovics *et al.* 1971	Characteristic of calcareous metal mines
			Bradshaw & Chadwick 1980	Metallophyte
		As,Cu,Fe,Pb,Zn	Porter & Peterson 1975	Tolerance recorded

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Agrostis capillaris (= *tenuis*)	Common bent-grass	Cd	Baker & Proctor 1990	Present on cadmium-rich soil (unpub.data from K. Ewart)
		Cu	Cox & Hutchinson 1979	Tolerance recorded
			Goodman *et al.* 1973	Present on copper tips in Lower Swansea Valley
			Ingram 1988 + McNeilly & Bradshaw 1968	Tolerance of collected adult plants
			Wilkins 1957 +	Tolerance recorded
		Pb	Craig 1977	Different populations varying in lead tolerance
			Jain & Bradshaw 1966+	Tolerant races demonstrated experimentally
			Jowett 1958	Tolerant races demonstrated experimentally
		Zn	Dueck *et al.* 1987	Tolerance recorded to zinc smelter waste
		Cu,Pb	McNeilly 1966 +	
		Cu,Zn	Ernst 1976 +	Tolerance recorded near copper refinery
			Walley, Khan and Bradshaw 1974 +	
		Pb,Zn	Baker & Proctor 1990	Elective pseudometallophyte
			Bradshaw 1952	Tolerant races demonstrated experimentally
		Cu + Pb, Pb + Zn	McNeilly 1968 +	Tolerant races demonstrated experimentally
		Cd,Pb,Zn	Simon 1977, 1978	Tolerance recorded on mine sites
		Cr,Cu,Mg,Ni,Pb,Zn	Gemmell 1977	Tolerance recorded, though Mg and chromate toxicity considered unlikely to be important on industrial wastes
		Bi,Cu,Pb,Zn,Cu + Ni	Gregory + Bradshaw 1965	Tolerance races demonstrated experimentally
		Metals	Antonovics *et al.* 1971	Elective pseudometallophyte; one of few species found on acidic mine wastes
			Bradshaw + Chadwick 1980	Metallophyte
			Dueck *et al.* 1984	
			Ernst *et al.* 1983 +	
		As,Cu,Fe,Pb,Zn	Porter & Petersen 1975	Tolerance recorded

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Agrostis tenuis x stolonifera		Zn	Archer 1964 + Gregory & Bradshaw 1965;	Tolerant races demonstrated experimentally
Agrostis vinealis	Brown bent grass	Pb	Craig 1977	Tolerance at lead mine, Tyndrum, Scotland
Anthoxanthum odoratum	Sweet vernal grass	Pb Zn	Karataglis 1978 + Antonovics 1966 Cox & Hutchinson 1979 Gemmell 1977 Gregory & Bradshaw 1965;	Tolerance recorded on mine sites Tolerance recorded Tolerant ecotypes on metal mine spoil Tolerant races demonstrated experimentally
Arrhenatherum elatius	False oat-grass	Cd Pb	Baker & Proctor 1990 Shaw *et al* 1984	Present on cadmium-rich soil (from unpub.data of K. Ewart) Characteristic of deep, organic nutrient-rich soil with lower metal concentrations
Avena pubescens	Downy oat-grass	Metals	Antonovics *et al.* 1971	Indifferent pseudometallophyte
Cynodon dactylon	Bermuda grass	Pb	Wu & Antonovics 1976	Lead tolerance constitutional
Dactylis glomerata	Cock's-foot	Cu Pb	Ingram 1988 + Shaw 1984	Tolerance of collected adult plants Characteristic of deep organic nutrient-rich soil with lower metal concentrations
Deschampsia cespitosa	Tufted hair-grass	Cd Cu,Ni Al,Cd,Cu,Ni,Pb,Zn	Baker & Proctor 1990 Cox 1979; Cox & Hutchinson 1981 Cox & Hutchinson 1979	Present on cadmium-rich soil (unpub.data from K. Ewart) Tolerant populations Tolerance recorded

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Deschampsia flexuosa	Wavy hair-grass	Cu	Ingram 1988 +	Tolerance of collected adult plants
		Pb	håg & Bølviken 1974	Tollerance to soil land enrichment from weathered galena
Festuca ovina	Sheep's fescue	Cd	Baker & Proctor 1990	Present on cadmium-rich soil (from unpub.data of K. Ewart)
		Pb	Shaw *et al.* 1984	Characteristic of shallow, coarse and nutrient poor soils
			Wilkins (1957,1960) +	Tolerant races demonstrated experimentally
		Zn	Gregory & Bradshaw 1965	Tolerant races demonstrated experimentally
		Pb,Zn	Baker & Proctor 1990	Electic pseudometallophyte
			Gemmell 1977	Tolerant ecotypes on metal mine spoil
		Cd,Pb,Zn	Simon 1977	Tolerance recorded on mine sites
		Metals	Antonovics *et al.* 1971	One of few species found on acidic mines
			Bradshaw & Chadwick 1980	Metallophyte
			Cox & Hutchinson 1979	Tolerance recorded
			Ernst 1965 +	Characteristic mine plant
Festuca rubra	Red fescue	Cd	Baker & Proctor 1990	Present on Cd-rich soil (unpub.data from K. Ewart)
		Cr	Gemmell 1973	
		Cu	Ingram 1988 +	Tolerance of collected adult plants
			Thompson & Proctor 1983	
		Zn	Gregory & Bradshaw 1965	Tolerant races demonstrated experimentally
		Pb,Zn	Baker & Proctor 1990	Electric pseudometallophyte
		Cd,Pb,Zn	Simon 1977	
		Cu,Pb,Zn	Gemmell 1977	Tolerant ecotypes in metal mine spoil
		Metals	Antonovics *et al.* 1971	Characteristic of calcareous metal mines
			Bradshaw & Chadwick 1980	Metallophyte
			Tyler 1989	Tolerant races

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Holcus lanatus	Yorkshire fog	Cd	Baker & Proctor 1990	Present on Cd-rich soil (unpub.data of K. Ewart)
			Brown 1983 +	Tolerant populations
			Brown & Martin 1981	Tolerant populations
		Cu	Ingram 1988 +	Tolerance of collected adult plants
		Zn	Antonovics 1966 + Gemmell 1977	
			Jenkins & Winfield 1964+	Tolerant races demonstrated experimentally
		Cd,Pb,Zn	Coughtrey & Martin 1977	Tolerance recorded near Pb/Zn smelter
			Wigham *et al.* 1980	
Juncus acutiflorus	Sharp-flowered rush	Metals	Harding 1981	Recorded as present on metal-rich soils
Juncus effusus	Soft rush	Metals	Harding 1981	Recorded as present on metal-rich soils
Koeleria macrantha	Crested hair-grass	Cd	Baker & Proctor 1990	Present on cadmium-rich soil (unpub.data of K. Ewart)
		Pb	Shaw *et al.* 1984	Characteristic of shallow, coarse nutrient-poor soil
Lolium perenne	Perennial rye-grass	Cd	Dijkshoorn *et al.* 1974	
Phalaris arundinacea	Reed grass	Cd,Pb,	Homer, Cotton & Evans 1980	Tolerant clones
Typha latifolia	Reedmace	Zn	McNaughton *et al.* 1974	Constitutional tolerance
		Cd,Pb,Zn	McNaughton *et al.* 1974	Tolerance recorded near Zn smelter
		Cu,Ni	Taylor & Crowder 1984	Constitutional tolerance

Latin Name	Common Name	Metals	References	Context of Citation/Comments
FORBS				
Armeria maritima	Thrift	Cu Zn Metals	Antonovics *et al.* 1971 Ernst 1974+, 1976+ Henwood 1857+ LeFebvre 1974 + Tyler *et al.* 1989	Local metallophyte Metal tolerant ecotypes at cupriferous inland sites in Cornwall, N.Wales and Killarney, Ireland. Metal prospecting Experimental rooting techniques to detect tolerance Tolerant races
Atriplex patula	Common orache	Se	Zhang-Zhi Huang *et al.* 1991	Tolerance recorded
Callitriche spp.	Starwort	Metals	Carpenter 1926	Early coloniser of polluted rivers
Calluna vulgaris	Ling	Cu,Zn As,Cu,Fe,Pb,Zn	Bradley *et al.* 1982 Porter & Petersen, 1975	Tolerant races from metalliferous soils Tolerance recorded
Campanula rotundifolia	Harebell	Zn	Antonovics *et al.* 1971 Schwanitz & Hahn 1954+	Elective pseudometallophyte Tolerant races demonstrated experimentally
Cochlearia pyrenaica	Pyrenean scurvy grass	Pb, Zn	Baker & Proctor 1990	Local metallophyte in Pennine orefields
Epipactis leptochila	Green-leaved helleborine	Pb,Zn	Baker & Proctor 1990; Richards & Swan 1976; Richards & Porter 1982	Local metallophyte on Rivers South Tyne and West Allen
Epipactis phyllanthes	Pendulous-flowered helleborine	Pb,Zn	Baker & Proctor 1990; Richards & Swan 1976; Richards & Porter 1982	Local metallophyte on Rivers South Tyne and West Allen

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Epipactis youngiana	Young's helleborine	Pb,Zn	Baker & Proctor 1990; Richards & Swan 1976; Richards & Porter 1982	Local metallophyte on Rivers South Tyne and West Allen
Genista tinctoria	Dyer's greenweed	Metals	Antonovics *et al.* 1971	Indifferent pseudometallophyte
Jasione montana	Sheep's bit	As,Cu,Fe,Pb,Zn	Porter & Petersen 1975	Tolerance recorded
Kobresia simpliciuscula	False sedge	Pb	Baker & Proctor 1990 Jeffrey 1971;	Local metallophyte in Teesdale
Linum catharticum	Fairy flax	Zn	Antonovics *et al.* 1971 Gemmell 1977 Schwanitz & Hahn 1954+	Indifferent pseudometallophyte Tolerance recorded Tolerant races demonstrated experimentally
Mercurialis perennis	Dog's mercury	Cd	Martin *et al.* 1980	Tolerance recorded near Pb/Zn smelter
Mimulus guttatus	Monkey flower	Cu Cu,Zn Cu,Ni,Zn Metals	Allen & Sheppard 1971 Searcy & Mulcahy 1985 Cox & Hutchinson 1979 Bradshaw & Chadwick 1980	Tolerant races demonstrated experimentally Tolerant populations Tolerance recorded Metallophyte

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Minuarta verna (= *Alsine*)	Vernal sandwort	Pb	Shaw *et al* 1984	Characteristic of shallow, coarse, nutrient-poor soil
		Zn	Schwanitz & Hahn 1954+	Tolerant races demonstrated experimentally
		Cd,Pb	Chaphekar 1978	
		Cu,Zn	Ernst 1965+	Grows on mine soils with fine texture high water capacity, high surface temperature; indicator of mineral deposits
		Pb,Zn	Baker & Proctor 1990	Distribution correlated with that of Pb/Zn mines
		Ag,Cu,Pb,Zn	Antonovics *et al.* 1971	Absolute metallophyte
			Ineson 1981	Metallophyte recorded on metalliferous soils including a site in Clapham
			Linstow 1929 +	Indicator of metal-containing soil
		Cd,Cu,Ni,Pb,Zn	Hajar 1987 +	Shown to have evolved races singly and multiply tolerant
			Halliday 1960 +	Shown to have evolved races singly and multiply tolerant
		Metals	Bradshaw & Chadwick 1980	Metallophyte
			Tyler 1989	Tolerant races
Plantago lanceolata	Ribwort plantain	Zn	Baker & Proctor 1990	Indifferent pseudometallophyte
			Gemmell 1977	Tolerance recorded
			Schwanitz & Hahn 1954;	Tolerant races demonstrated experimentally
			Williams & Morgan 1964	Tolerant races demonstrated experimentally
		Cu,Zn	Lolkema 1985 +	Tolerance recorded
		Metals	Antonovics *et al.* 1971	Indifferent pseudometallophyte
			Wu & Antonovics 1976	
Polygala vulgaris	Common milkwort	Metals	Antonovics *et al.* 1971	Elective pseudometallophyte
Ranunculus spp.	Water crowfoot	Metals	Carpenter 1926	Early coloniser of polluted rivers

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Rhianthus minor	Yellow rattle	Metals	Frizzell, 1993	Recorded on metal contaminated mine spoil
Rumex acetosa	Common sorrel	Cu Zn	Antonovics *et al.* 1971 Schwanitz & Hahn 1954+ Spilling & Thomas 1964+	Elective pseudometallophyte Tolerant races demonstrated experimentally Tolerant races demonstrated experimentally
Senecio vulgaris	Groundsel	Pb	Briggs 1976	Tolerance recorded on roadsides
Silene alba	White campion	Cu,Zn	Searcy & Mulcahy 1985	Tolerant populations
Silene dioica	Red campion	Cu,Zn	Searcy & Mulcahy 1985	Tolerant populations

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Silene vulgaris (= *cucubalus*)	Bladder campion	Cd	Verkleii & Prast 1989	Tolerance recorded under experimental conditions
		Zn	Antonovics *et al.* 1971	Tolerant races
			Baker & Proctor 1990	Inland distribution correlated with that of metalliferous sites on regional level
			Baumeister 1954 +	Tolerant races demonstrated
			Baumeister & Burghardt 1956 +	Tolerant races demonstrated
			Broker 1963 +	Tolerant races demonstrated
			Cox & Hutchinson 1979	Tolerance recorded
			Ernst 1965+	Grows on mine soil with coarse texture, low water capacity and low surface temperature
			Gries 1966 +	Tolerant races demonstrated
			Linstow 1929 +	Indicator of metal-containing soil
			Schiller 1974 +	Tolerant races
		Cu,Zn	Schwanitz & Hahn 1954+	Tolerant races
		Metals	Wachsmann 1961 +	Tolerant races demonstrated experimentally
			Bradshaw & Chadwick 1980	Metaliophyte
			Tyler *et al.* 1989	Tolerant races
Silene vulgaris subsp. maritima	Sea campion	Ag,Cu,Pb,Zn	Baker and Dalby 1980	Tolerance recorded
Taraxacum officinale	Dandelion	Cu	Repp 1963 +	Tolerant races demonstrated experimentally

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Thlaspi caerulescens (= *alpestre*)	Alpine penny-cress	Zn	Chapekar 1978	
			Gemmell 1977	Tolerance recorded
		Pb,Ni,Zn	Baker & Proctor 1990	Distribution correlated with that of lead/zinc mines
		Ag,Al,Cd,Co,Cr,Cu, Fe,Mn,Mo,Ni,Pb,Zn	Hajar 1987+	Experiment demonstrating non-specific metal detoxification mechanism
			Ineson 1981	Metallophyte; recorded on metalliferous soils, including a site in Clapham
		Metals	Bradshaw & Chadwick 1980	Metallophyte
			Tyler *et al* 1989	Tolerant races
Thymus pulegioides	Large thyme	Metals	Antonovics *et al.* 1971	Elective Pseudometallophyte
Tussilago farfara	Coltsfoot	Cu	Repp 1963 +	Tolerant races demonstrated experimentally
Viola lutea	Mountain pansy	Pb	Ineson 1981	Recorded from lead workings
		Zn	Schwanitz & Hahn 1954+	Tolerant races demonstrated experimentally
		Pb,Zn	Baker & Proctor 1990	Local metallophyte in Pennine orefield
Viola calaminaria	Zinc violet	Zn	Cannon 1971	Used in Belgium and Prussia for zinc prospecting
			Gemmell 1977	Tolerance recorded
			Lidgey 1897 +	Used in Belgium and Prussia for zinc prospecting
Viscaria alpina	Red alpine catchfly	Metals, especially Cu	Tyler *et al* 1989	Tolerant races
HORSETAILS				
Equisetum arvense	Field horsetail	Cu,Zn	Weatherly *et al.* 1980	Record of tolerance

Latin Name	Common Name	Metals	References	Context of Citation/Comments
TREES				
Betula sp.	Birch	Fe Zn	Lidgey 1897 + Dueck *et al.* 1987	Species used in Germany for iron prospecting Tolerance to zinc smelter waste recorded
Salix spp.	Willow	Pb,Zn	Robinson *et al.* 1976	Reports possible tolerance
MOSSES AND LIVERWORTS				
Amblystegium riparium		Metals	Say *et al.* 1981	
Bryum pseudotriquetrum		Pb,Zn	Shimwell & Laurie 1972	
Calypogeia muelleriana		Cu	Shacklette 1961 +	
Calypogeia trichomani		Cu,Fe	Url 1956 +	
Cephalozia bicuspidata		Zn Cu,Pb,Zn	Nicklasson & Soderberg 1980 + Shacklette 1961+, 1965+	
Cephaloziella massalongii		Cu,Fe	Persson 1948+	
Cephaloziella phyllacantha		Cu,Fe	Persson 1948+	
Ceratodon purpureus		Zn	Shaw *et al.* 1987	
Dicranella varia		Pb,Zn	Shimwell & Laurie 1972	

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Dryoptodom atratus		Cu,Fe	Persson 1948 +	
Fontinalis antipyretica		Metals	Say *et al.* 1981	
Fontinalis squamosa		Metals	Say *et al.* 1981	
Funaria hygrometrica		Cu,Zn	Shaw *et al.* 1987	
Gymmocolea acutiloba		Cu,Fe	Persson 1948 + Shacklette 1961+, 1965+	
Hylocomium splendens		Pb	LeBlanc. *et al.* 1974	Tolerant in copper smelter soils
Marchantia polymorpha		Pb	Briggs 1972 Monitoring and Assessment Research Centre 1986	Experimental vegetative technique to detect tolerance
Merceya ligulata		Cu Cu,Fe	Noguchi 1956 Persson 1948 +	
Merceya gedeana		Cu	Monitoring and Assessment Record Centre 1986 Noguchi 1956 +	
Mielichoferia elongata		Cu Cr,Cu,Fe	Martensson & Berggren 1954 + Url 1956 +	

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Mielichoferia nitida		Cu	Martensson & Berggren 1954 +	
		Cu,Fe	Persson 1948+; Url 1956+	
		Cu,Pb,Zn	Hartman 1969 +	
Nardia scalaris		Cu	Shacklette 1961+, 1965+	
		Cu,Fe	Url 1956 +	
Oligotrichum hercynicum		Cu,Ni	Shacklette 1961+, 1965+	
Oligotrichum parallelum		Cu,Ni	Shacklette 1965 +	
Philonotis fontana		Pb	Shimwell & Laurie 1972	
Physcomitrium pyriforme		Zn	Shaw *et al.* 1987	
Pleuroclada albescens		Cu	Shacklette 1961 +	

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Pohlia nutans		Cu	Beschel 1959 + Dykeman & de Sousa 1966 Monitoring and Assessment Research Centre 1986	
		Zn	Nicklasson & Soderberg 1980 +	
		Cu + Zn Metals	Folkeson 1983 + Webster 1985	
Rhynchostegium riparioides		Metals	Say *et al.* 1981	
Scapania undulata		Cu,Mn,Zn Metals	McLean & Jones 1975 Say *et al.* 1981	
Trematodon longicollis		Cu,Zn	Shaw *et al.* 1987	
Weissia controversa		Cu,Zn	Shaw *et al.* 1987	
LICHENS				
Cladonia chlorophaea agg.		Cu,Zn	Tyler *et al.* 1989	
Cladonia coniocraea		Cu,Zn	Tyler *et al.* 1989	
Lecanora muralis		Fe	Seaward 1973 +	Tolerance on urban asbestos roof
Parmelia sulcata		Cu	Tyler *et al.* 1989	
Peltigera rufescens		Fe	Seaward 1973 +	Tolerance in steel smelter soil

Latin Name	Common Name	Metals	References	Context of Citation/Comments
FERNS				
Asplenium septentrionale		Cu,Pb	Baker & Proctor 1990	Local metallophyte in northern and central Wales
ALGAE				
Hormidium rivulare		Cu,Mn,Zn	McLean & Jones 1975	Tolerance recorded
INVERTEBRATES				
Mollusca	Molluscs	Al	Wren and Stephenson 1991	Tolerance recorded
ARTHROPODA : INSECTA				
Coleoptera *Hygrobia sp*	Water beetles	Cu,Fe,Zn	Brown 1977	Tolerance recorded below mine drainage discharge to R.Hayle
Limnius volckmari		FeOH	Scullion and Edwards 1980	Tolerant of Fe deposits
Stenelmis sp	Water beetle larvae	Cu	Winner *et al.* 1975	Tolerance recorded
Collembola	Springtails	Cu,Zn Pb,Zn	Tyler 1989 Williams *et al.* 1977	More springtails on mine waste than on control sites Some species more tolerant than other microarthropods

