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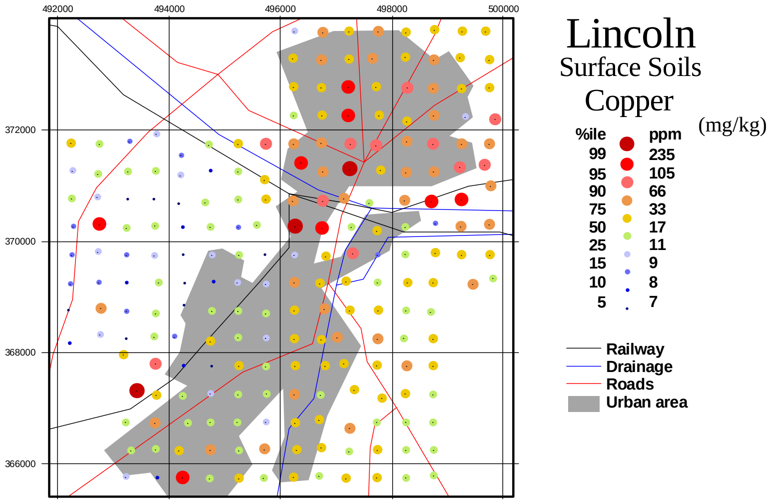
# Geochemical baseline data for the urban area of Lincoln

Urban Geoscience and Geological Hazards Programme

Internal Report IR/02/081



BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/02/081

# Geochemical baseline data for the urban area of Lincoln

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*Keywords*

G-BASE, soil, geochemistry, urban.

*Front cover*

Copper in Lincoln surface soils.

*Bibliographical reference*

O'DONNELL, K.E. 2005.
Geochemical baseline data for
the urban area of Lincoln
*British Geological Survey*
*Internal Report IR/02/081*, 71 pp.

Keyworth, Nottingham British Geological Survey 2005

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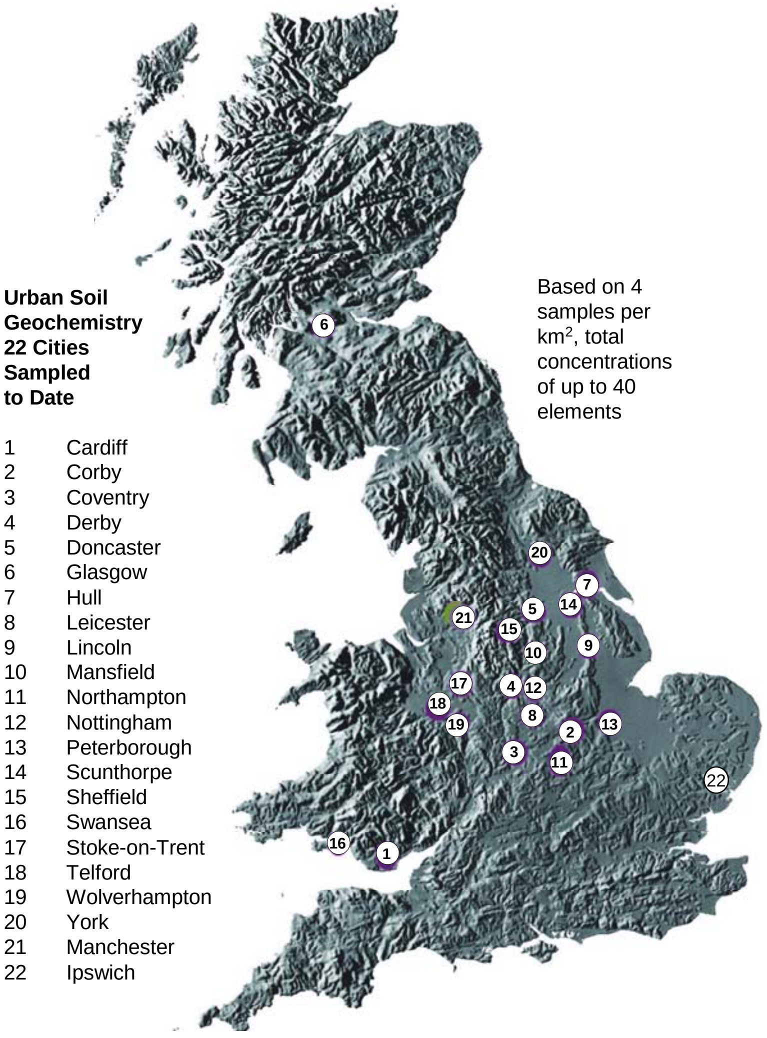
*The soil geochemical data presented in this report (and other urban reports from this series) are from individual sites, which were sampled as part of a baseline geochemical survey. The results should only be used to set a regional context, not as the basis for interpretations concerning specific sites. Interpretations relating to specific sites should be based on follow-up investigations. The data in this report, in addition to all geochemical data held by BGS, are available under licence. Their use is subject to the terms of a licensing agreement.*

# Foreword

This report is a product of the British Geological Survey's (BGS) Geochemical Surveys of Urban Environments (GSUE) project. The work is funded by the UK Government Office of Science and Technology and is part of the national Geochemical Baseline Survey of the Environment (G-BASE) programme. The report forms part of a publication series, which aims to make GSUE urban soil chemistry data publicly available with a minimum of interpretation, displaying the data as a series of graduated symbol maps.

A number of urban centres have been surveyed to date using systematic soil sampling procedures. These are indicated in the figure below. Wolverhampton, Manchester and Glasgow were sampled as part of larger multi-disciplinary projects.



*Urban centres sampled to date by the GSUE project*

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# Summary

This report presents the results of an urban soil geochemical survey of Lincoln carried out by the British Geological Survey (BGS) during 1997. The study was undertaken as part of the BGS systematic Geochemical Surveys of Urban Environments (GSUE) project. The concentrations of many potentially harmful elements (PHE) such as As, Cd, Cr, Ni and Pb are enhanced in city environments as a result of urbanisation and industrial processes and their distribution is of concern under current UK environmental legislation.

The GSUE data provide an overview of the urban geochemical signature and because they are collected as part of a national baseline programme, can be readily compared with soils in the rural hinterland to assess the extent of urban contamination. The aim of the present study was to generate urban soil geochemistry information for Lincoln to aid planning and development.

Urban surveying was based upon the collection of samples on a systematic 500 m grid. Soils were sampled at a density of 4 per km$^2$ across the built-up area. Samples were collected from open ground as close as possible to the centre of each 500 m grid cell. A summary of the sampling and analytical protocols adopted for Lincoln is presented in Table 1.

Preliminary interpretations of the data in relation to the underlying geology and past and present industrial history of Lincoln are presented in this report and demonstrate that there is a significant geological influence over soil geochemistry in Lincoln. Possible anthropogenic influences are likely to be largely related to city centre traffic and industrial activities.

**Table 1 Summary of the Lincoln soil sampling strategy**

| | |
|---|---|
| **Date Sampled:** | Summer 1997 |
| **Area Sampled:** | 54 km$^2$ (min E 492209; max E 499863; min N 365739; and max N 373787) |
| **Sample Density:** | 1 per 0.25 km$^2$ |
| **Number of Samples:** | 216 surface (0.05 – 0.20 m) and 214 profile (0.35 – 0.50 m) soils |
| **Elements Determined by XRFS:** *(elements in italics determined in surface samples only)* | *$Al_2O_3$, CaO, $SiO_2$, $P_2O_5$, $K_2O$, MgO*, $Fe_2O_3$, MnO, $TiO_2$, Cr, Mo, Pb, Zn, As, Cd, Cu, Ni, Sb, U, Ba, Co, Sn, V. |

XRFS = X-Ray Fluorescence Spectrometry

# 1 Introduction

This report summarises the results and methodology of a soil geochemical survey of the urban area of Lincoln, undertaken by the British Geological Survey (BGS) during 1997 as part of the Geochemical Survey of Urban Environments (GSUE) project. The GSUE project forms part of the national strategic geochemical survey of Great Britain and Northern Ireland, the Geochemical Baseline Survey of the Environment (G-BASE) programme (Johnson and Breward, 2004).

The programme is undertaking a systematic regional geochemical survey of soils, stream sediments and stream waters of the British Isles at a sample density in rural areas of 1 per 1.5 – 2 $km^2$. The data provide information on the surface chemical environment, which can be used to define environmental baselines and the extent of surface contamination and are published as a series of regional geochemical atlases for the country (see for example British Geological Survey, In Prep). The distribution of chemical elements in the environment is of concern because although many are essential to life, several including As, Cd, Cr, Ni and Pb are potentially harmful to plants and animals in high doses. Concentrations at any location are often controlled by factors such as geology, vegetation, soil forming processes and climate. In addition to natural sources of these elements, environmental concentrations can be enhanced by anthropogenic activities such as mining, industrialisation, urbanisation and waste disposal. The G-BASE data have a wide range of applications, including the assessment of risks to human health, with respect to potentially harmful elements (PHE) through environmental exposure.

The concentrations of many potentially harmful elements (PHE) are enhanced in urban environments as a result of atmospheric and terrestrial contamination and the nature of urban ground, which is often disturbed and in-filled and bears little relation to the soils, bedrock and superficial cover of the surrounding rural hinterland.

As part of the G-BASE programme, the GSUE project undertakes systematic soil surveys to define city-wide geochemical signatures over selected urban areas including that of Lincoln (Figure 1).

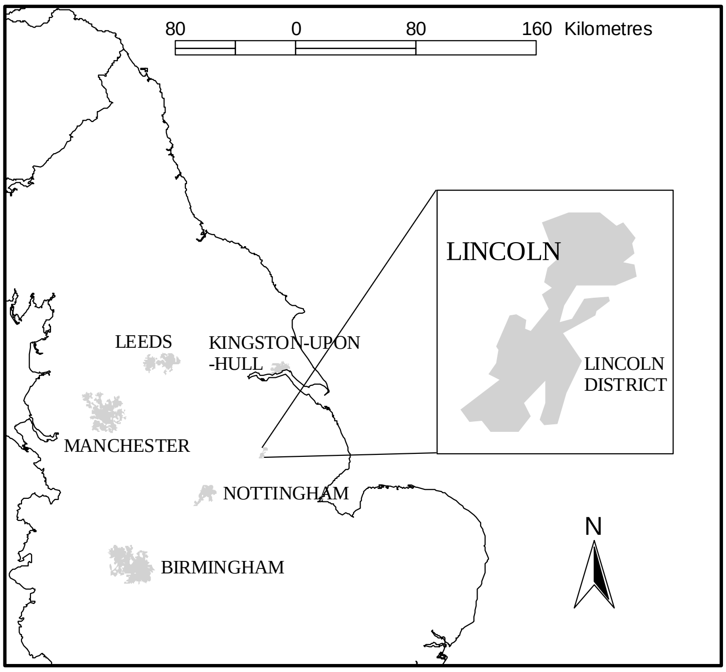

**Figure 1 Location map for Lincoln**

The city of Lincoln is the administrative centre for Lincolnshire, with a population of over 80,000. The distributions of approximately 23 major and trace elements including several PHE in the surface environment of Lincoln are described in this report in relation to present and historical land use. The concentrations of the elements are also considered in terms of the underlying geology and placed in context with respect to the typical rural background concentrations obtained from G-BASE regional soil data sets from the surrounding area.

# 2 Study Area

## 2.1 AREA SAMPLED

An area of 54 km$^2$ was surveyed during the summer of 1997, in which a total of 216 surface soils (0.05 - 0.20 m depth) and 214 profile soils (0.35 – 0.50 m depth) were sampled. This extends from British National Grid references 492209 m east to 499863 m east and from 365739 m north to 373787 m north (Table 1) and covers the Ermine, St. Giles and New Boultham areas of the city of Lincoln and the districts of Skellingthorpe, North Hykeham, Bracebridge Heath and Canwick, to the south of the River Witham. The survey area is shown in Figures 2 and 3.

## 2.2 HISTORICAL LAND USE

Lincoln has a long history, dating back to pre-Roman times. The city became an industrial centre in the mid-19th Century, developing from a market town. The spread of industry coincided with improvements to roads and services in the city. Early forms of industry included engineering (e.g. iron founders), brewing and brickmaking. Tanks and aircraft were made in Lincoln during World War I and light engineering continued to be the dominant industry during most of the 20th Century. Currently, manufacturing is a significant industry in Lincoln, with products including heavy machinery, automobile parts, electronic parts and food products. Service industries, such as tourism, have become more important with respect to heavy industry in Lincoln within recent years. Lincoln has a strong historical heritage, with Lincoln Castle and the third largest cathedral in the country, both dating back to the 11th Century AD[1].

Industrial works are located directly to the south of the River Witham, to the south-west of the city centre, whilst the city's sewage works are located to the south-east of the city centre. The main rail link also transects the urban area to the south of the city centre exploiting the valleys of the Fossdyke and River Witham (Figures 2 and 3). The southern margin of the urban area in North Hykeham is another focus of industrial activity. Former sand and gravel pits are fairly extensive around the south-west margin of the urban area in a region now hosting nature reserves (Figure 3). In the past, ironstone quarrying was also carried out, on the eastern outskirts of the city, north of the River Witham.

## 2.3 TOPOGRAPHY

The city centre, comprising the northern part of the urban area (Figure 2), is situated on a topographic high, which rises to approximately 60 m above sea-level. The suburbs (known as Lincoln District), extending from the south of the River Witham across a plain (approximately 10-20 m above sea-level) lie at the base of another topographic high, which rises along the eastern margin of the urban area, to 70 m above sea-level. The River Witham flows between these two topographic highs, from west to east and divides the city of Lincoln from Lincoln District.

## 2.4 SOLID AND SUPERFICIAL GEOLOGY

Geological information for the Lincoln area was obtained from the BGS 1:50 000 series maps and the BGS digital DigmapGB® data (British Geological Survey, 1973). The solid (bedrock) and superficial deposits of the region are shown in Figures 4 and 5.

Approximately two-thirds of the survey area, comprising the low-lying region of Lincoln District (section 2.3) is underlain by the Lower Liassic Scunthorpe Mudstone Formation, however, much of this formation is concealed by Quaternary river terrace deposits and alluvium. The higher-standing city centre of Lincoln comprises Middle Jurassic Inferior Oolite Group members, predominantly the Lincolnshire Limestone Formation, which is underlain by the Grantham and Northampton Sand formations. The latter has been exploited in south Lincolnshire as a low-grade ironstone and contains elevated levels of trace elements such as arsenic, associated with the high iron content. Between Lincoln and the Humber Estuary, however, the formation is thinner (approximately 1 to 3.5 m thick) and poorer in iron, generally comprising a calcareous ferruginous sandstone (Institute of Geological Sciences, 1980). The Grantham Formation consists of fine sands and clays with low-grade ironstone (Institute of Geological Sciences, 1980). Beneath these rocks lies a limited band of Whitby Mudstone, part of the Lower Jurassic Lias Group. In the far north-east of the survey area, mudstones of the Rutland Formation and

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[1] http://www.visitoruk.com/lincoln/index.htm

limestones of the Blisworth Limestone Formation, which are members of the Great Oolite Group, overlie the Lincolnshire Limestone.

Middle Jurassic rocks also form the topographic high to the south-east of Lincoln and east of Lincoln District (Figures 5 and 2). This sequence comprises the Lower Jurassic Whitby Mudstone overlain by the Lower Lincolnshire Limestone and the Marlstone Rock Formation.

## 2.5 SOIL TYPE

The National Soil Resources Institute (formerly the Soil Survey of England and Wales) produces soil maps for much of the UK landmass, however urban and industrial areas have not been surveyed for soil type. Therefore no information exists on soil type for the main urban area of Lincoln, although limited data are available for the outskirts of the urban area (Soil Survey of England and Wales, 1983; Hodge *et al.*, 1984) as follows:

The main soil type around the city centre of Lincoln (the northern part of the urban area shown on Figure 2) is a shallow calcareous clay loam, overlying limestone (the Lincolnshire Limestone Formation, Figure 5). This soil type is permeable, and well-drained (as it overlies well-fissured limestone), retaining rainwater in the wetter winter months, with little surface run-off. Fine loam over clayey typically stagnogley soils are reported between the city centre and Lincoln District, and to the east of Lincoln District. This soil type is associated with thin loamy drift overlying Jurassic and Cretaceous clay shales. These soils are seasonally waterlogged, with slowly permeable sub-soils.

A number of soil types are associated with the valley of the River Witham in the area. In the river valley to the south of Lincoln, a pelo-alluvial gley soil with a mottled, slowly permeable, clayey sub-soil is developed. This soil type is also found in association with the canal, to the west of the city centre. In contrast, the soils around the River Witham and the canal to the east of the city centre are amorphous and semi-fibrous lowland peat soils, with sandy soils that have peaty topsoils. These soils are permeable and water-retentive.

In addition to this general Soil Survey information for the area, soil characteristics are also reported as part of the GSUE survey. Basic information for the urban soils of Lincoln was recorded on computer-compatible field cards (see Appendix A), which are completed at site during sampling according to standard procedures (Johnson *et al.*, 2003). These contain data such as soil colour, texture, sample depth, clasts that are contained within the soil, as well as land use and any physical contamination that is observed. The field cards are completed using a set of standard database-compatible codes (Harris and Coats, 1992) and the information is held on the BGS corporate geochemistry database.

