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Human Health Risk Assessment for Exposure to Soil at London Road Allotments, Coventry (UK)

Environmental Protection Programme

Commissioned Report CR/04/045N



BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/04/045N

Human Health Risk Assessment for Exposure to Soil at London Road Allotments, Coventry (UK)

Barbara Palumbo, Barry Rawlins, Charlotte Herbert, Holger Kessler
and Ben Klinck

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Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ 01491-838800 Fax 01491-692345

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

Foreword

This report is the published product of a study by the British Geological Survey (BGS) carried out on behalf of Coventry City Council. The aim of the study was to investigate the human health risk associated with exposure to cadmium (Cd) in soil by tenants of the London Road allotments, Coventry.

Acknowledgements

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Summary

As a result of a soil geochemical survey undertaken throughout Coventry by the British Geological Survey (BGS), cadmium (Cd) concentrations above the Soil Guideline Value (SGV) issued by DEFRA and Environment Agency were recorded at the London Road allotments. In view of the presence of a potential exposure pathway it was deemed necessary to carry out a risk assessment in order to determine the current health risk to gardeners working at the site and families consuming home-grown vegetables from the site. The allotment site was sampled on a 20 m grid (164 sampling locations) with samples taken from the surface layer (top 15 cm) and at 20 locations down to 40 cm depth. Soil Cd concentrations ranged up to 4.1 mg kg⁻¹ with a mean value of 0.9 mg kg⁻¹. The levels of Cd in vegetables sampled from the site were all below the regulatory limit of 0.2 mg kg⁻¹ fresh weight (FW) for leafy vegetables and 0.1 mg kg⁻¹ FW for stem and root vegetables as laid down in Commission Regulation (EC) No. 466/2001. The CLEA (Contaminated Land Exposure Assessment) model was applied using site specific data to estimate the average daily exposure to Cd. The ratio of average daily exposure (ADE) over the Tolerable Daily Intake (TDI) for Cd was estimated for a female child aged 6, which represents a worst case scenario. The pathway considered in the analysis was oral uptake through soil ingestion. The exposure pathway through consumption of contaminated home-grown vegetables was excluded on the basis of the measured Cd levels in the vegetables grown at the site. The estimated ADE/TDI ratio is 0.01, suggesting that there is no significant toxic risk deriving from exposure to Cd in soil for gardeners working at the site.

This site specific risk assessment is intended to assist Coventry City Council in declarations concerning the status of the site with respect to Part IIa of the Environmental Protection Act (1990).

1 Introduction

This report is the published product of a study by the British Geological Survey (BGS) carried out on behalf of Coventry City Council. As part of a broader soil geochemical survey undertaken throughout Coventry by the BGS, cadmium (Cd) concentrations above the Soil Guideline Values (SGV) provided by DEFRA and Environment Agency (2002a) for allotments land use (Cd 1 mg kg⁻¹ for soil pH 6) were recorded at the London Road Allotments in Coventry (435000; 277500) (Figure 1). As there is a potential source-pathway-receptor linkage at the site the need for further investigation was recognised. The object of the work was to assess the risk posed to human health by the Cd concentrations in soils at the site.

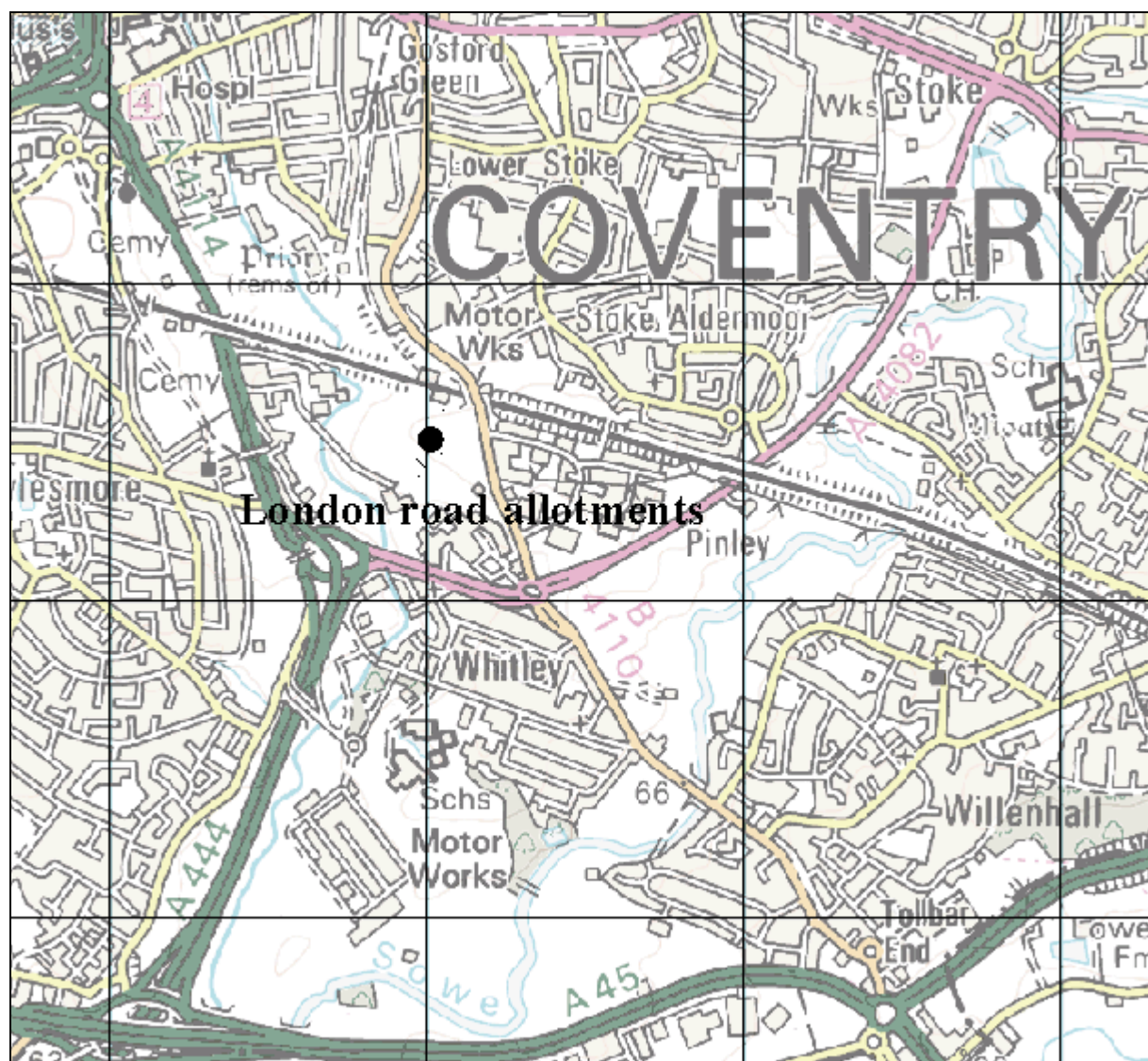


Figure 1 - Location of London Road allotments, Coventry. Ordnance Survey © Crown copyright. All rights reserved.

1.1 OUTLINE OF SITE-SPECIFIC RISK ASSESSMENT

A site-specific risk assessment was carried out and subdivided into the following phases:

- Tier 1 risk assessment

A comprehensive desk-based review (Tier I risk assessment) was carried out, giving an initial assessment of the environmental risk associated with the site.

- Site and source characterisation

A site investigation was undertaken to determine the magnitude and extent of Cd contamination.

A map of Cd concentrations and pH at the site was generated based on standard geostatistical methods.

- Pathway and target definition

Various ways in which direct and indirect exposure to Cd from soils might occur were considered. Analysis of Cd in vegetables grown at the site was carried out to evaluate plant uptake. Potential targets on the site or sensitive off-site targets were also considered.

- Conceptual Model

A conceptual model of pollutant linkage was developed for the site. The CLEA (Contaminated Land Exposure Assessment) model (DEFRA and Environment Agency, 2002b) for allotment sites was run using site specific data and the suitability of the CLEA model for human exposure was assessed.

2 Material and methods

2.1 SITE INVESTIGATION

A site investigation was undertaken in accordance with British Standard 10175:2001 to determine the extent of Cd contamination. Surface soil samples (0-15cm depth) were collected on a 20-metre grid throughout the site. At each sampling site, nine sub-samples were collected using a hand auger at the corners, along the edge and in the centre of a 1-metre square, and bulked to form a composite sample for a total number of 170 samples collected including 6 replicates. At 20 of these sites, composite samples were also collected at depths of 15-45 cm. Twenty one vegetable samples were also collected from the site.

2.2 MEASUREMENTS OF THE TOTAL Cd CONTENT IN SOILS AND VEGETABLES

Soil samples collected as part of the initial nested survey (Rawlins and Lark, 2002) were air dried and sieved to less than 2 mm and analysed for their total Cd concentration by energy dispersive, polarised, X-ray fluorescence spectrometry. In the present, more comprehensive survey samples were analysed by ICP-MS after digestion with a $\text{HClO}_4\text{-HNO}_3\text{-HCl-HF}$ attack.

Vegetable samples were prepared in the same way as if they were to be eaten (washed in water and, where necessary, peeled). Samples were freeze-dried and then subjected to a mixed $\text{HNO}_3\text{-H}_2\text{O}_2$ attack in a microwave digester with subsequent chemical analysis by ICP-MS.

2.3 DETERMINATION OF ORGANIC CARBON CONTENT

The organic carbon content of each sample was estimated by measuring the weight loss after heating to a temperature of 450°C. This method has been widely adopted in soil science because of its ease of use, it is inexpensive, rapid, requires no specialized training, and strong statistical relationships commonly exist between organic matter and organic carbon contents estimated by standard dry combustion procedures (Sutherland, 1998). Samples were initially dried at 105 °C to remove any residual water. Samples were then heated in a furnace at 450°C for four hours and allowed to cool in a dessicator prior to weighing to produce loss on ignition data, which was used as a measure of the organic carbon content of the sample. Each soil was weighed prior to and after heating, the decrease in weight was calculated as a proportion of the initial weight and expressed as a percentage weight loss. It has been reported that the average carbon content of organic matter is approximately 58% (Broadbent, 1953), therefore an estimate of carbon content was calculated by multiplying the assumed organic matter content (%) by 0.58.

2.4 DETERMINATION OF SOIL pH

The pH of each soil was determined using a standard protocol (Rowell, 1994). The pH was measured using a glass slurry electrode and Orion 720A meter. The pH meter was calibrated to 4 and 7 or 7 and 9 depending on the pH of the slurry to be measured. To 10.0 g of the <2mm sample, 25 ml of 0.01 M calcium chloride solution was added, the samples were magnetically stirred for one minute and then left to settle for 15 minutes. Prior to recording of the pH value the samples were stirred to reform the suspension.

2.5 DETERMINATION OF SOIL Cd EXTRACTED IN AMMONIUM CHLORIDE

Five hundred grams of soil from the rooting zone of each vegetable were sampled for the determination of proportion of plant-available Cd based on an ammonium chloride (NH₄Cl) extraction test described by Krishnamurti et al (2000).