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Diptera	Flies	Cd	Selby *et al.* 1985	Increase in abundance recorded
		FeOH	Greenfield & Ireland 1978	Tolerance recorded in coal-waste polluted steam
			Letterman & Mitsch 1978	Tolerance recorded in mine drainage
			Scullion & Edwards 1980	Tolerance recorded
			Williams *et al.* 1976	Early colonisers of polluted water
Chironomidae	Midge larvae	Cu	Winner *et al.* 1975	Tolerance recorded
		Cu,Zn	Sheehan and Knight 1985 +	More abundant than other taxa in stream polluted for 30 years
		Cu,Cd,Zn	Leland *et al.* 1989	Tolerance recorded
		Cd,Cu,Pb,Zn	Weatherly *et al.* 1980	Tolerance recorded in mine water
Orthocladiinae		Metals	Yasuno *et al.* 1985	Some species of orthocladiinae tolerant
Cricotopus sp		Cu	Butcher 1946 +	Among the first species to re-populate a polluted stream
Simuliidae	Blackfly larvae	Cd,Cu,Pb,Zn	Weatherly *et al.* 1980	Tolerance recorded in mine water
Simulium latipes	Blackfly larvae	Pb	Carpenter 1924	Tolerance recorded in mine effluent
Tanypus nebulosus		Pb	Carpenter 1924	Tolerance recorded in mine effluent
Ephemeroptera	Mayfly larvae	Cd,Cu,Pb,Zn	Weatherly *et al.* 1980	Tolerance recorded in mine water
Chloeon simile	Mayfly larvae	Pb	Carpenter 1924	Tolerance recorded in mine effluent
Rhithrogena semicolorata	Olive upright mayfly	Zn	Abel and Green 1981	Tolerance recorded but distribution restricted
Hemiptera	Water bugs	Cd,Cu,Pb,Zn	Weatherly *et al.* 1980	Tolerance recorded in rivers polluted with mine drainage

Latin Name	Common Name	Metals	References	Context of Citation/Comments
Megaloptera *Sialis lutaria*	Alder flies	Cu,Fe,Zn	Brown 1977	Tolerance recorded below mine drainage discharge to R.Hayle
Plecoptera	Stone flies	Cd FeOH	Wren and Stephenson 1991 Letterman and Mitsch 1978	Tolerance recorded Tolerance recorded in mine drainage
Chloroperla torrentium	Stone fly	Zn	Abel and Green 1981	Tolerance recorded but distribution restricted
Trichoptera	Caddis flies	Cd Cu,Fe,Zn Cu,Pb,Zn Metals	Wren & Stephenson 1991 Brown 1977 Weatherby *et al.* 1980 Chadwick *et al.* 1986 Clements *et al.* 1988 Clements *et al.* 1989	Tolerance recorded Caseless caddis appear more tolerant than case-bearing caddis Tolerance recorded in rivers polluted with mine drainage Tolerance recorded in metal mine waste water Tolerance recorded in metal mine waste water Tolerance recorded
Cheumatopsyche sp	Caddis fly larvae	Cu	Winner *et al.* 1975	Tolerance recorded
Hydropsyche sp	Caddis fly larvae	Cu,Zn	Clements *et al.* 1988 +	Tolerance recorded
Limnephilus sp	Sedge caddis	Zn	Abel and Green 1981	Tolerance recorded but distribution restricted
Rhyacophila spp	Caddis fly larvae	Cu	Leland *et al.* 1989	Some species tolerant
Zygoptera	Damsel fly larvae	Cu	Winner *et al.* 1975	Tolerance recorded
Enallagma sp		Cd,Cu,Pb	Mackie 1989	More tolerant than molluscs under investigation

Latin Name	Common Name	Metals	References	Context of Citation/Comments
ARTHROPODA : CRUSTACEA				
Astacus sp	Crayfish	Cd	Wren and Stephenson 1991	Tolerance recorded
Isopoda	Isopods	Cd Metals	Coughtrey 1978 + Tyler 1989	Tolerance recorded More tolerant than other invertebrates
	Woodlouse	Pb Zn	Williamson & Evans 1972 Andrews *et al.* 1989	Tolerance recorded Can regulate body Zn levels and thereby buffer polluted toxic effects of accumulation
Asellus aquaticus	Freshwater louse	Pb	Fraser 1980	Tolerance recorded
Asellus meridianus	Freshwater louse	Cu,Pb	Brown, 1976, 1977	Tolerance recorded in mine drainage in Cornwall
Porcellio scaber		Zn	Joose *et al.* 1981	Tolerance recorded
	Non-malacostracan crustaceans	Cd,Cu,Pb,Zn	Weatherly *et al.* 1980	Tolerance recorded in river polluted with mine drainage
ARTHROPODA : MILLIPEDA				
	Millipedes	Pb	Williamson and Evans 1972	Tolerance recorded
ARTHROPODA : ARACHNIDA (SPIDERS ETC)				
Clubionidae		Cd,Cu,Pb,Zn Metals especially Zn	Weatherly *et al.* 1980 Hopkin 1986	Tolerance recorded in rivers polluted with mine drainage Tolerance recorded

Latin Name	Common Name	Metals	References	Context of Citation/Comments
ANNELIDA: OLIGOCHAETA (WORMS)				
		Metals	Wielgolaski 1975	
		FeOH	Greenfield and Ireland 1978	Tolerance recorded in coal-waste polluted stream
		FeOH	Scullion and Edwards 1980	Tolerance recorded
		FeOH	Williams *et al.* 1976	Early colonisers of polluted water
Allolobophora caliginosa	Earthworms	Co,Cu,Hg,Zn	Van Rhee 1975	A proportion of populations showed loss of clitellum
Dendrodrilus rubidus		Cd,Cu,Pb,Zn	Morgan and Morgan 1988	Tolerant in metalliferous spoil
Limnodrilus hoffmeisteri		Cd,Ni	Klerks and Levinton 1987	Tolerance recorded
Limnodrilus sp.		Cd,Cr,Zn	Weatherly *et al.* 1980	Tolerance recorded in lake polluted with electroplating effluent
Lumbricidae	Earthworms	Pb	Ireland, 1977	Tolerance recorded
		Zn	Andrews et al. 1989	Can regulate body Zn levels and thereby buffer potential toxic effects of accommodation
		As,Cd,Cu,Pb,Zn	Ismail, 1986	Some evidence of tolerance, but population density reduced near smelter

Latin Name	Common Name	Metals	References	Context of Citation/Comments
ANNELIDA : HIRUDINEA (LEECHES)				
Trocheta subviridis		FeOH	Scullion and Edwards 1980	Increased in density in polluted zone
PLATYHELMINTHES				
	Flatworms	Cd,Cu,Pb,Zn	Weatherly *et al.* 1980	Tolerance recorded in river polluted by mine drainage
Polycelis sp.		FeOH	Scullion and Edwards 1980	Increased in density in polluted zone

+ cited by other authors but not actually obtained for this review

TABLE 5

METAL SUMMARY SHEETS

ANTIMONY (Sb)

SOURCES OF CONTAMINATION: Antimony; gold and copper mines and smelters.
ABIOTIC INDICATORS: Mine spoil.
BIOTIC INDICATORS: *TERRESTRIAL PLANTS* **Tolerant species:** Grasses etc: Cocksfoot; common bent; couch grass; red fescue. Forbs: Hogweed.
ENVIRONMENTAL FACTORS AFFECTING TOXICITY:
FACTORS PRODUCING SIMILAR SYMPTOMS:

ARSENIC (As)

SOURCES OF CONTAMINATION:

Metal mines and smelters; especially Pb or Cu; wood preservatives; coal burning; sewage sludge; pulverized fuel ash; pesticides; dredged material; iron and steel works; foundries, electroplating, anodising and galvanising; growth promoters for poultry and pigs.

ABIOTIC INDICATORS:

Spoil heaps; coloured deposits (mostly white); green colouration (copper, chrome, arsenic timber treatment: CCA).

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Tolerant species:

Grasses etc:	Common bent-grass; creeping bent-grass;.
Forbs:	Ling; sheep's bit.
Visible symptoms	Red-brown necrotic spots on old leaves; yellowing or browning of roots; depressed tillering; wilting of new leaves.

TERRESTRIAL INVERTEBRATES

Tolerant species:	No evidence of lethal or sub-lethal effects of arsenic on aquatic invertebrates; earthworms may be tolerant.

MAMMALS

Visible symptoms:	Some experimental studies on small mammals showed weight loss and anal bleeding.

SOIL MICROBIOLOGY

Visible symptoms:	Reduced decomposition leading to build-up of soil litter; bare patches.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:

Age of organism; concentration of other metals especially iron.

FACTORS PRODUCING SIMILAR SYMPTOMS:

BERYLLIUM (Be)

SOURCES OF CONTAMINATION:

ABIOTIC INDICATORS:

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Visible symptoms: Necrotic spots on leaves, more persistent on acid soils; plants stunted and roots slow-growing.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:

Be less soluble as pH increases.

FACTORS PRODUCING SIMILAR SYMPTOMS:

CADMIUM (Cd)

SOURCES OF CONTAMINATION:
Metal mine waste and drainage; metal smelters; combustion of organic materials and tyres. Production of electrical goods + alloys. Incinerators; sewage disposal; manufacture of batteries, fertilisers and pesticides; power station waste; plating, ceramics, pigments, fluxes, glass manufacture, lubricant additives, catalysts from industrial processes; dredged materials; iron and steel works, foundries, electroplating, anodising and galvanising.

ABIOTIC INDICATORS:
Spoil heaps; coloured deposits (white, yellow, orange).

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Tolerant species:

Grasses etc:	Common bent (*Agrostis capillaris*); crested hair-grass; false oat-grass; red fescue; reed grass; reedmace; sheep's fescue; tufted hair-grass; Yorkshire fog. Cabbage more tolerant than other vegetables.
Forbs:	Alpine pennycress; bladder campion; dog's mercury; vernal sandwort.
Visible symptoms:	Chlorosis (especially interveinal); purple or reddish-brown pigment in leaf and stem followed by leaf abscission (soy bean); reduced growth in macrophytes, especially of roots; wilting; necrosis; deformity of leaves and stems; sparse vegetation cover.

TERRESTRIAL INVERTEBRATES

Tolerant species: Earthworms

AQUATIC INVERTEBRATES

Tolerant species: Amphipods; *Astacus* (crayfish); chironomids (midges); isopods; *Limnodrilus hoffmeisteri* (worm); plecoptera (stoneflies); trichoptera (caddis flies).

MAMMALS

Visible symptoms: Experimental rats: reduced growth rate and bleaching of incisors; flushed extremities; flaccidity of muscles; rapid shallow respiration; apathy; impaired co-ordination of movement and convulsion; reddish secretion from the eyes.

SOIL MICROBIOLOGY

Visible symptoms: Reduction in decomposition, especially by bacteria, leading to build-up of leaf litter.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:
Other metals; nutrients; soil temperature; soil texture; moisture; redox potential; low pH increases Cd toxicity; concentration of organic complexing material - high concentration reduces Cd toxicity.

FACTORS PRODUCING SIMILAR SYMPTOMS:
Iron-deficiency chlorosis; Zn deficiency.

CHROMIUM (Cr)

SOURCES OF CONTAMINATION:
Chromium and other mines and smelters; metallurgy industries; power station ash; sewage sludge; timber preservation; pigments; tanning; plating; serpentine soils; dredged materials.

ABIOTIC INDICATORS:
Physical evidence of above industries; spoil from mining/smelting (greyish white to yellow/orange); green coloration (CCA timber treatment).

BIOTIC INDICATORS:
TERRESTRIAL PLANTS
Tolerant species:

Grasses etc:	Common bent; red fescue.
Forbs:	Alpine pennycress.
Lower plants:	
Visible symptoms:	Leaf necrosis; growth inhibited in water milfoil; necrotic spots and purpling tissues.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:
Concentration of calcium hydroxide present: high alkalinity increases toxicity; stage of weathering.

FACTORS PRODUCING SIMILAR SYMPTOMS:

COBALT (Co)

SOURCES OF CONTAMINATION: Pigments; metallurgy industries; hospitals	
ABIOTIC INDICATORS:	
BIOTIC INDICATORS: *TERRESTRIAL PLANTS* **Tolerant species:**	
Grasses:	Common bent-grass.
Forbs:	Alpine pennycress.
Visible symptoms:	Stunting and chlorosis resembling iron-deficiency; necrosis; leaf cupping; damaged root tips.
ENVIRONMENTAL FACTORS AFFECTING TOXICITY: Manganese has antidotal effect on cobalt toxicity.	
FACTORS PRODUCING SIMILAR SYMPTOMS: Iron deficiency.	

SOURCES OF CONTAMINATION:
Copper and other metal mine waste and drainage; copper and other metal smelters; fertilizers; herbicides; molluscicides; wood preservatives; fungicides; sewage sludge; pig manure; dredged materials; manufacture of electrical goods; piping; engineering works; ship building industries; scrap yards.

ABIOTIC INDICATORS:
Bare patches; variable vegetation cover; coloured deposits (green, blue, yellow, red, black); green colouration (CCA timber treatment).

BIOTIC INDICATORS:
TERRESTRIAL PLANTS
Tolerant plant species:

Grasses etc:	Cocksfoot; common bent (*Agrostis capillaris*); common bent (*Agrostis gigantea*); creeping bent; red fesscue; reedmace; tufted hair-grass; wavy hair-grass; Yorkshire fog.
Forbs:	Alpine pennycress; bladder campion; coltsfoot; common sorrel; dandelion; ling; monkey flower; red alpine catchfly; red campion; ribwort plantain; sea campion; sheep's-bit; thrift; vernal sandwort; white campion.
Horsetails and ferns:	Field horsetail; forked spleenwort.
Lower plants:	Mosses and liverworts generally more tolerant than higher aquatic plants. *Calypogeia muelleriana; Calypogeia trichomania; Cephalozia bicuspidata; Cephaloziella massalongii; Cephaloziella phyllacantha; Cladonia chlorophaea; Cladonia coniocraea; Dryophodom atratus; Funaria hygrometrica; Gymmocolea acutiloba; Hormidium rivulare; Merceya ligulata; Merceya gedeana; Mielichoferia elongata; Mielichoferia nitida; Nadia scalaris; Oligotrichum hercynicum; Oligotrichum parallelum; Parmelia sulcata; Pleuroclada albescens; Pohlia natans; Scapania undulata; Tremetodon longicollis; Weissia controversa.*
Visible symptoms:	Leaves of sea campion have higher length/width ratio than on non-contaminated sites; also some other species have smaller leaves and flowers and thinner stems. Inhibition of root-growth; interveinal chlorosis especially of youngest leaves; stunting of growth, possibly due to iron deficiency; poor root nodulation in most legumes; production of dark stubby poorly branched fibrous roots; chlorosis and necrosis of lower leaves from the tips; leaf cupping; variable vegetation cover.

TERRESTRIAL INVERTEBRATES

Tolerant species:	*Oniscus asellus* (isopod), springtail (collembola), earthworms.
Visible symptoms:	Reduction in number of groups; reduced growth rate; inability to complete stage of life cycle. Earthworms: loss of clitellum (in presence of other contaminants).

SOIL MICROBIOLOGY

Visible symptoms:	Reduced decomposition; especially by bacteria, leading to build up of leaf litter.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:
Toxicity ameliorated by Ca, soil Fe, and P; interaction between contaminants; high pH reduces toxicity; drought and nutrient deficiency increase toxicity.

FACTORS PRODUCING SIMILAR SYMPTOMS:
Nutrient deficiency, especially of iron, causes chlorosis.

GOLD (Au)

SOURCES OF CONTAMINATION: Gold mining and smelting; electrical industries; alloys.
ABIOTIC INDICATORS: Mine spoil.
BIOTIC INDICATORS: *TERRESTRIAL PLANTS* **Tolerant species:** *Equisetum* (horsetail) is tolerant of arsenic which is often associated geochemically with gold; therefore *Equisetum* has potential as an indicator for gold. **Visible symptoms:** Leaf wilting; leaf discoloration; stunted root growth in maize.
ENVIRONMENTAL FACTORS AFFECTING TOXICITY:
FACTORS PRODUCING SIMILAR SYMPTOMS: Arsenic.

LEAD (Pb)

SOURCES OF CONTAMINATION:
Lead, other metals, and fluorspar mine waste and drainage; lead and other metal smelters; foundries, manufacturing industries; pigments; batteries; plating; plastics stabilisers; traffic exhaust; fungicides; sewage sludge; water pipes; lead shot and weights; landfills; dredged materials; roofs; storage of acids, anodising and galvanizing works.

ABIOTIC INDICATORS:
Spoil heaps; bare patches; erosion; coloured deposits (white; yellow or black).

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Tolerant Species:

Grasses etc:	Bermuda grass; brown bent-grass; common bent; creeping bent; cocksfoot; crested hair-grass; false oat-grass; red fescue; reed grass; reedmace; sheep's fescue; sweet vernal-grass; tufted hair-grass; wavy hair-grass; Yorkshire fog.
Forbs:	Alpine pennycress; false sedge; green-leaved helleborine; groundsel; mountain pansy; pendulous-flowered helleborine; groundsel; mountain pansy; pendulous-flowered helleborine; pyrenean scurvy grass; sea campion; sheep's bit; vernal sandwort; Young's helleborine.
Horsetails and Ferns:	Forked spleenwort.
Lower plants:	*Bryum pseudotriquetrum; Cephalozia bicuspidata; Dicranella varia; Hylocorium splendens; Mielichoferia nitida; Philonotis fontana.*
Visible symptoms:	Vegetation cover sparse; chlorosis; dwarfing; deformity of leaves and stems; *Silene maritima* has higher length/width ratio of leaves than on non-contaminated sites; possibly smaller flowers and thinner stems. Characteristically small habit in vernal sandwort, bladder campion, harebell; inhibition of root growth; dark green leaves; wilting of other leaves.

TERRESTRIAL INVERTEBRATES

Tolerant species:	Earthworms; millipedes; woodlice

AQUATIC INVERTEBRATES

Tolerant species:	Freshwater louse (*Asellus meridianus*), a few dipteran and caddis larvae and flatworms.
Visible symptoms:	Low species diversity.

MAMMALS

Visible symptoms:	Can cause copper-deficiency in sheep, causing "sway-back".

SOIL MICROBIOLOGY

Visible symptoms:	Reduced decomposition leading to build up of leaf litter.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:
Age and stage of life cycle of organisms; nutritional status; pH (high pH reduces toxicity); soil texture; organic matter; phosphorus concentration; sulphate concentration; other metals; conifers (which reduce pH); season.

FACTORS PRODUCING SIMILAR SYMPTOMS:
Nutrient deficiency; drought; low pH; effects of wind; iron-deficiency chlorosis.

MAGNESIUM (Mg)

SOURCES OF CONTAMINATION: Serpentine soils; fireworks manufacture; alloys.
ABIOTIC INDICATORS:
BIOTIC INDICATORS: *TERRESTRIAL PLANTS* **Tolerant species:** Grasses etc: Common bent. Crops: Oat. **Visible symptoms:** Stunted growth.
ENVIRONMENTAL FACTORS AFFECTING TOXICITY: Toxicity ameliorated by addition of lime.
FACTORS PRODUCING SIMILAR SYMPTOMS:

MANGANESE (Mn)

SOURCES OF CONTAMINATION:
Pigments; dredged materials; manufacture of steel and other alloys; sewage sludge.

ABIOTIC INDICATORS:

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Tolerant species:

Forbs:	Alpine pennycress.
Lower plants:	Mosses and liverworts generally more tolerant than higher aquatic plants - *Hormidium rivulare; Scapania undulata.*
Visible Symptoms:	Can aggravate iron-deficiency in plants, leading to chlorosis, and necrosis; blackish-brown or red necrotic spots; drying tips of leaves; stunted roots and plant growth.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:
Cobalt has antidotal effect on manganese toxicity.

FACTORS PRODUCING SIMILAR SYMPTOMS:
Other causes of iron deficiency.

MERCURY (Hg)

SOURCES OF CONTAMINATION:

Mining and smelting; production of electrolytic chloride and alkali; electrical apparatus, paints, amalgams, instruments, catalysts, dental products, plastics, wood preservatives; burning of coal, gas, wood and oil; metal ore refining; sewage sludge; dredged materials; pulp and paper production; fungicides; glass manufacture; iron and steel works; foundries; electroplating; anodising and galvanising.

ABIOTIC INDICATORS:

Sewage sludge; coloured deposits (white, black).

