BACKGROUND LEVELS OF URBAN LAND CONTAMINATION

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A thesis submitted in partial fulfillment
of the degree of

DOCTOR OF PHILOSOPHY

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The University of Aston in Birmingham.

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SUMMARY

The research work reported in this thesis is concerned with the development and application of an urban scale sampling methodology for measuring and assessing background levels of heavy metal soil contamination in large and varied urban areas. The policy context of the work is broadly the environmental health problems posed by contaminated land and their implications for urban development planning. Within this wider policy context, the emphasis in the research has been placed on issues, related to the determination and application of 'guidelines' for assessing the significance of contaminated land for environmental planning.

In concentrating on background levels of land contamination, the research responds to the need for additional techniques which address both the problems of measuring soil contamination at the urban scale and which are also capable of providing detailed information for use in the assessment of contaminated sites. Therefore, a key component of the work has been the development of a land-use based sampling framework for generating spatially comprehensive data on heavy metals in soil. The utility of the information output of the sampling method is demonstrated in two alternative ways. Firstly, it has been used to map the existing pattern of typical levels of heavy metals in urban soils. Secondly, it can be used to generate both generalised data in the form of 'reference levels' from which the overall significance of background contamination may be assessed and detailed data, termed 'normal limit levels' for use in the assessment of site specific investigation data.

The fieldwork was conducted in the West Midlands Metropolitan County and surface soil has been sampled and analysed for a measure of plant-available' and 'total'lead cadmium, copper and zinc. The research contrasts with much of the previous work on contaminated land which has generally concentrated on either the detailed investigation of individual sites suspected of being contaminated or the appraisal of land contamination resulting from specific point sources.

environmental planning, contaminated land, heavy metals, mapping

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CHAPTER 1

1.0 A GENERAL REVIEW OF THE RESEARCH AREA

1.1 Introduction

The research work reported in this thesis is concerned with the development and application of an urban scale mapping methodology for measuring and assessing background levels of heavy metal soil contamination. The function of this chapter is to present and discuss the research area within which the research work has been undertaken and to identify key problems for research and policy in general. In so doing, it offers a research agenda to which this research work responds. This is followed by a summary of the problems which are to be addressed by the research. The chapter also sets out, in brief, the objectives of the research, the major methodological issues and the structure of the thesis.

1.2 Contaminated Land - the Research Area

1.2.1 Contaminated land, as a general issue, has been defined (Department of the Environment, 1981) as:

> "Land which may be hazardous to man, the environment or to some other target such as the materials of construction, due to the presence of toxic substances, combustibles, corrosive acids, or explosive and asphixiant gases".

1.2.2 There is potentially a wide range of hazards which may result from contaminated land, including the presence of highly corrosive acids, toxic and flammable gases, high concentrations of toxic and phytotoxic heavy metals such as lead, cadmium, zinc and nickel, and dangerous substances such as cyanides, phenols and certain hydrocarbons. The nature and extent of the hazard depends largely on the individual source of contamination and proximity to polluting activities. For example, landfill sites, a common contaminated land problem, used for the disposal of toxic wastes, will inevitably contain a wide range of toxic and dangerous substances. At the other end of the scale, garden soils may contain elevated levels of lead due to flaking of lead based paints, vehicle emissions or the burning of domestic refuse (see studies by JURUE, 1981; Davies, 1978, Harrison,1979).

1.2.3 The actual problems presented by contamination of the land are seen largely as the hazards and risks contamination may present to users or occupiers. This 'risk' is made up of a number of components including who, or what is exposed to a particular level of contamination and for how long. From a public health point of view, the hazards presented by contaminated land may be either short term, such as the problems of exposure of construction workers to aggressive chemicals or toxic and flammable gases, or long term, those stemming from the uptake of heavy metals by food crops grown on contaminated land. In the case of plant health, there may also be short term problems of establishing vegetation cover on contaminated land due to the presence of heavy metals, some of which are phytotoxic and completely inhibit plant growth (see Bradshaw, 1980).

1.2.4 Land becomes contaminated predominantly as the result of man's activities. The sources of such contamination have been discussed at length elsewhere (see for example Society of Chemical Industry, 1980; Smith, 1980; Haines, 1981; Harwell, 1981). However, typical examples include: metal mining operations; scrap yards; waste disposal sites; sacrificial land used for sludge disposal; and accidents such as that which occurred at Seveso in Italy. A further source of contamination is the deposition of airborne pollution as in the vicinity of primary and secondary metal working, from refuse incinerators and traffic sources. Garden soils in older residential areas may also become contaminated due to the flaking of lead paint. Secondary dispersal of waste by wind and water can lead to the widespread contamination of surrounding land. Examples of land which has been found to be contaminated include: town gas manufacturing sites;

land-fill sites; agricultural land overdosed with sewage sludge containing toxic metals, and railway land. The above examples are by no means exhaustive but they do serve to illustrate that contaminated land can be broadly divided into two main categories. Firstly, there is the localised, usually severe contamination of individual sites, and includes contamination from town gas works and the disposal of toxic wastes. The second category covers the usually less severe background contamination and includes that resulting from the elevated ambient concentrations of metals present in the urban environment due to traffic sources or secondary fume emission from smelters.

1.2.5 In recent years, attention has been focussed on the hazards of contaminated land as a result of a number of serious pollution incidents on specific sites. Foremost amongst these are the well known cases of chemical land-fill sites of 'Love Canal' in the U.S.A., 'Lekkerkirk' in Holland and 'Malkins Bank' and 'Ravenfield' in Britain. All four cases have presented considerable environmental problems due to the presence of large quantities of dangerous and in some cases, unidentified chemical wastes. Examples of other contaminated land problems which have received attention are those where contamination of the land was discovered only after redevelopment had started and include Beaumont Leys in Leicestershire and Thamesmead, London. The Beaumont Leys site, a former sewage farm, covers a total of 800 hectares, the majority of which had been subjected to sewage sludge disposal and effluent irrigation for over 70 years. In 1976 the site was to be redeveloped for residential and recreational use and a sub-regional shopping centre. Preliminary investigation revealed that the site was contaminated with toxic heavy metals, including arsenic, lead and cadmium, with a cadmium level in places of over 60 mg/kg. Before development could proceed, it was necessary to carry out extensive and costly ameliorative treatment, including removal of the more highly contaminated material.

1.2.6 The Greater London Council's Thamesmead development in part occupies the site of the former 'Woolwich Arsenal'. The development covers approximately 650 hectares, of which 250 hectares had been progressively and extensively developed for munition production. The 'Arsenal' was self supporting in every term, producing its own town gas, steam and electricity, the wastes from these plants being deposited widely across the site to a depth of several metres. In the 1960's the Thamesmead area was scheduled for redevelopment into a town for 60,000 people. After development had started, contamination soon became apparent during excavations. The 'Arsenal' area was found to be contaminated with asbestos, spent oxide and cyanide, and in places the ground was saturated in phenolic liquids. There was also the added problem of spontaneous combustion of waste material buried at depth. Development was halted and an extensive ameliorative programme has had to be undertaken, including the removal and disposal of several thousand cubic metres of 'contaminated soil'. Even today, there is still a large mound on the Arsenal, composed almost entirely of ash, industrial residues and gas works waste which has yet to be investigated fully.

1.3 Agenda for Research and Policy

1.3.1 The above brief synopsis of the research area of contaminated land suggests that large areas of former industrial land, and land close to industrial point source emissions may be contaminated. This poses problems for research and policy in two main areas:

i) in relation to contamination as a source of environmental pollution that can have general public health implications.

ii) and planning and policy issues related to the control over land contamination and the problems of redeveloping contaminated land.

With regard to this general context, there are a number of important issues to which the research community in general should respond and which require policy reponses from both central and local government. These are discussed below.

1.3.2 Environmental and Public Health Related Policy Issues.

The introduction to the origins, nature and problems posed by contaminated land in section 1.2 suggests that there are a wide variety of forms in which contamination may occur, and there are a great variety of targets that may be at risk from the presence of unacceptable levels of toxic elements. However, the environmental and public health risks associated with the presence of contaminated land, can be summarised as follows:

i) hazardous materials may be re-suspended in the air as dust and distributed over large areas, affecting the general population through inhalation.

ii) contamination in the soil may relocate into food and affect health either directly through the consumption of crops grown on contaminated soil or indirectly via animals and animal products.

iii) the contamination level may be sufficiently high to present a direct hazard to children displaying 'pica' or to the population generally through skin absorption.

iv) presence of contamination may inhibit plant growth thus creating a barren and bare landscape as is the case with mine-spoil waste dumps.

1.3.3 Land-related Policy Issues

In terms of the land-related policy issues, the problem is essentially a threefold one. There are the 'general' problems of control over contaminated land and the prevention of further land contamination. The second problem is one of 'background' contamination of land which has accumulated over a long period of time. The third problem is one of the redevelopment and re-use of potentially contaminated sites.

1.3.4 Control over Contaminated Land

In Britain, until very recently, there was no specific legilsation to control or prevent the contamination of land, even with regard to the case of disposal of contaminated waste to land. Indeed, it has only been within the last decade that contaminated land has been recognised as a serious environmental problem. There are only general procedures for control of land contamination, such as those provided by town planning legislation and the nuisance provisions of the Public Health Acts (1939, 1969). Moreover, these are generally weak and lack specific statutory provisions to prevent land contamination. The result of this long history of lack of control is that large areas, particularly in or in close proximity to industrial centres may be contaminated,and the full extent of the problem of contaminated land remains unquantified.

In addition, the problem of land contamination has been further compounded through a succession of Alkali Acts, Clean Air Acts, Water Acts and Public Health Acts, which have resulted in a progressive and stricter control over the discharges of pollutants to air and water. The result of these stricter controls is the diversion of emissions and wastes away from air and water to the land, in the form of landfilling of wastes. It is only in the field of waste disposal, with the introduction of the Deposit of Poisonous Waste Act (1972) and Control of Pollution Act (1974) that specific legislative control over land contamination is exercised. Even with the control, there remains the question of land contamination through what is effectively the storage of contaminated waste on land.

1.3.5 Background Contamination

The sources of land contamination, the environmental and public health problems associated with contaminated land, and the problems of control over land contamination, are common to both 'background' contaminated land and the re-use of contaminated 'sites'. The distinction is, however, a necessary one because in the case of background contamination the main concern relates to general problems of exposure to toxic elements - the so called long term, low dose exposure problem. Whereas the re-use of contaminated sites often involves a change of use which introduces the possibility of high dose, short and long term exposure problems to toxic elements.

The term 'background',referred to above, is taken to be ambient levels of contamination which are measurable at any point of area, and which are usually not identifiable with any particular source. It is, therefore, an expression to indicate local gradients and variation in contaminated land over large areas. Background contamination is an important and complex issue for three main reasons. Firstly, it is widespread contamination present in the environment predominantly at low levels, but to which there is a high degree of public exposure. Secondly, the environmental health problems associated with exposure to toxic elements may only be detected after a number of years due to low dose and slow accumulation rates of contaminants. Thirdly, since background contamination is a result of a wide range of sources (ranging from secondary fume emission and traffic to the use of lead based paints), the problem may become more acute in the long term, because there are no obvious point source emissions to control.

The problem is further complicated by the fact that to date, there is very little accurate data on background levels of contamination in urban areas. This lack of data has resulted in background contamination rarely being considered as a significant problem to which control agencies may respond, and therefore it remains as a continuing problem.

1.3.6 Re-use of Contaminated Land.

The problem of re-using and redeveloping contaminated land is a recent policy issue, due mainly to the discovery of severe contamination on sites after redevelopment has started. In the last five years central government, with the establishment of the Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL) and, to a lesser extent, local government, have come to realise that large parts of our towns and cities may be contaminated with toxic elements, through man's activities. The problem is more acute in the traditional industrial centres where structural industrial change is taking place and where there are increasing pressures to revitalise many of the older urban centres through redevelopment. Examples of such changes include the 'streamlining' of the iron and steel industry in the 1970's, and the change from town gas to natural gas in the 1960's. The consequences of these changes, is the existence of a large number of disused sites awaiting re-use. The classic example is the estimated (Harwell, 1981) 1,000 former town gas manufacturing sites, located close to city centres, which have been found to be severely contaminated (Harwell, 1981; Dean and Goalby, 1980; Wilson and Hudson, 1980).

1.3.7 As indicated earlier, the problem of contaminated sites is made more acute due to increasing pressures to redevelop such sites in an effort to regenerate the older inner city areas. Pressures to re-use contaminated sites arise from a number of factors, and these may be summarised as:

i) their location within the urban area means that they are often viewed as prime development sites. They may have the advantages of infrastructure services.

ii) for social reasons, the existence of disused land is often seen as a blight on the landscape.

iii) specific central and local government policies such as the 'inner city policy' and environmental improvement policies are geared to regenerating and improving inner city areas.

iv) pressure from the Ministry of Agriculture to minimise the use of agricultural land for development. In many cases, the only alternative 'available' land for development are former industrial sites.

v) pollution prevention to remove a source of unacceptable pollution and risk to public health on water courses.

1.3.8 <u>Key Research and Policy Issues</u>

The preceding discussion has demonstrated that both contaminated land in general and the re-use of contaminated sites, presents a number of significant problems for central government and local planning, and environmental control agencies. The main problems relate to assessing the significance of the environmental and public health problems presented by contaminated land. This in turn raises the question as to whether the scale and extent of contaminated land is significant enough to justify a policy response to control development in such circumstances. There is also the issue of the prevention of further land contamination. It is suggested by central government (Kenny, 1980) that the system of controls over industrial activity, through legislation controlling emissions to the atmosphere and water, and now over waste disposal, are rigorous enough to minimise the risk of further land contamination. Recent research (JURUE, 1981, 1982) indicates that this is unlikely to be the case while water authorities still adopt a policy of the disposal of metal contaminated sewage sludge to sacrificial land, and the fact that many point source emissions are still not adequately controlled.

1.3.9 It is evident from the above, and from preceding sections in this chapter, that there are a number of key research and policy issues related to contaminated land, to which the research community in general should respond. These may be set out in brief as research needs:

i) need to obtain further, detailed information on the extent and nature of contaminated land in general.

ii) to identify potentially contaminated sites in advance of development proposals.

iii) to determine the nature and extent of contaminated land problems as it affects both environmental and public health.

iv) produce guidance in the form of standards and guidelines, for the assessment of the significance of the environmental and public health problems presented by contaminated land.

v) to determine whether there is a need for further policy to control land contamination.

vi) to develop appropriate remedial, ameliorative and protective measures, particularly in relation to the redevelopment of specific contaminated sites.

1.4 Contaminated Land-the Research Problem

1.4.1 The above provides a summary of the research agenda which forms the context within which the work reported here is undertaken. Clearly, the wide variety of forms in which contamination of the land may occur, as demonstrated in section 1.2, and the variety of potential health hazards presented by, and targets affected by contamination, means that it is impossible, within the scope of a single research project, to tackle in sufficient depth all of the above issues. Therefore, there is a need to 'prioritise' these issues to identify a research problem to which this research work can respond.

1.4.2 The value of extensive research conerned with the development of ameliorative and protective treatment measures for contaminated land is clearly contingent upon demonstrating that the scale and extent of contamination is a significant problem and that the presence of contaminants on land is an unacceptable risk to environmental and public health. The question as to whether there is a need for further policy to control land contamination can only be determined by demonstrating that contaminated land is a growing problem, which in turn requires two inputs of information. Firstly, surveillance work to establish the extent of the problem, and secondly, monitoring to detect trends in the scale of land contamination.

1.4.3 It is evident from the above, that the research problem can be reduced to two key, parallel issues; to obtain further information on the scale and extent of contaminated land; and to demonstrate that the land contamination and the presence of elevated levels of toxic elements is an environmental and public health problem. This latter policy issue is being addressed directly by central government through the ICRCL, and is discussed further in Chapter 2, which concentrates on the determination and application of acceptable levels of individual contaminants on land. Therefore, within the framework of this research, the issue is limited to 'background contamination' of the land, which is present as a result of man's activities and which renders it actually or potentially harmful to human health or public health, or both. Within the context of this definition, the research work concentrates on measuring and mapping background levels of heavy metal land contamination in urban areas. This is because heavy metals are associated with a wide variety of urban sources including: emissions from metal producing and utilising industries; land disposal of metal contaminated sewage sludge; and elevated ambient concentrations due to traffic and the burning of fossil fuels. Therefore, there is widespread occurrence of elevated levels in the general environment.

1.4.4 Moreover, when heavy metals enter the environment through man's activities, they follow normal biogeochemical cycles, being transported by air, water, and gravity until they reach a geochemical sink. Land is an important sink and heavy metals have been shown to accumulate rapidly in soil. This problem is further compounded by the fact that once in the soil, heavy metals are depleted very slowly and therefore can remain at high levels for long time periods. The implication of the above is that the problem of heavy metal contaminated land is potentially widespread, and as such is a key component of the research and policy questions in this field.

1.4.5 The presence of both high concentrations and slightly elevated levels of heavy metals in the ambient environment has been shown to cause adverse effects on human health. For example, long term exposure to high levels of cadmium has been shown to cause cadiovascular diseases and renal damage and 'Itai-Itai' disease in Japan (Friberg et al, 1974). In the case of lead, exposure to high levels has been linked to brain damage, behavioural disorders and death. In recent years, the 'Lead and Health' debate has focussed attention on the potential adverse effects on health from low level exposure to lead in the environment. The major issue here is the link between certain neurological, intellectual and behavioural problems, particularly in young children (see for example, Barltrop, 1975, 1979; DHSS, 1980; Conservation Society, 1978), and exposure to slightly elevated levels of lead.

1.4.6 Information on background levels is also required as a pre-requisite to epidermiological studies which may be used to assess the significance to health of heavy metal contaminated land. In addition, central government's present approach (discussed in detail in Chapter 2) to developing standards and guidelines for contamination when contaminated sites are being considered for re-use, is based on the principle that conditions should not be significantly more hazardous than usual or normal. Clearly, such a principle requires that detailed information on typically occurring 'background' levels of contamination is available.

1.4.7 The general aim of this research work, therefore, is to measure and map background levels of heavy metal land contamination. More specifically, the objectives to which the research work responds are:

i) the need to demonstrate the scale and spatial variation of heavy metal contaminated land.

ii) the need to provide sufficiently detailed information on soil heavy metal levels in urban areas to enable the existing pattern of land contamination to be mapped and used to identify 'hot spots' or 'stress areas'.

iii) need for information on naturally occurring background levels in urban areas to provide baseline environmental information against which elevated levels may be assessed.

iv) need for information on background levels of heavy metals in urban soil to assist in the long term development of environmental and health protection standards.

v) the need to provide sufficiently detailed information on the spatial variation of heavy metals in urban soils to enable typical 'background levels' of heavy metal soil contamination to be established.

1.4.8 There are also methodological issues to which this research responds. The key issue is the fact that heavy metals in urban soils have been shown to exhibit high spatial variability. Therefore, there is a need in the research to reconcile the conflicting requirements of extended spatial coverage, versus a high density spatial sampling, to achieve reliable measures of background levels. The problem is further compounded by the fact that there have been very few systematic surveys of soil heavy metal contamination in urban areas and consequently there is a need in this research to develop a systematic sampling methodology to enable background levels of heavy metals to be measured and mapped.

1.5 Structure of the Thesis

Chapter 2 develops further the policy context of the research, specifically the determination and application of acceptable concentrations of heavy metals in soils. This is followed in Chapter 3 by a detailed and critical review of the adequacy of past approaches to mapping soil heavy metal levels. Chapter 4 reports the development of a mapping methodology which will allow for the measurement and representation of background levels of heavy metal soil contamination. In Chapter 5, the results of applying the mapping methodology in a case study area are presented and discussed. Chapter 6 contains an assessment of the significance of the results through comparison with published guidelines. This is followed by the generation of 'reference levels' and 'normal limit levels' from the information output of the sampling methodology. The final chapter examines the contribution this research study has made to the wider research and policy issues of contaminated land.

CHAPTER 2

2.0 STANDARDS AND GUIDELINES - A REVIEW OF EXISTING LIMITS FOR HEAVY METALS ON THE LAND

2.1 Introduction

The broad aim of this chapter of the research study is to review existing and proposed standards and guidelines for heavy metals in soils. The derivation of such limits, their usefulness (in terms of defining acceptable concentrations for general environmental health purposes) is also discussed. The chapter concludes with a discussion on the potential role of 'reference levels' (background levels in typical urban areas) as opposed to blanket standards in defining acceptable concentrations of selected heavy metals which would ensure a protection of public health.

2.1.1 Attempts at producing satisfactory standards or guidelines for heavy metal concentration in soils is very much a recent phenomena. The standards and guidelines, that have been produced to date, have been primarily concerned with the protection of animal and plant health from overdosing agricultural soils with contaminated sewage sludge. More recently, with constraints on new developments at the urban fringe and increasing pressure to develop former industrial land, the inter-departmental Committee on the Redevelopment of Contaminated Land (ICRCL) have been preparing tentative guidelines for toxic elements, including heavy metals for the protection of public health.

2.1.2 It is demonstrated that these present approaches to the setting of standards or guidelines for heavy metals in soils are beset with difficulties. In particular, there are increasing problems in interpreting results of site investigation in the light of proposed guidelines due mainly to the lack of knowledge on the toxicological effects of heavy metals in soils and gaps in knowledge in defining concentrations of heavy metals in which could then be translated into safe application rates for metal contaminated sludge. The guidance comes in the form of the Ministry of Agriculture Fisheries and Food's Advisory Paper (ADAS 10) which was produced in 1971, and concentrated upon defining safe application rates of sludge containing zinc, copper, nickel and boron. It was this advisory paper which first introduced the concept of a zinc equivalent which was based upon past experiments and the advisory work of ADAS. Experience at ADAS suggests that copper is twice, and nickel is eight times, as toxic as the same amount of zinc to plant growth. It was recommended that where zinc, copper and nickel are present in the sludges, the use of the zinc equivalent be adopted in interpreting permissible additions of metals to soil. Table 1 summarises the conclusions of this advisory paper. The values in the table are derived from experiments undertaken by ADAS, which suggested that it is permissible to add to the soil or zinc equivalent amounting to 250 ppm.

TABLE 2.1

MAXIMUM ZINC EQUIVALENT (ppm) IN SEWAGE DRY MATTER, FOR SAFE USE

Proposed frequency of use	Proposed rate of application (ton/ac dry matter)					
	5	10	20	30	40	50
Every year	1,510	750	370	250	190	150
One year in two	3,020	1,510	750	500	380	300
One year in three	4,530	2,260	1,110	750	570	450
One year in four	6,040	3,020	1,510	1,010	750	600
One year in five	7,550	3,770	1,880	1,260	940	750

Example:

A batch of sludge with a zinc equivalent of 1,400 ppm in the dry matter:

a. could be used safely at 20 ton/ac of DM one year in four (the figure is below the maximum permissible);

b. could not be used safely at 30 ton/ac of DM one year in five (the figure is above the maximum permissible).

Note - it is assumed that the soil pH is about 6.5

- it assumes that there are 2,000,000 lbs. top soil per acre.

soils at which a health effect on hazard can be detected. Therefore it is suggested that it is more appropriate, in the short term, to turn our attention to describing existing 'normal' levels in soils in urban areas, and then to use or adapt these as criteria in assessing whether or not a particular set of levels of heavy metals, from a site investigation for example, are anomalous or not.

2.2 Guidelines and Sewage Sludge to Land

2.2.1 The earliest attempts at producing standards or guidelines for heavy metals in soil stems from the increasing interest in disposing of sewage sludge to land. The report of the Working Party on sewage disposal (Jeger Report 1970) estimated that about 80% of the sludge from all inland treatment works was disposed of to land, about half of this being applied to productive land (agricultural and horticultural land). The report endorsed such practices with the premise that it did not lead to nuisance or a danger to human health. The possible hazard stems from the fact that many treatment works receive industrial effluents which often contain high concentrations of toxic elements (heavy metals, surfactants, phenols, herbicides and pcb's). These industrial effluents often lead to a contamination of the sewage sludge produced at treatment works, thereby creating a potential pollution hazard if such sludge is disposed of to land. *1.

2.2.2 The first quantitative guidance on sludge disposal to land recognised that sludges contained toxic elements and set about, initially for heavy metals, the task of defining acceptable, 'tolerable' levels in agricultural land

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*1. Currently 29% of sludge disposed in the U.K. goes to sea routes, 67% to land and the rest via incineration. (Water Research Centre, 1981). In Europe it has been estimated (New Scientist 1982) that approximately 130 tonnes of Cadmium alone are deposited on farmland in sewage sludge each year.

The guidance set out in ADAS 10 assumes there has been no previous contamination of the soil. If this is the case, then the levels present for zinc, copper and cadmium should be substracted from the permissible amount and the remainder is the maximum safe application rate

2.2.3 Such guidance is restricted to agricultural and horticultural land since it was based on an assessment of 'plant available' metals, which would have a phytotoxic effect on plant and crop growth. These permissible safe application rates were subsequently incorporated into and added to by the Working Party on the Disposal of Sewage Sludge to Land, (see DOE/MWC 1977). This Working Party was established in 1974 to review the need to dispose of sludge to land and, more importantly, to ascertain the consequential effects of the land disposal of various sludges on the soil, crops, public health and the environment, both in the short and long term. The main recommendations to come from the Working Party was the production of guideline limits for a range of major toxic elements (including heavy metals) found in sewage sludge to be applied to land over a 30 year period. Table 2.2 summarises these recommendations.

TABLE 2.2

GUIDELINES FOR THE DISPOSAL OF
SEWAGE SLUDGE TO LAND

Element	Normal Range Soils	(mg/kg.d.s.) Liquid Digested Sludge	Recommended Limit of Addition in Sludge (Kg/ha)d.s.*	Implied ** Maximum Content for Arable Soils (Mg/Kg).d.s.
Zn	10-300	1500-3000	560	550
Cu	2-100	600-800	280	230
Ni	5-500	50-80	70	22
Cr	5-500	100-400	1000	955
Cd	0.1-1.0	5-50	5	3.3
Pb	2-200	200-700	1000	655
Hg	0.01-0.3	3-5	2	1.2
Mo	2	5	5	4.3
As	0.1-40	7.5	10	44.6
Se	0.2-0.5	5	5	2.8

* d.s. - Dry Soil

** Interpreted from recommended limit of addition in sludge using fact that 1 h a. of soil, 200mm deep, has approximately 2,200,00Kg of dry solids - add this permitted addition to upper limit of the 'normal range' in soils.

Source: Adapted from DoE/N.W.C. (1977).

As can be seen from table 2.2, implicit in the recommended limits of addition of metals in sludges is an upper limit of acceptable total heavy metal content for soil. This is obtained by adding the permitted addition (over a 30 year period) to the upper limit of the 'normal range' in soils *2 and is shown in the last column of table 2. The role of these recommended 'limits of addition' are to allow contaminated sludges to be disposed of to land, over a long time period, but that in total, the levels of contaminants in the soil are not enhanced to any great extent.

2.2.4 The potential usefulness of these guidelines, outside of agricultural and horticultural purposes, is limited especially if such guidelines were adopted for use as criteria to judge whether or not an industrially contaminated site is suitable for sensitive development (e.g. residential or amenity purposes). The limitations result from the fact that a number of soil factors can affect the behaviour (and hence availability) of metals in soils, in relatio n to their uptake by crops. For example, the availability of metals in soil has been shown to be dependent upon redox potential, certain exchange capacity and the content of organic matter. It has been established (Berrow, 1977; Williams, 1977) that soils with a higher cation exchange capacity absorb and fix greater amounts of heavy metals reducing their availability to crops. In addition a high organic matter content reduces the availability of metals to crops. Further, the recommended additions of metals to soil in sewage sludge, and hence implied maximum levels of metals allowable in agricultural soils, is based on the assumption that the ph of the soil will be maintained at 6.5 for arable land and 6.0 for

*2 based on agricultural/rural soils - urban soils often contain significantly higher amounts.

grassland. Whilst pH may be reasonably controlled in agricultural and horticultural situations, pH maintenance cannot be guaranteed in other situations, (i.e. on industrially contaminated land). It is known, for example, that under certain environmental conditions (e.g. acid rainfall in urban areas) soils become more acidic.*3.This is an important consideration since it has been demonstrated (M.A.F.F. Bulletin 20) that soil pH can affect the availability and thus phytotoxicity of metals. In general, the uptake of metals from soils by plants and crops increases as soil acidity increases, with the exception of selenium and hexavalent chromium whose uptake increases with increasing alkalinity. Therefore it is important to maintain soil pH at the suggested levels for agriculture in order to reduce the likelihood of a greater amount of a particular metal being taken up by plants and crops.

2.2.5 Purves (1979) also takes issue with these guidelines on permitted additions and implied safe maximum limits of heavy metals in soils. Purves considers the values to be too high and that they are based upon a limited knowledge of heavy metal uptake by plants. In order to preserve soil fertility and reduce the potential environmental risks associated with heavy metals in soils, Purves suggests that the total amount of heavy metals in all soils should be kept to a minimum. Purves adopts a different concept for standards, in that he proposes to define maximum tolerable levels of potentially toxic trace metals in soils. These would take account of a number of factors including the relative ease with which each element is taken up by plants from contaminated soil and the fact that some elements are much more toxic to plants, crops or animals than others. This is illustrated by evidence from the Edinburgh School of Agriculture that copper, lead and mercury are not readily taken up by plants from contaminated soil, whilst cadmium and zinc readily enter crops. Other elements such as arsenic, cadmium, mercury, lead and

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*3 In the present research, the pH of soils tests for heavy metals varied between 3.7 and 8.7, see table F.1.appendix F).

selenium, have been shown to be highly toxic, at elevated levels, to animals. Therefore, in arriving at an assessment of the maximum metal addition which should be tolerated, and thus acceptable levels of heavy metal in soils, Purves considers that it is necessary to consider these toxicity properties in addition to their typical background levels in uncontaminated soil.

Purves places the potentially toxic trace metals in 3 categories according to their potential for producing toxicity problems. Table 2.3 illustrates this approach.

Table 2.3 Maximum tolerable additions of potentially toxic metals to soil.

Element	Times Typical Background Level
As, Cd, Mo, Ni, Cr, Pb,	1
Hg, Se, Zn,	2
Cu	3

The maximum tolerable concentration of each element in the soil is obtained by adding the maximum tolerable addition (from table 2.3) to the typical background level in uncontaminated soil (see table 2.4).

Table 2.4 Maximum Tolerable Concentrations of Selected Elements in Soil

Element	Typical Concentration in soil (Kg/ha) *4	Maximum Tolerable addition (Kg/ha)	Maximum Tolerable concentration in soil (Kg/ha)
As	15	15	30
Cd	1.5	1.5	3.0
Mo	2.5	2.5	5.0
Ni	100	100	200
Cr	250	500	750
Pb	75	150	225
Hg	0.25	0.5	0.75
Se	1	2	3
Zn	125	250	375
Cu	50	150	200

*4 Based upon assumption that this level is present in top 200mm - see table 2 for explanation of relationship between kg/ha and Mg/Kg.

2.2.6 The interpretation of results in the light of this 'maximum tolerable additions concept' is that when the content of any individual metal in the soil is found to exceed the maximum tolerable level, the land is regarded as contaminated and unsuitable for sludge application or 'other' uses. The underlying principle behind this concept is the need to; restrict the use of heavily contaminated sludges on land used for food production; reduce the burden of metal contamination in sewage sludge; and to persuade industry to reduce the levels of toxic heavy metals in trade effluents discharged to sewers. It is difficult to justify the application of such a concept to defining acceptable levels of heavy metals in urban soils (and standards with regard to redeveloping contaminated land) primarily because 'guideline levels' are based upon a situation where careful control and maintenance of the land will be on-going.

2.3 Guidelines Developed Specifically in Relation to Industrially Contaminated Urban Soil.

2.3.1 The preceding sections have briefly summarised the attempts at defining acceptable concentrations of heavy metals in soils in relation to agriculture or horticulture. These are essentially 'limits' or 'upper guideline values' which indicate levels of heavy metals above which it is considered unacceptable that a contaminant should be present. The next major attempt at producing guidelines or standards for heavy metals in soils stems from the problem facing many local authorities needing to develop areas of land which may have become contaminated by controlled or uncontrolled industrial use, waste disposal, etc. In recent years local authorities and developers have had to look more and more to areas of land which have been previously used by all types of industry, to supply their needs in respect of development land for housing, schools, public open space and amenity areas. It has only been recognised in the last decade that such sites may present possible health and safety hazards to potential users and occupiers if no regard is taken of the contamination. The Scientific Branch of the Greater London Council (G.L.C.) (see Chapman et al 1976) from their direct involvement with development on industrially contaminated land, very quickly came across a need for guidelines or standards for contaminants in soils, which could be used as a basis for interpreting the results of their site investigations. In the absence of published standards or guidelines, and the fact that the standards that already exist are only relevant for agricultural land and were not readily applicable in the context of urban contaminated land development, a decision was made by the G.L.C. to draw up their own set of guidelines. The approach, which is discussed by Chapman, (1976) and Kelly (1979), has been to define 'undesirable' levels which indicate pollution being present and consequently indicates a need for further investigation of a particular site. The need for guidelines is in response to the fact that if site investigation and analytical work is to have any meaning, some levels must be decided, above which the site conditions must be regarded as being unacceptable from an environmental viewpoint.

2.3.2 Chapman (1976), in drawing up the first set of guidelines for the G.L.C., considered that a wider range of environmental hazards than that presented by heavy metals, should be guarded against and therefore included the following problems:

i) physical - explosions, subsidence
ii) inhalation - contaminated dusts and toxic gases
iii) direct ingestion - contamination of food grown on contaminated land
iv) indirect ingestion - uptake of contaminant by edible plants
v) contact - skin irritation

The above 'risks' were identified from the G.L.C's direct involvement in developing a wide range of contaminated sites including sewage works, coalyards, river-side wharves, gasworks sites and railway land. The guidelines that were initially produced focussed attention on the problems of hazards resulting from direct and indirect ingestion of soil and dust and toxicity to plants from soils which may be contaminated by heavy metals. Table 2.5 summarises the first guidelines developed by the G.L.C. They have been primarily derived from 'judgements' as to levels which may give rise to a known effect.

Table 2.5 Tentative guidelines for suspicion of toxicity.

Contaminant	For residential population (ppm) in soil
As	40
Cd	1
Cu (EDTA av.)	100
Pb	200
Hg	1
Ni (acetic acid av.)	20
Zn " " "	200
Zinc equivalent	250

Chapman emphasises that these are tentative suggestions against which the results from site investigations for a particular site may be compared. In the application of such 'tentative guidelines' Chapman suggests that if all samples, taken from a representative grid sample, are below guideline values, then the indication is no hazards or risks are likely to arise. Very important is the fact that Chapman stresses the point that the converse of the above statement on interpretation is not necessarily true.

2.3.3 Kelly (1979) has added to the work of Chapman from the recent experiences of the G.L.C. in dealing with a wider range of land contamination problems and in the practical use of the earlier guidelines. An important addition to the proposals put forward by Chapman was the establishment of 'typical values' for heavy metals obtained in the analysis of 'uncontaminated' London soils as a basis for considering undesirable levels in urban soils. In addition, Kelly updates the technical basis of the approach adopted by Chapman in 1976. This was achieved by considering the range of values for each contaminant against the risk that contaminant presents to health and the environment. An example of this additional principle is that of cadmium which is considered critical to health with regard to its uptake by plants and crops, whilst for lead, the health risk would be from direct ingestion or inhalation. This principle is in agreement with the work of Purves (1979) (see section 2.2.3) on the toxic effects of heavy metals to plants and animals. Other principles which have been used in the establishment of the revised G.L.C. working standards included comparison of site investigation results to consumer protection regulations (e.g. Toys (Safety Regulations), available soil evidence on phytotoxic effects, threshold limit values and 'careful guesstimates'.

2.3.4 Using these principles, the present approach of the Scientific Branch of the G.L.C. is shown in table 2.6. In interpreting results from individual sites, it is suggested by Kelly that the range of values for all contaminants is considered against typical values and values indicative of slight or heavy contamination. Both Chapman and Kelly laid great emphasis on the tentative nature of the guidelines and of the fact that there are considerable gaps in the knowledge required to produce standards for environmental contaminants in soils. In particular, the toxicological effects of heavy metals was still very much judgemental rather than being based upon reliable research studies. They also stressed that further data was required on the low dose long term effects of some contaminants and more particularly on the levels of heavy metals which are acceptable from an environmental health point of view. Kelly also stated that the problem of setting 'acceptable guidelines' was a national problem requiring an urgent response from the relevant government departments.

TABLE 2.6

GUIDELINES ON CONTAMINATED SOILS - SUGGESTED RANGE OF VALUES (Mg/Kg^{1}) DRY SOIL

Element	Typical Value (See text)	Slight Contamination	Heavy Contamination
As	0-30	30-50	100-500
Cd	0-1	1-3	10-50
Cu (av)	0-100	100-200	500-2500
Rb	0-500	500-1000	2000-196
Pb (av)	0-200	200-500	1000-5000
Hg	0-1	1-3	10-50
Ni (av)	0-20	20-50	200-1000
Zu (av)	0-250	250-500	1000-5000
Se	0-1	1-3	10-50

Source: Adapted from Chapman 1976
Kelly R.T. 1979

2.4 Tentative Guidelines for Acceptable Concentration of Contaminants in Soils

2.4.1 In the last five years, the Department of the Environment has recognised the need to offer advice to local authorities and developers on the wide range of problems they may be faced with when developing former industrial land. The Inter-departmental Committee on the Redevelopment of Contaminated Land (ICRCL) was set up in 1976 (by the Department of the Environment's Central Directorate on Environmental Pollution) to give advice on the potential hazards of developing/redeveloping contaminated land.

2.4.2 Its terms of reference (see ICRCL 19/79) are to develop and co-ordinate advice and guidance on the potential human health hazards arising in connection with the re-use of contaminated land. More specifically, the committee sets itself the task of providing guidance that would give an adequate degree of protection against the potential hazards caused by the presence of toxic elements in soils. Within the context of defining 'acceptable levels', seven areas were identified on which guidance was considered necessary. These were:

i) appropriate methods for obtaining soil samples on which the metal concentrations are to be judged.

ii) appropriate limits in respect of plant uptake.

iii) appropriate limits in respect of toxicity to plants (phytotoxicity).

iv) appropriate limits in respect of ingestion or inhalation.

v) appropriate limits in respect of direct contact with contaminants (e.g. dermatitis effects and skin irritants).

vi) ameliorative measures for unacceptable concentrations.

vii) the appropriate analytical methods.

In part, the above areas reflect the concern expressed and approach adopted by the G.L.C. in dealing with new developments on former industrial land.

2.4.3 To date, the main thrust of the ICRCL's work has been to develop guidelines responding directly to items (ii - iv) above. The intention was to try and define levels which, following a thorough and adequate site investigation can be accepted as presenting no significant hazard to users or occupiers of the site. Such concentrations were to be termed 'acceptable' and ameliorative treatment measures would be required, depending on the particular end - use of the site, if these values were exceeded. It was recognised by the ICRCL (see ICRCL 16/78 and 47/81) that the main difficulty in defining acceptable concentrations is in detecting a risk or hazard presented by a particular contaminant in the environment. The only absolute criterion from a health point of view would be produced by defining unacceptable concentrations in soils which it is known would produce an adverse effect on human health. However, since many toxic elements are rarely present in humans in concentrations which produce recognisable effects, the links between these 'effects' and the levels in soils, is not an easy task and it is not surprising that there are problems in defining unacceptable concentrations. Therefore the ICRCL turned its attention to the task of producing 'guidelines' to judge whether or not a particular level of heavy metal in the soil is acceptable. There are a number of possible approaches to producing guidelines and these are summarised below:-

i) the simplest of all is to rely on the principle that conditions on a site should not become more hazardous than is usual or normal given the intended use of the site:

ii) a two-tier regulatory approach on the model found in the Control of Pollution Act (1974) with respect to the disposal of waste, where there are general restrictions relating to the prevention of an environmental hazard from the presence of waste on land and a more rigorous tier is incorporated in the site licensing provisions, which take account of local conditions and enable the waste disposal authority to attach conditions to a licence, specifying the maximum amount of contamination allowable in the waste which would not create an undue hazard in the landfill site:

iii) a guidelines approach such as that used in respect of drinking water quality where for substances such as nitrates, measured levels may be regarded as:

- unacceptable
- acceptable
- desirable

with regard to a combination of health protection and local circumstances.

iv) establishment of rigid standards above which it is known a health effect will occur.

2.4.4 The basic objective adopted by ICRCL is to ensure that contaminated land is restored to beneficial use without unnecessary risk and takes into consideration local economic, environmental and social factors. Therefore, ICRCL decided to produce 'guidelines' rather than 'standards', because standards imply "absolute" criteria at which known hazards and risks occur. Standards also impose artificial restrictions on the judgement of site investigation data in that they do not take into account local circumstances.

2.4.5 The approach which has been adopted by the ICRCL follows closely that outlined in (iii) above. A triple distinction is being developed along the lines of:

- unacceptable, must do something
- undesirable, should consider doing something
- acceptable, need not do anything

Within the above approach the main emphasis of the work of the ICRCL has been to establish guidelines for acceptable concentrations of contaminants in soil. In addition, the establishment and setting of a single set of guidelines, for all types of land and development situations, was believed to be inappropriate since of necessity, such guidelines would have to be based upon the worst possible case. This would be unacceptable from an economic point of view since in some situations *5 remedial measures would be far in excess of what was

*5 depends on the proposed end-use of a site, e.g., if site covered by warehousing may present less of a problem than if the same site were used for housing/allotments.

actually required. The ICRCL therefore, in formulating its guidelines, considered that a matrix of values was more appropriate, based upon the intended after-use of the site and the type of exposure/risk presented by the site. Four cetagories of land-use were identified (ICRCL 24/79) which it was considered are likely to be involved in comprehensive redevelopment schemes. These are:

- allotments and large gardens
- housing areas with small gardens
- amenity areas and recreational land
- public open space

2.4.6 The rationale behind selecting intended after-use as a basis for different guideline values is that different land-uses present a different route and time period of exposure to potential contaminants. Examples of this concept are, in the case of allotments and large gardens, the primary concern has been to identify levels which present a risk from the uptake of contaminants by edible crops. In the case of small gardens, children are considered to be at greatest risk, through direct or indirect ingestion and prolonged periods of contact with contaminants. As far as amenity areas and public open space is concerned, there are great variations in their intensity of use and in many cases the general degree of exposure is limited. Therefore less stringent standards could be applied.

2.5 Derivation of the ICRCL Guidelines

2.5.1 For allotments and large gardens, which the ICRCL considered were analogous to agricultural and horticultural land, the overriding requirement is to ensure levels in the soil would not give rise to elevated levels in crops. Therefore, it is proposed (ICRCL 47/81) to adopt the recommended limits and the implied maximum content for arable soils set out in the report on the 'Disposal of Sewage Sludge to Land' (see section 2.2.3 and table 2.2). The argument for adopting such values in these circumstances is that the land would be well maintained by users to retain fertility. Therefore, to a certain extent, the limitations of such guidelines, discussed in section 2.2.4, may not be applicable in the above situation.

2.5.2 As far as small gardens are concerned, the ICRCL see the primary concern as being the protection of small children who may accidentally or deliberately ingest small quantities of soil. Standards already exist for certain heavy metals in relation to ingestion in the form of consumer protection regulations. *6. The ICRCL proposed to adopt these regulations as a basis for limiting the levels of metals in soils for domestic gardens. Table 2.7 summarises the guidelines set out in these consumer protection regulations. In adopting these as tentative guidelines for soil, the ICRCL consider it was necessary to make an allowance for the greater volume of soil likely to be ingested and therefore set the 'limits' as summarised in the final column of table 2.7.

2.5.3 As far as guidelines for amenity and public open space areas were concerned the main risk is seen as being contact with contaminants rather than plant uptake orpossible risk of ingestion. Therefore it was proposed (ICRCL 16/78) to adopt industrial hygiene standards, adjusted to allow for different exposure patterns, as the basis of setting these guidelines.

2.5.4 From their experience in giving advice and working with these guidelines and from consultation with practitioners and developers who have used these 'suggested guidelines' in site assessment, the ICRCL recently produced a revised set of tentative guidelines. Table 2.8 summarises these revised 'tentative guidelines' for a selected range of elements. An important factor in the use of such guidelines is in the interpretation

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*6 The Toys (Safety) and Pencils and Graphics (Safety) regulations.

TABLE 2.7

TOYS AND GRAPHIC MATERIALS (SAFETY) REGULATIONS (1974) LIMITS FOR METALS

	Maximum Limit		
Element	Toys Mg/Kg paint film	Graphic Materials Mg/Kg crayon, lead	Suggested * limit in respect of soil Total Mg/Kg
Pb	2500	250 soluble	1500 250 soluble
As	250 100 soluble	100 soluble	100 25 soluble
Cd	100 soluble	100 soluble	12 10 soluble
Ba	500 soluble	500 soluble	1000 125 soluble
Sb	250 soluble	250 soluble	500 60 soluble
Cr	250 soluble	100 soluble	200 25 soluble
Hg	100 soluble	100 soluble	200 25 soluble

Source: The Toys (Safety) Regulations 1974
The Pencil and Graphic Instruments (Safety) Regulations 1974

* - Cadmium based on evidence available to DHSS for a particular site

- Derived by dividing limits by 4 to allow for greater volume of soil likely to be ingested (see text section 2.5.2) of results of analyses from individual sites. The guidelines set out in table 2.8 are intended only to apply to new developments or the redevelopment of known contaminated sites. They are also to be used only when a thorough site investigation has taken place. In ICRCL 47/81, it is recommended that when a particular site is assessed in relation to the guidelines it is necessary to assess each contaminant individually. This will enable a full assessment of the pattern and extent of contamination to be made for all contaminants likely to be present on a site. It is suggested that:

> "No individual 'spot' samples taken from the top 450mm (250 mm in grassed areas) *7 should exceed the acceptable concentrations detailed in table 8".

2.5.5 The above concept is difficult to apply since in reality, contamination is not likely to be present over the whole site, in fact it is only likely to be found in isolated pockets. Therefore, there will be instances where some of the contaminants are present above and below the proposed guidelines. These difficulties relate very much to the sampling programme for a suspected contaminated site. As no sampling programme can guarantee all hazards will be found, it may be more appropriate to make judgements on potential contamination problems, based upon 'enhancement above normal levels in soil' as one criterion and then to use the suggested guideline values as a means for defining 'unacceptable' concentrations. These issues are of critical importance and are developed in subsequent discussion.

2.5.6 There are in addition to the above points, a number of criticisms which can be levelled at the proposed ICRCL guidelines. Firstly, in defining acceptable concentrations, a distinction is made between different types of land-use. In many cases, the setting of less stringent guidelines in

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*7 This depth for acceptable concentration in soil is based upon the need to prevent contamination being brought to the surface during normal cultivation practices.

Table 2.8 Tentative Guidelines for Acceptable Concentrations in Soils [*1] (Total mg/kg)

Element	Small Gardens [*2]	Large Gardens Allotments [*3]	Amenity grass [*4]	Public Open space [*5]
Cd	5	3	12	15
Pb	550	550	1500	2000
Hg	1.5	1	4	20
As	20	10	40	40
Se	3	3	6	6
	Maximum Normally Tolerable Concentrations [*6]			
Zn	280	280	560	560
Cu	140	140	280	280
Ni	35	35	70	70

Phytotoxic Guidelines *6

'acceptable' or 'trigger' concentrations

Zn	130	)
Cu	50	) Z.E. 390
Ni	20	)

*1 Applicable to new development or redevelopment taking place on contaminated land.

*2 Assumed to be $75m^2$ in size and used mainly for grassed area - little contribution of home grown vegetables to total dietary intake.

*3 Assume vegetables and soft fruits grown to a greater extent - and may contribute significantly to dietary intake.

*4 Taken to be play areas and recreational areas in and around schools and residential areas.

*5 Taken to be parkland and 'large' informal open space areas.

*6 Based upon 'plant available' levels using standard ADAS techniques - higher concentrations allowable in amenity and public open space areas as such areas are usually under permanent grass. Lower values in small and large gardens are attributable to continuing growth of a variety of domestic garden plant.

amenity and public open space areas is questionable since, in many urban situations, such areas will be intensely used, giving rise to the likelihood of prolonged exposure to contaminants. This is particularly important for children since the risk of exposure and ingestion is likely to be similar for small gardens as for amenity areas. Further, the adoption of consumer protection regulations may be inappropriate since the limit values in the safety regulations are based upon an assessment of 'acid-soluble' metals, and to date very little is known about the response of soils to such tests and the relationship between 'acid-soluble' metal values and total metal values. In addition, the safety regulations state that the tests should be carried out using 0.07m Hcl acid concentration at 20° C. whereas it is known from medical evidence that the acidity of the human gut is approximately equivalent to 0.1m Hcl acidity and, of course, the temperature is 38° C. These subtle differences are important because there is evidence (JURUE 1982) that the availability of metals, particularly lead and cadmium, is significantly affected by variations in both temperature and acidity. In general, the higher the temperature and greater the acidity, the more of the metal will be soluble and thus available for absorption in the human body.

2.5.7 From the above it is concluded that existing standards and guidelines for 'allowable concentrations' of heavy metals are neither practical nor useful in assessing the significance of general levels of heavy metals in urban soil. To produce rigorous pre-determined standards requires that levels of heavy metals in soils are defined which would present no 'significant hazard' to health.

The ICRCL guidelines are therefore cautiously termed 'tentative' and are subject to further consultation. This is because the task of defining 'acceptable' or even 'unacceptable' levels of heavy metals in soil has proved to be very difficult, especially where public health exposure is concerned. The difficulty arises because the relationships between measures of soil contamination and the consequent potential health risk has not been well established. Indeed, there are considerable technical and ethical *8 difficulties encountered in trying to investigate these relationships and establish precise levels at which contaminants in the soil are a problem. The difficulties include uncertainties as to the relative contribution of soil as one of the many 'pathways' through which metals may enter the body and the diversity in peoples behavioural habits that effect the degree of their exposure to heavy metals in soil. The problem is further compounded by difficulties in identifying health effects due to the presence of elevated levels of heavy metals in the body, the compounding effects of different metals and pollutants and other factors influencing the individuals sensitivity to metals, such as socio-economic status and previous clinical ailments.

2.5.8 The recent Shipham case history is one example of these problems. In Toyama, Japan, a high incidence of bone disease (Itai Itai) was traced to elevated cadmium levels in the soil. In Shipham, where zinc mining and disposal of mine spoil has raised soil cadmium levels to 200 times 'normal' levels and 10 times the soil cadmium of Toyama, there was no detectable difference in terms of illness, between the people of Shipham and S.W. England as a whole. However, one of the problems in Shipham has been the lack of detailed information about individuals exposure to cadmium and there are still uncertainties as to the conclusions to be drawn over the whole range of possible toxic effects from cadmium exposure. In addition, recent literature (see for example D.H.S.S. 1980, Bryce-Smith & Stephens, 1980) suggests that subclinical symptoms of exposure to heavy metals are difficult

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*8 There are ethical reasons why experiments are not carried out on human exposure to heavy metal contaminants.

to diagnose due to the compounding effects of different metals and on individuals sensitivity to heavy metals. It is, therefore, now recognised that to set precise and unequivocal health protection standards for soil contaminants is questionable due to the many gaps in our knowledge.

2.5.9 The use of 'acceptable standards' in soil for heavy metals has also been shown to be relevant to food, which has been identified as a major pathway for heavy metals to the body. The practise of disposing of metal rich sewage sludge to productive agricultural land has led to a great deal of research being undertaken to define 'general' toxic limits of heavy metals in soil. *9. However, it has recently been established that even these 'plant health' guidelines are now being questioned. This is because it is now recognised that the uptake of metals by plants is dependent not only on the total concentration of metals in the soil, but also on the 'availability' of metals to plants and crops. There are a number of factors which affect the availability of metals in soil including soil characteristics such as organic matter content, cation exchange capacity, redox potential, pH and the chemical form of the metal (see work of Hughes et al, 1980; Williams 1980). In addition, several investigators (Bowen, 1971; John & Laerhoven, 1976) have shown that the uptake and translocation of individual metals by plants varies considerably. For example, cadmium is readily absorbed by the roots and translocated to plant leaves, while lead tends to be bound in the root cell walls. Such factors are further complicated by the fact that plant species differ in the degree to which they take up metals from the soil and even varieties of the same species show considerable variation in metal accumulation characteristics.

2.5.10. The above points clearly illustrate the practical difficulties of establishing precise standards for both public and plant health where soil

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*9 An example is the ADAS guidelines for the disposal of sewage sludge to land where limits on the total amount of metal in the soil have been set, see ADAS 10 and Chapter 3.

contamination may be a problem. An alternative approach discussed below is a move away from pre-determined standards to addressing the secondary question of comparison - how levels on a site suspected as being contaminated compare with typical urban levels.

2.6 Reference Levels and Guidelines - some concluding comments

2.6.1 From the above discussion it is apparent that it is becoming increasingly difficult to establish a conclusive definition of 'acceptable' levels of heavy metals that will ensure the protection of public health. It is also concluded that in the absence of detailed and extensive research into 'exposure profiles' of individuals to all sources of heavy metals in the environment, and a more detailed assessment of the contribution of land heavy metals to the body burden, it is likely to be a very long time before unequivocal standards are produced for heavy metals in soil. Given that there are these fundamental difficulties it is appropriate to focus attention on the secondary question of 'how do levels on a site being investigated compare with those found in similar urban environments?'. Such an approach not only allows an assessment of contamination to be made, but also contributes to the long-term development of standards and guidelines which is a clearly crucial policy issue at present time.

2.6.2 The approach implicit in the above is much more tractable, since it moves away from identifying health effects and defining appropriate limits in soils, to being concerned with surveillance, monitoring and comparison of results. This avoids many of the present uncertainties surrounding the relationship between soil heavy metal levels and known health effects. The principle of this approach is to set up 'reference levels' based on the 'normal' background levels of heavy metals existing in typical urban areas. The reference levels can then be used as a basis of comparison and their role is to establish, with a degree of certainty, whether or not the contamination problem is worse than that experienced in comparable areas, or where similar and/or sensitive developments already exist.

2.6.3 Comparison, in its simplest form, would take on the following structure: 'are the concentrations of the heavy metals of interest above or below those concentrations that one would normally expect to be present given the type and mix of land-use?'. If the situation occurs where all results of analysis for a site being investigated exceed the 'reference levels', then it identifies the need for action to be considered for reducing the pollution problem presented by the levels on the site. It must be emphasised, however, that interpreting site investigation data in this way is by comparison only and is only stating whether or not the pollution problem is worse or better than that experienced in comparable areas. Such 'reference levels' do not imply an 'acceptable concentration' nor do they detract from the need for further research into defining 'acceptable concentrations'; they are put forward primarily as an alternative means of assessment on which to base judgements.

2.6.4 In addition to the above, it is suggested that 'reference levels' may be taken a stage further through statistical analysis of the spatial variability of heavy metal levels in urban soils. Indeed, the ICRCL have frequently stated (see for example, ICRCL 38/80 and 47/81) in their guidance on interpretation that a full site investigation and interpretation should take account of the statistical distribution of 'spot-sample' observations. Furthermore, the suggestion is that guideline values should not be exceeded over more than 1% of the area under investigation. The reference level approach to 'standard setting' could enable estimates of the statistical probability of certain levels occurring naturally in the urban area to be obtained, which may then be used to interpret the results of individual site investigation data.

2.6.5 This chapter has presented, and discussed in detail, policy issues of standards and guidelines for allowable concentrations of heavy metals in soil. From this review, it is concluded that it is neither possible nor practical, given the present state of knowledge, to specify precise and unequivocal environmental health protection standards for heavy metals in soils. An alternative approach for assessing land contamination, the use of reference levels, has been introduced here because it is this that forms the major policy context to which the research strategy is responding. The development of this approach requires systematic knowledge of typical levels of urban land contamination. This in itself presents no small problem for research, in that it requires spatial information on the variability of urban soil heavy metal levels. The problem rests on the fact that heavy metals in soil exhibit high, short distance spatial variability, and to obtain spatially comprehensive information for large urban areas is difficult. It requires a sampling strategy which is sufficiently sensitive enough to enable spot samples to be representative of the expected spatial variability. These issues are taken further in the next two chapters. Chapter 3 is a detailed and critical review of the relevant literature on past approaches to obtaining information on heavy metal land contamination. This is followed by Chapter 4, the core of the research, which is concerned with developing a survey methodology which will allow heavy metals in urban soils to be measured and mapped.

CHAPTER 3

3.0 SURVEYS OF HEAVY METALS IN SOIL: A REVIEW

3.1 Introduction

The purpose of this chapter is to present and discuss the literature relating to the wide range of studies which have been undertaken to describe the spatial distribution of heavy metal trace elements in soils. In so doing, it offers a rationale for the selection of key heavy metals for examination and a critical review of methods of approach and results of reported studies in the field. It concludes with some basic requirements to which the research strategy and survey design must respond.

3.2 The Contaminants of Central Concern

3.2.1 The term 'heavy metal' is a broad one and includes metal elements of atomic weight higher than that of sodium and having a specific gravity in excess of 5 (Bowen, 1966; Lapedes, 1974). It can therefore be applied to over 70 metallic elements, of which only a small number have been identified as being of broad environmental concern. The heavy metals shown to be of critical environmental concern include: antimony, copper, cadmium, mercury, tin, lead, chromium, cobalt, zinc and nickel.

3.2.2 The assessment of heavy metals which can be classed as toxic or hazardous is, however, complicated by the fact that certain of the above heavy metals are essential in trace amounts for the normal functioning and growth of living organisms. The problem is further compounded by the fact that the difference between the concentration of a heavy metal required for adequate nutrition and that which it is known produces toxic symptoms is relatively narrow and in a number of metals is not well defined (for example, nickel, copper and zinc). However, there is broad agreement in the literature that the heavy metals cadmium, mercury, lead, cobalt, and more recently molybdenum, have no known functional role and have been shown to cause severe problems of non-occupational environmental poisoning.

3.2.3 With the limited amount of resources available, it is only possible and practical in this research to select a small number of heavy metals for study in urban soils. Four heavy metals have been selected for study, which have been the focus of considerable research effort; these are lead, cadmium, copper and zinc. Lead and cadmium are considered important for their potential adverse effects on human health, while copper and zinc are more important as phytotoxins. All four heavy metals are associated with historical and present day industrial activity.

3.2.4 Heavy metals are widely distributed in the environment and are present in all uncontaminated soils as a result of the weathering of parent material. In recent years, there has been increasing recognition that naturally occurring levels in soil can be elevated, often to toxic levels, through anthropogenic inputs. The principal sources of heavy metal contamination in the environment are reasonably well recognised and have been widely documented (see for example the work of Davies, 1977, Nriago, 1979, 1980, 1980a, Thornton, 1980, Greenland and Hayes, 1980.) The main anthropogenic sources of heavy metal emissions to the environment can be summarised as:

i) urban industrial aerosols created by the combustion of fuels, production of base metals, iron and steel production and other industrial sources.

ii) mining wastes.

iii) industrial and agricultural chemicals.

iv) disposal of liquid and semi- solid wastes from industrial activity.

v) disposal of sewage sludge.

3.2.5 The principal sources and emission of heavy metals for the four heavy metals to be studied in the research are summarised below:

Lead - The major source of lead in the environment comes from the combustion of alkyllead in motor fuels. Other major sources include iron and steel production, copper, lead and zinc smelting and the combustion of coal.

Cadmium - Cadmium emissions to the environment arise from the primary production of metals including zinc, copper and lead smelting. Additional sources include the manufacture of batteries, plastics, paints and the electro-plating industry. The disposal of residues from industrial activities and refuse incineration can be significant sources of 'general' emissions. In addition, the use of phosphate fertilizers and the application of sewage sludge from industrial centres are major sources of productive land contamination.

Zinc - Zinc is emitted to the atmosphere mainly as zinc oxide fume from industries producing copper and lead and from steel scrap processing. Industrial sources include galvanizing activities, brass and bronze manufacture and the use of zinc oxide in the paint, rubber and chemical industries.

Copper - Major sources of copper in the environment include zinc and lead smelting and secondary copper refining from scrap materials. Other sources include the combustion of coal and the use of phosphate fertilizers.

3.2.6 When heavy metals enter the environment through natural weathering processes and anthropogenic emissions, they follow normal biogeochemical cycles, being transported by air, water and gravity, until they reach a geochemical sink. Soil is an important sink and heavy metals have been shown to accumulate rapidly, but are depleted only slowly. Therefore land in general, and in industrial areas in particular, is a major reservoir of heavy metals in the environment and forms an important link through which heavy metals may be transferred to man.

3.3 Surveys of Heavy Metals in Soils

3.3.1 Previous work in the field has responded to a wide range of objectives but can broadly be classified as responding to four types of objective:-

i) to quantify the spatial variation in the 'normal' range of heavy metals in unpolluted soils.

ii) to investigate the relationship between levels of heavy metals in soils and uptake by plants and crops.

iii) to obtain information on background levels of heavy metals in a variety of urban situations as an aid in the assessment of potential land contamination.

iv) to quantify the contribution of man made sources of heavy metals (e.g. industrial activity, traffic) to naturally occurring levels both in urban and rural situations.

Clearly work responding to categories (iii) and (iv) has the most direct relevance for this study, but relevant points from studies responding to other objectives are also examined, where issues of methodological or analytical significance are raised.

3.3.2 <u>Large Scale Surveys</u>

The first type of survey undertaken to describe the spatial variation of soil heavy metal content were general 'reconnaissance' type surveys. Their broad aim has been to describe naturally occurring levels of heavy metals in soils in predominantly rural areas unaffected by pollution. Even these studies are wide ranging in their approach.

3.3.3 The first large scale survey in soils was undertaken by John (1971) who investigated some 700 soil samples taken from agricultural land in British Columbia, Canada. The aim of this particular study was to map lead contamination only, in surface soils in response to the growing concern of cultivating land near heavily trafficced routes. *1. The results of this study showed that the lead content of soils varied widely but that, in general, the highest levels of lead in the soil were correlated with proximity to industrial areas and population centres. In addition, the work by John (op cit) in British Columbia, found that the high lead levels in the soil were confined to surface horizons and that there was a marked decline in lead levels with soil depth.

3.3.4 A more ambitious reconnaissance survey of soil was undertaken by the United States Geological Survey in the State of Missouri, between 1969 and 1973.

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*1 The concern is from lead emitted in exhaust gases, due to its presence in petrol as an anti-knock agent. (See Blokker, 1972.)

The aim of this 'one-off' survey was to provide epidemiologists with geochemical information to enable them to investigate into the possible relationship between human and animal health and disease, and the levels of environmentally significant heavy metals in soil and water. The work had additional applications in the mapping of general environmental pollution and agricultural pollution with heavy metals. The survey was comprehensive in that 54 trace elements were determined in samples from bed rock, agricultural and uncultivated soils, natural vegetation, crops, and ground and surface water.The density of sampling varied according to the environment being investigated,with the most frequent sampling taking place in agricultural soils and crops. *2. At this scale of survey, however, a total of 1,140 samples were collected from surface agricultural land representing only 1 sample per 150 Km^2. Although the data from this survey, produced in map form, showed broad scale variation across the State of Missouri, the course sampling framework meant that firm conclusions could not be made. However, it was possible to show, in general, that the variation in soil levels was correlated with proximity to urban areas.

3.3.5 A variation of the large scale 'reconnaissance' survey was a study carried out by Broggan J.C. et al (1973) in Ireland. This was a restricted study in that it looked at the frequency and geographic distribution of high and low levels of copper and molybdenum in Irish pasture soils. A secondary aim of this study was to make a comparison of the levels in Irish 'rural' soils with other studies (see Alston, 1965).

3.3.6 The sampling framework was based upon the national grid and soil samples were collected,at random,from within each 10 Km square of the national grid. Soil samples were collected at 10 cm.depth in grid squares containing mineral

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*2 Due in part to the need to establish the relationship between crop uptake of heavy metals and public exposure to heavy metals in foodstuffs.

soils under pasture only. If a grid square was predominantly covered by water, peat, mountains or forest, then no soil sample was collected. In all, 678 soil samples were collected and a measure of 'plant-available' copper was determined, using 0.05m. EDTA extract solution with the metal concentration being determined by conventional A.A.S. procedures. In general, the results of this study showed that the soils had marked variation, with soil copper values ranging from 1.7 ppm to 44.4 ppm. (mean of 7.0 ppm). Well over 68% of the soil samples had values in the range of 2.0 ppm to 8.0 ppm., below the 10-15 ppm copper considered 'normal' for English agricultural soils by ADAS. *3. Further, and more importantly, the results showed that high and low values of copper in the soil were not randomly distributed. In fact, the highest levels of copper in the soil were found in S.W. Ireland, and in the East near Dublin. However, when Broggan attempted to correlate heavy metal content in soils with soil association, no clear relationship was found.

3.3.7 One of the most widely reported scale 'reconnaissance' surveys was the work carried out on stream sediments and reported by Webb et al (1973, 1978). To obtain a meaningful pattern of heavy metal distribution in the general environment, stream sediments were preferred to soil samples, because it is widely recognised that 'parent rock' determines soil heavy metal content, and many thousands of soil samples would be needed to cover the extensive range of parent rock types. Stream sediments were also preferred because surveys on stream sediments are now standard prospecting practice in the search for metaliferrous deposits throughout the world. (Thornton, 1980).

3.3.8 The technique developed by Webb, et al (op.cit) was based on the premise that stream sediments represent natures closest approximation to a composite sample presenting normal conditions, in that they are composed of the erosion of rock, overburden and soil up stream of the sampling point.

*3 (See Section 3.3.4).

Therefore 'natural' heavy metal levels in the rocks, overburden and soil upstream of a sampling point will be directly correlated to the levels in the stream sediment sample. A pilot study to test out the technique was conducted in 1964 over 12,000 Km^2 of W.Ireland (see Webb, 1973). The general aim of the pilot study was to assess the problem of sampling, analysis, and data handling under field conditions, arising from such large scale surveys.

3.3.9 Success in the pilot study meant that a full scale geochemical stream sediment survey of England and Wales was undertaken in 1969. The aim being to map stream sediment levels which reflect naturally occurring background levels of heavy metals in the environment, and to establish a direct relationship between stream sediment heavy metal content variation and reported levels in soils. If such a relationship is established then the approach would enable large areas to be mapped relatively easily and deficiencies/excesses in soils highlighted for further investigation. The sampling framework for the main study was based upon sampling 'active' stream sediments at stream/road intersections, in pre-defined drainage basins. Some 49,500 samples were collected from tributary drainages over 105,700 Km^2 of England and Wales. Because the aim was to map naturally occurring background levels, no samples were collected within urban areas. Each sample was analysed for 22 trace elements including arsenic, cadmium, copper, lead, nickel, and zinc, using direct reading spectrographic techniques.

3.3.10 The results from streat sediment analysis were plotted in map form (Webb, 1978) *4 for the whole of England and Wales,using a moving average smoothing technique to reduce 'noise' due to sampling and analytical variability. The categories used in deriving the maps were computer

*4 Published as the Wolfson Geochemical Atlas for England and Wales.

calculated percentile divisions for each element. For example, the results of lead in stream sediments were divided into 5 categories, (<40, 40-80, 80-160, 160-320, and >320 ppm) and the map shows that around 97% of England and Wales is represented by class limits ranging up to 160 ppm. This shows quite good correlation with the 'naturally' occurring levels of lead in soil reported in the literature, which range up to 200 ppm. (H.M.S.O. 1974; Berrow and Burridge, 1977; Alloway and Davies, 1971). Thornton (1980) also comments that the survey of stream sediments identifies a large area of Derbyshire as having abnormally high lead levels which correlates quite closely with the reported work of Colbourne, (1978), who found that surface soils in Derbyshire contain lead levels ranging from 200 - several thousand ppm.

3.3.11 In the case of cadmium and copper, there was also close agreement between levels normally found in unpolluted soils and the results of stream sediment analysis. For example, the map of cadmium results showed that over 80% of England and Wales was represented by the lowest class division of < 1 ppm. corresponding closely to the 'normal' levels reported by Davies (1977). A recent study by Archer (1980) *5 indicates that agricultural soils in England and Wales have an average cadmium level of less than 1 ppm. The stream sediment analysis also highlighted abnormally high levels of cadmium in the Swansea Valley area, Derbyshire and Somerset, with up to 100 ppm. Cd. being recorded. Further work in Somerset, in the Mendip Hills, *6 by Somerset County Analysts Department and the Department of the Environment (1979, 1980) found that total soil cadmium levels ranged from 11 ppm. to 998 ppm. In the case of copper, the computer printed maps of stream sediment analysis showed that the lowest category (< 7.5.ppm) correlated well with the known areas of copper

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*5 See section 3.3.4 for a full discussion.

*6 Around Shipham close to former lead and zinc mines and the area was used for mine spoil dumping.

deficiency in soils reported by Caldwell (1976) for E.Anglia and Hampshire and parts of Sussex.

3.3.12 In general, the results of stream sediment analysis for heavy metals have shown that there appears to be close agreement between levels in stream sediments and those reported in the literature for soil assumed to be 'uncontaminated'. It must be stressed, however, that the nature of geochemical stream sediment surveys means that they can only fullfill a 'primary reconnaissance' role. Therefore, in terms of their contribution to soil contamination, such surveys can do no more than focus attention on the observed pattern of low and high levels and identify broad areas where further detailed investigation should be conducted.

3.4 Urban baseline surveys

3.4.1 Several investigators (see for example, Purves, 1966; Davies, 1977; Warren, 1971; Beavington, 1973) have established, in recent years, that heavy metal levels in urban soils may be elevated and present environmental health problems. In fact, Davies (1977) has stressed the point that soil sampling is the ideal method of determining the broad levels of heavy metals in the environment in general. Studies by Purves (1966) and Davies (1977) have provided substantial evidence that the heavy metal content of soils in urban areas may show elevation above those considered to be naturally occurring. For example, Purves found that soils in two Scottish towns contained four times as much copper and three times as much water soluble boron as rural arable soils. In subsequent studies (Purves, 1968; Purves and McKenzie, 1969) lead, nickel and zinc were found at enhanced levels in urban soils and confirmed as soil contaminants through plant and herbage studies. Warren et al (1971) confirmed the work of Purves for English urban soils and included cadmium as a contaminant present in soils at levels above 'normal' for rural soils. Many of these studies on urban soils concluded that the 'contamination' of the soil was attributable to vehicle exhaust emissions and industrial point sources.

3.4.2 One of the first comprehensive surveys to quantify the mounting evidence that suggests a marked accumulation of heavy metals in urban soils was carried out by Beavington (1973) in Australia. The study was ambitious, in that it attempted a systematic investigation of the levels of heavy metals in soils over 56 Km^2 of the City of Wollongong, New South Wales, Australia. The principal aim of this particular study was to investigate how the levels of zinc, copper, cadmium and lead varied with land-use in urban situations and to compare the urban levels with corresponding results from a rural 'control' sample. Four land-use types were selected for study within the urban area (recreational, industrial, cultivated land and roadsides), and soil samples were collected from the 200m intersections of the national grid pattern. *7 A similar grid procedure for soil sample collection was adopted in the rural 'control' area. A total of 298 soil samples were collected from the urban area, and 21 soil samples from the rural area, the samples being taken from under grass cover, avoiding obvious areas of contamination. Each soil sample was analysed for a measure of plant available *8 lead, copper, zinc and cadmium.