2.6 SOIL PIT EXCAVATION

Four soil pits were excavated on site using a mechanical digger with the intention of assessing the presence of soil horizons (both natural and through historical application of soil material). The profiles were described according to the British Standard for Site Investigations (BS5930).

2.7 ESTIMATION OF MEASUREMENT UNCERTAINTY

The variation in soil geochemistry across a site can be conveniently separated into three components:

$$s_{total}^2 = s_{geochem}^2 + s_{samp}^2 + s_{anal}^2$$

The latter two components represent the measurement uncertainty of the sampling scheme, combining the sampling and analytical components. $s_{geochem}^2$ is the variance attributable to the spatial variation in concentration of the analyte throughout the site, s_{samp}^2 is the variation at a site (which includes a component of spatial variance up to 1 metre) and s_{anal}^2 is the analytical variance. During the survey of the London Rd allotments duplicates were collected and subsampled at six of the original survey locations (for a total of 24 samples).

A nested analysis of variance (ANOVA) was used to assess the relative importance of the three variance components for total Cd.

Table 1 – Results from ANOVA to estimate variance components (%) for i) the site, ii) duplicate samples (short scale variability) and iii) sub-sample (analytical) variability

	Site	Duplicate	Analytical
Cd	85.7	0	14.3

The results show that the vast majority of the variation (86%) in Cd at the site is due to spatial variation at scales greater than 1 metre, and the remainder is due to analytical error.

3 Tier One Risk Assessment

3.1 INTRODUCTION

The Tier 1 Risk assessment was a desk study designed to establish the history of the site and the surrounding area, and in particular to identify activities performed at the site that may have resulted in the elevated Cd concentrations identified at the site. It also identifies environmentally sensitive areas and activities that may affect the site. The data reviewed was from three main sources: BGS data holdings, Coventry City Council Environmental Health & Planning Departments' data holdings, and information held by the Coventry City Archives. Information on environmental designations comes from English Nature, and groundwater vulnerability information from the EA.

3.2 SITE HISTORY

3.2.1 Historical Maps & Plans

Ordnance Survey mapping for the area dates back to 1888. Both 25"/1:2500 and 6"/1:10,000 maps were examined as part of this study. Figures 2 to 10 illustrate the history of the site over time. In 1888 (Figure 2), the site, and most of the surrounding area, was shown as open farmland. The site was bounded to the north by the Rugby-Birmingham railway line and to the west by the River Sherbourne. To the northwest was a sewage works, and Swifts Corner Mill (the type of mill is not recorded). Pinley Green Farm was just outside the site to the south. Between 1888 and 1903 (Figure 3), little had changed on the site. The mill to the west was no longer indicated, and an additional sewage pumping works had been built to the south of the site. By 1925 (Figure 4), the site had been laid down to allotments. The sewage works to the northwest had expanded, and the fields bordering the river to the west and southwest had become filtration beds. By 1936 (Figure 5), the Whitley Hospital had been built to the south of the site. Between 1936 and 1947 (Figure 6), there were no significant changes shown on the map. A 1961 land use survey, held at the archive office, shows that the sewage works to the northwest were still active – a note on the plans indicates the sedimentation tanks were “used twice daily”. Many of the allotments on the western half of the site were vacant by this time. An electricity sub station was under construction to the east of the site. The 1969 National Grid map (Figure 7) only covers the western half of the site. The sewage works to the northwest may have closed by this point, as their site is now labelled as an unspecified “works”. However, the filtration beds were still present on the west bank of the river. By 1977 (Figure 8) the sewage works had definitely closed, and the associated buildings demolished and replaced. A chimney was now located on this site, but the purpose of the buildings is not indicated on the map. The sewage works to the south had been replaced by a depot, although a pumping station remained. The electricity sub-station to the east of the site had been completed. Sewage filtration activities to the west of the river appear to have ceased by this point. The 1992 map (Figure 9) shows the waste to energy plant to the northwest of the site, an expanded depot to the south, and an industrial estate developed to the east. Modern aerial photography (Figure 10) shows no changes in land use since 1992.

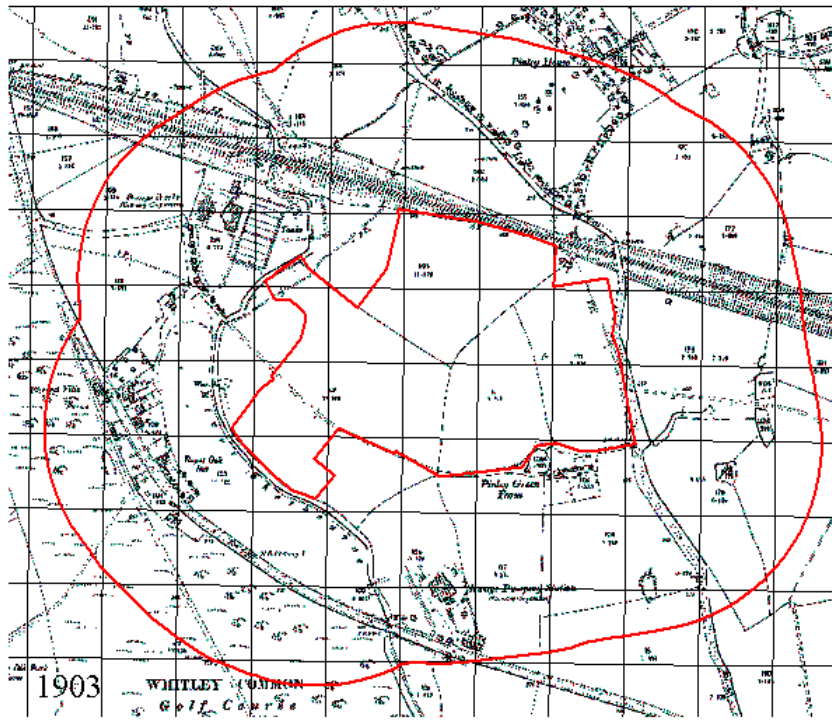


Figure 2 - 1888 25"/mile Ordnance Survey County Series map extract, showing site boundary and 250m buffer in red. Ordnance Survey © Crown copyright. All rights reserved.

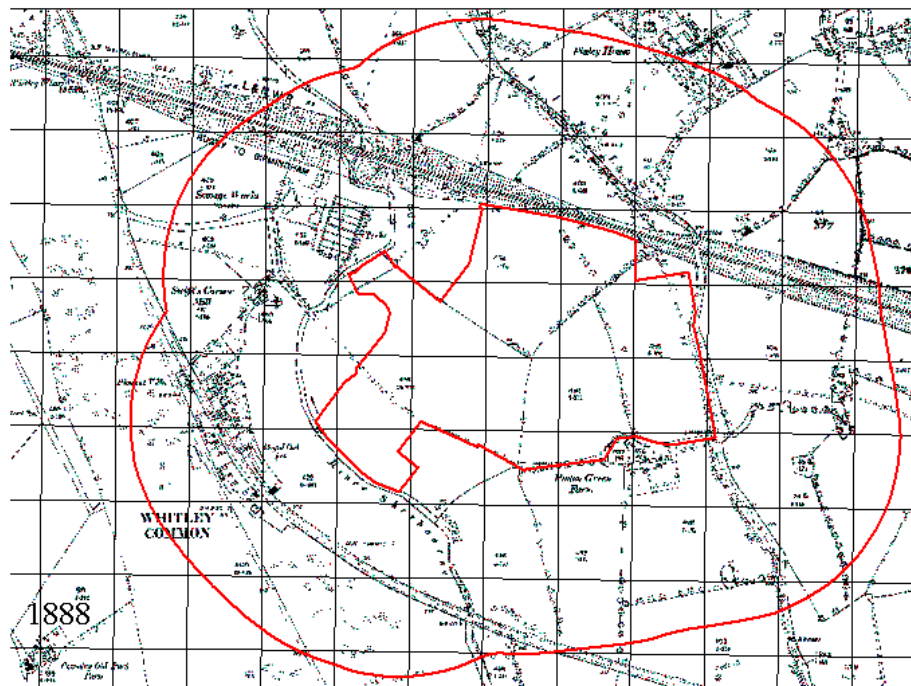


Figure 3 - 1903 25"/mile Ordnance Survey County Series map extract, showing site boundary and 250m buffer in red. Ordnance Survey © Crown copyright. All rights reserved.

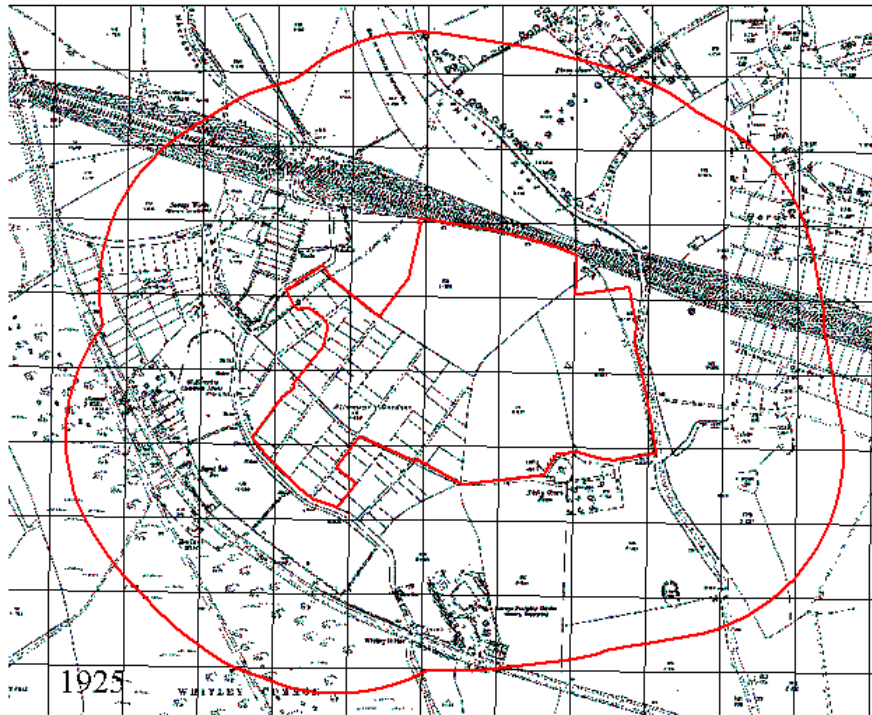


Figure 4 - 1925 25"/mile Ordnance Survey County Series map extract, showing site boundary and 250m buffer in red. Ordnance Survey © Crown copyright. All rights reserved.