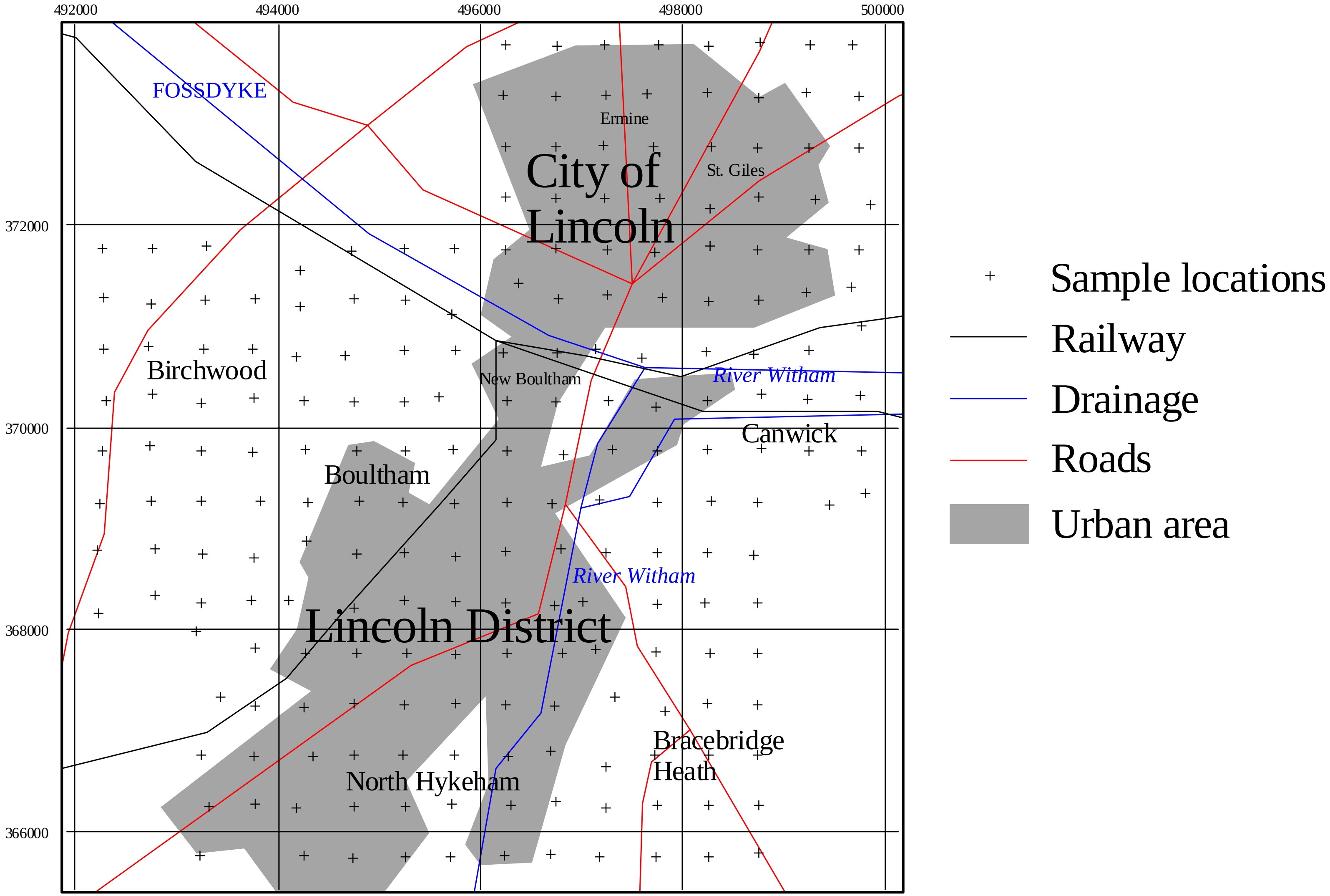


**Figure 2 Map of the sampling area (Grid squares shown at 2 km intervals)**

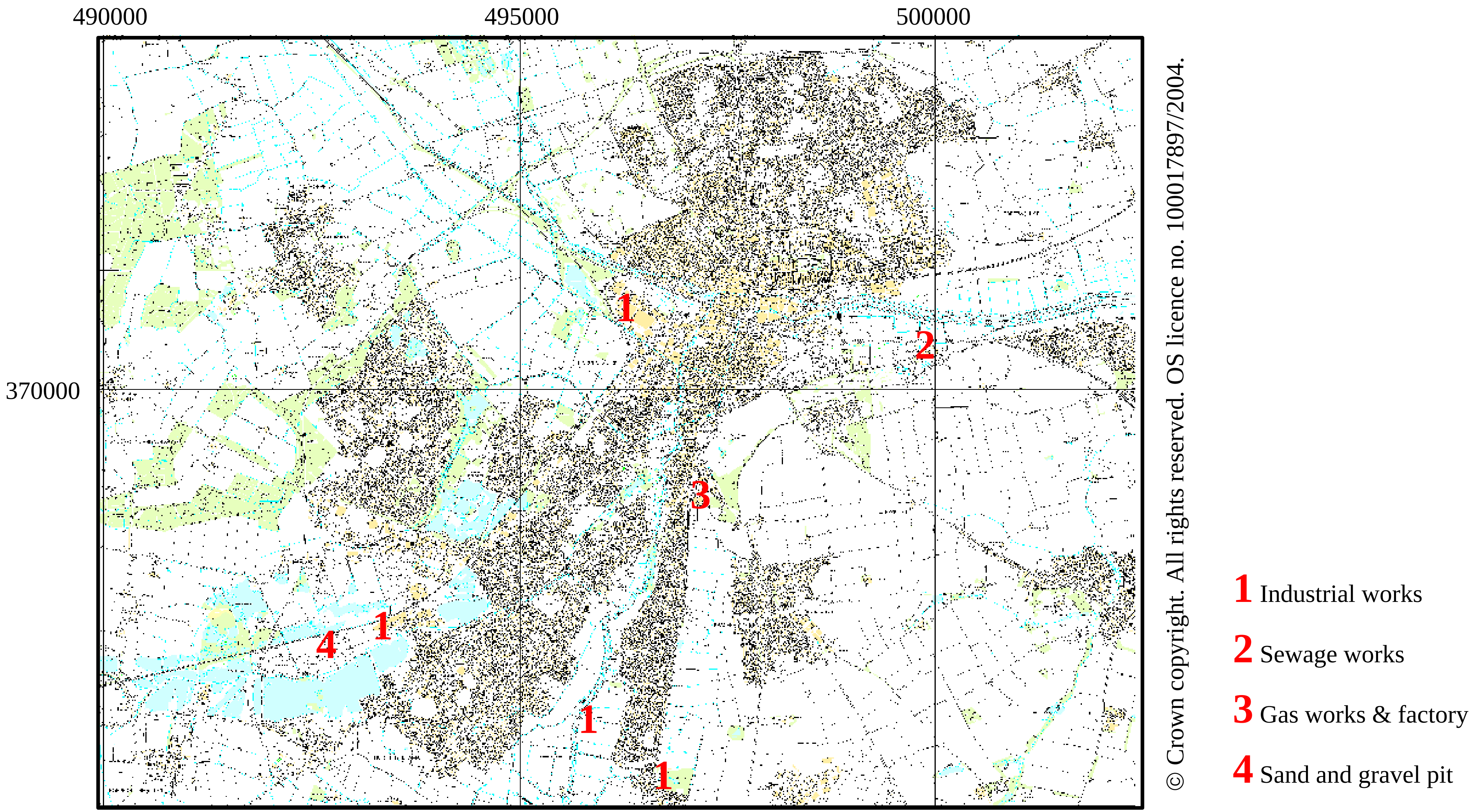


**Figure 3 Topographical map of the sampling area (Grid squares shown at 5 km intervals)**

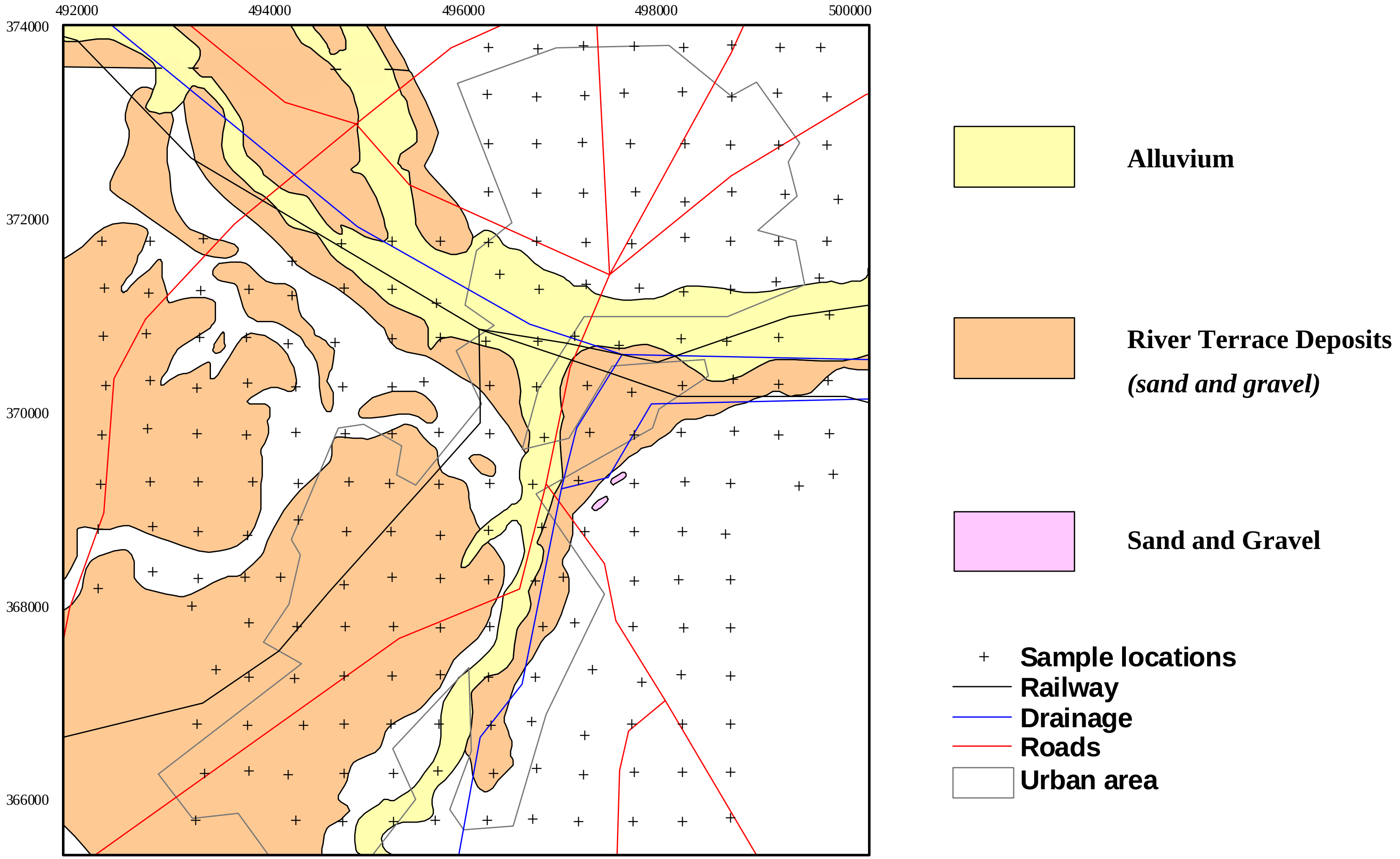


**Figure 4 Superficial deposit map of Lincoln and the surrounding area (based on 1:50 000 scale geological map; BNG shown at 2 km intervals) BGS DigmapGB®**

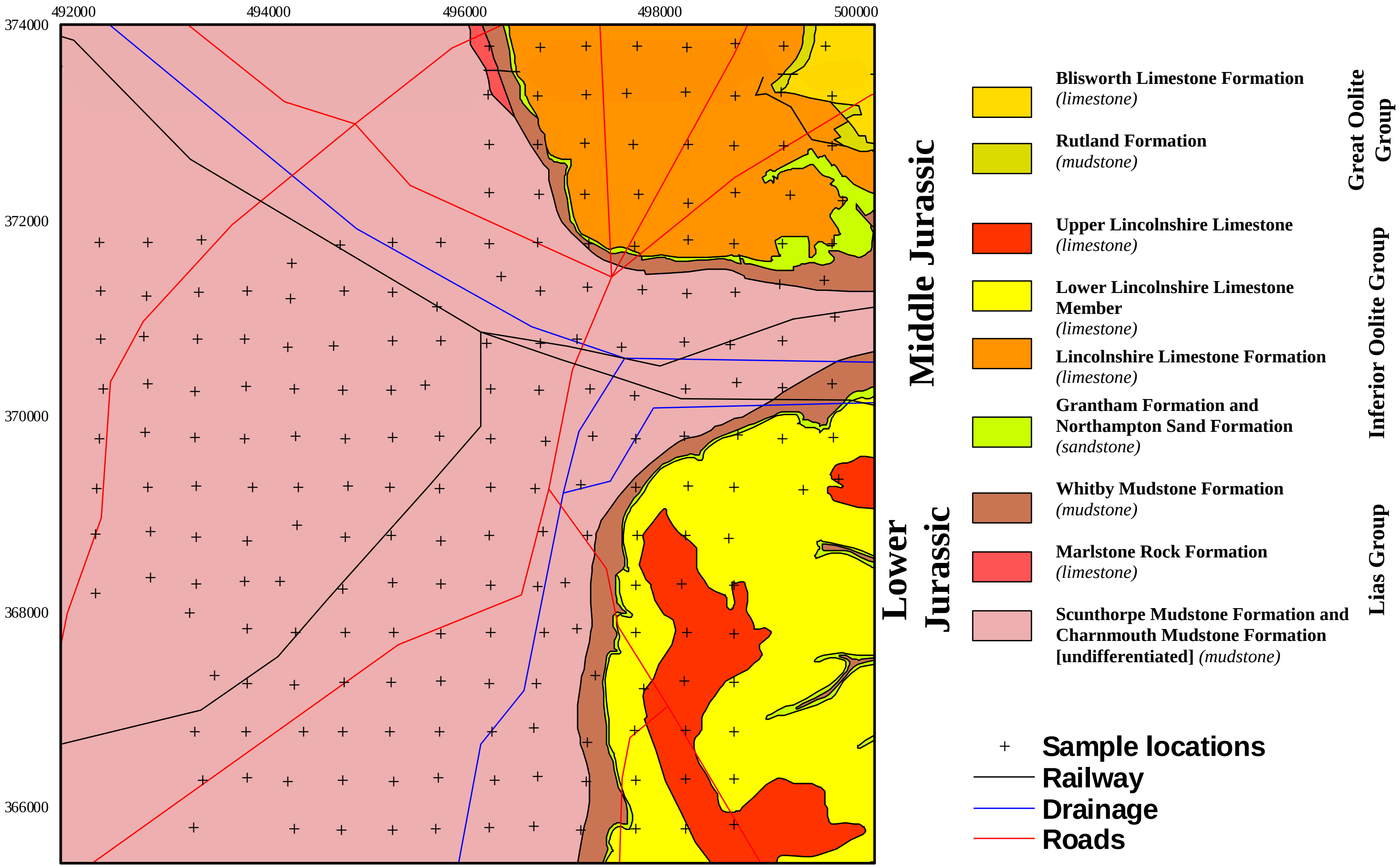


**Figure 5 Solid geology map of Lincoln and the surrounding area (based on 1:50 000 scale geological map; BNG shown at 2 km intervals) BGS DigmapGB®**

# 3 Methodology

## 3.1 SOIL SAMPLING

Sample sites were arranged on a systematic grid pattern at a density of 4 samples per km$^2$ across the built-up area whereby each BNG kilometre square as defined from 1:25 000 scale topographic maps (Ordnance Survey®) was split into four 500 m x 500 m sub-cells. Samples were collected from open ground as close as possible to the centre of each 500 m cell. Sample spacing was kept as regular as possible, namely 500 m apart, but was constrained by the actual conditions that were encountered on the ground (such as buildings and other constructions). Typical locations for sampling included gardens, parks, sports fields, road verges, allotments, open spaces, schoolyards and waste ground. Whilst attempts were made to select the least disturbed area of open ground as close as possible to the centre of the 500 m cell, contamination was not purposefully avoided as the aim of the survey was to provide an overview of the urban geochemistry and not to establish a 'near natural' geochemical baseline.

Soil samples were collected using a Dutch style hand auger with a 15 x 3 cm bore. Two samples were collected from different depths at each site. Surface samples were labelled A and were collected from a depth of 0.05 – 0.20 m. Deeper 'profile' samples were labelled S and were collected from the same auger holes as the A samples from a depth of 0.35 – 0.50 m (Johnson *et al.*, 2003). Both A and S samples comprised a composite of 3 sub-samples collected on the diagonal of a 2 x 2 m square. Duplicate sampling is described in section 3.3.2 of this report.

As indicated in section 2.5 above, information about the soils is recorded at each site on field cards and the sample locations are stored in the BGS corporate geochemical database where they can be retrieved via a user-friendly front-end (Harris and Coats, 1992).

## 3.2 SAMPLE PREPARATION

Samples were air and then oven dried at temperatures below 20ºC and then sieved. Surface soils were sieved to obtain the <2 mm fraction and profile soils to obtain the <150 µm fraction to be compatible with G-BASE regional <150 µm stream sediment data. The sieved material was coned and quartered and a split of the sample was ground using an agate ball mill until 95% reached a grain size finer than 53 µm. A 12 g split of the ground material was combined with 3 g of elvacite binder and pressed into a pellet for analysis by X-Ray Fluorescence Spectrometry analysis (XRFS) (see section 3.4).

Excess sieved and ground sample material is retained in the National Geoscience Records Centre sample store at the BGS.

## 3.3 ERROR CONTROL PROCEDURES

The accuracy and precision of the geochemical data were monitored using the methods of Plant *et al.* (1975), which are briefly described below.

### 3.3.1 Random numbering of samples

Samples were allocated numbers according to a random numbering system (Plant, 1973), but were analysed in numerical order. This allows any systematic error in either sampling or analytical methodologies to be identified and attributed to the appropriate process. At each site the A and the S samples were assigned unique numbers according to the random number lists. Therefore within each batch of one hundred samples there were 50 A and 50 S samples.

### 3.3.2 Duplicate and sub-samples

Within each batch of one hundred samples, a pair of sample numbers were assigned to a sampling duplicate, resulting in a field duplicate pair for both A and S samples. Duplicate samples were collected using identical sampling methodology adjacent to the original sample. At the sample preparation stage each of the field duplicate samples were split to obtain an analytical replicate sub-sample. Each sub-sample was assigned a different number and treated as a separate sample for analytical purposes.

The collection of field duplicate samples enables the sampling error, or sampling variation, to be estimated, thus providing a measure of the between-sample variance. Analytical replicate sub-sampling allows the analytical error or variance to be estimated as differences in results between the original and the sub-sample may indicate the influence of the sample preparation and analytical process.

The components of variance were estimated using analysis of variance (ANOVA). This statistical technique is used to determine the residual variance (introduced by sub-sampling, sample preparation and chemical analysis); the between-sample variance (attributed to within-site variation and variability introduced during sample collection); and between-site variance (representing the environmental variation in element concentrations across the survey area). All of the analyses form part of a single randomised dataset and a random nested model of ANOVA was therefore used (Snedecor and Cochran, 1989). Due to the relatively low number of duplicate samples collected in a single urban area, the ANOVA calculations were performed using replicate soils collected from 11 different urban centres: Cardiff, Swansea, Stoke, Telford, York, Hull, Doncaster, Mansfield, Scunthorpe, Lincoln and Sheffield (Lister, 2002; Lister, In Prep). A total of 50 replicate sets were measured for urban profile soils, while up to 37 were measured for urban surface soils. All elements except Cd and U (both depths) and $TiO_2$ (surface soils) were log transformed to improve the fit of the data to a Gaussian distribution. The ANOVA calculations were performed using the NESTED procedure from the statistical software package, MINITAB$^{TM}$. The results of the ANOVA indicate that for most elements the between-site variability is greater than 80% of the total variance (Table 2). This suggests that geochemical variation is the principal control on element concentrations in urban areas. The between-site variance of Cd is significantly lower than the other elements, with nearly half the variation in the surface soils attributed to residual factors. This is an indication of analytical error, most likely to result from low overall concentrations with respect to the detection limit.

### 3.3.3 Standards

G-BASE internal reference standards were analysed within each batch of field samples in order to monitor analytical instrument performance, and to provide continuity of data between different analytical campaigns. Internal standards were assigned unique sample Ids and inserted into each batch of field samples. In the case of Lincoln, G-BASE internal reference standards S13, S15, S24 and S3B were inserted during analysis of surface (A) and profile (S) soil samples. Each reference standard was analysed in duplicate, and mean concentrations for all elements in each standard are illustrated in Table 3.

The inclusion of G-BASE internal reference standards throughout all G-BASE and GSUE projects maintains data integrity between such projects. Lincoln lies within the Humber-Trent regional geochemical atlas area, and it is therefore essential that data for the urban centre of Lincoln are compatible with that of the surrounding regional dataset, of approximately 7000 soil sample sites (British Geological Survey, In Prep). A number of G-BASE standards were routinely analysed with the Humber-Trent samples, the mean element concentrations for these standards are compared with results for the Lincoln urban area in Table 3.

Where values differed significantly, the data were normalised using simple X-Y plots and regression calculations to correct for calibration variance between sample batches.

## Table 2 ANOVA percentage of variance in surface and profile soils from 11 urban centres attributable to between-site, between-sample and residual variance

| Surface Soils | | Variance | | | Profile Soils | | Variance | | |
|---|---|---|---|---|---|---|---|---|---|
| Element | Number of Replicate Sets | Between Site (%) | Between Sample (%) | Residual (%) | Element | Number of Replicate Sets | Between Site (%) | Between Sample (%) | Residual (%) |
| Sb | 16 | 88.03 | 1.15 | 10.82 | Sb | 50 | 87.68 | 3.05 | 9.27 |
| As | 37 | 97.69 | 2.02 | 0.29 | As | 50 | 97.87 | 1.82 | 0.31 |
| Ba | 37 | 97.63 | 1.79 | 0.58 | Ba | 50 | 97.39 | 2.56 | 0.05 |
| Cd | 27 | 47.88 | 6.77 | 45.35 | Cd | 50 | 65.44 | 3.95 | 30.61 |
| Cr | 37 | 94.14 | 3.07 | 2.79 | Cr | 50 | 93.46 | 5.55 | 0.99 |
| Co | 37 | 96.35 | 0.00 | 3.65 | Co | 50 | 94.00 | 5.62 | 0.38 |
| Cu | 37 | 97.63 | 1.66 | 0.72 | Cu | 50 | 98.87 | 1.08 | 0.06 |
| $Fe_2O_3$ | 37 | 97.69 | 2.06 | 0.25 | $Fe_2O_3$ | 50 | 96.62 | 3.36 | 0.01 |
| Pb | 27 | 97.48 | 2.23 | 0.29 | Pb | 50 | 96.51 | 3.43 | 0.06 |
| MnO | 37 | 98.28 | 1.39 | 0.33 | MnO | 50 | 96.03 | 3.92 | 0.05 |
| Mo | 33 | 94.24 | 0.71 | 5.05 | Mo | 50 | 93.59 | 3.23 | 3.17 |
| Ni | 37 | 98.06 | 1.59 | 0.34 | Ni | 50 | 95.96 | 3.83 | 0.21 |
| Sn | 36 | 93.45 | 2.91 | 3.63 | Sn | 50 | 95.77 | 2.42 | 1.81 |
| $TiO_2$ | 37 | 96.58 | 2.65 | 0.77 | $TiO_2$ | - | - | - | - |
| U | 37 | 85.95 | 1.24 | 12.81 | U | 47 | 76.92 | 10.99 | 12.09 |
| V | 37 | 97.89 | 1.79 | 0.32 | V | 50 | 97.85 | 2.09 | 0.06 |
| Zn | 37 | 94.77 | 5.16 | 0.07 | Zn | 50 | 92.64 | 7.34 | 0.02 |