3.4.3 The results from this urban/rural comparative survey are summarised in Table 3.1, for zinc and copper only. The levels of lead and cadmium in the rural 'control' samples and in many of the urban soil samples, were below 1.0 and 0.5 ppm. respectively and therefore not within the detection limits of the analytical procedures.

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*7 Based on the 1= 6,360 Planning Authority map of New South Wales, Australia.

*8 Lead, Zinc and Cadmium being determined on 0-0.5N acetic acid extract and copper with 0.02 M EDTA. extract.

Table 3.1

Available Zinc and Copper in Soils from N.S.W. Australia (ppm)

Land-use	Zinc		Copper	
	mean	range	mean	range
Rural control	2.7	0.5 - 8	5.3	1 - 20
Farm land	7.1	1 - 33	11.3	4 - 78
Recreational land	14	0.5 - 55	2.5	3 - 168
Industrial land	23.4	0.5 - 350	58	3 - 1380
Roadside	28	1 - 90	31	4 - 505

Source: Adopted from Beavington, 1973.

It is clear from the above data, that soils from urban areas contain higher levels of zinc and copper than in the rural areas. In fact statistical analysis of the zinc and copper data by Beavington revealed that there were highly significant differences ($p < 0.001$) between the mean levels of zinc and copper in rural areas and the urban land-use types. Using the guideline data on normal levels produced by Purves, of 40 ppm available copper in soils as inhibiting plant growth, Beavington also concluded that the majority of samples from the four land-use types in the urban area were present at toxic levels. The highest levels of copper and zinc were found in samples collected from within close proximity to a smelting complex.

3.4.4 A study with a similar approach to Beavington was a study of mercury and other metals in urban soils of the Metropolitan area of Grand Rapids, Michigan, (U.S.A.) reported by Klein, (1972). A much larger area was chosen for this study, covering 304 sq. miles of Michigan, of which the urban area occupied 120 sq. miles. Land-use categories were used as the basis of the sampling frame, and the total study area was subdivided into four categories of land-use:

i) Industrial area - includes industry, most commercial areas and high density residential areas.

ii) Agricultural area - predominantly agricultural land only.

iii) Airport area - the airport and a 1 mile 'fall-out' zone around the airport.

iv) Residential area - primarily low density residential area with a substantial amount of unimproved woodland.

3.4.5 The sampling pattern followed the 'grid iron' street layout of the area, in that soil samples were collected at the intersection of the 1 mile grid. A total of 264 samples were collected from the 4 land-use types and on each soil sample 11 determinations were made *9 including Hg, Pb, Zn, Cu, and Cd, using standard analytical techniques.

Table 3.2 below summarises the results of this study for 4 metals only.

Table 3.2 Mean Heavy Metal Concentrations for Four Land-Use Types (ppm)

Land-use	Cadmium	Copper	Lead	Zinc
Residential	0.41	8.0	17.9	21.1
Agricultural	0.57	8.8	15.4	22.1
Industrial	0.66	16.3	47.7	56.6
Airport	0.77	10.4	17.9	36.6

Source: Adapted from Klein 1972.

In general the results in the above table demonstrate that the level of heavy metals in soil samples taken from within the industrial area are higher than in the other 3 land-use categories. In fact, in comparing the results from industrial and residential categories, Klein found that in the case of cadmium, industrial soil samples showed on enrichment of 1.4 times, for copper it was 2 times, and for lead and zinc it was 2.7 times the levels in residential soil samples.

*9 Using a cold nitric acid digest and potassium permanganate for mercury.

3.4.6 In Britain, one of the earliest studies to demonstrate the fact that urban soils contain significantly higher amounts of heavy metals than rural soils in a similar area, was a study by Purves and Mackenzie (1969). In a comparison between urban parkland soils and rural permanent pasture soils from part of Scotland, Purves and Mackenzie demonstrated that there were highly significant differences between the mean levels of heavy metals in rural and urban soils ($p < 0.05$). The results also showed that for extractable copper, there was a tenfold difference between the mean levels in urban and rural soil samples.

3.4.7 A further demonstration of the existence of significant differences between the heavy metal content of urban soils from rural soils was made by Fleming (1977) and Broggan (1973) for part of Ireland. The results from these studies showed that although the levels of heavy metals in urban soils were wide ranging, a significant proportion of the soil samples had levels well above the 'normal' quoted levels for uncontaminated soil (the normal level on data from Swaine and Mitchell, 1960).

3.4.8 More recently, Davies et al (1979) have demonstrated that the lead content of London soils exhibits marked contamination. In this particular study, the aim was to assess whether urban land was suitable for use as allotments and for growing vegetables for consumption, with respect to its soil lead content. To assess the extent and significance of lead levels in London soils, soil samples were collected from 23 sites on a transect from Central London (Marble Arch) extending 75 Km. North into rural Hertfordshire (used as a comparison 'normal' site). Soil samples were collected from a variety of land-uses including parkland in central London, Municipal allotments and private gardens, in outer London and Hertfordshire. Each soil sample was analysed for a measure of 'available' *10 soil lead content using

*10 Using 0.05 M $(NH_4)_2$ EDTA. as an extract conventional flame A.A.S. The results, summarised in table 3.3, were grouped using distance from central London as the key criteria. Sample sites within 4 Km. of Marble Arch were identified as central London, between 4 and 10 Km. from Marble Arch as Inner London, Outer London as 10 - 30 Km. and sites beyond 30 Km. were taken to be rural (unpolluted).

Table 3.3 Soil Lead Levels in the London Area

Zone	Distance from Marble Arch (Km)	Available Lead Mean	Available Lead Range
Central London	0 - 4	523	109 - 1840
Inner London	4 - 10	242	149 - 374
Outer London	10 - 30	142	42 - 420
Rural	30	30	17 - 67

Source: Adopted from Davies et al 1979.

3.4.9 From the data summarised in table 3.3 it can be seen that the mean soil lead content for each zone indicates a progressive decline from central London to rural Hertfordshire. However, even in the central London category there was wide variation of soil lead levels, with results varying between 109 - 1840 mg / kg. dry soil. In fact, all three 'London' zones has some soil samples with lead levels considered to be 'normal' *11 for uncontaminated soil. Other data published by Davies (1978) on expected levels of 'available' lead in uncontaminated soils was used as guide-line data for the interpretation of the results in table 3.3. This earlier work of Davies established the upper limit of 'normal' levels of lead in soil at 65 mg /kg. which quite clearly demonstrates that the soil samples taken from the 'London' area exhibit marked contamination.

3.4.10 Although the above studies have demonstrated that urban soils will contain elevated levels of heavy metals, the variability of heavy metals in soils

* 11 According to data published by Swaine and Mitchell, 1960 and Bowen, 1966 who report normal soil lead level as being 2 - 200 ppm.

that exists within urban areas still remains unquantified. In fact in the work of Davies in London, a transect was used as a basis for soil sample collection and 'distance from central London' was used to orbitarily define zones or categories. It may well be the case that the type of land-use plays a more important role in determining the levels of heavy metals in urban soils than merely distance from city centre. In fact, surveys by Purves, Klein and Beavington have all shown that the levels of heavy metals in urban soils varies according to land-use type.

3.5 Large Scale Rural Soil Surveys

3.5.1 In the studies describing the spatial variation of heavy metals in soils taken from urban areas, the results were made more meaningful if they could be compared to 'expected' or 'normal' levels in unpolluted soils. This relies on a body of data being available which describes the expected normal range of heavy metals in rural/agricultural situations, where the soil is presumed to be unpolluted and represent the natural state. The final set of studies reporting the spatial variation of heavy metals in soils fall into this category. They have primarily been undertaken to establish the variation (if any) of levels of heavy metals in an area considered to be unpolluted.

3.5.2 One such study was carried out in Pembrokeshire and has been reported by Wilkins (1978). The study was restricted to assessing the range of soil lead levels likely to be found in 'unpolluted' areas, so that they could be used for comparative purposes with values from areas in which pollution is suspected or is being investigated.

The sampling framework for this 'rural basline' survey was based upon the Ordnance Survey Grid. Topsoil (at 10 cm depth), Subsoil (at 50 cm. depth) and herbage samples were collected from trial pits dug at 1 Km. intervals of the Ordnance Survey Grid, for the whole of Pembrokeshire. Soil samples were analysed for their available lead content only, and the level found ranged from 1 - 356 $\mu g\ g^{-1}$ soil lead, with over 500 soil samples containing less, 39 $\mu g\ g^{-1}$. Using the 'guidelines' put forward by Davies, Wilkins demonstrated that soil samples showing marked elevation above 69 mg/kg. were concentrated around the major built up areas of Pembrokeshire. Further, the results also showed that there were significant differences (P = 0.001) between mean topsoil lead and mean subsoil lead level in close agreement with the work reported by John for British Columbia. (See section 3.3.2).

3.5.3 There are a number of important conclusions to be had from this survey of lead in Pembrokeshire. Firstly, it is probable, given that the survey sampled in area of mixed geology and soil type, that the results reflect the expected range of variation for agricultural soils in general. This assumes that such soils are not affected by mining activities or industrial point sources which are likely to elevate the levels of heavy metals in the soil. In addition, it appears from the data of Wilkins that the large towns of Pembrokeshire influence the soil lead content of nearby rural land as much, if not more than, geology or soil type. A conclusion similar to the one for the survey by Klein and Beavington, discussed earlier.

3.5.4 A complementary, but much larger scale survey to establish 'normal' levels of heavy metals in agricultural (unpolluted) soils, has been undertaken by ADAS *12 and reported by Archer (1980). According to Archer, the survey was required because:-

i) ADAS have for a long time given advice on the significance of deficiencies and excesses of heavy metals in productive soils.

ii) ADAS considered it necessary to have baseline information on the 'normal' (mean and range) heavy metal content of productive soils against which to make calculations or pass judgements.

iii) no systematic study of the trace element content of soils in England and Wales had been reported.

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*12 Agricultural Development and Advisory Service of the Ministry of Agriculture Fisheries and Food which provides analytical services and research into farming practices.

3.5.5 The primary aim of the study was therefore to provide a basic data set on normal means and ranges of the heavy metal content of agricultural soils. The soils analysed in this survey were collected in connection with the Survey of Fertilizer Practice. This survey (see Church and Webber, 1971) has been undertaken every year since 1971, and involves the collection of soil samples from randomly selected farms in England and Wales, covering the range agricultural land-uses and cropping practices. For the heavy metal survey, soil samples from 16 farms in each of the 12 ADAS regions were taken for analysis. At each farm, four randomly selected fields were sampled, with soil samples being taken from a depth of 15 cm. A total of 750 soil samples were collected and analysed for 9 'total' and 5 'extractable' heavy metals using standard MAFF analytical procedures. *13.

3.5.6 The results of this rural baseline survey are summarised in table 3.4. below.

Table 3.4 Median Trace Element Content of Soils in England and Wales ('total' values expressed as Mg/Kg; extractable as Mg/litre air dry soil).

	Element	Median	Range
Total	Cd	1.0	0.08 - 10
	Cu	17	1.8 - 195
	Ni	26	4.4 - 228
	Pb	42	5 - 1200
	Zn	77	5 - 816
Extractable	Cu	4.4	0.50 - 74.0
	Ni	1.0	0.12 - 22.7
	Zn	6.6	0.40 - 97.6

Source: Adopted from Archer, 1980.

*13 Total Cd, Cu, Ni, Pb, and Zn, are the amount of metal brought into solution by digesting the soil in nitric/perchloric acid. Extractable Ni and Zn determined on 0.5 m acetic acid and Cu on 0.05 m EDTA extraction at pH 7.0 (see MAFF 1973 for details).

3.5.7 In general, the results in the above table show that the amount of total and extractable lead and zinc are wide ranging in agricultural soils. In addition, the survey demonstrated that the heavy metal content of agricultural soils was not consistently related to parent material (similar to the observations made by Wilkins for Pembrokeshire). More specifically, the data showed that in the case of cadmium more than half the samples had a total cadmium content of less than 1.0 mg /kg. For total lead, 85% of the soil samples were in the range 40 - 90 mg/kg and 85% of the soil samples had a total zinc content of less than 140 mg/kg. In the case of total copper, 90% of the soil samples had a median copper level of less than 40 mg/Kg. In addition Archer observed that high values of extractable copper tended to be closely related to soils with high total copper content. Other important comments on the results are that a wider range of values were found for lead than for any other element, and in many samples high values of lead were associated with high values of zinc. In fact, many of the high lead and zinc values were associated with former lead mining areas, but it was not possible to ascertain whether this observed enrichment has taken place as a result of industrial activity or was due to natural weathering of the enriched parent material.

3.5.8 Archer used data on the expected upper limits *14 of the normal range of total lead, copper and zinc in unpolluted soils (reported by Berrow and Burridge, 1977) to interpret the results of this survey. Of the soils analysed in the ADAS survey, 1.3% contained more copper, 2.1% more lead and 0.8% more zinc than the reported values. Archer concluded that of the results obtained, the majority of soil samples had a heavy metal content within the quoted ranges for normal (unpolluted) soil. However, the results also indicated that lead, zinc, cadmium and copper are often found

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* 14 Upper limit for total lead was taken to be 200 mg/kg; for total copper 100 mg/kg; and for total zinc, 300 mg/kg.

in 'abnormally large amounts' in soils in England and Wales. This data, coupled with the results presented from other surveys reported earlier, confirm that there is broad agreement as to the 'normal' level of heavy metals in 'unpolluted' soil. In addition, the data illustrates the fact that soil samples taken from different parts of the country have similar ranges of heavy metal content.

3.6 Spatial Studies of soil heavy metal levels and other policy issues

3.6.1 Chapter 2 has already reviewed, in detail, the major policy issues to which this research study is responding. However, the importance of identifying general heavy metal soil contamination in urban areas may be taken a stage further with the recent interest in 'environmental impact assessment' and the need for 'before' and 'after' studies. Davies (1977) for example, makes the comment that soil sampling for heavy metal analysis is an ideal method by which 'baseline' data can be obtained, which may then be used to determine potential environmental impacts in an area. In this context, Davies considers that a knowledge of naturally occurring or background levels' of heavy metals in soils may be useful in deciding the types of area which may be sensitive to new industrial developments which are likely to increase the soil burden of heavy metals.

3.6.2 Of all the studies reported in the literature to date, only one has responded directly to this question of the policy and planning implications of heavy metal land contamination. This was a study carried out by Merseyside County Council (1976) who, within the policy framework of Structure Plans, attempted to use the existing spatial pattern of environmental pollution to formulate their pollution control and land-use planning policies.

3.6.3 The objective of the Merseyside study, which was comprehensive, was to

> "investigate the condition of the physical environment ...... the characteristics and distribution of environmental pollution and the condition of the land......., also the origin and effects of pollution",

in order

> "to allow policies and programmes to be developed to deal with any problems".
> (Merseyside County Council, 1976).

The Merseyside study, therefore, examined a range of environmental conditions including smoke, sulphur dioxide, soil contamination by heavy metals and damaged and unused land.

3.6.4 In the case of contamination of the land by heavy metals, the core areas of interest related primarily to ensuring that new development (particularly housing and recreation) did not take place on contaminated land without prior knowledge and the possibility of a full site investigation. In addition, from a pollution control point of view, Merseyside County Council considered that information on land contamination would be useful in identifying 'sensitive areas' where pollution was already present at high level and where new, possibly polluting industries should not be located. Closely related to the above policy responses was a need to prevent further degradation of the land in urban areas and to establish a baseline from which the environmental quality of the urban area could be judged and compared and areas identified for improvement.

3.6.5 A key component in the above policies was the need for a systematic survey of the extent of heavy metal land contamination. The examination of heavy metal concentrations in the soil of Merseyside was also seen as providing a quantitative method for determining 'general' metal pollution levels in the urban environment. A soil survey was therefore undertaken over the 650 Km^2 of the County of Merseyside, which supports an estimated population of 1.58×10^6. 260 Km^2 of the County area is covered by urban development within which exist a wide range of industrial processes, including glass making, textiles and the chemicals industry.

3.6.6 The sample frame for this survey was based on the division of the County area into 2 kilometre square grids. Within each grid, soil samples were collected from examples of land-use types - parkland; gardens; allotments; agricultural grassland and agricultural arable land. A constant sampling density was maintained in each grid and therefore where a particular land use type was not available, a substitute category was used. In total, 200 soil samples were collected, each sample being a composite of 4 sub-samples. The soil samples were analysed for a measure of the available *15 lead, zinc, copper and cadmium content.

3.6.7 The results of this urban 'baseline' survey are summarised in table 3.5. The results were assessed through comparison to quoted normal levels in unpolluted soil (based on results of studies by Berrow and Burridge, 1977, and Purves, 1968). In general it was found that when compared to typical values of heavy metals, the Merseyside soil samples showed marked contamination with 79% of the soil samples for copper, 20% for cadmium and 30% for lead, exceeding the normal ranges. Parry et al (1981) who have written in detail about the results, suggest that there is sufficient evidence to conclude that urban soils in Merseyside may be defined as 'substantially contaminated'.

Table 3.5 Available Heavy Metal Levels in the Soils of Merseyside County

Land-use	Element (μg/g air dry soil)			
	Cadmium	Copper	Lead	Zinc
Garden/ allotments	0.25(0.01-4.2)	34.2(0.8-346)	8.4(0.1-64.7)	156.8(1.7-2730)
Parkland	0.22(0.1-3.3)	35.4(1.6-545)	4.5(0.1-63)	25.6(2.4-258)
Agricultural grassland	(<0.01-1.3)	(0.5-116)	(0.1-25.2)	(1.3-182)
Agricultural arable	(<0.01-5.4)	(0.4-284)	(LO.1-51.5)	(1.4-4.6)

Source: adopted from Merseyside County Council, 1976; Parry et al, 1981.

Because the principal aim of the survey was to provide a data base for land-use planning, soil contamination maps were drawn up, based upon the

*15 Analysis carried out according to ADAS analytical procedures (see MAFF 1973).

results of the soils analysis. These soil contamination maps were then used for direct comparison with existing land-use and mixes of land-use in the Merseyside County. The maps were produced using the SYMAP technique which involves smoothing out the 'noise' in the results and interpolation to define the class intervals for drawing the countour maps.

3.6.8 The resultant symaps were then compared with the existing pattern of industrial, residential and commercial development. The results from this exercise indicated that high levels of lead and zinc in soils were relatively evenly distributed throughout the urban area of the County. In contrast, high levels of cadmium and copper in soils were restricted to areas of industrial activity, in particular to areas where there are active or former metallurgical and refining processes. The information provided in mapped form could also be used (according to Parry et al, 1981) to identify areas that merit further investigation. In addition, Parry suggested that such information maps may have an application in informing the decision-making process related to land-use planning. In particular, in assessing the capacity of the environment to accommodate new developments that may impose additional pollution burdens in an area. Although in theory a valid application of such a data base, it must be remembered that the quantification of 'environmental capacity' for pollutants, in particular soil heavy metal levels, is not at the stage where firm decisions could be made as to the impact of likely additional pollutant loads in an area. Indeed, much of the hard battle being fought in the Universal adoption of 'Environmental Impact Assessment' relates to the problems of baseline studies and the specification of known impacts.

3.6.9 As with many of the surveys describing the spatial variation of heavy metals in soils in an area, the results above can do no more than indicate generally elevated levels of heavy metals in urban soils. They do not, at this stage, establish whether the contamination of soil is the result of former manufacturing processes, progressive accumulation over a long time period (including the influence of local geology) or current industrial activity. Therefore the role of such surveys in pollution control policies is obviously limited. In addition, the nature of the survey design and sampling programme, coupled with the limited knowledge on the relationship between soil heavy metal content and known health effects means that no firm conclusions can be made regarding the immediate environmental health problems associated with the presence of elevated levels of heavy metals in the Merseyside soils.

3.6.10 There are, however, a number of advantages in the approach adopted by Merseyside County Council which have implications for this research studies survey strategy. For example, the survey in Merseyside has clearly demonstrated that it is possible and practical to obtain information on soil contamination in urban areas in a cost-effective manner. Further, the survey technique is sufficiently sensitive enough to distinguish between the generally enhanced levels of heavy metals typical of the 'general' urban areas and the further contamination of soil by industrial point source emissions. This was particularly the case for measured levels of copper in soil, where 'hot spots' of high levels were closely correlated to present day and former metallurgical processes. In addition, such survey work has been shown to provide sufficient information to enable 'stress areas' to be identified where there is significant elevation of heavy metal levels.

3.7 Other 'General Environmental Surveys'

3.7.1 The preceding review of past approaches to describing and mapping the heavy metal content of soils in a variety of environments, clearly demonstrates that to date, there have been very few attempts at describing the spatial variation of soil heavy metal levels in large and varied urban areas. The majority of past studies have concentrated on the rural situation or have restricted the urban survey to identifying and quantifying the differences between broad land-use categories (e.g. differences between residential and industrial areas, or differences between urban areas and rural areas within the same locality). The result of the above is that although it is possible to draw out key issues from past studies to which the research strategy should respond (these are discussed in section 3.8), it has not been possible to identify and critically review a range of survey designs which could have been used to respond to the policy context set out in Chapter 2. Therefore, it is necessary to turn to other research related to large scale environmental surveys for additional concepts which may be useful to the present research study. This is the purpose of this section, which introduces examples of large-scale environmental surveys.

3.7.2 In recent years, there has been a whole body of research directed towards large scale environmental (mapping) surveys, describing the 'general' condition of the environment at the urban and even national scale. It is worth introducing at this stage in the research these large scale studies, since they provide useful information which will help to formulate the survey approach of this research study. The classic example of the large scale mapping surveys are the studies undertaken for 'State of the Environment Reports' which have attempted to provide spatial environmental information (impact of human activities on the environment), often at the urban scale, to assist in the definition, implementation and evaluation of environmental policies. The recent O.E.C.D. report 'The State of the Environment in Member Countries' (1979), is a useful summary of the role and scope of such work.

3.7.3 In addition to 'State of the Environment Reports' the problem of describing the environmental condition of large and varied urban areas has also been tackled by planning policy orientated research projects. For example, the O.E.C.D. (1978) have encouraged work on the selection and use of 'Urban Environmental Indicators' with the objective of preparing a basic set of indicators describing the quality (physical) of man's environment. The emphasis in this type of research has been the selection, aggregation and mapping of indicators of the exposure of the urban population to various pollutants. A key feature of such research is that it has concentrated on assessing pollution at the urban scale from secondary data sources. Pollution in this context being the quality of housing, provision of services such as mains drainage and the quality of the ambient environment (air and water quality, noise and land quality).

3.7.4 The E.E.C has also supported a wide range of research projects on the subject of urban scale environmental mapping through its 'Ecological Mapping' and 'Urban Environmental Indicators' research programme. Research studies under this programme have attempted to describe the spatial variation in environmental conditions over large areas (see for example studies by Ammer, 1976; South Yorkshire County Council, 1978a, 1978b,).

3.7.5 The aims of these environmental mapping studies has been to develop and apply techniques to provide basic environmental information for the regions of Europe, to identify current land-use potential and environmental problems in these regions and to act as an environmental early warning system. The method proposed by Ammer and tested in a case study by South Yorkshire County Council is known as 'use-value-analysis', and is based on the principle of using indicator variables as measures of environmental condition. In the South Yorkshire case study (see detailed discussion in SYCC, 1978a, 1978b) instead of dividing the environment into four basic 'environmental components' (air, water, soil and landscape) the method was based on selecting indicator variables (e.g. noise- pollution, soil erosion, waste land, etc.) as representative of various systems of land-uses. The value of these studies is that they have tackled many of the methodological issues related to sampling and mapping environmental conditions such as noise pollution in urban areas, and therefore are relevant to this research work. For example, it has been necessary in the SYCC case study to undertake extensive data collection and field measurements in order to obtain optimal information on environmental conditions. This has raised a number of issues, including deciding on an appropriate sample frame, size of zone to be sampled and detailed methodological problems such as how representative are sample point measurements of environmental conditions in surrounding areas. A key output of the urban indicators research has been the development of practical urban scale mapping techniques to enable within and between area comparisons to be made (for example, between urban areas in one country or similar urban centres in a number of countries).

3.7.6 Other contemporary and parallel research, notably the work of Wood et al (1974) and Pocock (1979) have developed further many of the underlying principles in the 'State of the Environment' and 'Indicators' work, with particular reference to the spatial mapping of environmental pollution in urban areas. In the research by Wood and Pocock, for example, the extent of pollution and its spatial variability in the urban area was found to be broadly dependent on the degree and type of land-use activity within an area. Therefore, the problem of describing and mapping the variation in environmental conditions over large areas, which is similar to the research problem of this work, was overcome by dividing the urban area into homogeneous zones based on an appropriate classification of urban land-use.

3.7.7 Although the above 'general environmental surveys' have no substantial output in terms of mapping heavy metal land contamination, they do provide contextural information and examples of 'practical' methodologies which may be used to help frame the general methodological approach of this research study. Chapter 4 developes further many of the methodological issues, particularly those found in the studies of Wood and Pocock, in the context of a research strategy and survey design for mapping heavy metal land contamination.

3.8 Summary and Conclusions

3.8.1 There are a number of general comments and conclusions which can be had from this review of heavy metal soil mapping studies, and these are summarised below. This is followed by a summary of the key findings from contemporary research which have implications for the survey design stage of the research.

3.8.2 Firstly, as Davies (1980) has stated,

> "the soil is like a palimpsest - it is the overwritten record of all the different environmental factors and conditions which prevailed during its formation".

This review of past studies has confirmed this statement and has demonstrated that there are a wide range of factors which contribute to the levels of heavy metals in soils in general, and urban soils in particular. These include the nature of the parent rock, climatic factors, human activity (in particular industrial activity) and urban development.

3.8.3 Further general observations relate to the fact that there have been relatively few systematic studies which measured and mapped the heavy metal content of soils in either rural or urban environments. Of the limited number of surveys that have been undertaken, the majority have adopted similar methods of approach - namely soil sampling has been undertaken on a grid basis with very large areas being covered by a small number of samples. (see for example the surveys by Merseyside County Council, ADAS and the work of Wilkins in Wales). To date, therefore, it can be concluded that there has been no systametic study to survey the spatial variation of heavy metal soil contamination in urban areas.

3.8.4 In addition to the above general comment there are a number of specific and detailed conclusions that can be had from the studies reviewed in this chapter. For example, the work of Thornton, Archer and Wilkins clearly illustrates that even in 'unpolluted' rural environments, soil heavy metals are wide ranging. In addition, in the work of Wilkins, there was a clear relationship between the presence of urban centres and raised level of lead in the soil samples.

3.8.5 The work of Purves, Beavington and Broggan served to identify a number of heavy metals which may be present in urban soils at elevated levels. In the work of Purves, copper and lead were identified as contaminants in urban soils. The work of Davies, which compared rural and urban soil heavy metals, also demonstrated that there is a high probability that urban soils will contain significantly higher levels of heavy metals than equivalent rural soils. The above studies have also provided information which suggests that heavy metal level of soil samples taken from within urban areas will have a wide range of heavy metal levels, ranging from 'normal' (unpolluted) levels to significantly high levels showing marked contamination. In addition, there is a wealth of evidence, supported from other research work (see, for example, Wun Lin and Bradshaw, 1972; Chow and Johnstone, 1965, Le Riche, 1968; Buchaver, 1973), which has demonstrated that there is a clear relationship between heavy metal soil pollution and particular urban sources, such as industrial activity, general urban land-use and high traffic flows.

3.8.6 On a more specific note, this review has served to highlight the fact that information on the heavy metal content of soils in urban environment may have a number of roles in environmental assessment. For example, information from large scale surveys in urban areas can be used to provide base-line information against which elevated levels may be assessed.

In addition, surveys which map soil heavy metal levels may provide a data base of environmental quality. If such information were incorporated into the surveys required for the preparation of strategic and local plans, then they may be a useful addition, to the evidence needed to identify areas that merit further detailed investigations either in the context of environmental health or in areas requiring environmental improvement.

3.8.7 In addition to the above general points, there are a number of particular conclusions from past studies which have direct implications for the research strategy and survey design and these are summarised below:

i) levels of heavy metals in urban soils may be elevated above naturally occurring levels in unpolluted soil.

ii) soil heavy metal levels in urban environments have been shown to be spatially variable exhibiting a high degree of short distance spatial variability.

iii) the work of John (1972, 1974) has illustrated that it is often only surface soils (up to 15 cm. depth) which contain elevated levels of heavy metals. At depth in the soil profile, the levels of heavy metal quickly approach normal (unpolluted) background levels.

iv) from the rural/urban comparative soil heavy metal surveys, there is evidence that in the urban situation, parent material and soil type may no longer be the dominant factor controlling the levels of heavy metals in the soil. The presence of industrial activity, proximity to industrial point sources and traffic may be more important.

v) the work of Davies, Parry, Klein and Beavington has demonstrated that the spatial variability of heavy metals in urban soils, in particular levels of copper, zinc and cadmium, are directly correlated to the type of land-use present in an area.

vi) the work on large scale mapping of general environmental conditions (introduced in section 3.7) has demonstrated that it is feasible to obtain field measurement of environmental conditions on a sample basis, and to represent the information obtained in mapped form, using land-use as a basis of the survey design.

3.8.8 The above points have obvious implications for the development of the research strategy, both in terms of the general development of a mapping methodology and the survey design. It is also clear from the above that the emphasis of this research is to be the development of a suitable sample frame to enable background levels of heavy metal land contamination to be measured and presented in mapped form. The following Chapter 4 draws together the policy discussion in Chapter 2 and the conclusions from this literature review into the framework of a research strategy for the work and proceeds to develop a sample frame to respond to a series of research needs.

CHAPTER 4

4.0 RESEARCH STRATEGY AND SURVEY DESIGN

4.1 Introduction

4.1.1 In the preceding chapters a number of key issues related to the presence of heavy metals in soils have been presented and discussed. In particular, the need for surveys of heavy metal soil contamination in urban areas has been raised as an important policy issue (see chapter 2 section 2.4). A detailed review of the adequacy of current and past approaches to and methods of mapping soil heavy metal content is contained in chapter 3. The major conclusion from this review was that to date there had been no systematic survey of heavy metal levels in large and varied urban areas.

4.1.2 The purpose of this chapter is to report the development of a mapping methodology which will allow for measurement and representation of heavy metal soil contamination over large and varied urban areas. The first section of the chapter concentrates on the presentation of the research strategy which has been developed from the policy issues of chapter 2, and the review of soil heavy metal mapping studies summarised in chapter 3.

4.1.3 Most of the chapter is concerned with the development of the survey design through which the mapping methodology has been formulated. This includes an account of the classification of the urban area into 'area-types' which were used as the sample frame. This is followed by a description of the application of the sampling methodology in the case study area of the West Midlands Metropolitan County.

4.2 Research Strategy

4.2.1 This section of the chapter reports the research strategy development. Chapter 2 has presented the key policy area to which this research study is responding. From the discussion in chapter 2, it is clear that there are a number of policy issues to which the research strategy should respond.

These may be summarised as:

i) the need to demonstrate the scale and spatial variation of land contamination in urban areas.

ii) the need to provide sufficiently detailed information on soil heavy metal levels in urban areas to enable the existing pattern of soil contamination to be mapped and used to identify 'hot-spots' or 'stress areas'.

iii) need for information on naturally occurring background levels in urban areas to provide baseline 'ambient' environmental information against which elevated levels in urban areas may be assessed.

iv) need for information on background levels of heavy metals in urban soil to assist in the long-term development of environmental health protection standards and guidelines.

v) the need to provide sufficiently detailed information on the spatial variation of heavy metal levels in urban soils to enable 'reference levels' for particular urban situations to be established.

4.2.2 The above needs suggest the following requirements for the research strategy:

i) there is demand for a simple cost-effective and readily applied methodology, utilising easily obtained information to map urban soil heavy metal content.

ii) requirements for a survey methodology which is spatially comprehensive and practical giving due regard to the range of possible soil heavy metal levels likely to be encountered in urban areas.

iii) there is a need for a survey methodology which can be extended beyond simple description and which is sufficiently sensitive to allow a statistically valid sample to be had in order thatreference levels can be determined.

iv) for the results of the survey to be meaningful in a general policy context, the requirement is for a survey methodology which enables the spatial variation of soil heavy metal levels to be obtained for an area at least the size of a conurbation or county.

The key conclusion from the above, is that there is a need for a survey methodology which will allow the spatial variability of background urban soil heavy metal levels to be measured and represented in map form.

4.2.3 As a generalisation, the design requirements of any survey involves a trade-off between what is considered desirable from a strictly technical point and what is feasible with a given amount of resources. In the case of this research, there is the additional need to reconcile the conflicting requirement of extended spatial coverage versus a close spacing of sample sites to achieve a reliable measure of the expected spatial variation of soil heavy metals. The review of literature on past heavy metal surveys (see chapter 3) demonstrated the fact that most soil surveys of heavy metals in urban areas have been conducted on a micro-scale with small areas sampled at great density, or have tended to be confined to small areas around a pollution source (see for example the work of Little and Martin, 1972; Lagerwerff, 1970; Griffiths and Wadsworth, 1980) and therefore do not provide a survey methodology which can be adapted to the needs of the present research study.

4.2.4 However, from the surveys that have been conducted in urban areas, there are a number of key conclusions (see chapter 3, section 3.6) which have relevance to the survey design of this research project. These are in essence:

i) soil heavy metal levels in urban environments have been shown to exhibit high short distance spatial variability.

ii) industrial activity, proximity to industrial point sources and degree of 'urbanisation' are dominant factors influencing the level of heavy metals in urban soils.

iii) in general, spatial variability of soil heavy metal levels in urban areas has been directly correlated to the type of land-use present in that area.

4.2.5 On the basis of the above recent research experience, it is concluded that there are only a limited number of practical methodologies which can respond directly to the need for a methodology which will allow ambient soil heavy metal contamination to be measured and mapped. These may be broadly summarised as:

i) a detailed survey of a small part of the urban area where specific sources of heavy metal contamination may be identified.

ii) a national-scale survey of all urban areas.

iii) the surveying of an urban area sufficiently large to incorporate the full range of land-use types.

4.2.6 Ideally, to respond to the needs and requirements set out in 4.2.5 above, in full, a survey of background urban soil contamination should be conducted in an urban area where;

i) past and present sources of potential soil contamination are wide ranging and

ii) the full range of urban land-use conditions will be present.

Clearly there are obvious reasons why the approach suggested in 4.2.4 (ii) above should be discounted. These include the fact that in selecting a small area for study, the effects of only a discrete number of potential sources of soil contamination will be taken into account in addition, by restricting the survey to a small part of an urban area, the variety of different land-use types and mixes of land-use needed to be surveyed may not be present. This latter point is important since adopting this approach may limit the usefulness of the information output in a policy context. * 1.

4.2.7 All things being equal, the approach suggested in 4.2.4 (ii) above would appear to fullfill all the requirements - all urban areas being surveyed and thus the complete range of types and mixes of land-use and contamination sources will be included. However, the literature clearly demonstrates that soil heavy metal levels are heterogeneous (see section 3.6 of Chapter 3) and therefore this approach would present a number of intractable operational problems. For example, to carry out a 'national' survey of this scale would require many hundreds of thousands of soil samples to be collected and analysed, which is beyond the scope and resources of this present research study.

4.2.8 In the light of the above comment, given the resources available and the fact that one of the objectives of the research was to develop a simple

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* 1 It is also suggested that the same would be true if a transect approach were adopted.

cost-effective mapping methodology, it is concluded that a more tractable approach would be a survey carried out in a case study context, in an urban area of sufficient size to incorporate the range of land-use types and sources of potential soil heavy metal contamination. The West Midlands Metropolitan County was selected as the case study area for a number of obvious and practical reasons, which will be evident from the description of the case study area below.

4.2.9 The case study area selected for the development and application of the mapping methodology was the West Midlands Metropolitan County (WMMC) which is one of England's six Metropolitan Counties. The area of the WMMC is approximately 900 sq.km. and includes a population of some 2.7m. From figure 4.1, which shows the predominant land-use types in the WMMC, it can be seen that the WMMC is, in fact, an agglomeration of industrial and commercial centres interspersed with housing and open space uses. Over 70% of the area is in fact urban in character, the remainder being urban fringe or rural agricultural land. The WMMC can be conveniently divided into three geographic units. Coventry, a free standing industrial city in the East is separated from the remainder of the County by a rural wedge of agricultural green belt. The remainder of the County, known as the West Midlands conurbation, is a heavily industrialised area and is one of the U.K. major industrial and commercial centres.

4.2.10. The industrial heart of the conurbation is known as the 'Black Country', consisting of Walsall, and the heavily industrialised districts of Dudley, Sandwell and Wolverhampton. Its historical connection with the 'metal' industry can be traced back to the earliest days of the industrial revolution, when, at one stage, the conurbation was responsible for the majority of the country's primary iron and steel production. For well over 200 years, the WMMC has had a close association with the manufacture of metal based products ranging from mineral and metal ore extraction

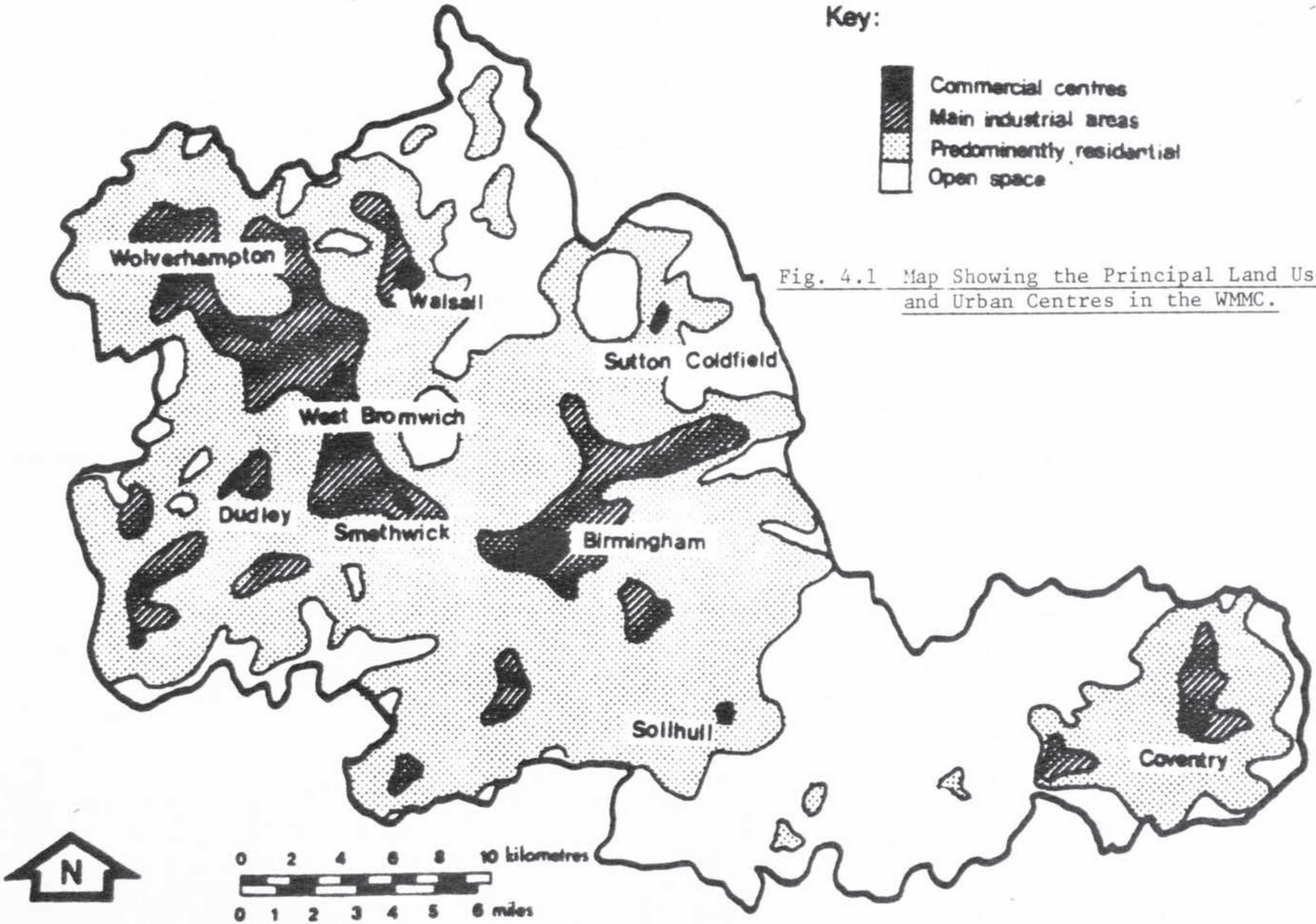

Fig. 4.1 Map Showing the Principal Land Use Types and Urban Centres in the WMMC.

through to the metal finishing industries and primary/secondary non-ferrous metal smelting operations. From the above description of the study area it is clear that the WMMC is particularly suited as a study area in which to develop and test a mapping methodology for background levels of heavy metal soil contamination.

4.3 Survey Design

4.3.1 The above has suggested that the research problem of mapping background levels of heavy metal soil contamination in urban areas would be more effective in a case study of a large Metropolitan County. This approach, however, introduces a number of methodological issues to which the survey design should respond. Results of research by several investigators (see for example studies by Wun Lin and Bradshaw, 1972; Chow and Johnstone, 1965; Le Riche, 1968; Buchauer, 1973, Davies, 1980) have clearly demonstrated that urban soils will exhibit high spatial variability of heavy metal levels. The problem rests on the fact that for survey results to be meaningful a relatively high density of sampling sites would be needed in order to achieve a representative sample for the whole study area. * 2. To achieve a sampling density of the required order, over an area the size of the WMMC, would require a total of many thousands of sites to be sampled and analysed (a conclusion supported by the work of Webb et al, 1978). Clearly this is an impractical task given the resources available, and the scope of the study.

4.3.2 Given the fact that it is neither possible nor practicable to sample, at a sufficient density, the whole of the case study area, there is a need to develop a sampling methodology from which the spatial variation of soil heavy metal levels may be mapped. How this may be achieved in practice is rather more difficult to resolve, since it is clear from the literature that a sample frame will have to be derived from first principles.

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* 2 i.e. a sample in which the sampling error variance is small enough for the results to be meaningful. Indeed, sampling itself can introduce errors on order of magnitude above those attributed to analytical error.

In addition, the use of a sample frame introduces other methodological issues - namely the problem of spatial auto-correlation. To what extent are observations at a single point representative of conditions at surrounding points, and, furthermore, to what extent are single observations representative of conditions at surrounding areas.

4.3.3 From the above discussion, it will be evident that the mapping methodology is essentially a two dimensional random sampling problem:

i) there is a need to divide the study area into suitable homogeneous units from which to sample.

ii) there is a need to decide on the most appropriate field sampling technique.

The above will be clearly influenced by:

i) expected spatial variation of urban soil heavy metal content.

ii) available resources for the survey.

iii) availability of data on which to base a sample frame.

The discussion below examines these issues in the light of the relevant literature.

4.3.4 It will be evident from the preceding discussion and literature review (chapter 3) that the present state of knowledge does not allow the definition of explicit criteria from which an appropriate sample frame and thus mapping methodology may be developed. Therefore, it is necessary to turn to other relevant literature for concepts which will aid the formulation of a suitable sample frame. The following section of this chapter reviews the most relevant literature and concludes with a discussion of the sample frame development.

4.4 Deriving the sample frame sampling units

4.4.1 Recent research, which has already been introduced in chapter 3 (see section 3.7) provides useful information on the problem of sampling and describing environmental conditions in large and varied urban areas. Of this 'State of the Environment' type work, it was concluded that the studies by Wood et al (1974) and Pocock (1979) contained concepts which are directly relevant to the research strategy of this study. The two studies tackled similar theoretical problems of mapping and describing the spatial variation of pollutants in urban areas. The first was a theoretically derived mapping study of Greater Manchester, which has been tested using secondary source data and has been reported by Wood et al (1974). The study by Wood, aimed at reviewing the geographical coincidence of urban pollution and to analyse there spatial relationship with other components of the pollution process, including the generation of pollutants. To study the 'geography of pollution' Wood proposed a sub-regional wastes-pollution model in which a two stage modelling process was envisaged, namely:

a) environmental condition in an area being primarily determined by the level of waste produced within the area.

b) the generation of wastes within an area is determined by the degree and type of land-use activity to be found there.

4.4.2 In spatial terms, therefore, Wood et al saw the degree and type of land-use activity in an area as being the prime discriminator of environmental conditions in an area. The model was developed to deal comprehensively with the spatial variation of air, water, land and noise pollution * 3. for a study area the size of a conurbation. Wood also recognised that land-use activities (and hence the wastes/pollution generation system), are not uniformly distributed over a study area. Therefore in applying

* 3 Although Wood recognised the importance of heavy metal land pollution, in this study, land pollution was taken to mean solid or semi-solid wastes deposited on land for which secondary source data was readily available.

the model, Wood considered it necessary to sub-divide the area selected for study into a number of smaller areas (homogeneous zones) to take account of such variation. The choice of boundary and the number and size of 'zones' into which a study area should be divided was important, and Wood suggests that a suitably sized grid square would be desirable. The actual size and choice of boundary, being determined primarily on data availability grounds and the wider policy issues to be developed from such a study.

4.4.3 The second study, reported by Pocock (1979) was an extension to the above work and took forward the theoretical proposition that environmental conditions in an area can be related to the urban land-use of that area. The research conducted by Pocock was to develop a simple and readily applied method for mapping ambient air pollution, noise conditions and sulphur dioxide pollution, in urban areas. Specifically, the study aimed at producing an 'area based spatial prediction model'. The research by Pocock was a spatial mapping methodology based on the classification of large and varied urban areas into typical 'urban fabric categories' termed 'Typical Area Elements'. Each 'Typical Area Element' was defined by two parameters - land-use and road network density, both of which were seen by Pocock as prime generators of air pollution in urban areas.

4.4.4 A key result from the work of Pocock, which has implication for the way in which the survey design of the present study should develop, was that the methodology allowed a spatially comprehensive coverage of thestudy area to be achieved without the almost impractical task of measuring at a very large number of sample sites. Ambient noise and sulphur dioxide air pollution, the pollutants studied, exhibit a high degree of spatial and temporal variability and yet through a classification of the urban areas based on land-use and road network density data, ambient environmental conditions (air pollution) were comprehensively and accurately mapped by sampling in 19 1.25 km. grid squares.

4.4.5 The major conclusion to be drawn from the above two studies is that the extent of pollution or 'environmental quality' within a zone is seen to be broadly dependent on the degree and type of land-use activity within that zone. In the case of heavy metal land contamination the above conclusion is supported by evidence from the literature (see chapter 3 section 3.6 and section 4.2.4 of this chapter) which clearly demonstrates that the extent of heavy metal land contamination in an area is dependent upon the degree and type of land-use in that area.

4.4.6 <u>Field sampling technique</u>

When agricultural or horticultural land is being sampled, to obtain information relating to soil fertility, plant health or public health exposure *4 the recommended practice (MAFF 1973) is to take numerous surface sub-samples on a 'W' pattern across the site or field being investigated and to combine the sub sample to give a single 'bulk' sample. Further, it is suggested that if the site or field is particularly large, or is one that needs to be studied in greater detail due to a suspicion of a high degree of variability, then the site should be divided into 'sub areas' and a 'composite' sample prepared for each sub-area in the manner described above.

4.4.7 In the guidance on sampling for field investigations of suspected contaminated sites, the ICRCL (see for example ICRCL, 16/78, 24/79) consider that 'spot' sampling on a random pattern across a site is more appropriate than the "1 sample per 'W' pattern" suggested by MAFF. Spot samples are preferred since it is considered by ICRCL that a 'W' pattern will inevitably combine high and low values to produce an average

* 4 Primarily related to the effect of deficiencies of nutrients and heavy metals (e.g. copper) in soils and their subsequent effect on plant growth.

'unrepresentative sample' *5, whereas spot samples have been shown to produce more meaningful results. Further advice on the approach to sampling by ICRCL includes the recommendation that the field sampling programme should be related to the stage of development and the intended after use of a particular site *6 Guidance on the actual field sampling technique is limited to suggesting that the most straightforward approach is to sample on a regular grid pattern (10, 25, 30 or 100 m grids are recommended) with individual samples being taken from surface layers (250 mm) and where necessary, at depth.

4.4.8 Although both of the above approaches to sampling obviously have their advantages, they have both been derived for a particular situation or for particular circumstances. When sampling contaminated land there is a need to know, in detail, where the high levels of heavy metals are to be found. In the case of the agricultural land sampling techniques, it will generally be the case that such land is unpolluted * 7 and only a small number of samples over a large area would be necessary to obtain meaningful data. However, it is considered that neither of the above approaches is appropriate to the problem of sampling in the context of the present research study. In the case of the MAFF 'W' pattern there may be operational difficulties in constructing suitable 'W' patterns in industrial or commercial centres. Sampling on a closely spaced regular grid, even at 100 m square, will involve the taking and analysing of many thousands of soil samples over the suggested study area (which is over 900 sq.km.in size.

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* 5 The results from past soil studies of heavy metals in urban areas has shown that even in polluted areas, low background levels will still be found.

* 6 The ICRCL offer guidance on the redevelopment of contaminated sites. The aim here is to match the sampling programme to the nature of the survey. For example, a preliminary survey is likely to be less comprehensive than a programme needed for the drawing up of remedial treatment.

* 7 Except in the case of the application of sewage sludge contaminated with heavy metals, but even in these there are codes of practice limiting the application role of metal sludge to land, see chapter 3.

4.4.9 From the above discussion, it is clear that in order to survey and map the background levels of heavy metal land contamination in the WMMC, the study area will have to be divided into a small number of homogeneous sampling units from which representative soil samples can be taken. This approach is consistent with the work of arrett (1974) who suggests that in soil surveys of large areas, the allocation of sampling units is made more statistically efficient if the study area is classified into relatively homogeneous units. Unit boundaries should separate areas where within class variance is less than between class variance.

4.5 Selection of the Survey Sample Frame Parameters

4.5.1 In section 4.3.1, it was stated that to achieve a sampling density to the required order, to take account of the expected variation in the soil heavy metal content, across an area the size of the WMMC, would require many thousands of sites to be sampled. It is suggested here that an alternative 'mapping methodology', based on the proposition put forward by Wood and tested by Pocock, is the more appropriate methodology to survey the spatial variation of soil heavy metal levels in the WMMC. The methodology is based on the proposition that different types of area have their own particular distinctive pollution conditions.

4.5.2 It will be evident that the key to the success of such a methodology lies in classifying the study area into categories of land-use that have distinctive and different characteristics, which in turn will give rise to differing levels of background heavy metal soil contamination. * 8. Therefore the next important task in the survey design was to choose suitable 'descriptions' of the urban area as parameters through which a usefully limited number of 'unique' sampling units may be identified.

* 8 Contamination is chosen to differentiate typical or naturally occurring levels of heavy metals in soils which are naturally present in the parent material.

4.5.3 There is considerable evidence in the literature, in both theoretical and practical studies (see for example Wood et al, 1974; Pocock, 1979, studies by Harrison, 1979, Duggan and Williams, 1977, Cool, 1980; and other relevant literature reviewed in chapter 3) that land-use type and intensity of land-use in an area should be selected as the parameters from which to classify the case study into sampling units. Although land-use type data is readily obtainable, 'intensity' of land-use is rather more difficult to deal with. However, intensity of land-use is a necessary component to the classification since it is recognised that in large and varied urban areas, environmental conditions may vary significantly between categories of area defined by the same land-use type. A similar argument is put forward by Wood et al (1974) who suggest that it is essentially the degree (or intensity) of land-use that causes conditions to vary between areas of otherwise similar land-use type.

4.5.4 To obtain further information on how 'intensity' of land-use may be defined, it is necessary to briefly examine the relevant literature. Information which may be used to describe the 'intensity' of land-use in an area is contained in an 'Urban Fabric and Building Intensity' study of Birmingham, conducted by JURUE (1977). This study concluded that there is a significant correlation between intensity of land-use and 'distance from the city centre'. Other studes (see for example, Davies, 1979; Klein, 1972) have used expressions such as 'rural', 'suburban', and 'central area' as expressions of intensity of land-use, implying a notion of 'distance from the centre'. However, the use of 'distance from city centre' as a measure of intensity of urbanisation is not a practical proposition in the context of large Metropolitan urban areas such as the WMMC. This is because the WMMC is an agglomeration of many small, intensely developed urban areas, with industrial and commercial centres intermixed with dense residential development, and in recent years, artificially imposed open,'rural' areas. The only typical structure of a free standing town is Coventry in the East of the WMMC., and therefore the idea of a free standing city centre is not relevant in this case study area.

In the work of Pocock, 'intensity' of land-use was taken to be represented by the number of 'road network nodes' in an area. * 9 The study by JURUE on building intensity, provided empirical evidence that 'road network density' and 'distance from the city centre' were correlated. In addition, from a geographical perspective, the road network density of an area implies how intensely developed and used an area is.

4.5.5 In the light of the above discussion it is now concluded that the sample frame will be based on the classification of the case study area into unique sampling units. The classification being developed from two parameters - land-use type and intensity of land-use, where 'intensity' is taken to be the density of the road network. It is the resulting unique units of area, which are to be used as a sample frame from which to estimate the total spatial variation of heavy metal levels in the WMMC.

4.5.6 Size of Zone

Having decided on the parameters to be used as a means of classifying the study area into sampling units; the next stage in the design of the mapping methodology is to select the most appropriate size of unit from which to sample. On the basis of available evidence, it appears that the favoured size of unit used in 'general environmental surveys' has

* 9 in this study, network nodes were either major junctions in the transportation network or network traffic loading points.

been one or two kilometre square grids (see for example, South Yorkshire County Council, 1978, 1979; Cheshire County Council, 1977; Pocock, 1979; Merseyside County Council, 1979). In line with this evidence, taking into consideration the need for a simple, cost effective and readily applicable methodology and the fact that up to date land-use data was readily available on a kilometre grid square basis for the study area, it was decided to use a one Km.grid as the basic sampling unit.

4.5.7 The stage has been reached in the research where the necessary conceptual basis for an appropriate sampling methodology has been established. Since the study is concerned with the division of the WMMC into homogeneous units based upon the type and intensity of land-use found across the WMMC, the next stage is to obtain spatially comprehensive data on land-use and road network density, from which a suitable classification may be made. This aspect of the study is summarised below and discussed in detail in appendix A.

4.6 Collection of Data

4.6.1 Land-Use Data

Land-use data for the whole of the WMMC area were directly available from secondary sources. A composite 1:50,000 scale land-use map of the WMMC was compiled from three data sources;

i) the 1976 land-use map available from the WMCC which consisted of 1:10,000 (1:20,000 in the case of Solihull) scale district council land use maps aggregated to a 1:50,000 scale map of the county as a whole.

ii) the WMCC 1979, derelict and vacant land map. * 10.

iii) the 1979, (2nd edition) 1:50,000 scale ordnance survey map of the WMMC.

From the detail in appendix A, it can be seen that eleven categories of

* 10 Included because over 1.7% of the total land area of the WMMC is derelict land and if waste land is included, this amounts to over 5% of the land area (Haines, 1978).

land-use were available on the WMCC land-use maps and it was decided to aggregate some of the categories to give six major categories of land-usc for use in the mapping study.

The six major categories of land use are:

i) residential - including schools, hospitals and prison buildings.

ii) industrial - including active mineral extraction sites and public utilities.

iii) commercial - including town halls and public assemblies.

iv) recreational - including school and hospital grounds, woodland, parks etc.

v) vacant land - including derelict, and waste land.

vi) agricultural.

4.6.2 A 1:50,000 scale km. grid base map was made from the 2nd edition O.S. map and overlaid on both the WMCC land-use map and vacant/derelict land map. A copy of the pattern of land-use for the WMMC was then made onto this base map, with the categories of land-use restricted to the six major categories summarised above. From this new land-use map, it was possible to obtain a measure of the proportion of each km. grid square occupied by the above six land-use types (see section A.4 of appendix A). It should be noted that at the spatial scale being used, it was neither possible nor necessary to include every detail of land-use. Thus, areas zoned 'residential', 'industrial', or 'commercial' do not imply that all such land is covered by buildings. Similarly, 'recreational' and 'agricultural' land may contain isolated buildings. In addition, transportation routes have been totally excluded, so that roads, railways and canals are allocated to the land-use category of the area they pass through. Each of the 1003*11 km.grids of the WMMC therefore contained a 'unique' individual combination of the six land-use categories.

* 11 Includes boundary grid squares.

4.6.3 Road Network Density

Road network density was taken as a measure of 'intensity' of land-use within an area. Data for road network density was obtained from secondary sources. In fact, as detailed in appendix A, it was decided to use the number of road intersections (nodes) as a measure of road network density. Nodes per km. grid were calculated by counting all road intersections as shown on the 1:50,000 scale (2nd edition) O.S. map. An 'intersection' is taken to be a normal 'T' junction and crossroads count as two 'intersections' - i.e. 2 nodes. An additional node is counted for every extra road at an intersection in excess of 4. *12.

4.6.4 In order to give a usefully limited number of categories for use as a sample frame, network density was grouped into 5 categories according to the following criteria:

i) there was a broadly even distribution of nodes in each category.

ii) there was a systematic interval size for the five groups.

iii) natural groupings within the distribution were to be taken into account.

The distribution of nodes within each of the five categories is shown in figure A.1 of appendix A. which also contains the detailed information on the grouping of nodes. Table 4.1 below summarises this classification.

Table 4.1

Classification of Road Network Density in the WMMC

	Range (Nodes per grid square)				
	0 -10	11-23	24-37	38-53	54
Code	E	D	C	B	A
No. of grid squares in each category	348	209	236	152	58
TOTAL	1003				

The sources and extent of error in this bivariate classification of the WMMC Urban Fabric Data are discussed in section A.5 of appendix A.

*12 For example, 6 roads intersecting at a roundabout would count as '4 nodes'.

4.7 Definition of 'Area-Types'

4.7.1 In order to achieve a number of sampling units from the above urban fabric data, it was necessary to classify the 1003 grid squares of the WMMC according to a typology of the urban fabric involving both the six land-use categories and five network density groups. The aim of this secondary grouping is to reduce the 1003 grid squares to a small number of unique 'area-types' *13 covering the range of land-use types and network density that exist in the WMMC. During the collection of data and subsequent statistical groupings it was recognised that a functional relationship exists between land-use and road network density. For example, in line with findings of the JURUE (1977) work in Birmingham, commercial land use will not generally be found in areas of sparse network density areas. (See figure A.4, appendix A). This relationship was also identified and utilised in the air pollution mapping study of Pocock (1979).

4.7.2 Therefore it was decided to produce a typology which resulted from a grouping of land-use types within each of the five network groups (A to E). Firstly, each grid square was allocated to one of the five network groups based on the number of road junctions (nodes) in that grid square. Next, each of the five network groups were then classified by land use type through a qualitative 'cluster analysis' of the land-use data. *14.

4.7.3 Through the above procedure, 20 'urban fabric' categories, termed 'area-types were achieved and are described in figure 4.2. The frequency distribution of the 1003 WMMC grid squares within those 20 'area-types' is shown in table 4.2. The next stage is field sampling and laboratory analysis of soil samples taken from within 20 'area-types'. This procedure is discussed below.

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*13 'Area-type' is the name given to the grid square once they have been categorised according to the six land-use categories and five network density groups.

*14 Because there is this functional relationship between land-use and network density in terms of their impact on environmental conditions in an area, it would be theoretically sub-optimal to define land-use categories independent of network density groups.

Fig. 4.2 Description of the Classification of Area Types.

ROAD NETWORK DENSITY

A. (High	B.	C.	D.	E. (Low)
1. Majority commercial, small amounts of industry and residential land.	1. Majority residential, small proportions of industry and recreational land.	1. Almost all residential, a very small amount of vacant or recreational land or small shopping areas.	1. Mainly industrial but also vacant land and residential areas.	1. Industrial vacant and recreational land, broadly mixed.
2. Majority residential but with a considerable mix of industry and/or commercial areas.	2. Broadly even mix at residential and industrial land.	2. Broad mixed industry and residential land.	2. Even mix of residential and recreational land.	2. Majority recreational but mixed with substantial residential areas.
3. Majority residential, small proportions (less than 20%) of recreational or vacant land.	3. Majority residential but also small commercial areas.	3. Majority residential, some vacant land possibly associated with industry.	3. Mosity residential but substantial presence of vacant land, also some industry.	3. Majority agricultural but noticeable amounts of residential land.
	4. Majority residential but also noticable amounts of recreational and/or some vacant land.	4. Majority residential but significant amounts of recreational and/or agricultural land.	4. Agricultural/residential mix, with agriculture predominant.	4. Majority usually agricultural land but also mixed with substantial recreational land.
				5. Almost entirely agricultural.

Table 4.2 Percentage of the Total WMMC Area in each Area-Type.

Land Use Categories	Road Network Density Catedories				
	A	B	C	D	E
1	0.8	6.8	7.3	4.6	3.0
2	3.1	3.8	6.0	6.8	3.8
3	0.8	1.2	4.1	4.0	4.8
4		4.4	6.6	5.7	7.0
5					15.6

4.8 Field Sampling

4.8.1 Decisions on the choice of the optimum sampling density is dependent upon the spatial variability of heavy metals in the study area and the desired accuracy in the mean soil heavy metal content. Chapter 3 and earlier sections of this chapter have shown that guidance on the appropriate sampling density is not readily available in the literature. In fact, of the studies reported in the literature, a variety of field sampling densities have been adopted to suit individual circumstances. The majority of the past studies have approached the mapping (and thus sampling) of the spatial distribution of heavy metals either at the micro-scale (small areas sampled in detail around point sources, e.g. smelter, or have restricted sampling to specific land-use types such as allotments or parkland within the urban area. Few, if any of these studies have statistically tested the results obtained from sampling, since their main purpose has been to simply obtain information on present levels of soil contamination. In addition, the choice of the number of samples to take in the field was conditional upon three factors:

i) the study has as one of its objectives, to obtain a measure of the spatial variation in soil heavy metal content in the most cost-effective and reliable way.

ii) the actual spatial variability of soil heavy metal levels in the WMMC.

iii) resources available in terms of field sampling time and subsequent laboratory analysis.

4.8.2 A pilot study undertaken in four grid square examples of the 20 area-types indicated that the use of 9 soil samples taken from within each one Km. grid square provides sufficient sample data to obtain a meaningful measure of the spatial variation of soil heavy metal levels. The result from the study also confirms that in order to achieve a much higher spatial coverage within each grid square, it would be necessary to collect soil from 6 sample points[*14] within a 30 metre radius of each of the 9 sample

*14 Additional data supporting the use of sample point and bulking of sample points is contained in appendix C, which is data from a parallel study under taken in Walsall Borough by JURUE (1982).

PAGE

NUMBERING

AS ORIGINAL

sites and to bulk the six sample point soils to form a 'composite' sample for each of the 9 sample sites. In this way, soil samples would be collected from a much larger area and thus reduce the sampling error associated with taking a small number of samples as being representative of a large area which may contain both very high and low levels of heavy metals. *15.

4.8.3 Therefore, a soil sampling programme was established using the 20 'area-types', discussed below, and as shown in figure 4.3. Soil samples were collected from randomly selected examples of each of the 20 'area-types'. As a check/validation of the accuracy of the method and to obtain a measure of the error, which could be statistically tested, a further set of 20 'area-types' were sampled in an identical way. The detailed discussion of the field soil sampling technique is contained in appendix B. Briefly, the km. grid to be sampled was located in the field. Within each km. grid, 9 sample sites were selected at random where suitable sampling conditions existed. For each 'sample area' grid square, 54 sample points and 9 independent measurements of soil heavy metal levels were achieved. For the WMMC as a whole, 3,240 sample point and 360 independent measures of soil heavy metal levels were made.

4.8.4 The decision to restrict the field sampling to surface soils was made because it has already been demonstrated (section 3.4, chapter 3) that pollution of soils by heavy metals is dominantly a surface contribution and it will be the surface horizons in soil which will bear the clearest indication of pollution. *16. In many respects, it is often the surface soil contamination that is of greatest concern, particularly where public health and plant health is concerned. Several studies have reported the

*15 It must be re-emphasised that the purpose of the research is to obtain information on the spatial variation of background levels of heavy metal soil contamination and therefore the study is not solely concerned with detecting extremes. Detailed data supporting the use of a composite sample is contained in appendix C.

*16 To prevent cross contamination from filed sampling and contamination of samples during the preparation and acid digestion stages prior to analysis for heavy metals, a rigorous cleaning procedure was adopted. See appendix B.

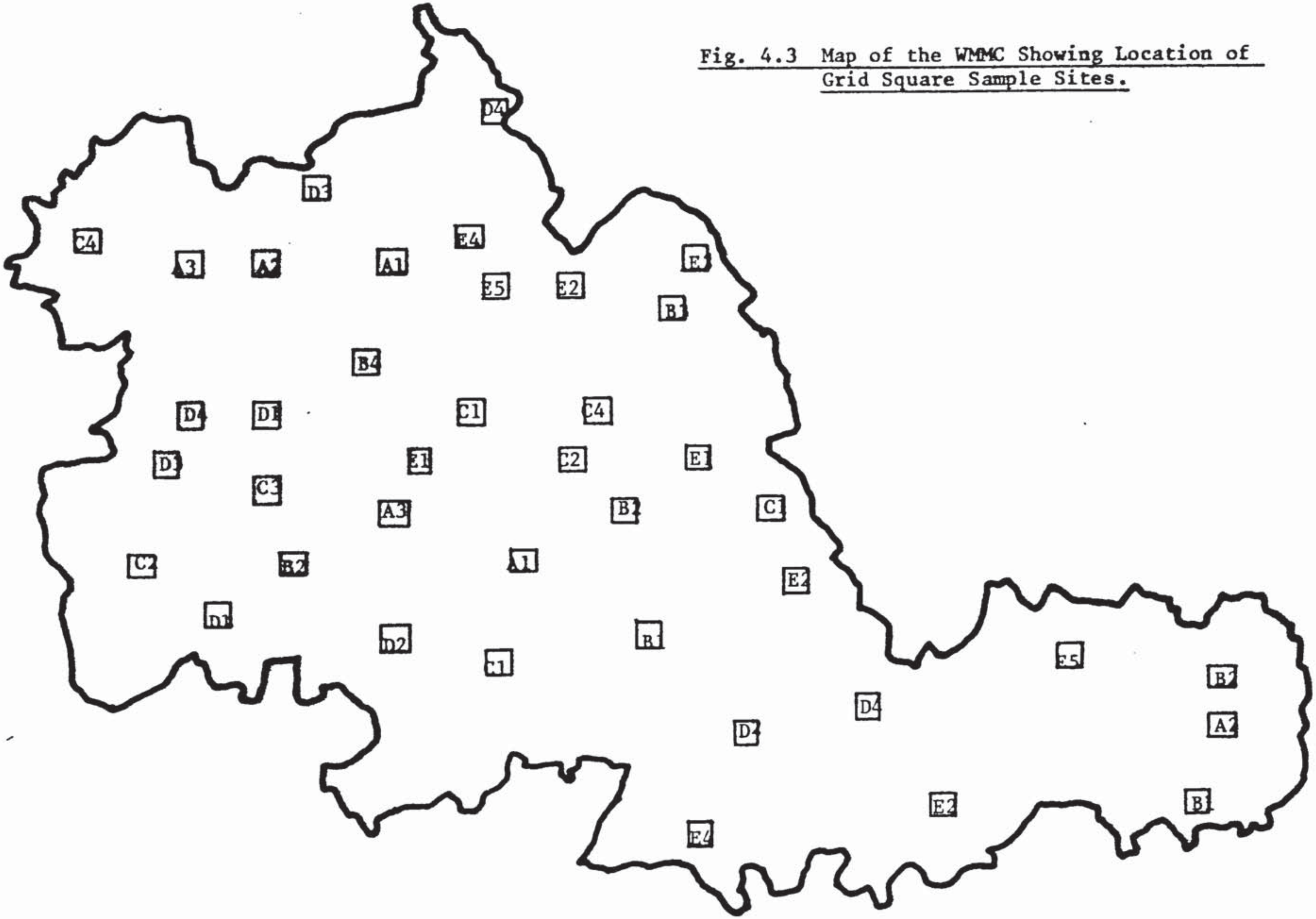

Fig. 4.3 Map of the WMMC Showing Location of Grid Square Sample Sites.

accumulation of heavy metals in the top 0-20 cm. soil, with slow migration of heavy metals down the soil profile (see for example Korte et al 1976, Chow 1970, Marten & Hammond 1966, Beavington 1975). Of these studies, many have reported that below 40 cm. soil depth, heavy metal levels reach levels which are considered to be naturally occurring background levels for the particular area. In the case of lead for example, John (1971) in studying 700 soil samples from British Columbia, concluded that the high lead levels in the soil samples was confined to surface horizons with a marked decline in lead levels with soil depth. A summary review of the data supporting the above statements is contained in appendix D.

4.8.5 In line with the above discussion, surface soil samples, taken to be soil below the first 10cm. of cover (see section B.2 of appendix B.) were collected using 'clean' stainless steel soil sampling equipment. *17. In all cases upper grass and 'debris' were removed prior to the collection of the surface soil at the sampling points. Each individual soil sample (being a composite of 6 sampling points) was stored in a labelled polythene bag, sealed until analysis, for return to the laboratory.

4.9 <u>Laboratory Analysis of Soil Samples</u>

4.9.1 The laboratory procedures used in the analysis of soil samples for their heavy metal content are presented in detail in appendix B. Several possible analytical techniques have been used to determine the concentration of heavy metals in soil. They can be broadly divided into two groups; techniques concerned with estimating the 'total' heavy metal content of soils and techniques concerned with estimating the 'readily available' * 18 heavy metal content of soils. The problem of selecting the most appropriate analytical technique is complicated by the variety of methods (see appendix B) and the fact that to date there are no "Standard" contaminated soils on

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*17 Slightly below the rooting depth of vegetation.

*18 'readily available' is a summary term for techniques which estimate bio-availability of heavy metals in soils. For example, the amount of heavy metal in the soil which may be taken up by plants or released from soil through acid dissolution in humans.

which analytical techniques have been developed and tested. In this study, both total and available heavy metal contents of soil are of interest. The total level is of interest because of potential public health effects from ingestion and inhalation of contaminated soil, and the available content is of interest due to potential phytotoxic effects of heavy metals on plant and crops.

4.9.2 Therefore, standard analytical procedures were used to obtain a measure of the 'total' and 'plant available' heavy metal lead, cadmium, copper and zinc. The 'total' heavy metal concentrations were determined from solution of metal extracted from the soil samples by wet digestion in concentrated nitric and perchloric acids. The 'plant-available' metal concentrations were determined from solution of metal extracted from soils using an ammonium acetate (EDTA) extractant. The concentration of the metals of interest were measured in the 'digests' and 'extracts' by flame and, where necessary, flameless atomic absorption spectrophotometry (AAS). A Perkin Elmer 560 AAS double beam instrument, using deuterium arc background correction was used for all determinations. The concentrations of the heavy metals were obtained through comparison to dilutions of stock standard solutions especially prepared for AAS by BDH Chemicals Ltd. Individual hollow cathode lamps were used in the determinations with lamp alignment, burner angle and sample aspiration rates adjusted to achieve maximum sensity of the machine.

4.9.3 To obtain the concentration of the four heavy metals in each sample, two separate methods were employed. In the first method, direct readings of concentration could be obtained from the instrument through the use of the 'internal' calibration of the instrument using three made up standards of the metal of interest. So long as the concentration of the metal being determined is below the linear range of that particular element, a direct reading of concentration could be had. The second method, used as a check of the instrument readings, involved the transfer of absorption signals to a potentio-meter recorder. A calibration plot of the 'standard' readings was made from the chart recording which is then used to convert readings obtained for the AAS in the absorbance mode to concentrations of the metal in the sample solution. In both cases, it was necessary to dilute samples to obtain readings that were beyond the linear range of the instrument for the element being determined. Both methods of obtaining the concentration of heavy metals did not produce significantly different results.