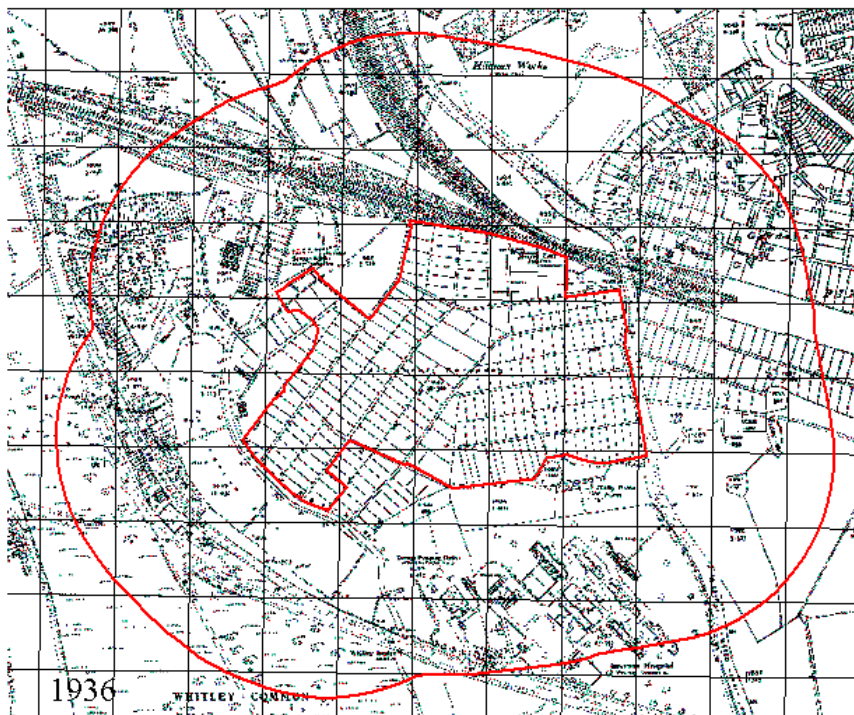


Figure 5 - 1936 25"/mile Ordnance Survey County Series map extract, showing site boundary and 250m buffer in red. Ordnance Survey © Crown copyright. All rights reserved.

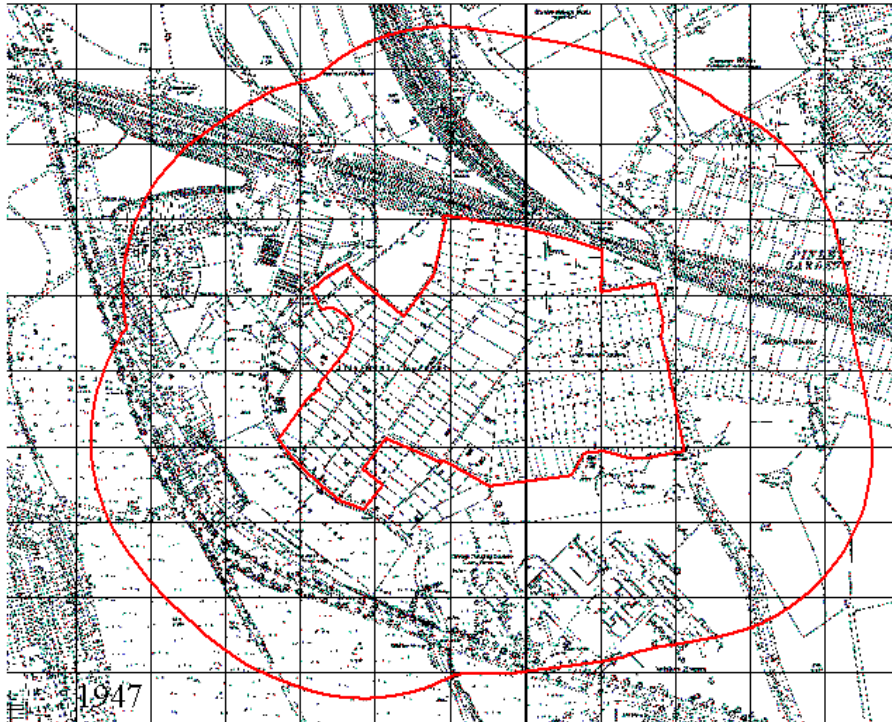


Figure 6 -1947 25''/mile Ordnance Survey County Series map extract, showing site boundary and 250m buffer in red. Ordnance Survey © Crown copyright. All rights reserved.



Figure 7 - 1969 Ordnance Survey National Grid 1:2500 map extract, showing site boundary and 250m buffer in red. Ordnance Survey © Crown copyright. All rights reserved.

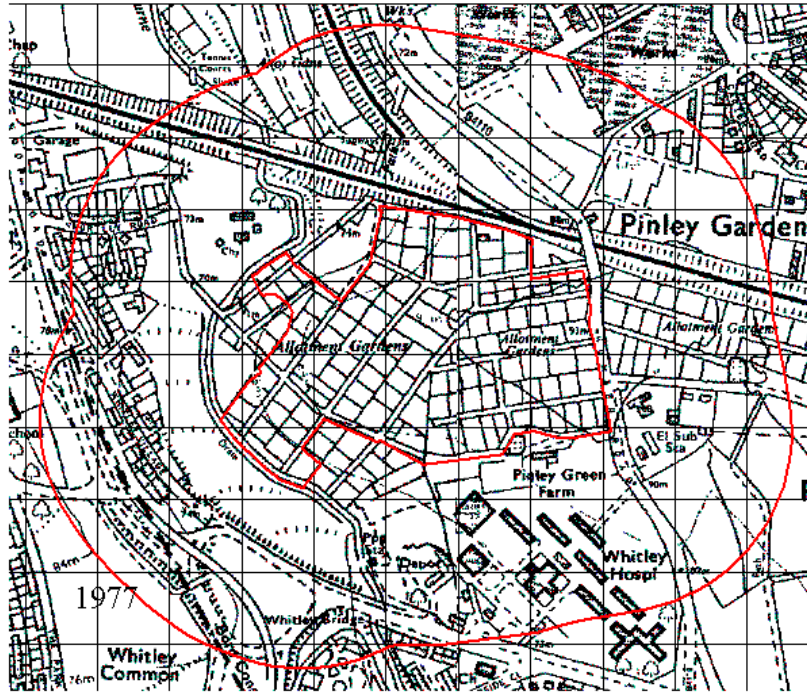


Figure 8 - 1977 Ordnance Survey National Grid 1:2500 map extract, showing site boundary and 250m buffer in red. Ordnance Survey © Crown copyright. All rights reserved.

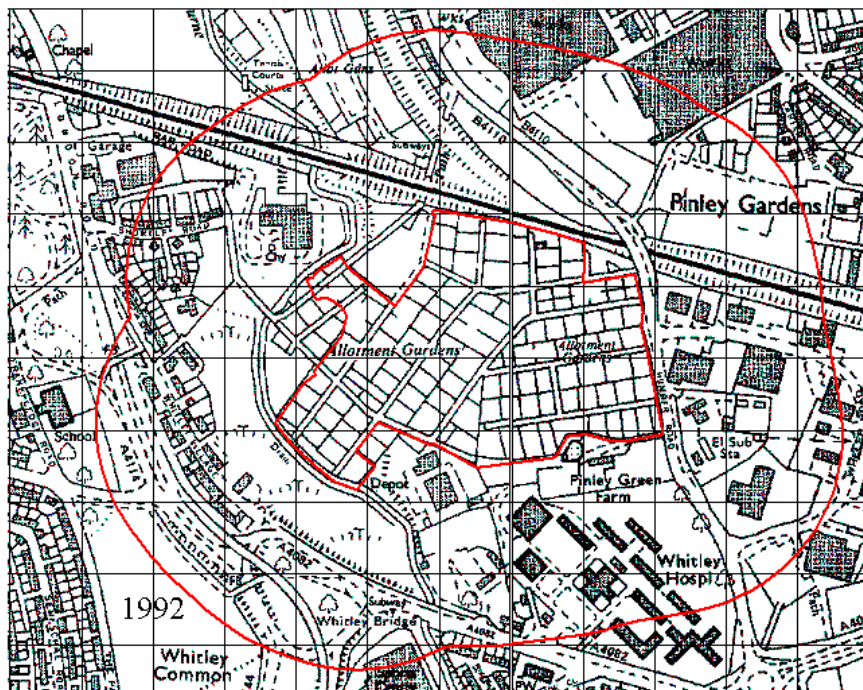


Figure 9 - 1992 Ordnance Survey National Grid 1:2500 map extract, showing site boundary and 250m buffer in red. Ordnance Survey © Crown copyright. All rights reserved.



Figure 10 - Modern aerial photograph.

3.2.2 Planning applications and site investigation reports

A thorough search of the planning applications archive was undertaken. No further potentially polluting activities/developments were identified aside from the installations indicated on the maps above.

The Environmental Health Department holds site investigation reports for the past ten years. No relevant reports were identified within the 250m buffer zone around the site. In 1994, a site investigation by Exploration Associates for Pinley Gardens, just outside the buffer zone to the east of the site, found elevated levels of arsenic, copper, nickel and zinc, and slightly elevated cadmium levels. The main part of the site was allotment gardens, but scrapyard activities had taken place in some parts of the site – this was the likely cause of contamination.

3.3 GEOLOGY

The site is covered by BGS 1:10,000 geological map sheets SP37NW and SP37NE. Extracts from these maps are shown in figures 11, 12, and 13.

3.3.1 Artificial deposits

No artificial (man-made) deposits are recorded beneath the site (Figures 11, 13). Areas of made ground occur to the west and southwest of the site. Made ground, of variable composition, occurs where the ground is known to have been deposited by man, such as spoil heaps. The area of made ground mapped immediately to the west of the site corresponds with the location of the sewage works filtration beds indicated on the 1969 and previous OS maps.

3.3.2 Superficial Geology

Alluvium occurs on the southwestern extreme of the site, along the river valley. The deposit normally comprises soft to firm consolidated, compressible silty clay, but can contain layers of silt, sand, peat and basal gravel. A stronger, desiccated surface zone may be present. BGS borehole SP37NW 81, located on alluvium in the filtration bed area to the west of the site, describes brown sandy clay, sandy silt, and grey silty clay with stones, overlying a basal sand and gravel unit. The Wolston Clay, comprising grey glaciolacustrine clay and silt, underlies the western part of the site. The majority of the site is underlain directly by bedrock (i.e. no recorded superficial deposits). Other superficial deposits occurring in the surrounding area are the Baginton Sand and Gravel, fluvial deposits thought to be associated with a preglacial river channel, and the Dunsmore Gravel, comprising flinty gravel with lenses of coarse sand.

3.3.3 Bedrock Geology

The majority of the site is underlain at rockhead by the sandstones of the Keresley Member (Salop Formation). These comprise thickly bedded sandstones with minor mudstone and conglomerate. The Eastern part of the site is underlain at rockhead by the Bromsgrove Sandstone formation, comprising red, brown and grey sandstones, commonly pebbly or conglomeratic at the bases of beds, interbedded with red and brown siltstones and mudstones.