## Table 3 Comparison of results for G-BASE bulk soil standards

| Sample Type Standard ID | Units | Humber-Trent S13 | Lincoln A S13 | Lincoln S S13 | Humber-Trent S15 | Lincoln A S15 | Lincoln S S15 |
|---|---|---|---|---|---|---|---|
| Sb | mg/kg | 0.1 | <1 | <1 | 1.1 | <1 | <1 |
| $Al_2O_3$ | wt% | - | 18.1 | - | - | 7.2 | - |
| As | mg/kg | 15 | 16 | 16 | 9 | 9 | 7 |
| Ba | mg/kg | 1704 | 1669 | 1888 | 291 | 378 | 376 |
| CaO | wt% | 0.35 | 0.33 | - | 0.20 | 0.21 | - |
| Cd | mg/kg | <1 | <1 | <1 | <1 | <1 | 1 |
| Cr | mg/kg | 98 | 97 | 100 | 41 | 39 | 37 |
| Co | mg/kg | 29 | 23 | 23 | 9 | 4 | 6 |
| Cu | mg/kg | 17 | 15 | 15 | 6 | 3 | 4 |
| $Fe_2O_3$ | wt% | 6.88 | 6.94 | 7.10 | 1.88 | 1.93 | 2.01 |
| Pb | mg/kg | 109 | 110 | 111 | 24 | 24 | 23 |
| MgO | wt% | 1.17 | 1.15 | - | 0.61 | 0.60 | - |
| MnO | wt% | 0.128 | 0.106 | 0.121 | 0.082 | 0.065 | 0.069 |
| Mo | mg/kg | 1.6 | 1.6 | 0.6 | 0.7 | 0.8 | 1.0 |
| Ni | mg/kg | 36 | 35 | 34 | 12 | 11 | 10 |
| $K_2O$ | wt% | 2.17 | 2.17 | - | 2.27 | 2.28 | - |
| $P_2O_5$ | wt% | 0.13 | 0.13 | - | 0.09 | 0.10 | - |
| $SiO_2$ | wt% | - | 56.25 | - | - | 67.70 | - |
| Sn | mg/kg | 3 | 3 | 2 | 5 | 4 | 4 |
| $TiO_2$ | wt% | 0.817 | 0.877 | 0.817 | 0.392 | 0.450 | 0.392 |
| U | mg/kg | 2.5 | 2.6 | 3.1 | 1.2 | 1.6 | 1.8 |
| V | mg/kg | 97 | 86 | 94 | 35 | 23 | 31 |
| Zn | mg/kg | 113 | 113 | 114 | 30 | 27 | 29 |

| Sample Type Standard ID | Units | Humber-Trent S24 | Lincoln A S24 | Lincoln S S24 | Humber-Trent S3B | Lincoln A S3B | Lincoln S S3B |
|---|---|---|---|---|---|---|---|
| Sb | mg/kg | 8 | 8 | 7 | <1 | <1 | <1 |
| $Al_2O_3$ | wt% | - | 23.2 | - | - | 10.3 | - |
| As | mg/kg | 124 | 127 | 128 | <1 | <1 | <1 |
| Ba | mg/kg | 983 | 1024 | 1038 | 10183 | 9179 | 9847 |
| CaO | wt% | 0.32 | 0.31 | - | 1.21 | 1.22 | - |
| Cd | mg/kg | 3 | <1 | <1 | 9 | 10 | 10 |
| Cr | mg/kg | 123 | 121 | 123 | 28 | 24 | 26 |
| Co | mg/kg | 97 | 85 | 83 | 51 | 43 | 44 |
| Cu | mg/kg | 64 | 63 | 63 | 47 | 46 | 47 |
| $Fe_2O_3$ | wt% | 10.22 | 10.22 | 10.50 | 13.45 | 13.51 | 13.71 |
| Pb | mg/kg | 1070 | 1013 | 1047 | 2075 | 1862 | 1910 |
| MgO | wt% | 1.1 | 1.0 | - | 0.5 | 0.5 | - |
| MnO | wt% | 0.458 | 0.43 | 0.49 | 3.773 | 3.642 | 3.773 |
| Mo | mg/kg | 1.9 | 1.9 | 0.4 | 145.8 | 146.8 | 147.6 |
| Ni | mg/kg | 45 | 43 | 44 | 30 | 29 | 28 |
| $K_20$ | wt% | 3.40 | 3.42 | - | 2.74 | 2.77 | - |
| $P_2O_5$ | wt% | 0.18 | 0.18 | - | 0.19 | 0.19 | - |
| $SiO_2$ | wt% | - | 45.70 | - | - | 38.85 | - |
| Sn | mg/kg | 6 | 6 | 4 | 2 | <1 | - |
| $TiO_2$ | wt% | 1.122 | 1.196 | 1.243 | 0.727 | 0.782 | 0.833 |
| U | mg/kg | 1.7 | 2.1 | 1.9 | 84.1 | 81.5 | 82.1 |
| V | mg/kg | 140 | 129 | 139 | 76 | 64 | 74 |
| Zn | mg/kg | 387 | 386 | 394 | 776 | 780 | 783 |

## 3.4 ANALYTICAL PROCEDURES

All samples were analysed at the BGS laboratories for a range of elements by Wavelength Dispersive X-Ray Fluorescence Spectrometry (XRFS) (Ingham and Vrebos, 1994). Three sequential XRF spectrometers were used. A Philips PW1480 fitted with a 216 position sample changer and a 3 kW/100kV tungsten anode X-ray tube was used to determine Cd, Sn and Sb. Two Philips PW2400 spectrometers fitted with 102 position sample changers and with 3 kW/60 kV rhodium anode x-ray tubes were used to determine $Al_2O_3$, CaO, $K_2O$, MgO, $P_2O_5$, $SiO_2$, $TiO_2$, MnO, $Fe_2O_3$, V, Cr, Co, and Ba in one suite and Ni, Cu, Zn, As, Mo, Pb, and U in another.

The elements determined and the lower limits of detection (LLD) and upper reporting limits (URL) for each analyte are shown in Table 4.

The quoted LLDs are theoretical values for the concentration equivalent to three standard deviations above the background count rate for the analyte in a pure silica matrix. High instrumental stability results in practical values for these materials approaching the theoretical.

**Table 4 Lower limits of detection (LLD) and upper reporting limit (URL) values for XRFS analysis of GSUE urban soil samples**

| Analyte | LLD (mg/kg) | LLD (%) | URL (mg/kg) | URL (%) |
|---|---|---|---|---|
| MnO | - | 0.01 | - | 10.0 |
| $Fe_2O_3$ | - | 0.01 | - | 100.0 |
| $TiO_2$ | - | 0.01 | - | 100.0 |
| V | 2.4 | - | 20000 | - |
| Cr | 3 | - | 250000 | - |
| Co | 1.9 | - | 10000 | - |
| Ni | 0.9 | - | 4000 | - |
| Cu | 0.9 | - | 6500 | - |
| Zn | 1 | - | 10000 | - |
| As | 0.9 | - | 10000 | - |
| Mo | 0.3 | - | 1000 | - |
| Cd | 0.9 | - | 500 | - |
| Sn | 1 | - | 10000 | - |
| Sb | 1.2 | - | 10000 | - |
| Ba | 2.9 | - | 600000 | - |
| Pb | 1.2 | - | 10000 | - |
| U | 0.5 | - | 650 | - |
| $SiO_2^*$ | - | 0.1 | - | 100.0 |
| $Al_2O_3^*$ | - | 0.1 | - | 100.0 |
| $P_2O_5^*$ | - | 0.05 | - | 1.5 |
| $K_2O^*$ | - | 0.05 | - | 15.0 |
| $CaO^*$ | - | 0.05 | - | 60.0 |
| $MgO^*$ | - | 0.1 | - | 50.0 |

*A-soils only.

## 3.5 DATA INTERPRETATION

Once full error control and data quality procedures were completed, the spatially registered Lincoln geochemical data were loaded into an Arcview© GIS software package. Graduated symbol geochemical maps for surface and profile soils categorised according to percentiles of the data distribution (Appendix B) were then generated (see Appendix C).

# 4 Geochemical Interpretation

## 4.1 BACKGROUND LEVELS

In order to aid the interpretation of the geochemical data for Lincoln, it is useful to be aware of typical background concentrations of elements in the surrounding rural environment to place the urban data in context. Rural soil geochemical data generated by the G-BASE programme are available for the Humber-Trent region, in which Lincoln is located. The median elemental concentrations for approximately 6561 surface soil samples are shown in Table 5 and the concentrations for approximately 6877 profile soils are displayed in Table 6. These data can be used to give an indication of the typical magnitude of elemental concentrations throughout the Humber-Trent region.

The median value of a soil dataset provides an indication of the typical concentrations for elements across the area, removing the influence of outliers caused by isolated regions of contamination. However, it should be noted that background values in the urban environment, as well as the rural environment (to a lesser extent), are likely to be elevated by some level of diffuse pollution.

**Table 5 Comparison of median concentrations in regional surface soil samples, from the Humber-Trent atlas area with Lincoln surface soil samples**

| Analyte | Units | Median Regional | Median Lincoln |
|---|---|---|---|
| $Al_2O_3$ | wt% | 11.5 | 6.3 |
| Sb | mg/kg | 0.5 | 0.6 |
| As | mg/kg | 13 | 11 |
| Ba | mg/kg | 376 | 279 |
| Cd | mg/kg | 1 | 0.45 |
| CaO | wt% | 2.12 | 1.35 |
| Cr | mg/kg | 71 | 44 |
| Co | mg/kg | 19 | 12 |
| Cu | mg/kg | 18 | 17 |
| $Fe_2O_3$ | wt% | 4.66 | 2.91 |
| Pb | mg/kg | 43 | 55 |
| MgO | wt% | 1.1 | 0.5 |
| MnO | wt% | 0.08 | 0.06 |
| Mo | mg/kg | 2.2 | 1.6 |
| Ni | mg/kg | 22 | 14 |
| $K_2O$ | wt% | - | 1.29 |
| $P_2O_5$ | wt% | 0.29 | 0.32 |
| $SiO_2$ | wt% | - | 62.5 |
| Sn | mg/kg | 4 | 4 |
| $TiO_2$ | wt% | 0.680 | 0.275 |
| U | mg/kg | 2.1 | 1.2 |
| V | mg/kg | 83 | 54 |
| Zn | mg/kg | 72 | 61 |

**Table 6 Comparison of median concentrations in regional profile soil samples, from the Humber-Trent atlas area with Lincoln profile soil samples**

| Analyte | Units | Median Regional | Median Lincoln |
|---|---|---|---|
| $Al_2O_3$ | wt% | - | - |
| Sb | mg/kg | 3 | 1 |
| As | mg/kg | 12 | 18 |
| Ba | mg/kg | 388 | 332 |
| Cd | mg/kg | 0.45 | 0.45 |
| CaO | wt% | 2.89 | - |
| Cr | mg/kg | 83 | 71 |
| Co | mg/kg | 21 | 16 |
| Cu | mg/kg | 20 | 22 |
| $Fe_2O_3$ | wt% | 5.04 | 3.96 |
| Pb | mg/kg | 38 | 58 |
| MgO | wt% | 1.3 | - |
| MnO | wt% | 0.10 | 0.07 |
| Mo | mg/kg | 1.8 | 2.3 |
| Ni | mg/kg | 27 | 22 |
| $K_2O$ | wt% | 1.98 | - |
| $P_2O_5$ | wt% | 0.25 | - |
| $SiO_2$ | wt% | - | - |
| Sn | mg/kg | 4 | 7 |
| $TiO_2$ | wt% | 0.735 | 0.495 |
| U | mg/kg | 2.5 | 2.3 |
| V | mg/kg | 88 | 66 |
| Zn | mg/kg | 77 | 79 |

In the Lincoln surface soils, only median values for the elements Sb, Pb and $P_2O_5$ are above the regional median, while As, Cu, Mo, Sn, Pb and Zn are above the regional median in the profile soils. The differences are, however, generally very small, with the most notable exception being Pb in both the surface and profile soils, suggesting that this element may be the most significant contaminant in Lincoln. The elevated concentrations of As and Sn in the Lincoln profile soils also appear to be significant, indicating possible contamination.

## 4.2 GEOCHEMICAL VARIATION WITH DEPTH

In a comparison of surface and profile soils, it should again be noted that during sample preparation the two sample types are sieved to different size fractions. The surface soils are sieved to <2 mm whilst the profile soils are sieved to <150 µm. This means that the sieved profile soil has a much larger surface area and will contain more clay particles (which possess the ability to attract and bind many metallic elements (Brady and Weil, 1999)) and this may affect the geochemical results.

A total of 23 major and trace elements were measured in Lincoln top-soils; aluminium (expressed as $Al_2O_3$), antimony (Sb), arsenic (As), barium (Ba), calcium (expressed as CaO), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (expressed as $Fe_2O_3$), lead (Pb), magnesium (expressed as MgO), manganese (expressed as MnO), molybdenum (Mo), nickel (Ni), phosphorus (expressed as $P_2O_5$), potassium (expressed as $K_2O$), silicon ($SiO_2$), tin (Sn), titanium (expressed as $TiO_2$), uranium (U), vanadium (V) and zinc (Zn). All elements except $Al_2O_3$, CaO, MgO, $K_2O$, $P_2O_5$, and $SiO_2$ were additionally measured in the profile soils.

Most of the elements analysed at both sample depths have higher median concentrations in the profile soils than in the surface soils. The only exception is Cd, which has a median value below the detection limit at both depths (Tables 5 and 6). There are several scenarios that could account for this situation. For example, aerially deposited and surface derived anthropogenic contamination may be transported through the soil profile over time, although higher concentrations would nevertheless be expected in the surface soils in this situation. Elevated concentrations of elements within deeper soils may also reflect a strong geogenic influence; for example, where surface soils have become depleted in major and trace elements due to weathering processes, whilst deeper soils are more enriched in weathered rock minerals. It is also possible that less-contaminated surface soils may have developed over older areas of made ground, resulting in lower concentrations of some elements in the surface soils. In the case of Lincoln, the differences between the soil depths are most likely to reflect the fact that many of these elements are concentrated within the finer soil fractions, leading to higher values in the profile soils. However, it is likely that the levels of diffuse pollution across the urban area of Lincoln are not particularly marked, as elevated concentrations of heavy metals and other potential contaminants would be expected in the surface soils of an area subjected to high levels of anthropogenic deposition.

## 4.3 GEOCHEMICAL DISTRIBUTION IN THE LINCOLN SOILS

A strong geological influence on geochemical distributions in the Lincoln soils is evident from the maps shown in Appendix C. Higher concentrations of As, CaO, Cr, Co, $Fe_2O_3$, MnO, Ni, U and V are found at both sample depths in soils on the eastern edge of the survey area, overlying the Inferior Oolite and Great Oolite Groups (Figure 5). There are particularly high concentrations of some of these elements, as well as Cu, Pb, MgO, Mo, $P_2O_5$, Sn and Zn, over Lincoln city centre in the north of the study area, which may reflect industrial and transportation sources. However, as this area also corresponds with exposures of the Inferior/Great Oolite Groups, it is difficult to separate any anthropogenic influence for these elements from the geological signature. Some elements do nevertheless show possible evidence of urban contamination, with elevated concentrations to the south of the city centre, where the main roads into Lincoln converge and along the railway line, which follows the River Witham valley (an area associated with industrial activities – see section 2.2). This pattern is particularly evident in the distribution of lead (at both sample depths), with other elements including As, Ba, Cu, Ni, $P_2O_5$ and Zn. High concentrations of Sn are observed to the south of the city centre in the profile soils, but are less evident in the surface soil distribution. This may reflect the greater affinity of anthropogenic Sn for the finer soil fractions.

There is an interesting distribution of Ba, which is largely low in concentration on the eastern edge of the survey area, whereas some of the highest concentrations occur to the south of the city centre, close to the main railway line, the River Witham and the canal. This may be related to the alluvial drift deposits in this area, but could also be a reflection of urban contamination derived from the river and canal, as well as from the railway and the industries in this sector of the city.

Concentrations of $SiO_2$ are higher in surface soils over the western half of the survey area, which includes Lincoln District. This is the only element to demonstrate such a pattern, which is likely to reflect a higher sand content in the alluvial deposits that are found in this region (Figure 4). This again indicates that there is a strong geological influence over the geochemical composition of the soils in Lincoln. Concentrations of $TiO_2$ are particularly elevated over the Inferior Oolite Group outcrop in the south-east of the survey area at both sample depths, suggesting that the composition of the oolite beds in this area may vary from the exposure to the north, underlying Lincoln city centre.

## 4.4 SOIL GEOCHEMISTRY OF LINCOLN IN RELATION TO OTHER HUMBER-TRENT URBAN AREAS

The results for selected elements from surface soils in Lincoln are presented in Figure 6 in the context of six other urban areas from the Humber-Trent region (Doncaster, Hull, Mansfield, Scunthorpe, Sheffield and York) and the results from the rural survey of the Humber-Trent region. Eight elements that may be affected by anthropogenic contamination in urban areas (Sb, As, Cd, Cu, Pb, Mo, Sn and Zn) are presented, as well as $TiO_2$ as a representative conservative element, unaffected by contamination.

Concentrations of $TiO_2$ are normally distributed in each urban area and fall within the range in concentration found on the regional scale as expected. In contrast, distributions of the other selected elements are in general positively skewed (indicated by a mean value significantly exceeding the median) in all the datasets and urban concentrations are higher than the regional values. These results indicate the degree of contamination in the urban environments as a result of anthropogenic contamination relative to the rural background.

In terms of the regional Humber-Trent data, recent work carried out by the BGS (Rawlins *et al.*, 2003) has demonstrated the importance of parent material type in determining the geochemical composition of soils. The main controls over variation in concentrations between different urban areas may therefore include parent material type, although population and past and present industrial activities are likely to be more important.

Soil Guideline Values (SGV) produced by the Contaminated Land Exposure Assessment (CLEA) model (Department of the Environment Food and Rural Affairs and the Environment Agency, 2002a; Department of the Environment Food and Rural Affairs and the Environment Agency, 2002b) for residential areas with plant uptake are shown on Figure 6 for Cd and As. Cadmium is present in concentrations below the detection limit (0.45 mg/kg) in over 75 % of the surface soil samples collected in Lincoln, below the SGV for this element. The values are relatively low compared to other urban areas in the Humber-Trent region, some of which exceed the SGV for low-pH soils in a number of samples, as well as to the regional values. The concentrations of As in Lincoln are largely below the SGV for this element and are similar to the levels of As found in the soils of Doncaster, Mansfield, York and the regional Humber-Trent soils. Levels of As exceed the 20 mg/kg SGV above the 75th percentile; the skewed distribution for this element suggests that there may be some contaminated samples within the dataset.

The six other potential contaminants selected in Figure 6 (Sb, Cu, Pb, Mo, Sn and Zn) do not appear to be elevated in the Lincoln surface soils, with respect to most of the other Humber-Trent urban areas. The median values are very similar to the Humber-Trent regional median values, suggesting that these elements may not be significant contaminants in the Lincoln soils; however, the levels of Cu, Pb and Sn are elevated at the 75th percentile, with respect to the regional values, which may reflect the influence of anthropogenic contamination in some of the samples collected.

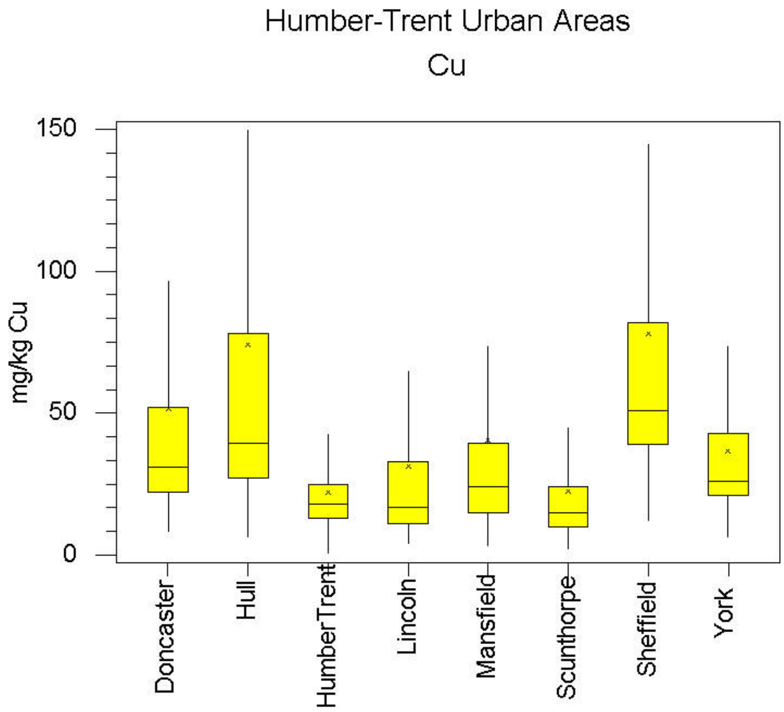


Figure 6: (a) Copper in surface soil

**Figure 6 (*(a) - (i)*) Box and Whisker Plots of the 5th, 25th, 50th, 75th and 95th percentiles of selected element concentrations in surface soils from seven urban areas in the Humber-Trent region presented with the regional Humber-Trent data. Soil Guideline Values (SGVs) for soils in residential areas involving plant uptake (derived using the CLEA model) are shown in red for As and Cd. Note that for Pb (450 mg/kg) and Cd (pH = 8, 8 mg/kg) SGV values are outside plot area. x = mean value.**

SGV = (Department of the Environment Food and Rural Affairs and the Environment Agency, 2002b)