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Tolerant species:

Forbs:	Dandelion; melilot; ribwort plantain; willowherb.
Trees and shrubs:	Dogwood; poplar.
Visible symptoms:	Chlorosis; detached roots in aquatic plants; leaves shrivelled; stunting of seedlings and roots; leaf chlorosis and browning of leaf points.

TERRESTRIAL INVERTEBRATES

Visible symptoms: Earthworms: loss of saddle.

MAMMALS

Visible symptoms: Locomotory disturbances, paralysis, anorexia, blindness.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:

Interaction between contaminants.

FACTORS PRODUCING SIMILAR SYMPTOMS:

MOLYBDENUM (Mo)

SOURCES OF CONTAMINATION:	
High molybdenum levels in cattle food; lubricants.	
ABIOTIC INDICATORS:	
BIOTIC INDICATORS:	
TERRESTRIAL PLANTS	
Tolerant species:	
Forbs:	Alpine pennycress.
Visible symptoms:	Stunting of roots and tops; golden-yellow/orange coloration in flax plants; potato tubers turned reddish-yellow.
MAMMALS	
Visible symptoms:	
Cattle:	Poor growth; reduced food intake; diarrhoea; anaemia; joint and bone abnormalities; achromotrichia; hypocupraemia; depression; laminitis; mastitis; very long hooves; stiff gait; death.
Deer:	More tolerant than cattle.
ENVIRONMENTAL FACTORS AFFECTING TOXICITY:	
FACTORS PRODUCING SIMILAR SYMPTOMS:	

NICKEL (Ni)

SOURCES OF CONTAMINATION:

Metal mining and smelting; vehicle exhaust; serpentine soils; sewage sludge; plating; dredged materials; catalysts; alloys; engineering works; ship building; scrap yards.

ABIOTIC INDICATORS:

Wastes from mining; sludge.

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Tolerant species:

Grasses etc:	Creeping bent-grass; common bent-grass (*Agrostis capillaris*); common bent-grass (*A. gigantea*); reed mace; tufted hair-grass.
Forbs:	Alpine pennycress; monkey flower; vernal sandwort.
Lower plants:	*Oligotrichum hercynicum; Oligotrichum parallelum.*
Visible symptoms:	Oat: white necrotic tissue in longitudinal stripes on leaves; features of nutrient deficiency; poor growth; iron-deficiency; chlorosis; stunting of roots and shoots; spotting of leaves and stems; deformation of various parts of plant; leaf cupping; in dicotyledons, general chlorotic mottling.

AQUATIC INVERTEBRATES

Tolerant species:	Caddis larvae; damselfly nymphs; *Tubifex tubifex.*

SOIL MICROBIOLOGY

Visible symptoms:	Toxic to micro-organisms and to many algae - hence build up of leaf litter.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:

Toxicity reduced by calcium carbonate and by copper; acidity increases toxicity; chlorosis caused by Ni alleviated by molybdenum; symptoms worse in low potassium or high phosphate concentrations. Degree of necrotic symptoms is similar over pH range 4 - 7. Nickel toxicity reduced when iron concentration is high.

FACTORS PRODUCING SIMILAR SYMPTOMS:

Other factors causing nutrient deficiency.

PLATINUM (Pt)

SOURCES OF CONTAMINATION: Catalysts; electrolytic products.
ABIOTIC INDICATORS:
BIOTIC INDICATORS: *TERRESTRIAL PLANTS* **Visible symptoms:** Inhibited growth; smaller leaf area, on bean plants; tomatoes similar; also with chlorotic lower leaves.
ENVIRONMENTAL FACTORS AFFECTING TOXICITY:
FACTORS PRODUCING SIMILAR SYMPTOMS:

SELENIUM (Se)

SOURCES OF CONTAMINATION:
Coal; lignite; fuel oil; natural gas; power station ash; electroplating.

ABIOTIC INDICATORS:
Physical evidence of above industries.

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Tolerant species:

Forbs:	Orache
Visible symptoms:	Interveinal chlorosis or black spots; complete bleaching or yellowing of younger leaves; pinkish spots on roots.

MAMMALS

Visible symptoms:	Cattle: develop "blind staggers"; anorexia; emaciation and collapse; skin rash; loss of hair.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:

FACTORS PRODUCING SIMILAR SYMPTOMS:

SILVER (Ag)

SOURCES OF CONTAMINATION:
Silver mines; photographic industries; plating; alloys.

ABIOTIC INDICATORS:
Mine spoil heaps (e.g. Wales and Sark).

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Tolerant species:

Forbs:	Alpine pennycress; sea campion; vernal sandwort.

SOIL MICROBIOLOGY

Visible symptoms:	Reduced decomposition leading to build up of soil litter; bare patches.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:

FACTORS PRODUCING SIMILAR SYMPTOMS:

URANIUM (U)

SOURCES OF CONTAMINATION: Nuclear industries.
ABIOTIC INDICATORS:
BIOTIC INDICATORS: *TERRESTRIAL PLANTS* **Visible symptoms:** *Epilobium angustifolium* shows whitening of the flowers.
ENVIRONMENTAL FACTORS AFFECTING TOXICITY:
FACTORS PRODUCING SIMILAR SYMPTOMS:

VANADIUM (V)

SOURCES OF CONTAMINATION:
Oil refining; orimulsion combustion in power stations; vanadium-steel alloys.

ABIOTIC INDICATORS:

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Tolerant species:

Forbs:	Milk vetch.
Lower plants:	*Amanita* (toadstool).
Visible symptoms:	Sorghum plants grown in vanadium culture showed colour deepening of the shoots followed by apical iron deficiency and chlorosis; stunting.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:

FACTORS PRODUCING SIMILAR SYMPTOMS:

ZINC (Zn)

SOURCES OF CONTAMINATION:
Zinc and other metal mine waste and drainage; fluorspar waste; zinc and other metal smelters; dredged materials; sewage sludge from industrial areas; plating; electricity pylons; and galvanised metal products; alloys; engineering works; ship building industries; scrap yards.

ABIOTIC INDICATORS:
Bare patches; spoil heaps; coloured deposits (usually white).

BIOTIC INDICATORS:

TERRESTRIAL PLANTS

Tolerant species:

Grasses etc.	Brownbent-grass; common bent *(Agrostis capillaris*); creeping bent; red fescue; reedmace; sheep's fescue; sweet vernal grass; tufted hair-grass; Yorkshire fog;
Forbs:	Alpine pennycress; bladder campion; common sorrel; fairy flax; green-leaved helleborine; harebell; ling; monkey flower; mountain pansy; pendulous-flowered helleborine; pyrenean scurvy grass; red campion; ribwort plantain; sea campion; sheep's-bit; thrift; vernal sandwort; white campion; Young's helleborine, zinc violet.
Horsetails and Ferns:	Field horsetail.
Lower plants:	*Bryum pseudotriquetrum; Cephalozia bicuspidata; Ceratodon purpureus; Cladonia chlorophaea; Cladonia coniocraea; Dicranella varia; Funaria hygrometrica; Hormidium rivulare; Mielichoferia nitida; Physcomitrium pyriforme; Pohlia nutans; Scaparia undulata; Tremotodon longicollis; Weissia controversa.*
Visible symptoms:	Leaves of sea campion have higher length/width ratio than on non-contaminated sites; also some species have smaller flowers and leaves and thinner stems; inhibition of root growth; chlorosis; stunting; some cereals develop light blue-green tinge at leaf tips which gradually spreads to the base; dwarfing; chlorosis and necrosis from the tips of the leaves; sparse vegetation cover.

TERRESTRIAL INVERTEBRATES

Tolerant species:	Earthworms; *Oniscus asellus* and *Porcellis scaber* (isopods); some molluscs; clubionid spiders, springtails (collembola).
Visible symptoms:	Earthworms: loss of saddle.

AQUATIC INVERTEBRATES

Tolerant species:	*Chloroperla torrentium* (stonefly); *Limnephilus sp.* (caddis fly), and *Rhithrogena semicolorata* (mayfly) more tolerant than *Gammarus pulex* (freshwater shrimp); *Baetis rhodani* (mayfly); *Leuctra* spp. (stoneflies). Chironomids, simuliids (flies) and some ephemeroptera and trichoptera (springtails, flatworms). Insect larvae more tolerant than other taxa.
Visible symptoms:	Reduced number of taxa; molluscs, malacostracan crustacea, and oligochaetes, least resistant.

MAMMALS

Tolerant species:	Monogastric mamals more tolerant than ruminants.
Visible symptoms:	Grazing in contaminated areas - weight loss; anaemia; abdominal pain; salivation; vomiting; diarrhoea; convulsions; collapse and death.

SOIL MICROBIOLOGY

Visible Symptoms:	Reduced decomposition leading to build up of leaf litter.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY:

pH: high pH reduces Zn toxicity; Ca + P reduces Zn toxicity; interaction between contaminants; drought.

FACTORS PRODUCING SIMILAR SYMPTOMS:

Nutrient deficiency; drought.

5. NON-METALS

5.1 INTRODUCTION

This chapter deals with boron, cyanide, flouride and sulphur. Because they have different characteristics they are discussed separately.

Summary sheets are given in Table 7 at the end of this chapter.

5.2 BORON

5.2.1 Sources

Boron plays an essential role in plant nutrition. Its most common industrial source is pulverized fuel ash (PFA) produced as a waste material from coal-fired power stations. PFA has been used as a cover material in restoration schemes.

5.2.2 Abiotic Indicators

Near its source PFA may be recognised as mounds of ash adjacent to power stations; its colour ranges from pink to grey.

5.2.3 Biological Effects

i) Plants

Plant growth on PFA is probably influenced more by its alkalinity than by its boron content. Gemmell (1980) provides a list of plant species growing on PFA, including several orchid species. Hodgson and Buckley (1973) list crops, trees and shrubs displaying varying degrees of tolerance to PFA. Crops belonging to the Chenopodiaceae and also *Melilotus spp.* are highly tolerant. In an experimental investigation of the growth of seedlings exposed to varying concentrations of boron, sitka spruce (*Picea sitchensis*), Canadian hemlock (*Tsuga canadensis*), ribbed melilot (*Melilotus alba*) and perennial rye-grass (*Lolium perenne*) were recorded as being more tolerant than a number of other plants.

Holliday *et al.* (1953) in an investigation of plant growth on PFA wastes found fodder beet, mangels, redbeet, spinach, swede, turnip and sweet clover to be more tolerant than cereals, legumes, carrots, parsnips and cock's-foot. Townsend and Gillham (1973) however found wheat to be less sensitive than other plants growing on PFA.

Visual symptoms of boron toxicity include uneven necrotic spots (at 1500 ppm boron) and chlorosis (at 1000 ppm) (Oertli and Kohl 1961). Holliday *et al.* (1953) recorded symptoms of marginal scorch. Barley showed leaf tip die-back and brown necrotic spots and blotches. Millikan (1949), investigating the effects of toxic concentrations of boron in flax, recorded death of older leaves, but no necrosis.

ii) Animals

No information is available relating to the visible effects of boron toxicity on animals.

5.2.4 Conclusion

Boron is a typical contaminant of PFA and hence species found on PFA waste heaps may be tolerant of boron as well as other components of PFA. Boron has also been shown to have a number of visual effects on plants including necrosis and leaf tip die-back.

5.3 CYANIDE

5.3.1 Sources

There are a number of industrial sources of cyanide including iron and steel manufacture, town gas production, plating, case hardening, non-ferrous metal production and metal cleaning (Hellawell 1986; Barry 1985). Spent oxide from town gas manufacture, one of the chief sources of cyanide in contaminated land, contains between 3 -6% total cyanide, mainly in the form of thiocyanate and complex cyanides (Wilson and Hudson 1980). Over 800 species of higher plants, as well as fungi and bacteria, produce cyanide naturally. In soils cyanide is broken down by micro-organisms to produce ammonia and carbon dioxide, and may also be oxidised to cyanate (DoE 1988).

In solution, and at low pH, hydrocyanic acid (HCN) is formed. This is the most toxic form and is known as free cyanide. Toxicity in aqueous media is inversely related to pH (Hellawell 1986) but there is also evidence (Barry 1984 cited in DoE 1988) for HCN generation from neutral soils.

5.3.2 Abiotic Indicators

A large volume of literature relates to spent oxides and the DoE publication "*Problems Associated with the Redevelopment of Gas Works Sites*" (1988), reviews this information, particularly in relation to health effects and some abiotic indicators.

Spent oxides (containing ferri/ferrocyanide) are coloured blue or blue/grey, particularly at concentrations in excess of 1% and when soil is wet. At concentrations in excess of 20% spent oxide, complex cyanides may cause blue staining of brickwork etc. (DoE 1988). Thiocyanates are red in water at concentrations between 5-10 mgl^{-1}, and can also stain brickwork red. The leaves of plants growing adjacent to spent oxide deposits have been observed to have a surface coating of blue coloured ferrocyanide dust (Loudon 1979).

Two cyanide containing gases may be produced: hydrogen cyanide (HCN) and cyanogen chloride. Hydrogen cyanide has the odour of bitter almonds, and cyanogen chloride has a pungent odour at a concentration of 1 ppm. Spent oxides are also reported to have a characteristic odour at 1%.

5.3.3 Biological Effects

i) Plants

There is relatively little information on the effect of cyanide and cyanide complexes on plants. Spent oxide wastes are frequently unvegetated but this effect has been attributed to low pH (<3) and high conductivity (>4000m mhos cm^{-1}), rather than to the direct effect of cyanides. Other limitations to colonisation of spent oxide wastes are low phosphorus, potassium and magnesium and possibly high iron (Loudon 1979). Silver birch and elder are two of the earliest colonisers of spent oxide wastes and other invading species include poplar (*Populus sp.*), ash (*Fraxinus excelsior*), buddleia (*Buddleja sp.*), oak (*Quercus sp.*) and hawthorn (*Crataegus sp.*) (Rae 1991; Swan and Rae 1991).

Characteristic symptoms of plants affected by spent oxides are die-back, poor germination, poor growth, wilting, leaf yellowing and premature senescence (Swan and Rae 1991).

ii) Animals

Toxicity testing in aquatic systems appears to have concentrated on fish, as reviewed by Hellawell (1986). There is little information on the effects of cyanide on macro-invertebrates.

5.3.4 Conclusion

When present in spent oxides cyanide, as ferri/ferrocyanide, is clearly visible as a blue/grey deposit, which may also cause staining of brickwork and plant material. Thiocyanates are red and can stain water and soil. The odours of hydrogen cyanide, cyanogen chloride and spent oxides are also characteristic. Information on plants and animals which may be useful visual indicators in preliminary site investigation is limited to observations on the extent of vegetation cover on spent oxide wastes. These tend to be bare or sparsely vegetated, with some early colonisation by shrubs and trees.

5.4 FLUORIDE

5.4.1 Sources

Fluoride occurs naturally as fluoroapatite ($Ca_{10}F_2 [P0_4]_6$), fluorspar (CaF_2) and cryolite (Na_3A1F_6). Sites may be contaminated by aerial deposition of fluoride from aluminium smelters by the application of fertilisers, and by wastes from mining and processing of fluorspar. In the UK fluorspar processing wastes are mostly located in the south (Derbyshire) and the north Pennine (W. Yorkshire and Durham) orefields (Cooke *et al.* 1976). These deposits are also associated with barytes ($BaSO_4$), galena (PbS), sphalerite (ZnS) and calcite (crystalline $CaCO_3$).

5.4.2 Abiotic Indicators

Abiotic indicators associated with mining include spoil heaps and settlement lagoons containing fine, possibly erodable, tailings. An aluminium smelter in the vicinity of a site being investigated for possible contamination may indicate a source of aerially derived fluoride.

5.4.3 Biological Effects

i) Plants

The literature regarding fluoride is mainly restricted to the colonisation of ore bodies which have associated metal contaminants, (Cooke *et al.* 1976; Johnson, 1976; Cooke and Morrey 1981), and the impacts of air-borne fluoride from aluminium smelters (eg. Buse 1986; Walton 1986).

There is little evidence that fluoride in mineral wastes causes visible injury to plants. This is likely to be caused by fluoride being non-toxic in the form of calcium, magnesium, aluminium or silicate complexes (Cooke *et al.* 1976; Johnson 1976). Johnson (1976) concluded that zinc was probably the prime factor determining species diversity rather than lead or fluoride which were both present in the wastes. Principal higher plants established on fluorspar mine waste (Johnson 1976 and Cooke and Morrey 1981) are shown in Table 6.

Table 6 Plant Species Colonising Fluorspar Tailings [1]

GRASSES	
Agrostis stolonifera	Creeping bent-grass
Agrostis capillaris	Common bent-grass
Dactylis glomerata	Cock's-foot
Festuca rubra	Red fescue
Holcus lanatus	Yorkshire fog
FORBS	
Cerastium fontanum	Mouse-ear chickweed
Chamaenerion angustifolium	Rosebay willowherb
Plantago lanceolata	Ribwort plantain
Ranunculus repens	Creeping buttercup
Rumex acetosa	Common sorrel
Trifolium repens	White clover
Tussilago farfara	Coltsfoot

[1] Cooke, Johnson, Davison and Bradshaw (1976). Species naturally established on a minimum of 4 out of 6 fluorspar mine wastes.

ii) Animals

In a study of small mammal populations around an aluminium smelter a correlation was noted between fluoride and a tooth wear index (Walton 1986). Cooke *et al.* (1990) reported the presence of lumps on teeth of small mammals collected from contaminated grassland on fluorspar tailings, and Andrews *et al.* (1989) found evidence of dental fluorosis (mottling), loss of enamel colour and banding of incisor teeth in the vole (*Microtus agrestis*) but not the shrew (*Sorex araneus*). Shupe *et al.* (1977) studied the effect of fluorides on domestic and wild animals and noted a number of symptoms including bone enlargement, lameness and stiffness.

5.4.4 Conclusion

Information on flouride concentrates on the characteristic flora on fluorspar processing wastes, and on the effect of fluoride on bones and teeth of small mammals. In a preliminary site investigation the most useful visual indicator is likely to be the plant species assemblage.

5.5 SULPHUR

5.5.1 Sources

Sulphate occurs naturally in soils and is an essential major nutrient for plant growth. Its deficiency in crops is reported by many authors (eg. Skinner 1984). It typically occurs in mineral soils at concentrations of up to 3,000 $mgkg^{-1}$, but may occur at concentrations up to 4,000 $mgkg^{-1}$ in organic soils (Allen 1989). Under anaerobic conditions sulphate is reduced to sulphide.

Excessive soil enrichment can occur from the deposit of mineral wastes from metal and coal mining, and from the presence of spent oxide wastes from town gas manufacture. Spent oxides contain up to 60% free sulphur, and up to 3% sulphate. Soils contaminated by spent oxides tend to contain lower concentrations of free sulphur but higher sulphate concentrations (Wilson and Hudson 1980), presumably as a consequence of sulphur oxidation.

5.5.2 Abiotic Indicators

Sulphate compounds are frequently white (zinc sulphate; lead sulphate), unless pigmented by the associated cation eg. copper sulphate which is blue in colour. Light yellow/whitish sulphur deposits have been reported in streams rich in hydrogen sulphide (Grayson *et al.* 1990). Sulphides, found in anaerobic conditions, are generally black. Deposits of black iron sulphide are frequently observed in water-logged soils and in stagnant water courses.

At pH less than 4.0 hydrogen sulphide (H_2S) is liberated from sulphides (DoE 1988), giving a characteristic odour of bad eggs.

5.5.3 Biological Effects

i) Plants

Free sulphur oxidises to produce high levels of soluble sulphate in the soil. The rate of oxidation is dependent on the presence of adequate carbon and nitrogen (Skiba and Wainwright 1984) and can be increased by application of organic substrates (Wainwright *et al.* 1986). Soluble levels of up to 100 $mgkg^{-1}$ are reported to have no adverse effect on plants (Etherington 1980 cited in DoE 1988). Hydrogen sulphide, released at low pH, is toxic to plants at low concentrations (DoE 1988).

The principal effect of sulphate on plants is likely to be indirect and related to the concentration of salts and the pH of soil and water courses. The effects of these changes on biological systems are discussed more fully in Sections 5.2 and 5.3.

ii) Animals

There is very little information available on the effects of sulphur compounds on animals. Mance *et al.* (1984) has provided data for freshwater invertebrates (mostly crustacea) and records that the toxicity of sulphide can be influenced by temperature.

5.5.4 Conclusion

The most useful indicators for the presence of sulphur, sulphate and sulphide are the colours of various compounds; the odour of hydrogen sulphide, released from soils at low pH; and the occurrence of plant species which are indicative of low pH and/or saline conditions.