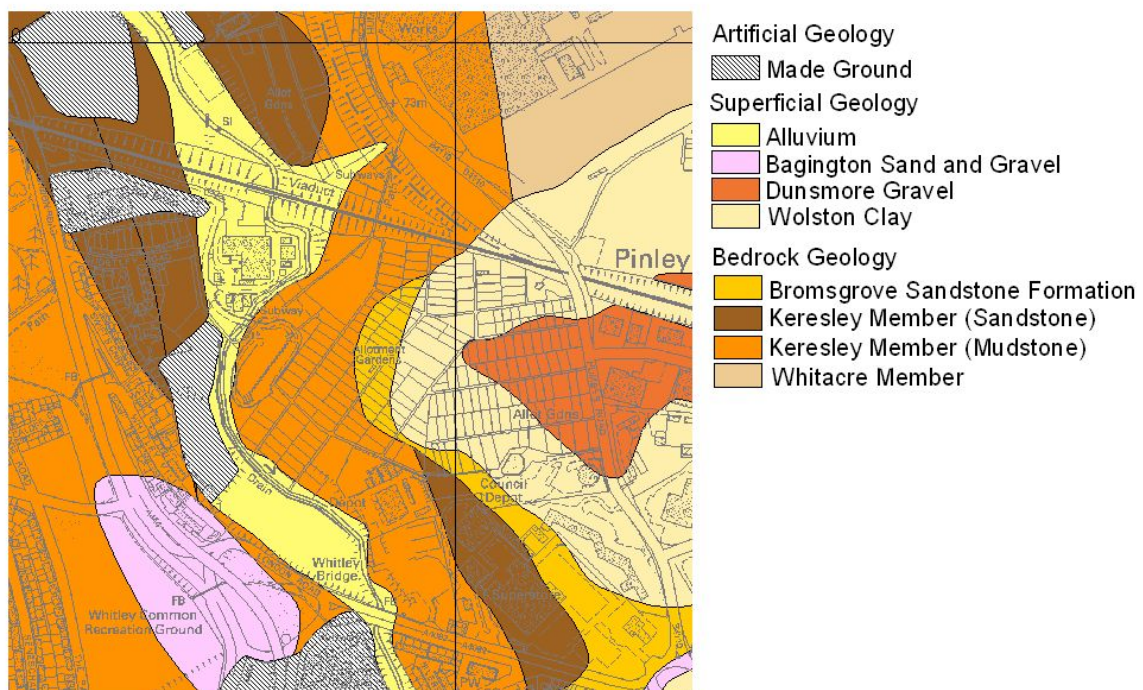


Figure 11 - Combined bedrock and superficial geology map of the London Road area (Extract from 1:10,000 scale digital map). Ordnance Survey © Crown copyright. All rights reserved.

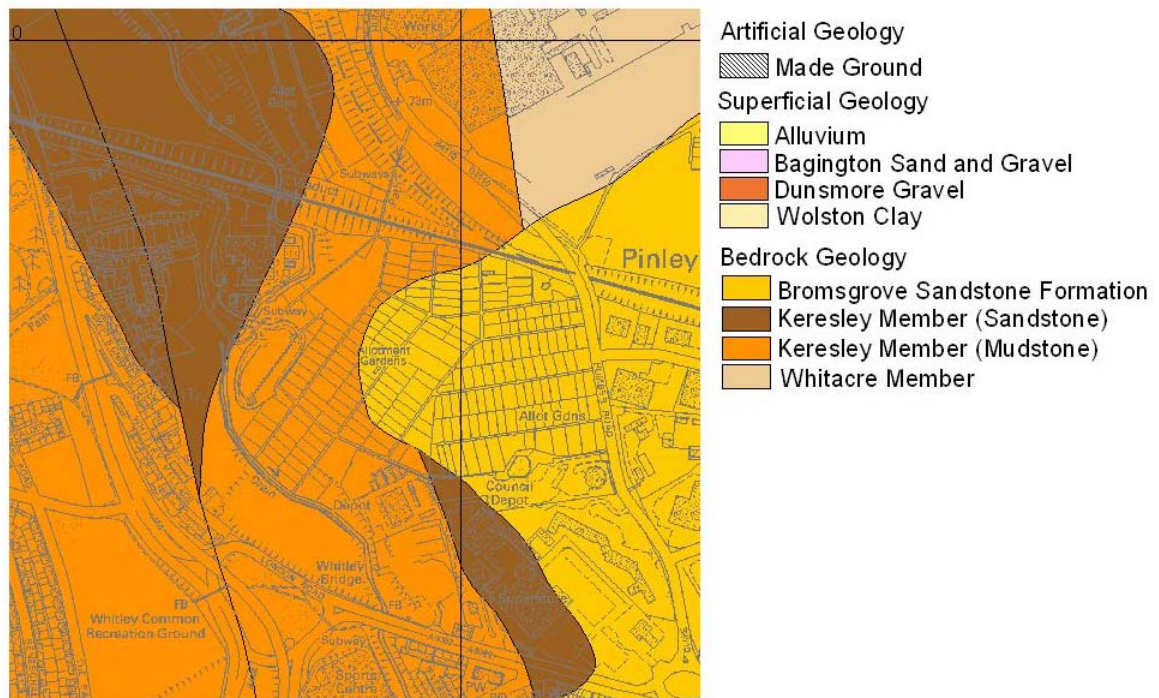


Figure 12 Bedrock geology of the London Road area (Extract from 1:10,000 scale digital map). Ordnance Survey © Crown copyright. All rights reserved.

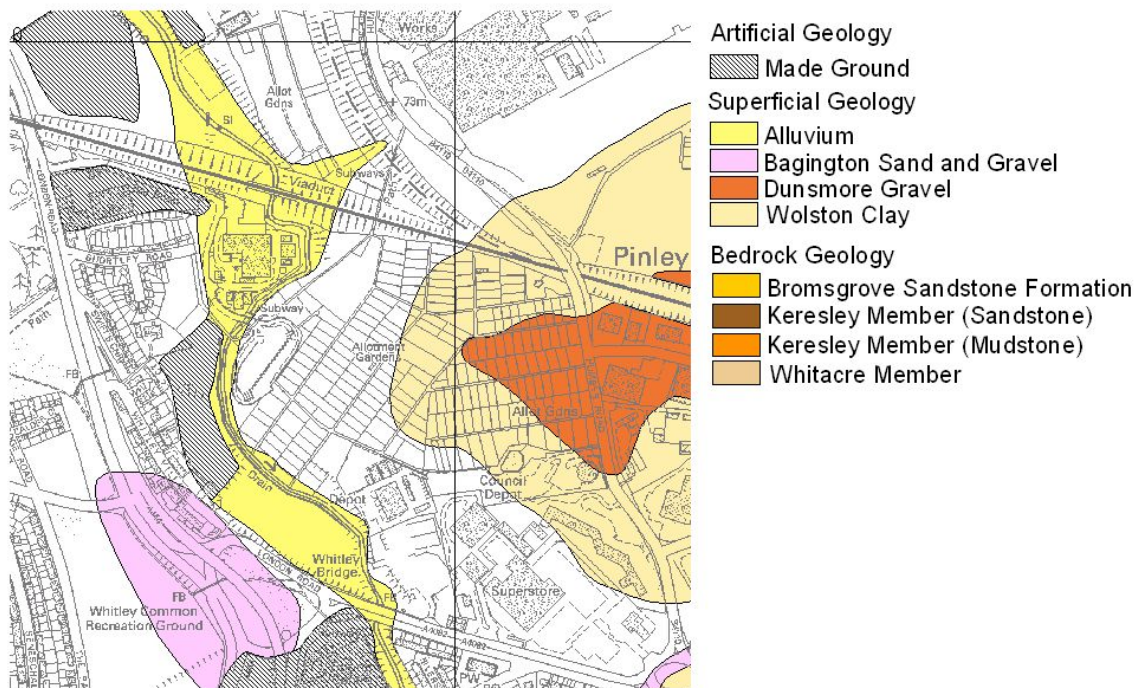


Figure 13 - Superficial and artificial geology of the London Road area (Extract from 1:10,000 scale digital map). Ordnance Survey © Crown copyright. All rights reserved.

3.4 OTHER BGS DATA

Figure 14 shows the locations of BGS held borehole records for the site and surrounding area. Selected borehole records were consulted whilst compiling the geological description above. There are no records of water wells or of pre-1973 landfills.

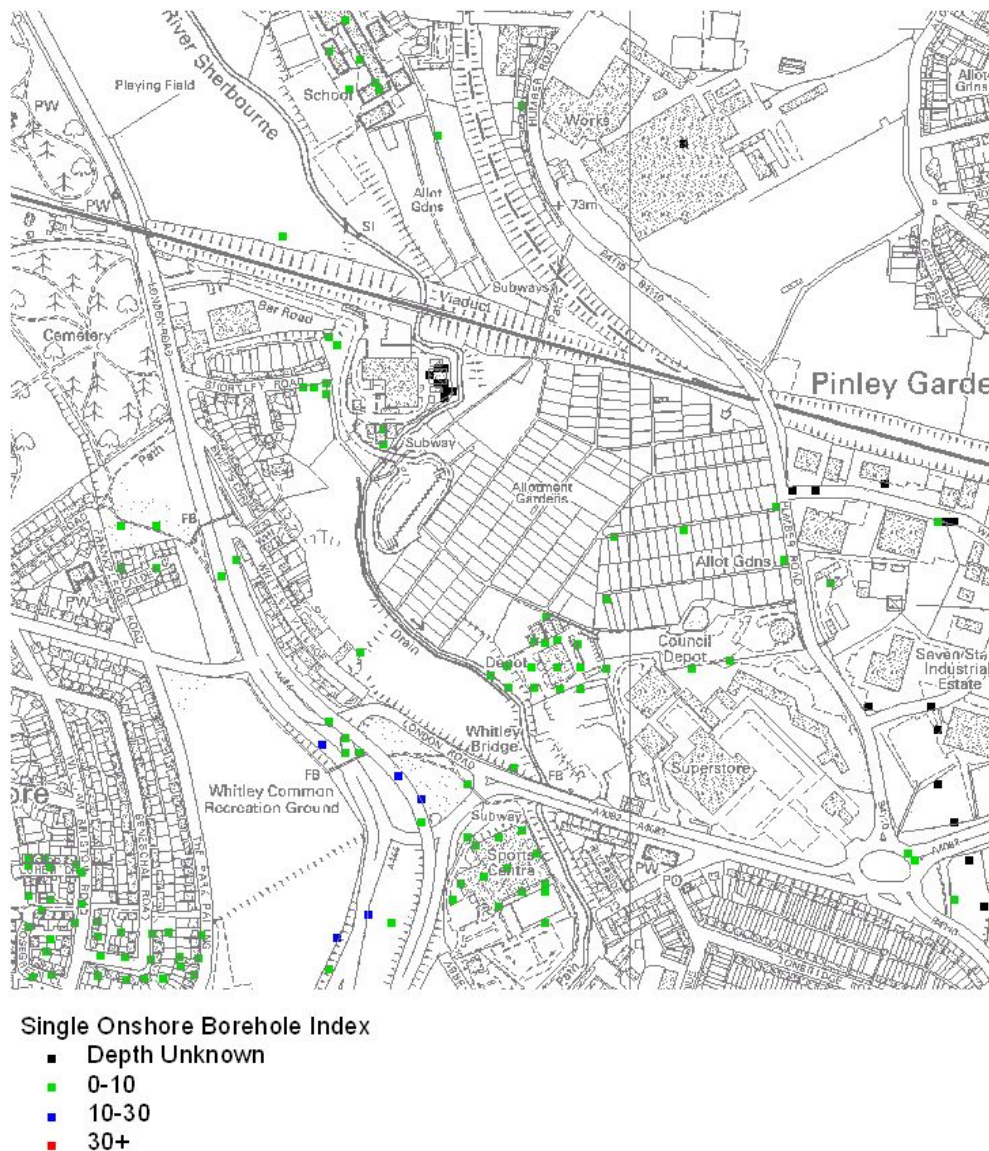


Figure 14 - Locations of boreholes held in BGS Borehole Index Ordnance Survey © Crown copyright. All rights reserved.