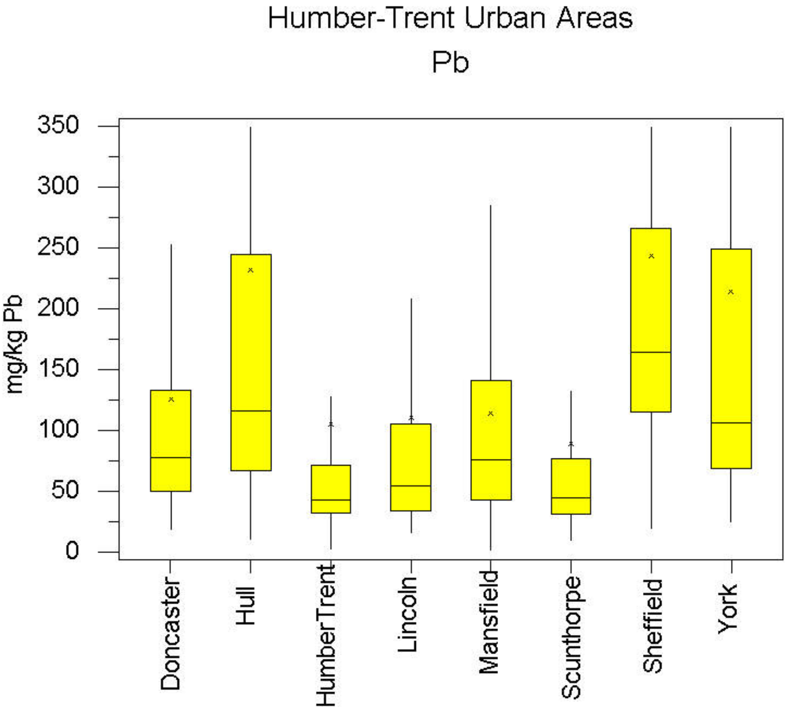


Figure 6: (b) Lead in surface soil

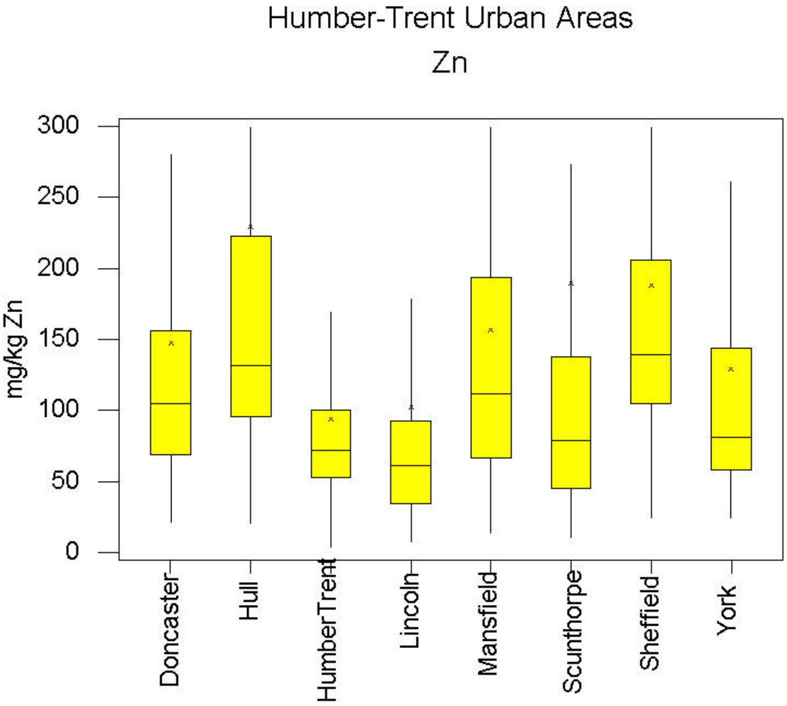


Figure 6: (c) Zinc in surface soil

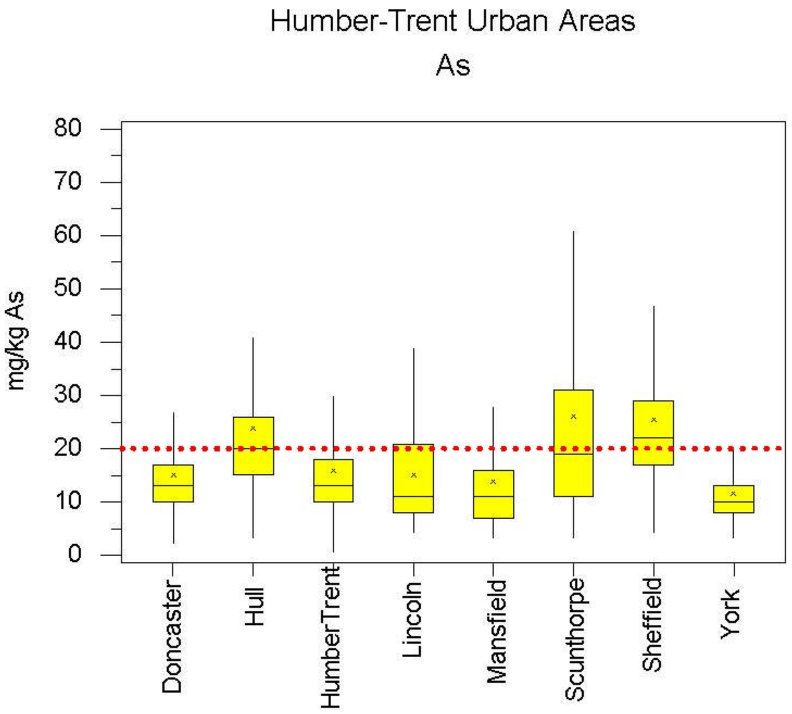


Figure 6: (d) Arsenic in surface soil

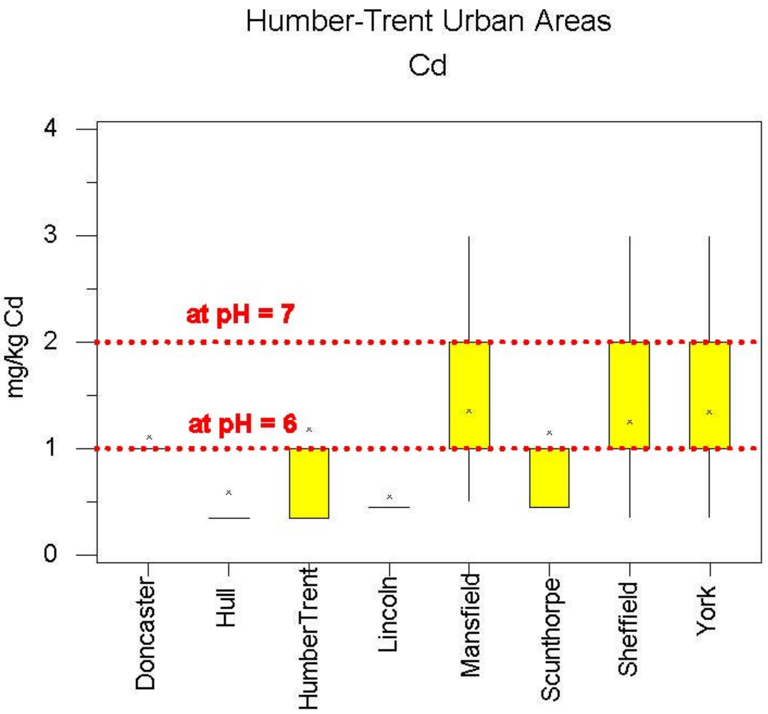


Figure 6: (e) Cadmium in surface soil

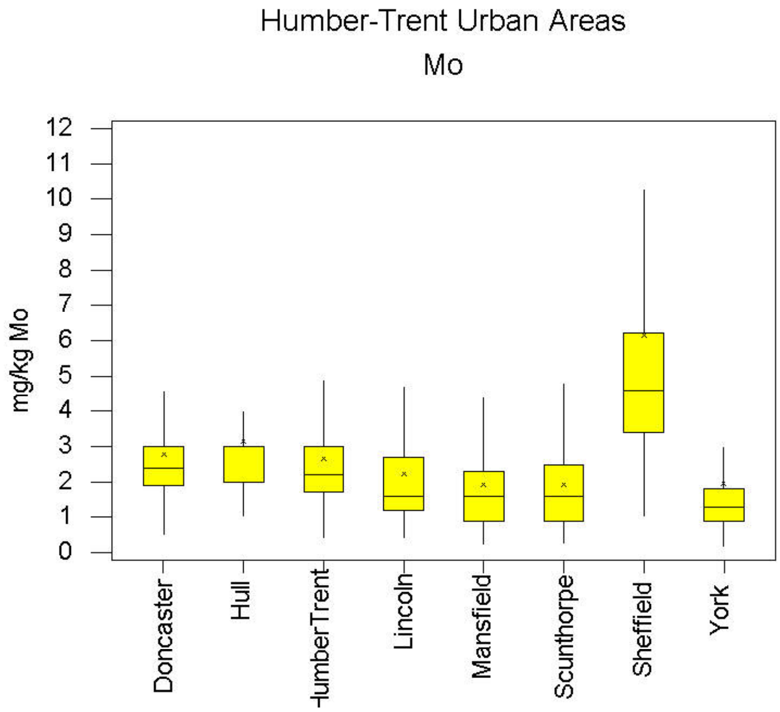


Figure 6: (f) Molybdenum in surface soil

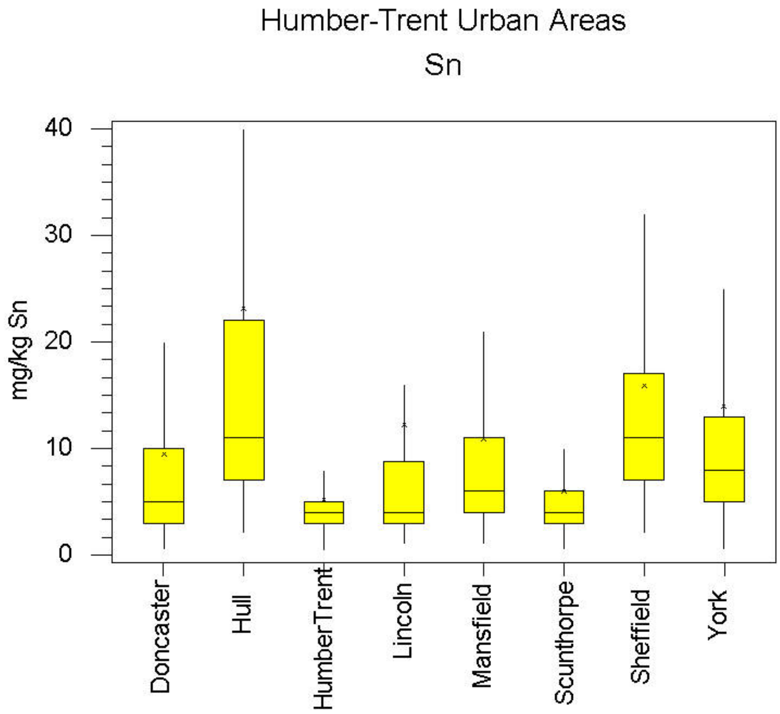


Figure 6: (g) Tin in surface soil

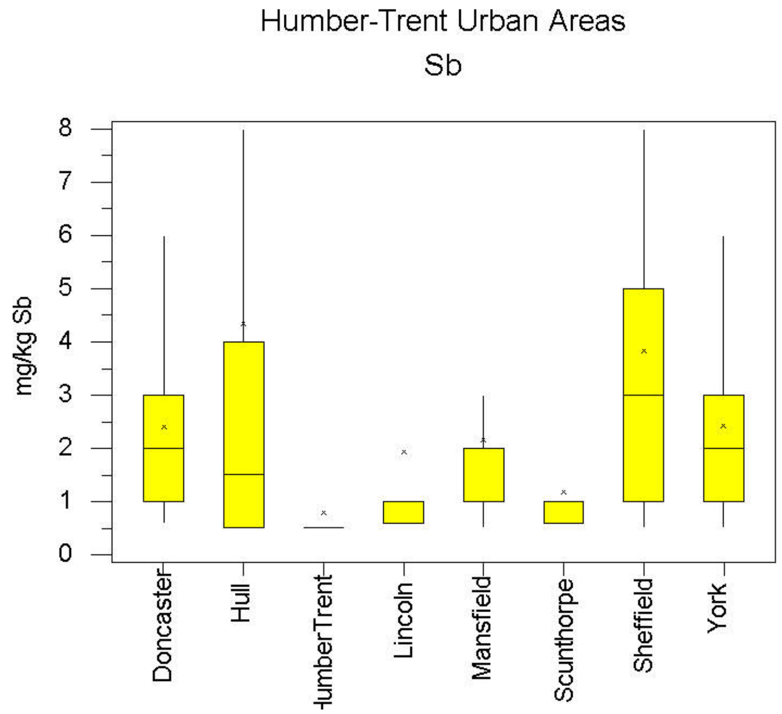


Figure 6: (h) Antimony in surface soil

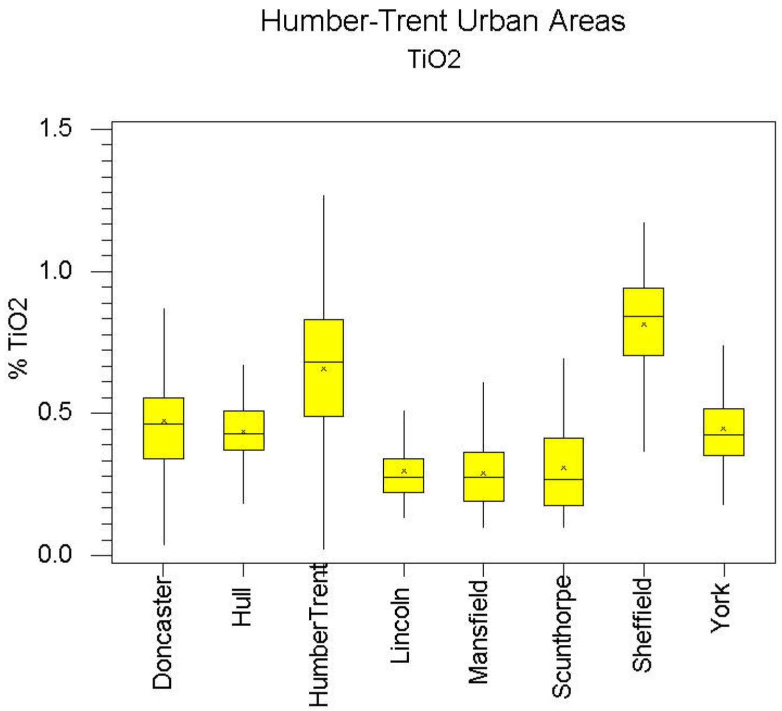


Figure 6: (i) Titanium oxide in surface soil

# References

BRADY, N C and WEIL, R R. 1999. *The Nature and Properties of Soils.* (New Jersey: Prentice Hall.)

BRITISH GEOLOGICAL SURVEY. In Prep. *Regional Geochemistry of the Humber-Trent Region.* (Keyworth: British Geological Survey.)

DEPARTMENT OF THE ENVIRONMENT FOOD AND RURAL AFFAIRS AND THE ENVIRONMENT AGENCY. 2002a. *The Contaminated Land Exposure Assessment (CLEA) Model: Technical Basis and algorithms.* R&D Publication CLR 10 (Bristol: Environment Agency.)

DEPARTMENT OF THE ENVIRONMENT FOOD AND RURAL AFFAIRS AND THE ENVIRONMENT AGENCY. 2002b. *Assessment of Risks to Human Health from Land Contamination: An Overview of the Development of Soil Guideline Values and Related Research.* R&D Publication CLR 7 (Bristol: Environment Agency.)

HARRIS, J R, and COATS, J S. 1992. *Geochemistry database: data analysis and proposed design.* Mineral Reconnaissance Programme. Technical Report WF/92/5 (Keyworth: British Geological Survey.)

HODGE, C A H, BURTON, R G O, CORBETT, W M, EVANS, R, and SEALE, R S. 1984. *Soils and Their Use in Eastern England.* Bulletin No. 13. (Harpenden: Soil Survey of England and Wales.)

INGHAM, M N, and VREBOS, B A R. 1994. High productivity geochemical XRF analysis. *Advances in X-ray Analysis,* Vol. 37, 717-724.

INSTITUTE OF GEOLOGICAL SCIENCES. 1973. Lincoln, Sheet 114. Solid and Drift. (Southampton: Ordnance Survey.)

INSTITUTE OF GEOLOGICAL SCIENCES. 1980. *Eastern England: From the Tees to the Wash (second edition).* British Regional Geology. (London: Her Majesty's Stationery Office.)

JOHNSON, C C, and BREWARD, N. 2004. *G-BASE Geochemical Baseline Survey of the Environment.* Commissioned Report, CR/04/016N. (Keyworth: British Geological Survey.)

JOHNSON, C C, BROWN, S E, and LISTER, T R. 2003. *G-BASE Field Procedures Manual version 1.1.* Internal Report No. IR/03/096N. (Keyworth: British Geological Survey.)

LISTER, T R. 2002. *Analysis of Variance (ANOVA) of G-BASE Sub-Surface Soil Data from 11 Urban Centres in England and Wales.* Internal Report, IR/02/009. (Keyworth: British Geological Survey.)

LISTER, T R. In Prep. *Analysis of Variance (ANOVA) of G-BASE Surface Soil Data from 11 Urban Centres in England and Wales.* Internal Report. (Keyworth: British Geological Survey.)

PLANT, J A. 1973. A random numbering system for geochemical samples. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science),* Vol. 82, B63-B66.

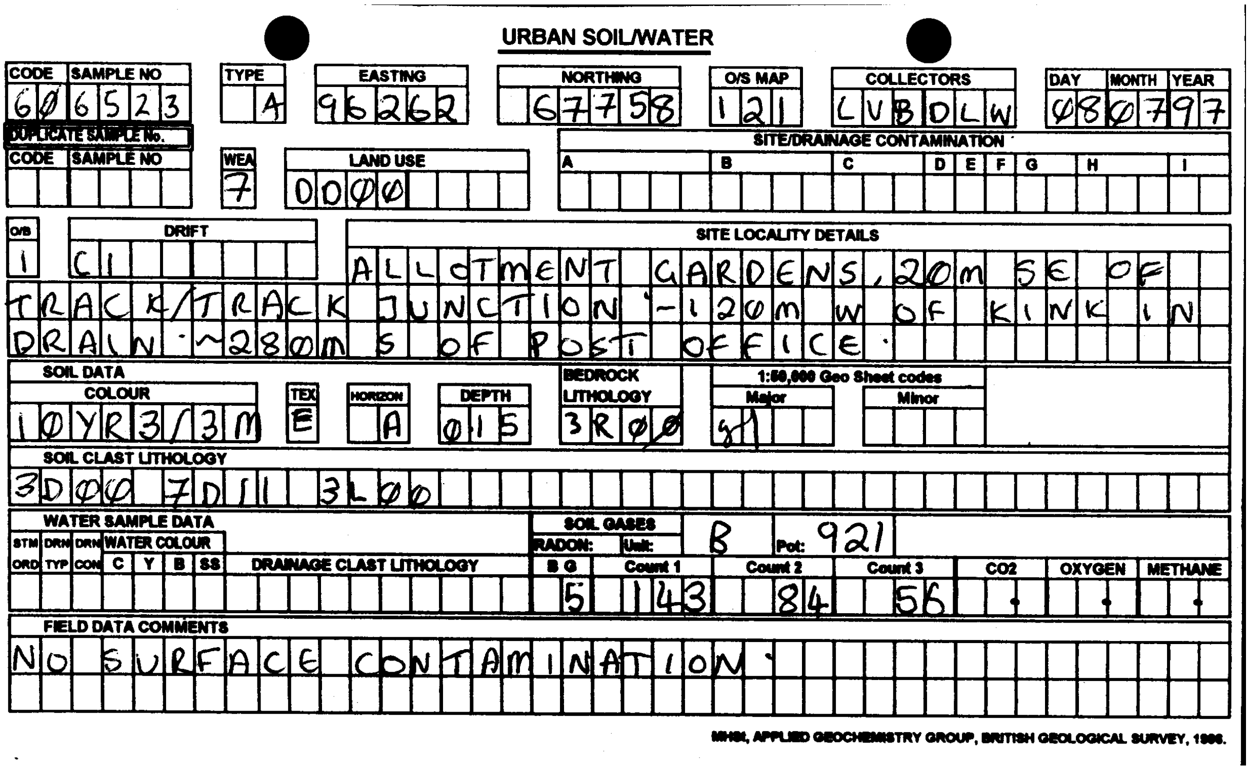
PLANT, J A, JEFFREY, K, GILL, E, and FAGE, C. 1975. The systematic determination of error, accuracy and precision in geochemical exploration data. *Journal of Geochemical Exploration,* Vol. 4, 467-486.

RAWLINS, B G, WEBSTER, R, and LISTER, T R. 2003. The influence of parent material on top soil geochemistry in eastern England. *Earth Surface Processes and Landforms,* Vol. 28, 1389-1409.

SNEDECOR, G W, and COCHRAN, W G. 1989. *Statistical Methods* (8th edition). (Ames, Iowa, USA: Iowa State University Press.)

SOIL SURVEY OF ENGLAND AND WALES. 1983. *Sheet 4, Soils of Eastern England. 1:250 000.* (Southampton: Ordnance Survey.)

# Appendix A: Examples of urban surface and profile soil field cards from Lincoln.



**URBAN SOIL/WATER**

CODE: 60 SAMPLE NO: 6523
TYPE: A
EASTING: 96262
NORTHING: 67758
O/S MAP: 121
COLLECTORS: LVBDLW
DAY: 08 MONTH: 07 YEAR: 97

DUPLICATE SAMPLE No. CODE: SAMPLE NO:
WEA: 7
LAND USE: 0000
SITE/DRAINAGE CONTAMINATION A B C D E F G H I:

O/B: 1
DRIFT: CI
SITE LOCALITY DETAILS: ALLOTMENT GARDENS, 20m SE OF TRACK/TRACK JUNCTION ~120m W OF KINK IN DRAIN ~280m S OF POST OFFICE.