TABLE 7

NON-METAL SUMMARY SHEETS

BORON

SOURCES OF CONTAMINATION

Pulverised fuel ash.

ABIOTIC INDICATORS

PFA: mounds of ash, commonly adjacent to power stations; colour ranging from pink to grey.

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Tolerant species:	Those growing on PFA and also tolerant of alkaline conditions (see Alkalinity).
Grasses etc:	Perennial ryegrass.
Forbs:	Canadian hemlock; ribbed melilot;
Trees/shrubs:	Sitka spruce.
Visual symptoms:	Uneven necrotic spots; chlorosis; marginal scorch; leaf tip die-back; brown necrotic spots and blotches; death of older leaves.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

FACTORS PRODUCING SIMILAR SYMPTOMS

CYANIDE

SOURCES OF CONTAMINATION

Iron and steel manufacture; spent oxides from town gas manufacture; electroplating effluent; non-ferrous metal production. Also produced naturally by plants.

ABIOTIC INDICATORS

Colour:	Ferri/ferrocyanide -	Blue or blue/grey. May cause staining of soils, brickwork or plants (spent oxides).
	Thiocyanate -	Red staining of soils or watercourses.
Odour:	Hydrogen cyanide (HCN) at low pH - bitter almonds .	
	Cyanogen chloride (CnCI) - pungent odour.	
	Spent oxides - musty odour.	

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Tolerant species:	On spent oxides
Trees and shrubs:	Ash; birch; buddleia; elder; hawthorn; oak; poplar; silver birch.
Visual symptoms:	On spent oxides vegetation cover sparse or absent; vegetation die back; poor growth; wilting; leaf yellowing; premature senescence.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

Toxicity of HCN in aqueous media inverely related to pH.

FACTORS PRODUCING SIMILAR SYMPTOMS

FLUORIDE

SOURCES OF CONTAMINATION

Wastes from mining and processing of fluorspar; aluminium smelting; fertilisers; coal combustion; brickyards; glass and china works.

ABIOTIC INDICATORS

Spoil heaps and settlement lagoons; proximity of aluminium smelter.

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Tolerant species:

Grasses etc:	Cocksfoot; common bent-grass; creeping bent; red fescue; Yorkshire fog.
Forbs:	Coltsfoot; common sorrel; creeping buttercup; mouse-ear chickweed; ribwort plantain; rosebay willow herb; white clover.

SMALL MAMMALS

Visible symptoms:	Toothwear; lumps on teeth; dental fluorosis; loss of enamel colour; banding of incisor teeth.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

Source of fluoride: less available when present as calcium; magnesium; aluminium or silicate complex.

FACTORS PRODUCING SIMILAR SYMPTOMS

SULPHUR

SOURCES OF CONTAMINATION

Metal and coal mine spoil; spent oxides; slag from blast furnaces.

ABIOTIC INDICATORS

Colour:	Zinc/lead sulphate	:	white
	Copper sulphate	:	blue
	Sulphides	:	usually black
	Sulphur	:	white/yellow
Odour:	Bad eggs (H_2S) in low pH soils.		

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Visual symptoms: Effects related primarily to pH changes and to high salt content. See acidity and salinity.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

Toxicity of sulphide to aquatic macroinvertebrates influenced by temperature.

FACTORS PRODUCING SIMILAR SYMPTOMS

6. ACIDS, BASES AND SALTS

6.1 INTRODUCTION

pH is one of the key factors determining the distribution of species in both the terrestrial and aquatic environments. The distribution of many species is limited to a particular pH range, making the presence of particular species or assemblages good indicators of soil pH. Salinity may be associated with a number of industrial process wastes and characteristic flora and fauna may develop on sites as a consequence of high soil conductivity.

Summary sheets are given in Table 14 at the end of the chapter.

6.2 ACIDITY

6.2.1 Sources

Acid soils are characterised by a deficiency of bases (for example calcium) and excess aluminium and manganese (both of these are soluble at pH less than 4.5). Acid soils with a pH between 3 - 4.5 can occur naturally and include acid peats in wet areas where lack of oxygen results in accumulation of undecomposed organic matter, and podzols in areas where rainfall, greatly exceeding evaporation, results in bases being leached from the soil.

Acidic industrial wastes include pyrite wastes from coal and non-metalliferous mining, china clay wastes, acidic boiler ash and cinders, spent oxides, acid tars and sulphuric acid produced during the manufacture of town gas, and some sand and gravel wastes. The run-off from pyritic and other acidic wastes can also cause acidification of pools, water courses and streams either on, or adjacent to, a site being investigated.

6.2.2 Abiotic Indicators

The colour and texture of many of the acidic wastes produced by manufacturing processes provide a clue to their origin. Typical descriptions are shown in Table 8.

Table 8 Description of Typical Acidic Waste Materials

Source	Description
China clay waste	Sandy pale yellowish/grey material; vegetation often sparse or absent.
Acid rock quarries	Large particles; usually little plant growth and poor water retention.
Gas works waste	Often contains "blue billy" (spent oxides), ash and coke.
Colliery shale	Fine to medium gravel, coal ash, shale and mudstone.

6.2.3 Biological Effects

i) Plants

Aluminium, released from soil at pH <4.5, indirectly lowers soil fertility by combining with phosphate to form insoluble compounds which are not available to plants. In acidic conditions reduced soil microbial activity and the decreased release of nitrogen also contributes to infertility. The effect of low pH (or excess of hydrogen ions) is to reduce the capacity of the soil's cation-exchange complex to adsorb metal ions. These metal ions may include toxic elements such as copper, nickel, zinc, cadmium. Crooke *et al.* (1954) investigated the link between nickel toxicity and iron supply: at pH 5 or less iron uptake was reduced by nickel causing leaf chlorosis. Hence plants which are found on acid soils (calcifuges) tend to be slow growing and to be tolerant of nutrient deficiency. On mineral wastes they also tolerate metal contamination.

Species which have been reported on acid soils in the UK are shown in Table 9.

Table 9 Plants Tolerant or Indicative of Acidic Soils

SHRUBS	
Betula pendula [4]	Silver birch
Genista anglica [2]	Petty whin
Lupinus arboreus [2]	Tree lupin
Pteridium aquilinum [2,4]	Bracken
Rhododendron ponticum [3]	Rhododendron
Rubus fruticosus [3]	Bramble
Salix aurita [2]	Eared willow
Salix cinerea ssp. atrocinera [2]	Fen sallow
Sarothamnus scoparius [2]	Broom
GRASSES	
Agrostis canina [1,5]	Brown bent
Agrostis setacea [3]	Bristle leaved bent
Agrostis capillaris [1,2,3,5]	Common bent-grass
Dactylis glomerata [5]	Cock's foot
Deschampsia flexuosa [1,6]	Wavy hair-grass
Festuca ovina [2,3,5]	Sheep's fescue
Holcus lanatus [3,6]	Yorkshire fog
Nardus stricta [6]	Mat-grass
FORBS	
Calluna vulgaris [2,3]	Ling
Digitalis purpurea [1,3]	Foxglove
Erica cinerea [3,4]	Bell heather
Erica tetralix [3]	Cross-leaved heath
Eriophorum vaginatum [4]	Cotton grass
Galium saxatile [3,4]	Heath bedstraw
Hyacinthoides non-scripta [4]	Bluebell
Jasione montana [3]	Sheep's bit
Lotus corniculatus [5]	Common birdsfoot trefoil
Luzula sylvatica [4]	Great woodrush
Lycopodium inundatum [4]	Marsh clubmoss
Potentilla erecta [2,3]	Upright cinquefoil
Rumex acetosella [1,3,4]	Sheep's sorrel
Trifolium repens [5]	White clover
Ulex europaeus [1,3,4]	Western gorse
Ulex gallii [3]	Summer gorse
Vaccinium myrtilus [1,3]	Bilberry
Vaccinuum vitus-idaea [4]	Cowberry

MOSSES AND FERNS	
Blechnum spicant [3] *Coscinodon cribrosus* [7] *Merceya ligulata* [7] *Merceya gedeana* [7] *Mielichhoferia elongata* [7] *Mielichhoferia nitida* [7] *Pohlia nutans* [7] *Polypodium vulgare* [3]	Hard fern

1 Bradshaw and Chadwick (1980). Species commonly associated with acidic substrates

2 Bradshaw and Chadwick (1980). Species typical of upland grazing pasture

3 Bradshaw *et al.* (1975). Natural colonisers of china clay waste

4 Cannon (1971). Calcifuges occurring at pH <5.2

5 Darmer (1973). Acid tolerant species selected for restoration trials

6 Gemmell (1977). Species tolerant of acid colliery spoil

7 Tyler (1990). Cited in review

Acidity has been shown by a number of authors to reduce the diversity of plants within aquatic systems. Warner (1973) noted that diversity of higher plant species was reduced in acid mine water at pH less than 4.5, although some tolerant green algae remained. Wolff *et al.* (1988), in a Water Research Centre review of the effects of pH, recorded a less frequent occurrence of common reeds *(Phragmites communis)*, water milfoil (*Myriophyllum* spp.), water lobelia (*Lobelia* sp.) and quillwort (*Isoetes* sp.) in low pH waters. These were replaced by bulbous rush (*Juncus bulbosus*), bog moss (*Sphagnum* sp.) and other mosses. Water lilies (*Nymphaea and Nuphar*) were unaffected. *Sphagnum* and reedmace (*Typha*) have been reported to be tolerant of acid mine drainage and hence are useful in schemes for wetland habitat creation designed to remediate acidic waters.

ii) Animals

There is some information in the literature regarding the effect of soil pH on terrestrial invertebrate species. pH appears to affect the distribution of earthworms and land snails. Earthworms are generally absent from low pH soils and soils without calcium, and account for a relatively small proportion of the soil fauna biomass below pH 4.5 (Russell 1973). *Lumbricus rubellus* and *Dendrodrilus rubidus* are both acid tolerant species of earthworm. In an experimental study of the distribution and diversity of land snails, five of the ten species examined only occurred in limed plots (Gardenfors 1992).

Research carried out on acidic effluents (for example, from acid mine heaps) has concentrated on the effect of low pH on species presence, diversity and community structure, particularly in respect of macroinvertebrates. There may be other factors, characteristic of the waste, which influence the composition of the flora and fauna, for example ferric hydroxide, and an increased sediment loading.

Acidity is known to cause a significant change in macroinvertebrate community structure. Dill and Rogers (1974) reported that species diversity of the invertebrate community was inversely related to hydrogen ion concentration. There tends to be a smaller number of species and individuals in acid water, with the benthic fauna dominated by non-biting midges (chironomidae), alder flies (megaloptera) and biting midges (ceratopogonidae). Warner (1973) determined a critical pH for reduction in macroinvertebrate diversity of between 4.0 - 4.4. At pH >4.5 there were more than 25 species of bottom dwelling invertebrates in a river system affected by acid mine drainage, while at pH <4.5 between 3 - 12 species of bottom dwelling invertebrates were recorded. These included alder fly larvae (*Sialis spp.*), the bloodworm midge (*Chironomus plumosus*), both adult and immature dytiscid beetles, and a caddis fly (*Ptilostomius* sp.).

In a comprehensive review Hellawell (1986) noted that water boatmen (corixidae; heteroptera), alder flies (megaloptera), and beetles (coleoptera) are groups which may be present in acid waters. Scullion and Edwards (1980) list species which were recorded in the Taff, a river into which acid mine effluent drains. Alabaster and Lloyd (1982) reviewed records of *Gammarus* spp. in streams with pH as low as 2.2, mosquito larvae at pH 2.3, and caddis larvae at pH 2.4. Wolff *et al.* (1988) reported that invertebrates with filamentous gills are more sensitive to low pH than air-breathing groups such as adult bugs (hemiptera) and beetles (coleoptera). Below pH 4.8 the freshwater louse (*Asellus aquaticus*) is absent. At low pH it has been observed to leave the water, only returning to feed. The freshwater shrimp (*Gammarus spp.*) is absent below pH 6.0, and below this pH the crayfish (*Astacus* sp.) has been observed to suffer softening of the carapace owing to a low concentration of calcium. The species diversity and abundance of oligochaetes is reduced at low pH; in an acid lake *Limnodrilus hoffmeisteri* was recorded as the dominant species. Macroinvertebrates which have been recorded as tolerant to acid wastes are included in Table 10.

Within the same order of macroinvertebrates there may be a different response to pH, with some members showing tolerance to pH and others being particularly sensitive. This is illustrated by the mayflies (ephemeroptera). *Baetis rhodani* (Scullion and

Edwards 1980) and *Heptophlebia marginata* (Weatherby and Ormerod 1987) are reported to be tolerant of acidic conditions while other species within the order are sensitive to pH less than 5.3 (Stoner *et al.* 1984). Other orders with sensitive species include caddis (trichoptera), stoneflies (plecoptera) and flies (diptera) (Weatherby and Ormerod 1987).

Wolff *et al.* (1988) record that the smooth newt (*Triturus vulgaris*) is rarely observed in water at pH <6.0, whereas the palmate newt (*T. helveticus*) is often found in peat bogs at pH 4. The number of frogs and toads was found to decline in a lake with pH reduced to 4.0.

6.2.4 Conclusion

Acidic wastes tend to only support low species diversity and to be colonised by characteristic plant species, the majority of which are unlikely to occur on high pH wastes. The macroinvertebrate fauna of acidic water bodies is also characteristic and relatively well documented. Good indicators of acidic wastes are the low diversity of species, floral and aquatic invertebrate assemblages, and the visual appearance of wastes.

Table 10

Aquatic Macroinvertebrate Species Recorded as Tolerant of Acidic Conditions

TOLERANT SPECIES		
ARTHROPODA	:	**Arachnida (spiders and mites)**
Hygrobatidae	:	*Hygrobates fluviatilis* [7]
ARTHROPODA	:	**Insecta (insects)**
Coleoptera (beetles) [3,4,5]		
Helminthidae	:	*Limnius volckmari* [7]
Diptera (flies)		
Ceratopogonidae [3]	:	*Bezzia - palpomyia gp.* [7]
Chironomidae [3,4,6]	:	*Brillia modesta* [7]
		Chironomus plumosus [8]
		Conchapelopia pallidula [7] *
		Micropsectra sp. [7]
		Rheocricotopus foveatus [7]
		Tanytarsus sp. [7]
Orthocladiinae	:	*Prodiamesa olivacea* [7]
Simuliidae	:	*Simulium ornatum* [7]
Tabanidae	:	*Tabanus sp.* [7]
Ephemeroptera (mayflies)		
Baetidae	:	*Baetis rhodani* [7] *
Heteroptera (true bugs) [9]		
Corixidae [5,9]		
Megaloptera (alder flies) [3,5]		
Sialidae	:	*Sialis sp.* [8,9]
Plecoptera (stoneflies)		
Leuctridae	:	*Leuctra hippopus* [7]
Nemouridae	:	*Amphinemura sulcicollis* [7]
		Protonemura praecox [7]
Trichoptera (caddis flies)		
Hydropsychidae	:	*Hydropsyche pellucidula* [7]
Polycentropodidae	:	*Plectrocnemia conspersa* [7]
Rhyacophilidae	:	*Rhyacophila dorsalis* [7]
ARTHROPODA	:	**Annelida (Oligochaeta) (worms)**

Enchytraeidae	:	*Lumbricus rivalis* [7]
Lumbricidae	:	*Eiseniella tetraedra* [7]
Naididae	:	*Nais alpinia* [7]
		Nais elingius [7]
Tubificidae	:	*Limnodrilus hoffmeisteri* [9]
INTERMEDIATE TOLERANCE		
Odonata (Dragonflies) [2,4]		
Plecoptera (Stoneflies) [2,4]		
INTOLERANT		
Ephemeroptera (Mayflies) [2,4,6]		
Odonata (Dragonflies) [6]		

1 Alabaster and Lloyd (1982).

2 Bell (1971). Tests under laboratory conditions of effect of pH on survival of mature larvae and nymphs of 9 spp. of aquatic insects.

3 Dills and Rogers (1974). Dominant benthic fauna at acidic stations affected by acid mine drainage.

4 Hellawell (1986). Cited references

5 Hellawell (1986). Groups which may be abundant in acid waters

6 Letterman and Mitsch (1978). Acid mine drainage

7 Scullion and Edwards (1980). Acid coal mine drainage - species alleged to be tolerant of acid conditions from the coal mine industry

7* Scullion and Edwards (1980). Species tolerant of pH <3.5

8 Warner (1973). Species present at pH <4.5 in river affected by acid mine drainage

9 Wolff, Seager and Orr (1988). Proposed environmental quality standards for List II substances in water:pH.

6.3 ALKALINITY

6.3.1 Sources

Alkaline soils (pH 6.5-8.5) occur naturally where the underlying geology or superficial deposits contain chalk or limestone. The typical soil profile which develops is known as a rendzina. It is relatively shallow but quite fertile, and often supports species-rich grassland.

Alkaline industrial wastes include:

- Limestone and chalk quarry waste
- Gas lime waste
- Le Blanc process waste - manufacture of sodium carbonate (Na_2CO_3) using limestone as a raw material. pH ranges from <8 - 12.7 depending on extent of weathering
- Solvay process waste - blast furnace slag: pH 10 - 10.5
- Chromate waste - chrome ore smelted either with soda ash or soda ash and lime: wastes may have a pH >10 due to hydroxides of Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}.
- Fly ash - high pH due to presence of magnesium and calcium oxides
- Wastes from Town gas manufacture - ammoniacal liquors

6.3.2 Abiotic Indicators

The physical appearance of a few of the more common of these waste types is described in Table 11 below:

Table 11 Descriptions of Typical Alkaline Waste Materials

Source	Descriptions
Chromate smelter waste	White when unweathered, yellowish-brown stained when weathered. Leachate from base of tips greenish-yellow/orange. If well weathered may have developed humified surface layer.
Blast furnace and steel slag waste	Various shades of grey, texture ranging from fine to coarse gravel to glassy/crystalline; or with cobble/boulder sized fragments, with the appearance of having melted then re-solidified.
Pulverized fuel ash from coal-fired power stations	Colour ranges from pinkish to grey to colourless, and texture from glassy spherical particles, some containing bubbles, to fine silty cement like layers.
Le Blanc waste	Greyish mottled, compacted, fine textured.

6.3.3 Biological Effects

i) Plants

Alkaline soils generally have an excess of calcium or sodium and a pH greater than 8. At these pH values trace elements which are necessary for healthy plant growth, including iron, manganese, boron and phosphate, become more difficult to absorb. Hence a characteristic flora develops which is frequently diverse but tolerant of low nutrient conditions. Over time some industrial wastes with high pH have developed distinctive plant communities, and in a few cases are of sufficient conservation value to warrant designation as Sites of Special Scientific Interest (SSSI).

Generally the effect of high pH is to reduce heavy metal toxicity in plants by increasing both adsorption to the cation exchange complex within the soil and sorption sites on clay minerals. However, for metal species which are negatively charged at high pH, such as chromate (CrO_4^{2-}), the toxicity may increase at higher pH. Gemmell (1973) reported an absence of vegetation on chromate heaps when water soluble levels of chromate were in excess of 2000 $mgkg^{-1}$. Weathering of these types of wastes over time frequently results in reduced toxicity. Plant species which have been recorded on high pH soils or wastes are included in Table 12.

ii) Animals

Alabaster and Lloyd (1982) and Wolff *et al.* (1988) report the lack of data on the effects of high pH on aquatic invertebrates.

6.3.4 Conclusion

Soils and waste materials with extreme pH often have characteristic flora. Solvay process waste and PFA tend to support a high plant species diversity. Less is known about aquatic fauna in highly alkaline conditions.