4.9.4 Error in the results can occur from a number of possible sources, the most obvious being cross contamination. To prevent cross contamination of soil samples, a thorough and rigorous washing procedure was adopted at all stages (see appendix B). Error can also occur from contaminants present in the chemicals used for digestion and extraction of heavy metals and in the dilution of the samples. To reduce this source of error, only high purity 'Aristar' grade chemicals were used in all analyses. In addition, to take account of any possible contamination of samples during sample preparation and dilution, reagent blanks were prepared in exactly the same way as the samples and analysed for the four heavy metals. Any results from the analysis of reagent blanks were then subtracted from the final results obtained for each soil sample.

4.10 Conclusions

4.10.1 This chapter has discussed in detail the approach adopted in the research to survey and map the spatial variation of soil heavy metal content. The principal methodology used has been an estimation mapping methodology using land-use type and intensity of land-use (road network density) as parameters through which the urban area could be categorised. The concluding sections of this chapter have briefly summarised the field sampling technique and choice of sampling density through which the 360 soil samples were collected. In addition the laboratory analytical procedures used to obtain the concentrations of lead, cadmium, copper and zinc have been summarised. The following Chapter 5 presents and discusses the results from the analysis of the soil samples collected from the 40 grid squares in the WMMC. Chapter 5 also contains the results of the statistical tests used to validate the sampling methodology. The discussion on the use of the information output of the survey results to derive 'reference levels' is contained in Chapter 6.

CHAPTER 5

5.1 Introduction

5.1.1 The function of this chapter is to present and discuss the results from the analysis of soil samples collected from the 20 'area-types' used as a sample from which to estimate the spatial variation of heavy metal levels in the WMMC. The chapter is divided into two parts. Part 1 reports the results and is structured as follows. The first three sections are concerned with the detailed description of the results for individual soil samples, their spatial variation both between and within the 'area-types'. This is followed by an interpretation of the measured levels of heavy metals in the soil samples. This is achieved in two ways; through reference to normal 'unpolluted' levels and in the light of data from other contemporary studies.

5.1.2 Part 2 of this chapter is concerned with examining the validity of the sample data as a sample. Therefore, section 5.5 presents the statistical testing and validation of the use of sample data from the 20 'area-types' to estimate the spatial variation of heavy metals for the whole case study area. This is followed in sections 5.6 and 5.7 by the presentation and discussion of the grouping of the data to produce 'background soil contamination' maps for the WMMC. Part 2 concludes with a discussion of the mapped spatial variation of soil heavy metal levels. The interpretation of the results in the light of current soil contamination standards and the use of the information on background levels to operate 'reference levels' for land contamination in urban areas is contained in the following Chapter 6.

5.2 Discussion of Results

5.2.1 Tables 5.1 and 5.2 are summary tables of the 'area-type' mean and ranges of 'total' and 'available' levels of lead, cadmium, copper and zinc. The

TABLE 5.1 AREA-MEAN AND RANGE OF 'TOTAL' METAL CONCENTRATIONS IN THE TWENTY AREA TYPES (Mg/kg)

Land Use Classif-ication	Metal	Road Network Density Category									
		A		B		C		D		E	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1	Lead	240	60-525	165	13-758	137	25-387	140	22-519	272	21-1591
	Zinc	1496	10-7843	309	42-747	324	76-813	616	67-2714	343	67-1625
	Copper	374	26-2566	95	8-333	134	13-369	98	28-647	174	15-604
	Cadmium	4.68	0.39-30.3	1.35	0.1-2.94	0.72	0.16-2.98	2.8	0.7-13.2	3.36	0.16-19.3
2	Lead	189	24-502	474	28-2232	219	59-760	109	22-751	76	13-266
	Zinc	674	133-5344	1010	87-5040	837	147-3024	179	85-357	161	26-414
	Copper	460	17-4574	285	16-1105	279	24-1426	28	10-77	23	4-89
	Cadmium	1.37	0.24-6.3	1.64	0.21-5.8	2.07	0.54-8.6	0.72	0.13-1.27	0.92	0.1-3.25
3	Lead	297	49-1883	161	12-763	92	8-250	119	15-91	149	23-1998
	Zinc	477	109-1676	283	41-797	126	30-250	418	122-1714	151	61-611
	Copper	108	26-449	83	9-209	39	10-72	90	21-511	18	9-55
	Cadmium	1.08	0.36-2.6	1.57	0.17-5.91	0.69	0.1-2.7	2.45	0.13-25.63	0.57	0.25-1.22
4	Lead			97	7-419	114	36-384	139	38-404	110	5-707
	Zinc			548	47-2747	255	45-806	353	109-798	144	45-271
	Copper			65	12-372	83	21-235	84	12-501	45	8-119
	Cadmium			0.82	0.35-1.89	0.9	0.25-2.7	1.32	0.64-3.18	0.65	0.15-2.3
5	Lead									49	14-104
	Zinc									134	67-229
	Copper									32	11-101
	Cadmium									0.55	0.21-1.5

TABLE 5.2 AREA-MEAN AND RANGE OF 'AVAILABLE' METAL CONCENTRATIONS IN THE TWENTY AREA-TYPES (Mg/kg)

Road Network Density Category

Land Use Classif-ication	Metal	A		B		C		D		E	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1	Lead	131	42-288	109	9-452	89	26-199	56	10-170	143	14-758
	Zinc	360	17-2488	83	5-227	87	16-297	183	3-1,288	89	6-410
	Copper	133	11-1220	33	4-129	50	7-105	36	6-202	57	8-189
	Cadmium	1.55	0.29-9.65	0.65	0.12-1.63	0.83	0.23-4.2	1.26	0.01-6.29	1.01	0.14-5.0
2	Lead	65	23-146	121	24-292	92	24-241	68	13-318	54	12-201
	Zinc	73	7-167	147	12-1109	200	18-990	60	8-149	38	5-142
	Copper	85	15-364	46	9-141	142	10-859	16	7-42	10	2-25
	Cadmium	1.17	0.2-5.65	0.83	0.2-2.25	1.42	0.45-5.35	0.48	0.22-8.81	0.51	0.12-2.1
3	Lead	108	35-743	69	8-149	57	3-162	69	4-331	34	14-103
	Zinc	232	15-1205	77	6-285	39	5-94	117	5-756	21	7-81
	Copper	44	15-162	24	6-70	18	2-76	38	7-241	9	4-26
	Cadmium	0.87	0.25-1.83	0.67	0.12-1.66	0.57	0.06-1.09	2.12	0.19-17.14	0.31	0.15-0.7
4	Lead			57	4-223	85	27-225	67	13-198	42	2-80
	Zinc			60	11-139	79	5-454	70	8-149	38	1-111
	Copper			21	2- 81	37	10-101	24	7-42	26	4-113
	Cadmium			0.69	0.21-1.3	0.88	0.25-2.65	0.70	0.22-0.89	0.44	0.07-1.07
5	Lead									36	7-77
	Zinc									31	6-89
	Copper									15	3-37
	Cadmium									0.50	0.09-1.12

mean is obtained from averaging the results for each heavy metal for the 18 individual soil samples collected as being representative of each 'area-type'. The range is the highest and lowest recorded value of each heavy metal for the individual 'area-type' obtained from the data for the grid squares where soil sampling took place. Tables 5.3 and 5.4 are the 'area-type' mean metal concentrations for the four heavy metals, ranked independently, from highest to lowest.

5.2.2 The data in tables 5.1 - 5.4 clearly llustrate the high variability of soil heavy metal levels in urban areas and confirm the survey results reported in the literature for urban soils (see for example Beavington, 1973; Davies, 1980; and section 3.4 of Chapter 3). It is also evident from the results tables, that significant differences exist between the 20 area-types in the means and ranges for all four heavy metals. For example, the results show that for inner urban industrial areas (A3, B1 for example) the levels of heavy metals are significantly higher than in the more rural area (E2 and E5). The data for measured levels of both total lead and cadmium in the soil samples illustrate this point. For example, total lead levels in 'area-type' B3 range from normal levels (100 mg/kg) *1 to results for individual soil samples having a total lead content in excess of 2000 mg/kg, showing marked contamination. For the total cadmium content of soil samples, there are several instances where the area-mean levels exceed 3 mg/kg and in the case of area-type A1 ranges up to 30 mg/kg. The above general comments are discussed in more detail for the individual heavy metals below.

5.2.3 <u>Total Lead Levels</u>

The mean total lead level in the 20 area-types ranged from 49 mg/kg in area-type H5 (rural agricultural land) to 474 mg/kg in area-type B2 (broad mix of industrial/commercial and residential land in inner urban

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*1 In chapter 3 see the discussion of mapping soil heavy metal levels, presented 'normal' taken from a range of data sources.

TABLE 5.3

'AREA - MEAN' TOTAL METAL CONCENTRATIONS RANKED

	LEAD		CADMIUM		ZINC		COPPER	
Rank	Area-type Code	Mean (mg/kg	Area-type Code	Mean (mg/kg	Area-type Code	Mean (mg/kg	Area-type Code	Mean (mg/kg
1	B2	474	A1	4.68	A1	1496	A2	460
2	A3	297	E1	3.36	B2	886	B2	285
3	E1	274	D1	2.80	C2	837	C2	279
4	A1	240	D3	2.45	A2	674	A1	217
5	C2	219	C2	2.07	D1	616	E1	174
6	A2	189	B2	1.64	B4	584	C1	124
7	B3	162	B3	1.57	A3	478	A3	108
8	B1	154	A2	1.37	D3	418	D1	98
9	E3	149	B1	1.35	D4	354	B1	95
10	D1	140	D4	1.23	E1	344	D3	90
11	D4	139	A3	1.06	C1	318	D4	84
12	C1	137	E2	0.92	B1	309	B3	83
13	D3	119	C4	0.90	B3	283	C4	83
14	C4	114	B4	0.82	C4	244	B4	65
15	E4	110	C1	0.72	D2	179	E4	45
16	D2	109	D2	0.72	E2	161	C3	39
17	B4	97	C3	0.69	E3	151	E5	32
18	C3	92	E4	0.65	E4	145	D2	28
19	E2	76	E3	0.57	E5	134	E2	23
20	E5	49	E5	0.55	C3	126	E3	18

TABLE 5.4

'AREA - MEAN' AVAILABLE METAL CONCENTRATIONS RANKED

	LEAD		CADMIUM		ZINC		COPPER	
Rank	Area-type Code	Mean (mg/kg)	Area-type Code	Mean (mg/kg)	Area-type Code	Mean (mg/kg)	Area-type Code	Mean (mg/kg)
1	E1	143	D3	2.12	A1	360	C2	142
2	A1	131	A1	1.56	A3	243	A1	133
3	B2	121	C2	1.42	C2	200	A2	85
4	B1	109	D1	1.26	D1	183	E1	58
5	A3	107	A2	1.17	B2	148	C1	49
6	C2	92	E1	1.01	D3	117	B2	46
7	C1	89	C4	0.88	E1	94	A3	44
8	C4	85	A3	0.87	C1	87	D3	38
9	B3	69	C1	0.83	B1	83	C4	37
10	D3	69	B2	0.83	C4	79	D1	36
11	D2	68	D4	0.70	B3	77	B1	33
12	B4	68	B4	0.69	A2	73	E4	26
13	A2	65	B3	0.67	D4	70	B3	24
14	C3	57	B1	0.65	B4	61	D4	24
15	B4	57	C3	0.57	D2	60	B4	21
16	D1	56	E2	0.51	C3	39	C3	18
17	E2	54	E5	0.49	E2	38	D2	16
18	E4	41	D2	0.48	E4	37	E2	10
19	E5	36	E4	0.44	E5	31	E5	10
20	E3	34	E3	0.31	E3	21	E3	9

areas). The range of lead levels in the 360 sample points was 5 mg/kg (area-type E4) to 2232 (area-type B2). Indeed it was in area-type B2 that the widest individual area-type range was recorded, being 28-2232 mg/kg. Even in the relatively unpolluted area-types this variability in soil lead content is high being 5-707 mg/kg in area-type E5. The general pattern of total lead content of soils in the WMMC is of high area-means and larger ranges in the inner urban industrial areas than in the more rural agricultural areas. Figure 5.1 is a histogram (log linear plot) showing the distribution of the measured concentrations of total lead in the 360 soil samples. The histogram shows that the distribution is normal with a peak of total soil lead levels in the range 70-100 mg/kg reflecting 'normal' concentration in a range of soils reported in several studies (see for example, Bowen, 1979; Swaine, 1955 and Williams, 1981). This histogram was taken from a dispersion graph plot of the 360 sample point results, grouped by area type, for total lead, plotted on long/normal graph paper as shown in figure 5.2. The use of log-scale graph paper had the effect of 'stretching' the 'bunching' of values at low levels whilst keeping the 'tail' of high levels in perspective. From the dispersion graph it can be seen that in the predominantly rural/agricultural areas (e.g. area types E5, C3, B4) average total lead content of soils are between 50-150 mg/kg. This contrasts with the results for inner urban residential and industrial areas (e.g. area-types B2, A2 and C1) where the average total lead content of soils are between 200 and 280 mg/kg. The dispersion graph also illustrates clearly that the majority of the results for total lead in the WMMC soils are in a broad range between 10-100 mg/kg, with some 21% of all results in excess of 200 mg/kg. In the case of measured concentrations of total lead, three characteristics are clearly discernible in the distribution plot. Firstly, there is a general elevation in lead levels from rural 'background' levels of 50-100 mg/kg to high concentrations in the more urban areas of higher network

Fig. 5.1 FREQUENCY DISTRIBUTION - TOTAL LEAD LEVELS.

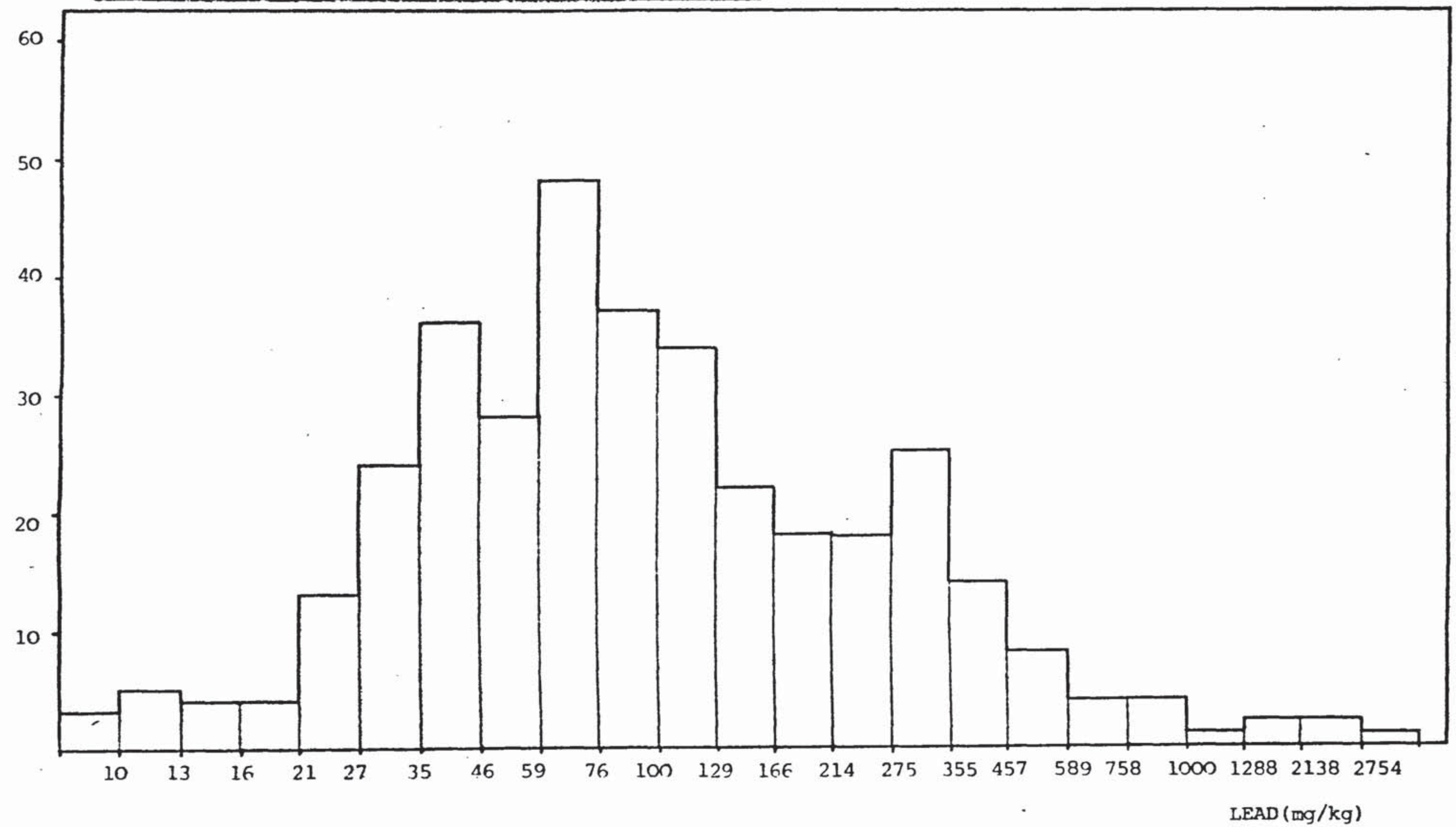
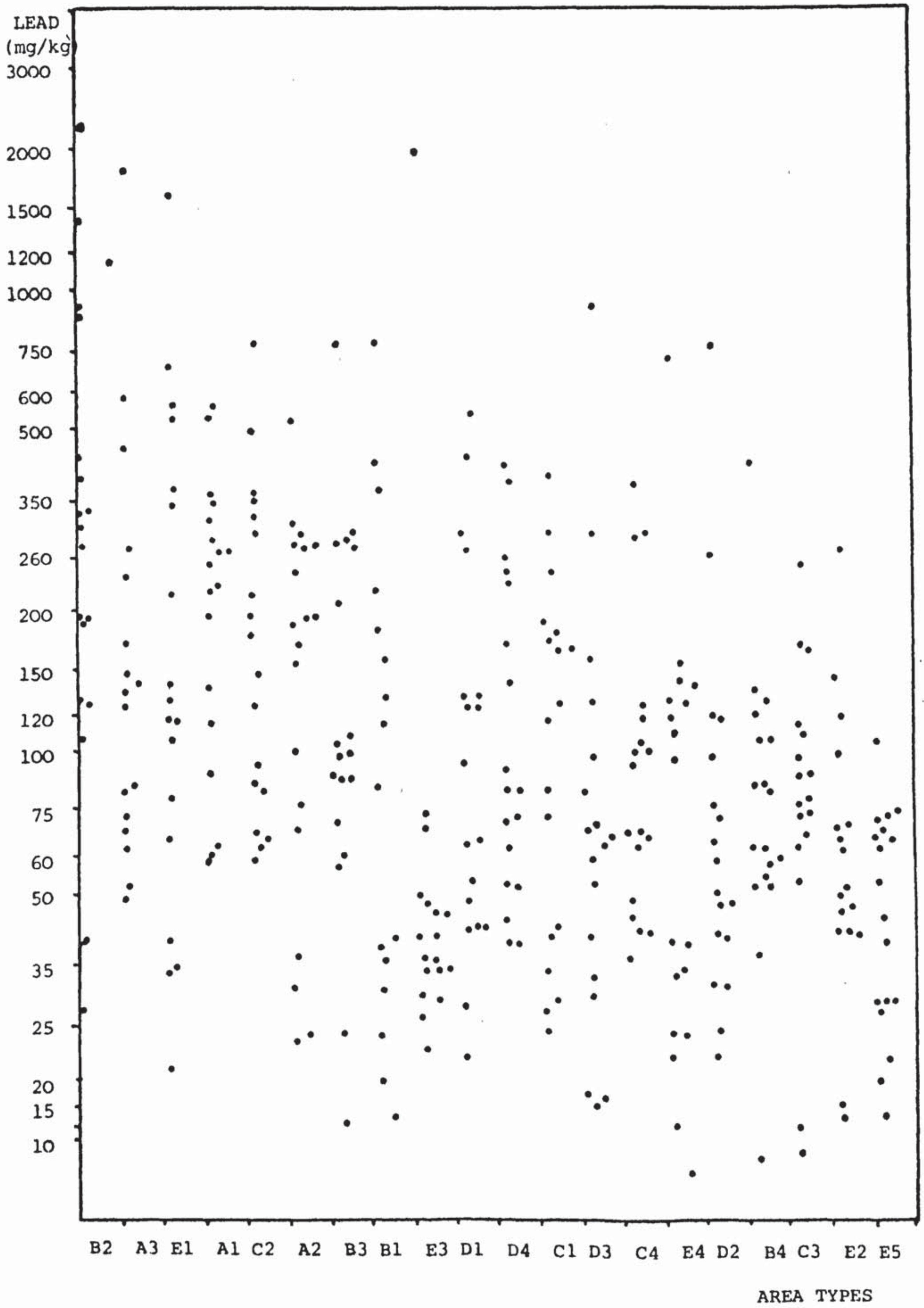


Fig. 5.2 DISPERSION PLOT TOTAL LEAD (mg/kg).



density and increased industrial activity. Secondly, in the more urbanised 'area-types' B3, A1, C2, there is an increasing frequency of occurrence of individual very highly contaminated sites. Thirdly, even in the more urbanised areas, with significant amounts of industrial land-use *2 (D1, A2) there are still some sites with virtually uncontaminated soil, equivalent to levels found in rural agricultural areas. In addition the spread of values in area types D1 and A2 are very much higher. Figure 5.2 also shows that there is significant grouping of soil levels around a medium value of 150 mg/kg. The above three characteristics of soil heavy metal data in the WMMC is common to all the four heavy metals determined in the WMMC soil samples and are shown in figures 5.4, 5.5 and 5.6.

5.2.4 Total Cadmium

Figures 5.3 and 5.4 are histogram plots and dispersion graphs for measured levels of total cadmium in the 360 soil samples. The pattern of results is clearly log normal with a 'tail' of higher values exceeding 3 mg/kg. The highest measured concentration of cadmium in the 360 soil samples was 33 mg/kg (area-type A1) whilst at the lower end of the range, the majority of soil samples (see figure 5.4) had a total cadmium content between 0.3 and 1.5 mg/kg. Some 14% of all results had total levels in excess of 3 mg/kg, the upper limit in normal soils (see section 5.3 and Archer 1977). It is also evident from dispersion graph of the data for total cadmium that there is a significant elevation of soil cadmium levels in the urban/industrial area-types A1, E1 and D1.

The range of total cadmium levels in the WMMC soil samples taken from the relatively unpolluted 'area-types' of C3, E4, C5 and E5, exhibit broad similarities, with values ranging between 0.1 and 1.5 mg/kg. In the

*2 Which it is known from past studies reviewed in Chapter 3. contribute significantly to the levels of heavy metals in soil in urban areas.

Fig. 5.3 FREQUENCY DISTRIBUTION - TOTAL CADMIUM (mg/kg).

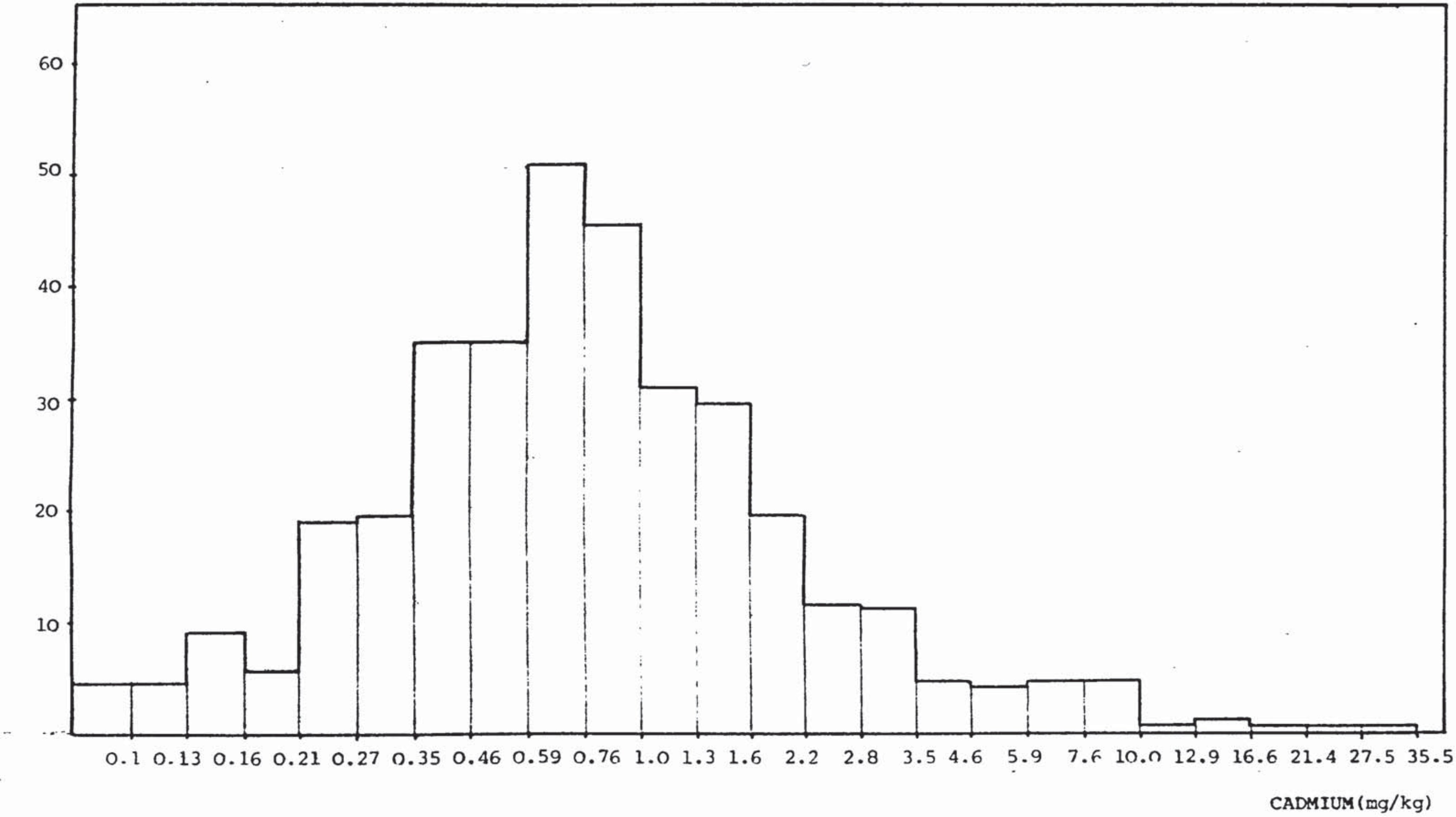
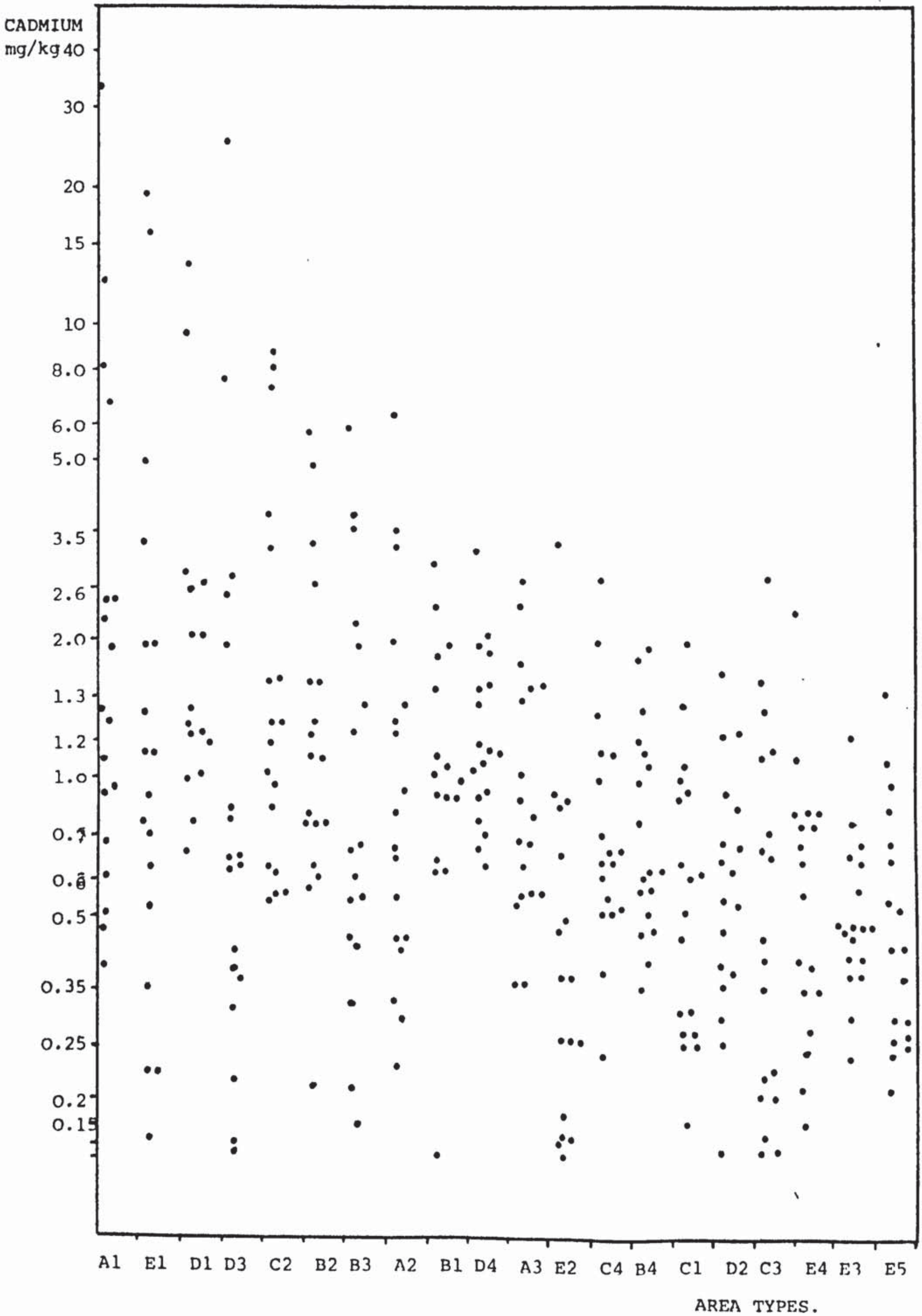


Fig. 5.4 DISPERSION PLOT - TOTAL CADMIUM (mg/kg).



suburban residential areas (D4, A3, C1) cadmium levels range between 0.4 and 3.3 mg/kg with a cluster of results around 1.0 mg/kg. However, in the industrialised inner urban areas, A1, D1, C2, for example, soil cadmium levels range between 0.5 and 6.0 mg/kg showing marked elevation. The spatial pattern of cadmium levels in the 20 'area-types' is similar to that for total lead and total zinc in the study area.

5.2.5 Total Zinc

Figure 5.5 is a dispersion graph for the measured content of total zinc in the 360 soil samples grouped by 'area-types'. From figure 5.5 it can be seen that the general pattern of soil total zinc levels is of levels ranging between 60-500 mg/kg with considerable 'bunching' of values around 250 mg/kg. In the agricultural/rural area-types of low road network density (E2, E3, E4 and E5) the range of total zinc levels is narrow, being between 60 and 200 mg/kg, well within the normal range in soils reported by Williams (1981). *3. However, in the more urbanised areas (A3, B4, A2) the lower level is at 120 mg/kg whilst the upper limit is as high as 1600-2000 mg/kg, indicative of marked contamination. The highest recorded total zinc level in the soil samples (table 5.1) was nearly 8000 mg/kg in area-type A1 and is associated with the highest cadmium level of 33 mg/kg. This observed relationship between levels of cadmium and zinc in soil has also been reported by several investigators for urban and rural soils (see for example Nriagu, 1980 and Thornton, 1979). From the dispersion graph, figure 5.5, it can be seen that well over 7% of the samples have total zinc contents in excess of 1000 mg/kg more than 5 times the 'upper limit' in normal soils, detailed in table 5.4.

5.2.6 Total Copper

The spatial pattern of measured levels of total copper in the soil samples was found to be similar to that for total zinc. The highest measured level

*3 See table 5.3 in this chapter and section 5.3.3.

Fig. 5.5 Dispersion Plot Total Zinc (mg/kg).

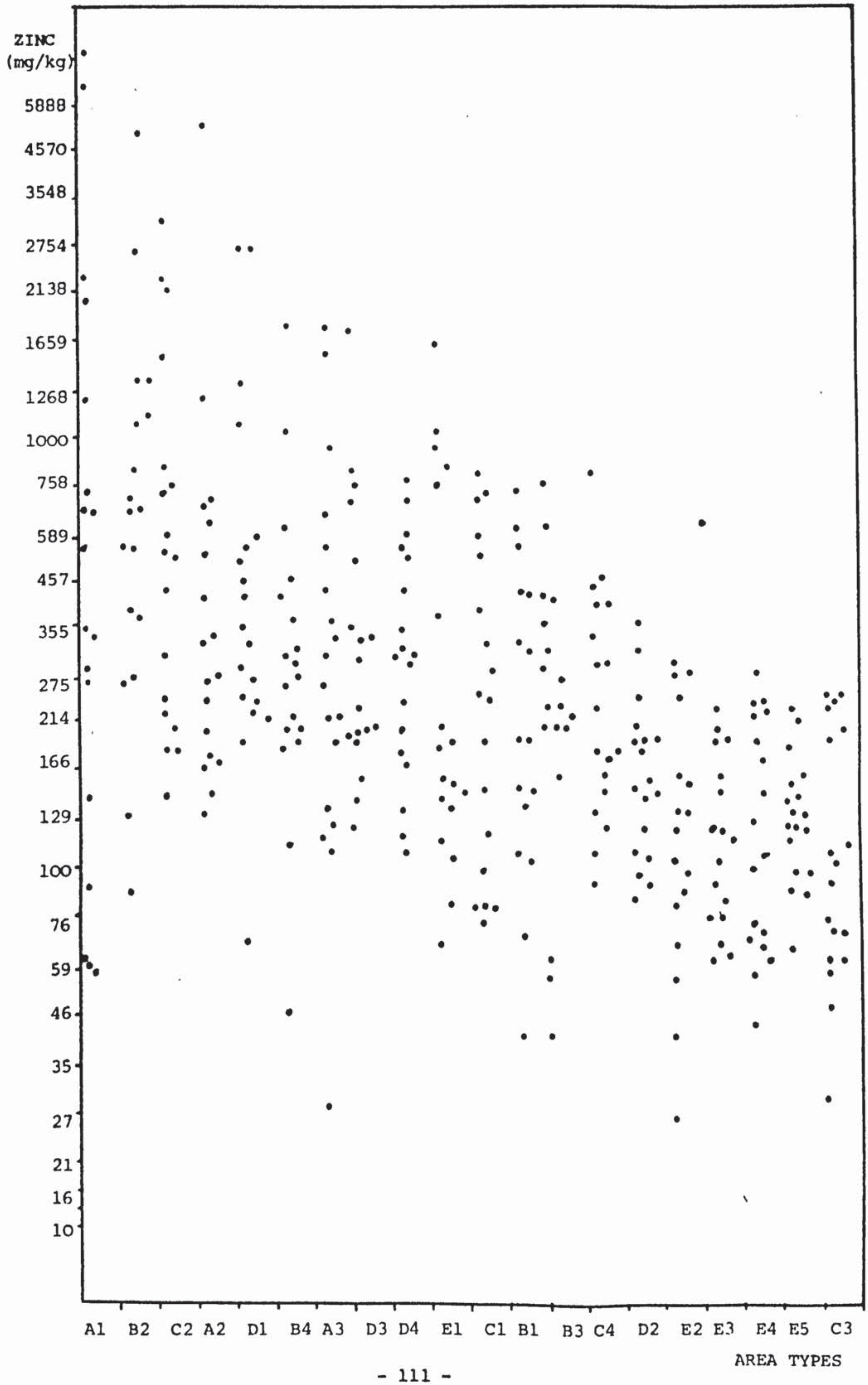
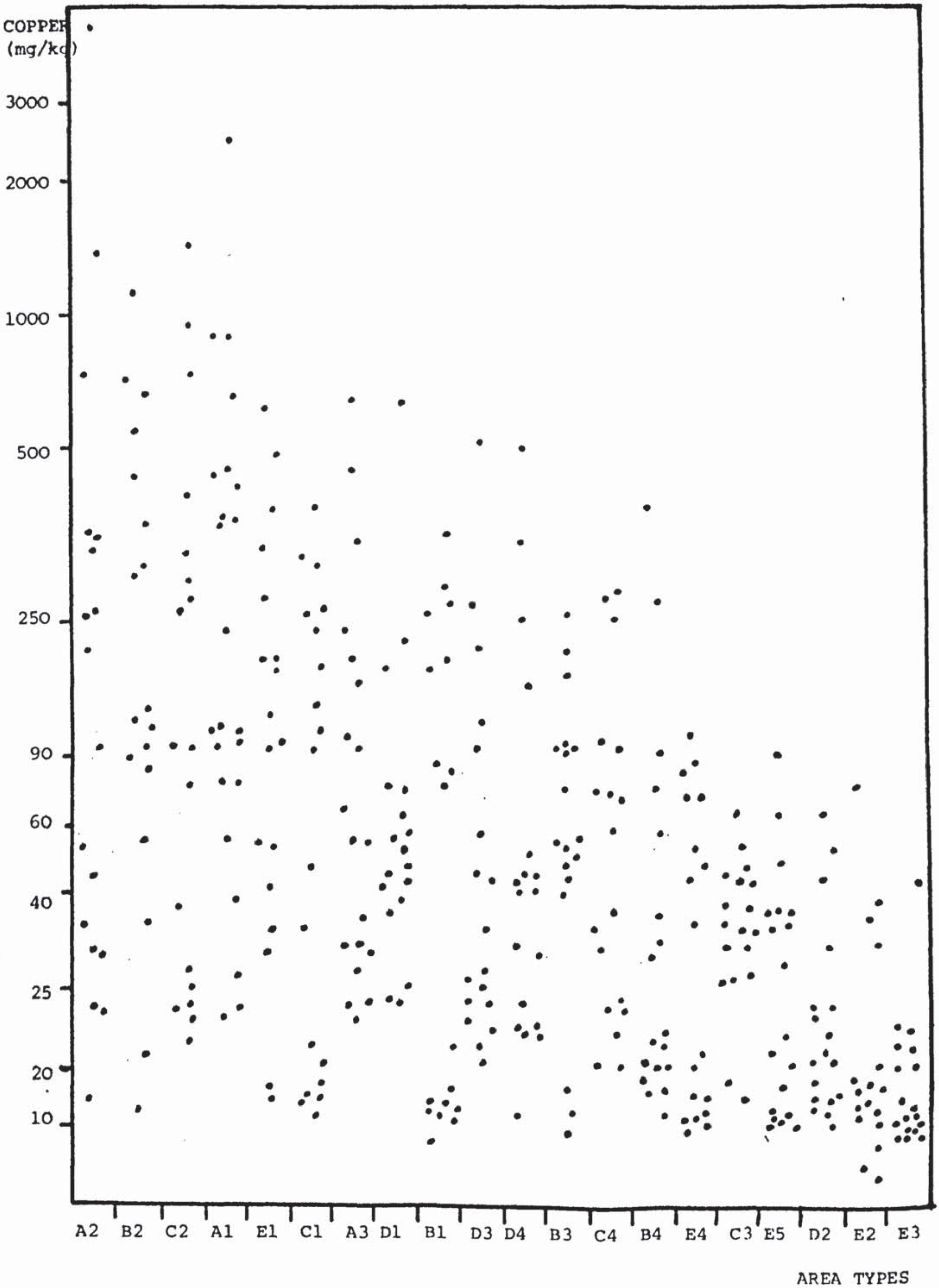


Fig. 5.6 Dispersion Plot Total Copper (mg/kg).



of total copper was 4,574 mg/kg in area-type A2, although the range of levels in this area-type was very wide, being 17-4574 mg/kg. The dispersion graph (fig. 5.6) also shows a 'core' of 'background' levels of total copper in the 360 soil samples between 50-130 mg/kg (also indicating elevation above the normal range in soils of 2-100 mg/kg (table.5.5)). From the data in table 5.1 it can be seen that 35% *4 of the area-types had a mean measured total copper soil content of more than 100 mg/kg with the highest mean being 460 mg/kg in area-type A2 (mix of industrial/ residential and commercial land-use).

5.3 Comparison with Normal Levels

5.3.1 The above is a general presentation of the results and has illustrated that the heavy metal content of urban soils is indeed highly variable. Such results take on more meaning when the data is compared to 'normal' levels reported in the literature for uncontaminated soils and for naturally occurring levels from agricultural land. The data for this comparison is summarised in table 5.5 for 'normal levels' (taken from various sources, see for example Berrow and Burridge 1977; Bowen, 1979; Swaine, 1955) and table 5.6 for agricultural soils (adapted from Archer, 1977).

Table 5.5 Normal (unpolluted) Range and Common Levels of Metals in Soils (mg/c)

Element	TOTAL Range	TOTAL Common Level	AVAILABLE 0.05m EDMA	AVAILABLE 0.5m HAC	Toxic*A
Pb	2-200	10	1.0 - 10.0	0.2 - 4	
Cd	0.1 -2.0	0.1	0.02- 0.2	0.02-0.2	
Cu	2 - 100	20	0.5 - 10	0.1-10	50-100
Zn	10 - 300	30	1.5 - 15	1 - 10	130-260
Ni	4 - 200	20	0.2 - 5	0.2 - 5	20-35
Cr	5 - 3000	100	0.1 - 4	0.01 - 4	

Source: Adapted from Williams, 1981.

*A Based on 'pot trials' by ADAS. Some sensitive crops on light textured soil at slightly acid pH's will be affected at the lower end of the toxic range, whilst tolerant crops grown at pH 6.5 or higher will only be affected at the upper end of the range.

*4 Area-types A1,A2, A3, B2, C1, C2, E1, where majority have high road network density.

5.3.2 The data in table 5.5 is typical naturally occurring (unpolluted) levels of heavy metals, obtained from published studies. By comparing the mean and ranges of measured levels of total heavy metals in the WMMC soil samples with this data, a number of points are evident. The lowest observed concentrations in the WMMC soil samples are similar to the lower end of the range reported for naturally occurring levels in soils for all four heavy metals. For example, in the case measured total lead levels in the WMMC, majority of the results are in the range 30-150 mg/kg. However, at higher concentrations the levels of total lead in the WMMC soil samples are some 5-8 times more than the suggested upper limit of 200 mg/kg (table 5.5). Indeed, if one took the 'common level' for total lead of 10 mg/kg, then only 3 of the 360 soil samples had a total lead content less than 10 mg/kg, suggesting considerable elevation of urban soils with regard to lead.

5.3.3 In the case of total cadmium content, soils are reported to generally contain between 0.1 and 2.0 mg/kg cadmium with a common level of 0.1 mg/kg. A recent survey in Britain of the cadmium content of some 750 soil samples taken in connection with the 'Fertilizer Practice Survey' *5 showed that most agricultural soils contained less than 1.0 mg/kg which also corresponds with the data reported by John (1973) for a soil survey in Canada. In the WMMC soil samples, the majority of samples contained a total cadmium level of between 0.5 and 2.1 mg/kg (fig. 5.4). However, the higher end of the range of total cadmium levels in the WMMC were some 3-8 times the reported normal upper level of 2 mg/kg. Very few of the soil samples analysed had a total cadmium level of 0.1 mg/kg. In addition, it should be noted from the data in table 5.1 that some 25% of the area-means total cadmium levels were above 2 mg/kg, the highest being 4.7 mg/kg.

5.3.4 In the case of measured levels of total zinc and copper in the WMMC soil samples there are some very marked differences. For example the normal

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*5 See section 3.4 of chapter 3 for a full discussion of this rural soil heavy metal survey.

range for total zinc in soils is reported as being 10-300 mg/kg. The data in table 5.1 and figure 5.5 shows that the higher concentration in the WMMC soils are some 10-20 times higher than the upper limit for naturally occurring levels and in the case of copper, many soil samples are between 5-20 times higher than 100 mg/kg reported as being the upper limit for normal levels of total copper. In detail, 40% of all the results for the WMMC were greater than 300 mg/kg and 60% of the area-type mean total zinc levels were above 300 mg/kg zinc. In the case of total copper, 10 area-type means were found to be greater than 100 mg/kg.

5.3.5 The above results show that there is significant elevation of the soil heavy metal content for total levels of lead, zinc, copper and cadmium in the soils . In particular, it appears that the levels of total lead in the WMMC soil samples are all generally elevated with significant enhancement in high road network density area-types and the older industrial urban areas *6. This enhancement probably results from a combination of factors including higher traffic flows and industrial activity (non-ferrous smelting in the Black Country areas). The levels of total cadmium, and particularly total zinc and copper in the WMMC soil samples reflect the high additional contamination of soils caused by pollutant emissions from industrial activity in the area. This is confirmed, to a certain extent, by the data presented graphically in figures 5.3, 5.4 and 5.5. These figures show that the higher area-type means in table 5.1, for the industrial/inner urban area area-types, is not the result of few very high values for individual samples, but is due to a general shift of the frequency distribution to high individual sample concentrations for zinc, copper and cadmium.

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*6 A full discussion of the spatial variation of heavy metal levels with land-use is contained in section 5.6

5.3.6 As mentioned earlier, the data can also be compared to the results of a study by Archer (1977) who carried out a systematic survey of trace element levels in agricultural soils in England and Wales. *7. The data from the study by Archer is summarised in table 5.8 for total heavy metal levels. From table 5.6, it can be seen that measured levels of total lead were the most variable, with several results indicating natural enrichment (i.e. greater than 200 mg/kg). When Archer's data is compared to the results reported by Berrow and Burridge (1977) for 'normal' levels in agricultural/rural soils (where the upper limit of the 'normal' range of total copper, lead and zinc is quoted as copper 100 mg/kg, lead 300 mg/kg, and zinc 300 mg/kg.), of the 750 soil samples analysed in Archer's work, only 1.3% contained more copper, 2.1% more lead and 0.8% more zinc than these values. In the case of cadmium, the majority of the soil samples contained less then 1mg/kg cadmium, although there are several instances where cadmium levels exceed 3 mg/kg. (table 5.6). Archer concludes that the results from this survey indicate the normal range of heavy metals in unpolluted soils for England and Wales.

5.3.7 When the data in table 5.6 is compared to the results in tables 5.1 and 5.2, and graphical dispersion diagrams for the WMMC, there are a number of significant differences. For example, in Archer's study, for total copper, almost all the soil samples had a copper soil content between 1 and 100 mg/kg, in the case of the WMMC, less than 40% of the soil samples had a level of total copper up to 100 mg/kg, with many samples ranging up to 100 mg/kg. The distribution of results for total cadmium in the WMMC soil samples corresponds fairly closely to the data of Archer, with over 50% of results containing less than 1 mg/kg cadmium. However, in the more industrialised 'area-types' (A1, D1 for example) the levels of total cadmium in the WMMC range between 0.8 and 15 mg/kg and are significantly different

*7 See chapter 3 section 3.4 for a full discussion of this survey which was carried out in connection with the 'Survey of Fertilizer Practise' and some 750 soil samples were collected and analysed for a range of heavy metals.

TABLE 5.6 NUMERICAL DISTRIBUTION OF TOTAL TRACE ELEMENT VALUES IN SOILS IN ENGLAND AND WALES (mg/kg).

	ELEMENT				
Range of Values mg/kg	Cu	Pb	Zn	Cd	Range
1 - 4	9		2	374	1
5 - 9	101	3		111	1 - 1.4
10 - 19	349	72	7	126	1.5 - 1.9
20 - 39	258	286	76	48	2.0 - 2.4
40 - 59	18	176	165	13	2.5 - 2.9
60 - 79	3	108	152	5	3.0 - 3.4
80 - 99	3	40	156	5	3.5 - 3.9
100 - 119	5	16	93	5	4.0 - 4.4
120 - 139	2	16	42		4.5 - 4.9
140 - 159	1	5	20	1	5.0 - 5.4
160 - 179		7	14	1	5.5 - 5.9
180 - 199	2	7	9	1	10
200 - 299		7	6		
300 - 399		5	3		
400 - 499		1	2		
500 - 599					
600 - 699					
700 - 799		1			
800 - 899		1	1		
900 - 999					
1200		1			
Median	17	42	77		1.0
Range	2-195	5-1200	8-816		0.08-10

to the data obtained by Archer. Similar differences in the distribution of results are found for total lead and total zinc in the WMMC soil samples.

5.3.8 The comparison of the WMMC soil heavy metal results with data for naturally-occurring (unpolluted) levels has shown that for all four heavy metals the highest concentration in the soils are on average, ten times higher than the highest naturally occurring levels. This is an indication of the elevation of soil heavy metal soils through pollution in the area, giving rise to soil contamination. This point is illustrated further by table 5.7 which shows mean area-type soil heavy metal concentrations for four characteristic *8 urban area-types. The four area-types cover most rural/agricultural areas; general urban residential areas of medium to high road network density; inner area mixed residential/industrial areas; and highly industrialised areas. The table indicates the typical average soil metal concentrations observed in these types of areas and illustrates the range of levels of heavy metal to be expected in urban and industrial areas.

Table 5.7

Representative mean area-type Soil Heavy Metal Concentrations in the WMMC (mg/kg dry soil)

	Area-Type			
Element	E5 (Agricultural)	D3 (Resid/Recr)	D1 (Mixed Resid/Ind.)	A1 (Ind/Comm)
Pb	49	109	140	240
Cd	0.5	0.7	2.8	4.7
Zn	134	179	616	1496
Cu	32	28	98	374

The table indicates that in the rural areas (E5), average levels are broadly similar to the naturally occurring concentrations detailed in

*8 Although the 20 area-types used in the calibration model cover the range of urban fabric types in the WMMC, these four 'area-types' are taken to be representative of the cross section of conditions likely to be encountered in any urban area.

table 5.3. The outer-suburban areas (D2) also show little elevation above natural background levels. However, in areas where industry is present, levels of heavy metal in the soil increase significantly, with levels in the highly industrialised areas (A1) on average 8-10 times as high as the rural levels.

5.4 Discussion of Results for 'Available' Metal Concentrations

5.4.1 Table 5.2 is a summary table of the 'available' *9 concentrations for four heavy metals determined on the twenty 'area-type' soil samples. The determination of available heavy metal concentrations is primarily an indication of the amount of the heavy metal that is readily available to the environment, for plant uptake for example. As such, therefore, they can be used as an indication of the extent to which heavy metal soil contamination is of more general environmental concern. From the data presented in table 5.2, it can be seen that the available metal concentrations exhibit a similar spatial distribution to that described for total heavy metal concentrations in section 5.3 above.

5.4.2 From the data in table 5.2, it can be seen that mean available soil copper levels range from approximately 10 mg/kg in rural (unpolluted) areas to well over 100 mg/kg in the more urbanised areas. The range for available copper in the 360 soil samples is from 2 - 1220 mg/kg with the highest range measured in area-type A1 being 11 - 1220 mg/kg. For available lead, the range of results for the 360 WMMC soil samples is between 2 - 758 mg/kg and area-type means range between 34 - 143 mg/kg. In the case of available cadmium, the range of measured concentrations in the 360 soil samples was 0.01 - 9.6 mg/kg, with the widest range in area-type A1 of 0.3 - 9.6 mg/kg. Area-type mean available cadmium soil concentrations range from 0.3 to 1.5, indicating that industrialised inner urban areas (A1 for example) are some 5 times more contaminated than rural areas. For

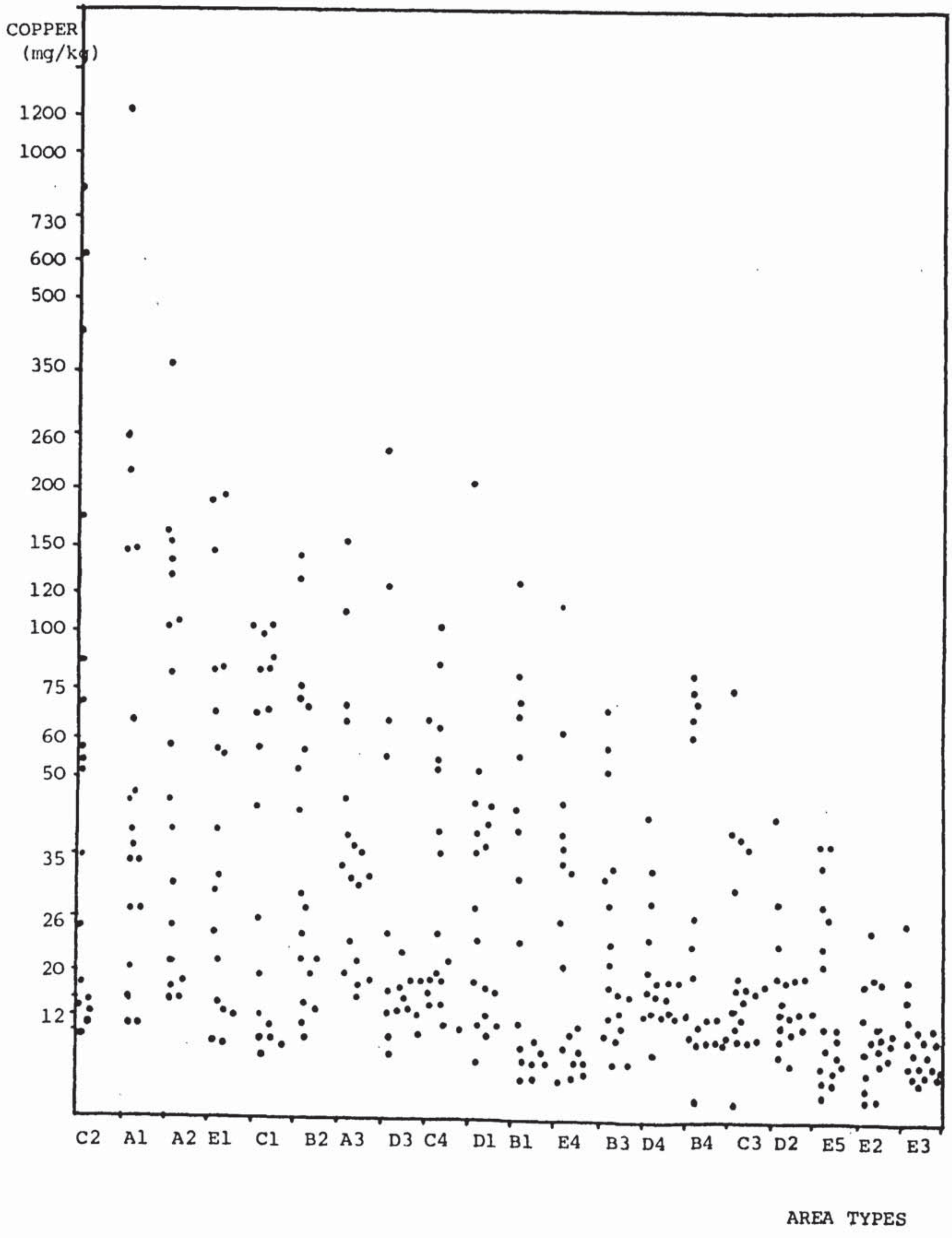
*9 See chapter 4, section 4.6 for definition of 'available' metal concentration and Appendix B. for details on analytical methods.

available zinc, the range in the 360 soil samples was 1 - 2488 mg/kg with highest observed range being in area-type A1 of 17 - 2488 mg/kg. From the discussion of contemporary soil studies for heavy metals in chapter 3, it is evident that much of the data on available soil heavy metal relates to copper and zinc, primarily due to the phytotoxic effects of these elements on crops and plants. Therefore, the remainder of the discussion and comparison of available soil metal concentrations in the WMMC, will concentrate on the observed levels of available copper and zinc.

5.4.3 Available Copper

Figure 5.7 is the dispersion graph plot for measured available copper levels in the 360 WMMC soil samples, grouped by area-types. In many respects, the pattern of results is similar to that discussed earlier for total copper in soils. From the data in figure 5.7 it can be seen that there is a general rise in the 'low' levels from around 2-10 mg/kg through to 10-25 mg/kg in area-types A1 and A2. However, such an elevation is not as clearly defined as was the case for total soil heavy metal levels, because there is still a high proportion of results (76%) below 20 mg/kg even in the most contaminated area-types. The dispersion plot clearly illustrates the differences in ranges between area-types, with the range in less contaminated area-types (E3, E5 for example) being 2 -20 mg/kg, whereas in the more contaminated area-types, the range is much higher, being 8 - 200 mg/kg (area-types A2 and C1 for example). The same three characteristics in the distribution discussed in section 5.3.2 for total heavy metal concentration, is also found for available copper levels. The fact that the higher area-type means (A1, A2, C1 & B2, in table 5.2) are not due to one or two very high copper levels, but due to a general increase in the number of soil samples with high copper levels, clearly indicates that industrial pollution has a significant influence in the levels of heavy metals in soils. In addition, since this has been observed to be the case for 'available copper'

Fig. 5.7 Dispersion Plot Available Copper (mg/kg).



levels, then it can be assumed that the more contaminated a soil is, the more metal in the soil is 'available' to the environment.

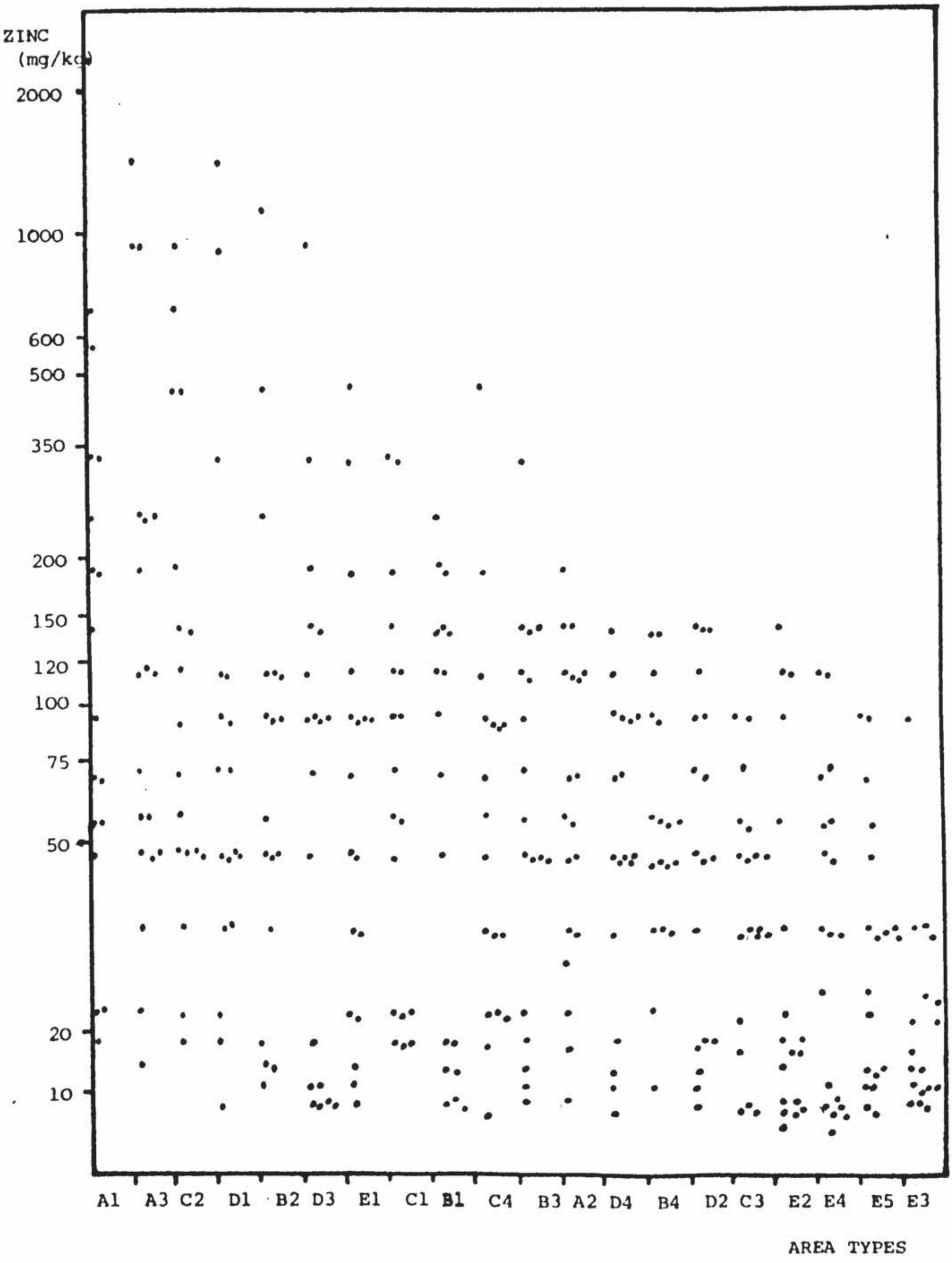
5.4.4 Available Zinc

Figure 5.8 is the dispersion graph plot for available zinc concentrations in the 360 soil samples. From figure 5.8 it can be seen that the lower end of the range of levels in the 20 area-types rises steadily from between 10-20 mg/kg (area-types E3, E4, and E5) to 50-100 mg/kg in area-types, A1, A3, C2 (industrial and mixed industrial residential and commercial area-types). The dispersion graph also clearly illustrates the point that as one goes from rural sites (E5) to more urban and inner industrial sites (A3), there is a higher incidence of sites with elevated levels of zinc contamination, with the levels peaking around 1000 mg/kg in the highly contaminated areas.

5.4.5 As mentioned in section 5.4.3, there has been a great deal of data published on 'available' levels of heavy metals, mainly due to concern from the phytotoxic effects of heavy metals in soils, in particular their effects on crop health. In fact, much of the published data related to 'available' heavy metal concentrations comes from agricultural soil science, because of the practice of using sewage sludge (often rich in heavy metals) as a fertilizer on arable land and grasslands (see for example studies by Williams, 1981; Berrow & Burridge, 1977). Table 5.5, summarises the published data on naturally-occurring (unpolluted) levels of available metals in soils and includes limited data on levels of heavy metals in soils considered to be phytotoxic. The upper limit of the 'normal' levels in soil, quoted by various investigators, for copper and zinc, are 10 mg/kg and 15 mg/kg respectively. *10.

*10 A certain amount of caution needs to be exercised when carrying out comparisons for 'available' levels in soils because of the variety of soil extraction procedures that are used. However, it is assumed that large differences in the results, cannot be attributed solely to differences in analytical method.

Fig. 5.8 Dispersion Plot Available Zinc (mg/kg).



From the data in figures 5.7 and 5.8, it can be seen that 76% of the available copper levels in the WMMC soil samples exceed 10 mg/kg and 82% of the available zinc results exceed 15 mg/kg. In addition, if the upper toxic limit for available copper is taken to be 100 mg/kg (table 5.5) it can be seen that 8% of all the soil sample results for the WMMC exceed 100 mg/kg, with highest levels being some 5 - 10 times this value. In the case of available zinc, where the upper toxic limit is quoted as 260 mg/kg, 7% of the WMMC soil sample results exceed this value, with the highest concentrations being ten times this value.

5.4.6 The data on available metal concentrations in the WMMC soil samples can also be compared with results from two other studies. The first, by Archer (1977) reports naturally occurring levels in agricultural soils for England and Wales and the data from this study is summarised in table 5.8.

Table 5.8 Numerical Distribution of Available/Extractable Metals in Agricultural Soils of England and Wales.

	ELEMENT		
RANGE (mg/l)	Pb	Zn *b	Cu *c
1	114	6	8
1-4	436	240	35
5-9	78	269	238
10-14	24	82	32
15-19	4	32	7
20-24	2	20	5
25-29	3	8	3
30-49	-	4	1
50-100	1	3	3
Median (mg/l		6.6	4.4
Range (mg/l)		0.4 - 97.6	0.5 - 74

Source: Adapted from Archer, 1980.

*b determined on an acetic acid extract.

*c determined on EDTA extract.

The data in table 5.8 is a numerical distribution of 'extractable' *11 heavy metals and illustrates that for lead, copper and zinc, the majority of the results are in a narrow band between 1 & 10 mg/kg, with very few samples having levels greater than 20 mg/kg. These results reflect a range of soil types taken from 'sample farms' covering England and Wales, and as such can be taken as representative of naturally occurring 'background' levels in uncontaminated soil. When the data in table 5.8 is compared to the data in table 5.2 and figures 5.7 and 5.8 for the WMMC, it is clear that soils in the WMMC show marked contamination. Only in the rural agricultural area-types (E4 & E5) do levels of lead, copper and zinc compare with those reported by Archer and even in these areas, there are a number of soil samples with levels of zinc and copper in excess of 100 mg/kg. In addition, in the WMMC soil samples it is quite common to find copper and zinc levels 10 - 30 times higher than the normal levels reported by Archer.

5.4.7 The second set of data which can be used to compare with the WMMC results is taken from work by Davies (1979) in London. The study of London soils was carried out on a transect basis from rural Hertfordshire through to the centre of London. Soil samples were collected from gardens, parkland and allotments. Table 5.9 summarises the results of this work for three broad areas; Rural Hertfordshire; Greater London Urban Parkland and Central London Parkland, and includes selected data from the research to aid comparison.

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*11 Extractable is another term for available and utilises a slightly different extraction technique, see Chapter 3, section 3.5, for further details.

Table 5.9 Comparison of Results Between London *12 Soils and the WMMC

	METAL							
	Lead		Zinc		Copper		Cadmium	
(Locality)	mean	range	mean	range	mean	range	mean	range
Hertfordshire	53	42-63	95	52-121	121	10-16	0.05	
(Rural) Area-type E4	42	2-80	38	1-111	26	4-113	0.4	0.07-1.07
Gt.London Urban Parkland	275	78-848	373	117-1047	45	18-103	0.5	0.5-1.6
Area-type B2	121	24-292	147	12-1109	49	9-141	0.8	0.2-2.3
Central London Parkland	966	521-2405	327	220-496	56	31-85	1.3	1.1-1.2
Area-type A1	131	42-288	360	17-2488	133	11-1220	1.5	0.9-9.6

If the three broad areas in the London study are taken to be similar to area-types E4, B2 and A1, respectively, then a number of points are evident. Firstly, the general trend of higher levels of heavy metals in the more urbanised centres of large cities is a feature of both sets of data. In addition, the results for the rural soils correlate well with the reported 'normal background' levels of heavy metals in soils. However, in the case of the WMMC soil sample results, there are a number of significant differences. Firstly, the mean lead levels are generally higher in the soils from the London Study - probably reflecting differences in traffic density, a significant source of lead in urban soil and dusts (see studies by Harrison, 1979, Duggan & Williams, 1977). In the case of copper and zinc in the WMMC soil samples, levels are on average much higher, reflecting the dominance of industrial pollution to *13 soil heavy metal levels in the WMMC.

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*12 Adapted from Davies (1978), measurements of heavy metals for London are available-determined on a 0.05m EDTA $(NH4)_2$ extract solution.

*13 Non-ferrous metal smelting and high conentration of metal using industries.

5.4.8 Other studies of 'available' levels of heavy metals in urban soil environments, which can be used to compare the results from this research study, have been reviewed in detail in chapter 3. Of these, the work of Klein (1972) and Merseyside County Council (1976) offer some useful data for comparisons. In the work of Klein (1972), trace metal concentrations in soils were mapped according to the land-use pattern for part of Grand Rapids, Michigan, U.S.A. The results from this mapping exercise are summarised in table 5.10 below.

Table 5.10 Mean Metal Concentrations (ppm) in Soils from Grand Rapids Michigan U.S.A.

	METAL			
Land Use	Pb	Zn	Cu	Cd
Agricultural	11	27	9	0.6
Residential	15	22	8	0.4
Industrial	48	57	16	0.7

Source: Adapted from Klein 1972.

Klein compared the spatial distribution of heavy metals with land-use and found that the industrial zones were clearly enriched with heavy metals. Taking all the results into account, Klein concluded that on average, heavy metal levels in industrial areas were 2-3 times higher than in the residential areas. It is also interesting to note that there was little difference between the levels in the agricultural area and residential areas, with both sets of results reflecting published naturally occurring levels in soils. The data for the WMMC soil samples are clearly significantly different to the data produced by Klein. The results for the Michigan soil are at the lower end of the ranges found in comparative area-types for the WMMC and probably result from the fact that in the WMMC the high density of metal using industries is a significant contribution to the higher levels of heavy metals generally in the soil.

5.4.9 The results from the study carried out in Merseyside County *14 support the general view of elevation of heavy metals in urban soils. This study, which determined 'available' copper, zinc, cadmium and lead on garden and parkland soils across the whole of the county, concluded that the levels of lead and zinc in soils were generally elevated and relatively evenly distributed throughout the county. In contrast, soils with high concentrations of copper and cadmium were found to be restricted to zones near active or former metallurgical and refining industries. In detail, the survey found that approximately 6% of garden and parkland soil samples contained more than 200 mg/kg copper (levels of this order are generally toxic to plants). In the case of extractable cadmium, between 3% and 6% of soil samples contained more than 1 mg/kg and for zinc only 2% of the soil samples contained in excess of 100 mg/kg extractable zinc. Therefore, although all the heavy metals were found at concentration greater than those regarded as normal in soils, only copper exceeded that concentration reported in the literature as being toxic to vegetation. This serves to further illustrate the point that urban soils, in general, will exhibit contamination from heavy metals and the presence of metal using industries, in particular non-ferrous smelting and plating works, can significantly increase the total levels of heavy metals in soils and the amount in the soil which may be 'available' to the environment.

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*14 Reviewed in detail in chapter 3, where soil samples collected from 2 km grids cross whole of the county area.

PART 2 VALIDATION AND MAPPING

5.5 Statistical testing of the sample data

5.5.1 The preceding sections of this chapter have summarised the results of the measured levels of heavy metals in the WMMC. The results have been compared with data on naturally occurring(unpolluted) levels of heavy metals in soil and have also been compared to published data from contemporary studies in other urban areas. The next sections of this chapter discuss in detail the statistical testing of the results and present the background soil contamination maps for the whole of the WMMC, which have been derived from the sample data.

5.5.2 Preceding chapters of this thesis (chapters 2 & 3) have demonstrated the need for further, detailed information on the spatial variation of heavy metal land contamination in urban soils. In addition, it has been concluded that there is, at present, no satisfactory methodology for comprehensive mapping of heavy metal soil levels in large and varied urban areas. The problem stems from the fact that soil heavy metal levels can vary substantially over short distances and so a relatively high density of sampling sites per unit area is needed in order to achieve a representative sample. Evidence from the literature suggests that to achieve a sampling density of the required order over an area of the size of the WMMC, would require a total of many thousand sites to be sampled and analysed, clearly an impractical task. It was decided, therefore, to adopt an alternative approach and in chapter 4, section 4.4, it was stated that the research was essentially an estimation mapping methodology,which is based on the general proposition that different types of area have their own particular distinctive pollution conditions *15 that are linked to certain definable characteristics of the area, such as the type and mix of

*15 A proposition which has been put forward by Wood et al (1974) in his Geography of Pollution and was developed for air pollution by Pocock (1979) see chapter 4 for a detailed review.

land-use. If this proposition holds, which will be tested statistically in part 2 of this chapter, then typical levels of heavy metal soil contamination in a given area can be estimated and mapped at an urban scale.