SOIL DATA
COLOUR: 10YR3/3M
TEX: E
HORIZON: A
DEPTH: 015
BEDROCK LITHOLOGY: 3R00
1:50,000 Geo Sheet codes Major: g1 Minor:

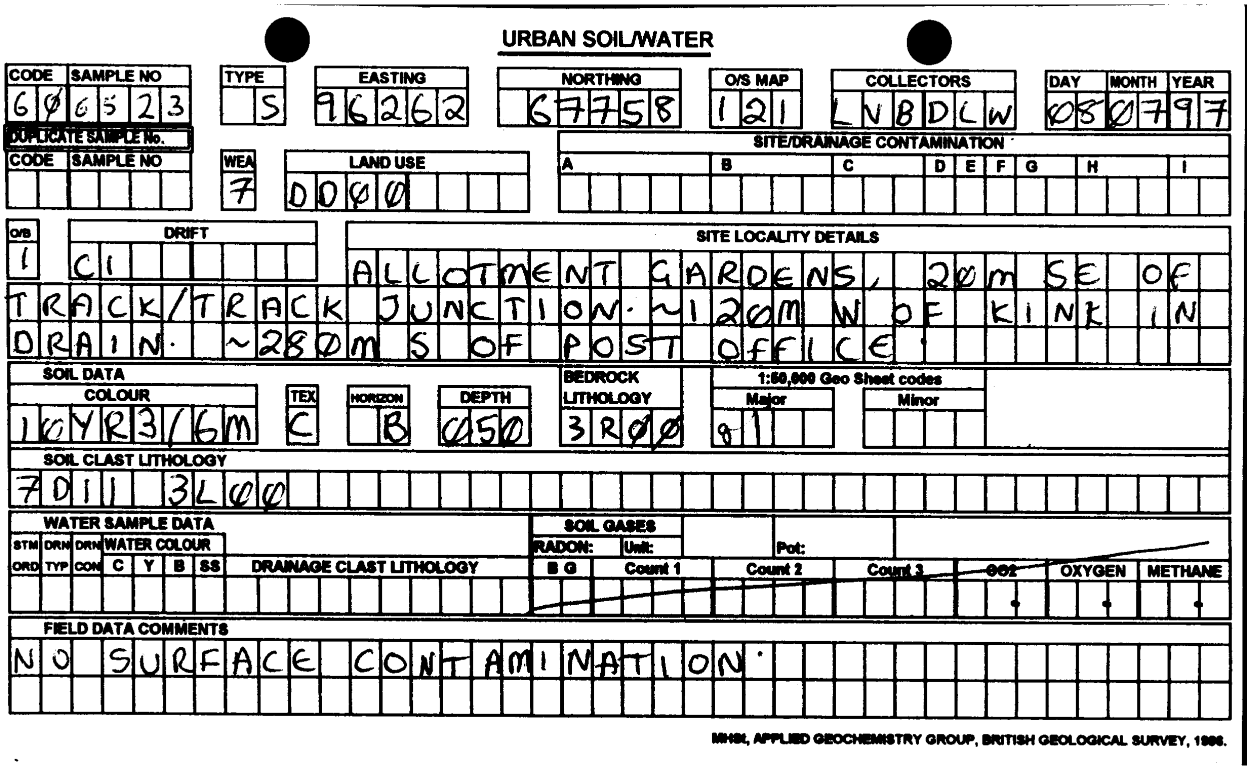
SOIL CLAST LITHOLOGY: 3D00 7D11 3L00

WATER SAMPLE DATA
STM ORD: DRN TYP: DRN CON: WATER COLOUR C: Y: B: SS: DRAINAGE CLAST LITHOLOGY:

SOIL GASES
RADON: Unit: B Pot: 921
B G: 5 Count 1: 143 Count 2: 84 Count 3: 56 CO2: . OXYGEN: . METHANE: .

FIELD DATA COMMENTS: NO SURFACE CONTAMINATION.

MHSI, APPLIED GEOCHEMISTRY GROUP, BRITISH GEOLOGICAL SURVEY, 1996.



**URBAN SOIL/WATER**

CODE: 60 SAMPLE NO: 6523
TYPE: S
EASTING: 96262
NORTHING: 67758
O/S MAP: 121
COLLECTORS: LVBDLW
DAY: 08 MONTH: 07 YEAR: 97

DUPLICATE SAMPLE No. CODE: SAMPLE NO:
WEA: 7
LAND USE: D000
SITE/DRAINAGE CONTAMINATION A B C D E F G H I:

O/B: 1
DRIFT: CI
SITE LOCALITY DETAILS: ALLOTMENT GARDENS, 20m SE OF TRACK/TRACK JUNCTION. ~120m W OF KINK IN DRAIN. ~280m S OF POST OFFICE.

SOIL DATA
COLOUR: 10YR3/6M
TEX: C
HORIZON: B
DEPTH: 050
BEDROCK LITHOLOGY: 3R00
1:50,000 Geo Sheet codes Major: g1 Minor:

SOIL CLAST LITHOLOGY: 7D11 3L00

WATER SAMPLE DATA
STM ORD: DRN TYP: DRN CON: WATER COLOUR C: Y: B: SS: DRAINAGE CLAST LITHOLOGY:

SOIL GASES
RADON: Unit: Pot:
B G: Count 1: Count 2: Count 3: CO2: . OXYGEN: . METHANE: .

FIELD DATA COMMENTS: NO SURFACE CONTAMINATION.

MHSI, APPLIED GEOCHEMISTRY GROUP, BRITISH GEOLOGICAL SURVEY, 1996.

# Appendix B: Percentile calculations for Lincoln soils

| **A-Soils:** | **MgO** | **$SiO_2$** | **$Al_2O_3$** | **$P_2O_5$** | **$K_2O$** | **CaO** | **$TiO_2$** | **MnO** | **$Fe_2O_3$** | **V** | **Cr** | **Co** | **Ni** | **Cu** | **Zn** | **As** | **Mo** | **Ba** | **Pb** | **U*** | **Cd*** | **Sn** | **Sb*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Percentiles** | **%** | **%** | **%** | **%** | **%** | **%** | **%** | **%** | **%** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** |
| **5%** | 0.2 | 42.3 | 4.1 | 0.14 | 1.07 | 0.18 | 0.161 | 0.03 | 1.04 | 30 | 27 | 5 | 4 | 7 | 20 | 6 | 0.7 | 208 | 23 | 0.5 | 0.45 | 2 | 0.6 |
| **10%** | 0.2 | 47.1 | 4.4 | 0.18 | 1.09 | 0.26 | 0.186 | 0.03 | 1.29 | 33 | 29 | 6 | 5 | 8 | 25 | 6 | 0.8 | 226 | 26 | 0.7 | 0.45 | 2 | 0.6 |
| **15%** | 0.3 | 49.6 | 4.7 | 0.20 | 1.11 | 0.31 | 0.202 | 0.03 | 1.55 | 34 | 32 | 7 | 6 | 9 | 27 | 7 | 1.0 | 235 | 29 | 0.8 | 0.45 | 2 | 0.6 |
| **25%** | 0.4 | 54.0 | 5.1 | 0.24 | 1.18 | 0.49 | 0.222 | 0.04 | 1.98 | 37 | 35 | 7 | 8 | 11 | 35 | 8 | 1.2 | 247 | 35 | 1.0 | 0.45 | 3 | 0.6 |
| **50%** | 0.5 | 62.5 | 6.3 | 0.32 | 1.29 | 1.35 | 0.275 | 0.06 | 2.91 | 54 | 44 | 12 | 14 | 17 | 61 | 11 | 1.6 | 279 | 55 | 1.2 | 0.45 | 4 | 0.6 |
| **75%** | 0.7 | 68.4 | 7.8 | 0.45 | 1.39 | 5.68 | 0.339 | 0.09 | 4.28 | 71 | 53 | 16 | 19 | 33 | 92 | 20 | 2.7 | 315 | 105 | 1.5 | 0.45 | 8 | 1 |
| **90%** | 0.9 | 72.1 | 9.4 | 0.61 | 1.52 | 11.37 | 0.441 | 0.10 | 5.60 | 90 | 68 | 16 | 28 | 66 | 184 | 28 | 3.9 | 419 | 232 | 1.9 | 1 | 24 | 3 |
| **95%** | 1.1 | 73.4 | 12.4 | 0.88 | 1.67 | 14.61 | 0.506 | 0.12 | 6.79 | 119 | 88 | 25 | 34 | 105 | 269 | 35 | 4.7 | 510 | 322 | 2.1 | 1 | 37 | 4 |
| **99%** | 1.6 | 75.6 | 15.6 | 1.19 | 1.89 | 20.16 | 0.716 | 0.16 | 9.37 | 178 | 134 | 33 | 60 | 235 | 777 | 60 | 10.8 | 839 | 1174 | 3.0 | 2 | 219 | 23 |
| **Maximum** | 3.5 | 77.4 | 18.1 | 1.31 | 2.46 | 22.68 | 0.774 | 1.06 | 12.28 | 215 | 260 | 35 | 101 | 348 | 2399 | 65 | 21.1 | 1412 | 1400 | 3.6 | 5 | 250 | 100 |
| **Minimum** | 0.1 | 35.3 | 2.9 | 0.09 | 0.80 | 0.06 | 0.130 | 0.02 | 0.61 | 23 | 19 | 4 | 2 | 4 | 7 | 4 | 0.4 | 150 | 15 | 0.25 | 0.45 | 1 | 0.6 |
| **Median** | 0.5 | 62.5 | 6.3 | 0.32 | 1.29 | 1.35 | 0.275 | 0.06 | 2.91 | 54 | 44 | 12 | 14 | 17 | 61 | 11 | 1.6 | 279 | 55 | 1.2 | 0.45 | 4 | 0.6 |
| **Mean** | 0.6 | 60.8 | 6.9 | 0.38 | 1.31 | 3.78 | 0.297 | 0.07 | 3.33 | 59 | 48 | 13 | 15 | 31 | 102 | 15 | 2.2 | 311 | 111 | 1.28 | 0.55 | 12 | 1.9 |

* minimum value reported as half detection limit

# Appendix B: Percentile calculations for Lincoln soils

| **S-Soils:** | **$TiO_2$** | **MnO** | **$Fe_2O_3$** | **V** | **Cr** | **Co** | **Ba** | **Ni** | **Cu** | **Zn** | **As** | **Mo** | **Pb** | **U*** | **Cd*** | **Sn** | **Sb*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Percentiles** | **%** | **%** | **%** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** | **mg/kg** |
| **5%** | 0.284 | 0.02 | 1.37 | 37 | 41 | 8 | 167 | 8 | 8 | 21 | 7 | 1.0 | 19 | 1.3 | 0.45 | 2 | 0.6 |
| **10%** | 0.338 | 0.03 | 1.66 | 41 | 47 | 8 | 195 | 9 | 9 | 29 | 8 | 1.2 | 25 | 1.6 | 0.45 | 3 | 0.6 |
| **15%** | 0.357 | 0.04 | 2.10 | 46 | 53 | 10 | 223 | 11 | 12 | 35 | 10 | 1.4 | 29 | 1.7 | 0.45 | 4 | 0.6 |
| **25%** | 0.393 | 0.05 | 2.81 | 51 | 58 | 11 | 280 | 14 | 14 | 47 | 12 | 1.8 | 36 | 2.0 | 0.45 | 5 | 0.6 |
| **50%** | 0.495 | 0.07 | 3.96 | 66 | 71 | 16 | 332 | 22 | 22 | 79 | 18 | 2.3 | 58 | 2.3 | 0.45 | 7 | 1 |
| **75%** | 0.561 | 0.10 | 5.49 | 89 | 83 | 20 | 383 | 30 | 42 | 119 | 28 | 3.1 | 131 | 2.7 | 1 | 12 | 2 |
| **90%** | 0.702 | 0.14 | 8.21 | 128 | 109 | 27 | 496 | 41 | 92 | 221 | 40 | 4.2 | 323 | 3.1 | 2 | 31 | 4 |
| **95%** | 0.751 | 0.16 | 9.76 | 167 | 124 | 33 | 647 | 54 | 157 | 367 | 51 | 5.0 | 700 | 3.4 | 2 | 46 | 6 |
| **99%** | 0.914 | 0.25 | 16.22 | 219 | 161 | 58 | 1386 | 136 | 867 | 1041 | 124 | 19.3 | 1600 | 4.0 | 4 | 318 | 71 |
| **Maximum** | 1.013 | 0.52 | 22.88 | 259 | 1349 | 74 | 5300 | 335 | 2687 | 7500 | 262 | 52.0 | 3500 | 4.9 | 34 | 1360 | 229 |
| **Minimum** | 0.186 | 0.02 | 0.63 | 28 | 26 | 5 | 92 | 6 | 3 | 9 | 3 | 0.6 | 10 | 0.25 | 0.45 | 1 | 0.6 |
| **Median** | 0.495 | 0.07 | 3.96 | 66 | 71 | 16 | 332 | 22 | 22 | 79 | 18 | 2.3 | 58 | 2.3 | 0.45 | 7 | 1 |
| **Mean** | 0.497 | 0.08 | 4.62 | 77 | 80 | 18 | 382 | 26 | 62 | 152 | 24 | 3.0 | 169 | 2.3 | 0.99 | 25 | 3.6 |

* minimum value reported as half detection limit

# Appendix C: Graduated symbol geochemical maps for Lincoln surface and profile soils

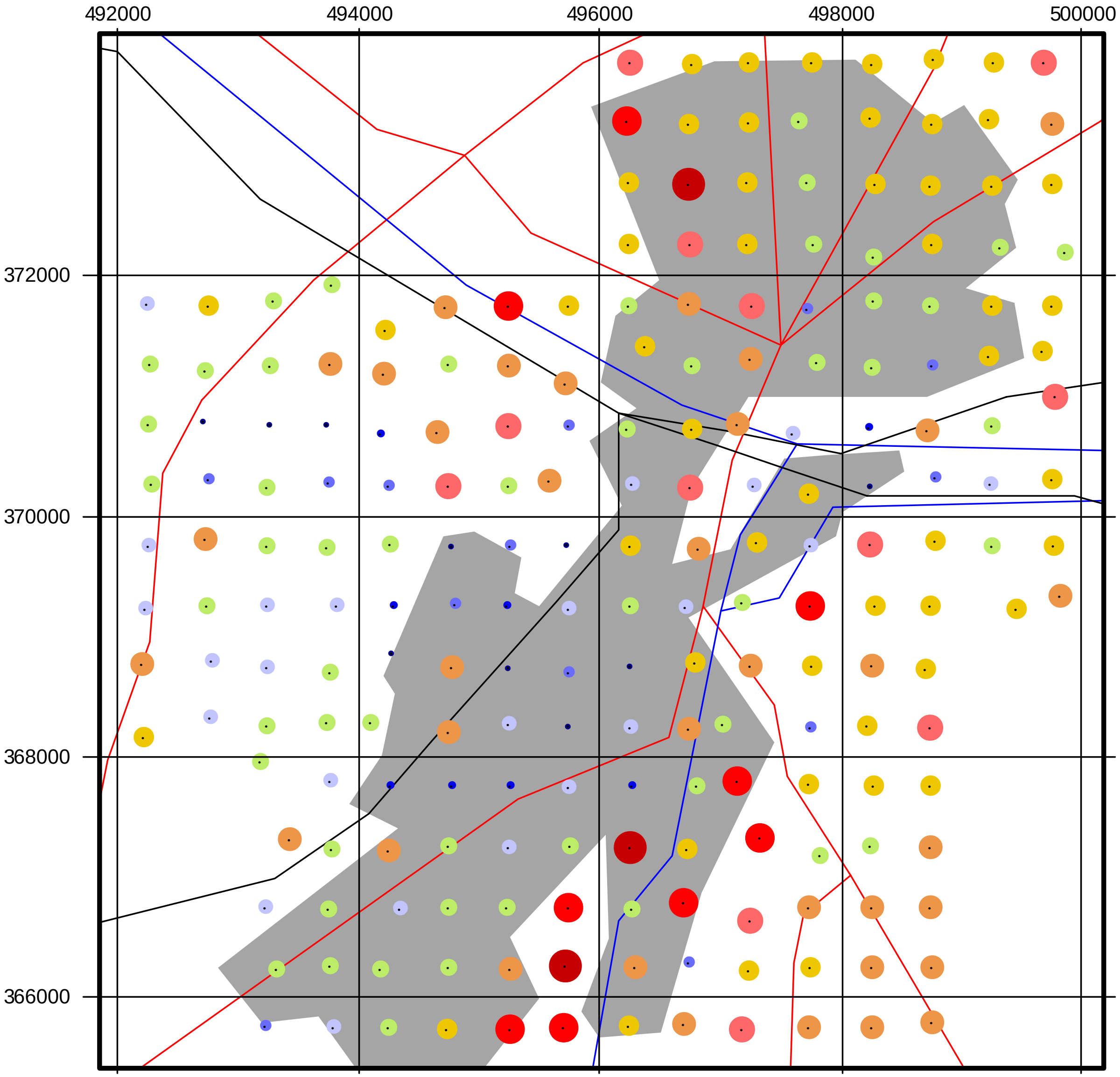
**Aluminium (surface soils only)**
**Antimony**
**Arsenic**
**Barium**
**Cadmium**
**Calcium (surface soils only)**
**Chromium**
**Cobalt**
**Copper**
**Iron**
**Lead**
**Magnesium (surface soils only)**
**Manganese**
**Molybdenum**
**Nickel**
**Phosphorus (surface soils only)**
**Potassium (surface soils only)**
**Silicon (surface soils only)**
**Tin**
**Titanium**
**Uranium**
**Vanadium**
**Zinc**

Note ppm = mg/kg on all maps

# Lincoln

## Surface Soils

## Aluminium



| %ile | | WT% |
|---|---|---|
| 99 | ● | 15.6 |
| 95 | ● | 12.4 |
| 90 | ● | 9.4 |
| 75 | ● | 7.8 |
| 50 | ● | 6.3 |
| 25 | ● | 5.1 |
| 15 | ● | 4.7 |
| 10 | ● | 4.4 |
| 5 | ● | 4.1 |

— Railway

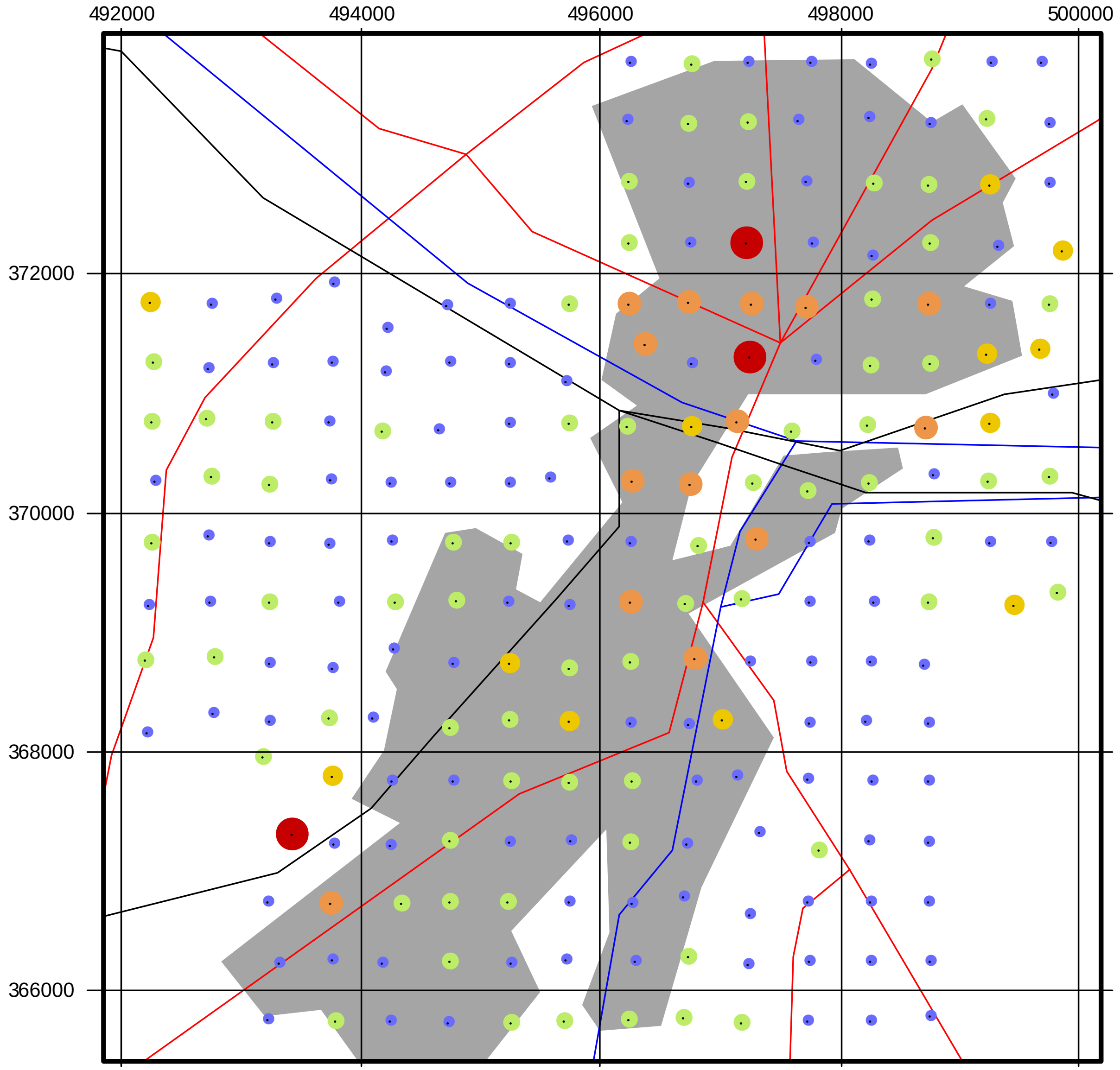
— Drainage

— Roads

▨ Urban area

| surface soil | $Al_2O_3$ (%) |
|---|---|
| number | 216 |
| minimum | 2.9 |
| maximum | 18.1 |
| median | 6.3 |
| mean | 6.9 |

Aluminium was not determined in the profile soils



# Lincoln

## Surface Soils

## Antimony

| %ile | | ppm |
|---|---|---|
| 99 | ● | 23 |
| 95 | ● | 4 |
| 90 | ● | 3 |
| 75 | ● | 1 |
| 50 | ● | 0.6 |
| | • | |