3.5 GROUNDWATER VULNERABILITY

The Bromsgrove sandstone formation is classified by the EA (Groundwater vulnerability Sheet 30) as a major aquifer, overlain in this area by soils of high leaching potential (urban). Major aquifers are highly permeable formations usually with a known or the probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Because soil information for urban areas is less reliable and based on fewer observations than in rural areas, the worst case is assumed and such land is classified as high leaching potential (High U) until proved otherwise. Soils of high leaching potential have little ability to attenuate diffuse pollutants and in which non-adsorbed diffuse source pollutants and liquids have the potential to move rapidly to underlying strata. The

remainder of the site, underlain by the Keresley Member, is classified as a minor aquifer overlain by soils of high leaching potential (urban). Minor aquifers can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability including unconsolidated deposits. Although seldom producing large quantities of water they are important for local supplies and in supplying base flow to rivers.

The southern half of the site lies within a Zone III Source Protection Zone. This zone is defined as the total area needed to support the abstraction or discharge from the protected groundwater source, and is the lowest zone of protection classified.

3.6 ENVIRONMENTAL DESIGNATIONS

Up to date environmental designations, including Sites of Special Scientific Interest, Special Areas of Conservation, Special Protection Areas, RAMSAR sites, Ancient Woodland, and National Nature Reserves, were downloaded from the English Nature website on 30/01/2004. There were no environmental designations within a 250m radius of the site.

3.7 OTHER INFORMATION

One water abstraction license is located within 250m of the site. This is a license to abstract water for evaporative cooling at the waste to energy plant to the northwest of the site.

3.8 CONCLUSIONS OF TIER 1 ASSESSMENT

The site history reveals little to suggest why elevated Cd levels are found on the site. A possible source of the contamination is the spreading of sewage sludge from the adjacent sewage plants, although this cannot be determined on the basis of the historical data examined. If this was the case, the contamination must have occurred prior to 1977, by which time both sewage plants had closed. The waste to energy plant seems highly unlikely as a possible source. Whilst low levels of cadmium are emitted from the plant, the dispersion characteristics afforded by the height of the stack leads to effective dispersion and fallout on London Road Allotments will be extremely low or non-existent. If fallout of cadmium from the plant was causing a land contamination issue, this would be observed in the surrounding area and at other sites under the influence of the plume. Soil samples taken in the vicinity of the allotments during the previous study revealed low levels of cadmium, effectively ruling out the possibility of deposition from the atmosphere. Aside from the human aspect of growing vegetables in contaminated soil, the location of the site above major and minor aquifers may give cause for concern. There is no evidence of groundwater contamination for the site.

4 Site characterisation

4.1 STATISTICAL AND GEOSTATISTICAL ANALYSIS

Table 2 shows the summary statistics from the two surveys. Higher Cd concentrations with a median of 2 mg kg^{-1} were generally determined in samples from the initial survey (Rawlins and Lark, 2002) in comparison to the full survey (median 0.7 mg kg^{-1}). The median values for the other parameters (pH and organic carbon content) are very similar. The full Cd, soil pH and organic matter content datasets are attached in Appendix 1.

Table 2 – Summary statistics for Cd concentration (mg kg^{-1}), soil pH and organic carbon content for samples from the full and nested surveys.

	Cd (full survey)	pH (full survey)	%C (full survey)	Cd (initial survey)	pH (initial survey)	%C (initial survey)
mean	0.9	6.1	4.3	2.1	6.3	6.1
median	0.7	6.2	4.0	2.0	6.3	6.2
Min	0.3	4.3	2.4	0.3	4.3	4.1
Max	4.1	7.0	10.1	4.1	7.0	17.3
Detection limit	0.1	N/a	n/a	0.2	n/a	n/a
Skewness	2.9	-0.9	1.9	1.0	-0.3	-0.3
Number samples	164	164	164	12	12	12
Log transformed data						
Skewness	0.9					

The sampling supports (size and orientation of the soil samples) were different for the two surveys because their objectives were quite different. To simplify the geostatistical analysis, only the full survey data set was used to produce a contoured map of the Cd distribution. The Cd values were log transformed to reduce the skewness from 2.9 to 0.9, giving a more normal distribution. The log transformed Cd data is a closer approximation to a normal distribution than the untransformed data as shown by the frequency distribution and the skewness co-efficient which is nearer to zero (Figure 15, Table 2).

The data were investigated for the presence of a regional trend; no significant trend was observed. An experimental variogram of the log transformed data was generated using lag intervals of 20 metres, up to a maximum lag distance of 180 metres. Various authorized geostatistical models were fitted to the data (Webster and Oliver, 2001) using a weighted least squares procedure in the statistical package Genstat (Payne et al., 2002). An exponential model gave the best fit and this was used to produce a series of estimates on a fine grid using punctual kriging. Contours were threaded through the map to produce the image in figure 18. In addition to the contoured map, data from the nested and full survey were combined to produce a proportional symbol map showing the concentrations at the individual sample locations (Figure

17). Similar geostatistical procedures were adopted for mapping soil pH (Figure 19) and organic carbon content (Figure 20).

Although there are several individual sites where the Cd concentrations are relatively high, there are no extensive areas of the site where this is the case following estimation of values on a regular grid and contouring (Figures 17 and 18). The high Cd values are indicative of a point contaminating process.

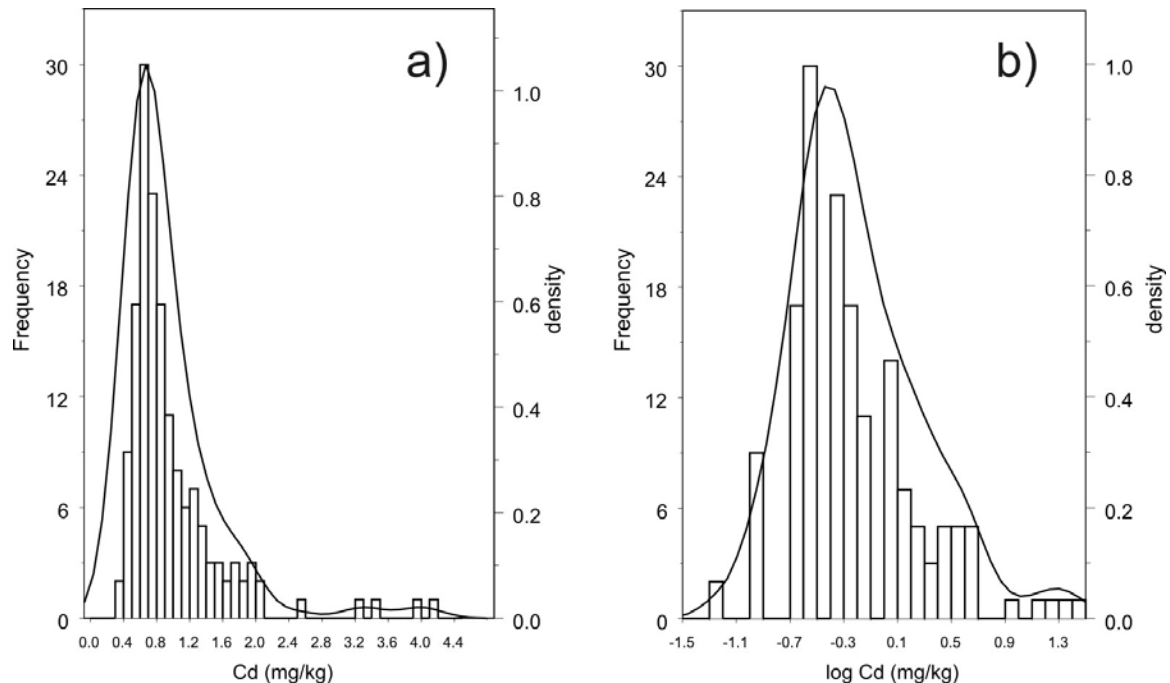


Figure 15 - Frequency histograms and density lines of the distributions for a) Cd concentrations and, b) log transformed Cd concentrations in soil samples at London Rd.

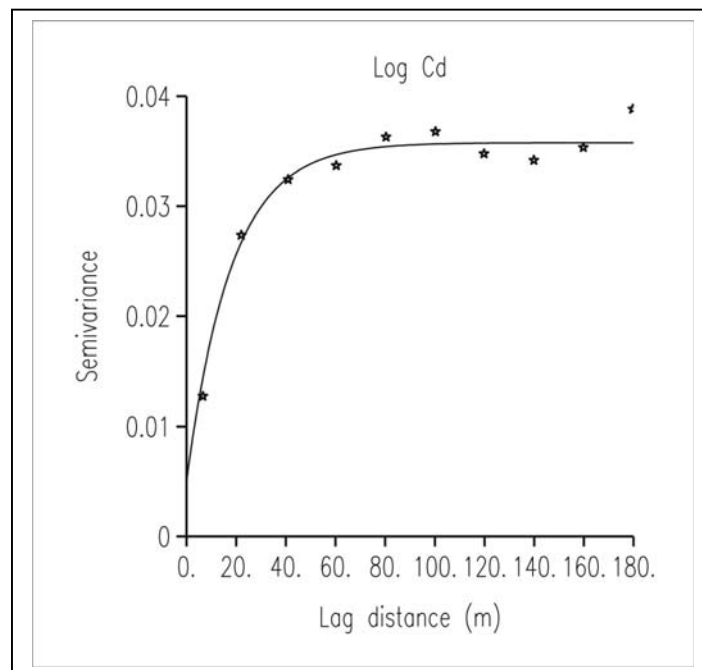


Figure 16 – Experimental values (*) of the variogram for log transformed Cd in soil (0-15 cm depth) and a line showing the fitted exponential model used to produce the kriged map.