5.5.3 The area-type means (see section 5.2) of the four heavy metals determined in the 360 soil samples are to be used as the basis from which to estimate and map the spatial pattern of soil contamination for the 1003 grid squares covering the whole of the WMMC. The key hypothesis which is to be tested holds that: 'the spatial variation of soil heavy metal levels over the WMMC. are significantly associated with the variation in the area-types over the study area'. Two important statistical tests were applied to the area-type mean soil heavy metal levels, as a test of the sample data. These were the students 't' test on the means of each pair of grid squares, taken to be representative of the 20 'area-types'. The second, which was to be a direct test of the above hypothesis was the classical analysis of variance 'F' test.

5.5.4 The 't' test and 'F' test, being parametric statistical tests, assume the following:

i) the samples are independently drawn from a normally distributed population.

ii) components of the variance are additive.

iii) parent population mean and variance are independent.

Appendix E. summarises the testing of these issues. However, the crucial question for statistical validation, is the issue of the degree to which the population from which the samples has been drawn is normally distributed. There are a range of methods which can be used to check for normality (see for example, Hammond & McCullogh, 1978); these may be summarised as:

i) common sense - are the data of a kind one might expect to cluster symmetrically about a mean.

ii) the use of probability paper - if the sample data are plotted cumulatively, they will yield a straight line if they are normally distributed.

iii) if the median is less than the mean, then this indicates that the distributions are not normal.

iv) if the data is normally distributed then the variance will be independent of the mean.

5.5.5 Of the five criteria above, it can be seen from dispersion plots of the sample data and histograms (see figures 5.2 - 5.6), that the data is not symmetrical about the mean. The measured concentrations of the four heavy metals shows a cluster of results at lower levels with a 'tail' towards the higher levels. The data is in fact positively skewed. In addition, the results of other checks for normality (appendix E) also indicate that the sample data is not in fact normally distributed with variance not independent of the mean. It would be inappropriate to apply parametric statistical tests to non-normally distributed data without the risk of considerable error. The use of alternative,non-parametric statistical tests was considered inappropriate since they are not as powerful as parametric tests and do not generally utilise all the information provided by the sample. Therefore, since the statistical testing of the research results involves the use of parametric tests, it was necessary to 'normalise' the data through the use of data information.

5.5.6 There are a number of 'transformations' that can be used to 'normalise' the data (see for example, Yeomans, 1977; Elliott, 1972). Examples of such transformation include replacing X by $\sqrt{X}$ or X by log (X+A). For positively skewed data of the kind found in the sample the more usual transformation is a log transformation. By substituting the logarithms for the numbers, a positively skewed distribution is transformed into one which is approximately normal and therefore satisfies the requirements of parametric tests. Provided all the data is transformed in exactly the same way, then the results of the testing, discussed below, holds good for the original data set. Since the soil heavy metal results data is skewed, it was necessary to transform individual sample point results for all four heavy metals into logarithms. A simple check on the adequacy of the transformation was carried out on the sample data. This is reported in detail in appendix E. The data for total lead clearly demonstrates that by taking the logarithms of the numbers, the distribution is transformed to one that is approximately normal, with variance independent of mean. Checks on the other heavy metals produced similar results.

5.6 Analysis of Variance 'F' Test

5.6.1 It is evident from the discussion in section 5.4 of this chapter, that differences exist between the mean and range of all four heavy metals in the twenty area-types. It is necessary to test whether this observed difference is a real difference between 'area-types' or is accounted for in error in the sampling method. This is tested through the application of the analysis of variance 'F' test to the sample data. The rationale of the 'F' test, which has been developed and widely applied in agricultural science, is to compare two different estimates of the variance of the assumed common normal population from which the samples have been drawn. Therefore, the test is in fact applied to the corresponding null-hypothesis (Ho), that samples of heavy levels taken independently from different 'area-types' came from the same background parent population. The first estimate, termed the between sample variance (B), is based on the observed variance of the means for each metal in the twenty area-types. The second, termed within sample variance (W), is based on the variance of the observation within each area-type. The F - ratio is given as:

$$F = \frac{\text{between sample variance (B)}}{\text{within sample variance (W)}}$$

5.6.2 If the above null-hypothesis holds, then the variation between sample means should be commensurate with the population variance, as indicated by the variation within samples, and the two estimates of variance should not be statistically significantly different. If it should prove that the 'between sample variance' were greater than the 'within sample variance' then the null-hypothesis should be rejected. One may conclude that there is statistical evidence that the 20 samples were not in fact drawn from the same parent population. The inference from the rejection of the null-hypothesis is that a significant proportion of the spatial variation in soil heavy metal levels over the study area can be explained by differences existing between area-types.

5.6.3 The calculated 'F' value for the four heavy metals determined on the 360 WMMC soil samples is contained in table 5.11 below.

Table 5.11. Calculated 'F' Values

Element	Total	Available
Lead	5.2	4.6
Cadmium	5.05	3.3
Copper	9.05	6.9
Zinc	7.5	4.3

The appropriate degrees of freedom are given by (K-1, N-K) and in this case work out to be (19, 340). For the appropriate degrees of freedom, the tabulated 'F' value at the 1% ($p = 0.01$) significance level is 1.9 and at the 0.1% level ($p = 0.001$) is 2.1. From the results in table 5.11 it is concluded that for all four heavy metals and for both available and total levels, the observed variance ratio is too great for the null-hypothesis to be sustained, and that there is sufficient statistical evidence to indicate a specific between sample variation. In other words, the indication is that there are significant differences in the population from which the samples were drawn.

5.6.4 The second statistical test applied to the results was a test of whether or not the two grid squares, selected at random as being representative of individual area-types, are in fact two samples drawn from the same parent population. This was tested using the student 't' test on the means of the two grid squares from each area-type. The 't' test null-hypothesis (Ho), is that there is no difference between the means and variance of the two samples data set for each area-type. The two samples are taken to be from a single background population and any observed difference between them is no more than might be expected due to random variation. The null hypothesis is accepted when the observed value of 't' is equal to or less than the critical value of 't' for the appropriate degrees of freedom. In testing the significance of the difference between sample means (grid squares) the null hypothesis includes the following assumptions:

i) the background population of the samples are approximately normally distributed.

ii) the standard deviation of the population from which the samples are drawn are equal.

In the case of 'normality' of the data, this has been checked *16 and the appropriate log transformation carried out. It is the log data which is used in the calculation of the 't' statistic.

5.6.5 As stated above, the validity of the 't' test also rests on the assumption that the standard deviations (and hence variance and mean) of the background populations of the two samples are equal. Since a significant difference between variances will also produce a significant value of 't', it will be evident that before carrying out the 't' test, it is necessary to investigate the above assumption. A check was therefore carried out as to whether the best estimates of the population standard deviations, derived

*16 See appendix E and discussion in section 5.5.5 on checks for normality and appropriate transformations of the data.

from the two samples taken separately, are not so different as to render the above assumption unacceptable. This check was carried out by applying the variance ratio 'F' - test to the data, where:

$$F = \frac{\text{greater estimate of the population variance}}{\text{smaller estimate of the population variance}}$$

If the variance ratio is found to be greater than the critical value, then the necessary assumption of a common population standard deviation must be regarded as inconsistent with the data and thus renders the 't' test invalid. The variance ratio test preceded all 't' test calculations, and the results are summarised in appendix E. table E.1.

5.6.6 Table 5.12 summarises the 't' test results and indicates where the variance ratio test produced a significant result. The critical value of 't' from the appropriate degrees of freedom (n - 2 = 16), is given as 2.12 at the 5% significance level and 2.92 at the 1% significance level. Where the variance ratio test produced a significant result, it would be invalid to obtain an estimate of a 'non-existent' common population variance. However, according to Yeoman, (1978) a 't' test can be performed on such means with S^2 and $S_2{}^2$ used as respective estimates of the two population variances in the formula set out below.

$$t = \frac{\bar{X} - \bar{X}}{\frac{S_1^2}{n_1} + \frac{S_2{}^2}{n_2}}$$

The critical value of 't' being obtained from revised degrees of freedom, which is calculated from the following formula.

$$\text{d. f.} + \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2{}^2}{n_2}\right)}{\frac{\left(\frac{S_1{}^2}{n_1}\right)^2}{n_1 + 1} + \frac{\left(\frac{S_2{}^2}{n_2}\right)^2}{n_2 + 1}} - 2 \quad \text{(to the nearest whole number)}$$

TABLE 5.12

STUDENTS 't' Test Data

Area Type	Lead		Zinc		Copper		Cadmium	
	Tot.	Av.	Tot.	Av.	Tot.	Av.	Tot.	Av.
A1	0.99	0.33	2.69	1.66	0.21	0.10	3.33	2.04
A2	2.34	0.20	0.72	1.51	1.10	2.49	3.14	3.26
A3	0.97	0.01	1.21	2.15	3.95	3.38	0.21	1.96
B1	0.82	5.36	0.03	15.97	1.76	9.95	2.41	5.68
B2	3.75	0.80	3.07	0.01	3.49	2.22	2.57	1.23
B3*	0.45	0.15	1.27	0.13	1.40	1.27	1.47	0.01
B4*	0.27	0.37	1.48	1.31	2.99	3.10	2.36	0.33
C1	3.98	2.69	5.53	3.41	8.17	7.08	4.63	6.73
C2	1.32	2.06	3.54	2.84	5.17	5.69	2.84	2.18
C3*	1.05	0.52	2.43	0.18	0.04	0.29	2.78	3.48
C4	1.45	1.56	0.33	0.32	4.38	2.09	0.36	2.06
D1	1.78	2.14	2.11	3.66	0.61	2.52	0.02	3.26
D2	2.07	3.69	0.31	0.46	0.19	1.42	0.67	1.34
D3	2.40	3.85	3.30	4.88	1.62	3.56	3.78	3.99
D4	1.44	0.56	3.11	0.79	2.26	0.08	0.69	0.85
E1*	0.95	0.81	1.58	1.11	0.05	1.23	3.67	1.91
E2*	1.07	0.97	1.71	0.50	0.52	0.57	2.39	0.17
E3*	1.71	2.91	4.35	2.53	4.26	8.04	1.10	1.39
E4*	5.99	3.82	9.37	4.08	10.73	9.00	6.12	2.37
E5*	4.06	4.68	1.47	5.46	5.61	3.59	6.34	3.07

*Where 'F' variance ratio is significant

Critical value of 't' 5% = 2.12) 2 tailed
1% = 2.92)

V_1 = 16 (degrees of freedom)

5.6.7 The recalculated 't' value, degrees of freedom and critical values of 't' are given in table E2 of appendix E. Figure 5.9 summarises the 't' test data where it was found that the null-hypothesis should be rejected, due to highly significant differences between the means of the two samples (grid squares) for each area-type.

Figure 5.9

Area-types with highly significant differences between the means (p 0.001)

Element		'Area-Types'
Lead	Total	B2 C1 E3 E4 E5
	Available	B1 D3 E3
Zinc	Total	B1 C1 C2 D3 D4 E3 E4
	Available	B1 C1 D1 D3 E4 E5
Copper	Total	A3 B1 B2 C1 C2 C4 D4 E3 E4 E5
	Available	A3 D1 B4 C1 C2 D3 E3 E4 E5
Cadmium	Total	A1 A2 C1 C2 D3 E1 E4 E5
	Available	A2 B1 C1 C2 C3 D1 D3 E5

From the above summary table, it can be seen that certain 'area-types' have been found to exhibit highly variable soil heavy metal levels such that two sample data sets, taken randomly from each 'area-type', have not explained a significant proportion of the 'within sample' variance. For example, area-types A3, C1, C2 and D3 are significant, in that they are examples of very mixed land-use with residential, commercial and industrial land-use equally represented. The 'E' statistic is reflecting the high variability of soil heavy metal levels in their area-type which can range from virtually uncontaminated soil to samples which contain very high levels.

5.6.8 From the data in figure 5.9 it can be concluded that the value of the within sample variance (W.), used in the analysis of variance 'F' test should have included an extra element of variance which is not accounted for by variation in land-use and intensity of use alone. An addition to the within sample variance would have the effect of reducing the calculated value of 'F' and as such may make it more difficult to reject conclusively the null-hypothesis. No estimate of this 'extra' variance was made and therefore it was not possible to make any addition to the 'within sample variance'. It is, however, suggested that this 'extra' variance would need to be very large to reduce the 'F' statistic to a level where it cannot be used to reject the null hypothesis. However, from the results presented to date and data from other studies (see Chapter 3 and work of Klein, 1972; Beavington, 1973; Davies, 1979; Merseyside County Council, 1978), there is sufficient evidence to conclude that land-use type is the dominant factor influencing soil heavy metal levels in urban areas. Therefore, it is concluded that although the 20 area-types explain a significant proportion of the total spatial variance of heavy metals in the WMMC, there is a certain amount of variance within individual 'area-types', which is not accounted for by land-use characteristics alone. Suggestions as to what may be responsible for this extra variance include geology, soil type and field sampling error. All of which would require further investigation and are beyond the scope of this present research study.

5.7 Mapping Background Levels of Soil Contamination in the WMMC

5.7.1 As stated in section 4.3, of Chapter 4, the role of the heavy metal soil survey in the 20 'area-types' is simply to estimate typical soil heavy metal levels for 'area-types' to enable comprehensive spatial soil contamination maps to be obtained. If the data is to be used as in a mapping exercise for display purposes and in recognition of the fact that there is 'unexplained variance' in the sample data, it is necessary to aggregate the data for individual area-types into a small number of useful (for display purposes) and different categories of 'area-type'.

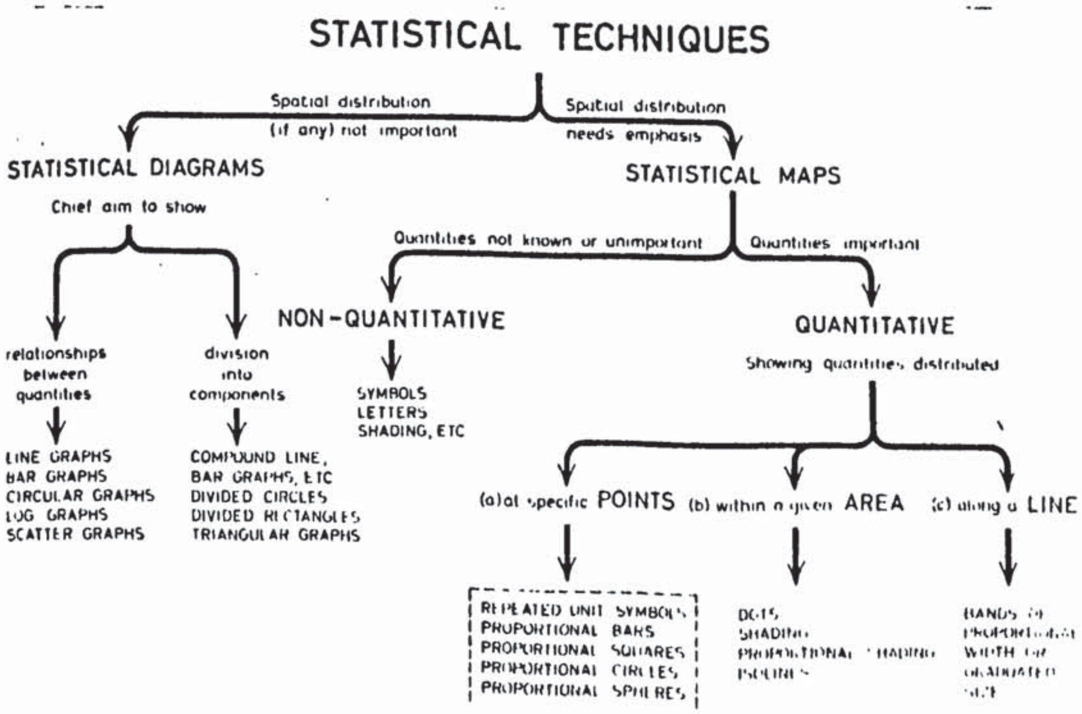
The next section of the chapter describes how the area-type data was grouped into five categories, which were then used to produce background soil contamination maps for the whole of the WMMC.

5.7.2 Grouping the data for display purposes.

As indicated above, and detailed in the objectives in Chapter 1, a central component of the research study was to obtain data on soil heavy metal levels in urban areas, which could then be used to describe the spatial pattern of soil heavy metal levels over the WMMC. The mapping of spatial data involves the use of two component techniques. The first are techniques for obtaining representative spatial data, and the second are techniques for representing the data geographically. The survey work, the collection of spatial data on soil heavy metal content in the 20 'area-types' has been discussed in earlier sections. This section briefly summarises the methods which may be used to map spatial data.

There are in fact a wide variety of means available to convey qualitative spatial information, the details of which are discussed more fully elsewhere (see for example Pocock, 1979; Dickinson, 1973; Hammond & McCullagh, 1978). It is only necessary to summarise such methods here. Dickinson (1973) has suggested various methods for mapping spatial data for display purposes and figure 5.10 is a taxonomy of the extensive range of possible methods.

Figure 5.10 Taxonomy of Spatial Statistical Techniques for Representing data



5.7.3 In the context of this research, using Dickinson's taxonomy, both 'spatial distribution' and 'quantities' are important. It can be seen from fig. 5.10 that there are four possible display techniques which could be used:

i) dot displays

ii) shading of zones

iii) proportional shading of zones

iv) isolines

In the work of Pocock (1979) summarised in chapter 4, a detailed review of the above mapping techniques concluded that of the above techniques, dot displays involved the reduction of the input data to a lower level of information and are therefore inefficient techniques for displaying spatial data. *17. In addition, since shading and proportional shading of zones, are both examples of choropleth maps, the available cartographic techniques for displaying the soil heavy metal data reduce to two possible types:

i) Choropleth (Shading) Zones - where the spatial pattern in the data is represented by the use of visually different (shaded) zones using either simple or proportional shading of zones. Within any single zone conditions, in the case of soil heavy metal levels, are assumed to be homogeneous, with discrete contiguous zones forming 'area-elements' across the study area.

ii) Isolines - this technique involves the use of lines to represent points of equal condition (e.g. isobars on a weather map or contours on a topographic map). The drawing of lines involves a certain amount of subjective judgement.

5.7.4 The suitability of these two classes of technique to a given set of spatial data is constrained by certain characteristics *18 of the data. The key constraining factors according to Pocock (1979) concern the spatial characteristics and scale properties of the data. In general, spatially

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*17 Reduces the information displayed to a visual, qualitative level and are normally used only where the visual impression is the overriding purpose of the mapping exercise.

*18 Characteristics of the data also restrict the choice of statistical tests that can be applied to a data set (see for example Hammond & McCullagh, 1978, P109).

continuous variables such as noise and air pollution are to be represented by isolines and discrete and discontinuous data, such as building condition, and soil pollution should be represented by choropleth zones. As far as scale properties of the data set are concerned, spatial data may possess any of the four scale properties, nominal, ordinal, internal or ratio. In general isoline surfaces require internal or ratio scaled data where individual observations are assigned to a category where the interval between each category is shown. Nominal or ordinal scaled data are more commonly mapped using choropleth techniques since all that is required is to distinguish each zone from its neighbour.

The mean soil heavy metal data for 'area-types' is ordinal scaled data, therefore, it is appropriate to choose the choropleth mapping technique to display the data. In addition, isoline methods are considered inappropriate, since they require that a regular, spatially comprehensive distribution of data, describing the attribute to be mapped, be obtained for points distributed as regularly as possible within the area of study. If it was intended to use an isoline technique for display purposes, then a different sampling approach would have been needed. In fact it would have been necessary to take representative soil samples from a systematic spatially continuous grid (for example from the central point of each km grid square) across the whole of the study. It is evident that since soil heavy metal levels vary significantly within each grid (see fig.5.4 for example) such an approach is not suitable and increasing the number of sample sites in each grid square would add significantly to the resources required.

5.7.5 Having selected choropleth zones as the most appropriate technique for the mapping of soil heavy metal data over the study area, it is necessary, for clarity of presentation of information, to aggregate the range of values (mean soil heavy metal levels for the 20 'area-type') into suitable groups. In dividing the data results into groups, the selection of the number of groups and necessary dividing points between groups needs careful consideration, because it is recognised that the process of grouping the data may have a significant effect on any maps produced from the groups. Gordon (1978) has suggested that choropleth maps should be limited to between 5 and 7 categories 'to produce a map which is readable and conveys the most information'. Fewer categories than five usually results in significant information loss, whereas more than seven categories can result in confusion of the reader. The choice of five categories of 'area-types' seems appropriate for the present study, since in the majority of large scale environmental surveys, five was the typical number of categories used to display information. (see for example, Wood et al, 1974; Cheshire County Council, 1977; South Yorkshire County Council, 1978).

5.7.6 It has already been stated above (section 5.6.4) that an essential part of the process of mapping statistical data is the division of the soil heavy metal data into groups, which share common characteristics and which can be represented by a particular shading. Dickinson (1973) has suggested five possible 'grouping techniques' for grouping data for display purposes:

i) 'simple' division techniques - in which the data set is divided arbitrarily using for example regular interval or round numbers.

ii) quantiles - where the individual measurements are grouped so that an equal proportion of the measurements lie within each group.

iii) standard deviation - where the data set is grouped outwards from the mean in units or class intervals of one standard deviation at a time, or a group one standard deviation wide.

iv) other mathematical intervals - where measurements are grouped according to geometric progression or logarithmic intervals.

v) natural grouping - where the data set itself suggests suitable division points. The distribution of observations along the scale is grouped on the basis of 'apparent' natural divisions in the data set such as 'natural clustering' or 'natural breaks' in the distribution.

5.7.7 On the selection of the most appropriate grouping techniques, Dickinson suggests that in the case of i) - iv) above, division points and class intervals are imposed on the data set, either arbitrarily or by using certain mathematical techniques, and therefore preference should be given to the possibility of using natural divisions. In addition, since the rationale behind 'grouping' is to display similarity between zones and distinctiveness on a map, account must be taken of clusters and natural breaks. Indeed in view of the fact that the purpose of the mapping exercise is descriptive in terms of the natural pattern and spatial variation of soil heavy metal levels in the WMMC, the use of natural groupings appears to be the most appropriate grouping technique.

Other methods of grouping the soil heavy metal data were investigated. For example, it may have been possible to divide the data into intervals according to recognised and published standards such as naturally occurring background levels in 'unpolluted' soil or to the guideline and standards established for plant phytotoxicity *19. However, it has already been established that soils in urban areas will exhibit elevation of heavy metals and therefore the use of naturally occurring levels is inappropriate. In the case of published standards and guidelines, there are at present no precise environmental health protection standards for soil contamination, only the ICRCL *20 guideline values for a number of elements where

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*19 See chapter 2 for a full discussion of such guidelines and standards.

*20 See section 5.3 of this chapter and chapter 6.

contaminated land is being redeveloped and therefore the use of existing standards for class intervals is also inappropriate. In addition, even if naturally occurring levels and standards had been selected as class intervals, probably two, at the most three, categories could be displayed which would have resulted in a significant amount of information loss in the data. The choice of natural grouping techniques is supported by Theys (1976) who has found that natural grouping methods minimise the information loss that is consequent upon grouping. In the light of the above discussions, the natural grouping method was preferred and is applied to the mean soil heavy metal levels for the '20 area-types' as discussed below.

5.7.8 Figures 5.11 and 5.12 are dispersal graphs of the 20 area-type mean soil heavy metal levels for total lead and cadmium and available zinc and copper. From these dispersal graphs, it can be seen that the division of the data set into the 5 groups, using natural clusters or breaks in the data is not an easy task. Although at the extremes (high and low values), natural breaks and clusters feature quite strongly, there is marked 'bunching' of means in the medium values with no clear 'breaks' in the data. For example, there is an obvious group of means around the natural background level reported for uncontaminated soil (100 mg/kg lead, 0.7 mg/kg cadmium, 50 mg/kg zinc, and 30 mg/kg copper). There is also a clear break in the means at the higher levels of heavy metal soil contamination; at 150 mg/kg for available copper and 2.5 mg/kg for total cadmium, for example.

5.7.9 Further evidence of natural groups in the data is available from cumulative frequency plots of soil heavy metal levels in the WMMC. As stated in section 4.4 of Chapter 4, the mapping methodology is essentially a sampling technique, where each of the 1003 grid squares in the WMMC can be assigned to one of 20 'area-types'. Therefore we can use the data of mean heavy metal soil levels for each area-type as typical heavy metal

Fig. 5.11 Distribution of Area Type Mean Soil Heavy Metal Levels.

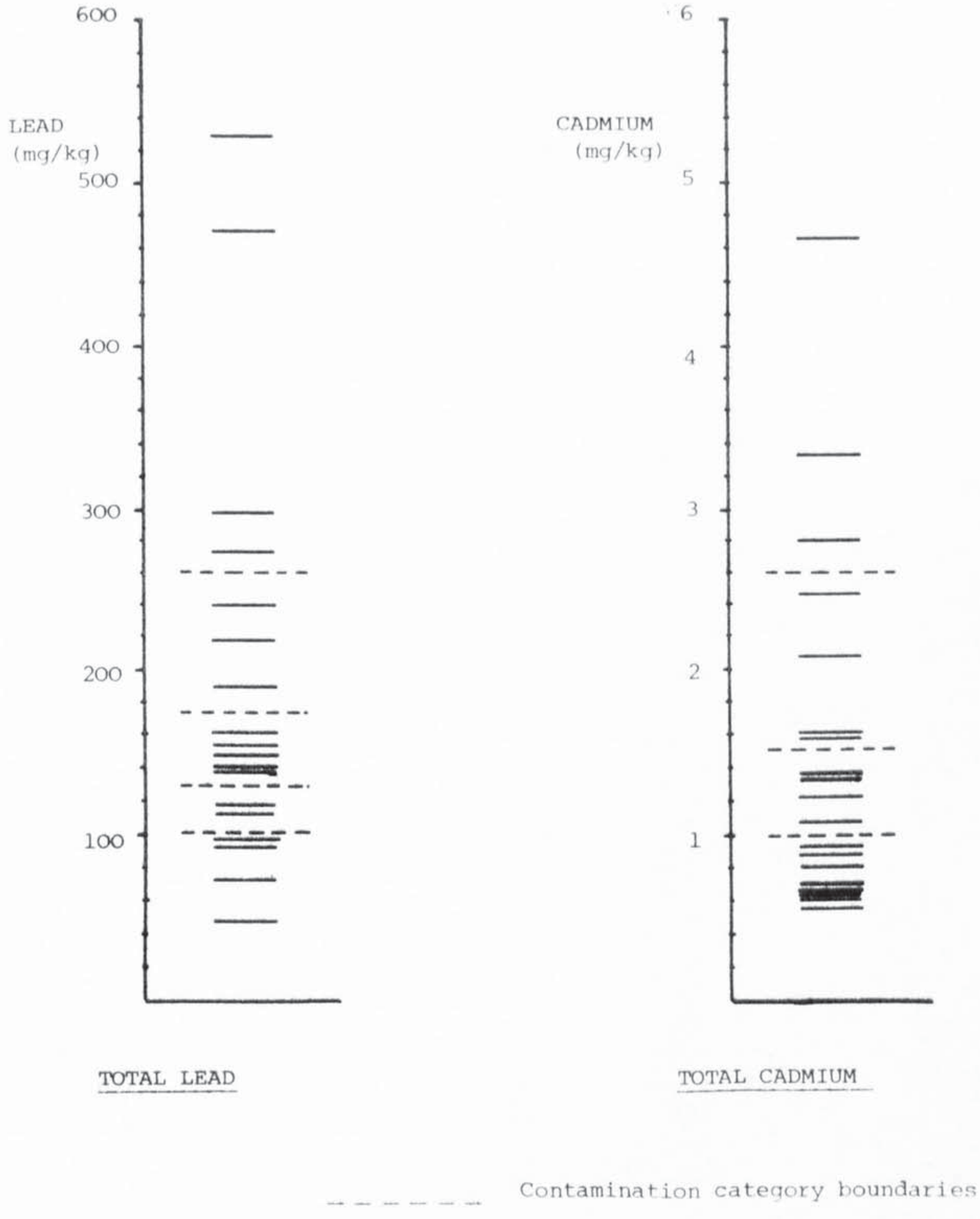
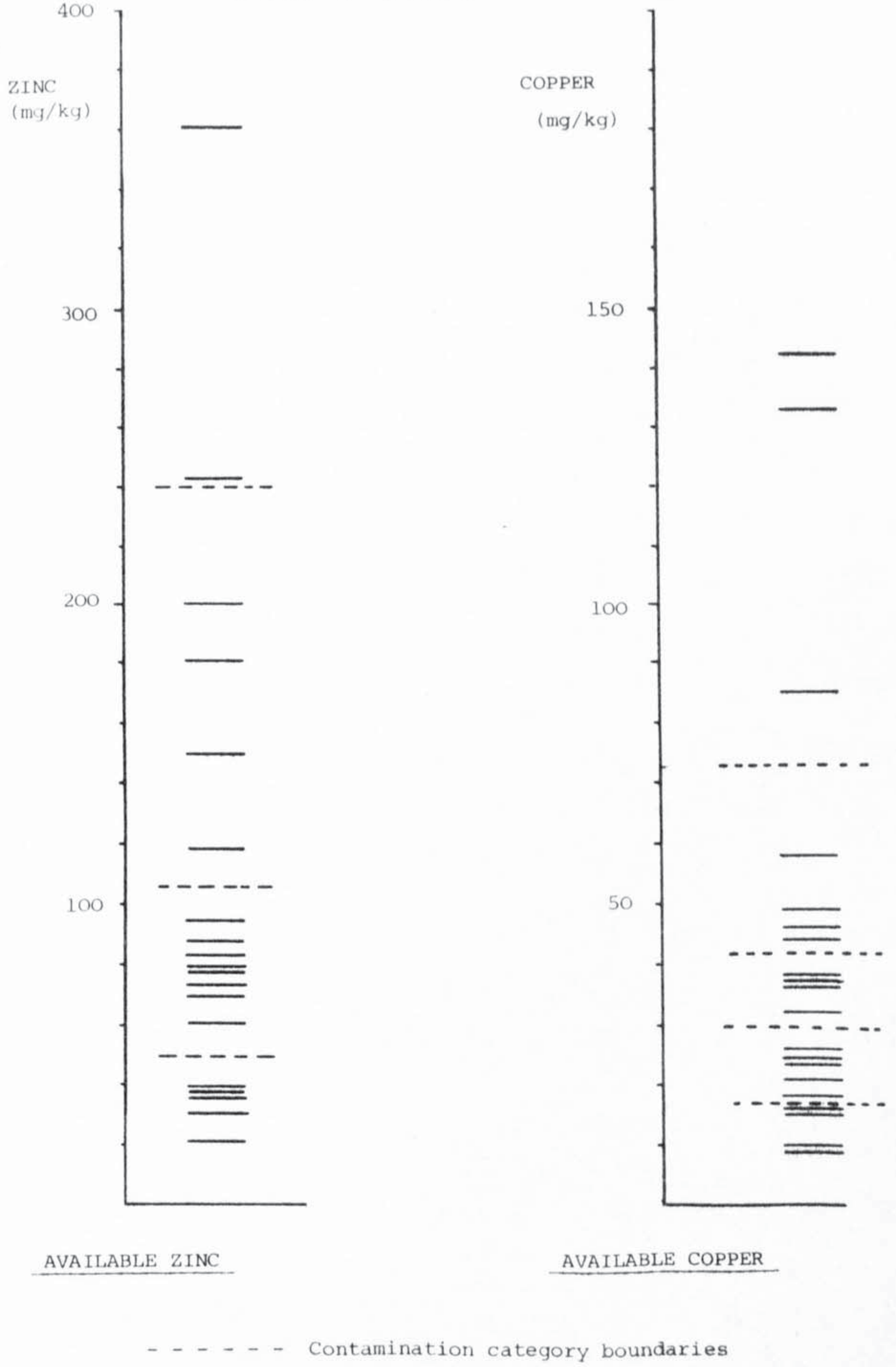


Fig. 5.12 Distribution of Area Type Mean Heavy Metal Levels.



levels for each grid square of a given area-type. Since we already know the percentage of grid squares in each area-type (table 4.2 of chapter 4), it is possible to plot graphically cumulative frequency distributions of soil heavy metal levels in the WMMC. These have been achieved and the cumulative frequency distributions for total soil lead and cadmium and available soil copper and zinc are shown in figures 5.13 - 5.16. It will be evident from figures 5.13 - 5.16 that the cumulative frequency plots of area-type mean soil heavy metal levels reflect the distribution of individual sample sites (discussed in section 5.2). There is for example a 'tail' of high soil contamination levels with a bunching of values at the lower end of the range. It is also evident from the cumulative frequency plots that there are noticeable breaks in slope of the curve and grouping of means. For example, in the case of the plot for total lead (figure 5.13) there are clear breaks in slope at 100 mg/kg; 180 mg/kg and 260 mg/kg with a bunching of means between 130 mg/kg and 160 mg/kg soil lead. In the plot for available copper (figure 5.22), there are clear breaks in slope at 70 mg/kg and 42 mg/kg with groups of means around 36 and 24 mg/kg soil copper.

5.7.10 Since no single grouping technique was universally applicable to the data set for all the four heavy metal measurements, a number of characteristics of the data were taken into account.

i) natural groupings and breaks in the dispersal graphs

ii) the breaks in slope and grouping of means as shown by the cumulative frequency plots.

iii) the fact that the results from individual samples and the means for area-types suggest that there are likely to be only a few highly contaminated 'area-types', with a broadly even number of area-types in the other four categories.

Using the above, the 20 area-type mean soil heavy metal levels, for the four heavy metals, were divided into the five categories of area-type as

Fig. 5.13 Cumulative Frequency Distribution of Levels of Total Lead in the WMMC.

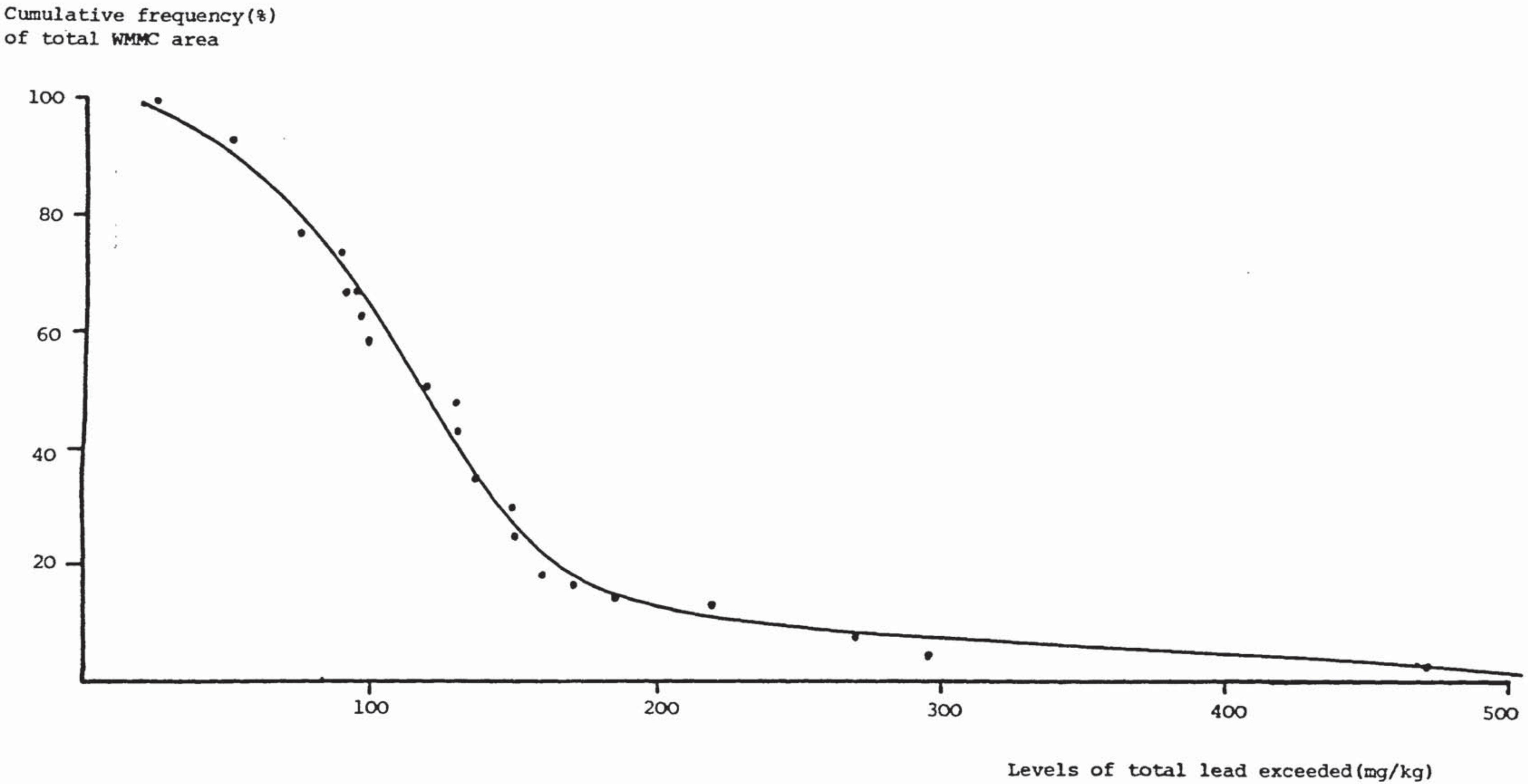


Fig. 5.14 Cumulative Frequency Distribution of levels of Total Cadmium in the WMMC.

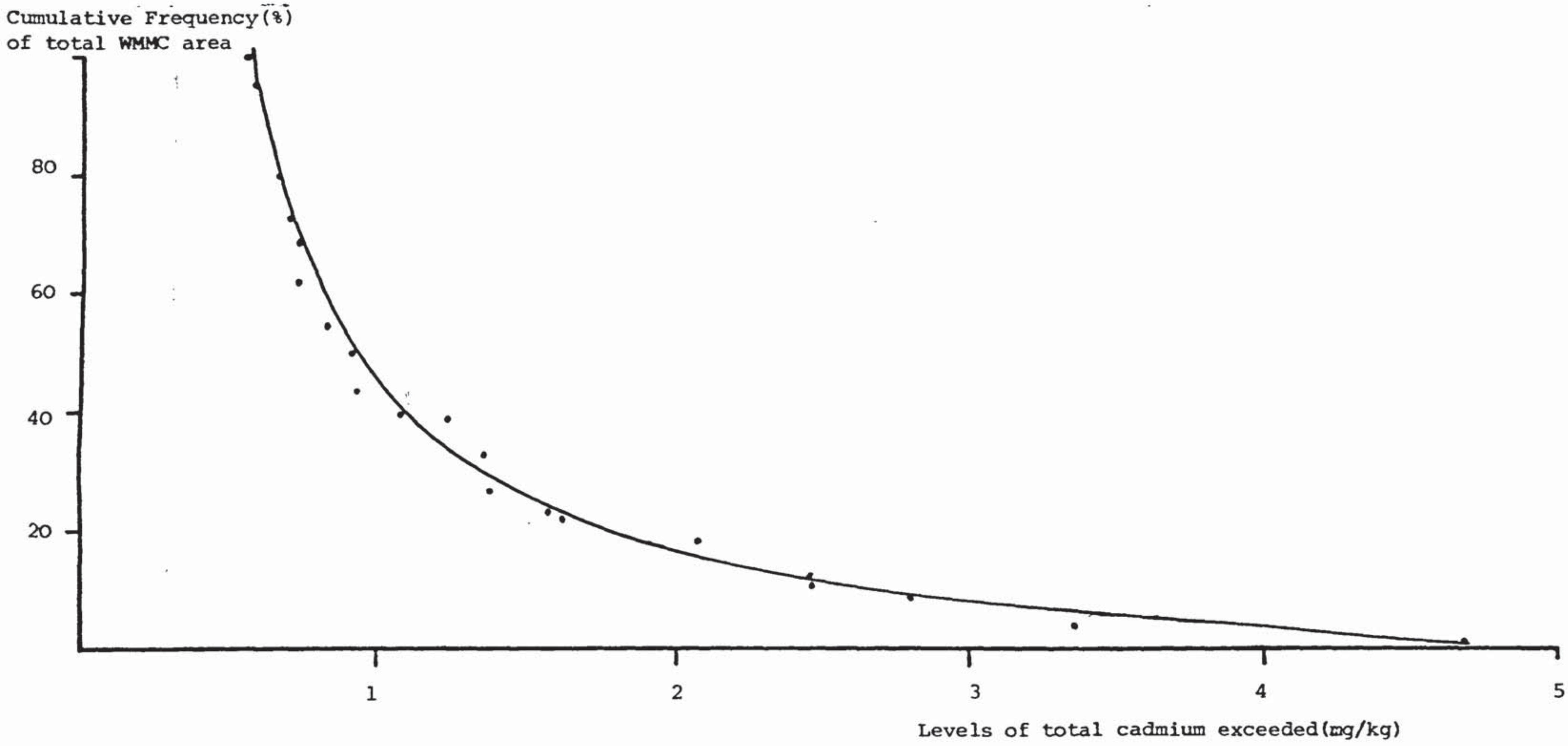


Fig. 5.15 Cumulative Frequency Distribution of Levels of Available Zinc in the WMMC.

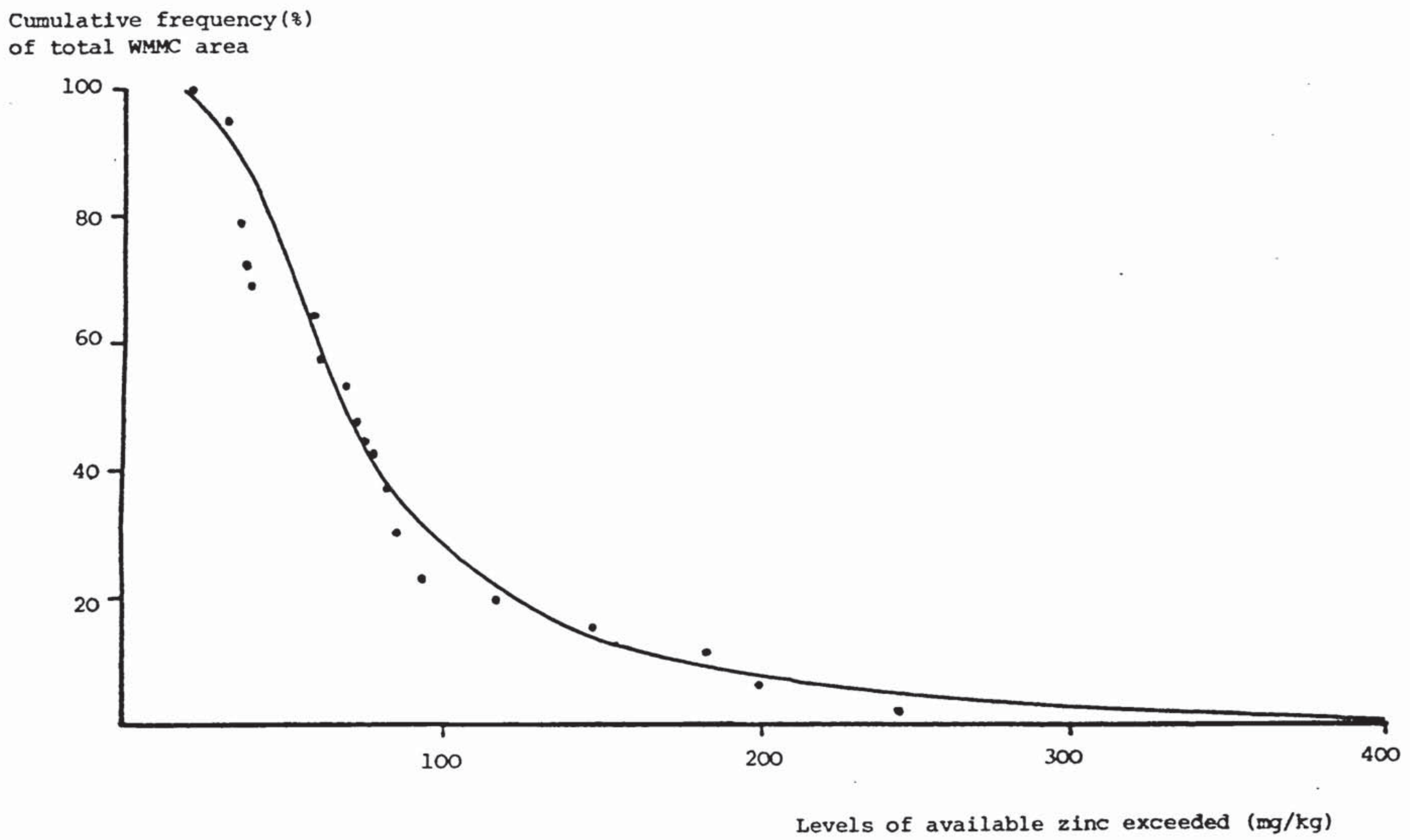
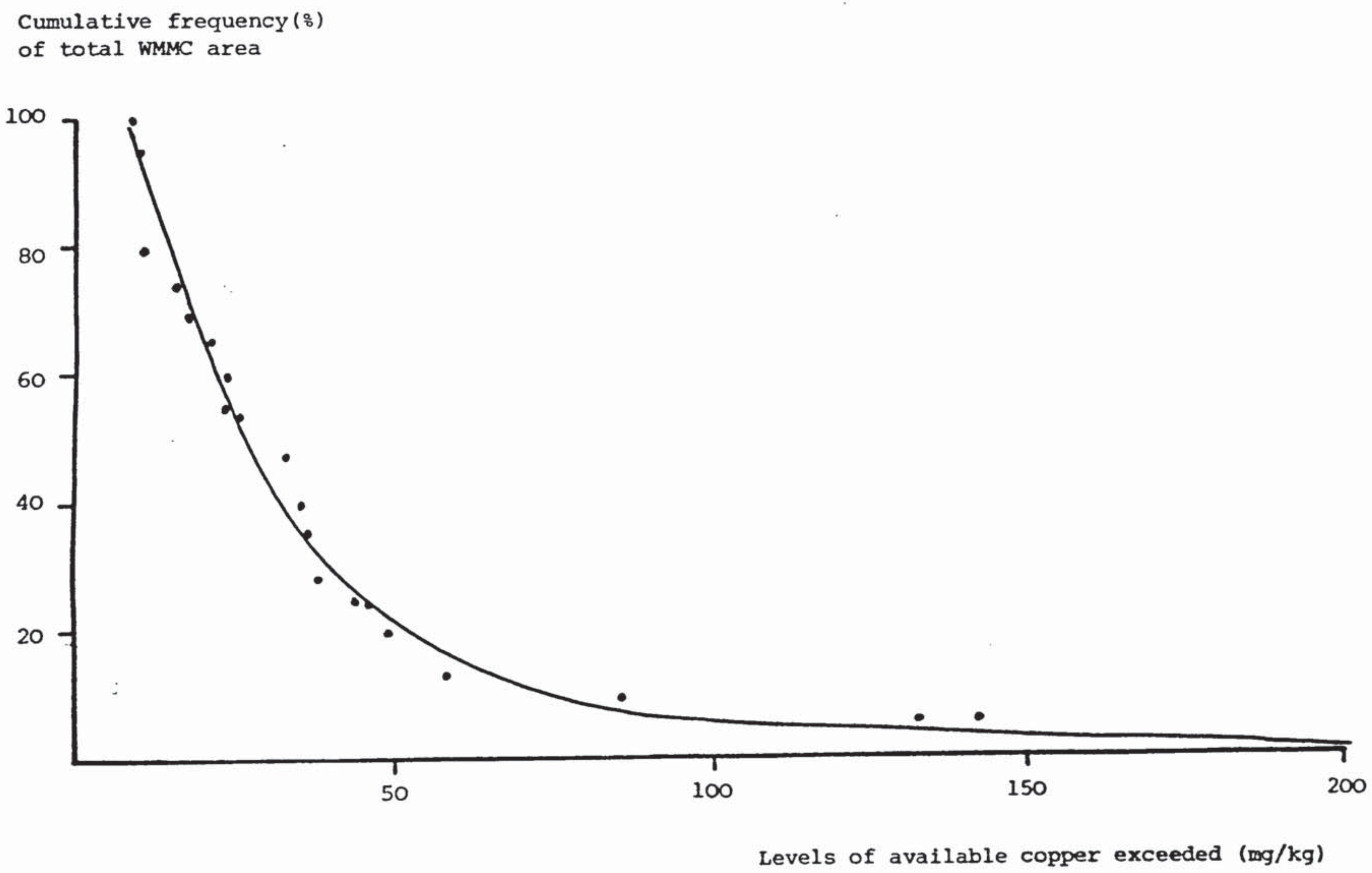


Fig. 5.16 Cumulative Frequency Distribution of Levels of Available Copper in the WMMC.



shown in figures 5.17 and 5.18. The categories (1-5) range from highly contaminated area-types (category 1) to category 5 which show little elevation of soil heavy metal levels. Figures 5.17 and 5.18 also contain data on the percentage of the WMMC in each of the five categories of soil contamination for both available and total heavy metal determinations.

5.7.11 From figure 5.17 it can be seen that in the case of total soil lead groupings, category 1 (highest levels of soil contamination) contains the mixed residential and industrial areas,while category 2 contains the high network density industrial and commercial areas. Category 3 is predominantly residential/recreational area-types of medium network density, while category 4 includes the outer suburban less dense residential areas, in sparse network density categories. Category 5 represents almost entirely the rural agricultural land-use. In addition, it is evident that on the whole, the groupings appear to be independent of road network density with each network density category represented in each of the five groups.

In the case of total cadmium, category 1 contains the principal commercial and industrial centres across the range of network density categories. In category 2, almost all the mixed residential /industrial areas are included. Category 3 is predominantly residential with some commercial and industrial land use present, while category 4 includes residential and recreational areas in the outer suburban areas of less dense road network density. Category 5 represents the least contaminated areas, where agricultural land, parkland and some semi-rural residential areas dominate. As was the case for the total lead groupings, categories 1 - 4 include the range of road network densities while category 5 is dominated by the sparsest network density.

In the case of the categories for total zinc and copper, a similar pattern

Fig.5.17 DESCRIPTION OF THE FIVE CATEGORIES OF SOIL CONTAMINATION - TOTAL METALS

Category	Heavy Metal	'Area-Type' Codes	Proportion of County (by Area) in each category
	Total Cadmium		
1	greater than 3	A1, E1, D1	8.4%
2	1.5 - 3.00	D3, C2, B2, B3	15%
3	1.0 - 1.49	A2, B1, D4, A3	17%
4	0.7 - 0.99	E2, C4, B4, C1, D2	28.9%
5	less than 0.69	C3, E4, E3, E5	31.3%
	Total Lead		
1	greater than 250	B2, A3, E1	7.6%
2	189 - 249	A1, C2, A2	10%
3	136 - 188	B3, B1, E3, D1, D4, C1	30%
4	108 - 135	D3, C4, D2, E4	24.4%
5	less than 107	B4, C3, E2, E5	27.7%
	Total Zinc		
1	greater than 675	A1, B2, C2	10.6%
2	547 - 624	A2, D1, B4	12.1%
3	343 - 547	A3, D3, D4, E1	13.5%
4	244 - 342	C1, B1, B3, C4	21.9%
5	less than 243	D2, E2, E3, E4, E5, C3	42%
	Total Copper		
1	greater than 278	A2, B2, C2	12.9%
2	124 - 277	A1, E1, C1	11.1%
3	90 - 123	A3, D1, B1, D3	15.4%
4	65 - 89	D4, B3, C4, B4	18.1%
5	less than 64	E4, C3, E5, D2, E2, E3	42%

to the groupings of area-types occurs. Categories 1 & 2 contain almost all the industrial areas and those area-types in mixed residential/ commercial use in relatively high network density categories. The suburban residential areas with some mixed industrial land use are in category 3, which also contain the medium to dense network density categories. Category 4 represents the majority of the residential areas where some recreational and agricultural land is also present. Category 5 is almost entirely represented by area-type E, the sparsest network density category, which includes all the recreational and agricultural land-use, mixed,in places,with small amounts of residential use.

5.7.12 A similar pattern to the groupings is seen in figure 5.18, the grouping of the four available heavy metal soil levels. It is interesting to note from figures 5.17 and 5.18 that category 5 for all eight data sets accounts for some 35-40% of the land area of the WMMC,whereas the highest soil contamination levels, group 1, accounts for only 7 - 10% of the land area. This indicates that using 'naturally' derived class intervals nearly two thirds of the WMMC land area has a soil heavy metal content, which is only slightly elevated above 'normal' levels, reported in the literature for 'unpolluted' soil (see section 5.4 of this chapter). For example, in the case of total lead and cadmium 60% of the WMMC has an estimated soil heavy metal content of less than 135 mg/kg lead and 1.0 mg/kg cadmium. In the case of available zinc, 62% of the WMMC has a soil zinc content of less than 80 mg/kg and for copper, some 74% of the WMMC has at soil copper level less than 42 mg/kg. At the other end of the scale, over 18% of the WMMC has an estimated total cadmium level greater than 2 mg/kg, the upper limit of the range of normal levels *21 in soil. For total lead, 12% of the WMMC has a total soil lead level in excess of 200 mg/kg. For available copper and zinc where the upper limit of the normal range in soil is 10 and 15 mg/kg respectively, almost the whole

*21 Based on M.A.F.F. ADAS guidelines discussed in section 5.3 of this chapter and referred to in chapter 3.

Fig. 5.18 DESCRIPTION OF THE FIVE CATEGORIES OF SOIL CONTAMINATION - AVAILABLE METALS

Category	Heavy Metal	'Area-Type' Codes	Proportion of County (by Area) in each category
	Available Lead		
1	greater than 100	E1, A1, B2	15.2%
2	85 - 99	B1, A3, C2, C1, C4	15.1%
3	65 - 84	B3, D3, D2, D4, A2	20.8%
4	54 - 64	C3, B4, D1, E2	16.9%
5	less than 54	E4, E5, E3	27.2%
	Available Copper		
1	greater than 85	A1, A2, C2	9.9%
2	42 - 84	A3, B2, C1, E1	14.9%
3	30 - 41	B1, C3, D1, D3	22%
4	17 - 29	B3, B4, C3, D4, E4	22.4%
5	less than 16	E2, E3, E5	30.8%
	Available Zinc		
1	greater than 201	A1, A3	1.6%
2	95 - 200	C2, D1, B2, D3	18.4%
3	80 - 94	E1, C1, B1	17%
4	60 - 79	C4, B3, A2, D4, B4, D2	28%
5	less than 59	C3, E2, E4, E5, E3	35%
	Available Cadmium		
1	greater than 1.4	D3, A1, C2	10%
2	1.0 - 1.39	D1, A2, E1	11.5%
3	0.71 - 0.99	C4, A3, C1, B2	19.5%
4	0.51 - 0.70	D4, B4, B3, B1, C3, E2	26%
5	less than 0.50	D2, E3, E4, E5	34%

of the WMMC has soil levels in excess of these 'guideline' values.

5.7.13 The use of other than purely statistical criteria for grouping is considered not to affect the validity of grouping or its use in display. Since, as discussed above, and pointed out by Edwards (1964), 'natural grouping' of a set of means allows the researcher

> "to section this ordering in such a way that we could say the means falling within a given section (group) are alike in that they do not differ significantly among themselves, but that there are significant differences between sections".

If the data set had formed a continuous distribution without significant natural breaks or clusters, then it would have been necessary to 'group' the data according to an arbitrary mathematical method such as the 'equal interval' or 'round numbers' approach, which is no more <u>statistically</u> valid than using natural groupings.

However, it is recognised that the grouping performed on the heavy metal soil data may be susceptible to 'grouping error'. Therefore it is necessary to carry out a statistical check on the groups to determine the extent of this 'error': the 'error' is taken to be the misallocation of an 'area-type' to one of the 5 groups. The actual checking for misallocation is a statistical test to determine the probability (percentage chance of error) of misallocating area-types to a group and involves the use of Fishers 'Z' score, given by the formula

$$'Z' = \frac{X - \bar{X}}{S}$$

Where $\bar{X}$ and S are the mean and standard deviation of the sample. The 'Z' score is based on the normal distribution and the number of standard deviations a value is above or below the mean for that group. In this particular case, the standard deviation (S) is the standard deviation of the sample means for an individual category, $\bar{X}$ is the mean for the area type in that group, and X is taken to the 'boundary value'. of the category being examined. Therefore, what we are interested in determining is the 'probabilities' corresponding to differences between the area-type mean and 'boundary value' (either above or below) for the group.

5.7.14 For the four data sets, total lead and cadmium and available zinc and copper, 'Z' scores were calculated for the 20 'area-types' (i.e. a category 1 mean being in category 2 or 3, or a category 2 mean being in category 1 or category 3 or 4). The tabulated calculations are contained in appendix E and Table 5.13 summarises the results of this calculation.

Table 5.13 Summary data on Percentage Chance of Misallocating an Area-Type to a Land Contamination Category

Metal	Number of categories misallocated							
	- 2		- 1		+ 1		+ 2	
	average	range	average	range	average	range	average	range
Total lead	3.8	0-11	27	0-38	21.5	0-42	2.9	0-16
Total cadmium	0.4	0-3.6	18.3	0.3-42	14.8	0.8-46	0.5	0-5.5
Available zinc	2.5	0.1-13.6	16.9	0.6-46	20.3	0- 46	2.9	0.1-13.6
Available copper	0.5	0 -1.8	17.3	0 - 38	12.0	0 -34.5	0.3	0 -2.9

See appendix E. for detailed tabulations.

From Table 5.13 it can be seen that in the case of total lead, on average there is a 25% change of an area-type being allocated 1 category out, but only a 3% chance of an 'area-type' being 3 categories out. *22. For total cadmium, on average there is a 16% probability of an area-type being allocated one category out, and a less than 0.56 probability of being two categories out. In the case of available zinc, there is a 20% probability of an area-type being in 1 category too high or too low, but only a 3% chance of an area-type being two categories out in its allocation, and for available copper the probabilities are 15% for 1 category misallocation,

*22 i.e.there is a 25% probability that an area-type in group 2 should be in group 1 or 3, and only a 3% probability that an area-type mean in group 3 should be in group 1 or 5.

and 0.5% for 3 categories misallocation. The results of this statistical test of the groupings serve to support the use of natural breaks as a 'grouping technique' for this data to produce categories which are significantly different from each other. Having established the categories (1-5) to be used for describing the spatial variation of soil heavy metal levels in the WMMC, the next stage in the mapping study is to produce maps of soil contamination; this is described below.

5.8 Background Soil Contamination Maps

5.8.1 The next stage in the mapping process is to produce background *23 soil contamination maps for the whole of the study area. Soil contamination maps were developed by allocating the relevant soil contamination category (1-5) to each of the 1003 grid squares in the WMMC on the basis of each individual grid squares 'area-type' code. For example, all grid squares of 'area-type A1' were allocated to category 1 for total lead in the soil. The mapped data for the 4 heavy metal data sets of total lead and cadmium and available copper and zinc are shown in figures 5.19 - 5.22, which are computer derived choropleth maps.

5.8.2 The maps were obtained from a specially written fortran programme for the research (presented in appendix F.) for use with an ICL 1904 'GINO-F' graph plotter. The mapping of the grouped data illustrates the spatial pattern of soil heavy metal levels in the WMMC clearly. Figures 5.19 - 5.22 should be compared with figures 5.23 and 5.24 which show the major industrial and residential/commercial centres in the WMMC.

5.8.3 In general, the soil contamination maps clearly distinguish the major industrial centres of Coventry, Walsall, Wolverhampton, West Bromwich and Dudley. The green belt areas and agricultural land at the urban fringe and that which separates Coventry from the conurbation, is also clearly

*23 The choice of 'background' soil contamination is deliberate since it is intended that such maps will describe normally occurring levels of heavy metals in urban soil environments.

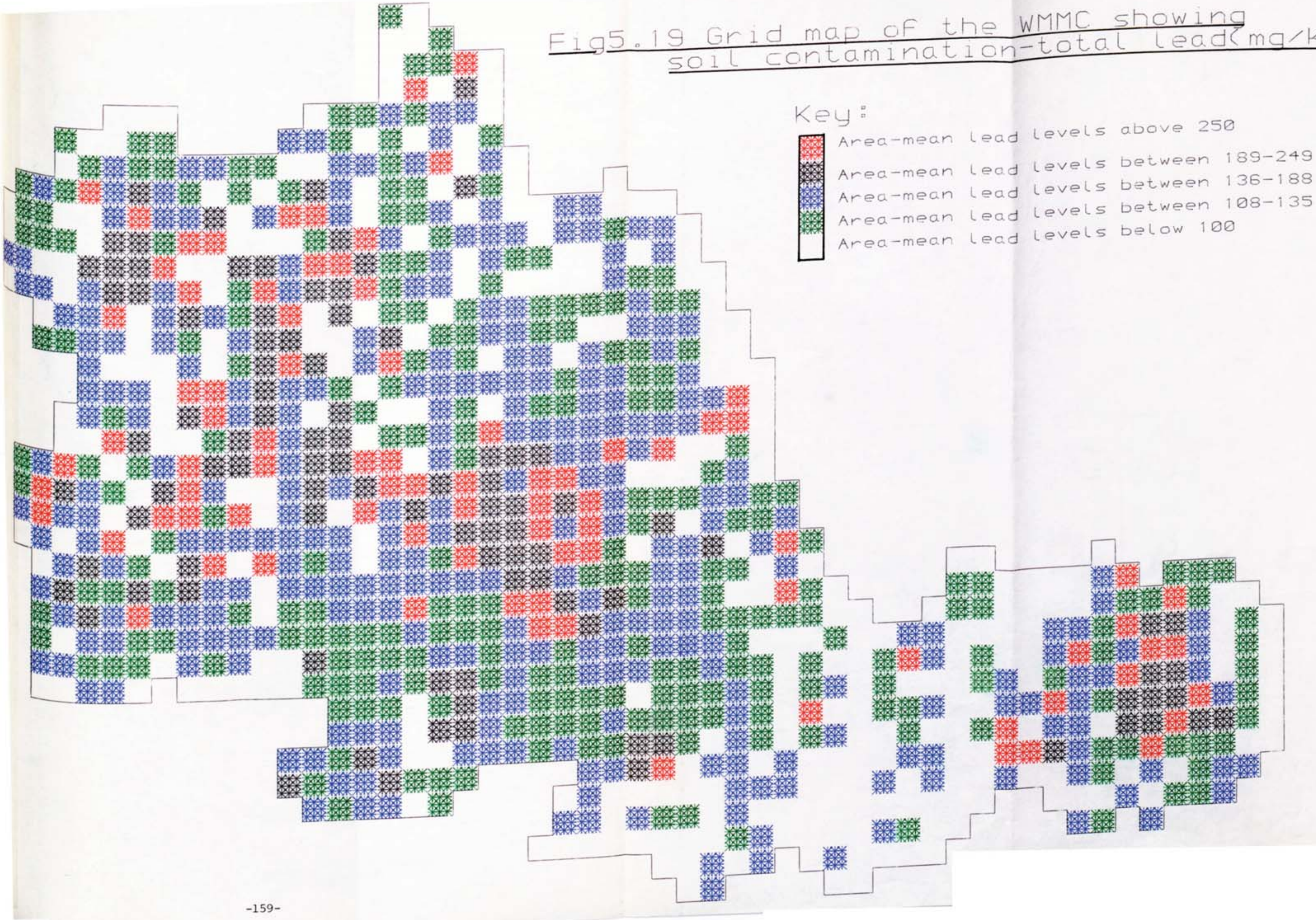


Fig5.19 Grid map of the WMMC showing soil contamination-total lead(mg/kg).

Fig5.20 Grid map of the WMMC showing soil contamination-total cadmium(mg/kg).

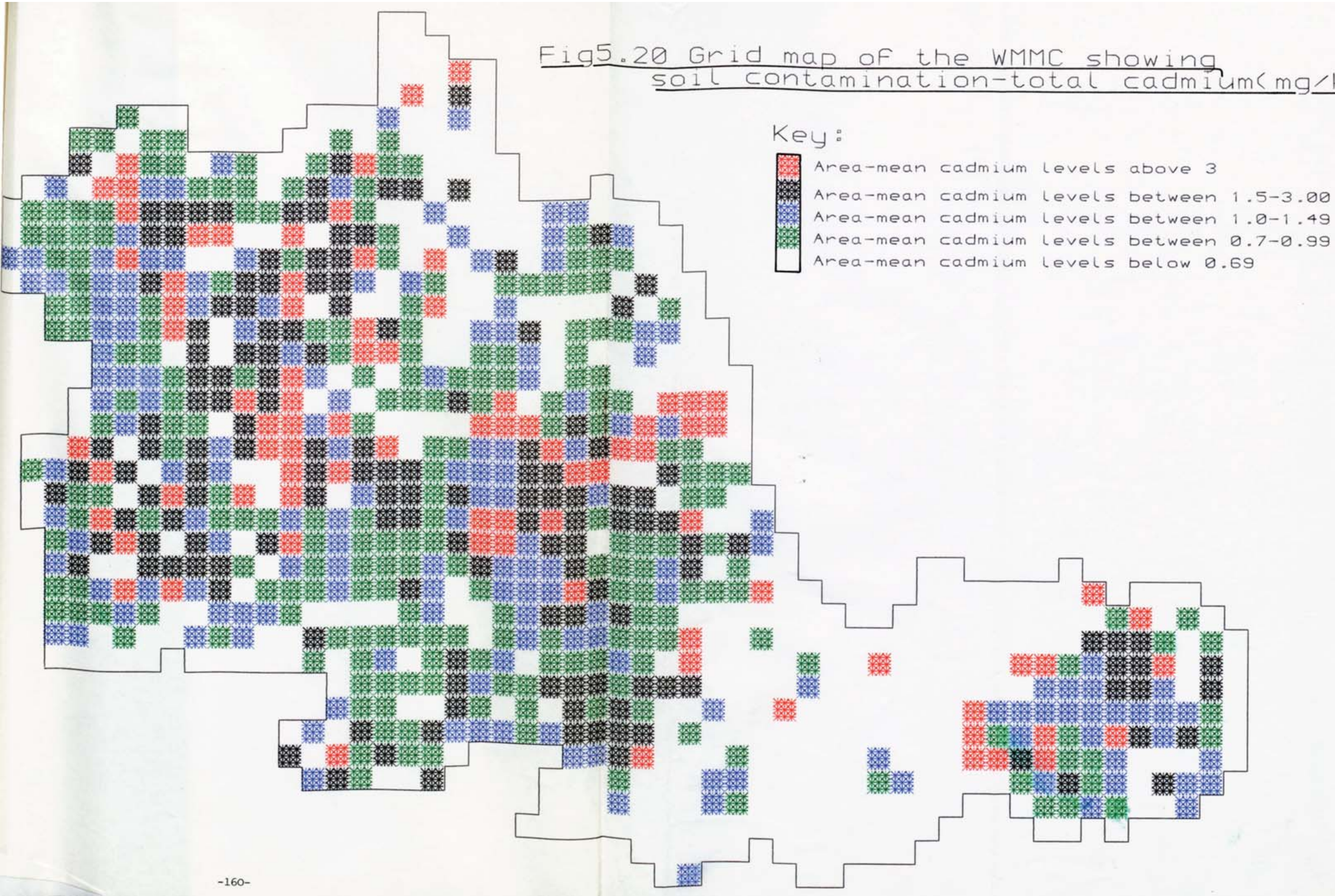


Fig5.21 Grid map of the WMMC showing soil contamination-available copper(mg/kg

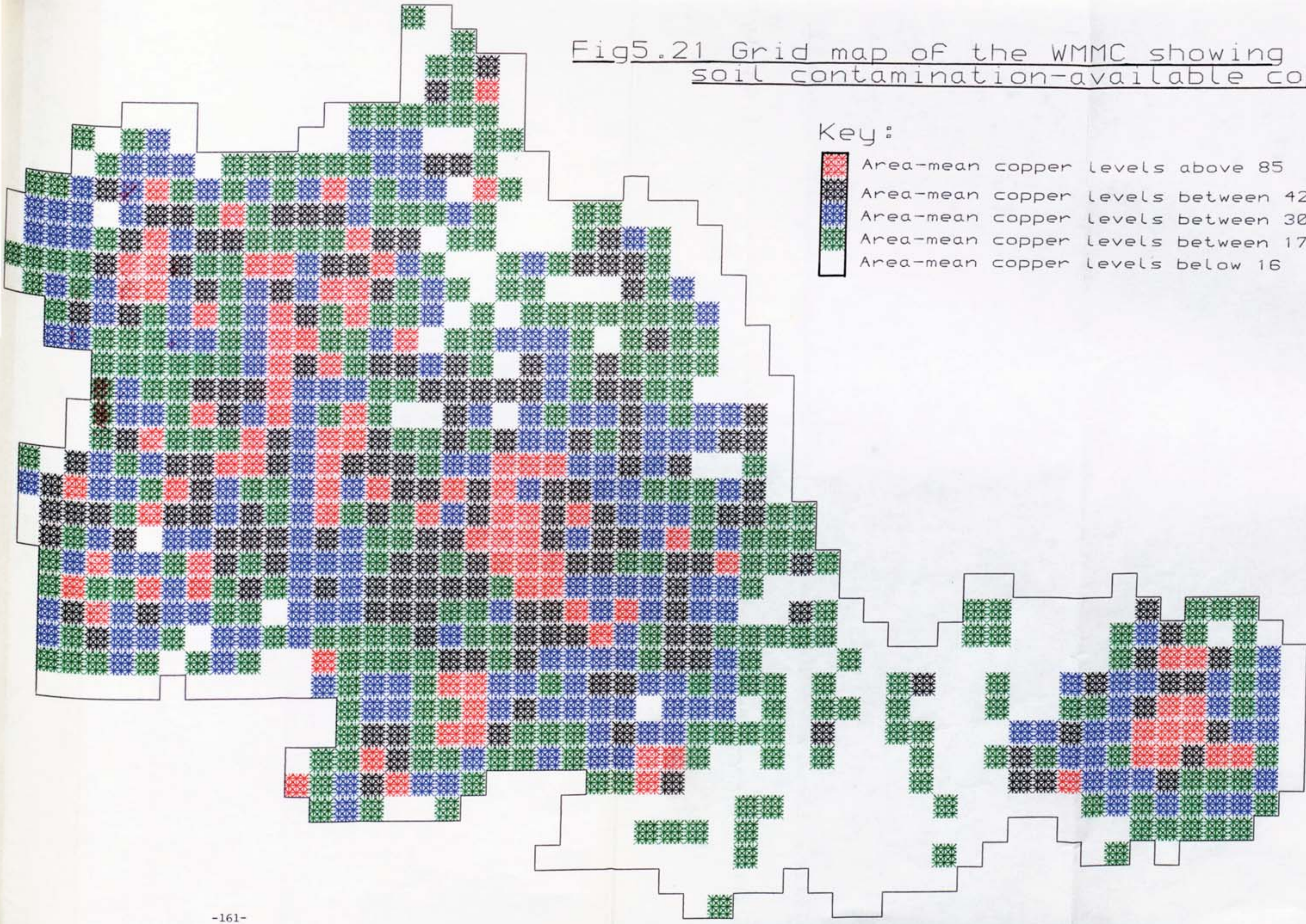


Fig5.22 Grid map of the WMMC showing soil contamination-available zinc(mg/kg).