— **Railway**
— **Drainage**
— **Roads**
▨ **Urban area**

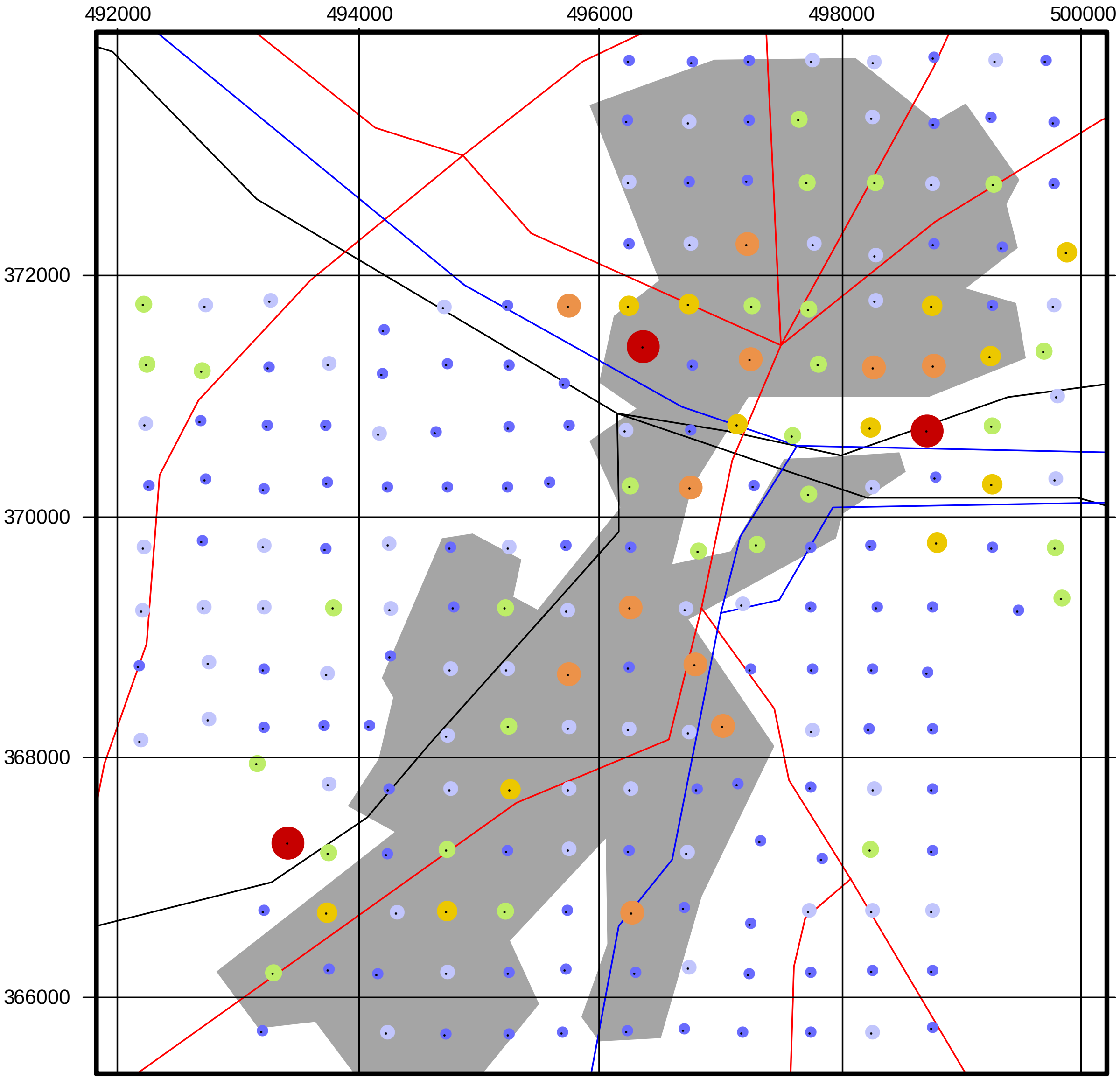
| surface soil | Sb (ppm) |
|---|---|
| number | 216 |
| minimum | 0.6* |
| maximum | 100 |
| median | 0.6 |
| mean | 1.9 |

*minimum value reported as half detection limit

# Lincoln

## Profile Soils

## Antimony

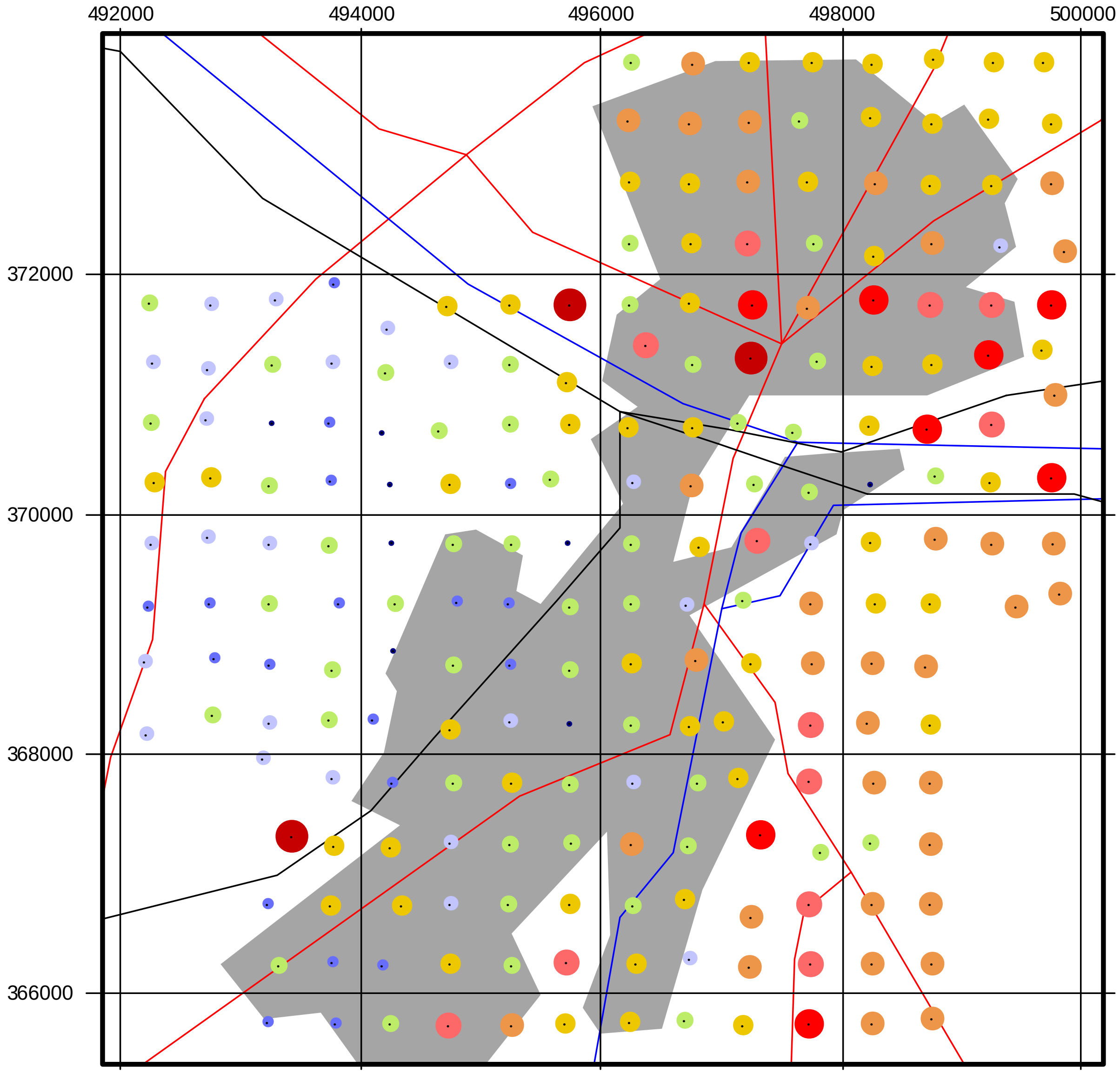


| %ile | | ppm |
|---|---|---|
| 99 | ● | 71 |
| 95 | ● | 6 |
| 90 | ● | 4 |
| 75 | ● | 2 |
| 50 | ● | 1 |
| 25 | ● | 0.6 |

— Railway
— Drainage
— Roads
▨ Urban area

| profile soil | Sb (ppm) |
|---|---|
| number | 214 |
| minimum | 0.6* |
| maximum | 229 |
| median | 1 |
| mean | 3.6 |

*minimum value reported as half detection limit



# Lincoln

## Surface Soils

## Arsenic

| %ile | | ppm |
|---|---|---|
| | ● | |
| 99 | | 60 |
| | ● | |
| 95 | | 35 |
| | ● | |
| 90 | | 28 |
| | ● | |
| 75 | | 20 |
| | ● | |
| 50 | | 11 |
| | ● | |
| 25 | | 8 |
| | ● | |
| 15 | | 7 |
| | ● | |
| 10 | | 6 |
| | • | |

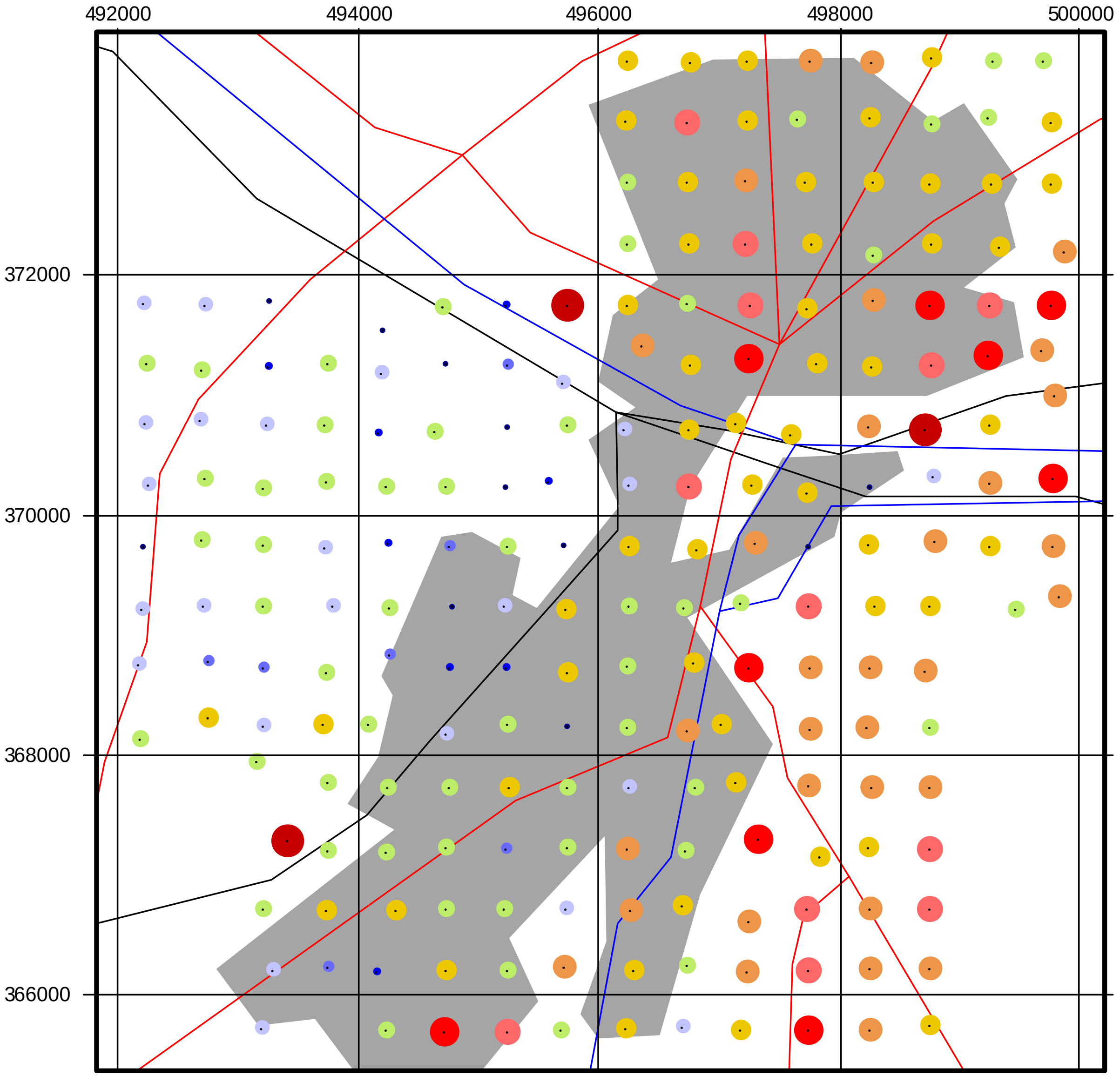
— Railway
— Drainage
— Roads
▨ Urban area

| surface soil | As (ppm) |
|---|---|
| number | 216 |
| minimum | 4 |
| maximum | 65 |
| median | 11 |
| mean | 15 |

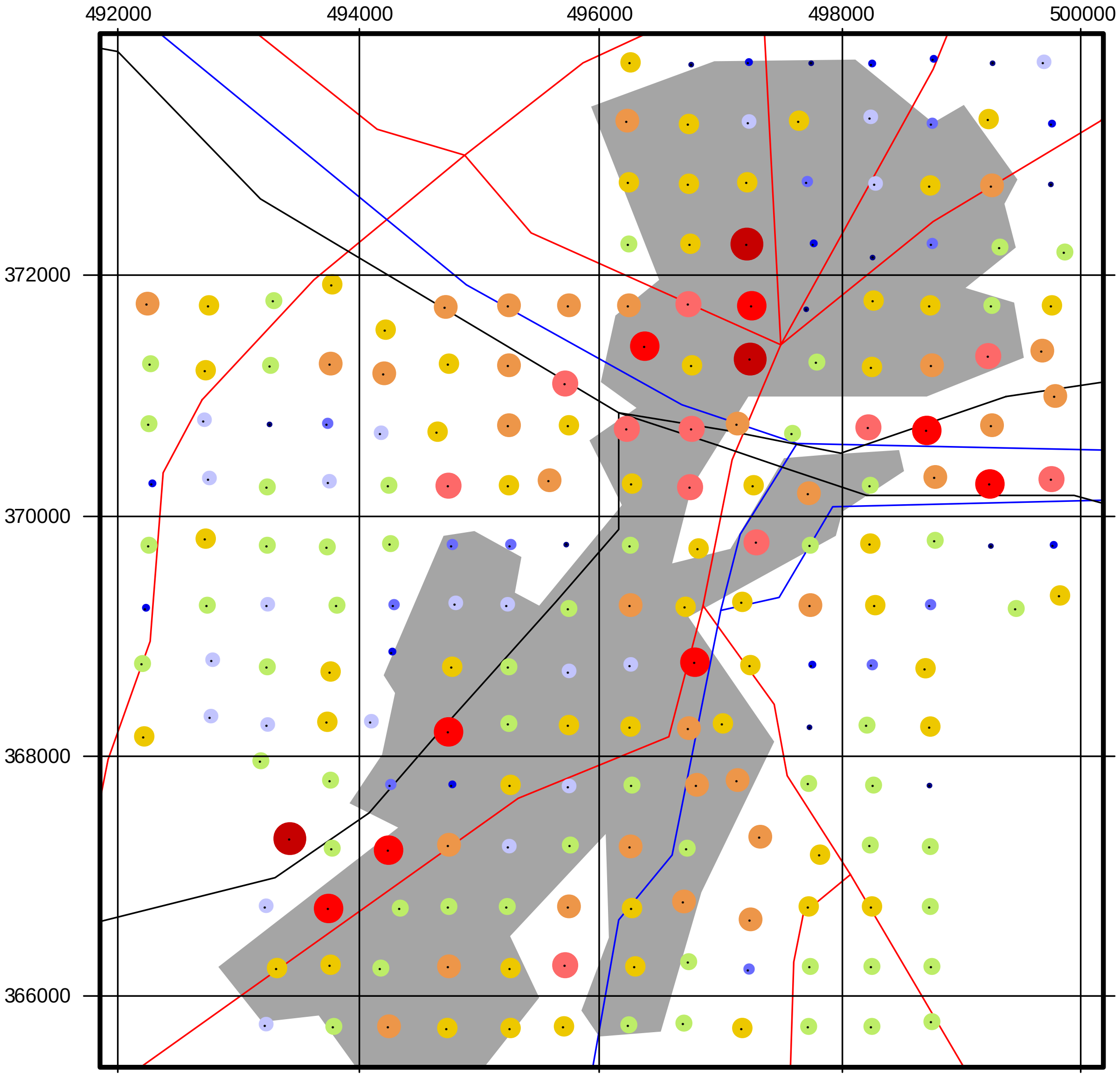
# Lincoln

## Profile Soils

## Arsenic



| profile soil | As (ppm) |
|---|---|
| number | 214 |
| minimum | 3 |
| maximum | 262 |
| median | 18 |
| mean | 24 |



# Lincoln

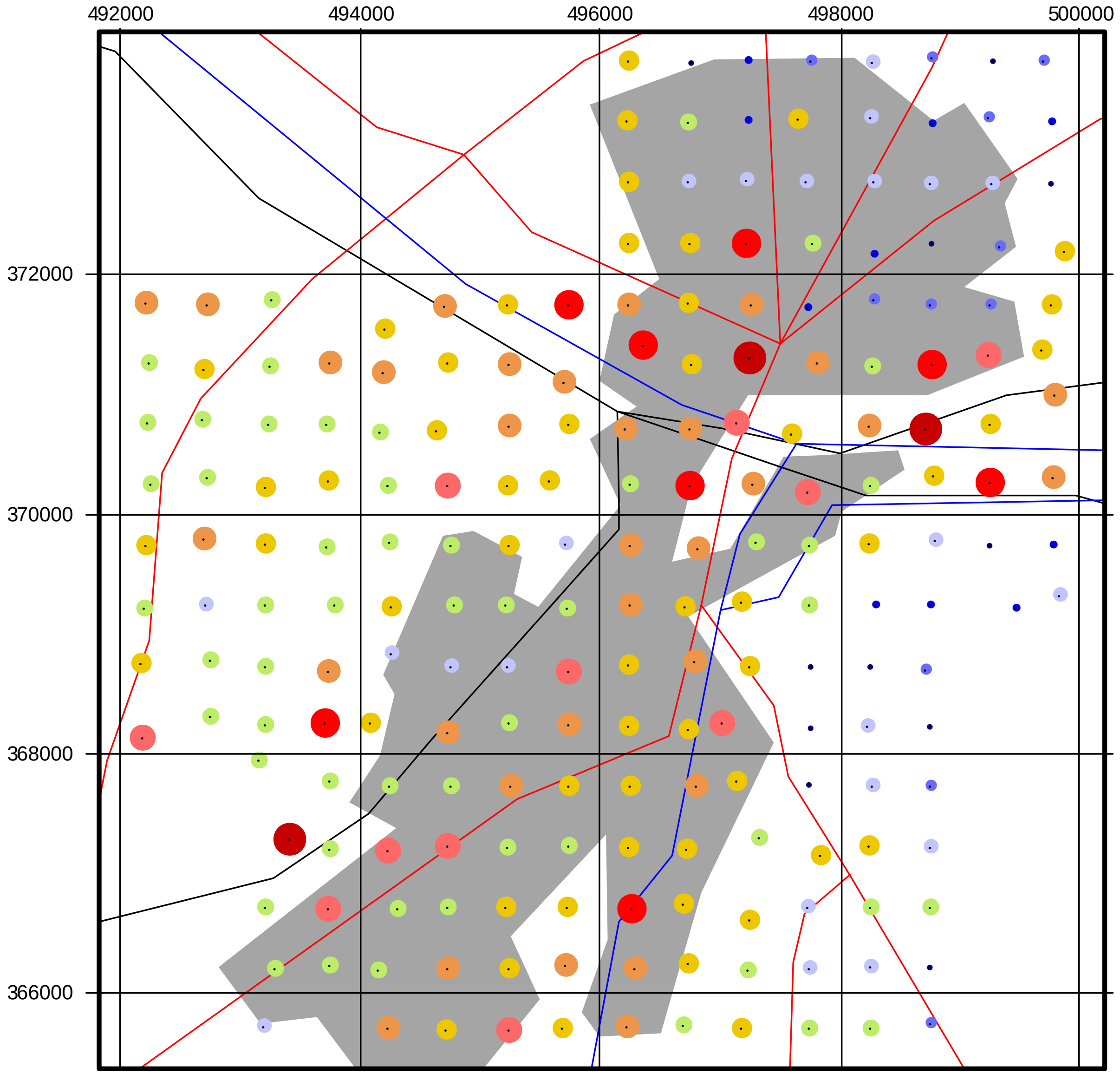
## Surface Soils

## Barium

| %ile | ppm |
|---|---|
| 99 | 839 |
| 95 | 510 |
| 90 | 419 |
| 75 | 315 |
| 50 | 279 |
| 25 | 247 |
| 15 | 235 |
| 10 | 226 |
| 5 | 208 |

— **Railway**
— **Drainage**
— **Roads**
▨ **Urban area**

| surface soil | Ba (ppm) |
|---|---|
| number | 216 |
| minimum | 150 |
| maximum | 1412 |
| median | 279 |
| mean | 311 |



# Lincoln

## Profile Soils

## Barium

| %ile | | ppm |
|---|---|---|
| 99 | ● | 1386 |
| 95 | ● | 647 |
| 90 | ● | 496 |
| 75 | ● | 383 |
| 50 | ● | 332 |
| 25 | ● | 280 |
| 15 | ● | 223 |
| 10 | ● | 195 |
| 5 | ● | 167 |
| | ● | |