Table 12 **Plants Tolerant or Indicative of Calcareous Soils**

TREES/SHRUBS	
Crataegus monogyna [6]	Hawthorn
Fraxinus excelsior [1]	Ash
Salix repens [5]	Creeping willow
GRASSES	
Agrostis gigantea [2]	Common bent grass
Agrostis stolonifera [2,6]	Creeping bent
Alopecurus pratensis [2]	Meadow foxtail
Brachypodium pinnatum [1]	Tor grass
Briza media [1,3]	Quaking grass
Dactylis glomerata [2,6 +]	Cocksfoot
Deschampsia caespitosa [2]	Tufted hair-grass
Festuca arundinacea [2]	Tall fescue
Festuca ovina [3,6]	Sheep's fescue
Festuca pratensis [2]	Meadow fescue
Festuca rubra [1,2,6]	Red fescue
Helictotrichon pratense [1]	Meadow oat-grass
Hordeum vulgare [4]	Barley
Lolium perenne [2]	Perennial rye-grass
Trisetum flavescens [1]	Yellow oat-grass
FORBS	
Achillea millefolium [1,6]	Yarrow
Achillea ptarmica [6]	Sneezewort
Allium ursinum [4]	Ransoms
Angelica sylvestris [6+]	Wild angelica
Arum maculatum [4]	Lords and ladies
Buxus sempervirens [4]	Common box
Carex flacca [3]	Glaucous sedge
Carlina vulgaris [5 *]	Carline thistle
Centaurium erythraea [5 *]	Common centaury
Centaurea nigra [6 +]	Knapweed
Dactylorhiza fuchsii [5]	Common spotted orchid
Dactylorhiza incarnata [5]	Early marsh orchid

Dactylorhiza purpurella [5]	Northern marsh orchid
Daphne laureola [4]	Spurge laurel
Erigeron acer [6*]	Blue fleabane
Euphrasia nemorosa var. calcarea [5*]	Eyebright
Gymnadenia conopsea [5]	Fragrant orchid
Hieracium spp. [6]	
Linum catharticum [5*]	Purging flax
Lotus corniculatus [6+]	Bird's foot trefoil
Melandrium album	Evening campion
Mercurialis perennis [4]	Dog's mercury
Ophioglossum vulgatum [5]	Adder's tongue
Orchis morio [5]	Greenwinged orchid
Orobanche minor [5]	Lesser broomrape
Pilosella officinalis [6]	Mouse-ear hawkweed
Plantago lanceolata [6+]	Ribwort plantain
Poterium sanguisorba [3]	Salad burnet
Senecio jacobaea [6+]	Ragwort
Sisyrinchium bermudiana [5]	Blue-eyed grass
Succisa pratensis [6]	Devil's bit scabious
Thymus praecox [3]	Wild thyme
Tussilago farfara [6+]	Coltsfoot
Valeriana officinalis [4]	Valerian

1 Bradshaw and Chadwick (1980). Species commonly associated with calcareous substrate

2 Bradshaw and Chadwick (1980). pH tolerant grasses (calcareous + neutral conditions)

3 Bradshaw and Chadwick (1980). Typical species of chalk grassland.

4 Cannon (1971). Indicator species for limestone soils

5 Gemmell (1977, 1980). Abundant species on alkaline waste from the Le-blanc process (* calcicoles)

6 Gemmell (1977). Some of the most common and characteristic species of base-rich wastes

+ Greenwood and Gemmell (1978). Species characteristic of orchid rich industrial habitats in South and West Lancs.

6.4 SALINITY

6.4.1 Sources

Saline conditions occur where there is an excess of free salts (eg. magnesium [Mg^{2+}], sodium [Na^{+}]) within the soil solution. In high rainfall areas these salts are leached from the soil and have no adverse effect on plants. However, in estuarine locations, areas which are underlain by saline groundwater, areas where saline industrial wastes have been deposited, and on roadside verges, there may be accumulation of soluble salts. In aquatic environments within or adjacent to such areas there may be an increase in salinity which limits the diversity of flora and fauna.

Soils with a high soluble salt content can be classified according to the dominant ions and their concentration (for example Bradshaw and Chadwick 1980). **Saline soils** have a relatively high soluble salt content with electrical conductivity >4m mhos cm^{-1}, combined with relatively low exchangeable sodium (<15%). In **sodic** or **alkaline** soils the exchangeable sodium content is in excess of 15%; conductivity is <4 m mhos cm^{-1}). pH is in excess of 8.5. **Alkaline - saline** soils have a pH <8.5 but excessive salts give a conductivity of greater than 4m mhos cm^{-1}. Exchangeable sodium exceeds 15% within these soils.

Industrial saline wastes include Pulverised Fuel Ash (PFA), mining wastes and colliery spoil, spent oxides, salt flashes from the salt industry, and spent oil shales. Additionally areas which have been used for the disposal of estuarine river dredgings have a high conductivity.

6.4.2 Abiotic Indicators

In areas with a high ratio of evaporation to precipitation, a white encrustation on the soil surface may indicate saline conditions.

6.4.3 Biological Effects

i) Plants

The conductivity of the soil is an important factor governing the distribution of plant species. According to Bradshaw and Chadwick (1980), when soil conductivity is 8m mhos cm^{-1} or greater, only tolerant species will grow satisfactorily. At conductivities in excess of 16m mhos cm^{-1} only a few tolerant species survive.

Salinity can affect plant growth in two ways (Gemmell 1977): indirectly through raising the osmotic potential of the soil solution to a high level which lowers the plant's ability to absorb water; and by the toxic effect of particular ions. Plants which require saline conditions are known as halophytes, while those which can develop tolerance to saline conditions are known as glyophytes. Ashraf, McNeilly and Bradshaw (1987 and 1989) investigated plant tolerance of sodium, magnesium and calcium chloride under laboratory conditions and concluded that frequently tolerance of salt, unlike tolerance of metals, cannot evolve unless tolerance of other soil conditions (for example waterlogging) also develops.

Industrial saline wastes may develop a characteristic flora as a consequence of additional pressures, for example PFA tends to have an alkaline pH and be low in nutrients as well as having a high concentration of calcium and magnesium that causes salinity. Trace metals, particularly boron, may also be present. Spent oil shale tends to be highly alkaline (between pH 9.0 - 9.9) (Schmehl and McCastin 1973) as well as saline. There is evidence that the distribution of plant species which are tolerant of saline conditions is changing in response to environmental pressures. For example, following the use of salt on roads in Britain, a number of coastal plants have been reported along verges, including plantain (*Plantago sp.*), lesser sea-spurrey (*Spergularia marina*), and annual seablite (*Suaeda vera*) (Moore 1982).

Plant species which are known to be tolerant of saline conditions in the UK are included in Table 13.

Table 13 **Plant Species Tolerant of Saline Soils**

TREES/SHRUBS	
Alnus glutinosa [6a]	Alder
Crataegus monogyna [5]	Hawthorn
Hippophae rhamnoides [1]	Sea buckthorn
Populus alba [6a]	White poplar
Quercus robur [2]	Pedunculate oak
Rubus fruticosus [2]	Bramble
Salix spp. [6a]	Willow
Sambucus nigra [2]	Elder
GRASSES	
Agropyron junceum [1]	Sand couch-grass
Agrostis capillaris [2]	Common bent-grass
Agrostis stolonifera [3]	Creeping bent
Cynodon dactylon [1,4,5b]	Bermuda grass
Dactylis glomerata [7a]	Cock's foot
Deschampsia flexuosa [2]	Wavy hair-grass
Festuca rubra [1,6b]	Red fescue
Holcus lanatus [2]	Yorkshire fog
Leymus arenarius [5a]	Lyme grass
Lolium multiflorum [6]	Italian rye-grass
Lolium perenne [6]	Perennial rye-grass
Phragmites australis [5b]	Common reed
Poa pratensis [3,6b]	Reflexed saltmarsh grass
Puccinellia distans [7a/b,8]	Common saltmarsh grass
Puccinellia maritima [1,5a]	Meadow grass

FORBS	
Artemisia vulgaris [3]	Mugwort
Aster trifolium [8]	Sea aster
Atriplex littoralis [1]	Shore orache
Atriplex patula [9]	Common orache
Atriplex prostrata [3]	Hastate orache
Cakile maritima [1]	Sea rocket
Chamaenerion angustifolium [2]	Rosebay willow herb
Chenopodium album [3]	Fat hen
Cirsium arvense [2]	Creeping thistle
Honkenya peploides [1]	Sea sandwort
Lotus corniculatus [2,3]	Common birdsfoot trefoil
Medicago lupulina [3]	Black medick
Melilotus alba [6a]	White melilot
Plantago maritima [8]	Plantain
Rumex acetosella [2,3]	Sheep's sorrel
Rumex obtusifolius [3]	Broad leaved dock
Senecio vulgaris [4]	Groundsel
Sisymbrium altissimum [3]	Tall rocket
Spergularia marina [8]	Lesser sea-spurrey
Suaeda maritima [8]	Annual seablite
Trifolium pratense [2,3]	Red clover
Tussilago farfara [2,3]	Coltsfoot
MOSSES	
Barbula tophacea [7a]	
Funaria hygrometrica [7a/3]	Hair moss
Pohlia annotina [7b]	
Spergularia marina [8]	Lesser sea-spurrey

1 Bradshaw and Chadwick (1980). Species commonly associated with saline habitats in the UK.

2 Bradshaw and Chadwick (1980). Most common species occurring on colliery spoil in Yorkshire.

3 Bradshaw and Chadwick (1980). Early colonisers of PFA wastes.

4 Briggs (1978). Tolerant of saline conditions on roadside verges.

5 Glenn (1987). Laboratory experiments to determine tolerance of a range of species to sodium chloride a) survived 540 mol m^{-3}; b) survived 180 mol m^{-3}.

6 Hodgson and Townsend (1973) cited in Gemmell 1977. Species tolerant of power station ash: a) tolerant; b) tolerant/semi-tolerant.

7 Mirza and Shimwell (1977). Colonisation of salt flashes in Cheshire a) saline colonisers; b) alkaline colonisers.

8 Moore (1982). Salt tolerant species which have invaded inland.

9 Zhang-Zhi, Huang and Lin Wu (1991). Species tolerant of salinity and selenium.

ii) ***Animals***

There is a lack of data on the response of invertebrates to saline conditions other than those found naturally in estuarine areas. Brackish waters are characterised by a relatively small number of species able to tolerate certain fluctuations in salinity. It is possible that species adapted to coastal environments can colonise inland saline environments associated with industrial wastes, but there is little in the literature to confirm this. In the few cases where brackish water species have been recorded in saline seepages from industrial waste it is likely that the local habitat was saline before the waste was deposited. For example, Eversham observed brackish water and grazing marsh species in a saline ditch at a PFA site at Barking Reach in 1988/89, but as the site had previously been grazing marsh conditions had probably not changed significantly (personal communication).

6.4.4 Conclusion

Saline wastes tend to be devoid of vegetation if newly deposited, or may be colonised by characteristic plant species. These have either developed tolerance of, or require, saline conditions. The composition of the plant community is likely to be the most useful indicator of saline conditions in a preliminary site inspection.

TABLE 14

ACIDS, BASES AND SALTS SUMMARY SHEETS

ACIDITY

SOURCES OF CONTAMINATION

Pyrite wastes from coal and non-metalliferous deposits; china clay wastes; acidic boiler ash and cinders; spent oxides; acid tars and sulphuric acid.

ABIOTIC INDICATORS

Characteristic appearance of wastes.

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Tolerant species:

Grasses:	Bent grass; bristle leaved bent; brown bent; cocksfoot; mat-grass; sheep's fescue; wavy hair-grass; Yorkshire fog.
Forbs:	Bell heather; bilberry; bluebell; cotton grass; common birdsfoot trefoil; cow berry; cotton grass; cross-leaved heath; foxglove; great woodrush; heath bedstraw; ling; marsh clubmoss; sheep's bit; sheep's sorrel; upright cinquefoil, western gorse; white clover.
Trees/shrubs:	Bracken; bramble; broom; eared willow; fen sallow; petty whin; rhododendron; silver birch; tree lupin
Mosses and ferns:	*Blechnum spicant; Coscinodon cribrosus; Merceya ligulata; Merceya gedeana; Mielichhoferia elongata; Mielichhoferia nitida; Pohlia nutans; Polypodium vulgare.*
Visible symptoms:	Low species diversity.

TERRESTRIAL INVERTEBRATES

Visible symptoms:	Reduced species diversity of ground dwelling organisms; probable absence of earthworms except *Dendrodrilus rubidus* and *Lumbricus rubellus*.

AQUATIC PLANTS

Tolerant species:

Forbs:	Bulbous rush; reedmace; water lilies.
Mosses:	Bog moss.
Visible symptoms:	Low species diversity; presence of tolerant green algae.

AQUATIC INVERTEBRATES

Tolerant species:

Orders/Families:	Adler flies; beetles; biting midges; non-biting midges; true bugs; water boatmen.
Species:	*Amphinemura sulcicollis; Baetis rhodani; Bezzia-palpomyia* gp; *Brillia modesta; Chironomus plumosus; Conchapelopia pallidula; Eiseniella tetraedra; Heptophlebia marginata; Hydropsyche pellucidula; Hygrobates fluviatilis; Leuctra hippopus; Limnius volckmari; Limnodrilus hoffmeisteri; Lumbricus rivalis; Microspectra* sp; *Nais alpinia; N. elingius; Plectrocnemia conspersa; Prodiamesa olivacea; Protonemura praecox; Ptilostomius* sp. *Rheocricotopus foveatus; Rhyacophila dorsalis; Sialis* sp.; *Simulium ornatum; Tabanus* sp.; *Tanytarsus* sp.

AMPHIBIA

Tolerant species:	Palmate newt.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

FACTORS PRODUCING SIMILAR SYMPTOMS

ALKALINITY

SOURCES OF CONTAMINATION

Chalk/limestone quarries; gas lime waste; wastes from the Le Blanc and Solvay processes; chromate waste; fly ash; ammoniacal liqours from town gas manufacture.

ABIOTIC INDICATORS

Characteristic appearance of wastes.

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Tolerant species:

Grasses:	Barley; cocksfoot; common bent-grass; creeping bent; meadow fescue; meadow foxtail; meadow oat-grass; perennial rye-grass; quaking grass; red fescue; sheep's fescue; tall fescue; tor grass; tufted hair-grass; yellow oat-grass.
Forbs:	Adder's tongue; birdsfoot trefoil; blue-eyed grass; blue fleabane; carline thistle; coltsfoot; common box; common centaury; common spotted orchid; devil's bit scabious; dog's mercury; early marsh orchid; evening campion; eyebright; fragrant orchid; glaucous sedge; green-winged orchid; knapweed; lesser broomrape; lords and ladies; northern marsh orchid; mouse-ear hawkweed; purging flax; ragwort; ramsons; ribwort plantain; salad burnet; sneezewort; spurge laurel; valerian; wild angelica; wild thyme; yarrow
Trees/Shrubs	Ash; creeping willow; hawthorn.
Visual symptoms:	High species diversity.

TERRESTRIAL INVERTEBRATES

Visual symptoms: Increased diversity of snails and earthworms.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

FACTORS PRODUCING SIMILAR SYMPTOMS

SOURCES OF CONTAMINATION

Pulverised fuel ash (PFA); mining wastes and colliery spoil; spent oxides from manufacture of town gas; salt flashes; spent oil shales; estuarine dredgings disposal; blast furnace slag.

ABIOTIC INDICATORS

White encrustation on soil surface; physical evidence of above wastes.

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Tolerant Species:

Grasses	Bermuda grass; cock's foot; common bent-grass; common reed; common saltmarsh-grass; creeping bent; Italian rye-grass; lyme grass; meadow-grass; perennial rye-grass; red fescue; reflexed saltmarsh grass; sand couch-grass; wavy hair-grass; Yorkshire fog.
Forbs:	Annual seablite; black medick; broad-leaved dock; coltsfoot; common birdsfoot trefoil, common orache; creeping thistle; fat hen; groundsel; hastate orache; lesser sea-spurrey; mugwort; plantain; red clover; rosebay willow herb; sea rocket; sea sandwort; sheep's sorrel; tall rocket; white melilot.
Trees/shrubs:	Alder; bramble; elder; hawthorn; pedunculate oak; sea buckthorn; white poplar; willow.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

FACTORS PRODUCING SIMILAR SYMPTOMS

7. ORGANICS

7.1 INTRODUCTION

Organics are both natural and man-made carbon-containing compounds.

This chapter deals with coal tars/polycyclic aromatic hydrocarbons (PAHs), oils, organic effluents with high Biochemical Oxygen Demand (BOD), polychlorinated biphenols (PCBs), pesticides and phenols. There are other organic compounds, but these show the effects the group can have on biological systems and reflect the current state of knowledge about the group. Table 15 at the end of the chapter contains summary sheets.

7.2 COAL TARS / PAHs

7.2.1 Sources

Polycyclic aromatic hydrocarbons (PAHs) are produced by industrial processes (notably in coal tar, a bi-product of coal and gas) but they also occur naturally in biological material. They are also produced following the incomplete combustion of coal, wood, petroleum and other organic material (DoE 1988). Some PAH compounds are suspected carcinogens. Typical contaminants of gas works sites besides coal tars are cyanide, phenols and heavy metals.

7.2.2 Abiotic Indicators

Coal tars are brown/black in colour. They tend only to be visible at concentrations in excess of 2000 $mgkg^{-1}$. They are relatively invisible in wet and/or peaty soils, and become less visible with time. At a soil concentration of 2% (20000 $mgkg^{-1}$) coal tar is visible in all soils (DoE 1988).

Coal tar deposits do not have an odour at 500 $mgkg^{-1}$, but odour may be evident at concentrations of 2000 $mgkg^{-1}$. It is not persistent. Toluene and xylene are reported to have a characteristic but undefined 'organic' odour at concentrations in excess of 250 $mgkg^{-1}$ (Lord cited in DoE 1988).

7.2.3 Biological Effects

i) Plants

There have been a number of studies on the concentration of PAHs in vegetation in the vicinity of industrial emissions, and these have been reviewed by Burton (1986). There is little evidence of any effects of PAHs within the soil on plant species distribution or visual appearance. PAHs have a large molecular weight and are relatively insoluble. It is thought that PAHs present within plants are derived primarily from airborne deposition, not from uptake from the soil (for example Yland 1986).

ii) Animals

At the time of this review no data were found relating to effects of PAHs on animals.

7.2.4 Conclusion

PAHs are a priority contaminant because of their suspected carcinogenicity. They are most commonly associated with coal tars and the colour, viscosity and odour of coal tars are the most useful sensory indicators of their possible presence. There is very little information on the visible effects of PAHs on plants and animals which could be used in a preliminary site inspection.

7.3 OILS

7.3.1 Sources

Oils and grease wastes derive from crude oil and petroleum, animal fats and vegetable oils (Overcash and Pal 1979). Industrial sources are numerous and include processing of agricultural products, mass food production, soap and pharmaceuticals manufacture, and transport and processing of crude oil and related products.

7.3.2 Abiotic Indicators

Oils may be visible on soil. They are also reported to be visible as a sheen on water at concentrations in excess of 10 mgl^{-1} (Woodward *et al.* 1981 cited in Crunkilton and Duchrow 1990). Constituents of the oil may be lost from soils by volatilisation. Huntjens *et al.* (1986) reported decomposition of hexadecane (C_{16} H_{34}) under laboratory conditions after 20 hours. Those oils which are readily volatilised are likely to give rise to characteristic odours.

7.3.3 Biological Effects

i) Soils

Oils affect the chemical, physical and biological characteristics of soil. In the short-term, the effect of oil contamination is to reduce gaseous exchange between soil and air, and to alter rainfall runoff patterns. The effect on soil chemistry is determined primarily by the composition of the oil, with oils containing a high ratio of carbon to nitrogen causing an initial reduction in soil nitrate as nitrogen is used up by the increased microbial population. After a period of time, and when some microbial breakdown of the oil has taken place, the nitrate and organic matter content of the soil increases. This can lead to improved soil structure and fertility. The rate of decomposition is highly dependent on the nature of the oil, with vegetable oils and animal fats being decomposed at a faster rate than petroleum and mineral oils. The long term effect of hydrocarbon addition to the soil is to increase the microbial population (Overcash and Pal 1979).

ii) Plants

Oils can affect seed germination, growth and yield, and can cause yellowing and death of leaves. These symptoms may be a consequence of suffocation, direct toxicity, reduced water availability, or induced nitrogen deficiency. The effect also depends on whether light or heavy oils are present: light oils tend to have a rapid and acute effect; heavy oils are likely to have a chronic effect, toxicity increasing in the order: paraffins, naphthalenes and olefins, aromatics (Baker 1970; Kinako 1981; Raymond *et al.* 1976). Tolerant species, ie. those surviving at concentrations in excess of 3%, include leguminous species and perennial grasses (Grudin and Syratt 1975; Overcash and Pal 1979). Umbelliferae and conifers are also reported to be tolerant of high concentrations of oils (Baker 1970). Species sensitive to oils at <0.5% tend to be those with tap roots. Following decomposition of oil and release of nutrients, growth stimulation may be noted (Baker 1970).