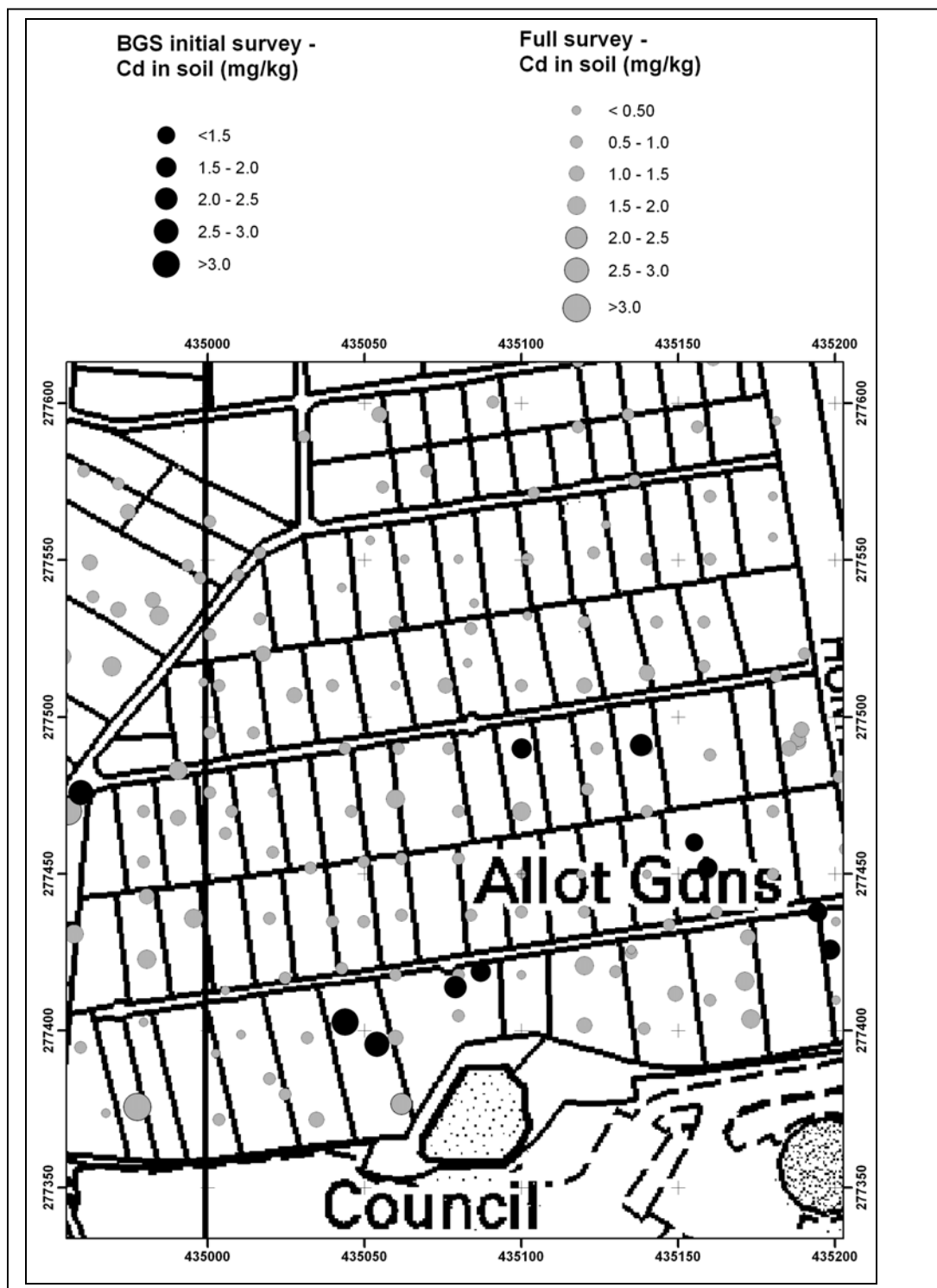


Figure 17– Proportional symbol map showing the distribution of Cd in soil (0-15cm depth) for the initial BGS survey (Oct 2001) and the full-survey (July 2003). The samples in these two surveys were collected according to different protocols – the former over a square of side length 20 metres and 1 metre respectively. Ordnance Survey © Crown copyright. All rights reserved.



Figure 18— Kriged map showing the distribution of cadmium in soil. Ordnance Survey © Crown copyright. All rights reserved.



Figure 19 – Kriged map of soil pH. Ordnance Survey © Crown copyright. All rights reserved.



Figure 20 - Kriged map of soil organic carbon content (%). Ordnance Survey © Crown copyright. All rights reserved.

4.2 CADMIUM CONTENT IN VEGETABLES

Cadmium levels were analysed in a variety of vegetables grown at the allotments. A full list of vegetable types and Cd content is reported in Appendix 2. Values in the analysed vegetables range from $<0.05 \text{ mg Cd kg}^{-1}$ dry weight (DW) to $0.80 \text{ mg Cd kg}^{-1}$ DW with the highest values shown in the lettuce samples (due to the tendency of Cd to enrich in leafy vegetables). Cadmium contents of the allotment vegetables are similar to levels of Cd in foodstuffs produced under non-contaminated conditions (“background” mean values reported by Kabata-Pendias, 2001).

The levels of Cd in vegetables sampled from the allotments are well below the regulatory limit of 0.2 mg kg^{-1} fresh weight (FW) for leafy vegetables and 0.1 mg kg^{-1} FW for stem and root vegetables laid down in Commission Regulation (EC) No. 466/2001. Factors given by Alloway

et al. (1988) were used for the conversion of Cd concentration from dry weight to fresh weight basis.

The soil to plant concentration factor (CF as $\mu\text{g g}^{-1}$ DW plant over $\mu\text{g g}^{-1}$ DW soil) ranged from 0.01 to 0.98 with the highest enrichment factors in the lettuce samples. No correlation was found between Cd content in vegetables and the levels of Cd in soil.

The amount of Cd available in the soil for plant uptake was estimated by a soil extraction in ammonium chloride (NH_4Cl). Concentrations ranged from 0.08 to 0.62 mg kg^{-1} and represented 8 to 40 % of the total Cd in the soil. Soil extraction of Cd with NH_4Cl gives a better estimate of Cd levels in the vegetables ($r_{\text{soil Cd NH}_4\text{Cl} - \text{plant Cd}} = 0.467$, $p = 0.05$).

5 The CLEA Model

The Contaminated Land Exposure Assessment (CLEA) model developed by DEFRA and Environment Agency (2002) was used to determine the current risk of Cd exposure to gardeners working at the site.

The parameters that were used to calculate the average daily human exposure (ADE) are the default values assumed in the CLEA conceptual model for “allotments” land use. Full information about the default database used in the CLEA model is contained in Reports CLR10, CLR7 and CLR9 (DEFRA and Environment Agency, 2002b, 2002c, 2002d). Cadmium soil concentration, soil texture, pH and organic matter are based on site-derived data. Exposure pathways available in the CLEA model that are considered appropriate to the allotment scenario are ingestion of soil and ingestion of household dust. Ingestion of contaminated home grown vegetables was excluded in the assessment as result of the analysis of plant uptake. A full justification for the assumption can be found in Appendix 4. However, this causes “the ingestion of soil attached to vegetables” pathway to be neglected too. The assumption is that good standards of food hygiene are practised. The critical receptor was set to be protective of young children (a young female child with the exposure occurring in the first six years of life), because in general they are more likely to have higher exposure to soil contaminants. The Tolerable Daily Soil Intake (TDSI) used in the CLEA model is $0.1 \mu\text{g kg}^{-1} \text{ bw day}^{-1}$ for a six-year old child.

By using the 95th percentile bound value of Cd (1.0 mg kg^{-1}) the predicted average daily exposure (ADE) is two order of magnitude lower than the TDSI for Cd ($\text{ADE/TDSI} = 0.01$).

The Soil Guideline Value (SGV), i.e. the concentration of Cd in soil where the estimated average daily exposure ADE for the critical receptor equals the relevant health criteria value, was indicated as 76 mg Cd kg^{-1} , if background exposure to Cd is not included.

Comparing the SGV with the Cd concentrations in soils from London Road allotments it is reasonable to say that the levels of Cd in these soils do not pose a risk to the health of young children who represent the worst case scenario for exposure to soil contaminants.

6 Conclusions

The Tier 1 did not find clear evidence of past contamination sources at the London Road Allotments. A possible source of Cd contamination might have been the spreading of sewage sludge from the adjacent sewage plants active until 1977. However, there is no documentary record of this practice.

The site investigation undertaken identified several local locations where the Cd concentrations are relatively high (up to 4.1 mg kg^{-1}). However, following estimation of values on a regular grid and contouring based on geostatistical methods there are no extensive areas of the site where this is the case. The high Cd values are indicative of a point contaminating process.

The concentrations of Cd in vegetables sampled from the allotments are well below the regulatory limit of 0.2 mg kg^{-1} FW for leafy vegetables and 0.1 mg kg^{-1} FW for stem and root vegetables laid down in Commission Regulation (EC) No. 466/2001. The soil to plant concentration factors ($CF_{\text{vegetables}}$) indicate lower plant uptake than predicted by the CLEA model and for this reason the vegetable ingestion pathway was discounted in the risk assessment modelling.

An average daily exposure to Cd in soils from the London Road allotments was estimated for a female child aged 6, which represents the worst case scenario. The pathway considered in the risk analysis was soil ingestion. The exposure through consumption of vegetables was excluded due to the low concentrations of Cd_{plant} determined by analysing vegetables grown at the site. The calculations using the CLEA model indicate that there is no significant toxic risk at the site deriving from exposure to soils. The Soil Guideline Value (SGV) calculated by the CLEA model for London Road Allotment scenario is of 76 mg Cd kg^{-1} . Cadmium concentrations found in soils at the site are all below this SGV.