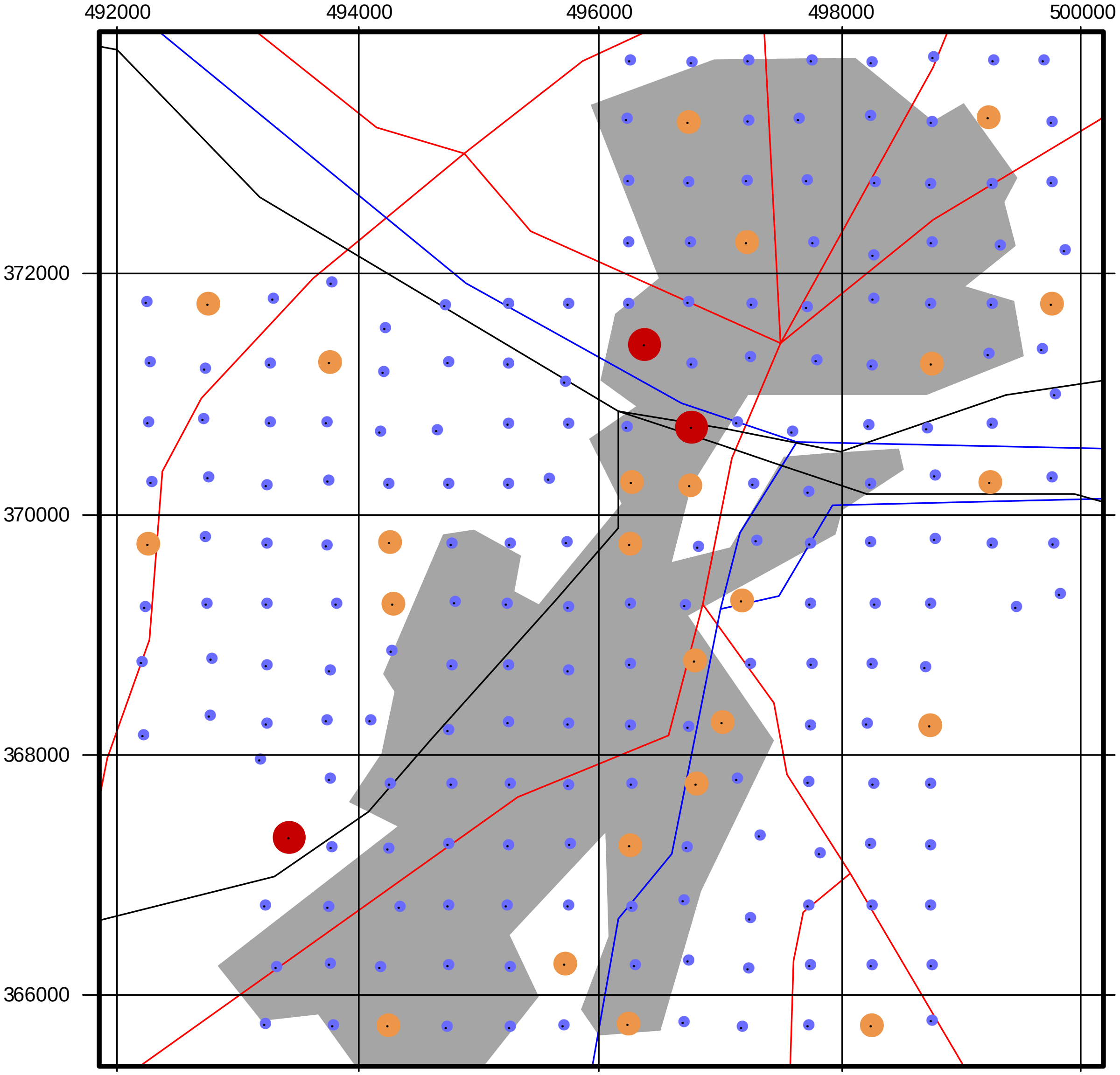
| | |
|---|---|
| — | Railway |
| — | Drainage |
| — | Roads |
| ▨ | Urban area |

| profile soil | Ba (ppm) |
|---|---|
| number | 214 |
| minimum | 92 |
| maximum | 5300 |
| median | 332 |
| mean | 382 |

# Lincoln

## Surface Soils

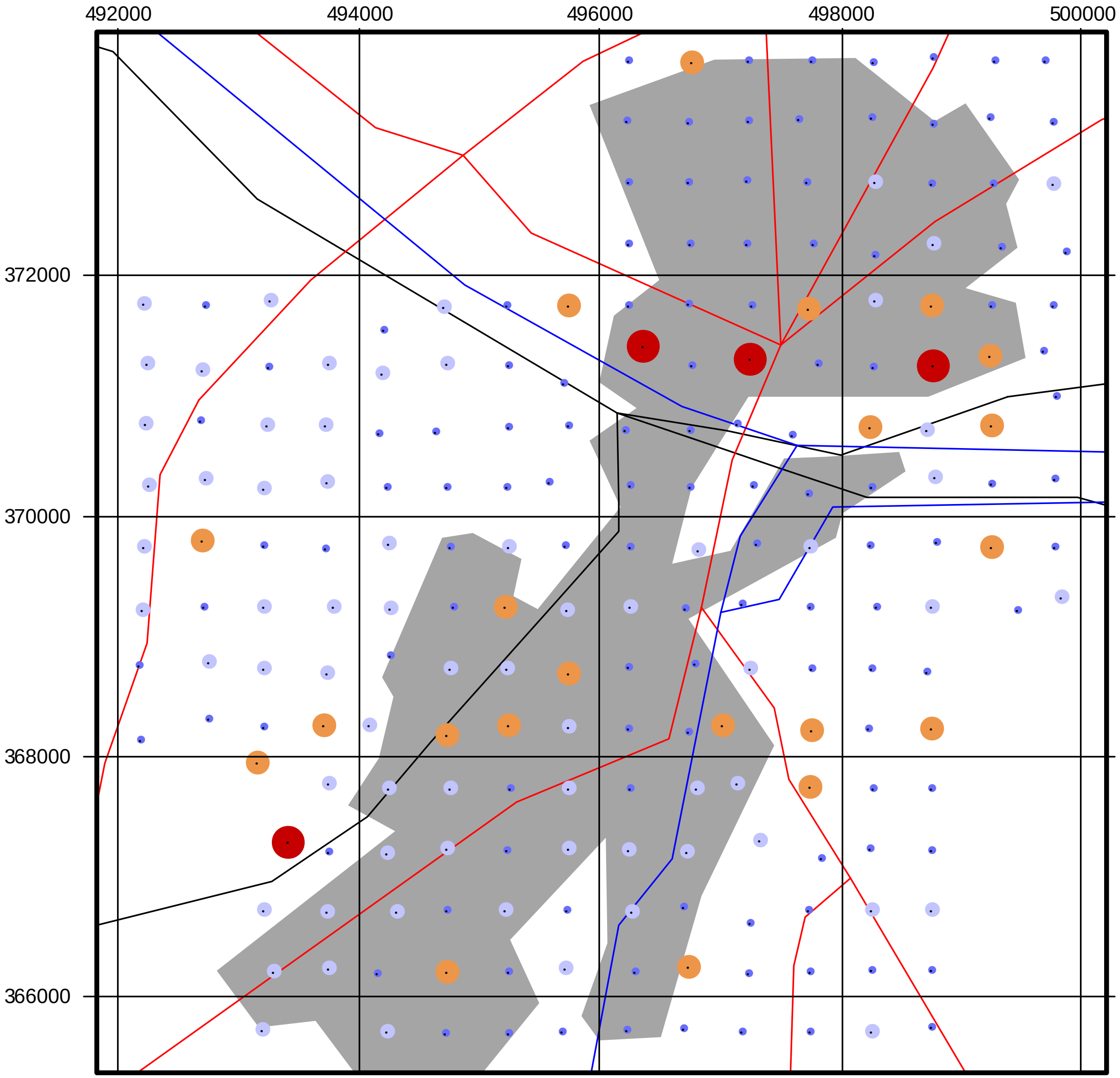
## Cadmium



| surface soil | Cd (ppm) |
|---|---|
| number | 216 |
| minimum | 0.45* |
| maximum | 5 |
| median | 0.45 |
| mean | 0.55 |

*minimum value reported as half detection limit

# Lincoln
## Profile Soils
## Cadmium

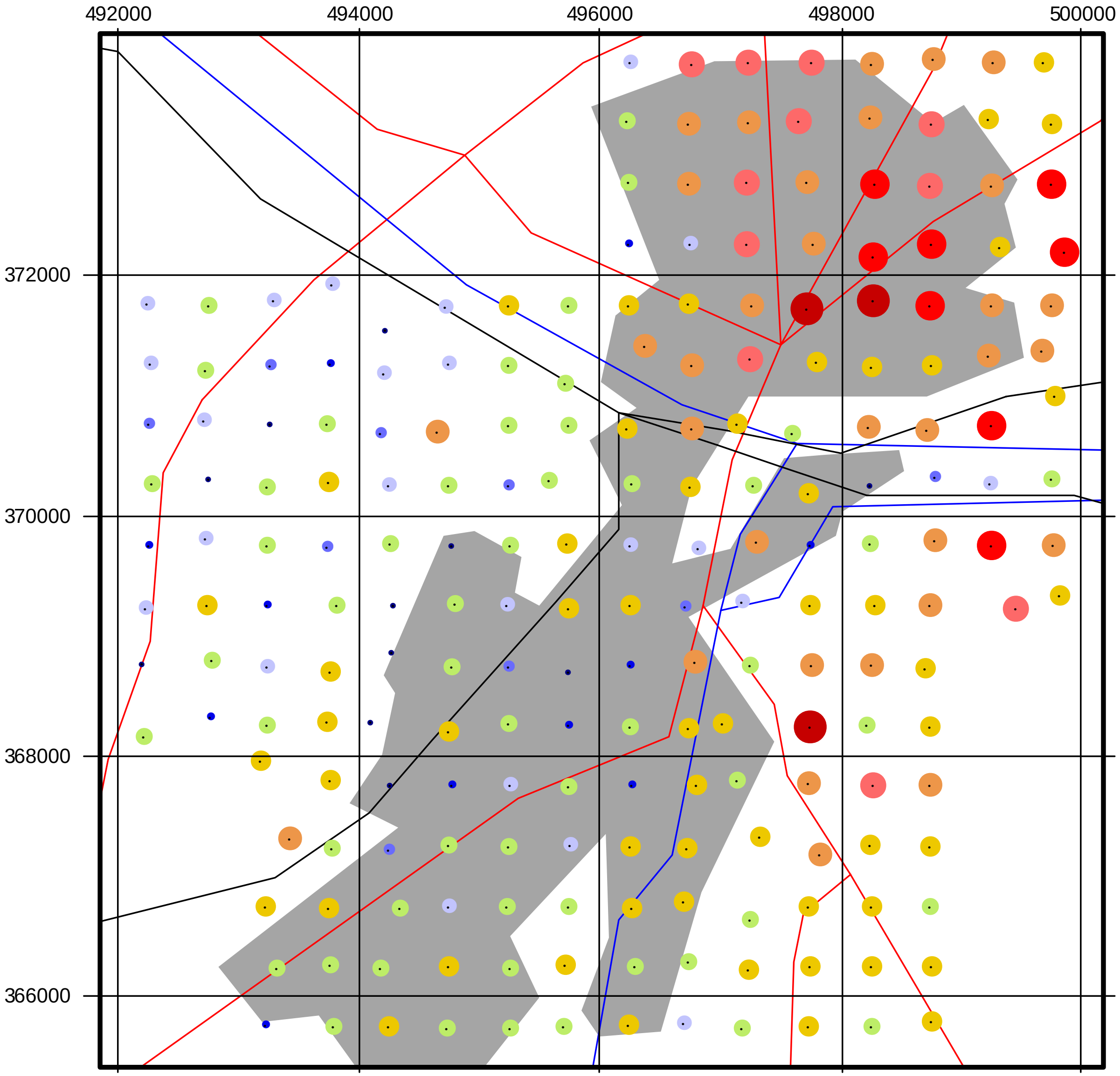


| %ile | | ppm |
|---|---|---|
| 99 | ● | 4 |
| 95 | ● | 2 |
| 75 | ● | 1 |
| 50 | ● | 0.45 |
| | • | |

— **Railway**
— **Drainage**
— **Roads**
▨ **Urban area**

| profile soil | Cd (ppm) |
|---|---|
| number | 214 |
| minimum | 0.45* |
| maximum | 34 |
| median | 0.45 |
| mean | 0.99 |

*minimum value reported as half detection limit



# Lincoln

## Surface Soils

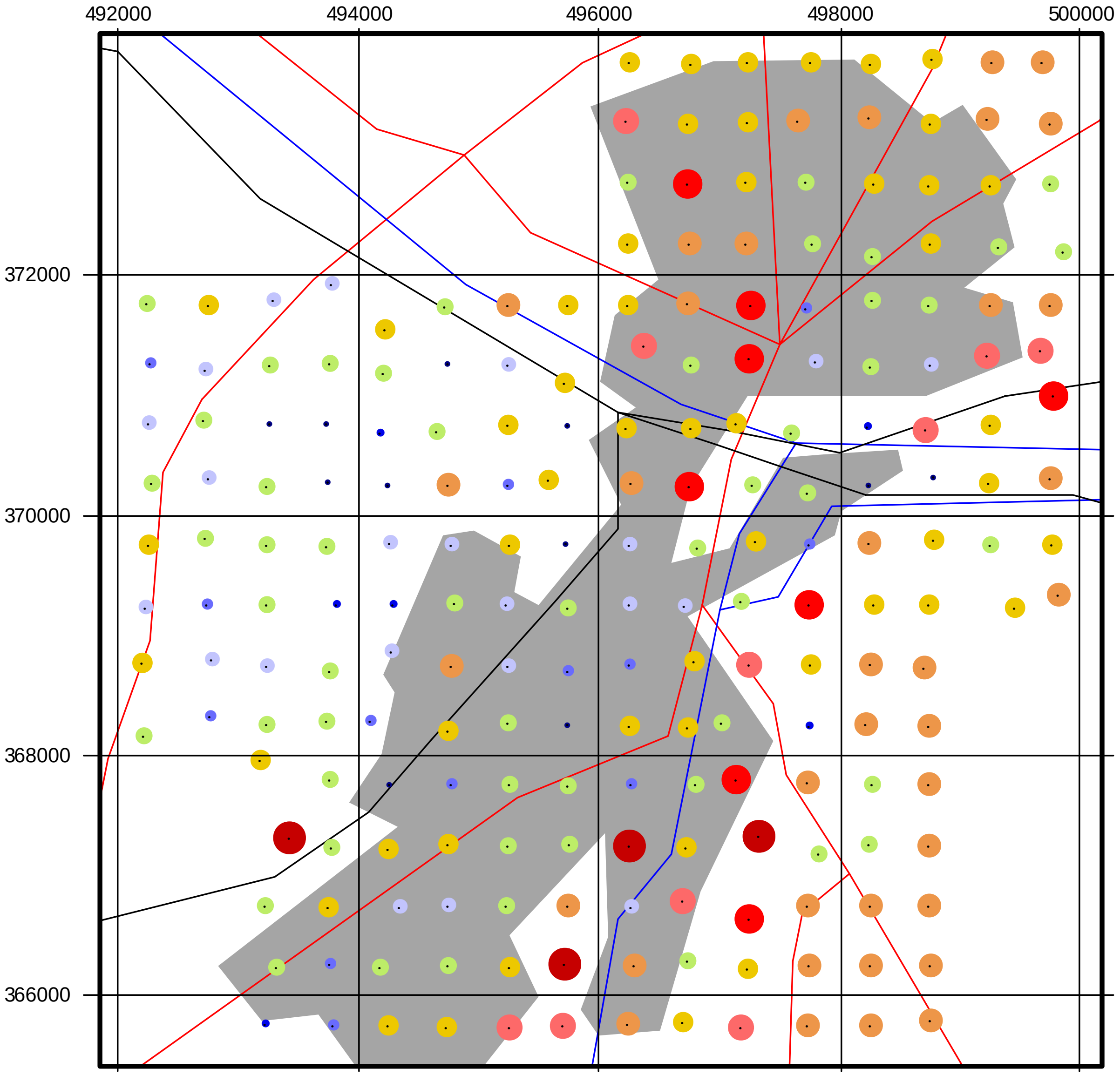
## Calcium

| **%ile** | **WT%** |
|---|---|
| **99** | **20.16** |
| **95** | **14.61** |
| **90** | **11.37** |
| **75** | **5.68** |
| **50** | **1.35** |
| **25** | **0.49** |
| **15** | **0.31** |
| **10** | **0.26** |
| **5** | **0.18** |

**Railway**
**Drainage**
**Roads**
▨ **Urban area**

| surface soil | CaO (%) |
|---|---|
| number | 216 |
| minimum | 0.06 |
| maximum | 22.68 |
| median | 1.35 |
| mean | 3.78 |

Calcium was not determined in the profile soils



# Lincoln

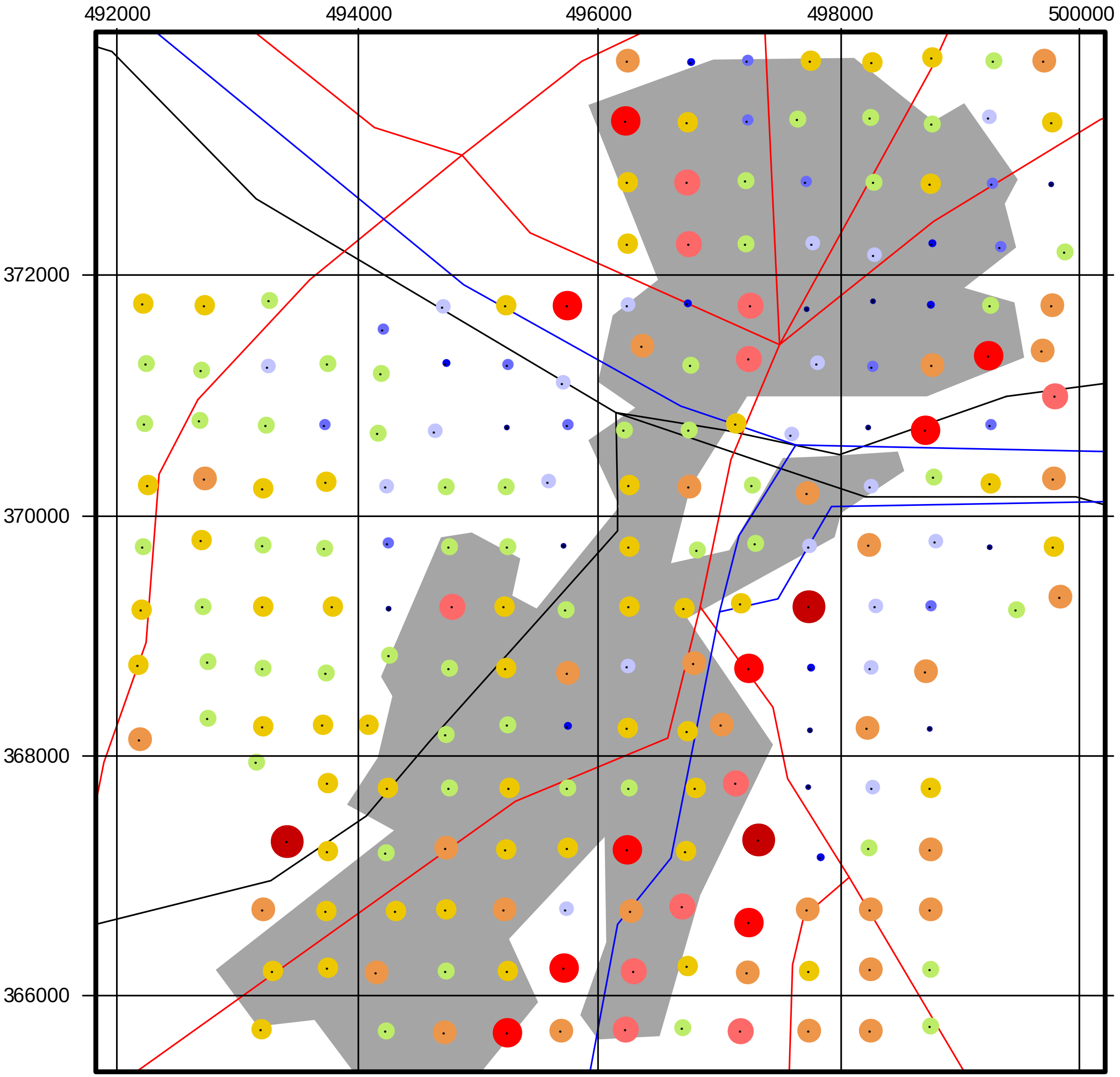
## Surface Soils

## Chromium

| %ile | ppm |
|---|---|
| 99 ● | 134 |
| 95 ● | 88 |
| 90 ● | 68 |
| 75 ● | 53 |
| 50 ● | 44 |
| 25 ● | 35 |
| 15 ● | 32 |
| 10 ● | 29 |
| 5 • | 27 |

— **Railway**
— **Drainage**
— **Roads**
▨ **Urban area**

| surface soil | Cr (ppm) |
|---|---|
| number | 216 |
| minimum | 19 |
| maximum | 260 |
| median | 44 |
| mean | 48 |