In water bodies one of the secondary effects of oil contamination may be algal production, presumably resulting from nutrient release (Crunkilton and Duckrow 1990).

iii) Animals

In soil systems oils have been shown to be toxic to nematodes which are particularly sensitive to the naphthalene series. Heating oil has also been shown to be toxic (Raymond *et al.* 1976; Vasquez Duhcht 1989).

The effects of oils on the aquatic macroinvertebrate fauna are dependent on a number of factors including the volume and composition of the oil, extent of oil penetration into the stream substrate, stream hydrology, time of year, and tolerance of the organisms (Crunkilton and Duckrow 1990).

Hoehn *et al.* (1974) reported that an oil spill into a small stream reduced the number of invertebrates but not the diversity. Harrel (1985) noted a delayed effect with changes in the physical conditions in a stream after six months. Oxygen declined to 0.3 mgl^{-1}, carbon dioxide increased to 57.5 mgl^{-1}, and temperature also increased. There was an accompanying large increase in the density of *Limnodrilus sp.* and *Tubifex harmani* and a decline in midges (chironomids), followed by their elimination. The community diversity was considerably reduced. In a Missouri stream affected by crude oil, the post-spill community was dominated by midges, blackflies (simuliidae) and segmented worms (oligochaetes). Stoneflies (plecoptera), caddisflies (trichoptera) and mayflies (ephemeroptera) were the most adversely affected. (Crunkilton and Duckrow 1990).

7.3.4 Conclusion

The most useful indicators of oil on a contaminated land site are colour and viscosity of material; associated odours which vary according to the oil composition; surface sheen on water bodies; and dominance of the aquatic fauna by midges, blackflies and segmented worms. Other effects are more difficult to discern, and include plant growth reduction/inhibition, improved fertility (following decomposition) and improved soil structure.

7.4 ORGANIC EFFLUENTS WITH HIGH BIOCHEMICAL OXYGEN DEMAND

7.4.1 Sources

The principal effect of organic effluents in water is to deplete dissolved oxygen, as microbes use it to decompose organic matter. BOD is commonly used to measure this deoxygenating effect (Hellawell 1986).

Sources of effluents with high BOD include: domestic sewage, paper manufacture, textile and dyeing processes, the food processing industry (for example distilleries, abattoirs, fruit and vegetable canning), and agricultural runoff from manure and silage. Leachates from landfill sites during the first years of decomposition will tend to have a higher organic content than later on.

7.4.2 Abiotic Indicators

Anaerobic conditions are generated in water bodies with a high BOD. Typical symptoms are the production of black sulphides; hydrogen sulphide production, giving an odour of bad eggs; and continuous bubbling from the substrate.

7.4.3 Biological Effects

i) Aquatic communities

A secondary effect is that organic effluents frequently carry organic detritus (solids) which provides a food source not only for microbes but also for macroinvertebrates when the oxygen levels become sufficient for them.

The overall effect upon biota of an organic discharge into moving water is a sequence of successional changes in community composition as oxygen levels increase with distance from the source of effluent (Bartsch 1948). In standing water this succession would either be absent or occur over a period of time rather than over a distance from the source, the community being characteristic of the degree of organic pollution present at that site.

ii) Plants

The effect of organic effluents on the plant community is less well documented than that on invertebrates. Higher plants are usually eliminated or depleted in organic effluent by the presence of organic detritus or sewage fungus (Hellawell 1986). Sewage fungus is a misnomer for a community of bacteria, protozoa and other saprophytes. It forms on any solid surface in the water including stream beds and banks, and is commonly associated with BOD values in the range 5 - 30mg $litre^{-1}$, and with soluble carbon levels between 6 - 30mg $litre^{-1}$ (Hellawell 1986).

Species of macrophyte able to tolerate highly contaminated waters include a number of species of pondweed (*Potamogeton sp.*), reedmace (*Typha latifolia*), reed sweet-grass (*Glyceria maxima*), and bulrush (*Schoenoplectus lacustris*) (Harding 1981; Haslam 1978). In addition two mosses *Amblystegium riparium* and *Rhynchostegium riparioides* have been reported in highly organically contaminated waters (Harding 1981; Hellawell 1986; Burton 1986; Whitton *et al.* 1981).

ii) Animals

The effects of high BOD effluent upon invertebrate communities have been extensively documented (Bartsch 1948; Butcher 1955; Edwards *et al.* 1972; Learner 1971; NRA 1991; Williams *et al.* 1976). The rat-tailed maggot (*Eristalis* sp.) may be associated with sewage fungus in grossly polluted conditions; Tubificid worms such as *Tubifex* and *Limnodrilus* spp. (Brinkhurst and Cooke 1974), and chironomids such as the bloodworm, *Chironomus* (Learner and Edwards 1966; AERC 1988) may occur where pollution is not so severe. The freshwater louse (*Asellus aquaticus)* is characteristic of the transitional zone between polluted and clean waters (Edwards *et al.* 1971). Clean waters have a high diversity of groups including the freshwater shrimp *(Gammarus* spp), caddis flies (trichoptera), mayflies (ephemeroptera), bugs (hemiptera), beetles (coleoptera), and leeches (hirudinea) (Hellawell 1986; Butcher 1955).

7.4.4 Conclusion

The effects of high BOD effluents on freshwater aquatic communities has been well documented. There are a number of tolerant macrophytic plants; and a distinct succession in the aquatic invertebrate fauna, with high BOD water bodies dominated by the rat-tailed maggot, tubificid worms and chironomids. Sewage fungus on solid surfaces in water is a good indicator of high BOD effluents.

7.5 PCBs

7.5.1 Sources

Polychlorinated Biphenyl (PCB) is a generic name for more than 200 cogeners which are distinguished chiefly by their chlorine content (Bletchley 1985). They have been used extensively in transformers and capacitors because of their high thermal and chemical stability and ability to store electrical charge. They have also been used in plasticisers, adhesives, copying paper, inks, fire retardants, stabilisers (for pesticide spray) and hydraulic and lubricating systems (Overcash and Pal 1979; Eduljee). Once in the soil the degradability of PCBs is dependent on percentage chlorination, position of chlorine within the benzene ring, and the purity of the compound (Overcash and Pal 1979). PCBs are persistent because of their non-ionic nature, high propensity for adsorption to fats, low volatility, low water solubility and resistance to degradation (Strek and Weber 1982).

7.5.2 Abiotic Indicators

Debris on the site surface from any of the industrial sources, including capacitors and transformers could provide some evidence for PCBs.

7.5.3 Biological Effects

PCBs are anthropogenic in origin and have been shown to accumulate within the environment. For this reason most research has focused on the concentrations of PCBs in the various parts of the ecosystem; biological material has provided an indication of the movement of PCBs within the food chain (for example Murdoch *et al.* 1989; Creaser 1991). There is relatively little information on visual indicators or effects on biotic community structure which could be used to provide evidence of PCBs during a preliminary site investigation.

i) Plants

Significant growth inhibition has been noted in soy bean and beet in soil with high concentrations of PCB (1000 $mgkg^{-1}$) (Strek *et al.* 1981; Strek and Weber 1980). Plant species, degree of chlorination of the biphenyl, and growth period appear to be the most significant factors affecting plant uptake (Strek and Weber 1980), although the route of movement from the soil into the plant is unclear.

ii) Animals

PCBs have been reported to cause breeding impairment, a decline in the metabolic rate, and reduced water proofing and heat insulation in birds (Furness and Hutton 1979; Holdgate 1980).

Some toxicity data are available on the effects of a number of PCBs on freshwater invertebrates, and these have been reviewed by Hellawell (1986). It is often difficult to compare data from different studies because the lengths of tests vary. However, in 7 day LC_{50} tests, tolerance to Aroclor 1254 followed the order *Macromia sp.* > *Ishnura verticalis* > *Orconectes nais.*

Toxicity varies according to the PCB cogenor and the invertebrate species. In a 21 day test Aroclor 1254 was more toxic than Aroclor 1242 to *Daphnia magna* whereas in a 7 day test Aroclor 1254 was less toxic than Aroclor 1242 to *Orconectes nais.*

7.5.4 Conclusion

There are few visual indicators of PCBs which are useful in preliminary site inspection. The presence of old capacitors and transformers may provide some evidence for PCB contamination.

7.6 PESTICIDES

7.6.1 Sources

Pesticides are a diverse range of chemicals designed to kill pests including insects (insecticides); plants (herbicides); fungi (fungicides); algae (algicides) etc. They are rarely specific and some are persistant.

Originally pesticides were based on inorganic components including copper (for example Bordeaux mixture) and lead and arsenic (for example lead arsenate used against insect pests in orchards). Over the last thirty years there has been a striking increase in the use and diversity of organically based pesticides. Early organic pesticides were based on organochlorines (for example DDT) but these have been replaced by organophosphorus pesticides and, more recently, by carbamates which are less persistent.

The most widespread uses of pesticides are in agriculture and horticulture to protect crops, and in materials preservation as insecticides or fungicides. Industrial sites which have been used for the manufacture of pesticides, or for industrial processes which include the use of pesticides (for example carpet manufacture, wood preservation) are likely to be contaminated. Additionally industrial sites where weed control has been widely exercised (for example railway land) may be contaminated by herbicides.

The material in this chapter concentrates on organic pesticides.

7.6.2 Abiotic Indicators

Discarded storage drums and other containers on a site may provide some evidence of pesticide contamination.

7.6.3 Biological Effects

i) Soil

A considerable amount of work has been carried out to assess the impact of pesticides on the functioning of soil micro-organisms. While effects have been noted, for example reduced soil respiration and nitrification (Gaur and Misra 1977), they may be short term. Domsch (1984) makes the point that any changes in soil function and recovery should be set in the context of natural changes in soil temperature, water potential, atmosphere, energy, and natural inhibition. He concluded that application of pesticides at recommended rates was not harmful to soil microbiological processes, with the exception of biocidal fumigants. At higher concentrations it can be assumed that irreversible changes in biological function are more likely to occur.

ii) Plants

A number of studies have been carried out to determine the effect of pesticides on plants in terrestrial habitats. Organophosphate pesticides have been shown to reduce seed germination in a number of forbs and grasses, and they may be toxic in combination when singly they have no effect (Gange *et al.* 1992). Dieldrin (an organochlorine pesticide) is reported to cause lawn chlorosis and DDT (also an organochlorine), is reported to cause thickening of primary and secondary plant leaves and loss of fibrous roots (Chaphekar 1978).

Herbicides are often relatively specific but may alter the mix of plant species present in both terrestrial and aquatic environments. The effect is likely to be particularly evident in aquatic systems in which death of submerged plants is likely to cause changes in oxygen and pH, thus altering the community structure of plants and associated invertebrates. Algal blooms have been noted on application of organophosphorus pesticides to water (Yasomo *et al.* 1985).

iii) Animals

The effect of pesticides on the terrestrial arthropod fauna can be important as some groups are natural predators. An investigation carried out in Holland which concentrated on the distribution of spiders and carabid beetles in fields exposed to pesticide spraying, showed spiders to be more susceptible to bromophos-ethyl and deltamethrin than beetles. Two species which are widely distributed but susceptible to these chemicals are *Erigione atra* and *Meioneta rurestris* and the authors suggest that the lack of these in the invertebrate fauna may be a good indication of pesticide contamination (Everts *et al.* 1986).

In aquatic systems organophosphate insecticides are as toxic as organochlorine insecticides to invertebrates. Carbamates are less toxic. The effect of DDT on the caddis fly larva, *Hydropsyche* has been noted. The larva normally spins a regular net but at DDT concentrations of between 0.05 - 10 μg $litre^{-1}$, it is reported to produce a net of increasing irregularity (Decamps *et al.* 1973 cited by Hellawell, 1986). In a model stream system, chironomids recovered quickly following application of two organophosphorus insecticides (Temephos and Chlorophoxin), while trichopteran larvae were more sensitive (Yasomo *et al.* 1985).

Aquatic invertebrates are very sensitive to permethrin (a synthetic pyrethroid) with 95% killed at concentrations of 5 - 10 μgkg^{-1}. The caddis fly larva, with an LC_{90-95} greater than $1mgl^{-1}$, appears to be relatively tolerant (Muirhead-Thomson 1978 cited by Hellawell 1986).

Takamura *et al.* (1991) have suggested that low numbers of odonate larvae may be indicative of pesticide contamination in rivers, while Boreham and Birch (1987) recorded a reduced number and type of invertebrates following a spillage of dursban into a brook. Again odonata, as well as ephemeroptera, trichoptera, and coleoptera appeared to be most sensitive, while *Tubifex, Sphaerium* and *Limnaea* species were the main constituents of the invertebrate fauna at a point below a sewage outfall contaminated by pesticides.

7.6.4 Conclusion

Pesticides are diverse in composition and function and, by definition, toxic to some form of animal or plant life. The impact of their use on biological systems is to cause selective death of some species resulting in subtle changes in abundance and distribution of remaining species. Broad indicators include build up of litter on the soil surface, presence of algal blooms on water bodies, and the composition of the terrestrial and aquatic invertebrate communities. Possible indicators of pesticide contamination include dominance of the aquatic fauna by *Tubifex sp., Sphaerium sp.* and *Limnaea sp.* and dominance of the predatory terrestrial fauna by carabid beetles.

7.7 PHENOLS

7.7.1 Sources

The term phenols applies to a group of aromatic compounds which may be divided into: monohydric (one phenol group), dihydric (two phenol groups) or trihydric (three phenol groups).

Phenols occur in wastes from industrial processes including: gas and coke production, petroleum refining, town gas manufacture, wood distillation, manufacture of paper, plastics, rubber, solvents, paints/wood preservatives, tanning, iron and steel and glass (Overcash and Pal 1979; Hellawell 1986). Phenols are also synthesised by plants, which contain higher levels of them than animals.

Chlorine may be substituted onto the benzene ring to give chlorophenols, for example the pentachlorophenols, sodium pentachlorophenoxide and pentachlorophenyl laurate. These are pesticides used in the preservation of wood, heavy fabrics (for example tentage) and cordage for military purposes.

7.7.2 Abiotic Indicators

Phenol has a characteristic antiseptic odour which is evident at concentrations in excess of 100 $mgkg^{-1}$ in an acid or neutral soil. At this concentration in alkaline soils there is no odour. In aqueous solution the odour detection threshold varies according to the phenol. For example, the detection threshold for phenol is 25 mgl^{-1} and for cresol is $2.5x10^{-3}$ mgl^{-1} (Patty 1981).

The presence of halogenated phenols in water can give rise to objectionable odours. Threshold limits for detection of chlorocresols is between 0.001 - 0.0002 mgl^{-1} and for chlorophenols between 0.001 and 0.0005 mgl^{-1} (Patty 1981).

7.7.3 Biological Effects

i) Soil and microbial processes

At concentrations of between 0.01 - 0.1% in the soil phenol may increase microbial biomass while concentrations of 0.1 - 1% have an increasing sterilising effect (Overcash and Pal 1979). Phenols have been shown to inhibit microbial activity and delay nitrification, thereby contributing to a decreased soil nitrate content (for example Douglas and Bremner 1971; Dolgova 1975, both cited by Overcash and Pal 1979).

Pentachlorophenol (PCP) has been known to inhibit nitrogen fixation in soils, (Tam and Trevors 1981), and to have an adverse affect on microbial activity, although the response appears to be influenced by soil type (Zelles *et al.* 1986; Vonk *et al.* 1985).

ii) Plants

There have been few investigations into the effects of phenols on terrestrial plants. Buddin (1914) cited in Rulangaranga (1986) reported increased growth of fibrous roots on tomatoes at a concentration of 0.2% phenol. Wang *et al.* (1967) cited by Rulangaranga (1984) found that at 50 $mgkg^{-1}$ a wide range of phenolics caused necrosis and loss of root hairs, together with yellowing of plant leaf tip and stunted growth in *Saccharum officinarum.* Concentrations of 160 $mgkg^{-1}$ phenol in lime sludge is reported to have had no adverse effect on the growth of radishes or mixed grass (DoE 1988). In an investigation into phenols in codisposed refuse, Rulangaranga (1986) found that ryegrass (*Lolium perenne*) survived in refuse in which phenols had been added at concentrations of up to 1000 $mgkg^{-1}$ dry weight refuse, with no observable effects on plant growth.

Some species of aquatic plant are sensitive to low levels of phenol (10 mgl^{-1}) with concentrations greater than 100 mgl^{-1} inhibiting the growth of most species (Babich and Davis 1981 cited in DoE 1988).

iii) Animals

In laboratory studies earthworms (*Eisenia foetida*) were incubated for a period of seven days in refuse spiked with either phenol or 2-6 dimethyl phenol. They survived in concentrations of up to 200 $mgkg^{-1}$ (Rulangaranga 1986). Live earthworms have been found in soil containing between 103 and 140 mg PCP kg^{-1} (Knuutrien *et al.* 1990) and experimental studies have shown 14 day LC 50s of 94-143 $mgkg^{-1}$ for *Eisenia foetida* and between 883-1094 $mgkg^{-1}$ for *Lumbricus rubellus* (Van Gestel and Ma 1988).

Phenols are toxic to aquatic macroinvertebrates. In a stream containing greater than 10mgl^{-1} phenol all aquatic flora and fauna died (Kromback and Barthel 1964 cited in DoE 1988) while no effect was noted at concentrations $<3mgl^{-1}$. Based on acute toxicity data Alekseyev and Antipin (1976) cited in Rulangaranga (1986) drew up the following broad order of tolerance:

Crustaceans < tolerant insects < worms < molluscs < highly tolerant insects < arachnids

The acute toxicity of PCPs in water is inversely related to pH. While there are acute toxicity data for a number of non-UK macroinvertebrates (for example Adema and Vink 1981; Hedtke *et al.* 1986) which demonstrate a variation in tolerance, there is little information on the tolerance of UK freshwater species.

7.7.4 Conclusion

Phenol is a broad term which includes a range of aromatic compounds, some of which contain chlorine. Phenols and phenolic compounds have characteristic odours which may be evident, dependent on concentration and pH. Their toxicity varies considerably. In general, phenols may reduce microbiological activity, leading to a build-up of litter on the surface of the site, and may cause a number of relatively non-specific symptoms in plants including necrosis. The effects of phenols on aquatic systems may be more readily discerned, as aquatic plants and macroinvertebrates are sensitive to phenol contamination. Arachnids are considered to be one of the most tolerant groups.

TABLE 15

ORGANICS SUMMARY SHEETS

COAL TARS/PAHs

SOURCES OF CONTAMINATION Coal tars from town gas manufacture; combustion of coal, wood, petroleum and other organic materials.
ABIOTIC INDICATORS <u>Colour:</u> Coal tars - black/brown, visible at concentrations >2000 $mgkg^{-1}$. <u>Odour:</u> Some odour from coal tars associated with components eg. toluene, xylene.
BIOTIC INDICATORS
ENVIRONMENTAL FACTORS AFFECTING TOXICITY
FACTORS PRODUCING SIMILAR SYMPTOMS

OILS

SOURCES OF CONTAMINATION Transport and processing of crude oil and related products; animal fats and vegetable oils from mass food production; soap manufacture.
ABIOTIC INDICATORS Physical: Discarded oil containers; improved soil structure; viscous deposits. Colour: Black/brown - visible on soils and occurring as a sheen on surface of water bodies. Odour: Characteristic tarry or oily smell, dependent on composition.
BIOTIC INDICATORS *TERRESTRIAL PLANTS* **Tolerant Species:** Grasses: Perennials. Forbs: Legumes; umbelliferae. Trees/shrubs: Conifers. *TERRESTRIAL INVERTEBRATES* **Visible symptoms:** Lack of nematodes. *AQUATIC INVERTEBRATES* **Tolerant Species:** Families/Phyla: Midges; blackflies; segmented worms. Species: *Limnodrilus sp; Tubifex harmani.* **Intolerant Species:** Orders: Caddisflies; mayflies; stoneflies. *AQUATIC PLANTS* **Visible Symptoms:** Production of algal blooms; change in species composition.
ENVIRONMENTAL FACTORS AFFECTING TOXICITY Composition of oil. For aquatic symptoms: stream hydrology; time of year.
FACTORS PRODUCING SIMILAR SYMPTOMS

ORGANIC EFFLUENTS WITH HIGH BOD

SOURCES OF CONTAMINATION

Effluents from: domestic sewage sludge; paper manufacture; textile and dyeing processes; food processing industry; agricultural run-off; landfill leachate.

ABIOTIC INDICATORS

Physical:	Continuous bubbling from substrate.
Colour:	Extensive black deposits.
Odour:	Bad eggs (H_2S).