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Appendix 1

Table A1- Concentrations of Cd, pH and organic matter (OM) in soils from London Road allotments (N=164)

Sample	Horizon	Easting	Northing	Cd mg kg ⁻¹	pH	OM %
609607	A	434998	277544	0.60	6.28	10.76
609619	A	434978	277546	0.85	5.61	6.63
609620	A	434975	277565	1.30	6.24	17.33
609621	A	434961	277578	0.60	5.92	7.56
609622	A	434972	277574	0.80	5.62	8.45
609623	A	435001	277562	0.70	5.92	7.23
609624	A	435031	277589	0.70	4.29	11.68
609625	A	435037	277560	0.43	5.69	4.82
609627	A	435043	277541	0.40	6.14	4.11
609628	A	435017	277552	0.80	5.78	7.72
609629	A	435017	277531	0.60	5.93	6.88
609630	A	435001	277526	0.60	6.09	7.69
609631	A	435083	277517	0.40	6.00	7.51
609632	A	435084	277528	0.60	6.36	6.71
609633	A	435085	277536	0.40	6.10	5.27
609634	A	435181	277513	0.70	6.45	9.83
609635	A	435185	277490	1.20	6.44	9.89
609636	A	434878	277464	1.15	6.17	5.18
609638	A	434874	277407	0.60	6.22	6.67
609639	A	434914	277412	0.60	5.65	4.08
609640	A	435044	277490	0.70	6.48	6.32
609641	A	435046	277470	0.90	6.49	6.78
609642	A	435050	277454	0.80	6.40	6.54
609643	A	435050	277435	1.00	6.03	7.24
609644	A	435181	277594	0.30	6.31	6.10
609645	A	435134	277596	0.70	6.12	5.27
609646	A	435173	277404	1.60	5.67	7.03
609647	A	435172	277430	1.20	5.99	6.47
609648	A	435171	277416	2.00	5.72	6.11
609649	A	435162	277438	0.80	6.20	9.55
609650	A	435147	277434	0.90	6.33	10.82
609651	A	435149	277412	1.20	6.12	8.98
609652	A	435135	277426	0.50	6.24	7.12
609653	A	435139	277401	0.60	6.36	6.58

Table A1 (continued)

Sample	Horizon	Easting	Northing	Cd mg kg ⁻¹	pH	OM %
609654	A	435025	277417	1.00	6.46	7.67
609655	A	435032	277398	0.80	6.27	6.45
609656	A	435035	277372	1.20	6.36	8.07
609657	A	435006	277413	0.50	6.44	10.30
609658	A	435011	277399	0.50	6.10	6.77
609659	A	435020	277385	0.80	6.29	7.51
609660	A	435102	277550	0.60	6.25	5.80
609661	A	435104	277571	0.90	6.49	6.52
609662	A	435156	277592	1.00	6.00	7.06
609663	A	434956	277470	3.40	6.87	5.19
609664	A	434929	277469	1.10	6.17	7.50
609665	A	434970	277516	1.60	6.42	7.24
609666	A	434954	277519	1.70	6.01	8.25
609667	A	434964	277538	0.70	5.66	6.14
609668	A	435025	277380	0.60	6.33	7.54
609669	A	435003	277393	0.40	6.45	5.44
609670	A	435004	277372	0.70	6.09	5.94
609671	A	435033	277452	0.70	6.68	7.42
609672	A	435040	277435	0.70	6.28	7.04
609673	A	434960	277395	0.60	5.72	5.63
609674	A	434968	277374	0.40	5.19	4.66
609675	A	434978	277376	3.20	5.57	6.14
609676	A	434958	277431	1.80	5.76	6.54
609677	A	434980	277403	0.50	5.57	5.78
609678	A	434981	277423	1.90	5.90	7.00
609679	A	434981	277443	1.50	6.09	5.86
609680	A	434996	277436	1.90	5.89	5.10
609681	A	435020	277436	0.80	6.38	8.09
609682	A	435021	277457	0.60	6.31	6.51
609683	A	435062	277437	1.00	6.08	6.94
609684	A	435062	277455	0.70	6.57	5.94
609685	A	435080	277455	0.60	6.39	5.50
609686	A	435043	277420	0.70	6.44	7.66
609687	A	435060	277418	0.80	5.69	5.72
609688	A	435060	277398	1.50	6.00	5.34
609689	A	435080	277418	0.70	5.59	6.70
609690	A	435100	277418	0.50	6.00	5.83
609691	A	435100	277438	0.90	5.97	5.75
609692	A	435100	277450	0.50	5.86	5.12

Table A1 (continued)

Sample	Horizon	Easting	Northing	Cd mg kg ⁻¹	pH	OM %
609693	A	435084	277437	0.60	5.70	7.79
609694	A	435119	277450	0.50	6.16	5.86
609695	A	435120	277438	1.00	6.25	8.15
609696	A	435160	277410	0.70	6.37	8.03
609697	A	435140	277450	0.50	5.35	5.41
609698	A	435160	277450	0.40	5.85	6.55
609699	A	435140	277470	0.70	5.02	5.55
609700	A	435158	277470	0.58	5.71	6.17
609702	A	435180	277450	0.70	5.87	6.95
609703	A	435180	277470	0.80	6.23	7.63
609704	A	435200	277435	0.50	5.93	7.10
609705	A	435200	277410	0.50	5.84	6.87
609706	A	435141	277619	0.40	5.65	5.80
609707	A	435063	277550	0.40	5.38	5.07
609708	A	435015	277495	0.70	6.17	6.73
609709	A	435004	277510	0.60	6.22	6.96
609710	A	434995	277460	4.10	6.41	9.34
609712	A	434991	277483	1.90	6.92	11.14
609713	A	434980	277454	0.80	6.74	9.73
609714	A	434980	277470	0.80	6.56	8.75
609715	A	435140	277490	0.80	6.40	5.88
609716	A	435160	277488	0.70	6.62	6.77
609717	A	434991	277468	1.20	6.63	11.75
609718	A	435077	277490	0.90	5.91	5.82
609719	A	435061	277490	0.90	6.38	6.97
609720	A	435080	277470	0.90	6.44	6.87
609721	A	435052	277556	0.50	6.35	6.14
609722	A	435188	277492	1.50	6.45	11.41
609723	A	435189	277496	1.10	6.22	13.36
609724	A	435188	277493	1.40	6.61	10.39
609725	A	435190	277520	0.80	6.58	17.06
609726	A	435158	277516	0.60	6.22	7.75
609727	A	435158	277530	0.60	5.94	5.93
609728	A	435143	277530	0.80	6.05	6.14
609729	A	435140	277514	1.10	5.96	10.20
609730	A	435120	277510	1.10	5.93	6.47
609731	A	435120	277530	1.00	5.70	5.19

Table A1 (continued)

Sample	Horizon	Easting	Northing	Cd mg kg ⁻¹	pH	OM %
609732	A	435160	277550	0.70	6.21	6.78
609733	A	435180	277557	0.50	5.52	5.92
609734	A	435180	277570	0.50	5.43	5.08
609735	A	435160	277570	0.60	6.11	6.82
609736	A	435100	277490	1.30	6.15	6.57
609737	A	435100	277470	1.70	6.20	8.16
609738	A	435121	277477	0.80	6.01	7.05
609739	A	435124	277490	0.60	6.19	5.42
609740	A	435020	277510	1.03	6.33	13.07
609742	A	435028	277507	1.30	6.09	7.60
609743	A	435018	277520	1.30	6.14	7.46
609744	A	435010	277545	0.70	6.22	11.20
609745	A	434994	277548	0.70	5.96	9.20
609746	A	434983	277537	1.20	5.93	7.13
609747	A	434972	277534	1.10	6.21	7.35
609748	A	435118	277573	0.53	5.42	5.83
609749	A	435123	277552	0.90	5.44	6.11
609751	A	435136	277575	0.60	6.48	5.90
609752	A	435140	277550	0.60	6.18	5.83
609753	A	435127	277561	0.50	5.67	6.47
609754	A	435102	277532	0.40	6.05	6.90
609755	A	435161	277614	1.40	6.31	7.94
609756	A	435055	277596	1.20	5.33	8.35
609757	A	435070	277578	1.00	6.56	11.20
609758	A	435080	277550	0.30	5.95	5.63
609759	A	435001	277495	0.70	6.76	6.32
609760	A	435021	277476	0.50	6.36	6.41
609761	A	435118	277592	0.80	6.53	7.07
609762	A	435006	277463	0.70	5.87	9.31
609763	A	435076	277510	1.30	6.44	5.97
609764	A	435060	277474	1.80	6.50	6.74
609765	A	434999	277511	0.50	6.71	7.14
609766	A	434985	277532	1.70	6.18	10.30
609768	A	435008	277470	0.90	5.58	10.11
609769	A	434963	277549	1.10	6.26	9.90
609770	A	435001	277476	0.90	6.04	8.34
609771	A	435118	277613	1.00	5.75	6.66
609772	A	435056	277573	0.60	5.77	7.26
609767	A	435091	277600	0.70	6.19	6.10

Table A1 (continued)

Sample	Horizon	Easting	Northing	Cd mg kg ⁻¹	pH	OM %
609768	A	435008	277470	0.90	5.58	10.11
609769	A	434963	277549	1.10	6.26	9.90
609770	A	435001	277476	0.90	6.04	8.34
609771	A	435118	277613	1.00	5.75	6.66
609772	A	435056	277573	0.60	5.77	7.26
609773	A	435100	277510	0.60	6.27	8.38
609774	A	434884	277510	3.90	6.26	7.94
609775	A	435040	277510	0.60	6.15	5.55
609776	A	435203	277458	0.60	6.36	7.64
609777	A	434954	277502	0.60	6.51	6.86
609778	A	435135	277425	0.60	6.21	6.71
609779	A	435060	277510	0.50	6.55	5.24
609780	A	435080	277405	0.80	6.53	7.34
609781	A	435130	277419	0.60	6.36	6.33
609782	A	435201	277481	0.90	7.03	11.88
609783	A	435120	277402	1.40	6.38	11.92
609784	A	435060	277530	0.60	6.03	7.78
609785	A	434930	277560	0.60	5.41	6.81
609786	A	435120	277421	2.00	6.33	7.01
609787	A	435062	277377	2.50	6.05	8.52
609628	S	435017	277552	0.20	4.85	5.79
609655	S	435032	277398	0.50	5.69	4.30
609660	S	435102	277550	0.30	5.77	4.13
609702	S	435180	277450	0.30	5.82	5.59
609708	S	435015	277495	0.60	5.98	5.99
609710	S	434995	277460	1.60	6.40	3.09
609735	S	435160	277570	0.20	6.20	3.08
609740	S	435020	277510	0.40	6.31	4.15
609749	S	435123	277552	0.30	5.75	3.13
609754	S	435102	277532	0.30	5.89	4.24
609755	S	435161	277614	0.50	6.37	5.32
609761	S	435118	277592	0.40	6.38	4.72
609764	S	435060	277474	0.60	6.67	4.06
609765	S	434999	277511	0.30	5.88	4.59
609766	S	434985	277532	1.20	5.95	7.03
609767	S	435091	277600	0.30	6.21	2.34

Table A1 (continued)

Sample	Horizon	Easting	Northing	Cd mg kg⁻¹	pH	OM %
609770	S	435001	277476	0.50	6.22	7.31
609773	S	435100	277510	0.30	6.33	4.83
609775	S	435040	277510	0.20	6.42	2.78
609786	S	435120	277421	0.50	6.35	3.55

Appendix 2

Table A2 – Concentrations of Cd in selected vegetables

Sample	Easting	Northing	Vegetable type	Cd	Cd
				mg kg ⁻¹ (dry weight)	mg kg ⁻¹ (fresh weight)
609632V	435084	277528	Lettuce	0.59	0.024
609648V	435171	277416	Lettuce	0.80	0.032
609709V	435004	277510	Broad Beans	<0.05	NA
609712V	434991	277483	Runner Beans	<0.05	NA
609717V	434991	277468	Lettuce	0.21	0.008
609721V	435052	277556	Potatoes	<0.05	<0.005
609722V	435188	277492	Carrots	0.18	0.018
609723V	435189	277496	Potatoes	<0.05	<0.005
609724V	435188	277493	Onions	0.09	0.014
609725V	435190	277520	Lettuce	0.24	0.010
609742V	435028	277507	Runner Beans	<0.05	NA
609743V	435018	277520	Onions	0.14	0.022
609744V	435010	277545	Courgettes	<0.05	NA
609745V	434994	277548	Broad Beans	<0.05	NA
609746V	434983	277537	Onions	0.21	0.033
609747V	434972	277534	Cabbage	<0.05	0.003
609753V	435127	277561	Runner Beans	<0.05	NA
609762V	435006	277463	Tomato	0.26	NA
609768V	435008	277470	Lettuce	0.59	0.024
609778V	435135	277425	Lettuce	0.58	0.023
609781V	435130	277419	Potatoes	0.08	0.017

The regulatory limit is of **0.2 mg kg⁻¹** fresh weight (FW) for leafy vegetables and **0.1 mg kg⁻¹** (FW) for stem and root vegetables. Commission Regulation (EC) No. 466/2001

Conversion factors: Lettuce 0.04; Cabbage 0.126; Carrots 0.097; Onions 0.156; Potatoes 0.21 after Alloway et al.(1988); NA: conversion factors not available.