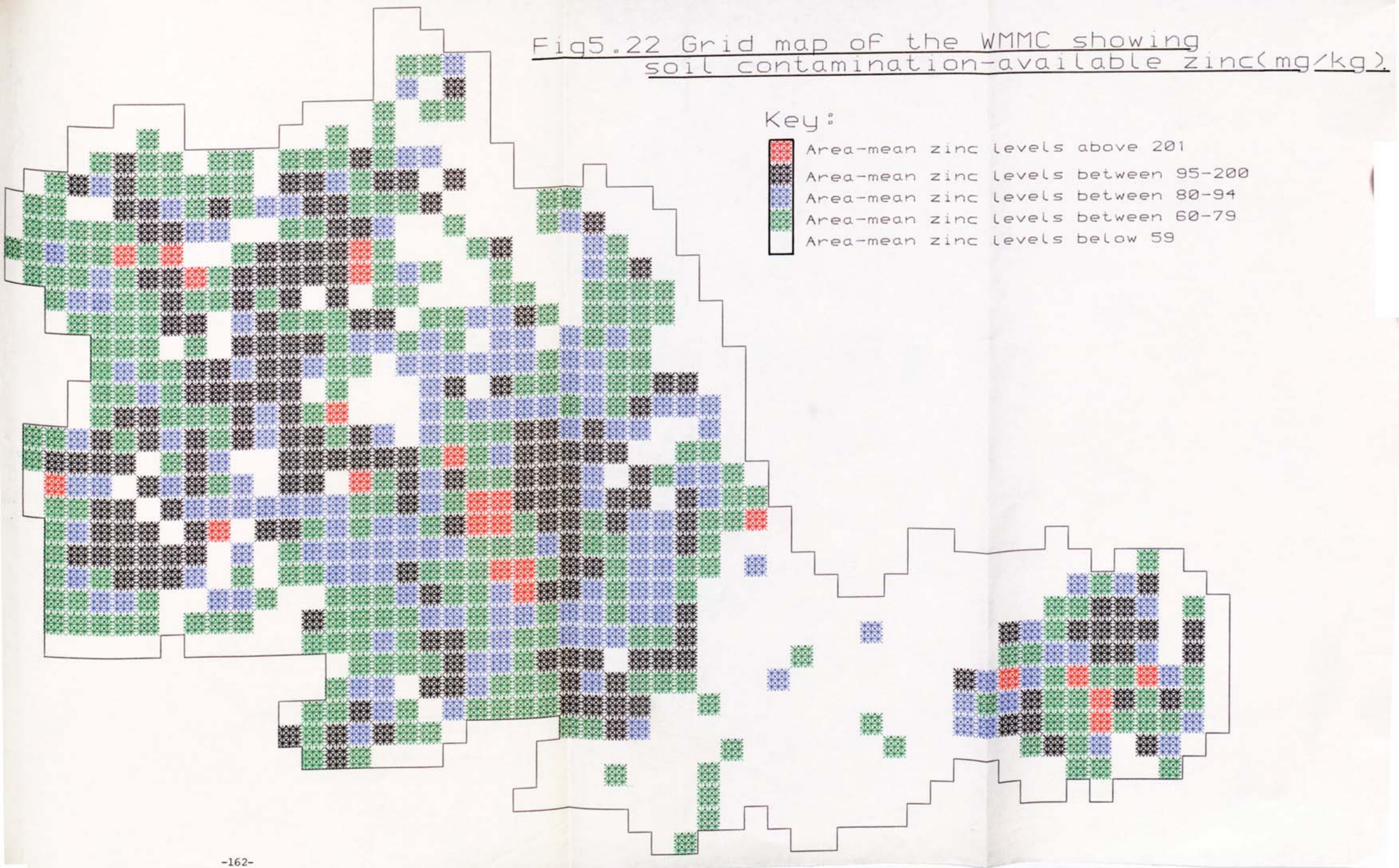


Fig. 5.23 Map Showing the Major Industrial Areas in the WMMC.

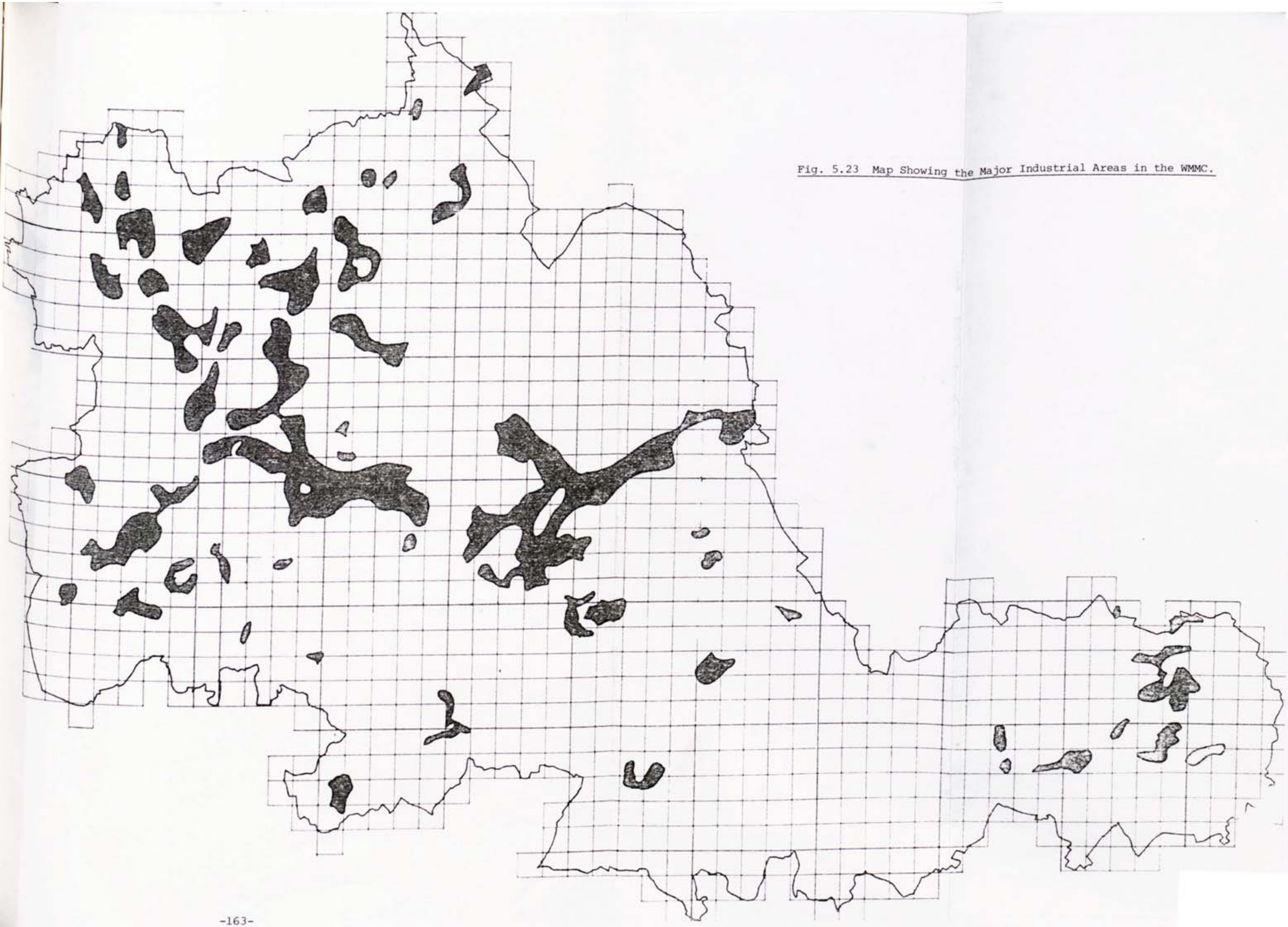
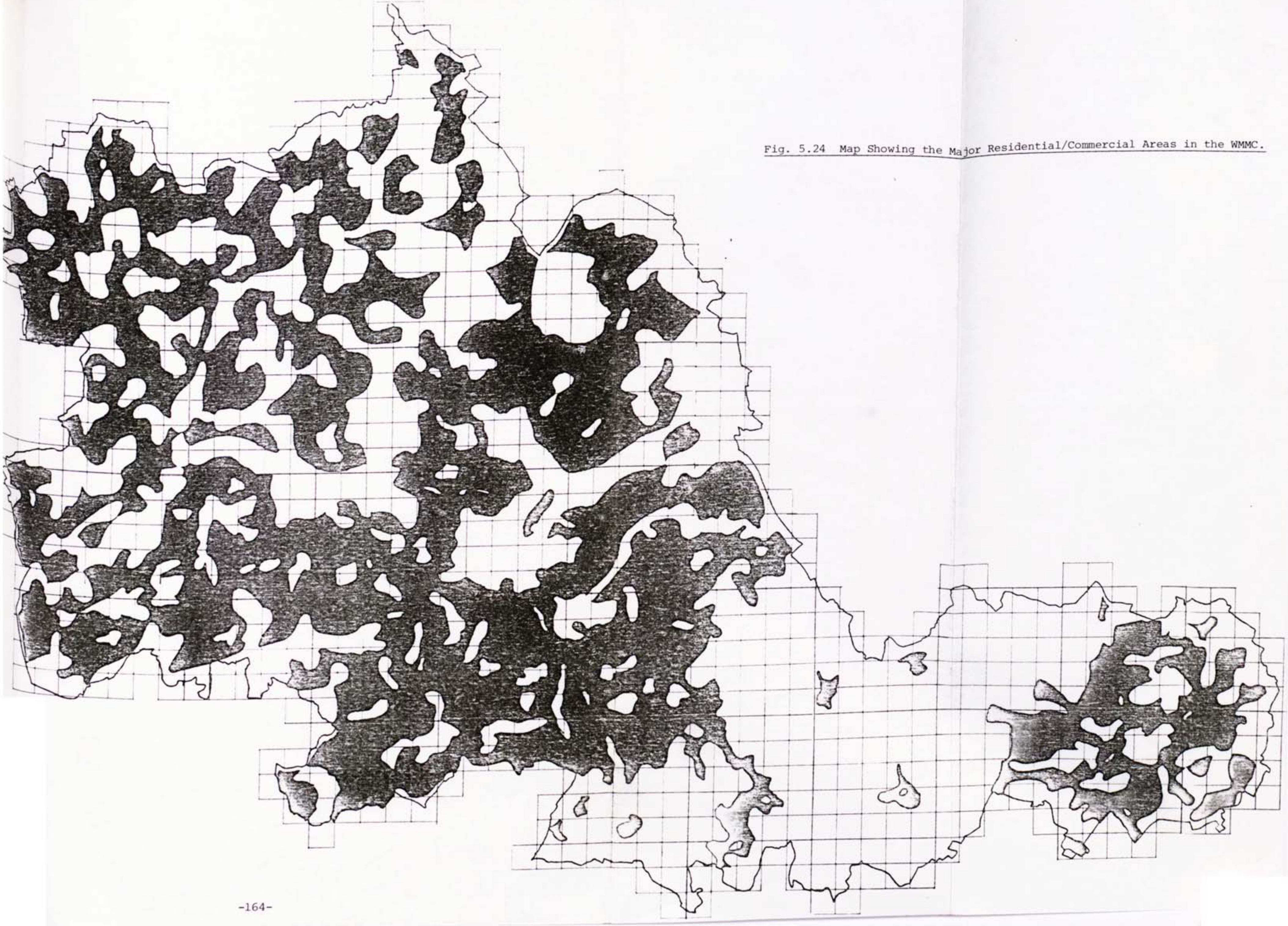


Fig. 5.24 Map Showing the Major Residential/Commercial Areas in the WMMC.



identified (category 5). In comparing the soil contamination maps to the land use maps, it is evident that there is an association between high soil heavy metal levels (category 1 and possibly 2 areas) and industrial land use, and between higher levels of soil contamination and the centres of the older urban areas in the WMMC. For example, central Coventry and central industrial Birmingham are clearly identified in all maps. In addition, for all four heavy metals, categories 3 and 4, indicative of slight contamination, correspond closely with the major residential areas in the WMMC. Detailed comments on individual soil contamination maps are presented below.

5.8.4 Figure 5.19 is the background soil contamination map for total lead. From figure 5.19 it can be seen that categories 1 and 2 (high levels of soil contamination) correspond to the industrial centres of Walsall, Coventry, Walsall and Wolverhampton, with two 'wedges' of high levels north east and north west of Birmingham. However, it is also noticeable that high soil lead concentrations are found more widely distributed across the WMMC. This is probably a direct result of the importance of traffic sources of lead (rather than industrial point sources) in urban environments. There is also a clear 'belt' of high soil lead concentrations running from Walsall in the north west of the conurbation to Brierley Hill and Dudley in the south west.

5.8.5 The soil contamination map for total cadmium (figure 5.20) shows a much tighter pattern. The green belt wedge of rural/agricultural land between the conurbation and Coventry, and around the County, are clearly distinguishable. A similar pattern of high soil concentrations (group 1 and group 2) is seen for cadmium as was found for lead. However, there is less on a concentration of higher levels in the Birmingham area, with higher concentrations in the Black Country areas of Wolverhampton, West Bromwich, Smethwick, Walsall and Dudley. This is probably due to the higher incidence of non-ferrous metal industries (plating works, smelters, etc) in the Black Country area.

5.8.6 The maps of available copper and zinc (figures 5.21 and 5.22), also delineate clearly the Solihull green belt of agricultural rural land between Coventry and the conurbation. As was the case in the cadmium soil contamination map, the highest concentration for both copper and zinc are found associated with a historical and present day metal using industrial centres of the Black Country,including Walsall, Bilston, Willenhall, Smethwick and West Bromwich. It is also interesting to note that the major recreational/rural land in the county is clearly identified, being land to the east of Coventry, north east of Birmingham, east of Walsall and in the south west part of the conurbation, bordering on Halesowen/Stourbridge areas. For all four heavy metals, the major residential areas of south west of Coventry, south and south east of Birmingham in the Solihull area and around Halesowen and in the area south of Wolverhampton and west of West Bromwich.

5.8.7 This final section of chapter 5 has shown how the pattern of five categories of area-types discussed in section 5.6, have been mapped to produce background soil contamination maps for the WMMC study area. Such a mapping exercise illustrates how readily obtainable urban, in particular land-use data, can be used in an estimation mapping model that allows background soil contamination maps to be obtained for large and varied urban areas.

5.9 Summary and Conclusion

5.9.1. This chapter has presented, in Part 1, a detailed discussion of the results from the analysis of soil samples for the four heavy metals. The first section of Part 1 summarised the results and illustrated how soil heavy metal levels in urban soil environments exhibit considerable spatial variation. From the data it was concluded that urban soil contamination exhibits three essential 'contamination' characteristics. Firstly, there is a general rise in background levels of heavy metals, from 'normal' levels in rural areas to higher levels of contamination in the older industrial centres of the WMMC. Secondly, as one moves to the more urbanised areas there is an increasing frequency of occurrence of individual, very highly contaminated sites giving rise to high area-type mean soil heavy metal levels. Thirdly, even in the most polluted, urbanised industrial areas, there are still some sites with virtually uncontaminated soil, equivalent to that in rural areas.

5.9.2 The data has been compared with the results of other contemporary studies including surveys in rural and urban areas. The conclusions from this comparison were that the lowest observed concentrations in the WMMC soil samples are comparable to the lower end of the range reported for naturally occurring levels in 'unpolluted' soil. However, at higher concentrations, the levels of heavy metals are often 10 - 15^{X} higher than the suggested upper limit for normal unpolluted soil. This was the case for both total and available soil heavy metal levels. When the results for the WMMC are compared to studies in other urban areas, the general trend of higher levels of soil heavy metal content in the more urbanised centres of large cities is confirmed by the results from this study. In addition, the presence of historic and/or present day metal using industries was found to have a significant contribution to the levels of heavy metals in the soil of the case study area.

5.9.3 The statistical testing of the data was contained in Part 2 and involved the use of the analysis of variance 'F' test to test the hypothesis that the spatial pattern in soil heavy metal level is underlaid by an associated pattern in the urban land-use. The results of the statistical testing substantiated that urban soil contamination by heavy metals can be mapped using a sampling mapping methodology based on the division and categorisation of the urban area into 'area-types' through the use of land-use and road network density data. The statistical testing of the data was followed, in Part 2, by a discussion of grouping and statistical mapping techniques through which the soil heavy metal data could be used to produce background soil contamination maps. The use of natural grouping techniques produced five groups of area-types which were then used for mapping of the data.

The mapped soil contamination data showed, in particular, that high levels of cadmium, copper and zinc are more prevalent in the Black Country than is lead, and the dominance of lead in Birmingham may be due to traffic sources. Lead is also found in relatively high concentrations in places on the periphery of the conurbation, again possibly due to traffic sources or past mining activities.

5.9.4 The data presented in this chapter provides the basis for a discussion of the significance of land contamination in an environmental planning and public health context. This discussion is taken forward in chapter 6 through an interpretation of the results in the light of current guidelines for acceptable concentrations of heavy metals in soil - the ICRCL 'tentative guidelines' discussed in chapter 2. However, the ICRCL guidelines have been developed specifically for assessing the significance of land contamination on <u>sites</u> being considered for redevelopment rather than for the general assessment of the significance of <u>background levels</u> of land contamination. Therefore, the issue of assessing both general background levels of land contamination in urban areas and individual contaminated sites, is taken further in chapter 6, through a consideration of how the information output from the sampling methodology can be used to generate 'reference levels' and 'normal limit levels'.

CHAPTER 6

6.0 INTERPRETATION OF THE RESULTS AND THE DEVELOPMENT OF REFERENCE LEVELS

6.1. Introduction

6.1.1 The preceding chapter has presented and discussed the levels of heavy metals in soil found in the WMMC. It demonstrated the feasibility of using a land-use based sampling framework for generating spatially comprehensive data at an urban scale and of presenting it in mapped form. It remains now, in the context of the policy discussion set out in Chapter 2, to interpret the results in the light of their significance for environmental planning and public health. This implies a knowledge of the levels at which, and the circumstances in which concentrations pose a threat to public health. It has been established (Chapter 2), that present state of knowledge does not allow the definition of levels at which contamination becomes a problem to people, plants or animals. Therefore interpretation and significance in the context of soil contamination are very much a matter of 'judgement' using the best available data.

6.1.2 Assessing the significance of land contamination may be considered at two levels:

i) there are the general issues of the significance of elevated background levels of heavy metals in urban soil.

ii) the issue of land contamination in the context of the redevelopment of specific sites.

It is recognised that the environmental health problems associated with the exposure of toxic/hazardous elements are common to both of the above issues. The distinction is, however, a necessary one because in (i) the main concern relates to <u>general</u> problems of exposure to toxic elements - the so-called long-term low dose exposure problem, whereas in (ii) the redevelopment of potentially contaminated sites often involves a change of use which introduces the possibility of <u>deliberate</u>, high dose short and long-term exposure problems to toxic elements, as would be the case if a former town gas manufacturing works were redeveloped into housing use.

6.1.3 Chapter 2 contains a detailed review of previous work related to the derivation of standards and 'acceptable concentrations' of elements including heavy metals in soil. Of this previous work, it has been established (see section 2.5.9) that the 'tentative guidelines' put forward by the Department of the Environment's Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL), being the nearest approximation to 'official' standards, could be used in interpretation. Section 6.2 of this chapter concentrates upon a discussion and interpretation of the results at two levels. Firstly, the information output of the mapping study is interpreted to determine the significance of the general condition of the land in the WMMC. This is followed by the assessment of the significance of the individual area-type results.

6.1.4 It is evident from the discussion in Chapter 2 and the material presented here, that the position with regard to standards and guidelines is far from satisfactory. There are particular limitations associated with the use of the ICRCL guidelines for assessing both background levels at the urban scale and the individual assessment of specific sites. These limitations are summarised in section 6.3. The chapter therefore goes on to set out and operationalise an alternative approach, which has been touched on in earlier chapters, namely the generation of 'reference levels' and 'normal limit levels' from the data on background levels of soil contamination. This approach addresses both the problem of area wide interpretation and individual site evaluation, the latter of which may be of greater utility to public planning agencies, and the development industry in the short to medium term.

6.2 ICRCL Tentative Guidelines

6.2.1 There are, to date, no statutory standards for allowable concentrations of heavy metals in soils. Concern over the lack of standards has recently been expressed in the D.H.S. report 'Lead and Health' (D.H.S.S.1980) which concluded that soil may be a significant exposure pathway for public health to heavy metals and the development of safe standards should be encouraged. As reviewed in Chapter 2, over the last four years, the ICRCL, in response to the need to provide guidance on allowable concentrations, has issued a series of consultation papers, containing 'tentative guidelines' aimed at establishing 'acceptable levels' for metal contaminants in soil for land being considered for redevelopment. The latest guidelines are set out in ICRCL 47/81, and are based on the matrix approach with the acceptable level dependent on the proposed end-use of a site.

6.2.2 The interpretation of the soil measurement data for the West Midlands concentrates on total lead and cadmium and available zinc and copper soil heavy metal levels. This is because total lead and cadmium are of interest due to their potential health effects, while available zinc and copper are of interest primarily because of their known phytotoxic effects on plants and crops. In addition the ICRCL guidelines are at present sub-divided, with the acceptable level being determined by the intended use of a site. Therefore, in order to simplify the interpretation, it was decided to restrict this comparison by considering only two sets of levels from the matrix presented in table 2.8 of Chapter 2, which cover the range of acceptable concentrations. These are shown in table 6.1 and refer to the most 'stringent' guideline for sensitive land-uses, such as allotments and the most 'lenient' guideline which applies to the less sensitive public open space land-use.

Table 6.1 ICRCL Tentative Guidelines used in Interpretation (mg/kg dry soil .

Metal	'Most Stringent'	'Most Lenient'
Pb	550	2000
Cd	3	15
Cu	140	280
Zn	280	560

Source: adapted from ICRCL 47/81

6.2.3 Area-wide results - Total Lead and Cadmium.

The information output from the mapping of background levels of soil contamination in the whole of the WMMC has been plotted on a cumulative frequency distribution log-probability curve. The average total lead levels in the 1 km. grid square have been plotted and are shown in figure 6.1. Points on the curve are equivalent to the estimated total area of the WMMC with a soil contamination level above the value on the curve. Therefore it is possible to use such distributions to obtain a best estimate of the percentage of the total lead area in the WMMC at risk of exceeding the ICRCL guidelines. From figure 6.1, it can be seen that approximately 8% of the WMMC area has an estimated soil contamination level in excess of the most stringent ICRCL guideline of 550 mg/kg. For total cadmium, figure 6.2, it will be evident that approximately 12% of the WMM area has an estimated background soil contamination level in excess of the most stringent ICRCL guidelines of 3 mg/kg. It has not been possible to assess the most lenient guideline values for lead and cadmium because the probability curves have been plotted from mean values for square kilometre units of area, and as illustrated in table 5.1. of Chapter 5, no grid square had a mean value approaching this lenient guideline.

6.2.4 Area-wide results - available zinc and copper.

Cumulative frequency distributions of mean heavy metal level of square

Fig. 6.1 Cumulative Frequency Distribution of Levels of Total Lead in the WMMC.

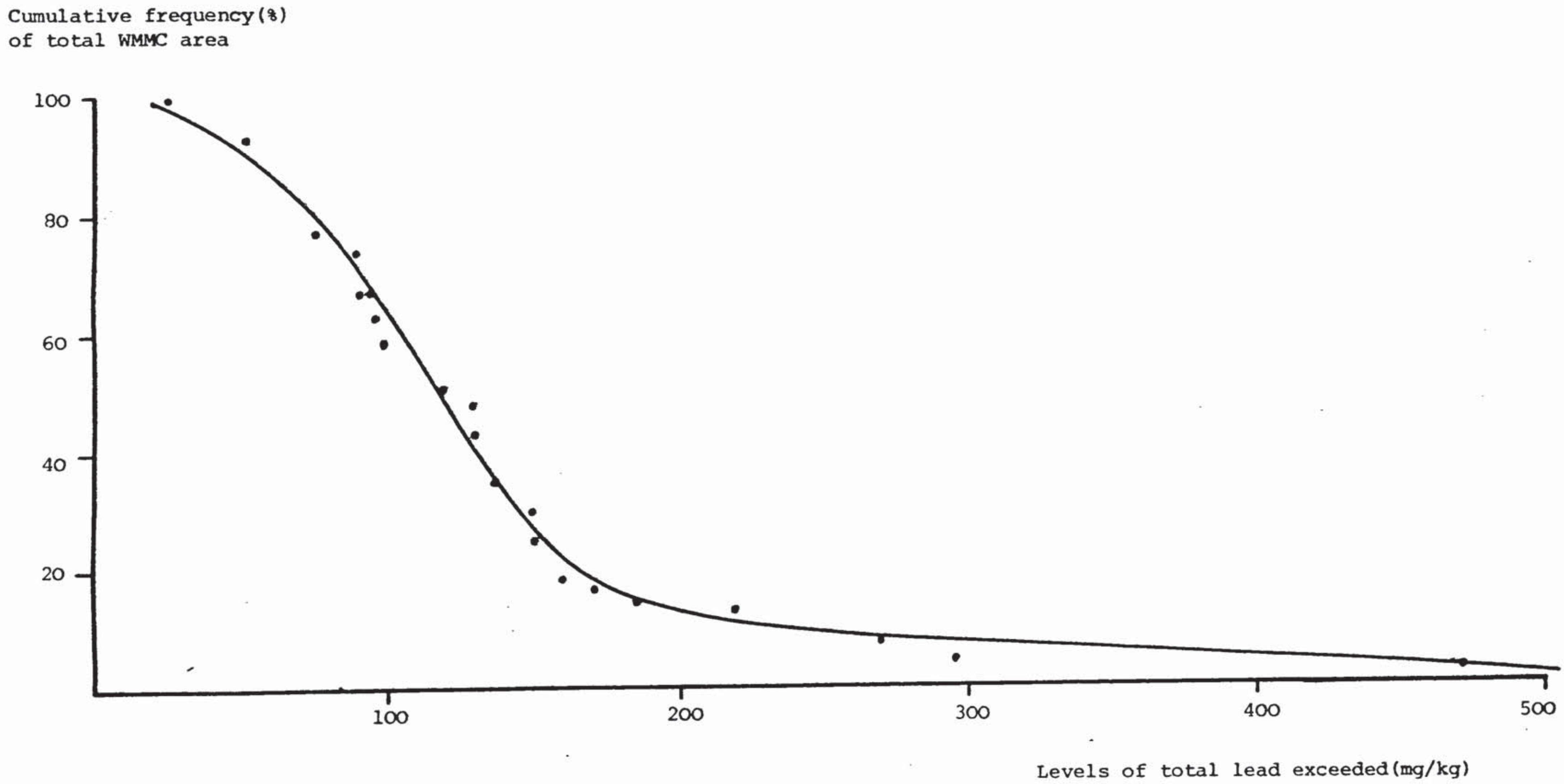
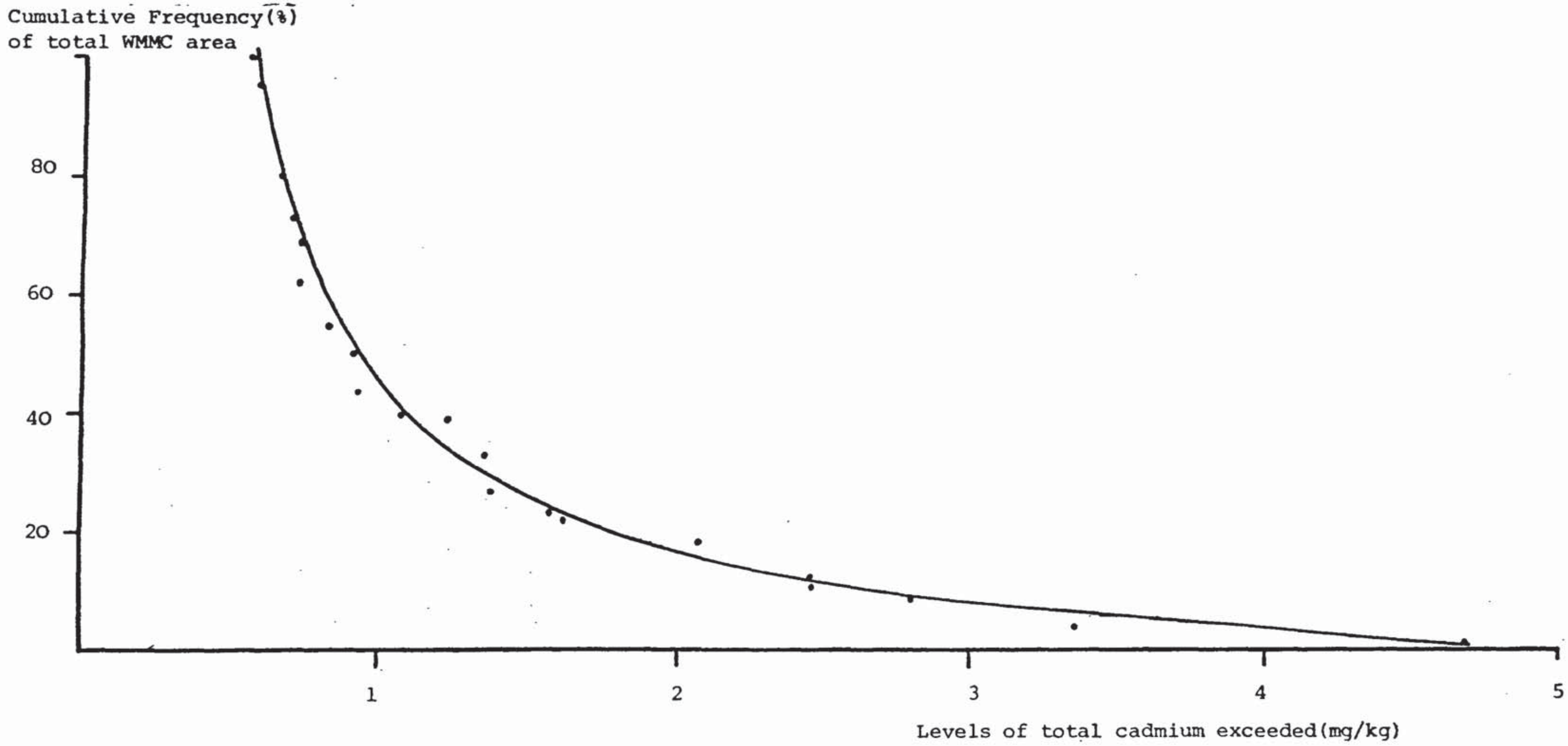


Fig. 6.2. Cumulative Frequency Distribution of levels of Total Cadmium in the WMMC.



kilometre units of area were also plotted for available zinc and copper and are shown in figure 6.3 and 6.4 respectively. In the case of available copper, it is evident from figure 6.3. that 70% of the county area has an estimated background soil contamination level in excess of 140 mg/kg (ICRCL stringent guideline). Approximately 1% of the county area has an estimated soil contamination level in excess of 280 mg/kg - the most lenient guideline. For available zinc, figure 6.4 illustrates that over 2% of the county area has an estimated background soil contamination level in excess of the stringent guideline value of 180 mg/kg. The data on available copper and zinc serves to illustrate that in the WMMC as a whole soil available copper levels are consistently higher than normal, even in the relatively unpolluted parts of the county. This is probably a direct result of the non-ferrous metals industry so prevalent in the WMMC.

6.2.5 The above has been a brief comparison and interpretation of the results on background levels of soil contamination for the whole of the WMMC, using currently available data on 'standards'. It should be noted that the ICRCL have not themselves endorsed the use of the guidelines in any other context than that of the redevelopment of potentially contaminated <u>sites</u>. The guidelines are to be used only where former industrial and other potentially contaminated land (e.g. scrap yards, gas works sites, steel works and sewage works) are being considered for re-use on redevelopment. The ICRCL do, however, provide specific guidance on how the guidelines should be applied to site investigation results. The guidelines are intended for use on 'spot samples' of soil, and the relevant documents state (ICRCL 47/81):

> "no individual spot sample taken from the top 450 mm should exceed the acceptable concentration and that there should only be an acceptably low probability (say 1 in 100) that any significant proportion of soil exceeds the limit".

Fig.6.3 Cumulative Frequency Distribution of Levels of Available Zinc in the WMMC.

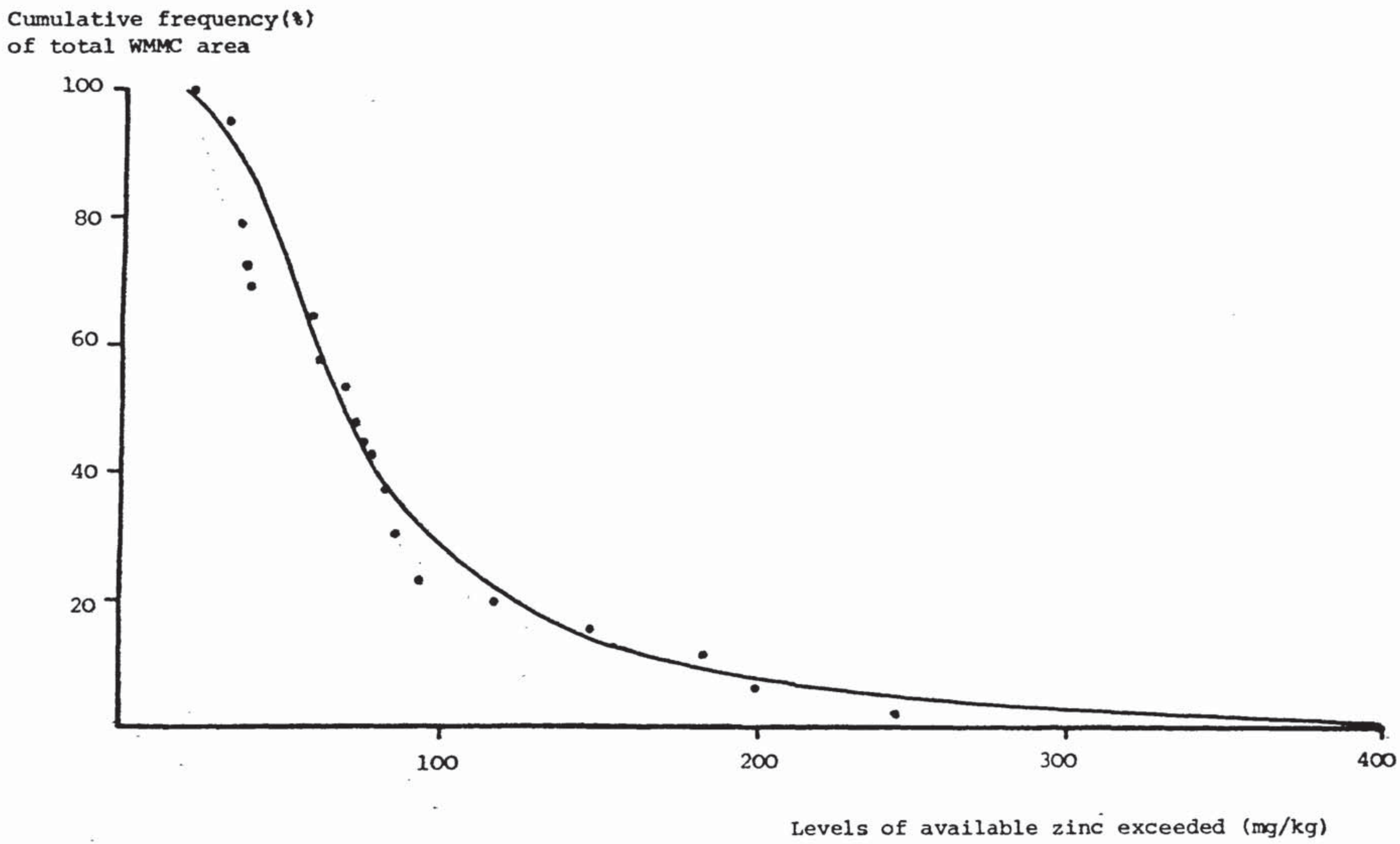
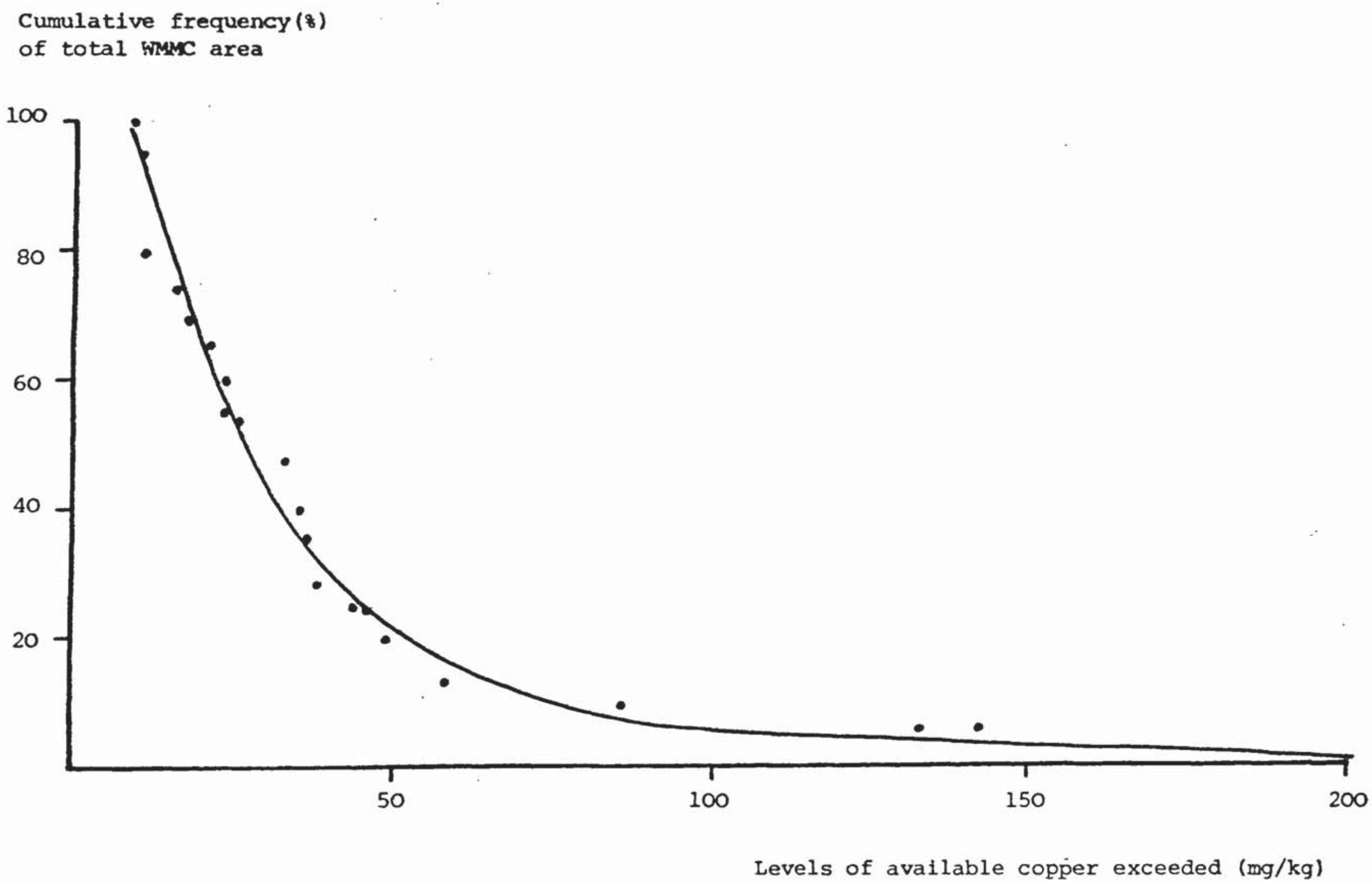


Fig. 6.4 Cumulative Frequency Distribution of Levels of Available Copper in the WMMC.



More generally, the above implies two things:

i) if any one spot sample of soil from an area of land exceeds the guidelines, the area as a whole should be regarded as 'exceeding' them.

ii) the soil metal levels of an area cannot be taken as 'acceptable' if more than 1% of that land area exceeds the guidelines.

6.2.6 The latter point above is important because it has been demonstrated in sections 6.2.3 and 6.2.4 that there are large parts of the County where existing background soil contamination levels are at risk of exceeding current ICRCL guidelines, particularly in the case of total lead and cadmium. This evidence serves to question further the suitability, on practical grounds, of using the current guidelines to assess general urban land contamination, when there is a high probability that in certain situations, existing 'naturally' occurring levels will exceed acceptable concentrations.

6.2.7 Interpretation of Individual Area-Type Results

In the light of the above comments on the application of the ICRCL guidelines to spot sample data, the individual sample site results for the 20 area-types were interpreted using the data presented in table 6.1. Figure 6.5 is a histogram plot of the measured levels of total lead in the 360 soil samples, grouped by area-types. Figure 6.5. shows that 6% of the sample sites are above 530 mg/kg and 0.3% are above 2000 mg/kg. The location of those sites above the guidelines are seen to be spread evenly through the urbanised parts of the WMMC (area-types A3, B2, B3 and B1 figure strongly).

6.2.8 For total cadmium, it can be seen from figure 6.6 that 10% of all sample sites are above 3 mg/kg and 1.1% are above 15% mg/kg. The location of the sample sites exceeding the guidelines are seen from figure 6.6 to be concentrated in the more industrialised urban area of the WMMC (e.g. area-types A1, B2, B1 and B3.

Fig. 6.5 DISPERSION PLOT TOTAL LEAD (mg/kg).

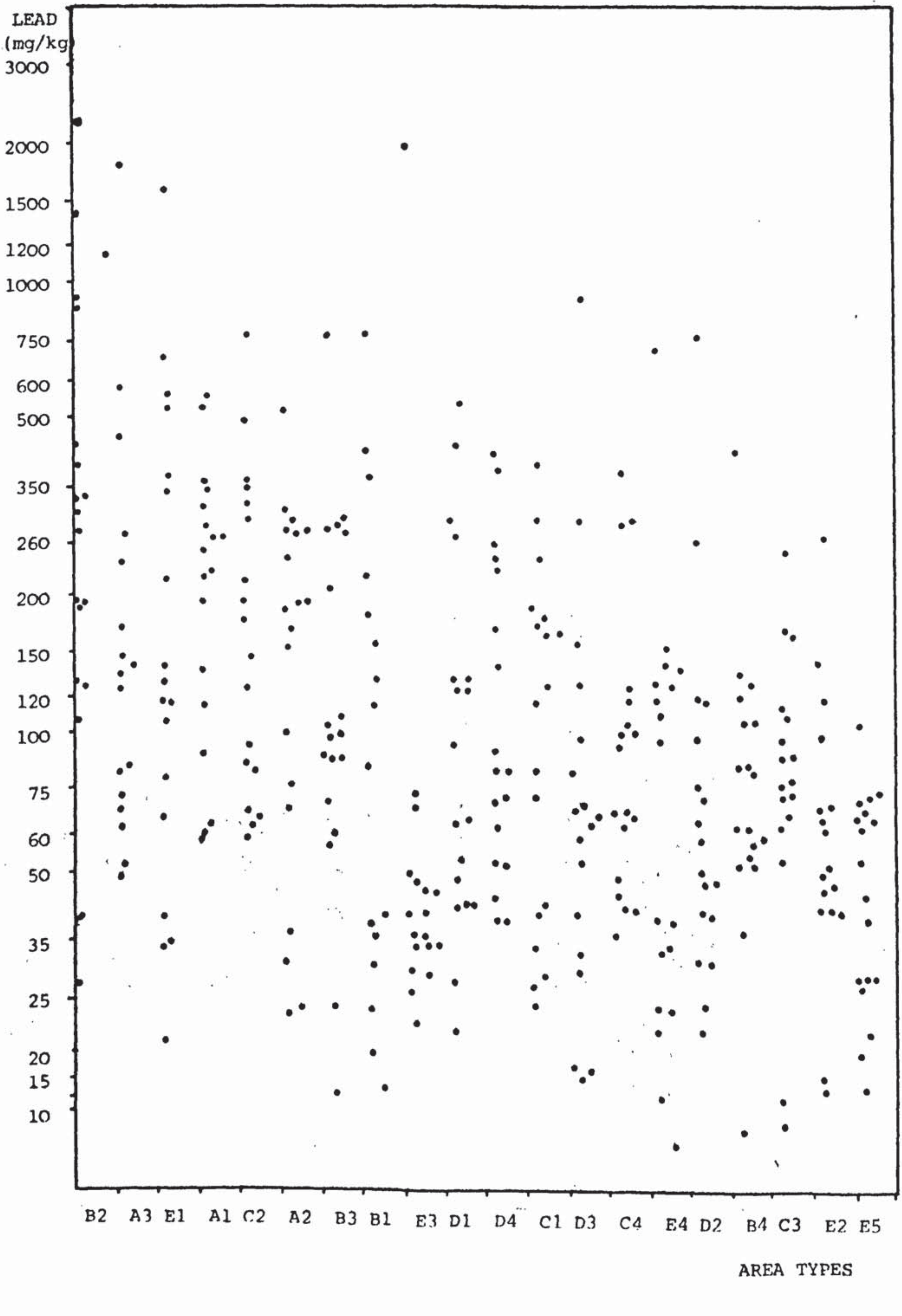
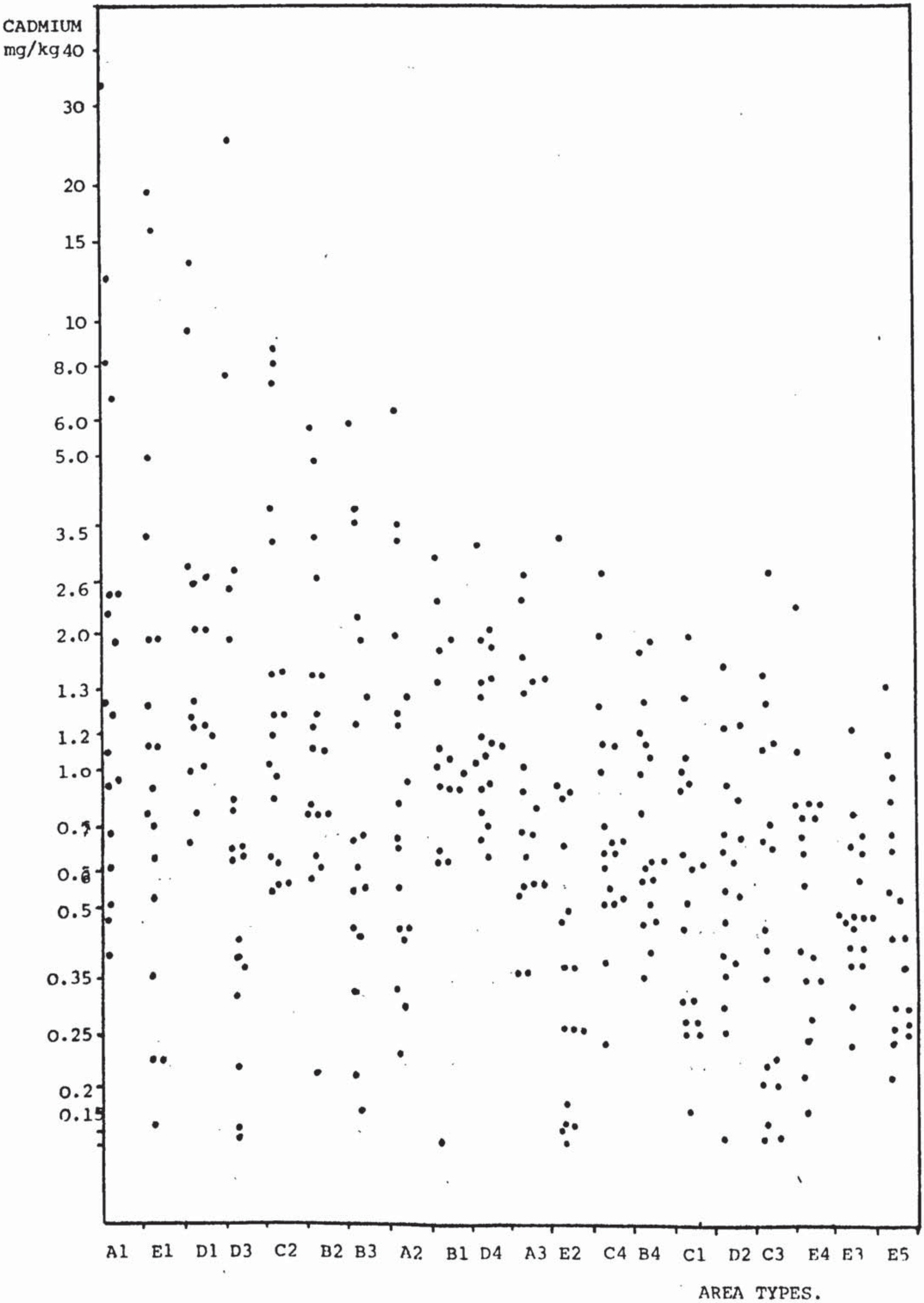


Fig. 6.6 DISPERSION PLOT - TOTAL CADMIUM (mg/kg).



6.2.9 In the case of measured levels of available copper and zinc in the soil samples, it can be seen from figures 6.7 and 6.8 that 5.5% for copper and 7.0% for zinc of all sample sites exceed the most stringent guideline in table 6.1. In the case of the most lenient guidelines, the percentage of sample sites above the values are 2.0% for copper and 3% for zinc.

6.2.10 The above assessment clearly demonstrates that if the guidelines are applied, as stated in section 6.2.5, to spot sample measurements from within areas of 1 sq.km.in zinc, then there is a small but significant fraction of the area at risk of exceeding current guidelines. This in turn leads to the conclusion that whole sq.km. units of area in the WMMC, have 'naturally occurring background levels of heavy metals' which exceed current guidelines.

6.2.11 The above interpretation of the results and subsequent conclusions may, at first sight, be somewhat alarming and suggest two problems:

i) that current guidelines for acceptable concentrations of heavy metals in soil may be unnecessarily stringent.

ii) background soil contamination levels in the WMMC are sufficiently elevated in certain areas to be considered to present a public health problem.

It is difficult to come to any firm conclusions on the above problems. This is because, as reviewed in Chapter 2, there are a number of limitations associated with the use of the ICRCL guidelines, some of which have been touched on earlier in this chapter. They may be summarised as:

i) all proposed levels are guideline values. They must be used by experts exercising 'professional judgement', taking into account local knowledge of a particular site.

ii) in general, assessment should be based on the 'worst' results from the site investigation.

iii) due to gaps in our present knowledge, particularly on general contamination of urban soil, many of the values must be regarded as preliminary.

iv) the guidelines were not devised as a 'remedial standard', nor were they to be used to assess the hazards presented by contamination on existing developments.

Fig.6.7 Dispersion Plot Available Zinc (mg/kg).

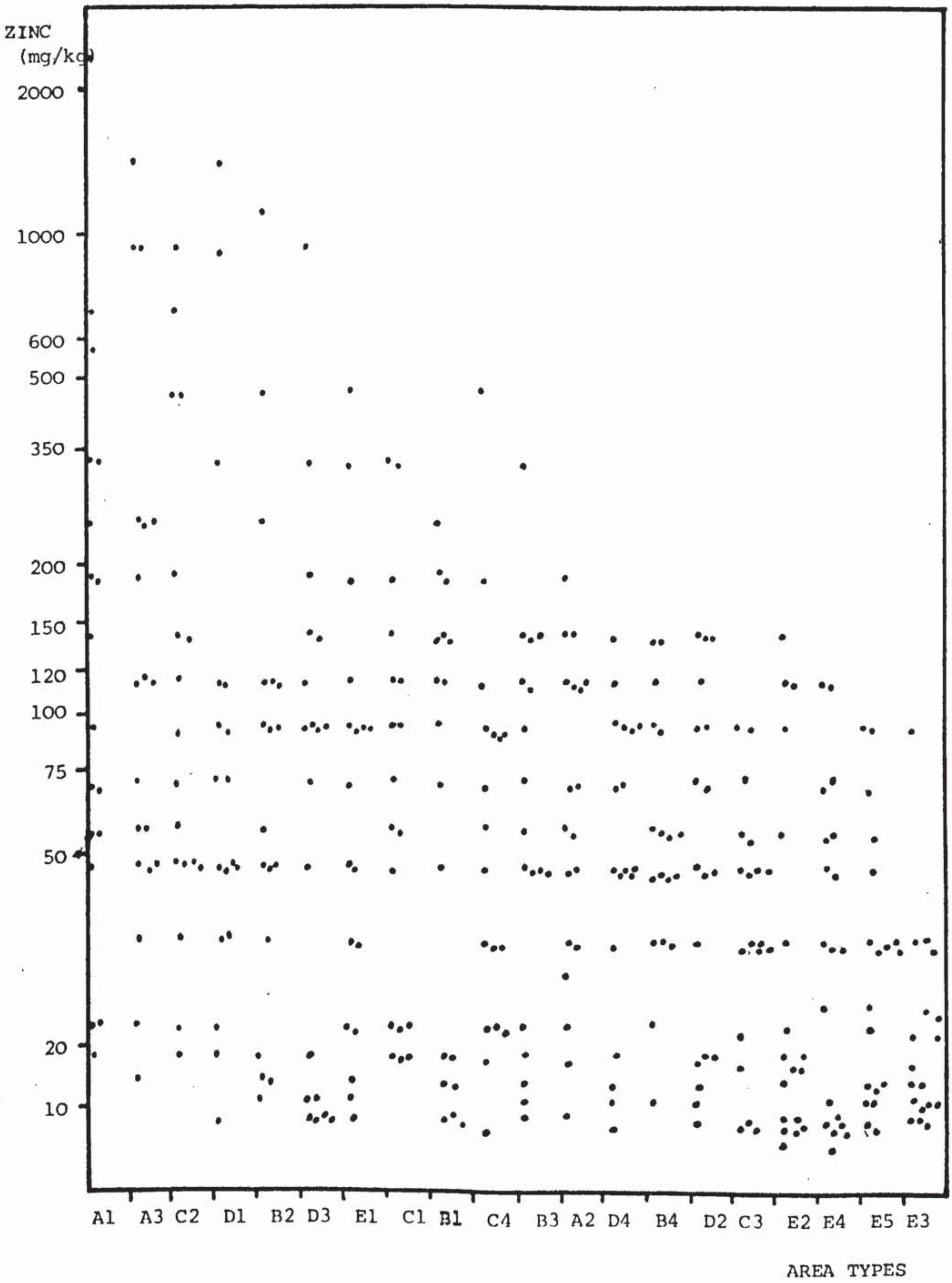
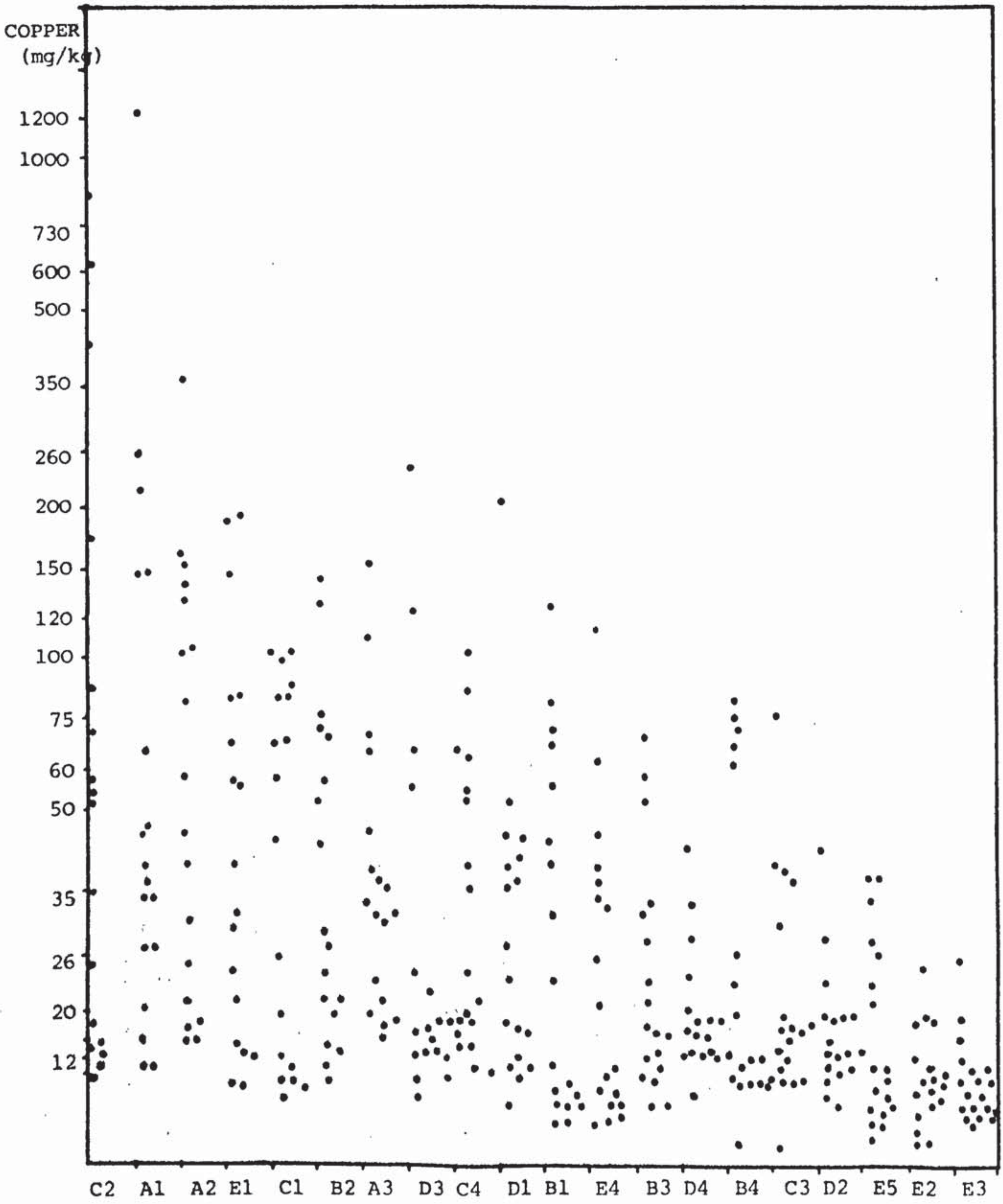


Fig. 6.8 Dispersion Plot Available Copper (mg/kg).



v) the guidelines are tentative only - it is difficult, given present knowledge, to define a 'safe level'.

6.3 Reference Levels and Normal Limit Levels

6.3.1 In the light of the preceding discussion, it is clearly difficult to judge the overall significance of background levels of soil contamination due to the lack of background standards'. In addition, the above limitations on the use of ICRCL guidelines suggest that they may be of limited value to local planning agencies wishing to assess the significance of urban land contamination, both at the general urban level and at the site specific level. Therefore, it is suggested that since current guidelines are still open to further consultation, given the present uncertainties as to what are 'unacceptable concentrations' and the results of interpretation presented in this chapter, that the further development of standards for soil contamination should take account of existing 'background levels' of soil contamination. Indeed, earlier guidance notes from the ICRCL (see for example, ICRCL 24/79) included reference, albeit by inference, to comparison of site investigation data to values considered 'typical' for urban soils. This approach was never pursued because to date, there has been very little reliable data on typical (background) levels of urban soil contamination. *1.

6.3.2 The chapter therefore goes on to set out and operationalise the concept of reference levels and normal limit levels which can be used to assess the significance of both general urban land contamination and specific site contamination problems. In so doing, they respond to some of the limitations which accompany the use of current guidelines. Obviously they cannot make any direct contribution to the problem of the relationship

*1 As reviewed in Chapter 3, very few studies have assessed the spatial pattern of urban soil contamination - most 'urban studies' have concentrated on point sources.

between soil contamination and health effects. They do, however, offer an assessment tool which may have more immediate utility to local planning agencies and the development industry.

6.3.3 To operationalise such an approach, requires that spatially comprehensive data on background levels of heavy metals in urban soils is available at both the general urban scale and site specific level. The information output from this research study can be used directly to provide the necessary data for 'reference levels' (to be used in area-wide assessment) and 'normal limit levels' (to be used in individual site specific assessment).

6.3.4 'Reference levels' are directly obtainable from the mapping methodology results presented and discussed in Chapter 5. This is because the mapping methodology is based upon assigning 'typical' values of soil contamination to the 'sample 'area-types', followed by grouping to produce five categories of land contamination which were subsequently used to produce background soil contamination maps.

6.3.5 Table 6.2 illustrates how the data output from the mapping model, used to produce the five categories of urban land contamination, has been translated into 'reference levels' for five different types of urban area. They were obtained by averaging the 'area-type' mean results for each of the five categories of land contamination used to produce the land contamination maps presented in chapter 5. The reference levels are defined as the levels of heavy metals in soil which one would normally expect to be present, given the type and mix of land-use. A description of the principal urban land-use of each category is also given in table 6.2. The role of the 'reference levels' is to interpret land contamination data by comparison, e.g., is the contamination problem of a site being investigated worse than that experienced in similar kinds of urban area, where developments of a similar kind to the one proposed already exist.

6.3.6 The way in which the 'reference levels' are used to interpret urban land contamination is straightforward. If, for example, an area in the densely developed industrial inner urban area was being sampled, (i.e., category 1 in table 6.2) the reference levels for total lead and cadmium would be 400 mg/kg and 3.5 mg/kg respectively. If after investigation of the site, it was found that the 'reference levels' were exceeded, then consideration should be given to further investigation and possible ameliorative measures. Alternatively, if the levels on the site were found to be below the 'reference levels' then we can say that the site, ceteris paribus, is no more contaminated than would be expected, given the type and mix of land use present in the area. From the data in table 6.2 it will be evident that the 'reference levels' are more lenient in the industrialised urban area than in the rural urban fringe areas (Category 4 and 5). This allows for a much more flexible and practical approach to assessment, in that areas likely to be contaminated due to their land-use characteristics, are, on average, likely to have a number of sites which are heavily contaminated. Whereas, in the relatively uncontaminated areas there should not be many sites with elevated levels of heavy metal and therefore the reference level is more stringent.

6.3.7 The use of reference level and the land contamination maps in the above context, is seen largely as a preliminary sieving technique, where the use of mapped information, the broad suitability of tracts of land for particular development can be determined. The reference levels are subjective criteria allowing interpretation of urban land contamination data to take place, on a comparative basis, in the absence of pre-determined and definitive standards or guidelines.

Table 6.2 Reference Levels of Heavy Metals for Different Types of Land-Use (mg/kg)

Land Contamination Category	Reference		Levels	Area-Type
1	Pb	(total)	400	Industrial and industrial/ commercial centres. Densely developed residential/ industrial mixed areas.
	Cd	(total)	3.5	
	Zn	(available)	300	
	Cu	(available)	120	
2	Pb	(total)	200	Inner urban area, dense residential development and residential/industrial mixed land use.
	Cd	(total)	2.0	
	Zn	(available)	160	
	Cu	(available)	50	
3	Pb	(total)	150	Mostly dense residential development with residential commercial mixed use.
	Cd	(total)	1.5	
	Zn	(available)	100	
	Cu	(available)	35	
4	Pb	(total	120	Outer suburban less dense residential development with recreational land.
	Cd	(total)	1.0	
	Zn	(available)	75	
	Cu	(available)	25	
5	Pb	(total)	90	Mostly rural open space areas with agricultural areas with some residential development.
	Cd	(total)	0.5	
	Zn	(available)	35	
	Cu	(available)	10	

6.4 Normal Limit Levels

6.4.1 The data on reference levels presented in table 6.2 and discussed above, is an aggregation of the soil heavy metal data and allows qualitative judgements only to be made as to the significance of heavy metal survey results for urban areas. Therefore, in their present form, the reference levels can do no more than 'trigger' concern that the levels of contamination in an area may be elevated above what is typical; they do not allow for the assessment of individual site investigation data. If the data output from the research is to be used in the assessment of site investigation data, as complementary to existing standards or as alternatives where no such guidelines exist, then it will be necessary to use individual area-type sample data, grouped as for the reference levels, as a measure of the significance (risk/hazard) presented by individual site measurements.

6.4.2 The need is for a set of criteria (levels) against which to determine whether the results obtained from site investigations are statistically significantly elevated above typical levels for that area. To do this involves examining the statistical distribution of individual sample site results for the five categories of land contamination. The method (sample collection and aggregation techniques) through which the land contamination data and reference levels were derived allows such a data set here termed 'normal limit levels', to be produced. The method involves a statistical analysis of the 'area-type' individual sample site measurements grouped according to the five categories of land contamination. The statistical technique is based on the standard error of the sampling distribution and the 't' distribution. Using the 't' distribution it is possible to obtain, for given probabilities and sample size, mean values (normal limit levels) which would occur due to the spatial variability of soil heavy metal levels.

6.4.3 Tables 6.3 and 6.4 are probability matrices of significant soil contamination levels for a range of sample sizes. They have been calculated for total lead and cadmium and available zinc and copper, to illustrate how normal limit levels can be used and assume for each sample size a random distribution of sample points. Each 'cell' in the matrix is the 'normal limit level' for a given category of land contamination, sample size and statistical probability. The application of the matrix to site investigation data can comprise of two approaches. The first relates to the percentage chance of a mean value occurring. For example, if 10 samples were collected from a site in contamination category 1, then there is a 5% chance that the mean of those 10 samples will exceed 510 mg/kg, but only 0.1% chance that the mean will exceed 755 mg/kg. For total cadmium, the values are 4.0 and 6.0 mg/kg respectively. What this means in practice is that mean values of 10 samples, higher than the expected value in the matrix, will not occur by random chance and are therefore anomalous. Results higher than the 'cell value' can be interpreted as indicative of significant contamination of the site above 'normal' for that area.

6.4.4 From the d ata in tables 6.3 and 6.4 it will be evident that the 'normal limit levels', at lower levels of contamination (categories 4 & 5), are not significantly different. For example, total cadmium levels in category 5 are all between 0.7 and 1.2 and are similar to levels for normal 'unpolluted' soil. This is a reflection of the fact that in the less polluted area-types (E2, E3, E4 etc.) the spatial variability of soil heavy metal levels is not as high as in the more polluted area-types (e.g. A1,A2, B2, etc.). *2. In addition, in the more contaminated areas, categories 1 & 2 for example, there are significant differences between normal limit

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*2 See results chapter section 5.6 for a detailed description of the within area-type spatial variability of sample site results.

Table 6.3 Normal Limit Levels for Total Lead and Cadmium

No. of Samples.		LEAD 95%	99%	99.9%*b	CADMIUM 95%	99%	99.9% *b
1*a	5	550	735	1364	4.5	6.0	11.9
	10	510	600	755	4.0	5.0	6.0
	15	500	575	680	4.0	4.5	5.5
	20	495	560	655	4.0	4.5	5.3
2	5	305	370	570	2.5	3.2	5.2
	10	288	320	378	2.4	2.7	3.3
	15	285	310	353	2.3	2.6	3.0
	20	283	307	343	2.3	2.5	2.9
3	5	207	252	391	1.5	1.8	2.4
	10	195	218	257	1.4	1.6	1.8
	15	193	211	240	1.4	1.5	1.7
	20	192	208	233	1.4	1.5	1.7
4	5	147	180	283	0.9	1.1	1.5
	10	138	155	184	0.9	1.0	1.1
	15	137	150	171	0.9	0.9	1.0
	20	136	148	166	0.9	0.9	1.0
5	5	112	135	200	0.8	0.9	1.20
	10	106	117	140	0.7	0.8	0.89
	15	105	114	130	0.7	0.8	0.84
	20	104	112	125	0.7	0.8	0.82

*a Land Contamination Category. *b Probabilities.

Table 6.4 Normal Limit Levels for Available Zinc and Copper

No. of Samples		ZINC 95%	99%	99.9%*b	COPPER 95%	99%	99.9% *b
1*a	5	450	661	1540	167	226	437
	10	403	497	686	154	181	233
	15	395	470	600	151	173	209
	20	389	458	568	150	170	200
2	5	240	320	590	70	80	125
	10	220	260	330	65	70	85
	15	220	250	300	63	69	78
	20	217	245	285	63	68	76
3	5	145	190	350	40	50	80
	10	135	160	200	40	45	55
	15	133	150	100	40	40	50
	20	132	148	170	40	40	48
4	5	90	105	145	30	35	45
	10	85	95	105	28	30	35
	15	85	90	100	28	30	33
	20	84	90	98	28	30	30
5	5	45	55	80	10	12	15
	10	40	50	55	10	10	13
	15	40	45	50	10	10	12
	20	40	45	50	10	10	12

*a Land Contamination Category *b Probabilities.

levels for sample size 5 and the other sample size categories, reflecting the higher spatial variability in soil heavy metal levels in the more polluted areas. This suggests that in assessing potentially contaminated sites it will be necessary to take more than 10 samples in order to obtain a representative sample. There is one further point on the use of the probability matrix. The data used to produce the normal limit levels is based upon bulked samples *3 as being representative of large areas. Given that soil heavy metal levels exhibit a high degree of spatial variability, this may be a source of error in the normal limit levels. However, there is evidence from other work (JURUE, 1982 and Appendix 4) which investigated the variability between bulked samples and sub-samples making up the bulked sample, that this error is not significant. The conclusions of this investigation were that there is very considerable variability between soil metal levels of sub-samples despite all sub-samples being collected from within 30m of a central sample site location. In addition, it was found that mean soil metal levels derived from 10 individual sub-samples were not significantly different from mean levels derived from the analysis of independent bulked samples. Therefore, the use of bulked samples in the probability matrix is thought not to be a significant source of error.

6.4.5 Since we are concerned with defining acceptable concentrations of heavy metals in soil, the normal limit levels approach can be taken a stage further by attaching 'risk factors' or acceptability to the probabilities in tables 6.3 and 6.4; this is the second of the two approaches suggested in section 6.4.3 For example, if a site is being proposed for redevelopment for recreational use where the contaminants are only significant from a phytotoxic point of view (as would be the case with copper and zinc), then we may decide to set the mean level at which it is

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*3 The original sample frame used 6 sample points, bulked for 1 sample site, with 9 sample sites per 1km.sq. grid. See appendix considered there is a problem on the 'lenient' side, say for example at the 0.01% probability. Alternatively, if the site being samples is to be redeveloped for housing use and the contaminant may present a risk to human health (as would be the case with high level of lead and cadmium) then it may be more appropriate to set the significance level at 5% which then determines a more stringent normal limit level. The use of normal limit levels in this manner, although being to some degree subjective, allows a more flexible approach to determining the significance of site contamination than is at present the case with the ICRCL tentative guidelines.

6.4.6 The above has been a discussion on use of background soil contamination data as guidelines for use in assessing both general urban land contamination and individual site investigation data. There are two additional points which need to be taken into account when using this approach. Firstly, the normal limit levels are based entirely upon 'typical' or 'normal' levels of soil contamination for five different categories of urban environment. They do not, therefore, take into account any linkages between elevated levels of heavy metals in the soil and either known health effects or phytotoxic effects. In addition they are not intended to detract from the pressing need to establish environmental health protection standards for allowable concentrations of heavy metal in soil. Their value is in providing additional information of the variability of soil heavy metal levels in urban areas, a data set, to aid in the assessment of the significance of elevated levels of heavy metals.

6.5 Summary

This chapter has concentrated upon the interpretation of the results of the research study in the context of the policy discussion set out in Chapter 2. Specifically, the chapter has assessed the results of background levels of soil contamination in the WMMC and individual area-type measurements in the light of current guidelines and has concluded:

i) there are large parts of the WMMC area which are at risk of exceeding current ICRCL guidelines.

ii) current ICRCL guidelines may be unnecessarily stringent.

iii) there is a need for a practical method for assessing:
  a) the overall significance of background levels of urban land contamination and
  b) individual site specific investigation data.