BIOTIC INDICATORS

AQUATIC PLANTS

Tolerant species:

Grasses:	Reedmace; reed sweet-grass; bulrush.
Forbs:	Pondweed.
Mosses:	*Amblystegium riparium; Rhynchostegium riparoides.*
Visual symptoms:	Reduced species diversity; loss of higher plants.

AQUATIC INVERTEBRATES

Tolerant species:	Rat-tailed maggot; *Tubifex sp; Limnodrilus sp;* bloodworm.
Sensitive species:	
Groups:	Freshwater shrimp; caddis flies; mayflies; bugs; beetles and leeches.

MICROBIOLOGICAL

Visible symptoms: Presence of sewage fungus.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

FACTORS PRODUCING SIMILAR SYMPTOMS

SOURCES OF CONTAMINATION Transformers; capacitors; adhesives; inks; fire retardants; hydraulic and lubricating systems.
ABIOTIC INDICATORS Physical: Cases of transformers, capacitors etc.
BIOTIC INDICATORS *TERRESTRIAL PLANTS* **Visible Symptoms:** Some evidence for growth inhibition eg. in soy bean and beet. *AQUATIC INVERTEBRATES* **Tolerant Species:** *Macromia sp.*
ENVIRONMENTAL FACTORS AFFECTING TOXICITY Percentage chlorination; position of chlorine within the benzene ring; plant species; growth period.
FACTORS PRODUCING SIMILAR SYMPTOMS

PESTICIDES

SOURCES OF CONTAMINATION

Pesticides manufacture; industrial processes involving use of pesticides for materials preservation; weed control (herbicides).

ABIOTIC INDICATORS

Discarded storage containers.

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Visible Symptoms: Reduced seed germination in some forbs and grasses; lawn chlorosis (dieldrin); thickening of primary and secondary plant leaves and loss of fibrous roots (DDT); direct toxicity to some species (herbicides) - may be selective or broad spectrum.

TERRESTRIAL INVERTEBRATES

Sensitive Species: *Erigione atra; Meioneta rurestris* (to pesticides).

AQUATIC PLANTS

Visible Symptoms: Death of some species leads to change in community structure; algal blooms (organophosphorus).

AQUATIC INVERTEBRATES

Tolerant Species: *Tubifex; Sphaerium; Limnaea* (to pesticides); *Hydropsyche* (to permethrin).

Sensitive Groups: Odonate larvae; ephemeroptera; trichoptera; coleoptera.

Visible Symptoms: Hydropsyche produces irregular net (DDT).

SOIL MICROBIOLOGY

Visible Symptoms: Reduced microbial function probable at elevated concentrations leading to build up of litter layer.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

Chemical composition of pesticide; specificity; concentration.

FACTORS PRODUCING SIMILAR SYMPTOMS

PHENOLS

SOURCES OF CONTAMINATION

Wastes from town gas and coal production; petroleum refining; town gas manufacture; wood distillation; manufacture of paper, plastics, rubber, solvents, paints/wood preservatives; iron and steel.

ABIOTIC INDICATORS

Physical:	Wastes from the above processes.
Odour:	Antiseptic (phenol in acid and neutral soils) .
	'objectionable' (halogenated phenols).

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Visible Symptoms: Increased growth of fibrous roots on tomatoes; necrosis; loss of root hairs; yellowing of plant leaf tips.

TERRESTRIAL INVERTEBRATES

Tolerant Species: Earthworms (*Lumbricus rubellus*).

AQUATIC PLANTS

Visible Symptoms: Considerably reduced species diversity.

AQUATIC INVERTEBRATES

Tolerant Groups: Spiders > molluscs > worms > crustaceans.

SOIL MICROBIOLOGY:

Visible Symptoms: Reduced microbial activity could result in increased litter layer.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

Soils: Extent of volatilisation, leaching, photodecay, microbial decay or polymerisation.

FACTORS PRODUCING SIMILAR SYMPTOMS

8. GASES

This chapter deals with the gases methane, carbon dioxide, ammonia, and the volatile organic carbon compounds which may also be present in landfill gas. Table 19 at the end of the chapter contains summary sheets.

8.1 INTRODUCTION

The soil provides both the physical and chemical environment for plant growth and for soil dwelling invertebrates. A number of publications consider this subject (for example Russell 1973; Foth 1978 and Thompson and Troeh 1957). About 50% of the volume of soil is pore space, occupied by water and gases in varying proportions. There is continual interchange between the gaseous component and the plant roots as biological activities such as root respiration and decomposition of organic matter consume oxygen and produce carbon dioxide.

A large volume of literature exists concerning the impacts of air-borne pollutants (including nitrogen oxides, sulphur dioxide, and ozone) on plant health and yield. Visual symptoms arising from airborne pollutants are described in detail within Taylor *et al.* (1984). There is relatively little information on the visual effects of gaseous contaminants within the soil.

8.2 METHANE

8.2.1 Sources

Methane (CH_4) is a major component of landfill gas occurring at concentrations of up to 65%. Methane also occurs in coal mine gas at concentrations of between 53 - 95%, and natural gas at a concentration of 95% (Campbell 1990), and is generated by the decomposition of organic components of soils, silts etc. under anaerobic conditions (Edwards and Pearson 1991).

8.2.2 Abiotic Indicators

Methane is an odourless gas, although landfill gas may smell because of the presence of volatile organic components. Symptoms of the presence of methane within landfill gas include bubbling from puddles and ponds (Crowhurst 1987), hissing of gas under pressure, heat shimmer, condensation plumes, and areas of melted snow caused by raised soil temperature (IWM 1989).

8.2.3 Biological Effects

i) Soils

The changes that methane can cause to the structure of soils are an indicator of the presence of gas. The initial effect of gas on the soil is to displace oxygen from the soil pore space. Once oxygen levels are lowered within the soil, anaerobic bacteria predominate, using oxidised components of the soil as a source of oxygen. Such components include nitrate, manganese oxides, ferric oxides, sulphate or phosphate. These compounds are reduced in the order: higher oxides of manganese and (MnO_2, Mn_2O_3, Mn_2O_4); ferric hydroxide ($Fe_3(OH)_3$); sulphate (SO_4^{2-}); and nitrate (Ponnamperuma 1964 cited by Townsend 1983). As a result manganous and ferrous (Mn^{2+} and Fe^{2+}) ions are produced together with sulphide. The effect of the reduction process is deterioration in the soil structure as both iron and manganese play an important role in maintaining its quality: poor soil structure leads to further oxygen depletion. Iron sulphide precipitates may also be formed. These are characteristically black. The ferrous ion (Fe^{2+}) is grey/green in colour and leads to a characteristic grey/green appearance to the soil, as reported by Hewitt and McRae (1985).

The effect of these soil reactions is to produce symptoms which are typical of waterlogged environments (Flower *et al.* 1978). In addition the temperature of the soil may be 1-3°C higher than surrounding areas (Hewitt and McRae 1985). It is thought that the elevated temperature effect is a cyclic one (Williams and Aitkenhead 1989). Methane migrates into the surface soil and is oxidised by methane oxidising bacteria to produce heat, water and carbon dioxide. Heat causes the surface of the soil to dry out and this gives rise to cracks through which gas can migrate more quickly, by-passing the zone of methane oxidation. Subsequent cooling of the soil accompanied by 'wetting' or 'weathering' may then result in the cracks closing and the recommencement of the methane oxidation cycle.

ii) Plants

It is not thought that methane has a directly toxic effect on vegetation although land containing landfill gas may be completely unvegetated or only support plants with stunted growth. This paucity of vegetation is thought to be primarily caused by oxygen depletion, possibly accompanied by some toxicity attributable to carbon dioxide, ethylene and other trace organic components within the landfill gas.

Vegetation which is established onto areas containing methane, in landfill gas or gas from other sources, tends to be typical of waterlogged environments. Tolerant species are shown in Table 16.

Table 16 **Species Associated with Waterlogging which may be Indicative of Landfill Gas**

TREES/SHRUBS	
Alnus glutinosa	Alder
Salix cinerea	Sallow
Salix fragilis	Crack willow
GRASSES	
Agrostis stolonifera	Creeping bent
Deschampsia cespitosa	Tufted hair-grass
Juncus articulatus	Jointed rush
Juncus sp.	Common rush
Phalaris arundinacea	Reed grass
Phragmites australis	Reed
Typha latifolia	Reed mace
FORBS	
Caltha palustris	Marsh marigold
Valeriana dioica	Marsh valerian

The effect of landfill gas on tree survival and growth has been assessed in some detail under field conditions (for example Insley and Carnell 1982; Gilman *et al.* 1981). Species grown on restored landfills exposed to elevated methane and carbon dioxide tend to have shallower rooting systems than the same species on control sites (Gilman *et al.* 1981).

Two mechanisms of root adaptation which have been noted (Gilman *et al.* 1982) are the growth of shallow roots on the trunk approximately 2 - 5cm below the surface (green ash), and the upward growth of roots from the trunk approximately 15cm below the surface (hybrid poplar).

Sites which have been covered with soil but have not been specially planted tend to support species typical of disturbed sites. Ettala *et al.* (1988) surveyed 40 landfills in Finland and found that the most dominant species were colonisers of bare soil including **field weeds** tolerant of windy sites and poor compacted soils (mugwort [*Artemisia vulgaris*], couch grass [*Elymus sp.*], fat hen [*Chenopodium album*], coltsfoot [*Tussilago farfara*], creeping thistle [*Cirsium arvensis*]); **ruderals** requiring a nitrogen rich substrata (stinging nettle [*Urtica dioica*], tomato and pale persicaria [*Polygonum lapathifolium*]) and **nitrogen fixing species** (clover [*Trifolium sp.*] and vetch [*Vicia sp.*]). Natural colonisation by woody plants was poor and consisted primarily of birch (*Betula sp.*) and sallow (*Salix cineria*). Donnelly (1983) has also described the following natural colonisation of landfills:

- early colonisers
  - nitrogen fixing blue green algae
  - lichens
  - liverworts and mosses
- annuals
  - annual meadow grass (*Poa annua*)
  - shepherd's purse (*Capsella bursa-pastoris*)
  - groundsel (*Senecio vulgaris*)
  - fat hen
- perennials
  - spear thistle (*Cirsium vulgaris*)
  - hawkbits (*Leontodon spp.*) and hawkweeds (*Hieracium spp.*)
  - legumes
  - rhizomatous and stoloniferous species

iii) Animals

There is little information on the direct effects of methane on soil dwelling fauna. However, the indirect effect of soil waterlogging/compaction is likely to influence the distribution of earthworms and other soil dwelling fauna.

8.2.4 Conclusion

On former landfills methane usually occurs with carbon dioxide and some trace organics within landfill gas. The effect of gas migration into the rooting zone appears to be to change the structure of the soil, which becomes anaerobic, and poorly structured, and, in extreme conditions, will not support vegetation growth. The following are useful visual indicators for landfill gas contamination:

Abiotic - dark iron sulphide staining on soil surface
- blue/green colour within freshly dug soil profile
- odour associated with the trace organics rather than the methane
- increased soil T° (1-3°C)
- bubbles in water bodies

Biotic - stunted root growth
- root pattern altered (trees)
- leaf loss (trees)
- vegetation die-back
- where vegetation does occur the species are likely to be typical of waterlogged environments

8.3 CARBON DIOXIDE

8.3.1 Sources

Carbon dioxide occurs normally in soils in the UK at a concentration of between 0.15 - 1.6% (Russell 1973) although significantly higher concentrations have been recorded in tropical soils. Higher concentrations also occur naturally in the UK because of oxidation of methane, interaction between acidic groundwaters and carbonate rocks, and decomposition of organic material under anaerobic or aerobic conditions (WMP 27, 2nd ed. 1991; Edwards and Pearson 1991).

Concentrations of carbon dioxide may be increased above background levels by landfill gas (containing up to 35% carbon dioxide) and coal mine gas (containing between 1.5 - 6% carbon dioxide) (Campbell 1990). Other low level sources of carbon dioxide include natural gas (0.3% Campbell 1990) and emissions from former iron and steel works (Barry 1985).

8.3.2 Abiotic Indicators

Abiotic indicators of carbon dioxide are the same as for methane.

8.3.3 Biological Effects

i) Plants

While methane is not considered to be directly toxic to plants, there is some evidence that carbon dioxide adversely affects root respiration (Nobel and Palta 1989). Carbon dioxide has been shown to change root morphology in rice by reducing the number of roots and depressing the rate of root elongation (Niranjan and Mikkelsen 1977).

ii) Animals

The effect of elevated carbon dioxide on soil dwelling fauna is likely to be as described for methane and be a consequence of changes in soil structure, for example the distribution of soil dwelling invertebrates, in particular earthworms may be altered.

8.3.4 Conclusion

The effects of carbon dioxide, as a component of landfill gas, are the same as for methane. There are few indicators which are specific to carbon dioxide.

8.4 TRACE GASES AND VAPOURS

8.4.1 Sources

Over 100 trace gases and vapours have been identified in landfill gas, including hydrocarbons, esters, terpenes, and organic sulphur compounds. Their presence and composition is dependent on origin and age of refuse, and operational conditions at the landfill (Young and Parker 1983). The most common trace components are reported to be: carbon monoxide (0.01%); ethane (0.005%); ethene (0.018%) and acetaldehyde (0.005%) (WMP 27, 2nd ed. 1991). Phenol, and coal tar vapours, are reported to be generated by iron and steel plants (Barry 1985) and ethane, butane and propane by coal gas (Campbell 1990). Ethylene has been reported in gas works' waste at concentrations of between 0.1 - 6.0 ppm (Roberts and Gemmell 1980), and is also formed naturally in soil by aerobic micro-organisms, anaerobic bacteria, and may also be produced abiotically (Pazout *et al.* 1981).

8.4.2 Abiotic Indicators

There is little information on the effect of individual volatile organic compounds (VOCs) on plant or animal health and the most useful indication on a contaminated site is likely to be odour. The characteristic odours of a number of VOCs are summarised in Table 17.

Table 17 Characteristic Odours of Volatile Organic Compounds (VOCs) [1]

VOC	Description of Odour
Methylene chloride	Strongly odorous; sweetish; not pleasant
Carbon tetrachloride	Strongly odorous; sweet; pungent; ether-like
Chloroform	Sweet
Benzene	Strongly odorous; sweet; aromatic
Chlorobenzene	Chlorinated moth balls; aromatic; faint; pleasant
Dichlorobenzene	Strong; irritating; aromatic; nauseating
Ethylbenzene	Strongly odorous
1,2 Dichloroethylene	Ethereal; slightly acrid
1,1 Dichloroethane	Chloroform-like; distinctive; irritating
1,2 Dichloroethane	Sweet; chloroform-like; unpleasant to neutral; aromatic
Trichloroethanes	Strongly odorous; sweet (1,1,1); chloroform-like
Tetrachloroethane	Sweet; pleasant; chloroform-like
Trichloroethylene	Strongly odorous; soft; solventy; ethereal; chloroform-like
Tetrachloroethylene	Etheric; chloroform-like
Vinyl chloride	Mild; sweetish; faintly pleasant at high concentrations
Toluene	Strongly odorous; burnt; unpleasant to neutral
Chlorotoluene	Lacrimator; aromatic; pungent; irritating
Vinylidene chloride	Sweet; chloroform-like
Xylenes	Strongly odorous; sweet; aromatic

[1] James *et al.* 1985. Odours from volatile organic compounds derived from landfills, waste lagoons and chemical storage areas.

8.4.3 Biological Effects

i) Plants

Ethylene is one volatile organic which has been studied in some detail. It can affect the microbial balance of soils, and retard the root growth of certain plants (Wainwright and Kowalenko 1977). It has also been shown to reduce the size and number of root nodules in two leguminous species (the pea and white clover [*Trifolium repens*]) (Broodless and Smith 1979), and has been implicated in causing damage to potato plants and tubers (Pazout *et al.* 1981).

ii) Animals

At the time of this review no data were found relating to affects on animals.

8.4.4 Conclusion

Trace gases and vapours are the odorous components of landfill gas, and are also generated by other wastes (for example oils and tars). There is little information regarding their effects on biological systems except for ethylene which, through inhibition of microbial processes, can lead to a build up of the surface litter layer. Root nodules on leguminous species may also be reduced.

8.5 AMMONIA

8.5.1 Sources

Ammonia is produced by iron and steel plants (Barry 1985), by the manufacture of coal gas and may be found in refrigerant units, etc.

8.5.2 Abiotic Indicators

Ammonia has a characteristic pungent odour.

8.5.3 Biological Effects

i) Plants

In soils ammonia has been shown to affect both root elongation and seed germination (Wong *et al.* 1983).

Ammonia is volatile and when present in soil may change foliar parts of the plant. The effects were reviewed and summarised by Temple *et al.* 1979. Liquid ammonia has been observed to cause severe stem and leaf necrosis in plants near to the point of a spill. Species particularly susceptible or resistant to injury are shown in Table 18.

ii) Animals

The gastropod *Potamopyrgus jenkinsi*, a relatively abundant species in freshwater systems in the UK, has been shown to be relatively intolerant of both ammonia and copper. Watton and Hawkes (1984) have suggested that its absence (presumably from waters where in similar waters nearby it is abundant) may be a good indication of contamination. Other work carried out in experimental streams has indicated that copepods and rotifers (many of which are not visible to the naked eye) may be tolerant of elevated ammonia concentrations.

8.5.4 Conclusion

The most significant effects of ammonia which may be evident on a preliminary site inspection are its characteristic and pungent odour, and, in cases of severe contamination, localised incidence of severe stem and leaf necrosis at or near ground level. While the absence of *Potamopyrgus jenkinsi* from particular areas in freshwater systems where it is generally abundant may indicate ammonia, this is unlikely to be a helpful indicator in water bodies on contaminated land sites.

Table 18 Species Susceptible to Acute Ammonia Injury

FORBS	
Ambrosia artemisiifolia	Common ragweed
Arctium minus	Burdock
Chenopodium album	Fat hen
Chrysanthemum leucanthemum	Ox-eye daisy
Dipsacus fullonum	Wild teasel
Lactuca serriola	Prickly lettuce
Melilotus alba	White melilot
Nepeta cataria	Cat mint
Trifolium pratense	Red clover
TREES/SHRUBS	
Crataegus spp.	Hawthorn
Philadelphus coronarius	Mock orange
Rubus idaeus	Raspberry
Symphoricarpos albus	Snowberry
CULTIVATED PLANTS	
Hordeum vulgare	Barley
Lathyrus odoratus	Sweet pea
Pisum sativum	Garden pea
Phaseolus vulgaris	Pole bean
P. coccineus	Scarlet runner bean
Raphenus sativus	Radish

Species Resistant to Acute Ammonia Injury

FORBS	
Cichorium intybus	Chicory
Daucus carota	Wild carrot
Hypericum perforatum	Perforate St John's-wort
TREES/SHRUBS	
Acer plantanoides	Norway maple
Hedera helix	Ivy
Picea abies	Norway spruce
CULTIVATED PLANTS	
Allium cepa	Onion
Poa pratensis	Smooth meadow-grass
Rheum rhaponticum	Rhubarb
Zea mays	Corn

TABLE 19

GASES SUMMARY SHEETS

AMMONIA

SOURCES OF CONTAMINATION

Iron and steel plants; coal gas production; refrigerant units.

ABIOTIC INDICATORS

Odour:	Pungent.

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Tolerant species:

Forbs:	Chicory; perforate St.John's-wort; wild carrot.
Cultivated plants:	Corn; onion; rhubarb.
Trees/shrubs:	Ivy; Norway maple; Norway spruce.
Visible symptoms:	Stem and leaf necrosis.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

FACTORS PRODUCING SIMILAR SYMPTOMS

CARBON DIOXIDE

SOURCES OF CONTAMINATION Landfill gas; coal mine gas; natural gas; former iron and steel works; also natural sources (methane oxidation; organic matter decomposition and acidic groundwater/carbonate interaction).
ABIOTIC INDICATORS Similar effects to methane where component of landfill, coal mine or natural gas.
BIOTIC INDICATORS Similar effects to methane where component of landfill, coal mine or natural gas.
ENVIRONMENTAL FACTORS AFFECTING TOXICITY
FACTORS PRODUCING SIMILAR SYMPTOMS

METHANE

SOURCES OF CONTAMINATION

Landfill gas; coal mine gas; natural gas; organic rich soils and silts.

ABIOTIC INDICATORS

Physical:	Bubbling (eg. from puddles and ponds); hissing (of gas under pressure); heat shimmer; condensation plumes; melted snow; waterlogged/compacted soil with poor structure.
Colour:	Black iron-sulphide staining on soil surface; blue/green colour in soil profile.
Odour:	None but may be associated with trace organic components (if landfill gas).