Appendix 3

Table A3 - Concentrations of Cd extracted by NH₄Cl in selected soil samples

Sample	Soil Cd NH ₄ Cl mg kg ⁻¹
609632	0.09
609648	0.62
609709	0.08
609712	0.15
609717	0.10
609721	0.18
609722	0.21
609723	0.11
609724	0.17
609725	0.08
609742	0.41
609743	0.29
609744	0.08
609745	0.08
609746	0.26
609747	0.25
609753	0.12
609762	0.27
609768	0.36
609778	0.11
609781	0.11

Appendix 4

SITE- SPECIFIC SUITABILITY OF THE CLEA MODEL TO CALCULATE Cd EXPOSURE FROM PLANT UPTAKE

In the CLEA model the soil to plant concentration factor (CF as $\mu\text{g g}^{-1}$ DW plant over $\mu\text{g g}^{-1}$ DW soil) is based on a literature review of Cd uptake by the garden vegetables of interest and it depends on the soil pH according to the equations:

$$\ln(\text{CF}) = 11.174 - (1.6461 \times \text{pH}) \text{ for root vegetables}$$

and

$$\ln(\text{CF}) = 11.206 - (1.634 \times \text{pH}) \text{ for leafy vegetables.}$$

However, under acidic soil conditions the relationships used for deriving the CF might overestimate the plant uptake and the SGV should be used carefully for soils with a pH of less than 6.5 (DEFRA and Environment Agency, 2002a).

The soil to plant concentration factors ($\text{CF}_{\text{vegetables}}$) were calculated for vegetables at the London Road allotments and were found to be lower than those estimated by the CLEA model. Figure 21 is a plot of the London Road CF's and the CLEA CF equations. It is evident that most of the data fall below the curves indicating that CLEA would overestimate exposure via the vegetable ingestion pathway if the model was applied.

This indicates a lower potential exposure for the plant uptake pathway than that indicated by the CLEA model.

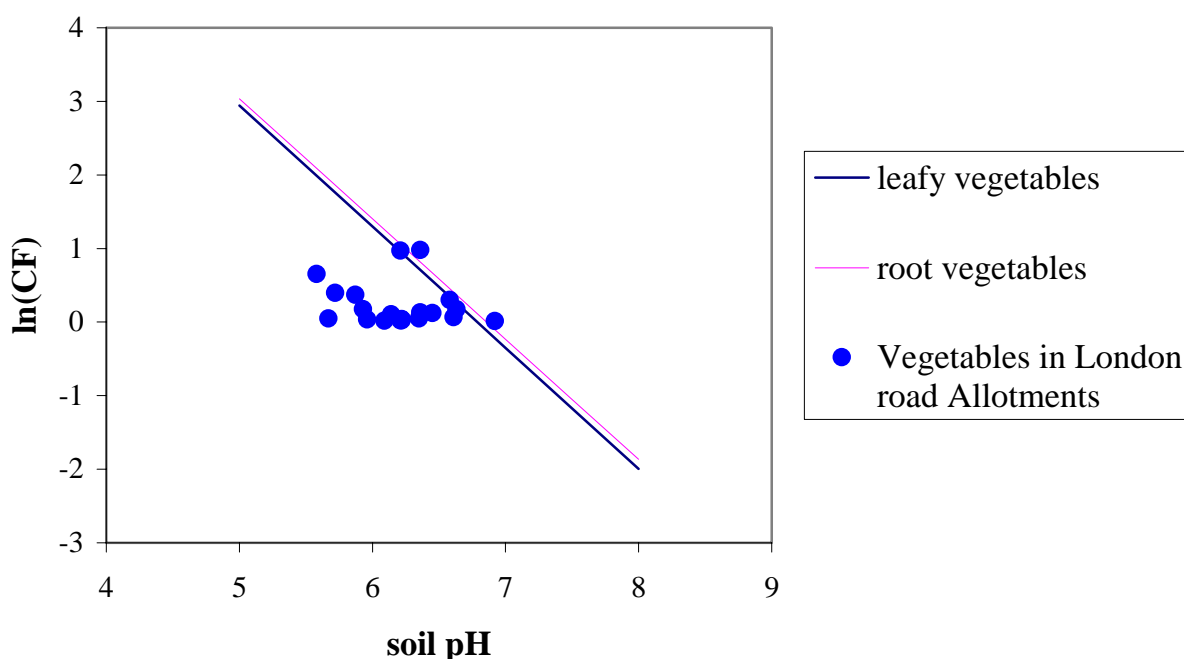


Figure 21 – Plot of the natural log of the soil to plant concentration factors for leafy vegetables and root vegetables against soil pH used in CLEA model. CF and pH of vegetables and related soils from London Road allotments are plotted for comparison.

Appendix 5

TRIAL PITTING IN THE LONDON ROAD ALLOTMENTS

Introduction and methodologies

At the top of the hill the allotments are underlain by Sand and Gravel of the Dunsmore Formation. These glacio-fluvial deposits overlay glacial clay and silt of the Wolston Clay Formation. Trial pit 1 and 3 are located on the Dunsmore Formation, 2 and 4 on the Wolston Clay Formation. The whole superficial succession overlies sandstone of the Bromsgrove Formation.

The OS historical maps show the land to have been under arable use at least since 1850, no potential contaminative land use can be found.

The BGS borehole archives hold records of 4 trial pits (4m depth) dug in 1981 (SP37NE501; SP37NE501; SP37NW804; SP37NW805)

The location of pits 1,2 and 3 were sited based on the different parent materials as well as on increased Cadmium values in their vicinity. Trial pit 4 is located in allotment number 73 and had been dug by the owner (Mr. Lewis) for sand extraction.

The 4 pits described in this report were dug to a maximum depth of 1.2 metres using a mini digger. The sections were described according to the British Standard for Site Investigations (BS5930) and 6 undisturbed samples were taken in “organic” horizons.

The presence of slag material found in the pits nearby the car park areas might be related to imported road surfacing material.

Description of TP1

This pit is located in the car park near the front entrance gate on Humber Road. (435189; 277520)



Depth to base (m)	Description	Geological Classification	Pedological Classification
0-0.23	Dense multicoloured red (2.5YR 4/6) and brown (10YR 2/3) and black (5YR 5/1) silty, sandy GRAVEL with brick and tiles, concrete and mortar, ceramics, glass, some plastic waste and slag. Medium CaCO ₃ reaction. Many fine grass roots.	TOPSOIL, MADE GROUND, recent car park cover	A horizon
0.23-0.48	Dense very dark grey (10YR 3/1) silty gravelly SAND. With some gravel, charcoal, tile and concrete fragments. CaCO ₃ free. Some fine roots and some older tree roots.	TOPSOIL, MADE GROUND	Older A horizon
0.48-1.15	Medium dense dark yellowish brown (10YR 4/4) gravelly silty SAND. Gravels are well rounded quartz and quartzite pebbles (20-40% vol). Some patches of grey brown organic clay is observed along fractures and root channels. Few roots developed. CaCO ₃ free.	Weathered sand and gravel of the DUNSMORE FORMATION	Weathered B horizon
1.15-1.25 (base of pit)	Medium dense light yellowish brown (10YR 6/4) and reddish brown (5YR 5/4) silty gravelly SAND. Gravels are well rounded quartz and quartzite pebbles (20-40% vol). No roots observed. CaCO ₃ free. Pit well drained and dry to base.	Sand and gravel of the DUNSMORE FORMATION	C horizon Brown Earth

Description of TP2

This pit is located on the verge of the lower car park near the triangular plot (site of TP4). (434958; 277477)



Depth to base (m)	Description	Geological Classification	Pedological Classification
0-0.25	Medium dense dark grey brown (5YR 4/1) clayey gravely SAND with lenses of clay (parent material) and some charcoal, slag, brick and concrete. Gravels are well rounded quartz and quartzite pebbles. Slight CaCO_3 reaction. Many roots developed.	TOPSOIL, MADE GROUND	A horizon
0.25-0.75 base of pit	Soft reddish brown (5YR 4/4) gravely, sandy CLAY with pockets of red brown sand. Gravels are well rounded quartz and quartzite pebbles. Very few roots developed. CaCO_3 free. Small water seepage in sand lense at 0.65m, temporary waterlogging is to be expected.	Weathered WOLSTON CLAY FORMATION	S horizon Surface-water Gley

Description of TP3

This pit is located in allotment 73 and was dug by the owner Mr. Lewis (435102; 277510)



Depth to base (m)	Description	Geological Classification	Pedological Classification
0-0.3	Loose very dark greyish brown (10YR3/2) silty gravely SAND with lots of organic garden waste (leaves and compost). Gravels are well rounded quartz and quartzite pebbles. Slight CaCO_3 reaction. Many roots developed. Virtually free from other man made materials. Total organic content est. at 5-10%	TOPSOIL,	A horizon
0.3-0.5	Medium dense dark greyish brown (10YR4/2) silty gravely SAND. Gravels are well rounded quartz and quartzite pebbles and some small pieces of charcoal were observed. CaCO_3 free. Many roots developed.	TOPSOIL older	A horizon
0.5-1.4 base of pit	Loose yellowish brown (10YR5/4) silty gravely SAND with white and reddish brown mottles towards base due to temporary waterlogging. The well next to the pit shows standing water at ca. 3 metres below OD.	Weathered sand and gravel of the DUNSMORE FORMATION	B/S horizon Brown Earth/ Surface-water Gley

Description of TP4

This pit is located in the fallow triangular field near the bottom car park. The land has been out of use for a number of years. The pit showed in principal the same soil and geology as TP2.



Depth to base (m)	Description	Geological Classification	Pedological Classification
0-0.23	Medium dense dark brown (7.5YR3/2) gravely very clayey SAND with very few small pieces of brick. Gravels are well rounded quartz and quartzite pebbles. CaCO ₃ free. Many roots developed.	TOPSOIL, MADE GROUND	A horizon
0.23-0.75 base of pit	Firm yellowish brown (10YR5/6) gravely sandy CLAY with pockets of yellow and reddish brown sand towards base (poss. Bedrock). Mottled from 0.6 m indicates temporary waterlogging. CaCO ₃ free. Very few roots developed.	Weathered WOLSTON CLAY FORMATION over poss. BROMSGROVE SANDSTONE FORMATION.	B/S horizon Surface-water Gley