To respond to the above, it was suggested that the mapping methodology used to obtain background levels of heavy metal soil contamination for urban areas may also be used to generate locally relevant information for use in the assessment procedures in iii) above. In sections 6.3 and 6.4 it has been demonstrated that the information output from the mapping study provided useful data to enable 'reference levels' and 'normal limit levels' to be obtained. It is these 'reference levels' and 'normal limit levels' which are put forward as alternative criteria for the assessment of land contamination and which may be of more immediate utility to local planning agencies and the development industry.

CHAPTER 7

APPRAISAL OF THE RESEARCH

7.1 The introductory chapter to the research presented and discussed the research area of contaminated land, which provides the framework within which the research reported here has been undertaken. The remaining chapters of the thesis have concentrated on the care of the work, which has been the measurement, mapping and assessment of background levels of heavy metal land contamination. The purpose of this final chapter is to place the work in the wider research and policy context. It also describes the contribution that the research and similar methodological approaches might make to the field generally. The chapter concludes with suggestions for further research which might build upon the work undertaken here.

7.2 The Wider Research and Policy Context

7.2.1 The review of the research area provided the general background to the problems of contaminated land which are essentially policy related issues of environmental pollution and control over contaminated land. This background to the research identified key research and policy issues which formed the context of this study, and these may be summarised under three broad issues. These relate firstly to determining the nature and extent of contaminated problems; secondly to produce guidance for the assessment of the significance of contaminated land; and thirdly, the development of appropriate ameliorative and protective measures when contaminated land is being redeveloped.

7.2.2 As stated earlier in this thesis, central government has become involved in the problems of contaminated land, and through ICRCL are funding an extensive research programme with the aim of ensuring that contaminated land is restored to beneficial use, without unnecessary risk. The emphasis in this programme has been placed in three main areas which in part respond to the wider policy issues summarised above. These relate firstly to the early identification of contaminated sites in advance of development proposals; secondly to the investigation and assessment of contaminated sites; and thirdly to developing ameliorative measures to ensure reliable methods of treatment are available for the protection of subsequent users. The issue of the assessment of the hazards presented by contaminated land has already been discussed in detail in earlier chapters, and therefore the discussion here is limited to considering those studies which are relevant both to this research work and the wider policy issues.

7.2.3 The early identification of potentially contaminated sites is very much a recent research area for ICRCL who have funded desk based research in the two pilot study areas. The two studies have been concerned with developing techniques which will enable local planning authorities to take contamination into consideration when exercising planning and development control functions. The aim of the work has been to move away from a 'fire-lighting' approach to a situation where contaminated land is identified at an early stage in the planning system, thus avoiding the problems which might be caused by the inappropriate use of a contaminated site. The general approach in the two pilot studies has been the assessment of information sources which can be used to identify activities which are taking place in an area, or have taken place, and to assess the likelihood with which the activities identified may have contaminated the sites they occupy. Preliminary results from the two projects (for further details see JURUE, 1981; Barxey, 1981), suggest that although it is possible to generate comprehensive information on current and past use of particular sites, its value is often severely limited due to the many uncertainties in establishing the link between the use of a site and potential contamination of a site. In the study carried out by JURUE in the WMMC, it has also been concluded that the use of desk study research only, and the absence of detailed information on industrial activity and land contamination, means that in practice it is only possible to allocate land to one of three broad categories of contamination. These are:

i) definitely contaminated - sites such as gasworks, scrap yards, steel works.

ii) may be contaminated - areas and sites which have activities that are likely to give rise to land contamination.

iii) probably not contaminated - no indication that the site has been occupied by a contaminating activity.

7.2.4 The latter two categories are large 'grey areas' and to determine whether a site presents an actual contamination problem would require a further significant input of resources, which in some cases approaches the level of resources required for a detailed site survey. The problem is more acute for areas and sites in category (ii), which are predominantly inner city locations of mixed industrial/residential/commercial land-use where sites are small and have often had multi-use over a long period of time. It is also in these inner city locations where redevelopment is most likely to occur, given current government policies. Therefore there remains a need for techniques which can be used to identify, with some degree of certainty, potentially contaminated sites. Since it is doubtful that desk based research alone is capable of providing the information required, it is suggested that there is a need for additional methodologies which are based on practical field research, similar to the work reported in this thesis.

7.2.5 The research work undertaken here has concentrated on the development of a sampling methodology to enable background levels of land contamination to be accurately measured. The results from applying the methodology in a case study area has demonstrated that the technique not only facilitates the mapping of the existing pattern of background land contamination, but also permits the fairly precise definition of sub-areas or'hot-spots' of significantly elevated levels of contamination. Thus, by providing a reasonably cost-effective means of quantifying contaminated land in urban areas, such techniques offer the possibility of identifying potentially contaminated sites. In this respect, the function of the sampling methodology is to act as a 'preliminary sieve' for large and varied urban areas in order that 'hot spot' areas of contamination may be identified, alerting the local authority to a potential contaminated site problem. The use of the sampling methodology and similar work in this way is described further in section 7.3.5.

7.2.6 Having identified that contaminated land or a contaminated site presents problems for redevelopment, it is necessary to consider ameliorating the pollution problem. It is in this area of remedial measures that central government has placed the largest research effort, and there are a range of studies assessing the effectiveness of conventional treatment methods (these include removal, mixing and covering). The techniques being researched are directed at protecting the general public from heavy metal soil pollution and are therefore of direct relevance to this research study. For example, research at Liverpool University (Jones, et al, 1981) is investigating the bioavailability of heavy metals in a range of contaminated materials (from soil to mine waste), and the effect of a top soil covering on metal absorption by plants. Results to date suggest that merely placing 0.5m of top soil directly over heavy metal contaminated soil is not effective in preventing metal uptake into vegetables and soft fruits.

7.2.7 A parallel study by Liverpool Polytechnic (Lepp and Harris, 1980) on the Beaumont Leys development site in Leicestershire has also produced similar results to those above, and is now investigating, under field conditions, the use of barrier materials (impervious seals of clay and chemical barriers of crushed limestone), to isolate the exposed surface and plant rooting zone from underlying contaminated material. The problem of movement of metals through the soil appears to be more acute for metals such as lead and cadmium which accumulate at high levels in surface soil horizons. The preliminary results from the research work on ameliorative measures has a number of implications for the present study, the most important of which relates to the practical task of ameliorating large areas of background land contamination. As has been demonstrated, this study has identified large tracts of land in the WMMC which has significantly elevated levels of both lead and cadmium in surface soil horizons. One practical option for protecting public health and plant health in areas of high pollution would have been simply to cover the contaminated soil with a suitable depth of top soil. However, since it appears that this may not be satisfactory, it raises the question of what remedial measures should be recommended if background land contamination was found to be an environmental health problem. The viable alternatives to covering contaminated soil are removal and the use of barriers; the latter is still under development. However, both of these alternatives involve the use of considerable resources, and in the case of barriers may not be a practical solution for very large areas. Clearly, this issue of remedial treatment suggests the need for further research in two areas. Firstly, there is a need to demonstrate that elevated levels of heavy metals in soil actually presents a health problem. This in itself presents no small task for research, as the recent case of cadmium pollution in Shipham illustrates. What is in fact required are extensive and detailed epidemiological studies, building upon this research and other similar work which provides comprehensive baseline environmental information, (this is taken further in discussion in section 7.3.4). The second course of action hinges upon the first, in that if background land contamination can be shown to present a health problem, then there is a need to develop more practical solutions to protecting public health.

7.2.8 In addition to projects on heavy metals in relation to contaminated land redevelopment, there have been a number of smaller studies concerned with the problems of specific heavy metals in soil. For example, research by Alloway and Butterworth (1980), is investigating the speciation and sorption of cadmium in a range of polluted and control soils. An important conclusion from this research is that sludge amended soils have been found to have a significantly higher proportion of exchangeable cadmium (that readily available to the environment) than soils polluted by mining waste or oxide fume emission. This result suggests that background land contamination, due to the widescale use of metal contaminated sewage sludge, may potentially be a more long term problem than individual highly contaminated sites.

7.2.9 Research work concerned with the investigation and assessment of contaminated sites has not been directed at the problems of heavy metals, but has concentrated entirely on the problems of redeveloping former gas work sites. The reason for this is that many former gas work sites were purchased by local authorities as prime development sites, obviously without recognising many of the pollution problems associated with town gas manufacturing. Therefore, the research on gas work sites, conducted by the Environmental Safety Group at Harwell (for details see Harwell,1981), is providing detailed information on the type of contaminated material present on such sites, and the hazards which they present to human health. Although the work is not directly relevant to the research study, it deals with organic pollution such as phenols and coal tars, it has had to respond to similar methodological problems of assessing the significance of elevated levels of contaminants in the absence of standards. It is interesting to note that the approach adopted by Harwell has been to develop a two-tier guideline of 'undesirable' and 'unacceptable' levels of contaminants. The guidelines themselves have been based on normal or 'typical' values for either uncontaminated soil or 'urban' soils, taking into consideration Health and Safety threshold values for certain carcinogenic pollutants.

7.3 Wider Policy Issues and the Research Work

7.3.1 In recent years, the quality of the general environment has become a central issue in the field of public policy, which has created a demand for research into the provision of environmental information for use in a wide variety of applied policy contexts. The foregoing chapters of the thesis have demonstrated that it is possible to develop simple and cost effective techniques which provide spatially comprehensive and accurate ambient data on the levels of land contamination in large and varied urban areas. Such techniques provide information on the generally enhanced levels of metals, typical of soils in the general urban environment, and permit the fairly precise definition of 'hot spot' areas. In so doing, they generate a potentially valuable data base for use in a number of applied policy applications. This section, therefore, describes those policy areas where the research and similar methodological approaches may make a positive contribution to the decision making process.

7.3.2 An important policy orientated use of spatial data on background levels of land contamination is in the technique of Environmental Impact Assessment (E.I.A.), a method for the assessment of the likely environmental consequences of both public and private development projects. It was an early tenet of the E.I.C. process that some information base (survey) was required from which to anticipate and assess the environmental impacts of proposed developments. The need for 'baseline studies' of environmental conditions is supported by Catlow and Thirlwell (1976) and Clark (1976) in their review and recommendations on the role of E.I.A. in the U.K. planning system. Indeed, Clark supports the argument for baseline data with the view that

> "baseline studies.....provide the planning officer with an understanding of the existing situation against which he

will be able to assess the likely advantages and disadvantages of development proposals".

7.3.3 The information output of the sampling method developed in this research provides such 'baseline data' in the form of background land contamination maps. It is suggested that the mapped information may be used to assess the capacity of the environment to accommodate new developments that may impose additional heavy metal pollution in an area. For example, the mapped data (see figures 5.21 and 5.22) for levels of zinc and copper, pollutants which are associated with a range of metal using industries, indicate broad areas where existing land contamination is already 10-15 times the 'normal' level in unpolluted soil, and in some cases exceeds current guidelines. These 'polluted' areas include large parts of Coventry, central Birmingham, West Bromwich and parts of Walsall, where it is suggested additional sources of heavy metal emissions may create environmental pollution problems, particularly if pollution control measures are not as effective as they ought to be. Therefore, not only does the mapped information highlight areas of potential concern, as far as additional sources of pollution are concerned, but also enables areas to be identified where the controlling authorities will need to be especially careful in ensuring the efficient control of any pollutant emissions.

7.3.4 From a public health perspective a more important potential use of the ambient information on levels of heavy metal soil pollution, is in the field of epidemiological studies. In recent years several investigators (Barltrop, 1981; Zeilhaus, 1981; Piotrowski and Coleman, 1980) have recommended that the only reliable method of assessing the health effects from exposure to heavy metals is through epidemiological studies. A critical component of such studies is the formation of 'exposure profiles' for individuals to the wide variety of potential sources of heavy metals (these include total diet studies, workplace exposure and the general environment). Clearly, to detect health effects from exposure to heavy metals and to identify the source, requires that detailed information is available on all possible sources of exposure to heavy metals, including metals present in the ambient environment. To date, however, such ambient information has not been readily available due to data collection problems and therefore the exposure profiles that have been undertaken are incomplete and of limited value. This study has demonstrated, however, that it is possible to develop a simple and accurate technique to enable the 'baseline pattern' of heavy metal contamination to be measured and mapped for large urban areas. The technique also enables 'hot spot' areas or 'stress areas' of significantly elevated levels of heavy metals to be objectively defined. Both sets of information may be used in exposure profiles either as a 'control' set of data on which to base judgements as to the significance of any detected health effects due to exposure to heavy metals, or, in the case of 'hot spots', as a significant source of exposure to heavy metals. An example of this dual role of the data in exposure profiles is in the mapped data for total cadmium (see figure 5.20 of chapter 5). The map of total cadmium provides the general pattern of environmental exposure to cadmium, and in addition identifies sub-areas where the typical background level of cadmium exceeds 3 mg/kg, the current most stringent ICRCL guideline for acceptable concentrations in soils.

7.3.5 A further policy orientated use of the identification of sub-areas or 'hot spots' of land contamination is in the definition of areas requiring investigation in the context of environmental health. In particular, the research has highlighted the existence of substantial tracts of elevated levels of land contamination in the traditional inner city areas of the WMMC. In view of the current interest in rejuvenating inner areas by encouraging new industrial and commercial activities and, more importantly, providing new housing and recreational facilities, it is suggested that the mapping methodology may be used to flag potential problem areas in relation to heavy metal land contamination. For example, if the inner city regeneration policy requires that sites within the 'hot spot' areas be developed for sensitive uses such as housing, then the mapped information provides an early warning of potential environmental health problems, and identifies areas where detailed surveys and/or remedial treatment would be necessary prior to specific redevelopment taking place.

7.3.6 This policy application of the mapping methodology has seen further practical development by JURUE, in a soil contamination survey of the Borough of Walsall (for details see JURUE, 1982). The survey, based on this research work, was commissioned by Walsall to map 'background' levels of heavy metal land contamination, on a grid by grid basis, for the whole of the Borough, to assist the Environmental Health Department in their role of providing environmental information for consideration in local plans, and in development control. Contoured soil contamination maps have been produced and are used as an 'early warning system', alerting the Borough to the need for further detailed site investigation in areas of planned development. Comparison of the soil contamination data with data from the West Midlands Structure Plan revealed that two proposed major housing developments, both in the inner urban industrial part of the Borough, were to take place on sites which exhibit significant soil contamination problems. In fact the levels of total lead and cadmium in the soil in these two areas were found to exceed current ICRCL guidelines for housing use. In the case of total lead, measured levels were over 2 times higher than the recommended level of 550 mg/kg, and in the case of cadmium the measured levels were nearly 4 times higher than the recommended acceptable concentration of 3 mg/kg. In addition, since carrying out the survey, the data base has been used by the local authority to identify a number of small sites which will require investigation in the near future because they have been earmarked for short-term allotment use.

7.3.7 Clearly, the above examples demonstrate that survey methodology developed in this research has a number of potentially valuable roles in an applied policy context. The argument in favour of using comprehensive and mapped baseline environmental information as an aid to policy and decision making has been supported by Karpe and Scholz (1976), who suggest that their value lies mainly

> "in the transformation of difficult and complex data into understandable and clear information......clearly indicates areas of heavy pollution impact and areas where standards are exceeded; also the origins of pollution can be traced".

7.4 Recommendations for further Research

7.4.1 The purpose of this final section of the chapter is to suggest ways in which further research might build upon the work undertaken here. Earlier sections of this chapter have already raised a number of potentially useful research areas, particularly in relation to the provision of baseline environmental information. However, the focus in this section is on further research which takes forward the techniques developed in the work reported here. These relate firstly to policy issues with respect to the regulation and control over the use of contaminated land; secondly to the further evaluation of the sampling methodology and assessment techniques developed in the study; and thirdly to the more detailed elements of the analytical techniques used in the research.

7.4.2 Throughout this research work, the emphasis in the control over the use of contaminated land has been restricted to considering the problems of developing standards and guidelines as a means of control over the redevelopment of contaminated land. However, the practical experience gained in carrying out this research study, suggests that a key issue in controlling the use of contaminated land is in preventing the development of contaminated sites without full recognition of the pollution problems.

To do this requires detailed knowledge on the extent and nature of the contamination present on an individual site. The collection of such information is not only a time consuming and costly exercise for local authorities to undertake, but is also complicated by the fact that a planning authority has no direct responsibility to collect such information.

7.4.3 In fact, the powers and duties of local authorities to control the development of contaminated land are weak and unclear. This is because contaminated land is not a planning problem in the sense of the Town and Country Planning Act, as the principle of use is not the issue, only its implementation is doubted with respect to pollution and public health risk. Therefore, a planning authority has no direct powers to require a potential developer to carry out a site investigation for contamination. However, the problem is not as straightforward as at first it may appear, because local authorities do have powers to impose conditions on planning permission. The relevant legislation allows them to grant planning permission, subject to 'such conditions as they think fit'. Therefore, if a planning authority were to regard contamination as a material consideration, it can in theory impose conditions designed to ensure that the problem of contamination is dealt with before development takes place. However, the use of conditions introduces further problems in that it is doubtful if a planning authority can be held to have any duty, or indeed have the resources, to check the physical suitability of all land for its proposed development. Moreover, suspicion of potential contamination of the land, and making it known in advance of detailed knowledge of the nature and extent of the problem introduces other issues, such as 'planning blight', and may also have a potentially disastrous impact on land values. Such issues place the local authority in a difficult legal position, and the responsibility of proving that a site is indeed contaminated to an unacceptable level may be left up to the local planning authority. If it were the case that the local authority were put in this difficult position, then in the future they may be unwilling to take potential land contamination into consideration when exercising their planning and development control functions.

7.4.4 In essence, the problem is one of identifying, with some degree of certainty, that an area or site of proposed development may be contaminated. In the light of the above comments, the most obvious extension of the work in this direction would therefore be in alerting the local authority to potential problem areas. This aspect of the work has already been touched upon in section 7.2.5; however the proposal here is to undertake a more detailed examination of those areas in the WMMC where soil contamination is already at elevated levels. In this respect, it would be a relatively simple matter to subdivide 'hot spot' areas according to their likelihood for redevelopment and to carry out a more detailed soil sampling programme in those areas of potential conflict. Thus, by using the sampling methodology as an 'early warning system', followed by more detailed investigations where necessary, the problem of the unwise development of contaminated land without the full knowledge of potential contamination should be avoided.

7.4.5 As was noted earlier, the mapping methodology provides a record of the existing situation regarding soil contamination,and cannot therefore be used in its present form to determine directly whether the contamination of the soil is the result of former activities, progressive accumulation over time, or current industrial activity. This implies it is not possible to demonstrate whether land contamination is an increasing problem, or whether it will be reduced as re-use and redevelopment takes place. It is, however, a relatively simple matter to obtain information on past and current uses of sites (see JURUE, 1981), and to compare such information with the land contamination maps. Where this comparison identifies a current source to a problem, the monitoring of emissions through, for example, air sampling, and deposition gauges, would soon demonstrate whether the current activity is creating further land contamination. A key advantage of this extension to the research work is that the additional information may also provide a means of assessing the effectiveness of existing environmental protection policies, and may also serve to highlight either areas or sources where additional control policies may be required to prevent further land contamination.

7.4.6 Methodology

The research work reported here has concentrated on developing a generalised methodology for measuring and mapping the spatial variability of heavy metals in soils and has produced an operationally useful tool. However, there has been no field testing of the mapping methodology in areas where soils have not been collected. If the sampling methodology is to see further development as a technique for providing 'baseline' information as well as identifying 'hot spots', it would seem advisable to structure further research work so as to validate the robustness of the technique. Such a study would also strengthen the data base used to generate the 'reference levels' and'normal limit levels', particularly if it were combined with the further work recommended below.

7.4.7 As has been emphasised in chapters 3 and 4, there are no set rules or procedures for sampling the spatial variability of heavy metals in urban environments. The sampling framework and sample size for the study were determined using the relevant literature and the results of a pilot study. However, it is recognised that any sample will provide an estimate of the population subject to some error. Generally speaking, error will decrease with sample size, but at a decreasing rate. For any given sample design, the accuracy of the sample will depend on the size of the sample and variance of the measures. The precise density of sampling adopted in this research was a stratified random sample, with all area-types being sampled at the same density. However, the results of the survey (see chapter 5, section 5.2) indicate that the variability of heavy metal levels within area types is not constant. For example, the densely developed area-types, with a high percentage of industrial land-use (A2, B1) have highly variable heavy metal levels compared to the more rural agricultural area-types (E4, E5). (This variability was taken into account during sampling by using a composite bulked sample). Therefore, it is suggested that in certain areas it may well be more statistically efficient to sample particular area-types or groups of area-types more intensely than others. Thus, for example, in area-types where the levels of heavy metals are highly spatially variable, it may be worthwhile sampling at a greater density than in area-types where the spatial variation is not so great. Relating the density of sampling to the expected variability in soil heavy metal levels, would serve to improve the accuracy of the sampling methodology and at the same time improve the statistical validity of both reference levels and normal limit levels. Moreover, such an approach would provide a useful source of additional information to enable potentially contaminated sites to be identified in a more systematic and cost-effective manner.

7.4.8 Specific Elements of the Analytical Techniques

The present study restricted the analysis of heavy metal contamination to considering pollution by lead, zinc, copper and cadmium for the reason outlined in chapter 3. However, in recent years, interest has been focussed on the other heavy metals such as mercury, thallium, arsenic and barium which, due to their environmental persistence and high toxicity at low levels of exposure, have been singled out by the EEC (see Ferrante and Berlin, 1981), for priority attention. Therefore, it is suggested that further work should include the extension of the range of heavy metals to cover those which are becoming more important as environmental intoxicants.

7.4.9 The interest in heavy metal soil contamination stems mainly from the public health problems associated with the uptake of metals by food crops grown on contaminated soil or due to direct ingestion. However, as has been demonstrated in this research, there are a wide variety of chemical extractants (see apendix B), which have been used to assess the bioavailability of metals in soil and this creates problems for interpreting the significance of elevated levels of heavy metals. The problem is further complicated by the fact that there are no recommended analytical techniques or 'standard' contaminated soils on which to assess the suitability of the various techniques. Therefore, there is scope for further research to determine both the precision of the various chemical extractants currently used, and their value as a soil test, to predicting the relative bioavailability of heavy metals in soils.

7.5 To conclude, the work reported here has touched the problem of contaminated land at the general urban scale, rather than concentrating on the detailed site specific issues. In so doing, it has demonstrated the feasibility of developing practical techniques which provide a simple, cost-effective and accurate means of quantifying the extent and nature of background land contamination. Moreover, it is contended that the major contributions of the work are that it not only provides an information base which has utility in a number of applied policy contexts, but has also made an initial contribution to the task of developing rigorous and practical standards for contaminated land. Such information is of intrinsic value to both planning and environmental control authorities.

APPENDIX A

BACKGROUND TO THE CASE STUDY AREA AND LAND-USE DATA CLASSIFICATION

A.1 Introduction

A.1.1 This appendix provides a general description of the case study area and describes in detail the methods by which land-use data were obtained, adapted, classified and used to derive the 20 'area-types' which formed the basis of the sampling framework.

A.1.2 The appendix first describes the study area, its location and the general pattern of land-use in the case-study area. Details are then given describing the structure of the industrial base, with particular emphasis on the spatial variation of the dominant manufacturing industries. This is followed by the technical details of the methods by which the land-use data and road network density data, derived mainly from secondary sources, were collected and categorised to give the 20 unique 'area-types' from which surface soil samples were collected. The technical details on the actual field sampling technique and analytical methods used in the research are contained in appendix B.

A.2 The Case Study Area

A.2.1 The study area selected for the development and application of the mapping methodology was the West Midlands Metropolitan County(WMMC). The WMMC was formed in the local government re-organisation of 1974 from parts of Warwickshire, Worcestershire, Shropshire and Staffordshire. The County covers an area of 900 sq.km. and has a population of 2.7m people. It is centred on Birmingham, the major regional centre of commerce and the second largest city in Britain. Figure A.1 shows the location of the WMMC in the U.K. and figure A.2 the pattern of predominant land-use types in the area. General statistical land-use data is available for the WMMC (West Midlands, 1978) and this shows that 39% of the land area is

Fig.A.1 The Relative Position of the West Midlands Metropolitan County.

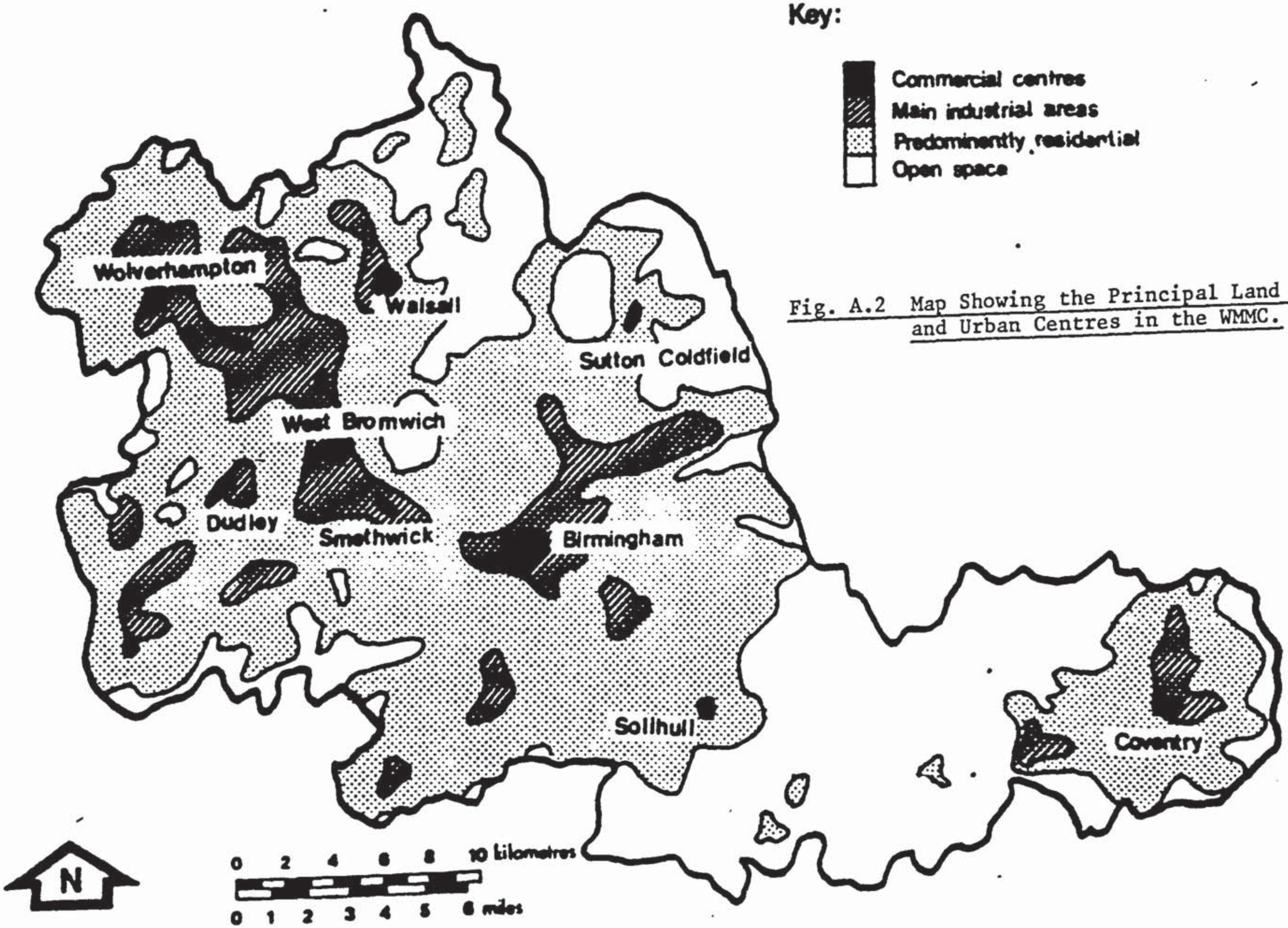


Fig. A.2 Map Showing the Principal Land Use Types and Urban Centres in the WMMC.

occupied by residential land-use, 22% by agricultural, 11% by leisure and open space use, 9% by vacant, derelict and other land and 7% by manufacturing uses.

A.2.2 The WMMC can, in fact, be conveniently divided into three geographical units. Coventry, a free standing city in the east is separated from the remainder of the County by Solihull, a rural area of agricultural green belt. The remainder of the County, known as the West Midlands Conurbation, is an industrial area founded on metal based manufacturing. The industrial heart of the conurbation is known as the 'Black Country' consisting of Walsall, Dudley, Sandwell and Wolverhampton. Its historical connection with the metals industry can be traced back to the earliest days of the industrial revolution when, at one stage, the conurbation was responsible for the majority of the Country's primary iron and steel production.

A.2.3 The major residential areas in the WMMC are dominated by Birmingham which occupies 29% of the land area of the county, and accounts for 38% of the residential land-use. Other important housing areas are Halesowen and parts of Wolverhampton, Walsall and Coventry. Open space is principally restricted to the rural area of agricultural green belt separating Coventry from the conurbation in the district of Solihull. In fact, the Borough of Solihull occupies approximately 20% of the land area of the WMMC, and has 53% of the total agricultural land-use of the WMMC in its area. Other areas of open space are principally large parks which are found widely distributed in the conurbation.

A.3 The Industrial Base

A.3.1 It has already been stated earlier, that the 'Black Country' comprises the dominent industrial areas of the WMMC, with something like 59% of all industrial land-use found in the 'Black Country'. The industrial base of the WMMC has been dominated by manufacturing industries for many years.

A recent report (JURUE, 1981) has shown that the manufacturing industry in 1976 was still dominated by metal-based manufacture and engineering industries, with nearly 40% of all employment in the County accounted for by these two sectors. The manufacturing activities range from small foundries in the 'Black Country' to large vehicle production factories in Birmingham and Coventry.

A.3.2 The WMMC has been shown (see JURUE, 1981) to represent by far the largest concentration of metal based manufacturing in the U.K. The important metal manufacturing industries in the WMMC are primary iron and steel production, non-ferrous metal manufacture and metal finishing industries. Large scale primary iron and steel production was an important feature of the industrial base of the conurbation, but has declined steadily since the early part of the century, to a point where there are no longer any major steel producing plants in the County. However, small scale iron foundries still proliferate in the Smethwick and Wolverhampton areas. Such industries are important to the research study, since the ferrous metals industry has been shown to be largely responsible for air pollution problems in the form of grit, dust and metallurgical fume emissions, and therefore contributes to heavy metal land contamination.

A.3.3 The non-ferrous metal manufacturing sector includes the production of aluminium, aluminium alloys, copper, brass and other copper alloys, and other base metals. In the WMMC the non-ferrous metal production is based on secondary refining, and represents 50% of the industry in the U.K. Secondary copper refining is concentrated in Walsall where two large plants have been operating for a number of years. The smelting and refining of lead, aluminium, zinc, magnesium and titanium is also an important industry in the WMMC, with 20% of the total U.K. lead smelting taking place in Birmingham.

A.3.4 The metal finishing industry is also important in the WMMC and includes a range of plating operations (cadmium, zinc, chrome, nickel and tin plating) as well as anodizing and galvanizing operations. The industry is centred on Birmingham and Sandwell with local concentrations in Dudley, Walsall and Wolverhampton.

A.3.5 In general, therefore, the most significant industrial areas in the WMMC are the north east part of Birmingham, Coventry and a broad band of industrial centres in the 'Black Country'. This broad band stretches from Dudley in the south west through Oldbury, Smethwick and West Bromwich to the Bilston area on to Wolverhampton and Walsall. The importance of the metal industries in the context of the research study are that they represent significant sources of metal rich grit, dust and fume emissions. Therefore such industries are important contributors to the high metal content of dust deposited in the area and have contributed significantly to contamination of the land with toxic heavy metals including lead, zinc, nickel, copper, cadmium and chromium.

A.3.6 The indication of the importance of industrial sources of heavy metals in the general environment can be gained by comparing the results of dust analysis conducted in the largely non-industrial town of Lancaster (Harrison, 1979) with those obtained in the West Midlands (Archer and Barratt, 1976; JURUE, 1981). The data are shown in Table A.1

Table A.1. Mean Levels of Selected Heavy Metals in Roadside Dusts (Mg/Kg)

Metal	Lancaster	West Midlands
Lead	1,880	1,000 - 4,500
Cadmium	3	8
Chromium	29	102
Nickel	35	73
Copper	143	1,300
Zinc	534	1,600

The data in Table A.1. clearly demonstrates that the levels of most metals, especially cadmium, copper and zinc, are much higher in the WMMC dusts.

The available data appears therefore to verify the suggestion that the metal industries contribute significantly to the metal contamination of dusts in the West Midlands.

A.4 Land-use Data Collection

A.4.1 In section 4.6 of the main text, a summary was given on the collection of land-use data for the WMMC. This data was directly available from secondary sources and was derived from the following three sources:

i) the 1976 land-use map available from the West Midlands Metropolitan County. This map was derived from 1:10,000 (1:20,000 in the case of Solihull) scale district council land-use maps, which had been updated.

ii) the 1979 vacant and derelict land map of the WMMC available from the West Midlands County Council.

iii) the 1979 (2nd edition) 1:50,000 Ordnance Survey Map of the WMMC.

A.4.2 The procedure for obtaining a comprehensive and detailed base map of land-use data for the WMMC was as follows. Firstly, eleven categories of land-use were available on the 1976 land-use map and because the research study is interested only in mapping the spatial variations of heavy metal content in major land-use types (e.g. variation between agricultural and industrial or residential and industrial areas), it was necessary to aggregate some of the eleven original land-use categories to give six categories of major land-use for use in the research study. The comparison between the two categories is illustrated in table A.2 below.

TABLE A.2 COMPARISON OF THE LAND-USE CATEGORIES

WMMC CATEGORIES	RESEARCH CATEGORY
1. Residential 2. Education 3. Public assemblies, (e.g. hospitals, prisons)	1. Residential (including schools, hospitals and prison buildings).
4. Industrial 5. Minerals 6. Public utilities (e.g. sewage)	2. Industrial (including active mineral extraction sites and public utilities).
7. Commercial	3. Commercial (including town halls).
8. Recreation 9. Other open land (inc. vacant land, cemeteries).	5. Recreational (including school and hospital grounds, woodland and cemeteries).
10. Agricultural.	6. Agricultural.
11. Transport (road, rail, etc.)	

A.4.3 A 1:50,000 scale Km.grid base map was made from the 2nd edition O.S. Map covering the WMMC. This was to ensure correct geographical delineation land-use zones and Km grid when transferring the land-use data. This grid base map was then overlaid on the County vacant land map and a copy made of the 'vacant' land-use category. The remaining five categories of land-use were taken from the 1976 land-use map giving consideration to possible new land-use developments (e.g. residential on reclaimed derelict sites) not recorded on the 1976 land-use map.

A.4.4 It should be noted that at the spatial scale being used, and with the use of only six land-use categories, it was neither possible nor necessary to include every available detail on land-use. Thus, for example, gardens and grass verges in residential areas are recorded only as residential land

and not as recreational land-use. Similarly, open land in industrial areas is recorded as industrial land. Thus areas zoned 'residential', 'industrial' or 'commercial' do not imply that all such land is covered by buildings. In addition, transportation routes (roads, canals, railways) have been totally excluded and have been allocated to the land-use category of the area that they pass through.

A.4.5 By the means described above, a base land-use map was produced which was as spatially and typologically detailed as possible. The next stage was to use this land-use map to obtain a measure of the proportion of each Km grid square occupied by the six land-use types. Estimates of the percentages of the grid square in each category were achieved by placing a transparent overlay divided into twenty five sub-grids, each sub-grid therefore being equal to 4% of the sq.km. By disaggregating the sq.km. grid into 25 sub-grids, the task of adding up the proportion of each land-use category in the km. grid was therefore simplified. This measurement procedure resulted in obtaining for each of the 1003 sq.km. grids (including boundary squares), a 'unique' individual combination of land-use category proportions.

A.4.6 It was recognised that there would inevitably be inaccuracies in this base land-use map. Two possible sources of inaccuracy were the cartographic transformation of land-use data from secondary source maps, and the method used to estimate proportion of each grid square occupied by each of the six land-use types. However, since the mapping study is being undertaken at an aggregate scale, it was not considered necessary to assess the extent of any error.

A.5 Road Network Density Data

A.5.1 Section 4.6.3 of the main text summarised the rationale behind the choice of road network density as an indicator for 'intensity' of urbanisation and hence land-use, in an urban area, to be used as the principle parameter in the definition of 'area-types'. The selection of road network density was also based on the fact that such data is readily obtainable for the whole of the WMMC and, unlike 'distance from city centre', allows a comprehensive coverage of the WMMC to be achieved. The data for road network density was obtained from secondary sources, being the number of road intersections on the 1:50,000 (2nd edition) Ordance Survey Map.

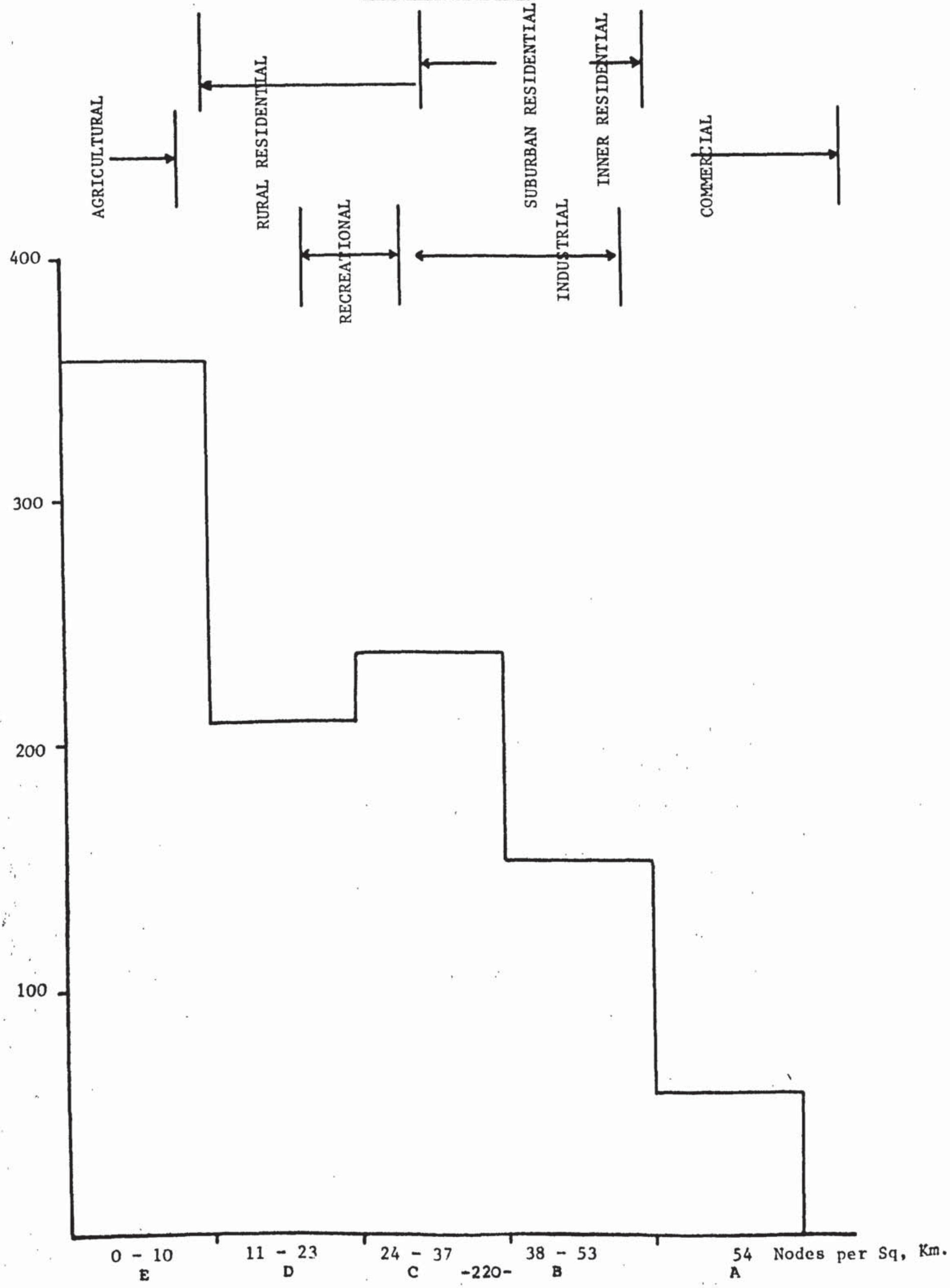
A.5.2 The number of intersections, termed nodes, were calculated by counting all road intersections in a 1 sq.km. grid on the 1:50,000 O.S. Map. An 'intersection' was taken to be a normal 'T' junction, with crossroads counting as two intersections (i.e. 2 nodes) and an additional 'node' is added for every extra road at an intersection. For example, 6 roads intersecting at a junction would be counted as 4 nodes. By these means, the number of 'nodes' per sq. km. grid were obtained for the whole of the WMMC. The number of 'nodes' per grid ranged from 0 in agricultural land through to 92 in the traditional industrialised inner city areas.

A.5.3 It was recognised that 'errors' could occur in obtaining the data on road network density, largely from miscounting, omitting or double counting junctions. Since road network density was to be used (see section 4.6.4 of chapter 4) as the primary differentiator for grouping the data into 'area-types', it was necessary to assess whether this error was significant. To test the magnitude of the error due to repeated manual counting, four grid squares were selected at random and six independent assessments were made of the 'nodal density' for each of the four grid squares. The results are given in table A.3. below.

TABLE A.3. CHECK ON THE ACCURACY OF THE ROAD INTERSECTION COUNTING PROCEDURE

Grid Square	A	B	C	D	E	F	Mean	Map
91/99	68	64	64	70	65	65	67	65
88/99	36	33	34	32	33	34	34	34
83/95	44	46	57	53	47	45	48	45
85/94	30	30	32	38	35	34	35	34

Fig. A.3 Frequency Distribution of Road Network Density.



A.5.4 The above table indicates the kind of consistency that may be obtained in measuring the 'node density' for the 1003 Km grid squares in the WMMC. The data in table A.3 demonstrates that although there is a certain amount of error in the repeated counting of road intersections, the magnitude of this error is likely to be small enough so as not to have a significant effect on the final data collection. The table also compares the mean of the six estimates of 'node density' and the measure actually achieved in the application of the procedure to the grid squares of the WMMC, which also indicates that any error is likely to be very small.

A.6 <u>Derivation of 'Area-Types'</u>

A.6.1 As stated in section 4.6.4 of the main text, it was decided that in order to achieve a usefully limited number of grid squares from which to sample soil to determine the spatial variation of background levels of heavy metals in the soil of the WMMC, it would be necessary to categorise the land-use data and road network density into a smaller number of units of area, termed 'area-types'. It is these 'area-types' that were used as the sample frame. During the collection of both land-use data and road network density data, it was recognised that a functional relationship exists between the two sets of data. For example, industrial land-use is not normally associated with areas of sparse network density, and agricultural land-use is not normally associated with dense network areas. Therefore, it was decided to produce a typology of 'area-types' which resulted from a categorisation of land-use within a primary grouping of road network density.

A.6.2 The first task in deriving 'area-types' therefore was to group the 1003 grid square measurements of 'node density' into a statistically valid number of categories. Since the use of road network density as a measure of intensity of land-use in the context of soil mapping is 'unique', there is no available literature on which to base such grouping. Therefore it was decided to group the 'node density' data into 5 categories according to the following criteria:

i) there was a broadly even distribution of the number of nodes in each category.

ii) there was a systematic interval size between categories taking into account the fact that in highest category (representing urban centres) there are likely to be only a few grid squares.

iii) natural groupings within a frequency distribution were taken account of (see chapter 5, section 5.7).

A.6.3 The distribution of 'nodes' within each of the five categories is shown in figure A.3, which also contains a verbal description of the predominant land-use types in each category. Having established the number of node density categories (A - E), and the class interval of each category, each grid square in the WMMC was allocated to one of the 5 categories according to its 'node density'. The number of grid squares in each category is given in table 4.1 of the main text. The next stage in the derivation of the sample frame was to group the grid squares in each node density category according to land-use data. This was achieved through a qualitative cluster analysis and is described below.

A.6.4 For each node density category, a frequency distribution of grid squares occupied by the six land-use categories was produced and these are shown in figures A.4 - A.9. Each grid square was allocated according to the dominant land-use type in the square. It can be seen from figures that in node density E, only agricultural land and a limited amount of residential and recreational land-use is found. Residential land-use tends to be a dominant feature in node density categories A, B and C. There is also a strong presence of commercial and industrial land-use in node-density A, while in category C, residential land-use is a dominant feature. In node density category B, there is a much more mixed pattern of land-use including residential, recreational, industrial and vacant land. Commercial land-use appears to be dominant with residential in network density category B.

Fig. A.4 Distribution of Residential Land Use in the WMMC.

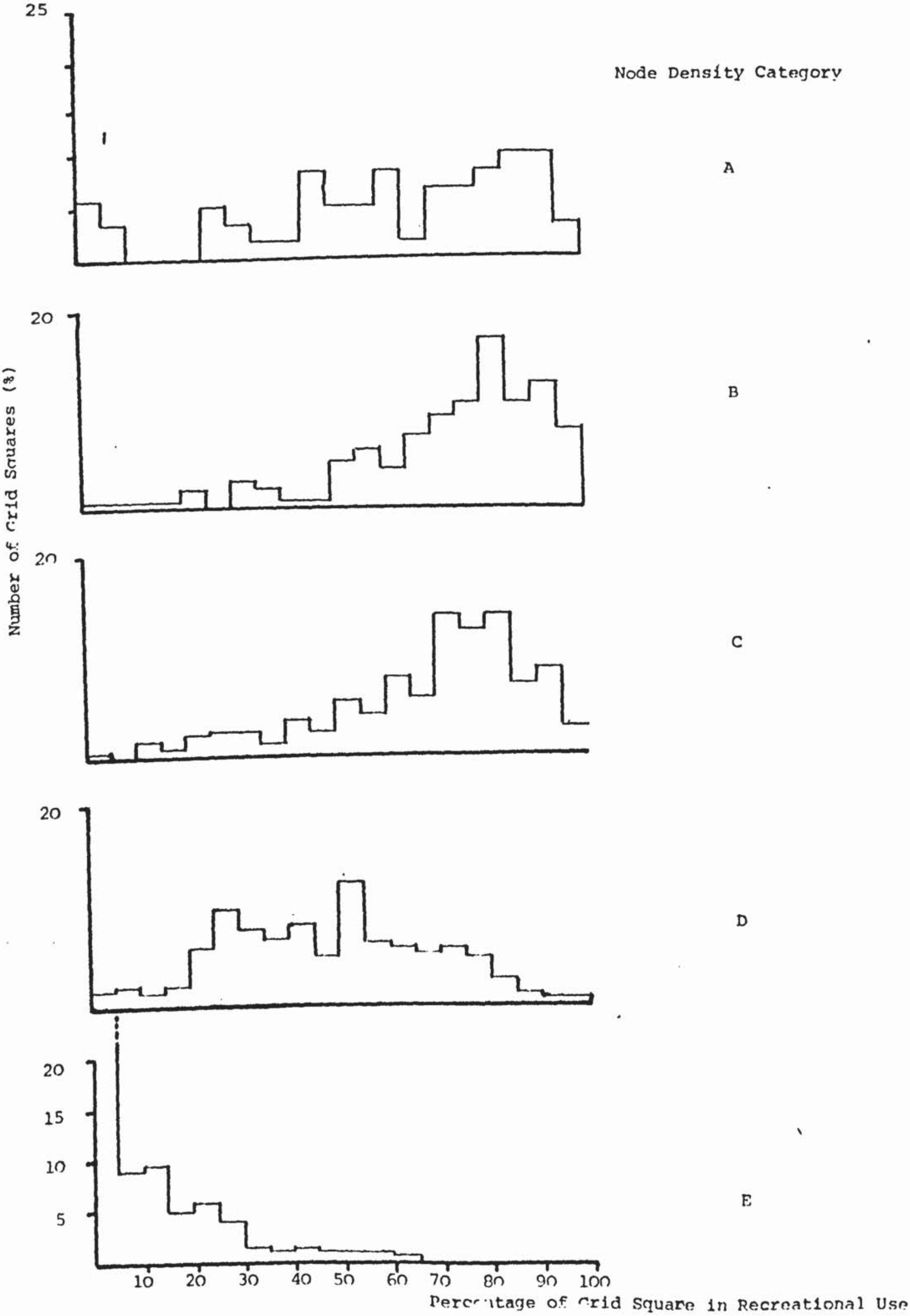


Fig. A.5 Distribution of Industrial Land Use in the WMMC.

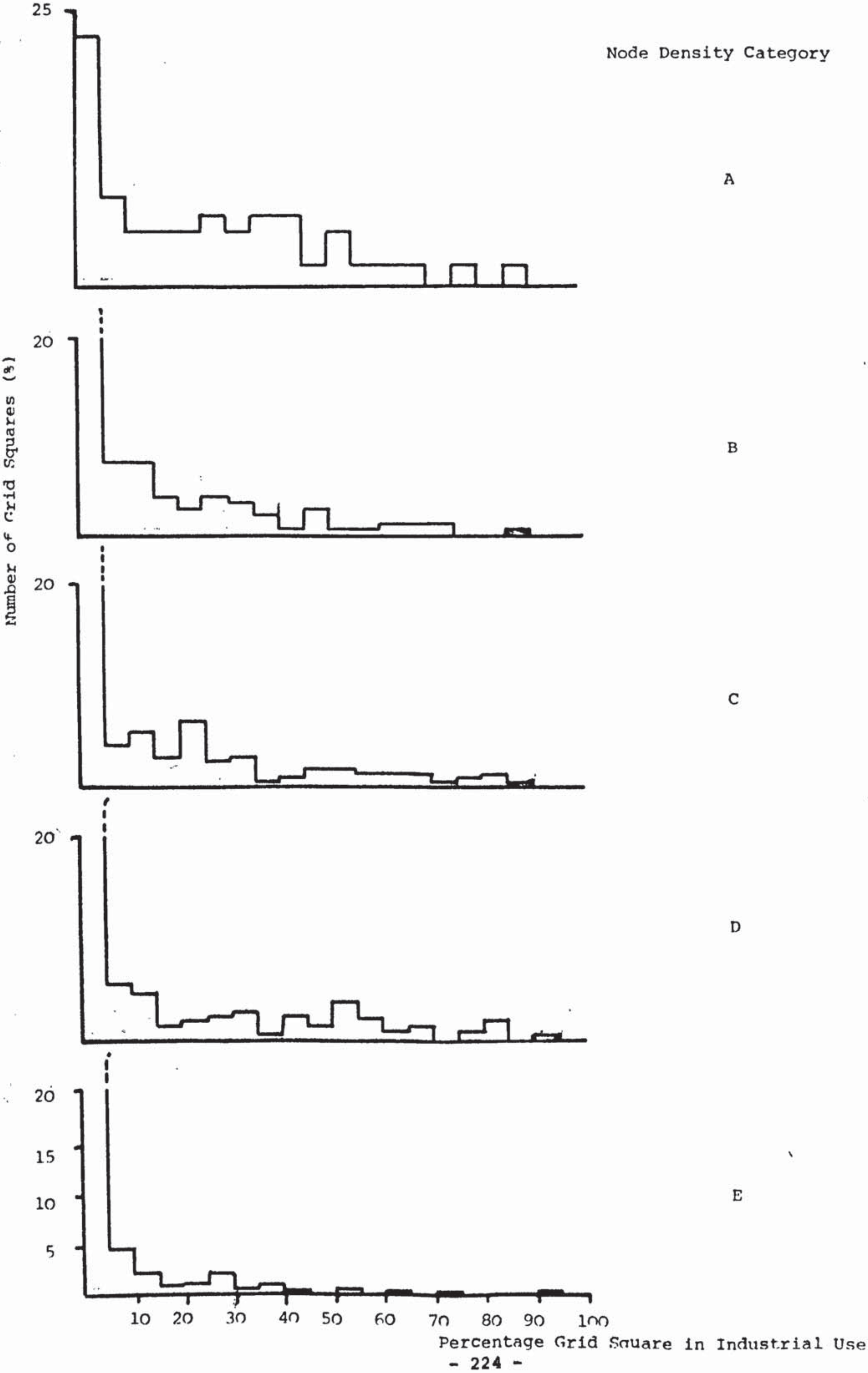


Fig. A.6 Distribution of Commercial Land Use in the WMC.

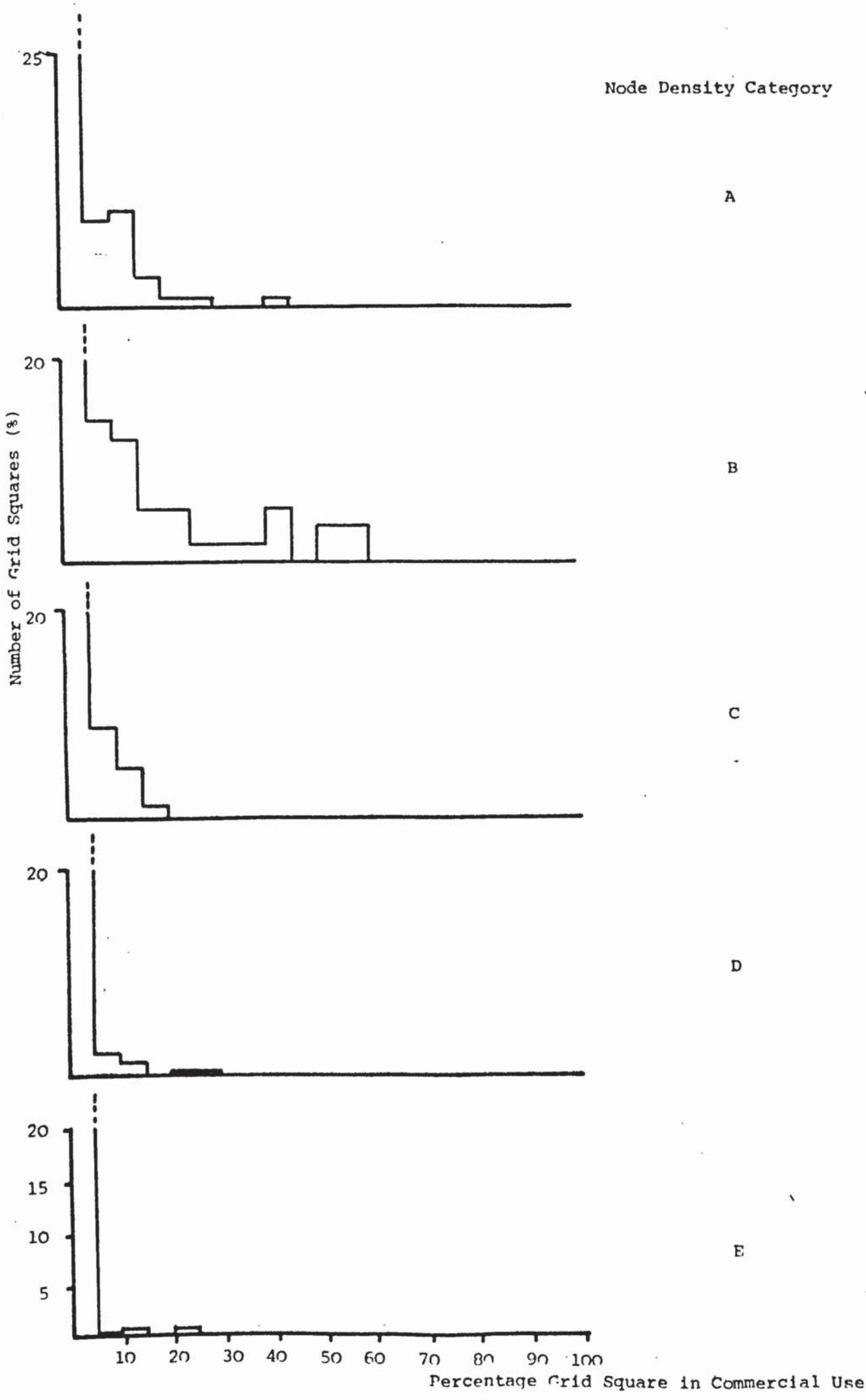


Fig. A.7 Distribution of Vacant Land Use in the WMMC.

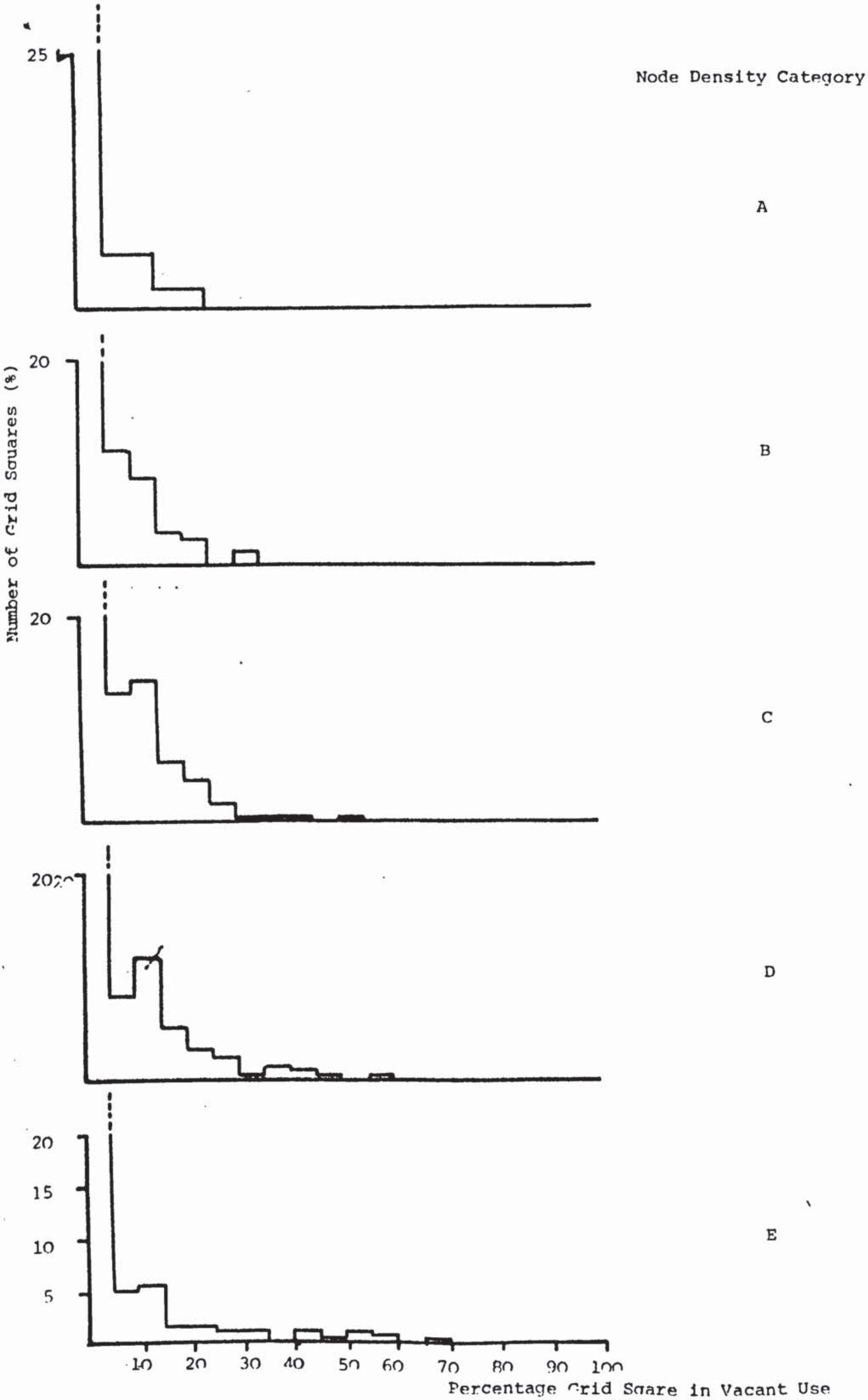


Fig. A.8. Distribution of Recreational Land Use in the WMMC.

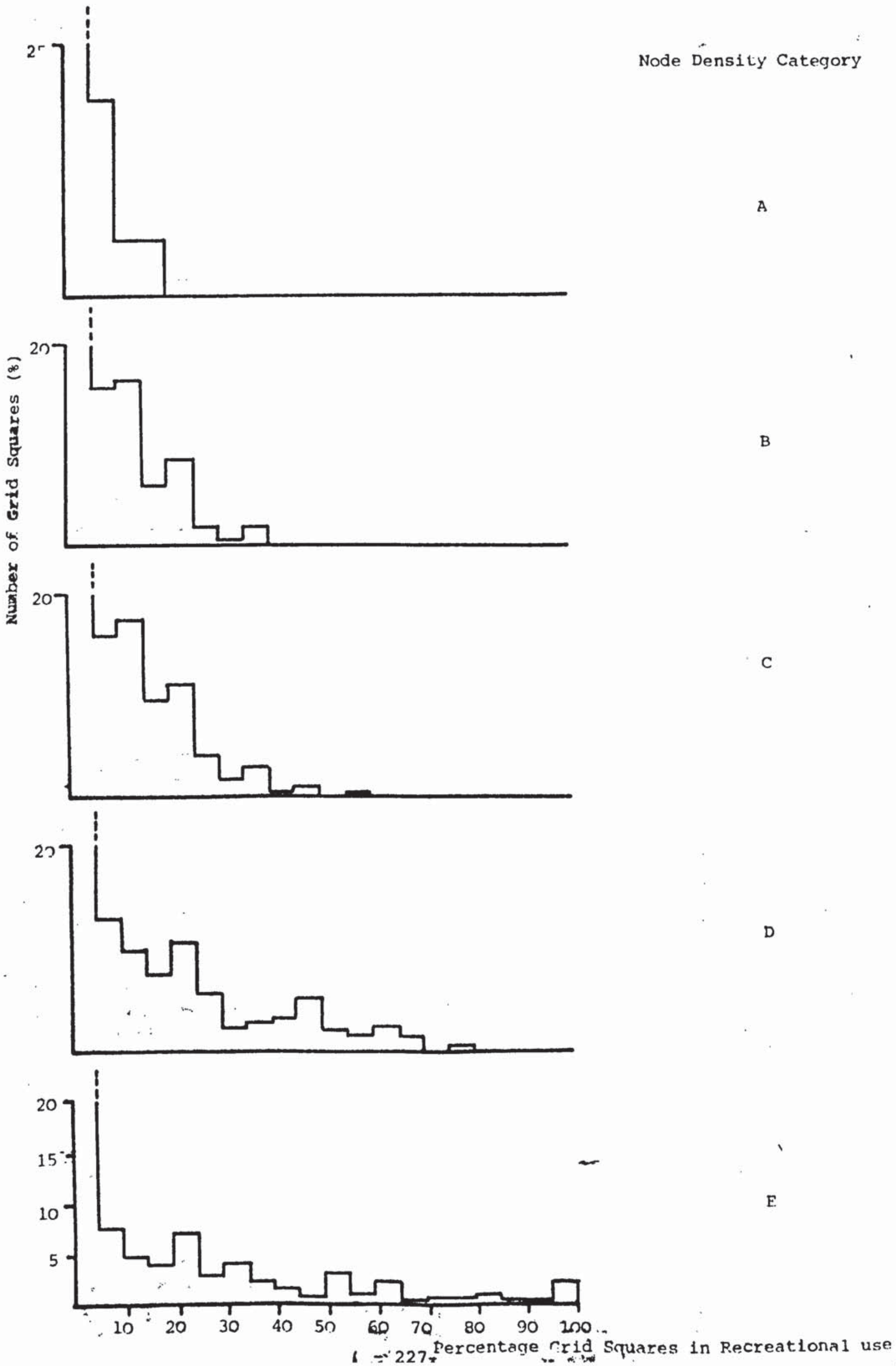
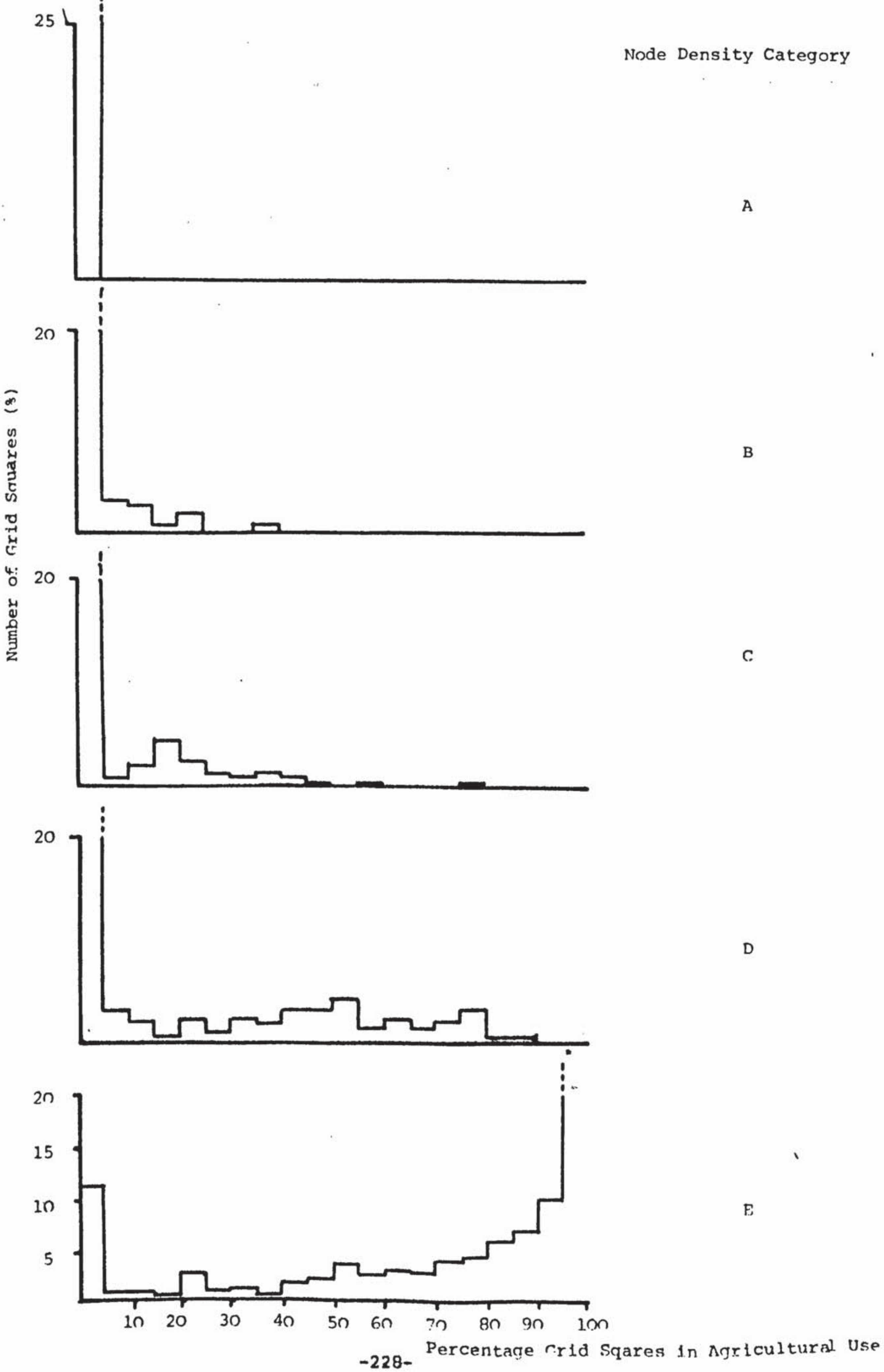


Fig. A.9 Distribution of Agricultural Land Use in the WMMC.



A.6.5 On the basis of this pattern of clustering of land-use and mixes of land-use in each node density category, a 'qualitative cluster analysis' of all grid squares was performed, which resulted in the definition of the 20 'area-types' which were to be used as the sample frame. A description of the 20 'area-types' is given in figure 4.2 of the main text. Table A.4 contains summary data on the 40 grid squares selected at random as representing the 20 'area-types'. It is these grid squares which were sampled in the WMMC and the following appendix gives details on the technical issues related to soil sample collection and laboratory analysis.

TABLE A.4. PERCENTAGE LAND-USE, ROAD NETWORK DENSITY AND GRID SQUARE CODE FOR THE 20 'AREA-TYPES'

Area-type Category	Grid Square	Resid-ential	Indust-rial	Commer-cial	Vacant	Recrea-tional	Agric-ulture	Nodal Density
A1	8606	00	45	55	00	00	00	85
A1	9801	28	32	40	00	00	00	79
A2	9896	64	13	15	08	00	00	58
A2	7934	60	22	08	10	00	00	90
A3	8801	79	00	08	00	13	00	60
A3	9893	90	00	00	00	10	00	55
B1	7633	94	00	01	05	00	00	52
B1	8311	88	12	00	00	00	00	42
B2	8134	15	60	24	01	00	00	49
B2	8810	66	24	02	00	08	00	50
B3	9612	68	00	12	00	20	00	38
B3	8697	82	04	10	00	04	00	50
B4	9293	50	00	00	15	36	00	45
B4	9400	76	00	00	04	20	00	42
C1	8205	100	00	00	00	00	00	33
C1	8816	90	00	00	00	10	00	27
C2	8690	64	32	00	04	00	00	37
C2	9008	20	80	00	00	00	00	32
C3	8996	64	00	00	26	20	00	32
C3	9204	74	04	04	12	06	00	24
C4	9988	52	00	00	00	36	12	32
C4	9209	76	00	00	00	24	00	33
D1	8493	34	32	00	12	06	16	18
D1	9296	12	68	00	10	10	00	18
D2	7915	50	00	24	00	26	00	14
D2	8301	41	00	00	04	55	00	18
D3	9092	50	00	00	50	00	00	20
D3	0198	46	14	00	40	00	00	23
D4	0405	50	00	00	02	00	48	18
D4	8020	30	00	00	00	08	62	14
E1	9002	04	54	00	07	35	00	8
E1	9013	24	72	00	04	00	00	6
E2	9708	40	00	00	00	60	00	10

TABLE A.4. cont'd.

Area-type Category	Grid Square	Resid-ential	Indust-rial	Commer-cial	Vacant	Recrea-tional	Agric-ulture	Nodal Density
E2	8517	50	00	00	00	34	16	9
E3	8913	28	00	00	00	10	62	8
E3	7623	43	00	02	00	22	33	8
E4	7513	06	00	00	00	42	52	3
E4	9904	10	00	00	00	50	40	7
E5	8228	00	00	00	00	00	100	3
E5	9705	00	00	00	00	00	100	5

APPENDIX B

SOIL SAMPLING PROCEDURES AND ANALYTICAL TECHNIQUES

B.1 Introduction

This appendix provides a detailed description of the soil sampling procedures adopted in the research study. The appendix also provides the technical details of the laboratory methods by which the concentrations of heavy metals in the soil samples were determined.

B.2 Procedures used for collecting soil samples

B.2.1 Section 4.7 of the main text referred to the fact that surface soil samples were collected from within the 40 sample grid squares of the WMMC. The details of this are described below.