BIOTIC INDICATORS

TERRESTRIAL PLANTS

Tolerant Species:	Possibly those which are tolerant of waterlogged soils.
Grasses etc:	Common rush; creeping bent; jointed rush; reed; reed grass; reed mace; tufted hair-grass.
Forbs:	Marsh marigold; marsh valerian.
Trees/Shrubs:	Alder; crack willow; sallow.
Visible Symptoms:	Vegetation die-back; stunted root growth; altered root pattern along soil surface (trees); leaf loss.

ENVIRONMENTAL FACTORS AFFECTING TOXICITY

FACTORS PRODUCING SIMILAR SYMPTOMS

APPENDIX

SUMMARY OF UK SPECIES CITED AS TOLERANT OF:

i) Metals

ii) pH, salinity, fluoride, boron, waterlogging and ammonia

Summary of UK Species Cited as Metal-tolerant

Latin Name	Common Name	Metals																
		Metals	Pb	Zn	Cu	Cd	Cr	As	Ni	Co	Mo	Fe	Se	Mn	Mg	Al	Ag	Bi
GRASSES																		
Agrostis canina	Brown bent-grass		✓	✓														
Agrostis capillaris	Common bent-grass	✓	✓	✓	✓	✓	✓	✓	✓			✓			✓			✓
Agrostis capillaris x stolonifera				✓														
Agrostis gigantea	Common bent-grass			✓	✓				✓	✓								
Agrostis stolonifera	Creeping bent-grass	✓	✓	✓	✓			✓	✓			✓						
Agrostis vinealis	Brown bent-grass		✓															
Anthoxanthum odoratum	Sweet vernal grass		✓	✓														
Arrhenatherum elatius	False oat-grass		✓			✓												
Avena pubescens	Downy oat-grass	✓																
Cynodon dactylon	Bermuda grass		✓															
Dactylis glomerata	Cocksfoot		✓		✓													
Deschampsia cespitosa	Tufted hair-grass		✓	✓	✓	✓			✓							✓		
Deschampsia flexuosa	Wavy hair-grass		✓		✓													
Festuca ovina	Sheep's fescue	✓	✓	✓		✓												
Festuca rubra	Red fescue	✓	✓	✓	✓	✓	✓											
Holcus lanatus	Yorkshire fog		✓	✓	✓	✓												

Latin Name	Common Name	Metals																
		Metals	Pb	Zn	Cu	Cd	Cr	As	Ni	Co	Mo	Fe	Se	Mn	Mg	Al	Ag	Bi
Juncus acutiflorus	Sharp-flowered rush	✓																
Juncus effusus	Soft rush	✓																
Koeleria macrantha	Crested hair-grass		✓			✓												
Lolium perenne	Perennial rye-grass					✓												
Phalaris arundinacea	Reed grass		✓			✓												
Typha latifolia	Reedmace		✓	✓	✓	✓			✓									
FORBS																		
Armaria maritima	Thrift	✓		✓	✓													
Atriplex patula	Common orache												✓					
Callitriche spp.	Starwort	✓																
Calluna vulgaris	Ling		✓	✓	✓			✓				✓						
Campanula rotundifolia	Harebell			✓														
Cochlearia pyrenaica	Pyrenean scurvy grass		✓	✓														
Epipactis leptochila	Green-leaved helleborine		✓	✓														
Epipactis phyllanthes	Pendulous-flowered helleborine		✓	✓														
Epipactis youngiana	Young's helleborine		✓	✓														
Genista tinctoria	Dyer's greenweed	✓																
Jasione montana	Sheep's-bit		✓	✓	✓			✓				✓						

Latin Name	Common Name	Metals																
		Metals	Pb	Zn	Cu	Cd	Cr	As	Ni	Co	Mo	Fe	Se	Mn	Mg	Al	Ag	Bi
Kobresia simpliciuscula	False sedge		✓															
Linum catharticum	Fairy flax			✓														
Mercurialis perennis	Dog's mercury					✓												
Mimulus guttatus	Monkey flower	✓		✓	✓				✓									
Minuartia verna	Vernal sandwort	✓	✓	✓	✓	✓			✓								✓	
Plantago lanceolata	Ribwort plantain	✓		✓	✓													
Polygala vulgaris	Common milkwort	✓																
Ranunculus spp.	Water crowfoot	✓																
Rhianthus minor	Yellow rattle	✓																
Rumex acetosa	Common sorrel			✓	✓													
Senecio vulgaris	Groundsel		✓															
Silene alba	White campion			✓	✓													
Silene dioica	Red campion			✓	✓													
Silene vulgaris	Bladder campion	✓		✓	✓	✓												
Silene vulgaris subsp. maritima	Sea campion	✓	✓	✓	✓												✓	
Taraxacum officinale	Dandelion				✓													
Thlaspi caerulescens	Alpine pennycress	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		✓	✓	
Thymus pulegioides	Large thyme	✓																
Tussilago farfara	Coltsfoot				✓													

Latin Name	Common Name	Metals																
		Metals	Pb	Zn	Cu	Cd	Cr	As	Ni	Co	Mo	Fe	Se	Mn	Mg	Al	Ag	Bi
Viola lutea	Mountain pansy		✓	✓														
Viola calaminaria	Zinc violet			✓														
Viscaria alpina	Red alpine catchfly	✓			✓													
HORSETAILS																		
Equisetum arvense	Field horsetail			✓	✓													
TREES																		
Betula sp.	Birch			✓								✓						
Salix spp.	Willow		✓	✓														
MOSSES AND LIVERWORTS																		
Amblystegium riparium		✓																
Bryum pseudotriquetrum			✓	✓														
Calypogeia muelleriana					✓													
Calypogeia trichomani					✓							✓						
Cephalozia bicuspidata			✓	✓	✓													
Cephaloziella massalongii					✓							✓						
Cephaloziella phyllacantha					✓							✓						
Ceratodon purpureus				✓														
Dicranella varia			✓	✓														
Dryoptodom atratus					✓							✓						
Fontinalis antipyretica		✓																

Latin Name	Common Name	Metals																
		Metals	Pb	Zn	Cu	Cd	Cr	As	Ni	Co	Mo	Fe	Se	Mn	Mg	Al	Ag	Bi
Fontinalis squamosa		✓																
Funaria hygrometrica				✓	✓													
Gymmocolea acutiloba					✓							✓						
Hylocornium spendens			✓															
Marchantia polymorpha			✓															
Merceya gedeana					✓													
Merceya ligulata					✓							✓						
Mielichoferia elongata					✓		✓					✓						
Mielichoferia nitida			✓	✓	✓							✓						
Nardia scalaris					✓							✓						
Oligotrichum hercynicum					✓				✓									
Oligotrichum parallelum					✓				✓									
Philonotis fontana			✓															
Physcomitrium pyriforme				✓														
Pleuroclada albescens					✓													
Pohlia nutans		✓		✓	✓													
Rhynchostegiumriparioides		✓																
Scapania undulata		✓		✓	✓									✓				
Trematodon longicollis				✓	✓													
Weissia controversa				✓	✓													

Latin Name	Common Name	Metals																
		Metals	Pb	Zn	Cu	Cd	Cr	As	Ni	Co	Mo	Fe	Se	Mn	Mg	Al	Ag	Bi
LICHENS																		
Cladonia chlorophaea agg				✓	✓													
Cladonia coniocraea				✓	✓													
Lecanora muralis												✓						
Parmelia sulcata					✓													
Peltigera rufescens												✓						
FERNS																		
Asplenium septentrionale	Forked spleenwort		✓		✓													
ALGAE																		
Hormidium rivulare				✓	✓									✓				

Latin Name	Common Name	Metals																
		Metals	Pb	Zn	Cu	Cd	Cr	As	Ni	Co	Mo	Fe	Se	Mn	Mg	Al	Ag	Bi
INVERTEBRATES																		
MOLLUSCA	Molluscs															✓		
ARTHROPODA: INSECTA																		
Coleoptera *(adults and larvae)*	Water beetles																	
Hygrobia sp.				✓	✓							✓						
Limnius volckmari																		
Stenelmis sp.					✓													
Collembola	Springtails		✓	✓	✓													
Diptera *(larvae)*	Flies					✓												
Chironomidae	Midge larvae		✓	✓	✓	✓												
Orthocladiinae		✓																
Cricotopus sp.					✓													
Simuliidae	Blackfly larvae		✓	✓	✓	✓												
Simulium latipes	Blackfly larvae		✓															
Tanypus nebulosus			✓															
Ephemeroptera *(larvae)*	Mayfly		✓	✓	✓	✓												
Chloeon simile	Mayfly larvae		✓															

Latin Name	Common Name	Metals																
		Metals	Pb	Zn	Cu	Cd	Cr	As	Ni	Co	Mo	Fe	Se	Mn	Mg	Al	Ag	Bi
Rhithrogena semicolorata	Olive upright mayfly			✓														
***Hemiptera** (adults + larvae)*	Water bugs		✓	✓	✓	✓												
***Megaloptera** (larvae)*	Alderflies																	
Sialis lutaria				✓	✓							✓						
***Plecoptera** (larvae)*	Stone flies					✓												
Chloroperla torrentium				✓														
***Trichoptera** (larvae)*	Caddis flies	✓	✓	✓	✓	✓						✓						
Cheumatopsyche sp.					✓													
Hydropsyche sp.				✓	✓													
Limnephilus sp.	Sedge caddis			✓														
Rhyacophila spp.	Caddis fly larvae				✓													
***Zygoptera** (larvae)*	Damsel fly larvae				✓													
Enallagma sp.			✓		✓	✓												
ARTHROPODA: CRUSTACEA																		
ISOPODA	Isopods	✓				✓												
	Woodlouse		✓	✓														
Asellus aquaticus	Freshwater louse		✓															
Asellus meridianus	Freshwater louse		✓		✓													
Porcellio scaber				✓														

Latin Name	Common Name	Metals																
		Metals	Pb	Zn	Cu	Cd	Cr	As	Ni	Co	Mo	Fe	Se	Mn	Mg	Al	Ag	Bi
	Non-malacostracan crustacea		✓	✓	✓	✓												
Astacus sp.	Crayfish					✓												
MILLIPEDA																		
	Millipedes		✓															
ARTHROPODA: ARACHNIDA (Spiders etc.)																		
Clubionidae		✓	✓	✓	✓	✓												
ANNELIDA: OLIGOCHAETA																		
	Worms	✓										✓						
Lumbricidae	Earthworms		✓	✓	✓	✓		✓										
Allolobophora caliginosa	Earthworms			✓	✓					✓								
Dendrodrilus rubidus			✓	✓	✓	✓												
Limnodrilus hoffmeisteri					✓			✓										
Limnodrilus sp.				✓		✓	✓											
ANNELIDA: HIRUDINEA (Leeches)																		
Trocheta subviridis												✓						
PLATYHELMINTHES																		
	Flatworms		✓	✓	✓	✓												
Polycelis sp.												✓						

Summary of Tolerance to Low and High pH, Salinity, Fluoride, Boron, Waterlogging and Ammonia

		Contaminating Substance [1]						
Latin Name	**Common Name**	H^+	OH^-	Sal	F	B	H_20	NH_3
GRASSES								
Agrostis canina	Brown bent-grass	✓						
A. capillaris	Common bent-grass	✓		✓	✓			
A. setacea	Bristle leaved bent	✓						
A. gigantea	Common bent-grass		✓					
A. stolonifera	Creeping bent-grass		✓	✓	✓		✓	
Alopecurus pratensis	Meadow foxtail		✓					
Avenula pratensis	Meadow oat-grass		✓					
Brachypodium pinnatum	Torgrass		✓					
Briza media	Quaking grass		✓					
Cynodon dactylon	Bermuda grass			✓				
Dactylis glomerata	Cocksfoot	✓	✓	✓	✓			
Deschampsia caespitosa	Tufted hair-grass		✓				✓	
D. flexuosa	Wavy hair-grass	✓		✓				
Elymus farctus	Sand couch-grass			✓				
Festuca arundinacea	Tall fescue		✓					
F. ovina	Sheep's fescue	✓	✓					
F. pratensis	Meadow fescue		✓					
F. rubra	Red fescue		✓	✓	✓			

		Contaminating Substance [1]						
Latin Name	**Common Name**	H^+	OH^-	Sal	F	B	H_2O	NH_3
Heliototrichon pratense	Meadow oat-grass		✓					
Holcus lanatus	Yorkshire fog	✓		✓	✓			
Hordeum vulgare	Barley		✓					
Juncus articulatus	Jointed rush						✓	
Juncus spp.	Common rush						✓	
Leymus arenarius	Lyme grass			✓				
Lolium multiflorum	Italian rye-grass			✓				
L. perenne	Perennial rye-grass		✓	✓		✓		
Nardus stricta	Mat-grass	✓						
Phalaris arundinacea	Reed grass						✓	
Phragmites australis	Reed			✓			✓	
Poa pratensis	Meadowgrass			✓				
Puccinellia distans	Reflexed saltmarsh grass			✓				
P. Maritima	Common saltmarsh-grass			✓				
Typha latifolia	Reed mace						✓	
FORBS								
Achillea millefolium	Yarrow		✓					
A. ptarmica	Sneezewort		✓					
Allium ursinum	Ransoms		✓					
Angelica sylvestris	Wild angelica		✓					
Artemesia vulgaris	Mugwort			✓				

		Contaminating Substance [1]						
Latin Name	**Common Name**	**H^+**	**OH^-**	**Sal**	**F**	**B**	**H_20**	**NH_3**
Arum maculatum	Lords and ladies		✓					
Atriplex littoralis	Shore orache			✓				
A. patula	Common orache			✓				
A. prostrata	Hastate orache			✓				
Buxus sempevirens	Common box		✓					
Cakile maritima	Sea rocket			✓				
Calluna vulgaris	Ling	✓						
Caltha palustris	Marsh marigold						✓	
Carex flacca	Glaucous sedge		✓					
Carlina vulgaris	Carline thistle		✓					
Centaurium erythraea	Common centaury		✓					
C. nigra	Knapweed		✓					
Cerastium fontanum	Mouse-ear chickweed				✓			
Chamaenerion angustifolium	Rosebay willow herb			✓	✓			
Chenopodium album	Fat hen			✓				
Cichorium intybus	Chicory							✓
Cirsium arvense	Creeping thistle			✓				
Dactylorhiza fuchsii	Common spotted orchid		✓					
D. incarnata	Earlymarsh orchid		✓					
D. purpurella	Northern marsh orchid		✓					
Daphne laureola	Spurge laurel		✓					

		Contaminating Substance [1]						
Latin Name	**Common Name**	H^+	OH^-	Sal	F	B	H_20	NH_3
Daucus carota	Wild carrot							✓
Digitalis pururea	Foxglove	✓						
Erica cinerea	Bell heather	✓						
E. tetralix	Cross-leaved heather	✓						
Erigeron acer	Blue Fleabane		✓					
Eriophorum vaginatum	Cotton grass	✓						
Euphrasia nemorosa var. calcarea	Eyebright		✓					
Galium saxatile	Heath bedstraw	✓						
Gymnadenia conopsca	Fragrant orchid		✓					
Hieracium spp.	Hawkweed		✓					
Honkenya peploides	Sea sandwort			✓				
Hyacinthoides non-scripta	Blue bell	✓						
Hypericum perforatum	Perforate St John's Wort							✓
Jasione montana	Sheep's bit	✓						
Linum catharticum	Purging flax		✓					
Lotus corniculatus	Common birdsfoot trefoil	✓	✓	✓				
Luzula sylvatica	Great woodrush	✓						
Lycopodium inundatum	Marsh clubmoss	✓						
Medicago lupulina	Black medick			✓				
Melandrium album	Evening Campion		✓					
Melilotus alba	Ribbed melilot			✓		✓		

		Contaminating Substance [1]						
Latin Name	**Common Name**	**H^+**	**OH^-**	**Sal**	**F**	**B**	**H_20**	**NH_3**
Mercurialis perennis	Dog's mercury		✓					
Ophioglossum vulgatum	Adder's tongue		✓					
Orchis morio	Greenwinged orchid		✓					
Orobanche minor	Lesser broomrape		✓					
Pilosella officinalis	Mouse-ear hawkweed		✓					
Plantago lanceolata	Ribwort plantain			✓		✓		
Potentilla erecta	Upright cinquefoil	✓						
Poterium sanguisorba	Salad burnet		✓					
Ranunculus repens	Creeping buttercup				✓			
Rumex acetosa	Common sorrel				✓			
R. acetosella	Sheep's sorrel	✓		✓				
R. obtusifolius	Broad leaved dock			✓				
R. vulgaris	Groundsel			✓				
Senecio jacobaea	Ragwort		✓					
Sisyrinchium bermudiana	Blue-eyed grass		✓					
Sisymbrium altissimum	Tall rocket			✓				
Succisa pratensis	Devil's bit scabious		✓					
Thymus praecox	Wild thyme		✓					
Trifolium pratense	Red clover			✓				
T. repens	White clover	✓			✓			
Tsuga canadensis	Canadian hemlock					✓		

		Contaminating Substance [1]						
Latin Name	**Common Name**	**H^+**	**OH^-**	**Sal**	**F**	**B**	**H_20**	**NH_3**
Tussilago farfara	Colts foot		✓	✓	✓			
Ulex europaeus	Common gorse	✓						
Vaccinium myrtillus	Bilberry	✓						
V. vitus-idaea	Cowberry	✓						
Valeriana dioica	Marsh valerian						✓	
V. officinalis	Valerian		✓					
TREES/SHRUBS								
Acer platanoides	Norway maple							✓
Alnus glutinosa	Alder			✓			✓	
Betula pendula	Silver birch	✓						
Crataegus monogyna	Hawthorn		✓	✓				
Fraxinus excelsior	Ash		✓					
Genista anglica	Petty whin	✓						
Hedera helix	Ivy							✓
Hippophae rhamnoides	Sea buckthorn			✓				
Lupinus arboreus	Tree lupin	✓						
Picea abies	Norway spruce							✓
P. sitchensis	Sitka spruce					✓		
Populus alba	White poplar			✓				
Pteridium aquilinum	Bracken	✓						
Quercus robur	Pedunculate oak			✓				

		Contaminating Substance [1]						
Latin Name	**Common Name**	**H^+**	**OH^-**	**Sal**	**F**	**B**	**H_20**	**NH_3**
Rhododendron particum	Rhododendron	✓						
Rubus fruticosus	Bramble	✓		✓				
S. aurita	Eared willow	✓						
S. cinerea	Sallow	✓					✓	
S. fragilis							✓	
S. repens	Creeping willow		✓					
Salix spp.	Willow			✓				
Sambucus niger	Elder	✓		✓				
Sarothamnus scoparius	Broom	✓						
AMPHIBIA								
Triturus helveticus	Palmate newt	✓						
ARTHROPODA								
Arachnida								
Hygrobates fluviatilis		✓						
Insecta **Coleoptera (Beetles)**								
Limnius volckmari		✓						
Diptera								
Brillia modesta		✓						
Conchapelopia pallidula		✓						
Micropsectra sp		✓						
Rheocricotopus foveatus		✓						

		Contaminating Substance [1]						
Latin Name	**Common Name**	**H^+**	**OH^-**	**Sal**	**F**	**B**	**H_20**	**NH_3**
Tanytarsus sp.		✓						
Prodiamesa olivacea		✓						
Simulium ornatum		✓						
Tabanus spp.		✓						
Bezzia palpomyia gp.		✓						
Ephemeroptera (Mayflies)								
Baetis rhodani		✓						
Trichoptera (Caddis flies)								
Hydropsyche pellucidula		✓						
Plectrocnemia conspersa		✓						
Rhyacophila dorsalis		✓						
Plecoptera (Stone flies)								
Leuctra hippopus		✓						
Amphinemura sulcicollis		✓						
Protonemura praecox		✓						
Heteroptera (True bugs)								
Corixidae		✓						
Megaloptera (Alder flies)								
Sialis sp.		✓						
OLIGOCHAETA (Worms)								
Limnodrilus hoffmeisteri		✓						

		Contaminating Substance [1]						
Latin Name	**Common Name**	**H^+**	**OH^-**	**Sal**	**F**	**B**	**H_20**	**NH_3**
Lumbricus rubellus		✓						
L. rivalis		✓						
Eiseniella tetraedra		✓						
Nais elingius		✓						
N. alpinia		✓						

1 **Key:**

H^+	Low pH	B	Boron
OH^-	High pH	H_2O	Waterlogging
Sal	Salinity	NH_3	Ammonia
F	Fluoride		

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