The sampling area (1 Km. grid square of the 1:50,000 O.S. map) was located in the field and nine sample sites selected at random where surface soil samples could be easily obtained and where suitable sampling conditions existed. The following criteria were used in the field to determine where soil samples should be taken from:

i) soil samples were not taken from obviously newly disturbed areas which may result in concentration or dilution effects;

ii) soil samples were not taken from areas under fences, overhanging porches, roofs or trees which may be concentration pathways for heavy metals;

iii) soil samples were not collected from newly landscaped bedding areas where topsoil or fertilizers may have been added;

iv) soil sampling avoided locations where obvious and erroneous point sources existed leading to higher concentrations, (e.g. deposits of ashes, refuse, abandoned vehicles, etc.).

B.2.2 For each of the nine sample sites, soil was collected from 6 sub-sample points in a 30m radius of the estimated central location of each sample site. The six sample points were then bulked to give a composite sample of soil representing the soil quality of the 30m zone around the sample point. Thus, for each Km grid sample, soil was collected representing approximately 3% of the grid square. The total sample collected in the field normally weighed approximately 500g (wet weight).

B.2.3 At each sampling point, upper grass and loose surface debris were removed prior to sampling. The 6 sample points were taken from approximately 10 cm depth of soil using stainless steel soil sampling equipment which was cleaned between each sampling (see section B.4). The six sample points were bulked together and sealed into labelled polythene bags for return to the laboratory.

B.3 <u>Laboratory Preparation of Samples</u>

In the laboratory, soil samples were placed in aluminium foil trays and dried to constant weight in an uncontaminated oven (see section B.4.1) at 105° for 24 hours. After drying, soil samples were removed from the oven and cooled in a dessicator. Each soil sample was then hand ground with a porcelain mortar and pestle to pass through a 'clean' stainless steel sieve with a 2mm mesh. Soil sub-samples were further ground to pass through a 70 B.S. mesh stainless steel sieve and sealed into labelled polythene bags. To reduce cross contamination of soil sample from this preparation stage, mortar, pestle and sieves were thoroughly cleaned according to the procedures detailed in Section B.4 before a fresh sample was introduced.

B.4 <u>Precautions taken to avoid cross contamination</u>

B.4.1 Cross contamination of soil samples could have occurred during drying in the oven and sample preparation stages, and therefore certain measures were taken to avoid such a possibility. To take account of possible contamination from the soil drying stage, three ashless filter papers were placed in foil trays at varying points in the oven. Oven temperature was set as for foil samples and the filters remained in the oven for 24 hours. The filters were then removed and each was acid digested (see section B.5.4) together with three control filters, and analysed for lead, copper, cadmium and zinc. A comparison between 'exposed' and control filters indicated no contamination from the oven.

B.4.2 Standard Washing Procedures

To avoid the contamination of soil samples and soil sample solution from equipment used in the preparation of samples for analysis by atomic absorption, a detailed washing procedure was adopted. All containers, sieves, glassware, pestles and mortars used in the preparation, extraction and digestion of soil samples and sample solution storage were thoroughly washed, using a three stage washing procedure. All equipment received an initial rinse and soak in a 10% solution of 'Decon 90' concentrate, followed by several rinses in glass distilled water. This was followed by an acid wash in 50% nitric acid (v/v). Finally, all equipment was rinsed several times with glass distilled water prior to drying.

B.4.3 In addition, to reduce contamination of soil samples from chemical reagents, only low metal content 'Anistar' grade chemicals were used in all determinations. Reagent blanks and duplicated samples were included in the digestion and extraction procedures (see section B.5.1) and subjected to all experimental procedures and conditions. Concentrations of the heavy metals within 'blanks' were subtracted from the final sample readings.

B.5 Procedures for the 'acid digestion' of soil samples

B.5.1 It has already been stated in Section 4.9, Chapter 4, of the main text that, to obtain a measure of 'total' lead, zinc, copper and cadmium in the soil samples, an acid soil digestion procedure, using concentrated nitric and perchloric acids was used. The decision to use an acid/wet digestion procedure was based on evidence from past studies.

B.5.2 There is, in estimating 'total' heavy metal concentrations a choice of dry ashing or acid/wet digestion procedures. Both procedures have their advantages and limitations which have been summarised by Manning and Kerber (1978). In the dry ashing technique, the soil sample is taken to a very high temperature to 'ash' the organic material in the sample, before dissolution with an acid. The advantages of this technique are that a minimum of acid is required and therefore the possibility of reagent contamination reduced. However, several investigators have opted for an acid/wet digestion procedure in preference to dry ashing (see for example Isaac & Kerber, 1971; Manning and Kerber, 1978). The limitations of dry ashing are that heavy metals may be lost through volatilization, in particular cadmium, due to the high temperatures used, whereas acid digestion takes place at a much lower temperature, 100-150°c compared to 500°c. In addition, acid dissolution of the ash may be difficult or not complete, due to the presence of pyrophosphates in the ashed sample. Other limitations are that dry ashing requires a much longer time to complete and involves the use of more complex equipment. In the wet digestion procedure, however, the equipment is not involved (see below B.5.4) and many samples can be handled at one time, reducing analysis time. The main limitation of wet digestion procedures is that there may be reagent contamination of the sample. However, this can be taken into account, (see section 3.4).

B.5.3 Due to the need in the present research study to use a simple, reliable, reproducable and easily managed procedure for the analysis of 360 soils for heavy metals, a wet/acid digestion procedure was adopted. Numerous wet digestion techniques, involving a wide range of reagents have been recommended for total heavy metal analysis (see for example, Rees & Hilton, 1978; Ritter et al, 1978; Thompson & Wagstaff, 1978). These include digestion using nitric and perchloric acids, nitric and sulphuric acids, nitric acid, nitric acid and hydrogen peroxide, 'aqua-regia' (nitric/hydrochloric 1:3v/v) and hydrochloric/hydroflouric acids, all with varying degrees of success. From the literature, it appears that the use of a mixture of nitric and perchloric acids is the favoured technique for routine soil heavy metal investigative work, and it ensures solution of both the organic and inorganic fractions of the metal.

B.5.4 Duplicated sub-samples of each ground soil, containing approximately 0.5g of soil were transferred to 'clean' 50ml digestion flasks, and 10ml of 'Aristar' grade concentrated nitric acid were added to each flask and the contents were thoroughly mixed. Digestion flasks were then positioned on an electric micro-distillation stand and left to stand for 24 hours. The digests were then gradually heated to approximately 50^{o}c for 2 - 3 hours. The temperature of the digests was then increased to boiling point and heating continued until organic matter digestion was complete. Flasks were removed from the heat and allowed to cool. After cooling, 2 ml of 'Aristar' (70%) perchloric acid were added to the residual mixture in each flask. The contents of the flasks were heated until perchloric acid fumes were emitted and the digest lightened. The remaining nitric acid was then boiled off leaving approximately 2 - 3 ml of solution. The residual solution was allowed to cool and then filtered through ashless filter paper (Whatman 41). The digest residue was washed with several aliquots of distilled water and the filtrate made up to a volume of 25 ml. Reagent blanks were prepared and run in exactly the same manner as samples,to take account of any heavy metals introduced into the samples through the glassware from the chemicals.

B.6 Extraction of heavy metals from soil samples

B.6.1 Many investigators have used 'extraction' solution to obtain a measure of the heavy metal in the soil which may be readily available to plants and potentially toxic to both plant health and human health (through the ingestion of metal contaminated food crops). There is broad agreement that the total metal content of a soil frequently will not provide the information required to assess the likely toxic effects of heavy metals in soil. What is required is information on whether the heavy metal in the soil is in a form which is usable or 'available' to plants. Scott et al (1968) has suggested that the 'total' content of heavy metals in a soil can provide no more than a general indication of contamination and is limited in assessing the importance of that element as far as crop health and human health are concerned.

B.6.2 The laboratory procedures to estimate the available quantity of metals in soils normally involve extracting the metal from the soil with various reagents, including water. Water extraction removes the ionic and molecular forms of trace metals present in the soil. Readily exchangeable metal ions from inorganic clay or organic material can be extracted by ion exchange using neutral salts, such as ammonium acetate, while more firmly bound ions in the exchange complexes are displaced by H^+ ions from dilute acetic acid (Berrow and Burridge, 1972). Thus, it is seen that a number of different extraction methods are used for determining available levels of heavy metals in soil. In addition to the range of extractants used, availability of metals in soils for plant uptake is also dependent upon soil properties including chemical form of the metal in the soil, fertility, pH, moisture status and cation exchange capacity, (see Williams, 1979). Ideally, an extractant for measure of 'availability' would be selected on its ability to extract or exchange the metal(s) of interest at levels comparable to that provided by natural processes of plant growth, which release the metal for uptake. This, however, is virtually impossible to simulate in the laboratory, and therefore several extraction solutions have been used as a measure of 'plant available' heavy metals in soils. The problem is also complicated by the fact that some extraction methods, involving, for example, complicated leaching and re-extraction with concentrated solvent solutions such as M.I.B.K., may not be the most convenient from an analytical point of view, nor indeed practical, in terms of being reproducable for many hundreds of samples.

B.6.3 Purves (1968) has suggested the following extraction solution as being useful for general advisory purposes.

i) 0.5.N acetic acid for Co, Zn, Ni and Pb.

ii) 0.02 M EDTA (Dianimonium salt) for Cu.

iii) Hot water for B.

In addition, a number of investigators have shown a good correlation between extractable soil metal, using various methods, and plant uptake (see for example Maclean et al, 1969; Kerin, 1975; John, 1972), which in many respects is the only appropriate way to obtain measures of 'plant availability'. John (1972) for example, has shown a significant correlation between the lead content of soil extracted with 1N nitric acid and the amount of lead in lettuce plants grown in the soil. Mira and Pandey (1978) evaluated four extractants which are used regularly for measures of 'plant available' metal extracted from soil. The amounts of lead extracted from the soil with the four extractants were correlated with the lead concentration in wheat crops grown on the soil. The results of this comparison showed that acid ammonium oxalate, closely followed by ammonium acetate, correlated significantly with heavy metal levels in wheat, whereas EDTA did not give a significant correlation. Although such an approach to deciding on the most suitable extractant to be used for 'available' metals is ideal, in practice this is almost impossible to achieve where there is a wide range of soil types, as is the case in this research study. In addition, different and similar plant species behave differently in a range of soil environments and because of the variations in the distribution of heavy metals in plants and uptake at different stages of growth, no one extractant is likely to be universally acceptable.

B.6.4 The above problems associated with the estimation of 'availability' of metals in soils has led several investigators to use only one particular method, being aware of the limitations and the confidence which can be placed in any results. For example, Scott et al (1968) recommends that for general investigative analysis, 0.5N acetic acid has proved reliable, a factor borne out by the work of Berrow and Burridge, 1977) in their analysis of sewage sludge amended soils. However, Dolar and Keeney (1971) found that the amount of copper extracted by various extractants was strongly influenced, among others, by soil pH and organic matter in the soil (a similar conclusion to Williams, 1979). They concluded that it might be preferable to use a neutral extractant such as normal ammonium acetate in place of an acid extractant. In the case of lead analysis, Roberts (1975) has reported that a major disadvantage in the use of 0.5N acetic acid for the extraction of 'available' lead is that the metal is extracted below the normal soil pH, and any results should be regarded as an estimate of 'maximum availability'.

B.6.5 A number of workers have reported 'acceptable' results from the use of chelating agents for organically complexed metals (see for example Jones and Clements, 1972; Thornton, 1979). However, Jones and Clements (1972) have pointed out that in the case of lead, a chelating agent such as EDTA extracts a considerable proportion of 'total' lead and it is unlikely that all of it, in the short term, would be available for plant uptake.

B.6.6 The ICRCL. in their guidance on analytical techniques, which is limited at present, have suggested that it might be preferable to adopt the analytical procedures set out in the Toys and Graphics Safety Regulations (1974) for a measure of available lead in soil, particularly where children, who may voluntarily ingest soil, are concerned. The 'safety' regulations specify the use of an acid extractant which would simulate the behaviour of soil in the gut. Other guidance on the choice of suitable extractants for measures of 'available' heavy metals in soil comes from the Ministry of Agriculture Fisheries and Food's Agricultural Development and Advisory Service (ADAS). Their involvement stems from the practice of spreading heavy metal rich sewage sludge as a fertilizer on arable and pasture land. For many years, ADAS has offered advice and an analytical service for heavy metals in sludge amended soils and have obviously been concerned with the amount of metals in sludges and soils which may be 'available' to plants and crops and thus have phytotoxic effects. For many years, ADAS used acetic acid in the routine analysis of available lead, cadmium, zinc and nickel and 0.5M EDTA for available copper. Recently it was decided to switch to 0.5M EDTA for all routine analysis of available lead, cadmium, copper, zinc and nickel. A comparison between EDTA and acetic acid methods (reported by Williams) found that EDTA extracted slightly more zinc and similar amounts of nickel and cadmium as acetic acid. In the case of lead, EDTA extracted 10 times more lead than did acetic acid. Williams (1980) suggested that in the case of cadmium and lead in sludge amended soils, it might be preferable to use the results from the analyses of total content, due to the unpredictability of plant uptake from soil measurements of both EDTA and acetic acid extractable lead and cadmium.

B.6.7 To summarise, the major extractants used in past studies have been weak acids, chelating agents and neutral salts. The use of weak acids, (i.e. 0.1N Hcl, 0.05M acetic acid) have been used mainly for the determination of the exchangeable form of the metal, i.e. that which is immediately insoluble, but capable of being brought into solution. Such extractants have been shown to easily dissolve exchangeable metals in soil, but also dissolve some metals which have moved into forms beyond exchangeable. Therefore, the estimates of 'exchangeable' metal in soils are likely to be higher than the crops or plants can actually absorb. Chelating agents, such as the Diammonium salt of EDTA, at varying concentrations have also been used for measuring the levels of available metal in soils. It removes all of the organically complexed forms and has provided a more satisfactory diagnostic correlation with plant uptake than dilute acids. However, there is some concern as to the actual amounts extracted, since it is known to extract heavy metals at levels which are not likely to be 'readily available' to plants. Neutral extractants such as ammonium acetate have also been used. The problem with neutral extractants is that for certain elements (i.e. lead and copper) they only extract small amounts and therefore may be an underestimate of the metals in soils which may be 'available' to plants.

From the above detailed discussion, it has been difficult to decide on the most appropriate method for the analysis of available metals, in the WMMC soil samples. In the absence of detailed experiments on plant/soil metal level correlations, using various extract solutions, it was decided that an analytically convenient extraction method would be used which has also been shown to provide a reasonable estimate of'available' heavy metals in soils. The extraction solution used in the study was therefore a solution of 1m ammonium acetate - 0.01m EDTA at pH 6.5; the detailed method of extraction being discussed below.

B.6.8 Extraction of heavy metals from soil samples. 5g duplicated sub-samples of each ground soil were transferred to clean 125 ml Enlenmeyer Flasks and 25 ml of the extractant was added to each flask. The pH of the solution was adjusted to pH 6.5, if necessary, by the addition of a few drops of sodium hydroxide or concentrated hydrochloric acid. The flasks were then shaken for one hour at 250 r.p.m. in a orbit shaker. After shaking, the flasks were removed and the solution filtered through ashless filter paper into clean, 'uncontaminated' and labelled sample tubes. As with the procedure for acid digestion, reagent blanks were run at the same time and any readings obtained deducted from final sample results.

B.7 Measurement by Atomic Absorption Spectro-Photometry

B.7.1 The concentrations of lead, zinc, copper and cadmium in both extracts and digests were measured on a Perkin Elmer 560 double beam instrument. Conventional flame absorption was employed, using a single slot burner head and air-acetylene flame. In the case of cadmium, where soil samples were at the normal flame detection limits, a heated graphite analyser was used. Deuterium arc background correction was used where necessary.

B.7.2 The concentration of heavy metals in the sample solution were obtained from a calibration graph using commercially prepared (B.D.H. Chemicals) stock standard solutions of lead, zinc, copper and cadmium. Suitable dilutions of the stock standards were freshly prepared on each day of analysis by dilution with 10% acid solution made up with glass distilled water.

B.7.3 Individual hollow cathode lamps were used as radiation sources for each of the metals determined. Cadmium was measured using the 228.8 nM wavelength; copper using 324.8 nM wavelength; lead the 283.3 nM wavelength and zinc the 213.9 nM wavelength all with a 0.7 slit setting. Hollow cathode lamp alignment, burner angle, gas flow and nebulizer (sample aspiration rate) were adjusted to achieve maximum sensitivity of the machine using duplicated standards.

B.7.4 The performance and calibration of the machine was checked by frequent atomisation of standards during each analysis run. This was to ensure wavelength drift or lamp/burner misalignment did not occur. Results obtained from a calibration graph of absorbance readings using suitably diluted standards were corrected for sample dilution.

APPENDIX C

AN INVESTIGATION OF THE VARIATION OF SOIL METAL LEVELS OF SUB-SAMPLES

C.1 Introduction

C.1.1 This appendix provides detailed technical information of an investigation into the variability of soil heavy metal levels in soil sub-samples that are taken and bulked to give individual samples used in this survey of background levels of heavy metals in soil. The data is taken from a study conducted by JURUE in 1980 (see JURUE, 1982), as a parallel study to the work reported in this thesis. The study was undertaken in the Borough of Walsall, which is a traditionally industrialised part of the West Midlands Metropolitan County (see figure 4.1 of Chapter 4), and was conducted on a grid by grid (1 sq.km.) basis across the whole of the Borough.

C.1.2 The field sampling technique, soil sample collection, use of composite samples and analytical techniques were identical to the procedures developed and carried out in this research. The study in Walsall gave the opportunity to investigate in more detail, pilot study results in the WMMC (see Chapter 4, section 4.8.2) which confirmed the need for sub-sample soil collection at sampling points. In the study for Walsall, the variability of copper and lead levels between individual sub-samples and a composite sample, formed from bulking the sub-samples, were compared.

C.2 Sub-sample collection

C.2.1 The investigation of sub-sample variability was made on soil samples collected at four sites in the survey of Walsall; these were W12/2, W81/1, W90/3 and W99/1. * The sample sites were selected to include a cross section of land use types, and covered the range of metal contamination levels from high to low.

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* These are soil sample codes and for further details of the study, see JURUE (1982).

C.2.2 The procedure was for the sub-samples to be collected and stored individually (marked A-J) rather than being bulked on site, as with other main survey samples. Back at the laboratory, a bulked sample for each of the four 'trial sites' was made up from half the soil in the sub-samples; these bulked samples were then forwarded for analysis in an identical manner to the remainder of the bulked samples of the main survey. The remaining half of the individual sub-samples were prepared and analysed separately. The measurements of copper and lead were determined on a 'plant-available' extraction, using identical laboratory procedures to that in this research.

C.3 Results

C.3.1 Table C.1 shows the results of this analysis expressed in terms of the 10 sub-sample metal measurements. The mean and standard deviation of these 10 measurements was also calculated, and compared to the mean for the site in question, as obtained through the analysis of the relevant bulked samples.

C.3.2 Two points are evident from the data in table C.1. One is that the variation in metal levels in the sub-samples is high; in half the cases, the standard deviation is higher than the sample mean. Site W81/1, the commercial site, is the most variable, with sub-sample metal levels varying from 4 to 567 mg/kg lead and from 11 to 1123 mg/kg copper. The site showing least sub-sample variability is the rural site, W99/1, which also has the lowest level of contamination. This is consistent with expectations for soil where the metal present is natural in origin, and therefore broadly homogeneously spatially distributed. The other sites show evidence of elevated levels as a result of pollution of some kind, and indicate how unsatisfactory and unreliable it is to assess soil contamination problems in these areas on the basis of a single spot sample of soil.

TABLE C.1

VARIATION IN SOIL METAL LEVELS OF SUB-SAMPLES

Sub-sample and Statistics	SITE DATA (mg/kg)							
	W12/2 (Industrial)		W81/1 (Commercial)		W90/3 (Residential)		W99/1 (Rural)	
	Pb	Cu	Pb	Cu	Pb	Cu	Pb	Cu
A	152	106	12	21	105	247	33	10
B	154	109	224	422	100	93	114	9
C	120	84	567	1123	85	118	28	12
D	148	101	402	847	72	58	23	10
E	190	97	109	218	124	454	25	12
F	153	107	43	62	79	155	23	11
G	131	90	8	13	93	62	25	11
H	194	144	184	398	73	39	28	10
I	203	145	4	11	44	27	29	12
J	176	128	21	41	73	71	31	12
$\bar{x}$	162	111	158	316	85	132	36	11
σ	28	21	193	390	22	130	27.5	1.1
Bulk mean	161	113	159	243	84	122	36	16
Diff. from $\bar{x}$	1	2	1	73	1	10	0	5
't'statistic	0.08	0.11	0.01	0.43	0.10	0.55	0	10.2

C.3.3 The second point to emerge from Table C.1 is that the mean soil metal levels derived from 10 individual sub-samples, are not significantly different to the levels derived by the analysis of independent bulked samples. Only one example of a statistically significant difference between the sub-sample mean and the bulked mean was found, and that was on the rural site where the levels of metal present are sufficiently low to reveal other probably analytical sources of systematic error, such as atomic absorption machine set up bias. Generally these analytical errors are too low to be detectable on the majority of the soil metal results reported in the study.

C.3.4 This investigation has clearly demonstrated the very considerable variability that exists between the soil metal levels of sub-samples despite the fact that all sub-samples were collected from within a 30 m radius of the central sample location. This conclusion strengthens the arguments in favour of the bulking of sub-samples, prior to analysis, in order that a much higher area is covered by each sample and the final sample data are representative of conditions at the site in question.

APPENDIX D

SUMMARY DATA ON THE VARIATION OF SOIL HEAVY METAL CONTENT WITH DEPTH

D.1 Introduction

D.1.1 This appendix provides summary data in the form of tables illustrating the variation of soil heavy metal levels with depth in the soil profile. The data is taken from a wide variety of studies which have investigated the distribution of a range of heavy metals in soil profiles. The majority of the studies have concentrated on the contamination of soil from point source emissions, such as non-ferrous metal smelters. Nevertheless, the results are relevant to the survey of background levels of heavy metals in the WMMC, because in both circumstances the heavy metal enters the soil from deposition on the soil surface layer.

D.1.2 Section 4.8.4 of the main text referred to the fact that in the study, soil sampling was restricted to surface soils because the pollution of soils by heavy metals was considered to be denominantly a surface contribution, and it will be surface soil horizons which will bear the clearest indication of contamination. The data presented below in summary tables, confirms this observation and strengthens the argument in favour of the taking and analysing of surface soils to represent background levels of heavy metal contamination.

D.2 Summary data

D.2.1 Soil profile data are available from a range of studies showing the variation in the levels of heavy metals in the soil profile. It is known that soil organic matter acts as a sink for heavy metals, and the data below substantiates the fact that heavy metals accumulate in the top layers (Ao Horizon) of soil.

D.2.2 Soil samples from five depths were taken from a range of soils in the urban area of Wollongong City (see table D.1). The soil is contaminated mainly from industrial emissions, in particular, secondary non-ferrous metal smelting. The data illustrates that below 5 cm, levels of heavy metals are significantly reduced.

Table D.1.

Distribution of Lead, Zinc, Copper and Cadmium in Contaminated Soils of Wollongong City Area, Australia

Depth (cm)	Acidic Acid extract ug g^{-1} Pb	Zn	Cd	EDTA Extract ug g^{-1} Cu
0 - 5	17.0	102.5	1.0	488.3
5 - 15	1.6	39.4	0.3	51.3
15 - 30	0.7	15.2	0.1	26.2
30 - 45	0.6	2.1	0.1	12.2
45 - 60	0.4	1.0	0.1	8.7

Source: Adapted from Beavington (1975).

D.2.3 The data in tables D.2 and D.3 are summary data from two detailed studies of pollution around Avonmouth near Bristol. The Avonmouth industrial complex contains Europe's largest non-ferrous smelting complex and both soil and herbage samples from a variety of locations have been sampled and analysed for their heavy metal content. The data clearly illustrates the accumulation of heavy metals in surface layers, particularly zinc and cadmium.

Table D.2.

Distribution of Lead, Zinc and Cadmium in Contaminated Soils from Avonmouth, Severnside

	METAL		
Depth (cm)	Pb *	Zn *	Cd *
0 - 3	126	1,000	6.5
3 - 6	27	720	0.4
6 - 9	10	280	1.5
9 - 12	1	175	1.2
12 - 15	10	250	1.6

Source: Adapted from Little and Martin (1971)

* acetic acid extract ug g^{-1} (oven/dry soil) using 2.5% acetic acid.

Table D3.

Distribution of Lead, Zinc, Copper and Cadmium in Contaminated Soils from the Bristol area. (µg g^{-1} dry soil)

		METAL						
		Total				Available		
	Depth (mm)	Pb	Zn	Cu	Cd	Zn	Cn	Cd
A	0 - 75	163	816	23	8.6	117	9	2.9
	75 - 100	102	408	20	3.7	29	8	1.0
B	0 - 75	75	258	17	2.0	18	5	0.6
	75 - 100	75	163	15	0.7	4	3	0.2

Source: Adapted from Griffiths and Wadsworth (1977)

A = 3 km in direction of prevailing wind
B = 7 km in direction of prevailing wind
total = soil digested with HNo3 and Hclo4
available = Zn and Cd 0.5m acetic acid and Cu with ammonium E.D.T.A.

D.2.4 Most*1 of the sewage sludge produced inland in the U.K. is disposed of to agricultural land usually after treatment. It contains useful amounts of plant nutrients, particularly nitrogen and phospherous; it can also have a beneficial effect on soils by increasing their organic matter contents. However, many sludges contain heavy metals and in some sludges, particularly from industrial areas, the levels may be very high. Once applied to the soil, metals are slow to be leached and if the metal rich sludge is applied at heavy rates, or applied frequently over a long period of time, metal levels may reach a point at which they are phytotoxic to plant health. *2. Several studies have investigated the metal content of agricultural soil dosed with sewage sludge, and the data in table D.4 summarises data from a three year study of soils from fields sampled throughout England and Wales which had received sewage sludge (Richardson, 1980). The data is average levels in soils taken from fields with a long

*1 The exception is the West Midlands where the very high metal content prevents its use in agriculture and therefore over 60% is incinerated (see JURUE 1982)

*2 Due to plant and animal health problems from sewage sludge disposal to agricultural land, there are codes of practice governing the application of sludge to land and chapter 3 contains details of this.

history of sewage sludge application, which also serves to illustrate the fact that at depth in the soil profile, metal levels are significantly reduced.

Table D4

Variation in Metal Levels with Depth of Sampling

Depth (cm)	Pb	Zn	Cu	Ni	Cd
0 - 7.5	183	329	174	76	1.1
7.5- 15	161	260	121	54	0.9
15 - 30	113	220	76	43	0.6

Source: Adapted from Richardson (1980).

D.2.5 The data in table D.5 is summary data of the results of a study of heavy metal levels in roadside soils in the U.S.A. Soil samples were collected at 8m distance from roads in Maryland, U.S.A. and analysed for a range of heavy metals, including lead, zinc, nickel and cadmium. The range of levels is accounted for by the variation in traffic flow which ranged from 7,000 cars per 24 hours, to 48,000 cars per 24 hours.

Table D5

Distribution of Lead, Zinc, Nickel and Cadmium in Roadside Soils of U.S.A.

Depth (cm)	Pb	Zn	Ni	Cd
0 - 5	242-522	54-172	4.7	0.9 - 1.5
5 - 10	112-460	24- 94	1.0	0.6 - 0.8
10 - 15	95-416	16- 72	0.8	0.48- 0.54

Source: Adapted from Lagerwerff and Sprecht (1970).

D.3. Summary

The data in the above tables demonstrate that in soils contaminated with heavy metals from a variety of sources, the concentration of metal is frequently elevated in the surface layers. In many cases there is marked accumulation of metals in the 0 - 5 cm layer, which corresponds to the rooting zone of plants. The high accumulation occurs in the top few cm.

mainly because of the deposition of metals onto the soil surface, and the deposition of plant residues. The summary data also illustrates the fact that in contaminated soils, the concentration of heavy metals at depths below 20 cm. closely approach the reported 'normal' (unpolluted) levels in soil, (See chapter 3 and section 5.4 of chapter 5).

APPENDIX E

SUMMARY DATA ON STATISTICAL TESTING OF SOIL SAMPLE RESULTS

E.1 Introduction

E.1.1 This appendix sets out in brief issues related to the statistical testing and validation of the sampling method. It also contains summary data on the statistical testing of the grouping of area-type mean data used to produce the background soil contamination maps and reference levels.

E.1.2 Statistical tests may be divided into two families:

i) 'classical' or 'parametric' tests such as the 't' and 'F' test, which have dominated statistical theory and practice, and

ii) 'distribution free' or 'non-parametric' tests such as the Chi square or Mann Whitney U test, which have recently become important.

E.1.3 It was stated in section 5.5 of chapter 5, that the statistical testing of area-type mean data was to use the 't' test, the most powerful test available, and the analysis of variance 'F' test as a test of the central hypothesis. Although such tests are the most powerful, they make certain assumptions about the background population from which the samples are drawn. The most important assumption is that the background population of the sample is approximately normally distributed and the smaller the sample being tested,the more nearly normal must the background population be for the parametric tests to be valid. Therefore, as stated in the main test in chapter 5, before any parametric statistical tests were applied to the data, it was necessary to check the sample data for normality.

E.2 Checks for normality

E.2.1 It has been pointed out above that the 't' and 'F' test are only valid if the background population of the samples are approximately normally distributed. There are four checks which can be used to determine whether this is the case, and these are:

i) common sense and some knowledge of the factors affecting the variable in question - are the data of the kind one might expect to cluster symmetrically about a mean.

ii) use of probability paper - if the sample data are plotted cumulatively on probability paper, they will yield a straight line.

iii) if the median is less than the mean, then this indicates that the distributions are not normal.

iv) if the data is normally distributed, then the variance will be independent of the mean.

E.2.2 The soil sample data was checked for normality using the above criteria. In the case of common sense and knowledge of the data, it may be stated that whenever there are two groups of factors affecting a variable, one dominant group acting consistently, and another acting randomly, then there are a priori grounds for expecting that a frequency distribution of values will, in the long run, approximate to a normal distribution; i.e. cluster symmetrically about the mean. The roundness of pebbles on a beach, temperature and other weather data, pedestrian and traffic densities for particular places at particular times, are just a few variables that show a tendency towards a normal distribution.

E.2.3 Levels of soil contamination by heavy metals in urban areas are known to be affected by a number of groups of factors, including multi sources, local climate, soil pH and parent rock type. From present knowledge it is assumed that no one group of factors is dominant, and therefore it is unlikely that soil heavy metal data will approximate to a normal distribution. This is confirmed by the data presented in figures E.1 - E.3, which are frequency distributions for total and available lead and total cadmium levels in the 360 soil samples. The figures clearly demonstrate that the distribution is not symmetrical about a mean, but is in fact positively skewed, with the majority of results concentrated around medium to low heavy metal levels and a 'tail' of very high levels. The data presented in figures 5.1 to 5.6 of chapter 5 also serves to confirm

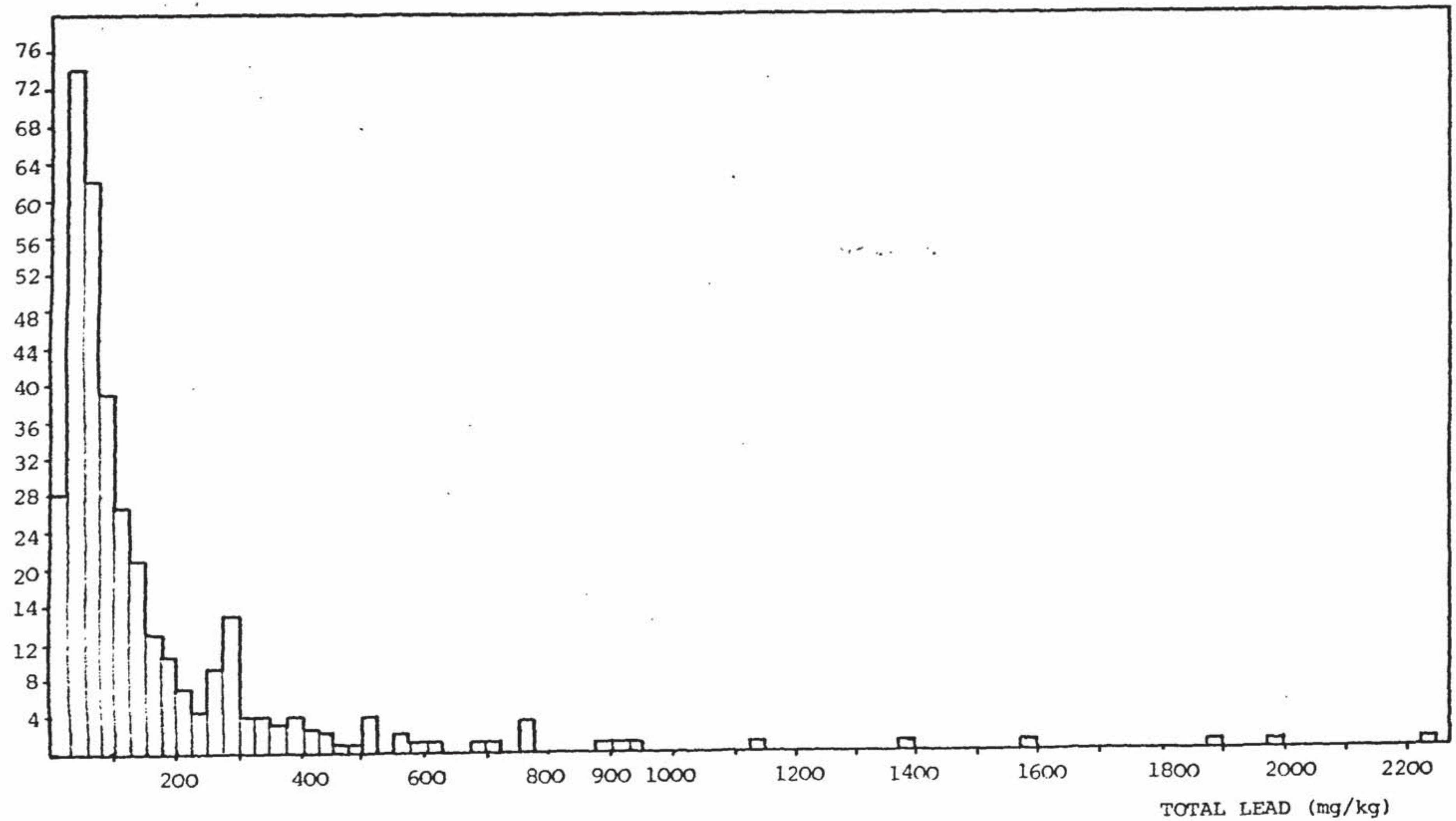

Fig. E.1 Distribution of Measured Levels of Total Lead in the WMMC Soil Samples.

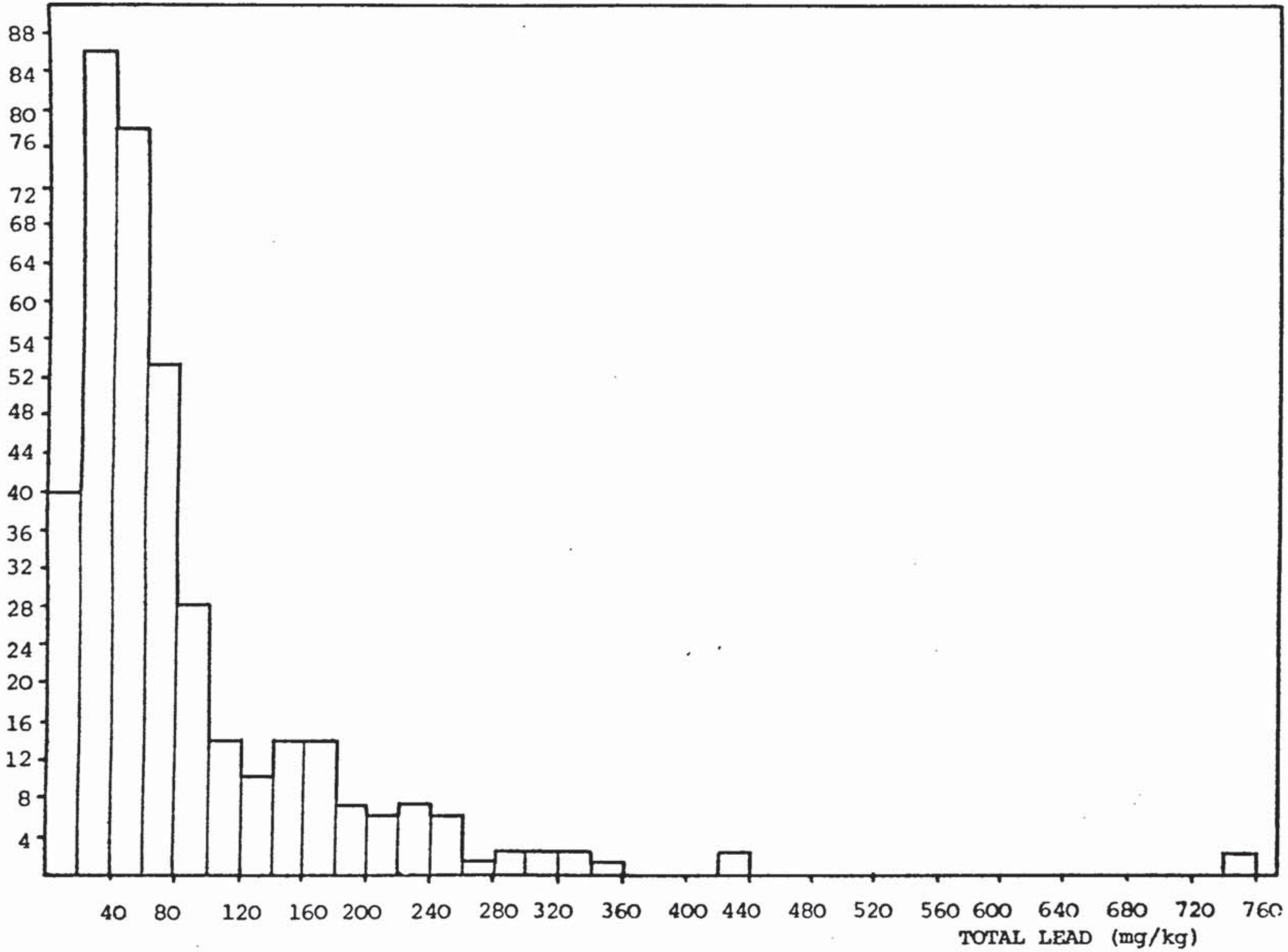

Fig. E.2 Distribution of Available Levels of Lead in the WMMC Soil Samples.

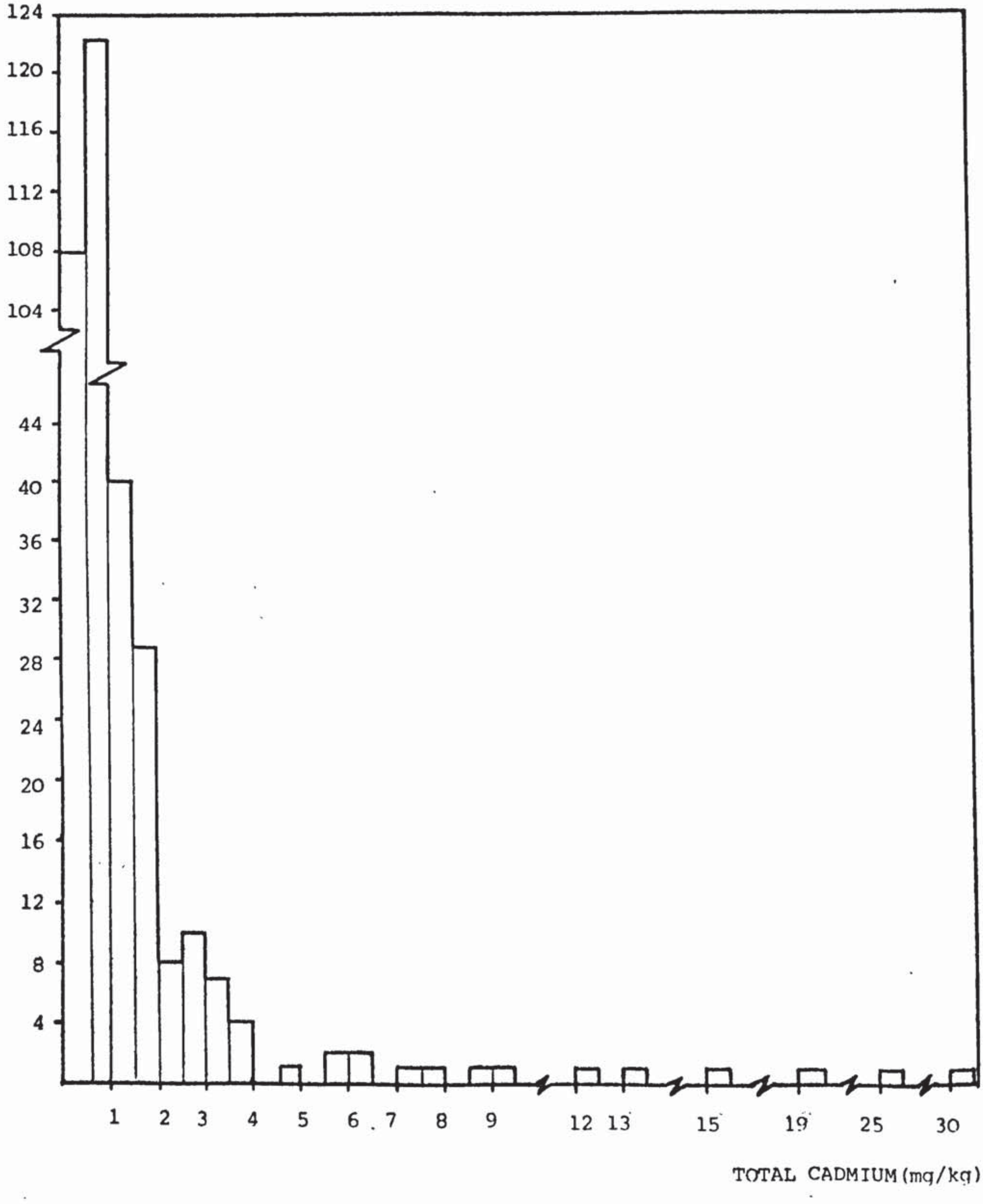

Fig. E.3 Distribution of Measured Levels of Total Cadmium in the WMMC.

that the soil heavy metal data is positively skewed for all four metals.

E.2.4 In view of the obvious skewness in the frequency distribution, it was concluded that it would not be necessary to carry out any further checks on the data.

E.3 Transformation of Skewed Distributions

E.3.1 If samples are not normally distributed, as is the case with this data, it is impossible to transform the data so that they are more nearly normal and therefore amenable to parametric tests. There are a number of mathematical transformations that can be used to 'normalise' data, and a useful summary is found in Elliott (1972), and Yeomans (1977). Examples of transformations include replacing x by $\sqrt{x}$, or x by log (x+A) or x by log x. The most widely used transformation for positively skewed distributions is that in which the numbers are replaced by their logarithms.

E.3.2 By substituting the logarithms for the numbers in the soil heavy metal data, it is possible to transform the skewed distribution into one which is approximately normal and therefore satisfies the requirements of parametric tests. Of course, since in this research a number of sets of data are being compared, all the data must be transformed in exactly the same way. Provided this is done, the results of any hypothesis test carried out on the transformed data holds good for the original values.

E.3.3 In view of the fact that all four heavy metal results had skewed distributions, it was necessary to transform all individual sample point results into logarithms. After transformation, a further set of checks were made as to the adequacy of the logged data, to represent a normal distribution. These checks are shown in figures E.4 - E.6. Figure E.4. is a plot of the variance and mean for the 40 grid square total lead sample results, and demonstrates that the variance is independent of the mean, from which it is concluded that the data now approximates a normal

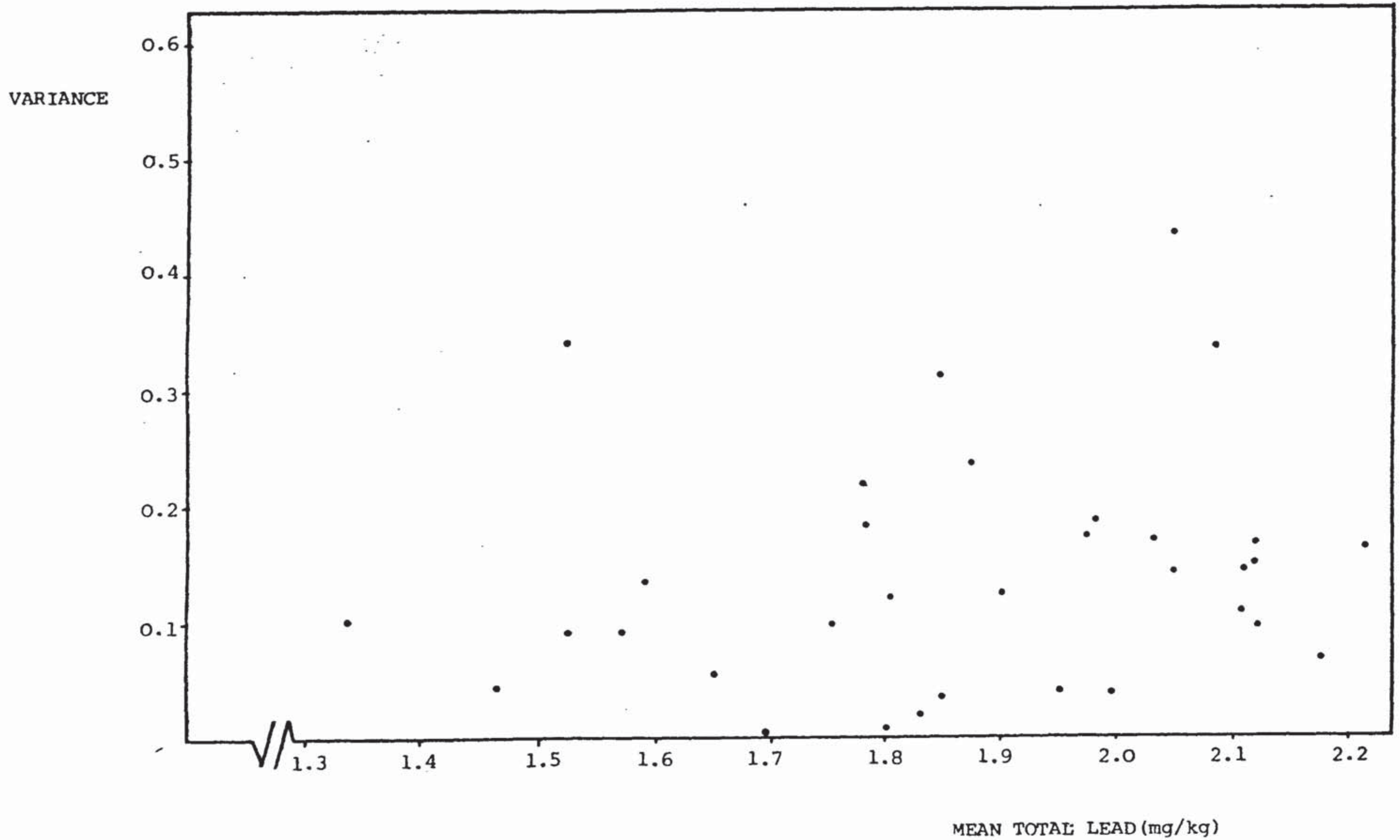

Fig. E.4 Plot of the Variance and Mean of Logged Total Lead Levls.

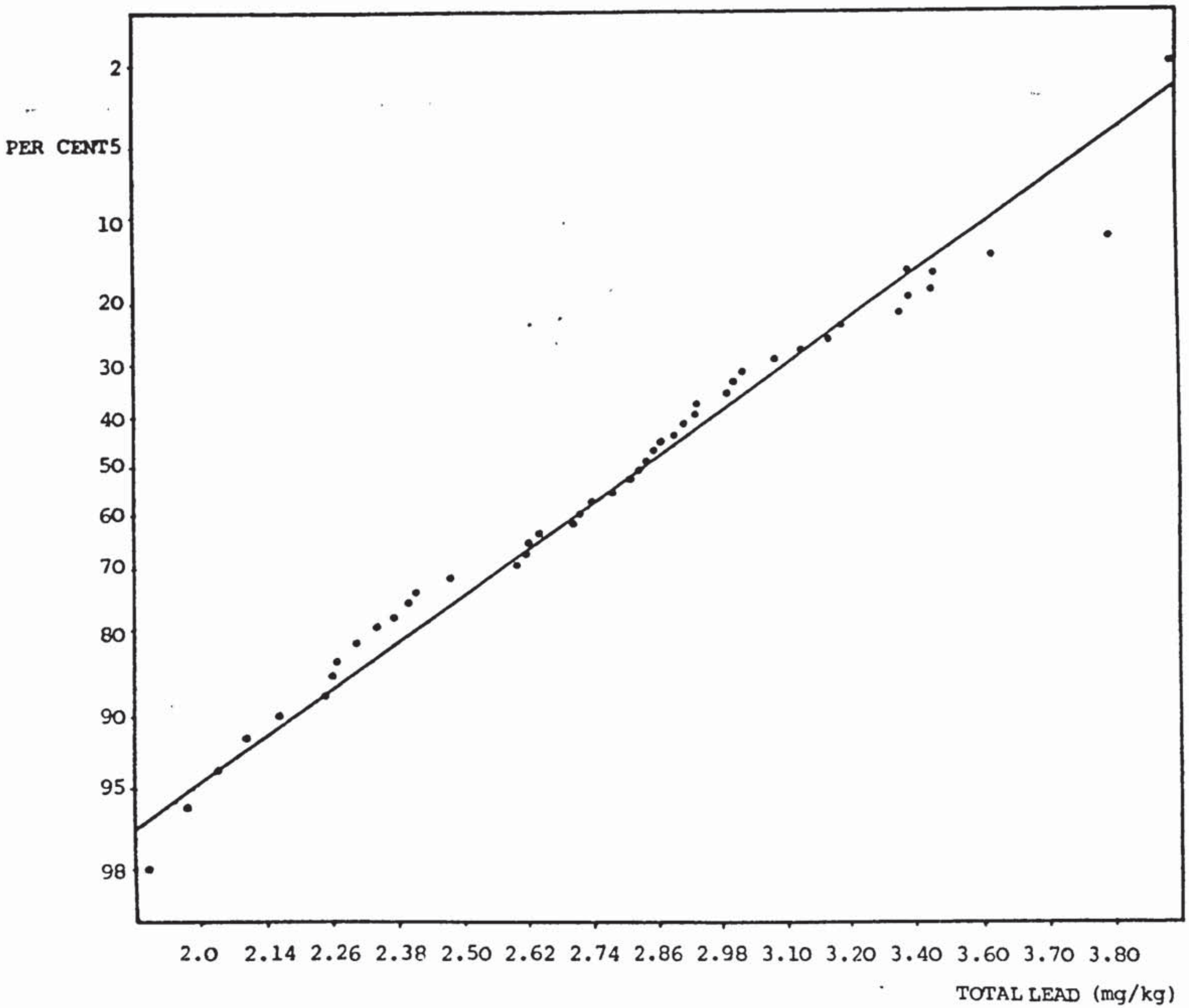

Fig. E.5 Mean Measured Total Lead Levels in the WMMC Plotted on Probability Paper.

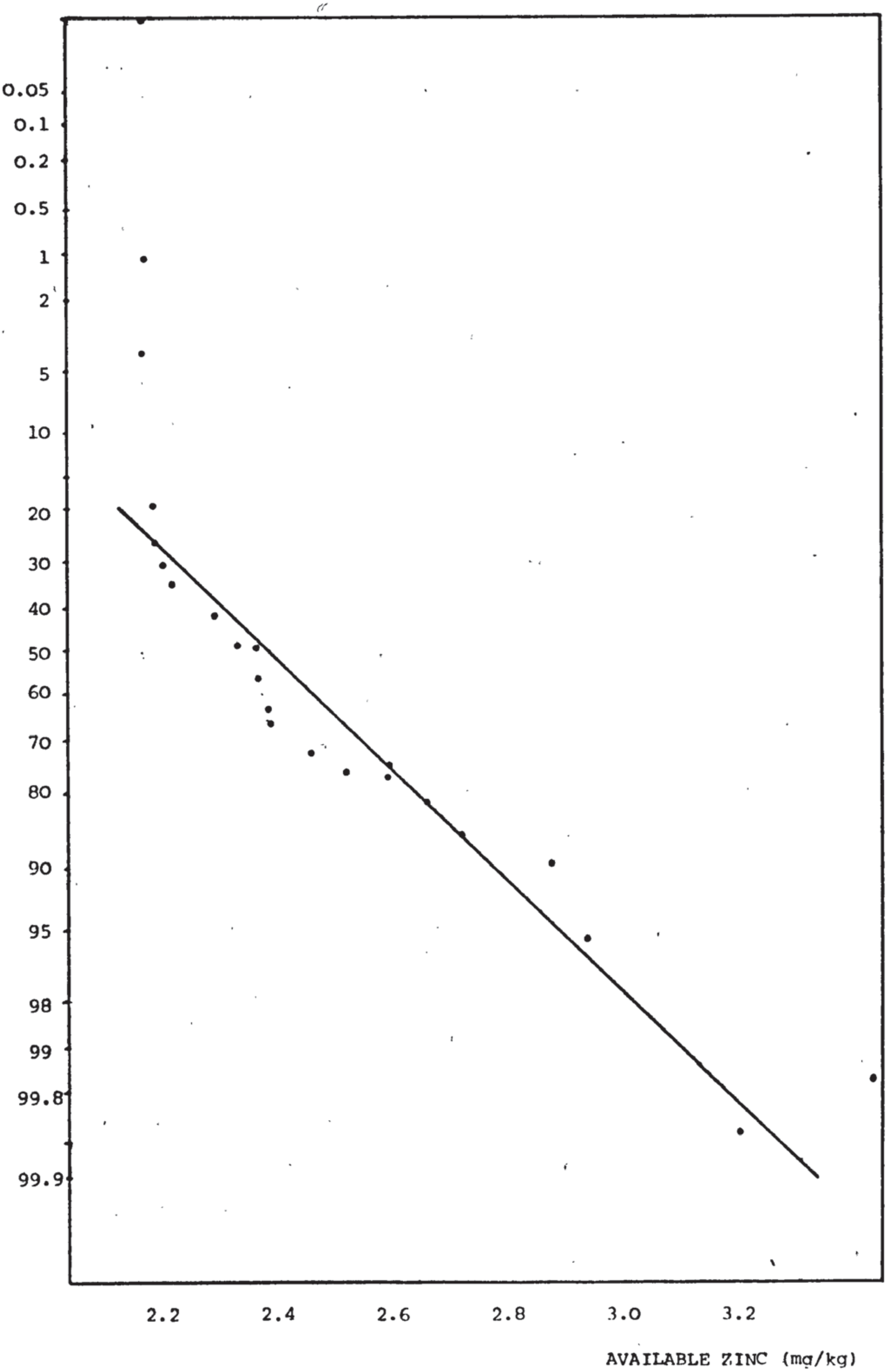

Fig.E.6 Mean Measured Available Zinc Levels in the WMMC Plotted on Probability Paper.

distribution. Figures E.5 and E.6 are plots on probability paper of the cumulative frequency distribution of log data for total lead and available zinc results. From figures E.5 and E.6, it can be seen that both plots yield a straight and are therefore taken to be near normally distributed.

E.4 Further observations on the 't' test

E.4.1 As stated in section 5.6.4 of chapter 5, the 't' test was used to determine whether the two grid squares, selected at random as being representative samples of individual area-types, are in fact two samples drawn from the same parent population. The validity of the 't' test, as well as requiring the background population of the samples to be approximately normally distributed, also rests on the assumption that the standard deviation of the background population of the two samples are equal. Therefore, before carrying out the 't' test, it was necessary to determine that the best estimates of the population standard deviation derived from the two samples taken independently, are not so different as to render the above assumption unacceptable. This can be checked by applying the variance ratio test (variance is the square of the standard deviation) as follows:

i) calculate the best estimate of the population variance from each sample.

ii) calculate the variance ratio (F) from:

$$F = \frac{\text{greater estimate of the population variance}}{\text{lesser estimate of the population variance}}$$

E.4.2 If the variance ratio is calculated to be less than the relevant critical 'F' value for the appropriate degrees of freedom, then the difference between the best estimates of the population variance (and therefore standar deviation) based on the two samples, is not so great as to be incompatible with the assumption that the standard deviation of the two populations are equal. The 't' test can then be carried out. If, on the other hand, the variance ratio is found to be greater than the critical value, then the necessary assumption of a common population standard deviation must be regarded as inconsistent with the data, and the 't' test may not be used.

E.4.3 The variance ratio test was performed on the data and table E.1 summarises the calculated 'F' values for the 20 area-types, for all four heavy metals. The table also indicates where the calculated value of 'F' is greater than the critical value of 'F'. It is evident from the data in table E.1, that in the case of all four heavy metals, there are a number of area-types where a common population variance cannot be assumed, on which the validity of the 't' test lies. The area-types where this is the case, cover the range of land-uses, although area-types B3, B4 and E3 are notable anomalies, in that all four heavy metals produced a significant result. This result tends to suggest that the variability of heavy metals in these area-types is more highly spatially variable, to the extent that there is a source or sources other than land-use and road network density influencing soil heavy metal levels. One suggestion could be that in these area-types, local geology may be more dominant in influencing the spatial variability of heavy metal levels.

E.4.4 Although it has been stated earlier that the validity of the 't' test rests on the assumption that the standard deviations of the background populations of the two samples are equal, it is possible to perform a 't' test on the grid square means using the formula set out below, which has almost the same power as the conventional 't' test formula (see Yeomans,1978)

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\dfrac{s_1^2}{n1} + \dfrac{s_2^2}{n2}}$$

The critical value of 't' being obtained from a revised degree of freedom, which is calculated from:

TABLE E1

VARIANCE RATIO TEST SCHNEDECOR 'F'

Area Type	Lead		Zinc		Copper		Cadmium	
	Total	Av.	Total	Av.	Total	Av.	Total	Av.
A1	4.026	2.022	1.41	2.34	1.03	1.71	3.01	1.33
A2	3.071	3.470	3.04	1.68	4.75	1.10	1.25	3.12
A3	1.871	1.310	2.55	1.05	2.97	2.76	2.06	1.21
B1	2.154	2.230	29.22	7.70	57.3	1.85	2.00	1.85
B2	1.116	1.210	1.09	2.46	1.36	2.26	1.03	1.04
B3	9.360	5.32	3.09	2.41	10.50	6.07	6.10	3.82
B4	12.36	22.73	22	8.7	19.80	83.66	1.44	2.75
C1	2.15	2.66	1.04	1.03	3.68	6.35	1.85	4.35
C2	1.13	1.25	4.23	4.85	1.57	7.24	5.00	12.18
C3	6.03	10.96	1.16	0.43	1.90	1.97	1.48	4.76
C4	4.08	2.25	4.22	3.74	3.20	2.91	2.55	1.39
D1	1.34	1.31	1.04	2.16	4.54	1.01	1.25	3.27
D2	3.64	1.15	1.08	1.43	1.50	2.00	1.70	7.16
D3	1.29	2.51	4.00	2.16	3.33	13.00	3.88	4.73
D4	1.11	1.23	2.72	3.30	10.07	2.88	4.38	2.69
E1	4.47	7.0	2.31	2.00	3.33	2.94	2.09	3.30
E2	1.88	11.92	11.92	4.14	1.12	3.94	1.35	4.64
E3	34.77	2.58	3.77	2.03	7.8	4.00	7.66	3.69
E4	1.48	13.31	1.90	7.33	1.30	1.68	1.04	1.44
E5	2.81	4.64	1.18	1.46	1.13	1.84	3.22	1.36

<u>9.36</u> = Where calculated value of F is greater than the critical value

$$\text{degrees of freedom} = \frac{\left(\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}\right)^2}{\left(\dfrac{\dfrac{s_1^2}{n_1}}{n_1+1} \quad \dfrac{\dfrac{s_2^2}{n_2}}{n_2+1}\right)^2} - 2$$

In essence, this re-formulation of the 't' test and appropriate degrees of freedom make it more difficult to reject the null-hypothesis tested using the 't' test.

E.4.5 Table E.2 summarises the recalculated 't' values where the variance ratio test produced a significant result. It also indicates where there are highly significant differences, between the means of the two samples (grid squares) taken as being representative samples of the same background population. From the data in table E.2 it can be seen that copper and lead are the most prominent metals where there are significant differences between the means of grid squares. The significant differences are also most prevalent in the highly mixed land-use area-types of B3, C4 and E3, also indicating that a classification based entirely on land-use and intensity of use does not appear to account for all the variance in the data.

E.5 Misallocation of grouped data

E.5.1 The background soil contamination maps presented and discussed in chapter 5 section 5 . 8, and the 'reference levels' presented in chapter 6, are based on the 'natural grouping' of area-type mean data to produce five categories of land contamination. It is stated in section 5.7.13 of the main text that the grouping performed on the heavy metal data may be susceptible to 'grouping error' and a statistical test, the Fishers 'Z' score, was used to estimate the percentage probability of misallocating an area-type to one of the five land contamination categories.

E.5.2 The data presented in tables E.3 - E.6 shows for each area-type, the percentage chance of misallocating on area-type two categories, above or

TABLE E.2

RECALCULATED STUDENT (t) VALUES USING FORMULA SET OUT IN SECTION 3.4.1

AREA TYPE	Lead		Zinc		Copper		Cadmium	
	Tot.	Av.	Tot.	Av.	Tot.	Av.	Tot.	Av.
A2					1.53			
B1			0.04	15.97**	2.49*			
B3	0.64	0.21			1.98	1.79	2.08	
B4	0.38	0.51	2.09	1.85	4.24**	4.39**		
C1						10.01**		
C2						8.04**	4.02**	3.09**
C3	1.48	0.74						4.52**
D1					1.03			
D2								1.89
D3						5.04**		5.63**
D4					3.09**		0.98	
E1	1.34	1.15						
E2		1.38	2.41*					
E3	3.82**	5.41**			6.03**		1.47	
E4				5.77**				
E5		6.61**						

* Significant differences between means of the two samples (grid squares) but not highly significant.

** Highly significant differences between means of the two samples (grid squares) for each area type.

TABLE E.3

TOTAL LEAD

Percentage Chance of Error of Misallocation of 'Area Types' to a Category

	-2 Categories	-1 Categories	+1 Categories	+2 Categories
A1	0	4.5	3.0	-
A2	3.6	42	4.5	-
A3	2.3	27	-	-
B1	11	27	42	16
B2	0.0	5.5	-	-
B3	2	16	31	2
B4	-	-	42	6.7
C1	5	38	8	0.1
C2	0.3	13	16	-
C3	-	-	34	3.6
C4	-	21%	21%	0.3
D1	7	38	11	0.3
D2	-	34	18	0.5
D3	-	24	24	4.5
D4	4	34	11	0
E1	6.7	42	-	-
E2	-	-	16	2.9
E3	4	27	21	0.8
E4	-	38	27	3.6
E5	-	-	0.0	0.0
Average	3.8	27%	21.5%	2.9%

- not determined

3-4% chance of being 2 groups out.

25% chance of being 1 group out.

20% chance should be in a higher group.

TABLE E4

TOTAL CADMIUM

Percentage Chance of Error of Misallocation of 'Area Types' to a Category

	-2 Categories	-1 Category	+1 Category	+2 Categories
A1	O	1.8	-	-
A2	O.1	6.7	34	O.1
A3	O.1	31	1.1	O
B1	O	1.8	24	O
B2	O.5	31	O.8	-
B3	3.6	42	2.3	-
B4	-	9.7	5.5	O
C1	-	42	3.6	O
C2	O	5.5	13.6	-
C3	-	-	46	5.5
C4	-	3.6	21	O
D1	O.1	34.5	-	-
D2	-	42	1.4	O
D3	O.3	6.7	42	-
D4	O	O.3	9.7	O
E1	O.1	21.2	-	-
E2	-	9.7	34.5	1.1
E3	-	-	1.1	O
E4	-	-	31	O.4
E5	-	-	4.5	O
Average	O.43%	18.3%	14.8	O.5%

- not determined

O.5% chance being 2 groups out.

15% chance of being 1 group out.

14% chance of being in a higher group.

TABLE E5

AVAILABLE ZINC

Percentage Chance of Error of Misallocation of 'Area Types' to a Category

	-2 Categories	-1 Category	+1 Category	+2 Categories
A1	0	5.5	-	-
A2	-	2.9	31	5.5
A3	0.2	42	-	-
B1	4.5	46	27.4	0.1
B2	1.8	9.7	8.1	-
B3	-	3.6	42	13.6
B4	-	11.5	2.9	0.0
C1	0.6	34	27.4	0
C2	0.1	0.6	38	-
C3	-	-	11.5	0
C4	-	2.9	46	16
D1	0.3	2.9	27	-
D2	-	22.2	9.7	1.1
D3	13.6	31	3.6	-
D4	-	4.5	24.2	3.6
E1	1.4	34	34	0.0
E2	-	-	13.6	0.1
E3	-	-	0	0
E4	-	-	18.4	0.6
E5	-	-	0.4	0
Average	2.5	16.9	20.3	2.9

= not determined

3% chance of being 2 groups out.

20% chance of being 1 group out.

20% chance should be in a higher group.

TABLE E6

AVAILABLE COPPER

Percentage Chance of Error of Misallocation of 'Area Types' to a Category

	-2 Categories	-1 Category	+1 Category	+2 Categories
A1	O	1.8	-	-
A2	O.1	24.2	-	-
A3	O.6	38	O	-
B1	O.8	38	21	O.3
B2	1.4	31	O.1	-
B3	-	2.3	9.7	O.1
B4	-	18.4	6.7	O.2
C1	1.8	24	O.2	-
C2	O	2.3	-	-
C3	-	38	O.3	O
C4	O	11.5	24	O
D1	O	18.4	21	O
D2	-	-	31	O
D3	O	11.5	34.5	O.2
D4	-	O	1.1	O
E1	O.5	11.5	O.5	-
E2	-	-	O.1	O
E3	-	-	O	O
E4	-	5.5	27.4	2.9
E5	-	-	27.4	O
Average	O.5%	17.3%	12.O%	O.3%

- not determined

O.5% chance of being 2 groups out.

15% chance of being 1 group out.

with only 12% chance being in a higher group.

below its present position is very small. For total cadmium, table E.4, the average is a less than 1% and there are several instances where the percentage chance approximated to zero. The data in table E.3, for total lead groupings, is much more variable where, in cases, there is nearly a 50% probability of misallocating an area type one category out. This reflects the much higher spatial variability of lead in urban soils which is primarily the result of high densities of traffic flows in the WMMC. Whereas for cadmium, copper and, to a lesser extent zinc, the percentages are on the whole much lower, reflecting the dominant influence of land-use in the variability of these heavy metals.

E.5.3 The results of this statistical test of the groupings of area-types, serves to support the use of natural breaks in the data, rather than imposing class intervals using certain mathematical techniques, as a 'grouping technique', which produces categories of land contamination which are significantly different from each other.

APPENDIX F.

SOIL SAMPLE HEAVY METAL RESULTS

This appendix contains the results of the analysis of the 360 soil samples for their heavy metal content. The data is presented in table F.1 and includes the results for both 'total' and 'available' heavy metal concentration for lead, zinc, copper and cadmium. Also included in table F.1 is the data on soil pH.

Figure F.1 is the specially written fortran programme used to generate the background soil contamination maps presented in Part 2 of Chapter 5.

TABLE F.1 INDIVIDUAL SOIL SAMPLE HEAVY METAL RESULTS

AREA TYPE	GRID SQUARE	TOTAL				AVAILABLE				
		LEAD	ZINC	COPPER	CADMIUM	LEAD	ZINC	COPPER	CADMIUM	PH
A1	98011	222.64	1246.20	128.20	8.10	87.21	264.00	45.10	1.44	6.3
A1	98012	136.60	682.60	48.20	1.10	62.80	181.50	27.30	1.05	5.7
A1	98013	254.71	725.40	64.80	2.20	189.26	566.00	34.20	1.65	7.4
A1	98014	113.60	2337.40	336.00	12.40	83.00	690.10	216.00	9.65	7.2
A1	98015	224.20	682.00	117.20	1.40	65.51	144.00	45.80	1.06	7.2
A1	98016	525.07	7843.00	2566.10	30.32	227.31	2488.00	1220.40	2.30	7.3
A1	98017	197.00	142.60	32.60	1.31	129.30	76.90	11.20	0.61	3.6
A1	98018	315.60	6572.00	347.60	6,41	206.25	17.40	19.80	1.64	3.8
A1	98019	284.20	2139.00	121.20	1.90	124.65	52.20	33.90	0.52	3.8
A1	86061	356.40	1121.40	900.00	2.47	175.26	226.89	259.60	2.33	7.3
A1	86062	60.45	96.60	477.00	0.47	59.52	72.45	10.90	0.33	6.5
A1	86063	58.17	109.20	88.20	0.39	42.05	20.80	38.40	0.29	7.3
A1	98018	315.60	6572.00	347.60	6.41	206.25	17.40	19.80	1.64	3.8
A1	98019	284.20	2139.00	121.20	1.90	124.65	52.20	33.90	0.52	3.8
A1	86061	356.40	1121.40	900.00	2.47	175.26	226.89	259.60	2.33	7.3
A1	86062	60.45	96.60	477.00	0.47	59.52	72.45	10.90	0.33	6.5
A1	86063	58.17	109.20	88.20	0.39	42.05	20.80	38.40	0.29	7.3
A1	86064	343.80	1486.80	671.40	2.45	204.90	302.40	145.20	2.10	7.0
A1	86065	269.10	397.70	190.50	0.50	148.77	57.60	63.30	0.47	8.0
A1	86066	558.30	805.65	477.00	0.93	287.61	189.00	148.85	0.60	8.1
A1	86067	90.20	180.60	25.60	0.73	69.42	36.00	15.10	0.52	7.4
A1	86068	277.35	260.40	110.25	0.95	145.44	66.60	36.30	0.87	7.1
A1	86069	63.05	112.35	27.25	0.63	46.55	23.69	26.70	0.49	6.5
A2	98961	36.30	176.70	42.90	0.70	23.41	44.40	24.90	0.62	6.3
A2	98962	31.80	533.20	63.00	0.95	27.26	113.90	30.30	0.75	4.9
A2	98963	23.80	260.40	207.90	0.85	34.00	60.30	58.50	0.65	7.5
A2	98964	182.90	689.40	321.30	6.30	86.77	127.30	127.50	5.65	7.2
A2	98965	99.50	264.60	174.30	1.30	46.15	133.90	81.00	1.31	5.5
A2	98966	155.30	270.90	210.00	1.20	86.00	116.30	105.00	7.15	4.2
A2	98967	77.25	705.60	291.90	2.00	66.60	31.20	139.80	1.83	6.8
A2	98968	307.20	630.00	306.60	1.45	146.00	24.72	163.35	1.27	7.2
A2	98969	279.00	1268.82	764.40	3.20	88.00	166.75	363.70	2.35	5.6
A2	79341	298.50	332.88	109.20	0.67	64.80	104.00	39.30	0.54	7.0
A2	79342	167.40	133.35	54.60	0.45	51.70	54.20	20.90	0.53	6.2

AREA TYPE	GRID SQUARE	TOTAL LEAD	TOTAL ZINC	TOTAL COPPER	TOTAL CADMIUM	AVAILABLE LEAD	AVAILABLE ZINC	AVAILABLE COPPER	AVAILABLE CADMIUM	PH
A2	79343	502.20	207.70	16.55	0.33	70.00	39.80	15.00	0.55	6.9
A2	79344	272.10	5344.35	4573.80	3.50	90.35	106.38	167.40	1.48	7.0
A2	79345	279.00	169.05	1039.05	0.55	58.95	6.50	100.80	0.58	5.5
A2	79346	191.70	147.25	29.05	0.30	41.00	26.76	16.75	0.50	6.2
A2	79347	240.60	238.70	36.80	0.24	55.90	19.56	45.00	0.20	7.7
A2	79348	195.30	344.10	28.10	0.45	96.70	74.70	14.80	0.50	7.2
A2	79349	68.35	418.19	36.15	0.43	35.00	71.30	18.45	0.58	7.2
A3	98931	237.30	285.60	194.25	0.52	147.90	113.40	64.60	0.67	5.9
A3	98932	272.10	1675.80	448.75	1.78	96.30	1205.30	110.20	1.83	5.3
A3	98933	139.50	554.40	141.75	1.50	61.00	247.50	32.50	1.80	4.8
A3	98934	48.55	117.60	76.65	0.36	46.80	57.40	30.90	0.45	4.8
A3	98935	51.25	109.20	37.80	0.36	39.90	44.30	29.60	0.41	6.5
A3	98936	585.90	667.80	302.40	1.55	43 .35	244.20	70.00	1.70	6.4
A3	98937	454.85	260.40	105.00	0.73	35.10	102.90	37.70	0.86	6.7
A3	98938	1882.80	1599.00	165.91	2.35	130.20	792.00	162.00	1.80	5.5
A3	98939	84.50	447.30	65.10	0.55	50.00	151.80	36.00	0.60	6.0
A3	88011	82.25	218.40	33.45	0.56	56.19	52.20	20.40	0.46	4.8
A3	88012	122.80	216.30	37.75	0.58	76.02	43.20	21.40	0.38	4.5
A3	88013	69.40	135.45	25.90	0.64	44.00	25.35	16.50	0.25	4.2
A3	88014	133.75	373.80	43.90	0.90	85.95	113.90	35.40	0.88	5.8
A3	88015	62.50	194.25	27.70	0.73	40.65	34.20	23.40	0.38	5.7
A3	88016	72.30	126.00	29.50	1.60	40.00	14.85	14.75	0.30	4.2
A3	88017	146.20	348.60	61.70	0.81	142.14	73.80	45.00	0.82	6.1
A3	88018	1130.40	957.60	107.10	2.60	743.40	808.00	30.90	1.12	6.6
A3	88019	171.60	310.80	39.95	1.00	56.00	46.80	18.00	1.06	5.2
B1	83111					184.20	155.10	56.34	1.02	7.1
B1	83112					116.40	85.70	22.70	0.73	5.8
B1	83113	424.00	604.80	210.00	2.35	204.00	227.20	81.00	0.45	6.9
B1	83114	220.00	747.60	247.00	2.94	172.50	137.16	69.90	1.63	6.2
B1	83115	757.80	562.80	159.60	1.53	451.50	146.00	31.90	0.97	6.9
B1	83116	178.00	438.90	98.70	1.92	110.00	194.40	39.00	1.35	5.8
B1	83117	363.00	438.00	333.90	1.05	196.80	115.50	128.85	0.89	6.4
B1	83118	114.00	331.80	94.50	0.91	73.50	109.40	45.57	0.90	6.1
B1	83119	156.00	310.80	88.20	1.00	106.20	125.10	66.00	0.77	6.4
B1	76341	37.50	153.40	14.85	0.92	35.20	15.26	7.90	0.26	7.5
B1	76342	83.65	197.40	23.45	1.10	66.12	48.60	11.20	0.33	7.6
B1	76343	37.45	193.20	15.90	1.80	21.00	66.40	8.55	0.75	5.8

- TABLE F.1 continued

AREA	GRID		TOTAL				AVAILABLE			
TYPE	SQUARE	LEAD	ZINC	COPPER	CADMIUM	LEAD	ZINC	COPPER	CADMIUM	PH
B1	76344	31.25	138.60	11.05	0.66	26.70	19.35	5.70	0.26	5.3
B1	76345	130.95	149.10	12.10	1.00	125.61	20.03	6.30	0.38	5.0
B1	76346	25.45	107.10	13.30	0.62	18.00	9.57	7.00	0.20	4.6
B1	76347	40.20	70.35	7.95	0.19	31.97	7.50	5.50	0.12	4.5
B1	76348	19.75	101.85	11.20	0.63	18.68	13.47	3.50	0.21	5.9
B1	76349	13.45	42.00	14.20	0.91	8.50	4.98	3.50	0.32	5.6
B2	88101	307.20	260.40	139.20	0.84	262.50	83.52	71.50	0.70	4.2
B2	88102	106.60	266.60	65.80	0.58	129.30	92.30	51.60	0.35	4.1
B2	88103	199.20	390.60	93.60	0.64	270.00	16.28	76.80	0.60	4.0
B2	88104	130.00	669.60	43.00	0.80	72.75	108.90	21.10	0.55	7.1
B2	88105	27.60	86.80	15.80	0.21	23.50	11.50	11.15	0.20	4.5
B2	88106	196.60	706.80	100.00	1.60	144.00	118.08	69.95	2.20	7.1
B2	88107	128.60	557.38	268.80	0.80	96.24	87.37	141.35	1.00	6.4
B2	88108	391.20	1078.80	252.00	2.60	209.70	234.30	128.70	2.25	7.1
B2	88109	40.40	130.20	22.20	0.60	33.00	52.80	19.90	1.05	5.2
B2	81341	2232.00	5040.00	701.40	5.80	292.20	1108.80	42.70	1.70	6.7
B2	81342	1400.80	2714.10	336.50	4.90	209.70	458.21	21.00	1.52	6.3
B2	81343	190.38	1348.90	430.50	3.03	28.50	101.90	28.70	0.85	7.1
B2	81344	892.80	1109.80	126.00	1.22	132.00	47.85	8.60	0.40	7.5
B2	81345	934.80	1360.80	667.80	1.60	74.45	43.00	23.50	0.40	7.5
B2	81346	442.40	840.00	529.20	1.10	60.00	35.30	27.00	0.27	7.4
B2	81347	334.40	558.00	137.40	0.80	43.60	13.68	14.20	0.20	4.3
B2	81348	277.00	384.40	107.00	1.37	44.65	12.45	13.10	0.22	4.4
B2	81349	338.90	693.00	1104.60	1.10	45.50	29.40	56.10	0.30	5.9
B3	86971	275.73	797.45	156.45	1.90	135.54	284.80	23.65	1.36	5.4
B3	86972	89.10	208.95	109.20	0.70	63.23	63.00	17.30	0.64	4.2
B3	86973	70.10	160.65	60.90	0.45	44.50	15.00	9.25	0.40	4.0
B3	86974	86.95	212.10	87.15	0.32	62.10	48.60	16.35	0.20	4.8
B3	86975	57.05	232.05	61.95	0.55	43.10	45.00	13.40	0.36	4.6
B3	86976	100.55	602.70	103.95	1.25	51.30	49.10	10.50	0.65	4.6
B3	86977	99.45	234.15	57.75	0.60	66.12	46.80	15.70	0.50	5.0
B3	86978	107.25	266.70	101.85	0.65	72.72	57.60	28.05	0.58	5.0
B3	86979	95.65	215.20	64.05	0.45	32.50	21.39	9.75	0.63	4.9
B3	96121	25.45	63.00	13.25	0.43	22.90	11.08	6.30	0.14	7.7
B3	96122	286.65	357.00	208.50	3.58	128.94	142.20	70.20	1.23	5.2
B3	96123	763.35	428.40	113.20	5.91	61.50	102.80	51.25	0.47	7.2
B3	96124	286.65	420.00	152.40	3.75	112.41	144.00	59.10	1.27	5.9

_ TABLE F.1 continued

AREA TYPE	GRID SQUARE	TOTAL LEAD	TOTAL ZINC	TOTAL COPPER	TOTAL CADMIUM	AVAILABLE LEAD	AVAILABLE ZINC	AVAILABLE COPPER	AVAILABLE CADMIUM	PH
B3	96125	202.65	211.05	66.00	2.17	148.77	90.00	31.50	0.85	5.1
B3	96126	294.00	315.00	67.20	3.75	85.50	140.90	32.70	1.66	6.7
B3	96127	60.35	56.70	17.15	0.21	53.17	15.85	11.80	0.19	4.4
B3	96128	12.00	40.95	9.40	0.17	7.89	5.97	5.40	0.12	6.9
B3	96129	86.55	281.40	50.10	1.42	48.00	107.30	21.25	0.87	6.4
B4	94001	418.80	1010.60	99.40	1.80	222.60	137.70	66.60	1.20	7.3
B4	94002	85.00	458.80	36.50	1.20	64.23	138.60	20.45	0.55	6.2
B4	94003	83.00	477.40	69.80	1.16	35.00	84.10	22.58	1.30	5.4
B4	94004	103.80	1804.20	372.00	1.89	87.20	85.50	75.60	0.70	6.8
B4	94005	127.20	2746.80	231.00	0.60	90.50	116.30	81.30	0.75	7.0
B4	94006	132.80	601.40	88.00	1.06	75.50	59.20	61.50	0.95	7.7
B4	94007	37.20	111.60	23.80	0.58	37.20	28.80	74.25	0.27	4.3
B4	94008	62.20	316.20	45.40	0.98	30.85	39.60	27.00	0.35	7.8
B4	94009	6.80	47.25	12.00	0.46	3.50	11.30	2.25	0.21	4.3
B4	92931	61.15	423.15	23.50	0.80	40.94	47.50	10.40	1.21	7.1
B4	92932	119.72	189.00	19.80	0.63	52.11	51.80	8.90	0.78	4.7
B4	92933	57.25	201.50	17.60	0.35	39.50	30.30	9.25	0.40	---
B4	92934	54.40	223.20	18.15	0.50	40.95	58.70	9.00	0.71	4.9
B4	92935	103.40	257.30	19.60	0.57	68.50	41.00	10.50	0.58	4.8
B4	92936	59.35	306.90	24.60	0.63	29.50	48.70	11.95	0.80	6.1
B4	92937	52.15	193.75	21.00	0.40	36.61	26.01	9.95	0.38	4.6
B4	92938	51.25	206.15	20.85	0.46	35.10	32.40	9.10	0.44	5.1
B4	92939	85.40	291.40	39.80	1.40	36.50	51.50	12.25	0.87	7.2
C1	82051	240.60	592.20	210.00	0.90	199.00	55.80	68.40	0.90	7.5
C1	82052	82.70	247.80	159.60	0.65	62.21	95.70	81.00	0.86	5.4
C1	82053	171.00	705.60	283.50	1.43	82.00	297.00	104.50	1.50	6.0
C1	82054	177.90	392.70	130.20	0.93	102.48	108.00	43.50	1.23	5.0
C1	82055	93.95	190.05	122.85	0.45	79.75	58.70	68.40	0.62	5.3
C1	82056	188.40	325.50	212.35	0.50	109.16	138.60	81.25	0.65	5.3
C1	82057	296.40	724.50	268.80	1.03	144.30	293.70	97.50	1.19	5.5
C1	82058	387.00	812.70	369.60	2.98	74.45	181.80	87.00	1.18	4.9
C1	82059	163.80	535.50	198.45	1.00	168.10	37.10	101.75	4.20	6.2
C1	88161	73.25	82.95	18.65	0.31	72.72	22.58	11.80	0.30	3.7
C1	88162	114.65	150.40	23.05	0.16	99.15	117.00	19.75	0.23	3.8
C1	88163	27.75	75.60	17.70	0.28	25.86	15.95	9.40	0.25	4.8
C1	88164	25.00	79.80	16.05	0.28	30.15	20.37	9.20	0.26	4.3
C1	88165	40.45	80.85	16.66	0.26	36.63	25.65	10.50	0.25	4.8

TABLE F1 continued

AREA TYPE	GRID SQUARE	TOTAL LEAD	TOTAL ZINC	TOTAL COPPER	TOTAL CADMIUM	AVAILABLE LEAD	AVAILABLE ZINC	AVAILABLE COPPER	AVAILABLE CADMIUM	PH
C1	88166	28.60	97.65	12.50	0.26	28.02	18.75	6.90	0.24	4.9
C1	88167	164.70	249.90	40.50	0.31	138.84	61.20	25.80	0.24	7.7
C1	88168	127.15	285.60	124.50	0.60	109.08	95.40	59.10	0.56	6.1
C1	88169	41.85	119.70	20.90	0.61	39.51	25.65	8.40	0.28	6.9
C2	86901	497.70	585.90	45.72	1.32	241.32	140.40	18.20	1.08	6.8
C2	86902	193.35	184.00	28.05	0.55	148.77	34.20	12.70	0.66	6.1
C2	86903	760.25	203.70	107.10	0.96	57.00	67.50	25.00	0.75	7.4
C2	86904	67.40	224.70	26.60	0.63	48.40	37.80	11.60	0.62	6.8
C2	86905	122.80	441.00	27.90	1.32	76.02	57.60	10.90	0.99	6.9
C2	86906	215.25	305.45	23.75	0.64	141.00	49.70	10.00	0.65	5.2
C2	86907	349.80	244.20	33.45	0:78	234.72	42.20	14.70	0.80	5.2
C2	86908	174.90	520.70	209.10	1.61	63.23	77.40	35.10	0.98	6.4
C2	86909	84.80	181.65	30.20	0.56	59.40	17.65	13.25	0.55	6.1
C2	90081	359.60	2378.00	1425.60	8.60	102.30	722.20	613.90	5.00	5.6
C2	90082	319.20	3024.00	975.60	7.20	162.20	493.00	433.29	5.35	5.1
C2	90083	298.00	756.00	734.40	3.80	114.00	196.38	171.00	1.56	4.8
C2	90084	59.00	147.00	224.40	0.54	30.21	23.10	87.40	0.45	4.2
C2	90085	82.60	541.80	116.60	1.60	33.40	138.20	50.50	0.95	4.8
C2	90086	142.20	1599.00	282.00	3.20	52.89	367.20	858.80	1.80	6.0
C2	90087	65.20	2115.60	87.40	1.20	25.20	990.00	54.20	1.20	6.3
C2	90088	92.90	772.80	390.00	1.80	44.98	39.40	56.70	1.23	6.8
C2	90089	61.52	843.36	250.80	1.00	24.00	106.20	73.50	0.60	7.4
C3	92041	112.00	92.40	53.40	1.20	91.90	34.10	39.30	0.50	4.0
C3	92042	8.20	62.00	10.20	0.23	3.30	4.74	2.10	0.06	4.3
C3	92043	60.80	111.60	32.40	0.67	54.00	25.30	14.35	0.41	3.8
C3	92044	77.40	192.20	43.00	1.38	77.45	93.60	38.10	0.47	5.2
C3	92045	12.40	75.60	56.80	1.16	11.49	5.63	17.30	0.16	5.1
C3	92046	70.60	204.60	33.00	2.70	54.50	40.80	11.75	0.40	5.2
C3	92047	96.80	248.00	48.80	0.45	86.65	47.50	37.20	0.43	5.8
C3	92048	165.20	229.40	55.00	0.73	162.00	59.90	29.70	0.30	3.8
C3	92049	163.20	248.00	63.60	0.40	150.48	50.76	16.80	0.60	3.6
C3	89961	250.00	63.00	38.00	0.20	51.21	29.58	11.20	1.09	5.6
C3	89962	52.00	57.75	30.00	0.11	20.22	17.25	9.00	0.66	4.4
C3	89963	66.00	72.40	38.60	0.24	26.55	26.73	14.75	0.50	6.6
C3	89964	74.00	72.45	51.60	1.60	31.35	39.80	17.00	0.61	4.5
C3	89965	88.75	108.65	47.15	0.35	53.17	9.48	9.20	0.99	3.9
C3	89966	88.00	47.45	41.40	0.13	29.50	27.00	75.75	0.41	5.8

- TABLE F.1 continued

AREA	GRID	TOTAL				AVAILABLE				
TYPE	SQUARE	LEAD	ZINC	COPPER	CADMIUM	LEAD	ZINC	COPPER	CADMIUM	PH
C3	89967	108.00	100.80	42.20	0.20	58.10	90.70	18.30	0.81	4.8
C3	89968	78.00	30.45	16.40	0.10	47.85	28.32	10.40	0.99	3.9
C3	89969	90.15	250.10	71.75	0.70	56.00	70.95	19.36	0.87	4.0
C4	92091	63.10	92.25	108.65	0.55	45.98	19.26	11.25	1.04	5.8
C4	92092	291.10	106.60	206.20	0.38	224.79	26.76	85.50	0.45	4.0
C4	92093	65.47	132.30	85.80	0.66	54.00	56.30	54.00	0.83	4.5
C4	92094	114.10	340.20	118.50	1.38	82.65	93.60	52.20	1.63	6.2
C4	92095	100.00	289.80	81.60	1.17	147.00	453.60	100.50	2.65	6.4
C4	92096	292.50	806.40	234.90	2.70	32.33	5.45	9.90	0.28	6.5
C4	92097	42.80	45.15	23.70	0.25	85.95	26.59	35.40	0.87	5.9
C4	92098	41.08	185.85	84.90	0:73	195.00	170.00	68.40	1.25	7.1
C4	92099	384.30	465.15	229.95	1.10	82.65	84.60	39.30	1.37	6.2
C4	89991	48.40	147.00	21.20	0.60	45.30	23.49	13.60	0.38	6.1
C4	89992	36.10	121.80	20.60	0.50	36.15	21.06	13.60	0.26	5.4
C4	89993	45.40	176.40	27.00	0.66	27.75	20.70	15.80	0.32	5.8
C4	89994	93.80	289.80	69.60	1.00	70.20	75.80	66.30	0.66	7.5
C4	89995	66.60	163.80	27.80	0.50	54.24	27.87	19.80	0.37	5.5
C4	89996	98.40	415.80	46.40	0.70	79.20	61.90	17.75	0.60	7.5
C4	89997	66.60	184.80	37.10	0.50	58.83	112.80	24.40	0.52	6.9
C4	89998	103.20	231.00	26.60	0.70	92.55	97.90	18.10	0.67	5.7
C4	89999	124.20	407.40	42.20	2.00	105.60	42.30	21.25	1.80	7.2
D1	92961	121.40	465.00	60.80	1.00	72.55	101.70	38.10	1.10	6.1
D1	92962	519.20	421.60	68.20	0.80	80.31	83.50	45.00	0.90	6.3
D1	92963	121.20	545.60	65.80	1.20	72.00	77.00	34.50	0.95	6.5
D1	92964	44.20	229.40	28.40	1.00	28.80	64.30	18.30	0.50	6.8
D1	92965	273.00	351.60	88.00	2.60	112.30	287.00	40.20	2.25	6.1
D1	92966	47.60	328.60	30.00		29.40	41.80	16.65	0.55	7.8
D1	92967	51.80	595.20	48.80	2.00	37.35	107.30	27.10	0.45	7.0
D1	92968	434.60	2714.20	647.52	13.20	168.41	1287.60	201.60	6.29	7.0
D1	92969	128.80	1327.20	184.40	2.00	48.00	851.40	36.00	1.60	7.2
D1	84931	27.25	193.75	58.50	0.70	25.86	24.80	11.15	0.39	6.1
D1	84932	43.25	227.85	85.20	2.90	18.08	18.33	23.10	0.97	7.7
D1	84933	44.20	282.10	55.60	1.30	30.50	41.20	11.50	0.50	4.8
D1	84934	130.27	241.80	45.90	1.25	115.80	36.30	44.30	2.25	5.3
D1	84935	22.10	66.65	52.50		10.10	3.93	9.20	0.01	6.5
D1	84936	95.40	503.75	55.40	2.60	46.50	49.10	15.50	0.80	5.2
D1	84937	63.45	269.70	29.10	1.40	22.86	28.05	6.10	0.28	5.6

TABLE F.1 continued

AREA	GRID		TOTAL				AVAILABLE			
TYPE	SQUARE	LEAD	ZINC	COPPER	CADMIUM	LEAD	ZINC	COPPER	CADMIUM	PH
D1	84938	298.20	1089.90	154.50	9.50	36.18	31.05	10.60	0.50	7.2
D1	84939	64.40	235.60	68.40	1.25	51.50	65.16	51.90	0.75	6.1
D2	79151	50.45	153.45	19.10	0.39	49.85	27.10	12.60	0.28	4.8
D2	79152	41.35	184.45	15.10	0.46	40.51	67.00	9.40	0.43	4.2
D2	79153	47.20	96.10	15.80	0.38	46.00	16.56	10.50	0.30	4.4
D2	79154	38.55	85.25	13.00	0.36	38.28	18.80	7.10	0.22	4.3
D2	79155	751.80	357.00	54.60	1.70	318.30	99.00	15.00	0.77	5.5
D2	79156	120.05	244.90	28.50	1.27	116.40	61.74	22.65	0.50	6.0
D2	79157	71.95	196.35	16.30	0.67	58.47	136.10	9.70	0.45	4.7
D2	79158	265.20	213.15	76.65	0.72	154.50	123.80	20.10	0.60	5.4
D2	79159	118.80	122.45	21.30	0.54	105.00	17.19	14.00	0.32	4.1
D2	83011	31.80	92.40	17.00	0.30	27.12	15.24	12.70	0.26	4.7
D2	83012	98.20	316.20	38.60	0.91	85.18	87.30	27.70	0.62	4.8
D2	83013	76.20	292.74	62.40	1.22	52.50	148.90	42.00	0.86	5.3
D2	83014	64.20	193.20	27.00	0.13	61.80	36.50	20.00	0.51	6.8
D2	83015	58.00	157.00	25.60	0.62	57.43	44.30	18.90	0.58	7.0
D2	83016	33.20	100.80	28.80	0.53	12.50	46.40	12.75	8.81	7.4
D2	83017	22.00	103.74	10.20	0.26	15.95	7.59	6.60	0.22	5.3
D2	83018	24.80	148.80	22.00	0.70	19.67	11.76	18.80	0.45	5.8
D2	83019	47.00	142.60	21.20	0.86	25.00	117.29	14.45	0.71	6.2
D3	90921	81.35	356.50	26.55	0.65	62.97	80.80	13.40	0.62	6.6
D3	90922	17.50	122.45	24.75	0.22	3.70	4.92	7.20	0.24	6.6
D3	90923	14.80	192.20	21.25	0.38	8.00	6.15	9.00	0.20	6.5
D3	90924	152.85	331.80	116.55	0.81	87.85	78.26	14.80	0.56	4.8
D3	90925	96.20	230.95	55.80	0.66	63.17	47.50	18.10	0.69	6.8
D3	90926	30.15	142.60	54.00	0.13	11.50	10.44	13.25	0.42	5.2
D3	90927	15.75	159.65	23.85	0.34	4.75	6.84	10.10	0.19	6.5
D3	90928	33.25	204.60	69.30	0.31	9.51	10.05	12.10	0.23	6.2
D3	90929	40.45	212.35	30.70	0.16	21.00	19.65	13.00	0.53	5.9
D3	01981	126.10	828.20	220.80	7.63	82.65	313.20	121.80	6.15	6.8
D3	01982	68.45	510.30	174.30	2.50	52.45	133.20	66.00	2.65	6.5
D3	01983	70.10	344.40	41.70	0.86	52.89	109.80	23.60	0.90	6.2
D3	01984	51.65	199.71	28.35	0.63	38.95	73.80	15.90	0.81	5.3
D3	01985	63.05	768.60	29.75	0.68	49.95	93.60	17.10	0.62	5.1
D3	01986	65.85	300.30	34.10	1.90	62.82	126.00	21.80	1.09	5.2
D3	01987	908.10	1713.60	511.20	25.63	331.20	756.00	241.20	17.14	5.4
D3	01988	58.15	207.90	32.40	0.67	57.48	77.40	17.60	0.75	5.1

TABLE F.1 continued

AREA TYPE	GRID SQUARE	TOTAL LEAD	TOTAL ZINC	TOTAL COPPER	TOTAL CADMIUM	AVAILABLE LEAD	AVAILABLE ZINC	AVAILABLE COPPER	AVAILABLE CADMIUM	PH
D3	01989	292.50	711.35	130.24	2.78	238.02	167.40	55.80	3.60	4.4
D4	04051	260.00	550.20	501.60	1.18	27.12	15.24	12.70	0.26	5.7
D4	04052	140.00	596.40	147.60	3.18	85.18	87.30	27.70	0.62	7.2
D4	04053	224.00	798.00	304.80	1.60	52.50	148.90	42.00	0.86	6.2
D4	04054	90.00	352.80	49.40	0.70	61.80	36.50	20.00	0.51	5.8
D4	04055	404.00	705.60	210.00	2.00	57.43	44.30	18.90	0.58	5.0
D4	04056	168.00	533.40	50.00	0.80	12.50	46.40	12.75	0.81	5.8
D4	04057	84.00	441.60	56.80	0.94	15.95	7.59	6.60	0.22	6.1
D4	04058	70.00	310.80	38.00	0.73	19.67	11.76	18.80	0.45	6.3
D4	04059	44.00	109.20	12.00	0.64	25.00	117.29	14.45	0.71	4.1
D4	80201	37.50	246.45	28.05	1.58	19.14	46.50	12.90	0.65	5.6
D4	80202	50.95	320.85	52.50	1.92	22.35	73.80	16.10	0.89	5.8
D4	80203	71.44	204.60	35.70	1.45	54.50	32.60	18.80	0.55	5.4
D4	80204	83.45	134.85	26.60	0.90	70.20	16.30	13.40	0.35	4.1
D4	80205	61.50	119.35	25.30	1.20	28.18	61.90	23.60	0.75	6.8
D4	80206	38.45	296.05	50.40	1.75	22.50	85.10	33.00	0.80	7.2
D4	80207	50.55	179.80	25.80	1.08	44.13	36.70	16.70	0.45	7.4
D4	80208	238.35	306.60	62.40	1.13	64.87	90.30	16.10	0.54	7.4
D4	80209	382.20	173.25	24.20	1.03	198.00	84.40	13.40	0.60	6.9
E1	90131	34.25	136.50	51.45	1.42	33.14	28.80	28.20	0.66	5.7
E1	90132	35.30	140.70	61.95	1.16	34.49	39.60	39.30	0.68	5.6
E1	90133	65.20	210.00	113.40	1.93	53.00	45.90	68.10	0.80	6.9
E1	90134	695.71	1625.40	498.60	19.30	304.15	410.40	187.00	5.00	7.1
E1	90135	1591.20	863.10	299.25	3.30	757.80	109.80	143.70	1.20	7.5
E1	90136	21.25	82.05	17.70	0.80	13.64	5.60	7.35	0.14	8.0
E1	90137	116.30	943.00	222.90	5.00	69.42	75.60	82.20	1.42	7.9
E1	90138	39.60	196.35	14.65	0.92	38.10	92.80	8.00	0.48	4.9
E1	90139	363.30	1025.00	603.75	15.25	173.84	311.60	189.00	3.70	5.7
E1	90021	525.00	378.00	374.85	1.12	82.95	82.40	84.00	0.50	4.7
E1	90022	116.90	186.90	116.85	0.75	90.30	75.20	32.10	0.84	4.1
E1	90023	560.70	772.02	168.00	1.93	204.00	167.40	57.00	1.40	7.1
E1	90024	105.20	159.90	36.30	0.23	74.40	12.90	13.90	0.26	3.5
E1	90025	346.50	157.20	134.40	0.34	229.50	62.50	56.10	0.41	3.4
E1	90026	127.70	67.20	65.10	0.23	126.00	22.68	13.00	0.27	3.5
E1	90027	136.95	114.45	162.75	0.52	58.49	22.14	11.50	0.26	3.5
E1	90028	215.25	147.00	156.45	0.64	154.80	30.25	24.40	0.54	3.3
E1	90029	80.20	106.95	40.80	0.16	79.25	11.70	20.75	0.28	3.3

TABLE F.1 continued

AREA	GRID	TOTAL				AVAILABLE				
TYPE	SQUARE	LEAD	ZINC	COPPER	CADMIUM	LEAD	ZINC	COPPER	CADMIUM	PH
E2	85171					36.85	19.29	11.10	0.30	7.3
E2	85172	41.20	100.80	13.16	0.10	31.90	20.97	4.90	0.35	4.7
E2	85173	48.40	96.60	19.42	0.27	61.43	54.20	10.20	0.50	5.7
E2	85174	50.20	121.80	18.80	0.27	40.00	17.37	8.40	0.46	6.2
E2	85175	68.40	96.60	17.86	0.18	32.50	16.14	9.20	0.30	4.7
E2	85176	43.20	155.40	17.54	0.14	34.73	13.81	9.90	0.38	---
E2	85177	97.00	414.20	45.40	0.90	55.30	100.60	24.50	1.26	5.6
E2	85178	45.00	67.20	13.48	0.37	28.71	27.09	6.20	0.35	4.5
E2	85179	41.40	25.60	11.90	0.37	30.50	16.83	6.80	0.43	5.0
E2	97081	141.30	274.75	49.25	1.20	92.55	115.20	18.90	0.52	6.5
E2	97082	118.45	294.00	39.55	0.92	79.08	91.80	17.70	0.68	5.5
E2	97083	265.80	247.80	89.40	3.25	201.00	142.02	11.80	2.10	3.5
E2	97084	13.40	81.90	3.55	0.14	12.21	5.45	2.20	0.12	3.7
E2	97085	69.60	277.20	18.10	0.87	67.42	9.00	8.00	0.76	3.7
E2	97086	14.65	88.20	4.30	0.27	12.50	6.96	2.21	0.20	3.9
E2	97087	64.30	132.30	15.85	0.47	62.12	9.72	8.60	0.16	3.7
E2	97088	47.05	132.30	7.25	0.49	45.62	8.78	3.00	0.19	3.7
E2	97089	59.50	163.80	21.45	0.68	58.00	9.48	19.30	0.22	3.6
E3	76231	27.00	75.60	10.40	0.37	16.48	10.48	5.20	0.20	4.7
E3	76232	34.20	75.60	13.00	0.48	23.39	12.48	5.80	0.20	---
E3	76233	28.80	121.80	12.60	0.48	17.37	10.44	6.10	0.29	5.6
E3	76234	34.00	92.40	10.40	0.47	20.73	20.58	5.10	0.31	4.8
E3	76235	39.60	61.32	11.00	0.38	29.24	6.90	5.60	0.20	5.1
E3	76236	36.00	67.20	10.40	0.41	28.75	12.36	5.10	0.24	4.6
E3	76237	34.00	84.00	9.00	0.67	22.33	12.27	4.80	0.28	4.6
E3	76238	23.40	63.00	9.40	0.49	13.84	10.08	4.20	0.21	5.3
E3	76239	48.60	121.80	15.40	0.41	37.39	28.85	9.40	0.43	4.0
E3	98131	1998.32	611.10	54.60	1.22	102.90	26.13	26.10	0.32	7.4
E3	98132	47.20	190.65	21.95	0.68	31.48	32.60	11.40	0.42	6.1
E3	98133	44.50	150.35	21.75	0.80	27.50	18.10	9.00	0.70	5.2
E3	98134	40.45	193.75	25.50	0.71	32.97	81.00	14.50	0.61	6.0
E3	98135	44.95	201.50	23.40	0.57	30.41	20.90	11.10	0.40	6.9
E3	98136	30.13	102.30	11.75	0.25	26.50	11.90	5.95	0.15	4.9
E3	98137	35.05	119.35	11.95	0.30	25.51	10.80	7.70	0.20	6.3
E3	98138	69.25	161.20	26.60	0.45	76.55	29.20	19.40	0.25	4.1
E3	98139	73.50	227.85	22.10	0.47	55.00	22.40	9.50	0.27	7.3
E4	75131	4.07	56.70	8.00	0.21	1.08	0.60	7.70	0.07	7.7

TABLE F.1 continued

AREA TYPE	GRID SQUARE	TOTAL LEAD	TOTAL ZINC	TOTAL COPPER	TOTAL CADMIUM	AVAILABLE LEAD	AVAILABLE ZINC	AVAILABLE COPPER	AVAILABLE CADMIUM	PH
E4	75132	38.95	128.10	22.75	0.40	37.37	51.70	10.00	0.38	6.8
E4	75133	25.00	78.75	10.80	0.34	14.50	10.11	5.50	0.40	7.0
E4	75134	11.55	45.15	10.90	0.15	10.76	4.77	3.60	0.09	5.5
E4	75135	24.44	67.20	15.30	0.28	18.62	10.40	6.70	0.28	6.5
E4	75136	21.50	71.40	8.75	0.28	15.00	9.99	3.75	0.33	5.5
E4	75137	32.55	99.75	14.20	0.34	29.46	10.31	5.40	0.33	5.5
E4	75138	34.20	74.55	9.80	0.39	28.02	11.59	4.70	0.35	5.2
E4	75139	38.95	107.10	20.90	0.53	25.00	27.36	10.50	0.47	6.4
E4	99041	115.71	235.20	98.91	0.85	80.29	65.90	38.40	0.73	4.2
E4	99042	707.07	61.91	63.00	1.09	78.06	102.70	36.00	1.07	5.5
E4	99043	127.87	270.69	81.90	0.79	58.50	110.70	45.00	0.30	5.4
E4	99044	151.20	228.90	118.80	0.82	80.18	61.40	112.80	0.57	4.5
E4	99045	95.97	193.20	54.60	2.30	46.26	38.10	24.70	0.60	6.1
E4	99046	142.38	174.30	58.80	0.78	75.50	34.90	61.48	0.62	4.8
E4	99047	106.68	149.10	44.10	0.65	36.79	36.70	21.10	0.55	7.1
E4	99048	124.11	226.80	94.50	0.82	65.95	60.30	33.90	0.65	5.6
E4	99049	133.56	233.11	81.90	0.70	45.00	35.15	33.00	0.15	5.4
E5	82281	28.75	89.90	10.65	0.25	15.80	10.60	3.75	0.33	5.7
E5	82282	29.25	67.10	12.10	0.27	24.43	12.00	6.20	0.26	5.1
E5	82283	70.15	184.45	35.50	0.43	35.00	6.21	37.20	0.65	5.7
E5	82284	21.85	113.15	11.45	0.30	12.22	14.70	3.80	0.25	5.4
E5	82285	13.50	96.11	10.50	0.21	6.47	10.10	3.20	0.09	4.3
E5	82286	29.25	156.39	13.85	0.37	10.00	15.40	4.85	0.40	6.9
E5	82287	20.20	142.60	17.10	0.30	13.64	15.30	7.35	0.28	6.4
E5	82288	52.45	134.85	21.55	0.28	49.95	28.40	9.15	0.32	4.7
E5	82289	28.33	99.20	11.78	0.26	11.50	15.50	5.95	0.37	5.1
E5	97051	72.00	130.20	58.80	0.54	57.43	28.70	27.20	0.40	6.4
E5	97052	104.00	228.90	100.90	1.50	76.99	88.60	36.80	1.12	5.7
E5	97053	67.00	138.60	44.10	1.05	42.00	24.30	10.60	0.90	5.0
E5	97054	72.00	212.10	46.20	0.95	59.55	87.70	26.10	0.87	5.9
E5	97055	62.00	123.90	44.10	0.85	56.68	46.75	33.70	0.65	4.4
E5	97056	65.00	159.60	45.15	0.73	56.40	33.70	11.00	0.75	6.0
E5	97057	44.00	88.20	25.20	0.44	35.74	30.90	22.80	0.28	4.5
E5	97058	64.00	126.00	46.20	0.51	51.58	29.13	20.80	0.40	5.6
E5	97059	38.00	126.60	23.10	0.67	28.80	63.00	8.20	0.53	5.7

TABLE F.1 continued

Fig. F.1 Fortran Computer Programme used to Produce the Background Soil Contamination Maps.

```
UAFORTRAN *GP GINO,PLOT
      MASTER FORT17
      INTEGER MAT
      DIMENSION X(9),Y(9),MAT(52,37)
      COMMON X,Y,ICOL
      DO 10 K=1,9
      READ(1,12) X(K),Y(K)
   10 CONTINUE
   12 FORMAT(2F0.0)
      CALL OPENGINOGP
      CALL SOFCHA
      CALL UNITS(10.0)
      CALL MOVTO2(2.35,7.6)
      CALL LINBY2(0.0,4.5)
      CALL LINBY2(-0.75,0.0)
      CALL LINBY2(0.0,3.0)
      CALL LINBY2(1.5,0.0)
      CALL LINBY2(0.0,1.5)
      CALL LINBY2(0.75,0.0)
      CALL LINBY2(0.0,1.5)
      CALL LINBY2(-1.5,0.0)
      CALL LINBY2(0.0,1.5)
      CALL LINBY2(-1.5,0.0)
      CALL LINBY2(0.0,3.0)
      CALL LINBY2(0.75,0.0)
      CALL LINBY2(0.0,0.75)
      CALL LINBY2(1.5,0.0)
      CALL LINBY2(0.0,1.5)
      CALL LINBY2(1.5,0.0)
      CALL LINBY2(0.0,0.75)
      CALL LINBY2(2.25,0.0)
      CALL LINBY2(0.0,-1.5)
      CALL LINBY2(3.0,0.0)
      CALL LINBY2(0.0,0.75)
      CALL LINBY2(0.75,0.0)
      CALL LINBY2(0.0,0.75)
      CALL LINBY2(2.25,0.0)
      CALL LINBY2(0.0,3.0)
      CALL LINBY2(1.5,0.0)
      CALL LINBY2(0.0,-0.75)
      CALL LINBY2(0.75,0.0)
      CALL LINBY2(0.0,-0.75)
      CALL LINBY2(1.5,0.0)
      CALL LINBY2(0.0,-3.0)
      CALL LINBY2(0.75,0.0)
      CALL LINBY2(0.0,-1.5)
      CALL LINBY2(2.25,0.0)
      CALL LINBY2(0.0,0.75)
      CALL LINBY2(0.75,0.0)
      CALL LINBY2(0.0,-0.75)
      CALL LINBY2(1.5,0.0)
      CALL LINBY2(0.0,-0.75)
      CALL LINBY2(0.75,0.0)
      CALL LINBY2(0.0,-1.5)
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      CALL LINBY2(0.75,0.0)
      CALL LINBY2(0.0,-1.5)
      CALL LINBY2(0.75,0.0)
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CALL LINBY2(0.75,0.0)
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CALL LINBY2(1.5,0.0)
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CALL LINBY2(0.75,0.0)
CALL LINBY2(0.0,1.5)
CALL LINBY2(1.5,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(3.0,0.0)
CALL LINBY2(0.0,0.75)
CALL LINBY2(0.75,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(0.75,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(0.75,0.0)
CALL LINBY2(0.0,0.75)
CALL LINBY2(2.25,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(0.75,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(0.75,0.0)
CALL LINBY2(0.0,-4.5)
CALL LINBY2(-0.75,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(-0.75,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(-2.25,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(-0.75,0.0)
CALL LINBY2(0.0,0.75)
CALL LINBY2(-0.75,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(-1.5,0.0)
CALL LINBY2(0.0,0.75)
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CALL LINBY2(0.0,-0.75)
CALL LINBY2(-2.25,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(-1.5,0.0)
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CALL LINBY2(-0.75,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(-1.5,0.0)
CALL LINBY2(0.0,-0.75)
CALL LINBY2(-1.5,0.0)
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      CALL LINBY2(0.0,0.75)
      CALL LINBY2(-0.75,0.0)
      CALL LINBY2(0.0,0.75)
      CALL LINBY2(-3.75,0.0)
      CALL LINBY2(0.0,0.75)
      CALL LINBY2(0.75,0.0)
      CALL LINBY2(0.0,1.5)
      CALL LINBY2(0.75,0.0)
      CALL LINBY2(0.0,0.75)
      CALL LINBY2(-3.0,0.0)
      CALL LINBY2(0.0,-0.75)
      CALL LINBY2(-0.75,0.0)
      CALL LINBY2(0.0,-0.75)
      CALL LINBY2(-4.5,0.0)
      CALL LINBY2(0.0,0.75)
      CALL LINBY2(-0.75,0.0)
      CALL LINBY2(0.0,1.5)
      CALL LINBY2(1.5,0.0)
      CALL LINBY2(0.0,1.5)
      CALL LINBY2(-4.5,0.0)
      CALL LINBY2(0.0,0.75)
      CALL LINBY2(-0.75,0.0)
      CALL LINBY2(0.0,-0.75)
      CALL LINBY2(-3.75,0.0)
      CALL MOVTO2(18.0,27.0)
      CALL CHASIZ(0.6,0.5)
      CALL CHAHOL(48HF*LIG5.19 *UG*LRID MAP OF THE *UWMMC *LSHOWING*.
      CALL MOVTO2(21.6,26.3)
      CALL CHAHOL(40H*LSOIL CONTAMINATION-TOTAL LEAD(MG/KG)*.)
      CALL MOVTO2(25.5,24.5)
      CALL CHAHOL(8HK*LEY:*.)
      CALL MOVTO2(26.8,23.7)
      CALL CHASIZ(0.4,0.3)
      CALL CHAHOL(35HA*LREA-MEAN LEAD LEVELS ABOVE 250*.)
      CALL MOVTO2(26.8,22.7)
      CALL CHAHOL(41HA*LREA-MEAN LEAD LEVELS BETWEEN 189-249*.)
      CALL MOVTO2(26.8,22.0)
      CALL CHAHOL(41HA*LREA-MEAN LEAD LEVELS BETWEEN 136-188*.)
      CALL MOVTO2(26.8,21.3)
      CALL CHAHOL(41HA*LREA-MEAN LEAD LEVELS BETWEEN 108-135*.)
      CALL MOVTO2(26.8,20.6)
      CALL CHAHOL(35HA*LREA-MEAN LEAD LEVELS BELOW 100*.)
      CALL CHASIZ(0.4,0.4)
      DO 90 I=1,52
   90 READ(1,99)(MAT(I,J),J=1,37)
   99 FORMAT(37 I1)
      DO 91 I=1,52
      DO 91 J=1,37
      IF (MAT(I,J).EQ.0) GO TO 91
      X1 = FLOAT(I)*0.75
      Y1 = FLOAT(J)*0.75
      ICOL = MAT(I,J)
      CALL MOVTO2(X1,Y1)
      CALL FILL(X,Y,ICOL)
   91 CONTINUE
      CALL DEVEND
      STOP
      END
      SUBROUTINE FILL(X,Y,ICOL)
      DIMENSION X(9),Y(9)
      CALL PENSEL(ICOL,0.0
```

```
      CALL SYMBY2(X,Y,9,8)
      RETURN
      END
      FINISH
0.22 0.22
0.0 0.22
0.0 0.22
0.22 0.0
0.0 -0.22
0.0 -0.22
0.22 0.0
0.0 0.22
0.0 0.22
000000000000000000000000007000000000
000000000000000075500000077555000000
000000000755707227000050705570000000
000000000707170712000057005050500000
000000000757151777507777771002500000
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0000000000552150105177000111215500000
0000000000057505217000077725775500000
0000000000777117222012751202757000000
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0000000000775707201177575510055000000
0000000000070027002211111210705000000
0000017000055777777777212770250700000
0000757005155757111107100125210700000
0000575755557777071115001121777550000
0000771755557700212050770212007050000
0000717757557777722505215557555570005
0000050005572777212050750575055705 2500
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0007007555521727127755055007700000000
0007775557717522277777705007700000000
0000075757771557772777505775000000000
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0005005555777770500777575000000000000
7700070557755517750270000000000000000
0057777775550505775220000000000000000
0770705555050075500000000000000000000
0000770000052727500000000000000000000
0000005255055050000000000000571200000 0
0700007070500000000000000000000000000
0000000000000000000000000000000000000
0070700555000000000000000000000000000
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0000770707700000000000000000000000000
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0000005055055000000000000000000000000
0000722770000000000000000000000000000
0000020700000000000000000000000000000
0000017257700000000000000000000000000
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0050550575577000000000000000000000000
0007051127252000000000000000000000000
0070721112150000000000000000000000000
0005052112125000000000000000000000000
0005551277755000000000000000000000000
0007751700005000000000000000000000000
0000705555500000000000000000000000000
0000255700000000000000000000000000000
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REFERENCES

ADAMSON, A.H. (1980) 'Lead and arsenic pollution of grass around a smelter.' In Inorganic Pollution and Agriculture MAFF Ref. book 326, pp 121-150 H.M.S.O. London.

ALLOWAY, B.J. & F.E. BUTTERWORTH, (1980) Studies on the Speciation & Sorption of Cadmium in Soils. Unpublished paper to Symposium, Hove 1980.

ALSTON, A.M. & S. MCCONAGHY, (1965) Rec. Agr. Res., Vol 14: pp 49-59

AMER, U. (1976) 'Ecological Mapping of the Community'. Report & Recommendations, EEC, Brussels.

ARCHER, F.C. (1980) 'Trace Elements in soils in England and Wales.' In Inorganic Pollution and Agriculture, MAFF Ref. Book 326, HMSO London 1980 pp 184-190.

AVERY, B.W. (1973) "Soil Classification in the Soil Survey of England and Wales". Jn. Soil Science, Vol 24, pp 324-338.

BAKER, D.E. & L. CHESSIN (1975) "Chemical Monitoring of Soils for Environmental quality and animal and human health". Adv. Agron. Vol 27, pp 305-374.

BARLTROP, D., C.D. STREHLOW, I. THORNTON & S.J. WEBB (1975) "Absorption of Lead from Dust & Soil". P.M.J., Vol. 51, pp801-804.

BARLTROP, D. (1979) 'Health Effects of Lead in the Environment'. Paper to Management & Control of Heavy Metals in the Environment. London, Sept. 1979

BARRETT, E.C. & L.F. CURTIS, (1974) Introduction to Remote Sensing, London.

BARRY, D.L. (1981) Prospective Survey for Contaminated Sites. Unpublished project report to DOE, Atkins Research & Development.

BEAVINGTON, F. (1973) "Contamination of Soil with Zinc, Copper, Lead and Cadmium in the Wollongong area of New South Wales, Australia." Aust. Jnl. Soil Research Vol. II pp 47-51.

BEAVINGTON, F. (1975) "Heavy Metal Contamination of Vegetation and Soils in Domestic Gardens around and Smelting Complex". Environmental Pollution, pp 211 - 218.

BECKETT, P.H.T. (1980) 'The Statistical Distribution of Sewage and Sludge Analysis'. Env. Poll. Vol I. No. I. pp 27-37. (Series B).

BEESON, K.C. (1945) "The occurrence of mineral nutritional diseases of plants and animals, U.S." Soil Science Vol. 60, pp 9-13.

BERGER, R.C. (1962) "Micro nutrient deficiencies in U.S." Jnl. Agr. Food Chem., Vol. 10, pp 178-181.

BERROW, M.L. & J.C. BURRIDGE (1980) 'Trace Element levels in Soils effects of sewage sludge'. In Inorganic Pollution and Agriculture, MAFF Ref. Book 326 pp 159-183, HMSO London.

BLOKKER, P.C. (1972) "Literature Survey on some Health Aspects of Lead Emissions from Gasoline Engines". Atmos. Env., 6, pp 1-18.

BOWEN H.W. (1966) Trace Elements in Biochemistry, Academic Press, London.

BRADLEY, R.I., C.C. RUDEFORTH, & C. WILKINS (1978) "Distribution of some chemical elements in the soils of North-West Pembrokeshire". Jn. Soil Science., Vol 29, pp 258-270.

BRADSHAW, A.D. (1980) 'Metal Contamination and the significance of the Metal of Metal Tolerance'. In Reclamation of Contaminated Land Proc. Conf. S.C.I. London

BROGAN, J.C., G.A. FLEMING; I.E. BYRONE, (1973) "Molybdenum and Copper in Irish Pasture Soils". In Irish Jnl. Agric Research Vol. 12 pp 71-81.

BUCHAUER, M.J. (1973) "Contamination of Soil and Vegetation near a zinc smelter by Zinc, Cadmium, Copper and Lead". Env. Sci. & Technol., Vol 7, pp 131-135.

BUTLER, J.R. (1954) "Trace element distribution in some Lancashire Soils". Jn. Soil Science, Vol 5, pp 156-166.

BURKITT A., LEICESTER P. & NICKLESS G. (1972) Nature Vol. 238, pp 327-328.

CALDWELL, T.H. (1971) 'Copper Deficiency in Crops'. In Trace Elements in Soils and Crops. Ministry of Agriculture Fisheries and Food. Technical Bulletin 21, pp 62 -87, HMSO.

CALDWELL, T.H. (1976) Copper in Trace Elements Deficiences in Crops. ADAS Advisory Paper No. 17 MAFF, London.

CATLOW J., THIRLWALL C.G. (1976) "Environmental impact analysis study, interim report" DOE Research Report II, HMSO, London.

CHAPMAN, W.B., P. BAKER, BURNS L. (1976) Development Materials Bulletin (GLC) 98, pp 1-8. Some guidelines in the re-use of industrially contaminated land.

CHESHIRE COUNTY COUNCIL, (1977) Structure Plan Report of Survey, County Hall, Chester.

CHOW, T.J. (1970) "Lead accumulation in roadside soils and grass". Nature, Vol. 25, pp 295-296.

CHOW, T.J. & M.S. JOHNSTONE. (1965) "Lead isotopes in gasoline and aerosols of Los Angeles Basin; California". Science, Vol 147, pp 502-3.

CHUMBLEY, C.G. (1971) Permissible levels of toxic metals in sewage sludge used on agricultural land. ADAS Advisory paper No. 10 MAFF London.

CHURCH B.M. & WEBBER J. (1971) Fertiliser practice in England & Wales: a new series of surveys. Jn. of science of Food & Agric. Vol 22 pp 1-7.

CIVIC TRUST (1977) Urban Wasteland. Civic Trust, London.

CLARK B. (1976) "Evaluating environmental impacts", in Environmental Impact Assessment, O'Riordon T., Hey R. (eds) Saxon House, Farnborough.

CLARK, B.D., K. CHAPMAN, R. BISSET & P. WALHAM (1976) Assessment of Major Industrial Applications: A Manuf, DOE Research Report 13, DOE, HMSO.

COLBOURNE, P. & THORNTON I. (1978) "Lead Pollution in Agricultural Soils in Southern Peak District". Jnl. Soil Science, Vol. 29, pp 513-526.

CONSERVATION SOCIETY (1978) Lead Pollution & Health Effects Symposium.

COOL, M., MOREAUX, F., POULIN, A. & M.C. MEHAN (1980) "Metallic contaminants in street soils of Moncton, New Brunswick, Canada". Bull. Environ. Cont. Toxic., Vol 25: pp 409-415

DAVIES, B.E. (1971) "Trace Metal Content of Soils affected by base metal mining in the West of England." Oikos 22, 336-372

DAVIES, B.E. (1976) Conference Trace Metals in the Environment, Toronto (World Health Organisation)

DAVIES, B.E. (1978) Science of Total Environment pp 243-262

DAVIES, B.E. (1980) Trace Element Pollution. In Applied Soil Trace Elements, pp 289-350, Ed. B.E. Davies, J. Wiley & Sons, London.

DAVIES, B.E., CONWAY, B. & HOLT, S. (1979) "Lead Pollution of London Soils - A Potential Restriction on their use for growing vegetables." Jn. Agric. Science, Vol 93, pp24-35.

DAVIES, B.E., & ROBERTS L.J. (1975) "Heavy metals in soils and radish in a mineralised limestone area of Wales." Science of the Total Environment Vol. 4 pp 249-263

DAVIES, B.E., CONWAY D., & HOLTS (1979) "Lead Pollution of London Soils. A Potential Restruction on the use for

DAVIES, B.E. & P.L. HOLMES (1972) "Lead Contamination of Roadside Soil and Grass in Birmingham, England, in Relation to naturally occurring levels". Jn. Agric. Sci. Vol. 79, pp 479-484.

DAVIES, B.E., & ROBERTS L.J. (1975) "Heavy Metals in soils and radish in a mineralised limestone area of Wales." Science of the Total Environment Vol. 4 pp 249-263

DEAN, F.E., & B.B. GOALBY (1980) Successful Redevelopment of Gaswork Sites in Reclamation of Contaminated Land, Society of Chemical Industry.

DEPARTMENT OF THE ENVIRONMENT (1977) Report of the Working Party on the Disposal of Sewage Sludge to Land., DOE & N.W.C., London

DEPARTMENT OF THE ENVIRONMENT (1980) Cadmium in the Environment and its significance to man. Central Directorate on Environmental Pollution, paper No. 17, HMSO London.

DEPARTMENT OF THE ENVIRONMENT (1979) Soil Contamination at Shipham - Interim Report on Survey.

DEPARTMENT OF THE ENVIRONMENT (1979) ICRCL 16/78, Redevelopment of Contaminated Land: Acceptable Levels of Contaminants in Soils.

DEPARTMENT OF THE ENVIRONMENT (1979) ICRCL 24/79 Standards for the Redevelopment of Contaminated Land. (ICRCL 24/79) DOE CDEP.

DEPARTMENT OF THE ENVIRONMENT (1980) ICRCL 38/80 Redevelopment of Contaminated Land: Tentative Guidelines for Acceptable Levels of Selected Elements in Soils (ICRCL 38/80), DOE, CDEP

DEPARTMENT OF THE ENVIRONMENT (1981) ICRCL 47/81 Tentative Guidelines for Acceptable Concentrations of Contaminants in Soils. (ICRCL 47/81), DOE, CDEP.

DEPARTMENT OF SCIENCE AND INDUSTRIAL RESEARCH (1967) Soil Bureau Atlas D. SIR, Wellington N.Z.

DICKINSON, G.C. (1973) Statistical Mapping and the Presentatiion of statistics. Edward Arnold, London

DOLAR, S.G. & D.R. KEENEY (1971) "Availability of copper, zinc and manganese in soil: Influence of soil pH, organic matter and available phosphorous". Jn. Sci. Food and Agric., Vol 22, pp 273-278.

DUGGAN, M.J., & S. WILLIAMS, (1977) Scien. Tot. Env., Vol 7, p 91

EVERETT, J.L., DAY C.L., & REYNOLDS B. (1976) "Comparative Survey of Lead at selected sites in British Isles in relation to Air Pollution". Cosmetics Toxicology Vol. 55 pp 29-35

FERRANTE, E. Di., & A. BERLIN (1981) Research & Rregulatory Actions on Heavy Metals in the European Community Paper to Conference Metals in the Environment, Amsterdam.

FLEMING, G.A., & P.J. PARKE (1977) "Heavy Metals in Soils, Herbage & vegetables from an industrial area of the West of Dublin City." Jnl. Agric Research 16 pp 35-48

FOLLETT, R.H. & W.L. LINDSAY (1970) Colorado Agricultural Experimental Station Technical Bulletin 110

FRIBERG, L. & M. PISATOR, G.E. NORDBERG & T. KJELSTROM (1974) Cadmium in the Environment. CRC Press

GOODMAN, G.T. & T.M. ROBERTS (1971) "Plant and soils as indicators of metal in the air". Nature, Vol. 231 pp 281-292

GREENLAND, D.J. & M.H.B. HAYES (Eds) (1980) The Chemistry of Soil Processes. John Wiley & Sons. London

GRIFFITHS, J. & G. WADSWORTH (1977) "Heavy metal pollution of farms near an industrial complex. In Inorganic Pollution and Agric. MAFF Ref. Book 326 HMSO Land (1980) pp 70-76

HAINES, R.C. (1981) Mapping Background levels of Heavy Metals in Urban Soils. Paper to conference: Heavy Metals in the Environment, Amsterdam 1981

HAINES, R.C. & J.L. CHALLINOR, (1979) Fact Sheets for a workshop on Derelict land. JURUE R.N.2.

HAINES, R.C. & R.L. POCOCK (1980) Heavy Metal Land Contamination: Background Levels and site Case Histories. JURUE Research Note 17, University of Aston.

HARRISON, R.M. (1979) "Toxic Metals in Street and Household Dusts". Scien. Tot. nv., Vol II: pp 89-97

H.M.S.O. DEPARTMENT OF THE ENVIRONMENT (1976) Lead in the Environment and its Significance to Man. Pollution Paper No. 2 HMSO London.

HARWELL, (1981) Problems Arising from the Redevelopment of Gasworks and similar sites, Env. & Medic. Services Div. AERE, Harwell

HODGSON, J.M. (1978) Soil Sampling and Soil Description - Monographs in Soil Survey, Clarendon Press, Oxford.

ISAAC, R.A. & J.D. KERBER (1971) "Atomic absorption and flame photometry: Techniquies and uses in soil, plant and water analysis". In: Instr. methods for Analysis of Soils and Plant Tissue., L.M. WALSH (ed). Soil Science Society of America, Madison Wisconsin: pp 17-37

INSKIP, M.J. (1973) "Cadmium levels in the Environment". In: Inter-Research Council Committee on the Pollution, 1973, W.E.R.C. London.

JENNY, H. (1941) Factors of Soil Formation, McGraw Hill, New York.

JOHN, M.K. (1971) Environmental Science & Technology, Vol. 5 pp 1199-1203

JOHN, M.K. (1972) "Lead availability related to soil properties and extractable lead". Jn. Environ. Qual. Vol I, No 3: pp 295-298

JOINT UNIT FOR RESEARCH ON THE URBAN ENVIRONMENT (1981) Environmental Pollution and Structural Industrial Change: A Pilot Study of the West Midlands. University of Aston in Birmingham

JOINT UN IT FOR RESEARCH ON THE URBAN ENVIRONMENT (1981) 'Contaminated Sites in the West Midlands: Unpublished report. A prospective survey to the D.O.E.

JOINT UNIT FOR RESEARCH ON THE URBAN ENVIRONMENT (1982) Reducing Metals in the Environment. Unpublished Report to the DOE.

JONES, L.H.P. & C.R. CLEMENTS (1972) 'Lead in the Environment'. P. Hepple (ed), Applied Science Publishers: pp 29-33

JONES, A.K., M.S. JOHNSON & R.M. BELL (1981) The Movement of Metals in Reclaimed Metal Contaminated Lane. Paper Conf. Heavy Metals in the Environment, Amsterdam, 1981

JORDAN, L.D., & M.J. HOPPER (1975) "Survey of lead in Christchurch soils, New Zealand". Jn. Science, Vol 17 pp 253-260

KAHN, H.L., FERNANDER, F.J. & S. SLAVIN (1972) "The determination of lead and cadmium in soils and leaves by A.A.S.' At. Absorpt. Newsl. II: p 42.

KARPE H.J. & SCHOLZ, D. (1976) "Environmental pollution and its social impact". N.A.T.O. conference paper October 1976, Instanbul

KERIN, Z. (1975) "Relationship between the lead content in the soil and in plants contaminated by industrial emissions of lead aerosols". In Heavy Metals in the Environment, Conference proceedings (1975) Int. Conf. Toronto.

KHAN, A.Q. (1980) 'Investigation and Treatment of Roverfield Tip'. In Reclamation of Contaminated Land. Proc. Conf. S.C.I. London

KHAN, D.H. (1980) Lead in the Soil Environment. M.A.R.C. Technical Report 21, Monitoring Assessment and Research Centre, Chelsea College, University of London.

KELLY, R.T. (1979) Site Investigation & Materials Problems. Proceeding Reclamation of Contaminated Land Conference Eastbourne Society of the Chemical Industry.

KENNY, A.W. (1980) Opening Address, Conference on the reclamation of contaminated land'. S.C.I. London.

KIRKHAM, M.B. (1975) "Trace elements in corn grown on a long term sludge disposal site". Env. science Technical Vol. 9 pp 265-268.

KLEIN, D.H. (1972) 'Mercury and Other Metals in Urban Soils'. Env. Science & Tech. Vol. 6 & 23, pp 93-100

KORTE, N.E., SKAPP, J., FULLER, W.H., NIEBLE, E.E. & B.A. ALLESSI (1978) "Trace element movement in soil: Influenceof soil physical and chemical properties". Soil Science, Vol. 122: pp 350-359

KUBOTA J., & ALLOWAY L.J.H. (1972) Geographic Distribution of Trace Elements Problems. In Micro-nutrients in Agriculture (Ed) Morvedt J. Soil Science Soc.

LAGERWERFF, J.V. & A.W. SPRECHT (1970) "Contamination of roadside coil and vegetation with cadmium, nickel, lead and zinc." Env. Sci. & Technol. Vol. 4 pp 583-586

LAGERWERFF, J.V. (1973) 'Accumulation of cadmium copper lead and zinc in soils and vegetables in proximity of a smelter'. In Trace Substances in Environmental Health VI pp 71-78 Ed. D.D. Hemphill

LEPP, N.W. & M.R. HARRIS (1980) A Strategy for Evaluation of soil covering techniquies to reduce trace metal uptake by soft fruits and vegetables. Paper Proc. Conf. Reclamation of Contaminated Land S.C.I. London.

LE RICHE, H.H. (1968) "Metal Contamination of Soil in Worburn Market Garden Experiment resulting from the application of Sewage Sludge". Jn Agric. Sci., Vol 71: pp 205-208

LE RICHE, H.H. (1959) "The distribution of certain trace elements in lower lias of Southern England". Geochemica & Cosmochemica Acta Vol. 16 pp 101-102

LE RICHE, H.H., & A. WEIR, (1963) "A Method of Studying trace elements in soil fractions". Jn. Soil Science Vol. 14: pp 223-235

LINDSAY, D.G. (1980) 'Evaluation of the Impact of Inorganic soil pollutants on consumers'. In Inorganic Pollution and Agriculture M.A.F.F. Ref. Book 326, H.M.S.O. London

LISK, D.J. (1972) "Trace Metals in Soils, plants and animals". Adv. Agron: Vol 24 pp 267-325

LITTLE, P. (1974) Airborne Zinc, Lead and Cadmium Pollution and its effects on Soils and Vegetation. Phd. Thesis, University of Bristol.

LITTLE, P. & M.H. MARTIN (1974) "Biological monitoring of heavy metal pollution". Environ. Poll., Vol 6: pp 311-319

LITTLE, P. & M.H. MARTIN (1972) A survey of zinc, lead and cadmium in soil and natural vegetation around a smelting complex. Env. Poll. 3 241-254

MINISTRY OF AGRICULTURE FISHERIES & FOOD (1973) The Analysis of Agricultural Materials, Technical Bulletin No. 27 Ministry of Agriculture Fisheries & Food HMSO London

MANNING, D.C., & J.D. KERBER (1975) "The use of Atomic Absorption Spectrochemical Analysis in the field of Agronomy. A.A. Applied Study No 579".

McCLEAN, A.J., R.L. HOLSTED & B.J. FINN (1969) "Extractability of added lead in soils and its concentration in plants". Can. Jn. Soil. Sci Vol 49: pp 327-334

MARTEN, G.C. & P.B. HAMMOND (1966) "Lead uptake by bromegrass from contaminated soils". Agron. Jn. Vol 58: pp 553-554

MERSEYSIDE COUNTY COUNCIL, (1980) Merseyside Structure Plan - written statement, Merseyside County Liverpool

MINISTRY OF AGRICULTURE, FISHERIES & FOOD (1971) Advisory Paper, ADAS 10, Permissible Levels of Toxic Metals in Sewage based on Agricultural Water Pollution Research Laboratory 1972, Water Pollution Paper No. 57.

MISRA, S.G., & G. PANDEY (1976) "Evaluation of suitable extracts for available lead in soils". Plant and soil, Vol 45: pp693-696

MITCHELL, R.L. (1963) The Spectrochemical Analysis of Soils Plants and Related Materials. Tech. Comm. No 44A. Commonwealth Bureau of Soils.

NRIAGO J.O. (Ed) (1979) Copper in the Environment. Wiley Interscience

NRIAGO J.O. (1980) Cadmium in the Environment, Wiley Interscience

NRIAGO J.O. (Ed) (1980) Zinc in the Environment, Wiley Interscience

O.E.C.D. (1978) Urban Environmental Indicators OECD Paris

O.E.C.D. (1979) The State of the Environment in Member Countries. OECD Paris

OSMOND, R.G.D. (1980) 'Landfill Research in the U.K. - Some Results and Implications'. Paper to ISWA Meeting June 1980 London

PALMER, K.T. & C.L. KUCERA (1980) Jn. Env. Qual. Vol. 9 pp 106-111

PECK, T.R. & S.W. MELSTED (1967) "Field Sampling for soil testing" In: Soil Testing and Plant Analysis, Soil Science Society of America, Special Publication No. 2: pp 23-35

PERRY G.D.R., JOHNSON, M.S. & BELL R.M., (1981) "Trace metal surveys of soil as a Component of Strategic & Local Planning Policy Development". Environmental Pollution Series B. Vol. 2 pp 97-107

PIOTROWSKI J.K. & D.O. COLEMAN (1980) Environmental Hazards of Heavy Metals. Summary evaluation of lead, cadmium and mercury. M.A.R.C. Report 20 Chelsea College

POCOCK R.L. (1979) The measurement and prediction of Ambient Environmental conditions in Urban Areas. PhD Thesis, University of Aston

POWLUK, S. (1967) "Soil analysis by Atomic Absorption". At. Ansorpt. Newsl. 6, p 53

PREER, J.R. & W.B. ROSEN (1978) "Lead and Cadmium Content of Urban Garden Vegetables". Trace Substances in Env. Health Vol. II pp399-406

PURVES D. (1966) "Contamination of Urban Garden Soils with Copper and Boron. Nature 210 pp 1077-1078

PURVES D. (1968) Trace Element Contamination of Soils in Urban Areas. 9th Int. Congress Soil Science Adelaide pp 351-355

PURVES, D. (1968) "Trace Element Content of Garden Soils". Welsh Soil Discussion Group Report, Vol 9: pp 31-40

PURVES, D. (1979) Trace Element Contamination of Soils from Sewage Sludge Application. Proceedings of conference on Heavy Metals in the Environment London.

PURVES, D. & MACKENZIE E.J. (1979) Trace Element Contamination of Parkland in Urban Areas. In Jnl. Soil Science Vol. 20 No. 2 pp 288-290

RICHARDSON, S. (1977) "Composition of Soil and crops following treatment with Sewage Sludge". In: Inorganic Pollution and Agriculture. M.A.F.F. Ref. Book 326, H.M.S.O. London (1980): pp 252-264

REES, T.D. & J. HILTON (1978) A rapid method for the determination of heavy metals in sewage sludge". Water and Sewage works Ref. No. 32

RITTER, C.J., BERGMANN, S.C., COLTERN C.R. & E.E. ZAMIEROWSKI (1978) "Comparison of sample preparation techniquies for A.A. analysis of sewage sludge and soil". At. Absorpt. Newsl. No. 17: pp 70

ROBERTS T.M. (1975) A review of Some Biological Effects of Emission from Primary and Secondary Smelters. In Symp. procedures. Int. Conf. on Heavy Metals in the Environment Institute for Env. Studies, Toronto Canada pp 503 - 532

ROLFE, G.L. & JENNET J.C. (1975) Environmental Lead Distribution in Relation to Automobile and Mine Smelter Sources. In Progress in Water Technology Supplement pp 231-246 Pergamon Oxford

SCOTT, R.O. MITCHELL R.L., PURVES D. & R.C. VOGUE (1968) Spectrochemical Methods for the Analysis of Soils, Plants and Other Agricul tural Materials, Commonwealth Bureau of Soils

SMITH, M.A. (1980) 'Contaminated Land in Cities' Paper to Biology Section, British Association for the Advancement of Science, Salford U.K.

SMITH, M.A. (1981) Controlling the Development of Contaminated Land. In Local Government and Environmental Pollution Control, Ed. F.E. Joyce , Gower Press Aldeshot p 118-130

SOLOMON, R.L. & J.W. HARTFORD (1976) "Lead and Cadmium in dusts and soils in a small urban community". Env. Sci. Technol. Vol 10: p 773

SOUTH YORKSHIRE COUNTY COUNCIL (1978a) Environmental Mapping of the European Community - Second Report Borsley S.Y.C.C.

SOUTH YORKSHIRE COUNTY COUNCIL (1978b) County Environment Study. Barnsley S.Y.C.C.

SOUTH YORKSHIRE COUNTY COUNCIL (1978c) Environmental Mapping of the European Community - Preliminary Report, Barnsley S.Y.C.C.

SWAINE, D.J. (1955) Commonwealth Bureau of Soil Science Technical Communication No. 48 Commonwealth Agric. Bureau

SWAINE D.J., & MITCHELL R.L. (1960) "Trace Element distribution in soil profiles". Jnl. Soil Science Vol II No. 2

THOMPSON, K.C. & K. WAGSTAFF (1978) Development of a Technique for the Analysis of Certain Toxic Metals. Internal Report No TP 116/ML19, Severn Trent Water Authority, Malvern

THORNTON I., (1975) Some Aspects of Env. Geochemistry in Britain in Proced. of Heavy Metals in Environment Toronto Canada

THORNTON I. & WEBB J.S. (1980) Regional Distribution of Trace Element Problems in Great Britain. In Applied Soil Trace Elements (Ed) Davies B.E., J. Wiley & Sons London

THE TOYS (SAFETY) REGULATIONS (1974) Statutory Instrument No. 1367, HMSO

THE PENCILS & GRAPHIC INSTRUMENTS (SAFETY) REGULATIONS (1974) Statutory Instrument No. 226, HMSO

TOWNSEND, W.N. (1973) An Introduction to the Scientific Study of the Soil. Adward Arnold Ltd.

WALDRON, H.A. (Ed) (1980) Metals in the Environment Acedemic Press, London

WARREN, H.V.,DELAVAULT, R.E., & FLETCHER K.W. (1971) Canadian Mineral and Metals Bulletin pp 1 - 12

WATER RESEARCH CENTRE (1981) Sewage Sludge Disposal: A Strategic Review and Assessment of Research Needs". W.R.C. Medenham

WEBB, J.S., LOWENSTEIN, P.C., HOWARTH, R.J., & FORTER, R. (1973) Provisicanal Geochemical Atlas of N. Ireland A.G.R.G. Technical Communication no. 60, Imperial College, London

WEBB, J.S., & THORNTON, I., THOMPSON, M., & LOWENSTEIN, P.H. (1978) The Woolfson Geochemical Atlas of England & Wales. Oxford University Press, Oxford.

WEST MIDLANDS COUNTY COUNCIL (1979) Structure Plan Report of Survey, Land Resources, County Hall, Birmingham.

WILKINS, C. (1978) "The Distribution of Lead in Soils & Herbage of West Pembrokeshire". Env. Pollution Vol. 15 pp 23-30

WILLIAMS, C. (1974) "The Accumulation of Lead in soils & herbage at Rothamstead Experimental Station". Journal Agricultural Science, Vol. 82 pp 189-192

WILLIAMS, J.H. (1980) 'Metal concentrations in soils and crop phytotoxicity'. In Reclamation of Contaminated Land, Conference Proceedings, Society of Chemical Industry, London

WILLIAMS, J.H. (1980) Private Communication, A.D.A.S. Wolverhampton

WILSON, D.C. & B.C. HUDSON (1980) Spent Oxide Pollution from former Gas Works Sites - S.C.I. Conference

WILSON, D.C. & E.T. SMITH (1980) 'Investigation & Treatment of Rovenfield Tip'. In Reclamation of Contaminated Land Proc. Conf. S.C.I. London

WOOD, C.M., LEE, N., LUKER, J.A. & P.J.W. SAUNDERS (1974) The Geography of Pollution. A Study of Greater Manchester, University of Manchester Press.

WRIGHT, J.R., LEVICK R. & H.J. ATKINS (1955) "Trace element distribution in virgin profiles representing four great soil groups". Soil Science Society of America Proceeedings, vol 19: pp 340 - 344

WUN LIN & A.D. BRADSHAW (1972) "Areal pollution and the rapid evolution of copper tolerance". Nature 238: pp 167 - 9