# Lincoln

## Profile Soils

## Chromium

| %ile | | ppm |
|---|---|---|
| 99 | ● | 161 |
| 95 | ● | 124 |
| 90 | ● | 109 |
| 75 | ● | 83 |
| 50 | ● | 71 |
| 25 | ● | 58 |
| 15 | ● | 53 |
| 10 | ● | 47 |
| 5 | ● | 41 |
| | · | |

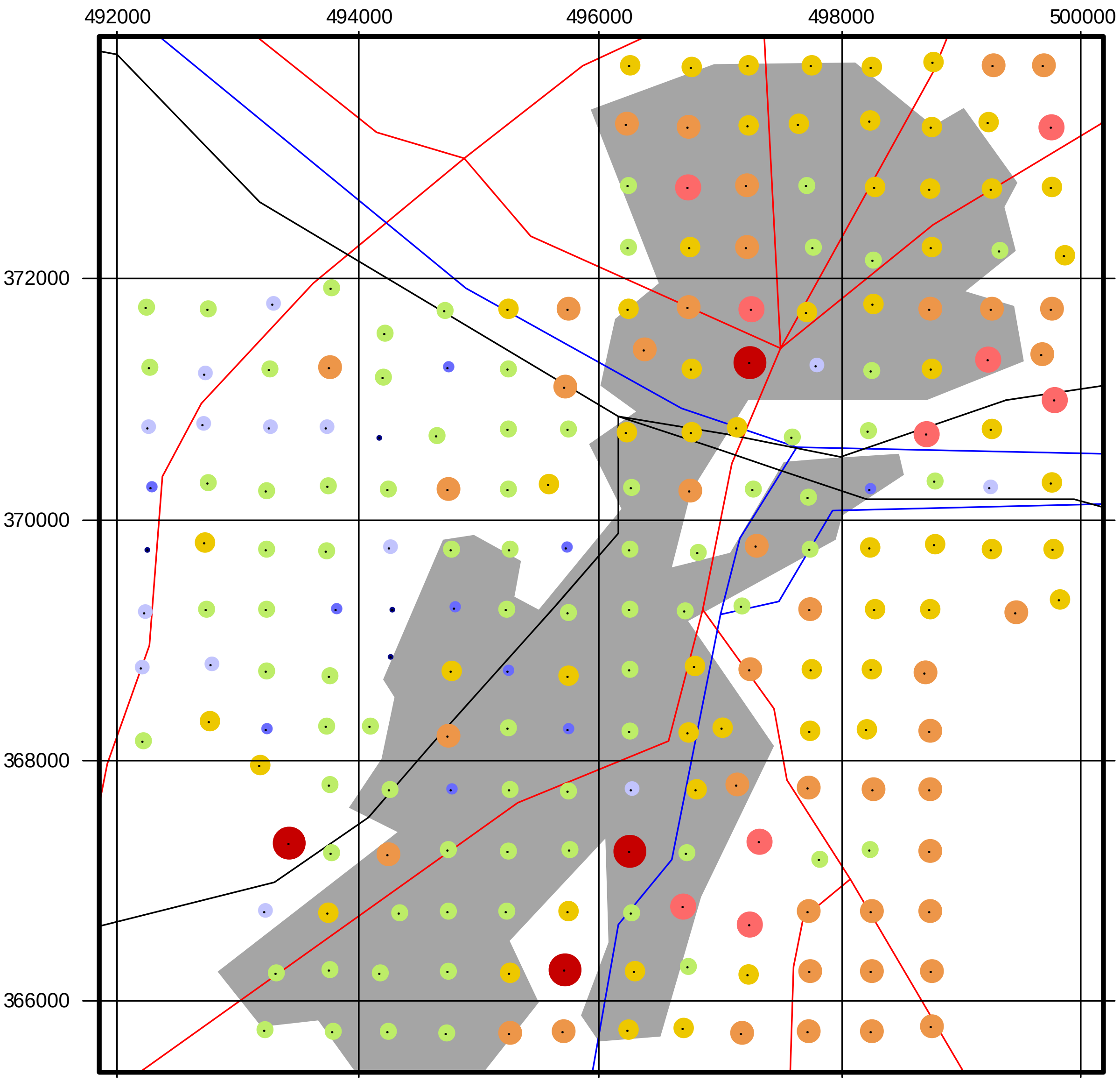
**Railway**
**Drainage**
**Roads**
**Urban area**

| profile soil | Cr (ppm) |
|---|---|
| number | 214 |
| minimum | 26 |
| maximum | 1349 |
| median | 71 |
| mean | 80 |

# Lincoln

## Surface Soils

## Cobalt



| %ile | | ppm |
|---|---|---|
| 99 | ● | 33 |
| 95 | ● | 25 |
| 90 | ● | 16 |
| 50 | ● | 12 |
| 25 | ● | 7 |
| 10 | ● | 6 |
| 5 | ● | 5 |

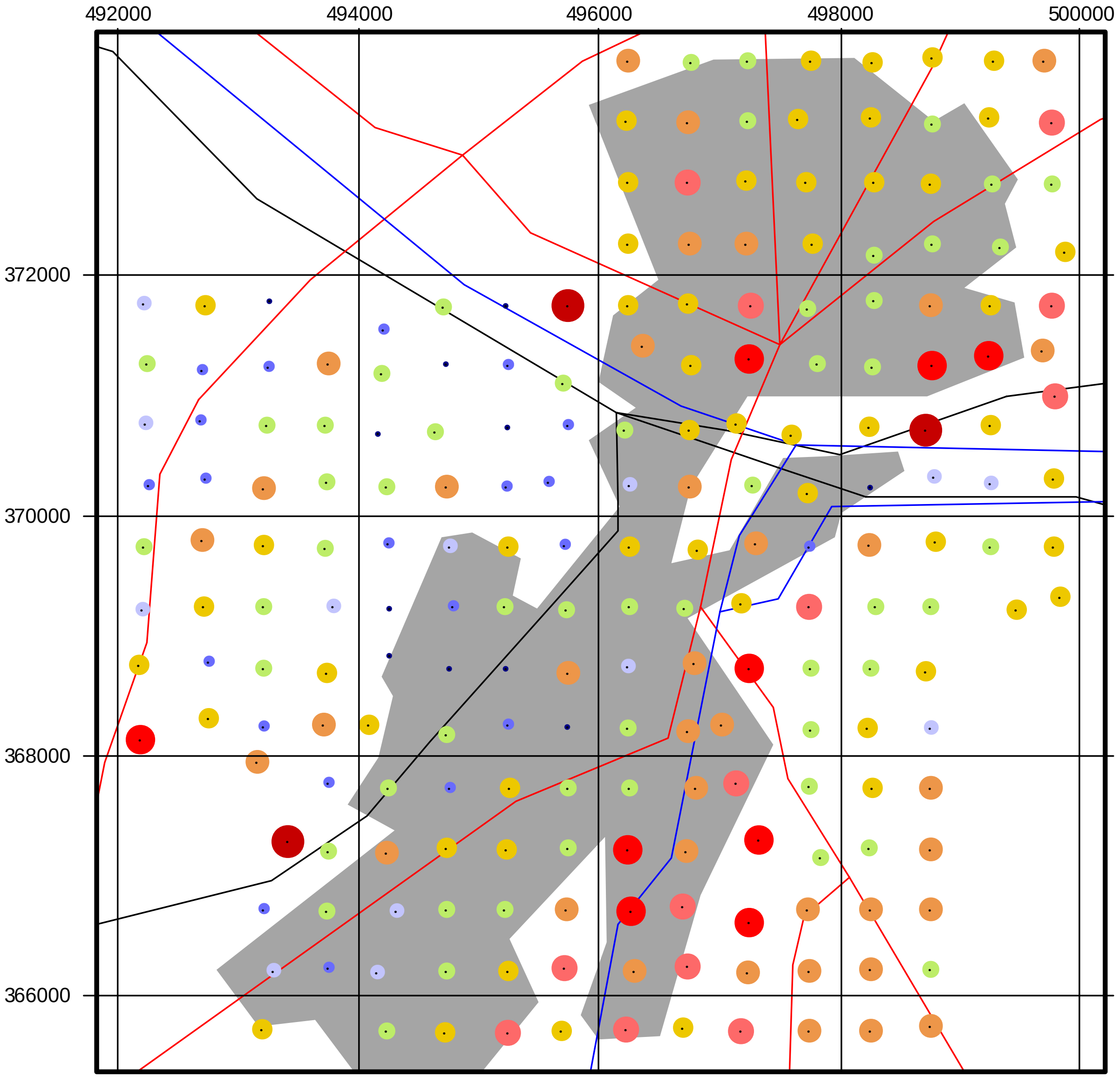
— **Railway**
— **Drainage**
— **Roads**
▨ **Urban area**

| surface soil | Co (ppm) |
|---|---|
| number | 216 |
| minimum | 4 |
| maximum | 35 |
| median | 12 |
| mean | 13 |

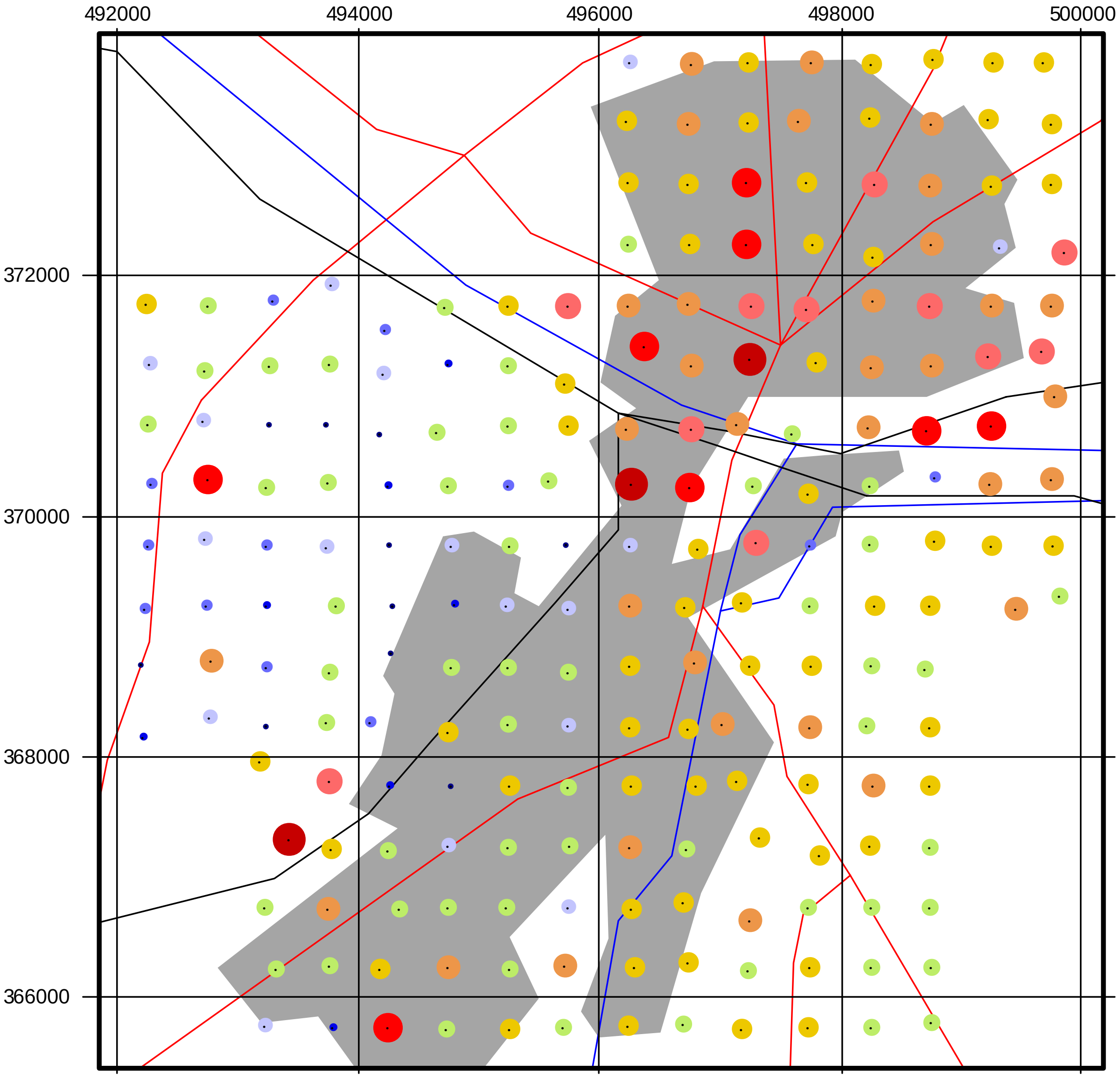
# Lincoln

## Profile Soils

## Cobalt



| profile soil | Co (ppm) |
|---|---|
| number | 214 |
| minimum | 5 |
| maximum | 74 |
| median | 16 |
| mean | 18 |



# Lincoln

## Surface Soils

## Copper

| %ile | | ppm |
|---|---|---|
| 99 | ● | 235 |
| 95 | ● | 105 |
| 90 | ● | 66 |
| 75 | ● | 33 |
| 50 | ● | 17 |
| 25 | ● | 11 |
| 15 | ● | 9 |
| 10 | ● | 8 |
| 5 | ● | 7 |
| | ● | |

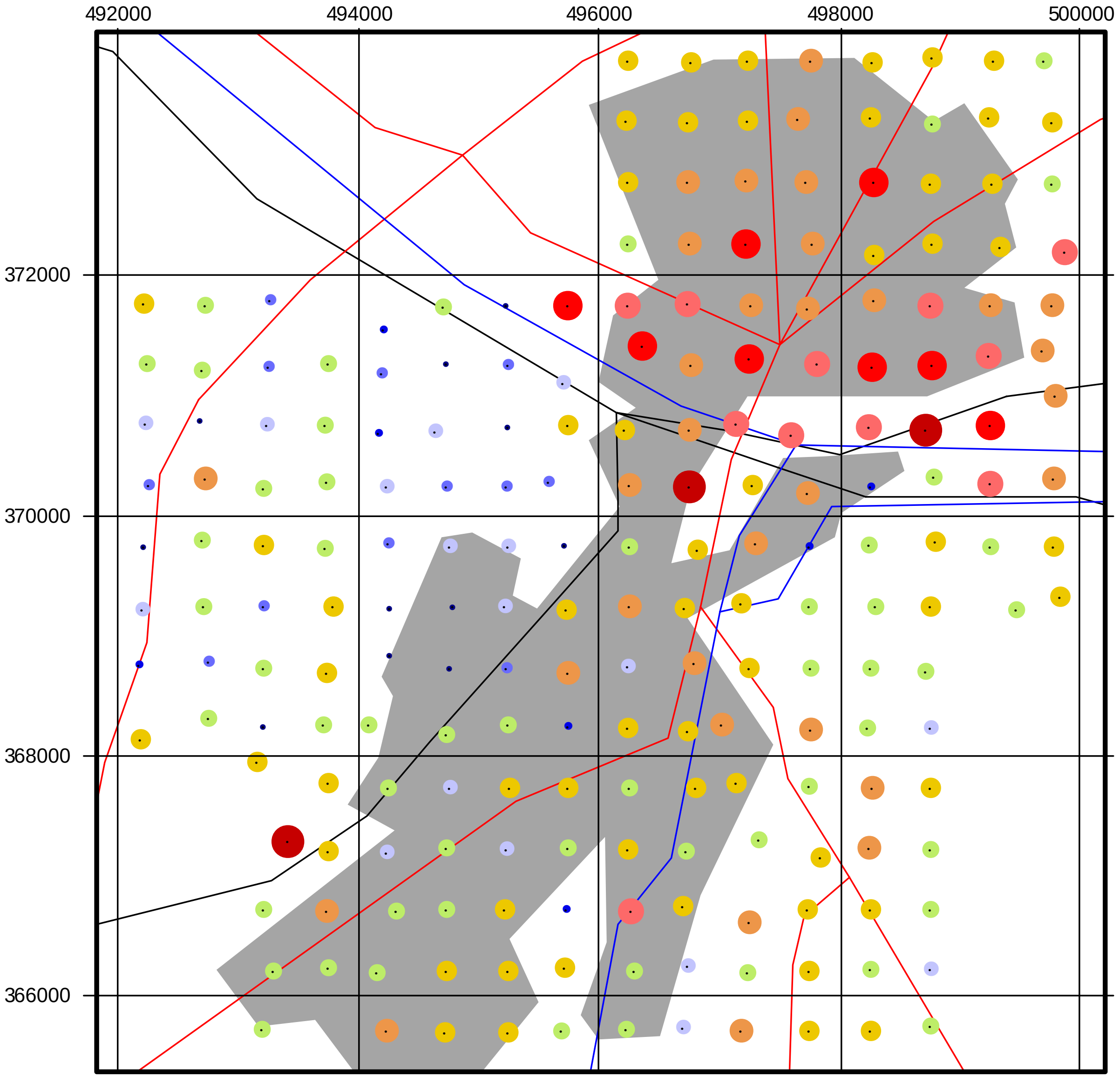
— Railway
— Drainage
— Roads
▨ Urban area

| surface soil | Cu (ppm) |
|---|---|
| number | 216 |
| minimum | 4 |
| maximum | 348 |
| median | 17 |
| mean | 31 |

# Lincoln

## Profile Soils

## Copper



| %ile | | ppm |
|---|---|---|
| 99 | ● | 867 |
| 95 | ● | 157 |
| 90 | ● | 92 |
| 75 | ● | 42 |
| 50 | ● | 22 |
| 25 | ● | 14 |
| 15 | ● | 12 |
| 10 | ● | 9 |
| 5 | ● | 8 |
| | • | |

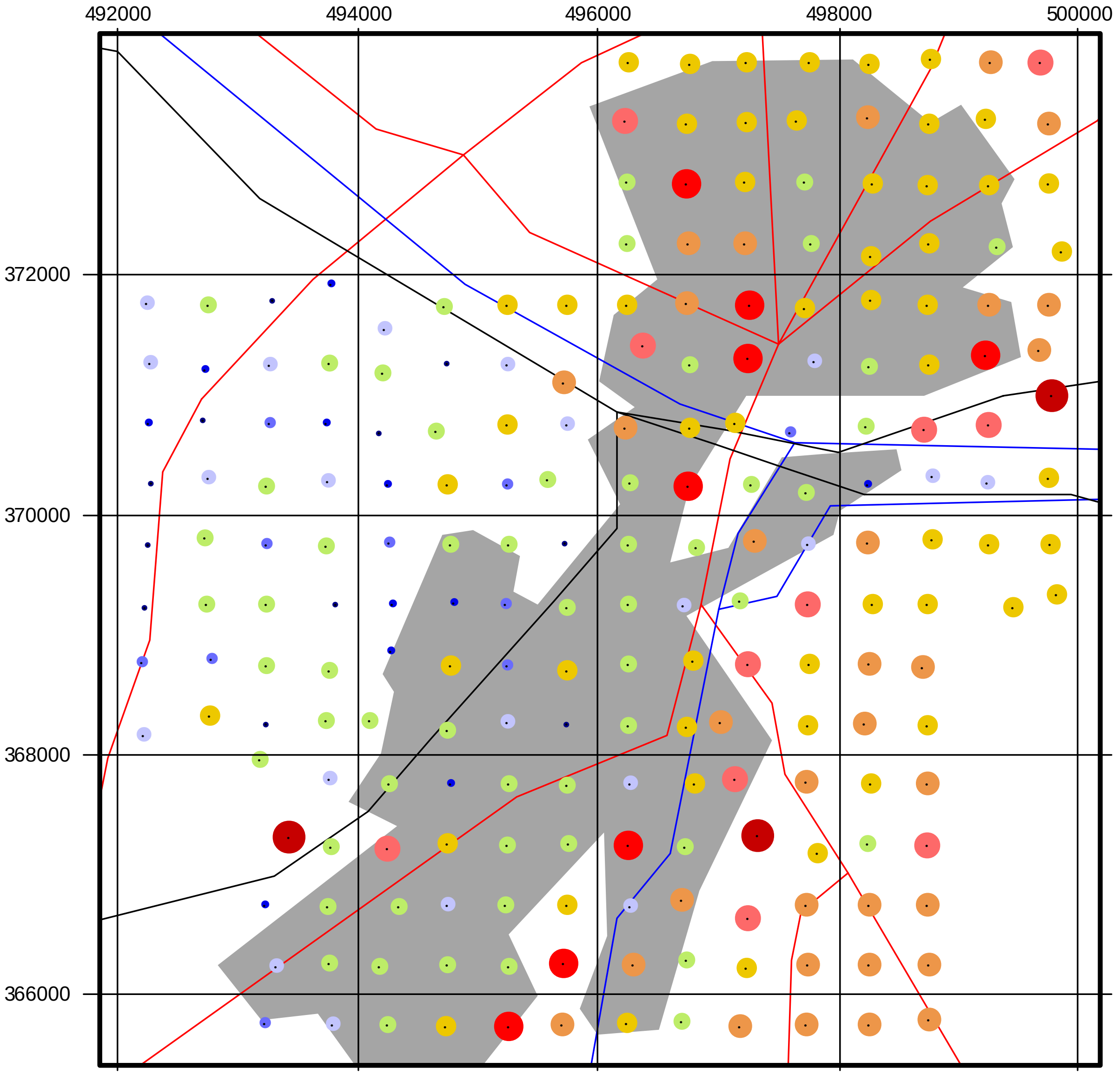
— **Railway**
— **Drainage**
— **Roads**
▨ **Urban area**

| profile soil | Cu (ppm) |
|---|---|
| number | 214 |
| minimum | 3 |
| maximum | 2687 |
| median | 22 |
| mean | 62 |

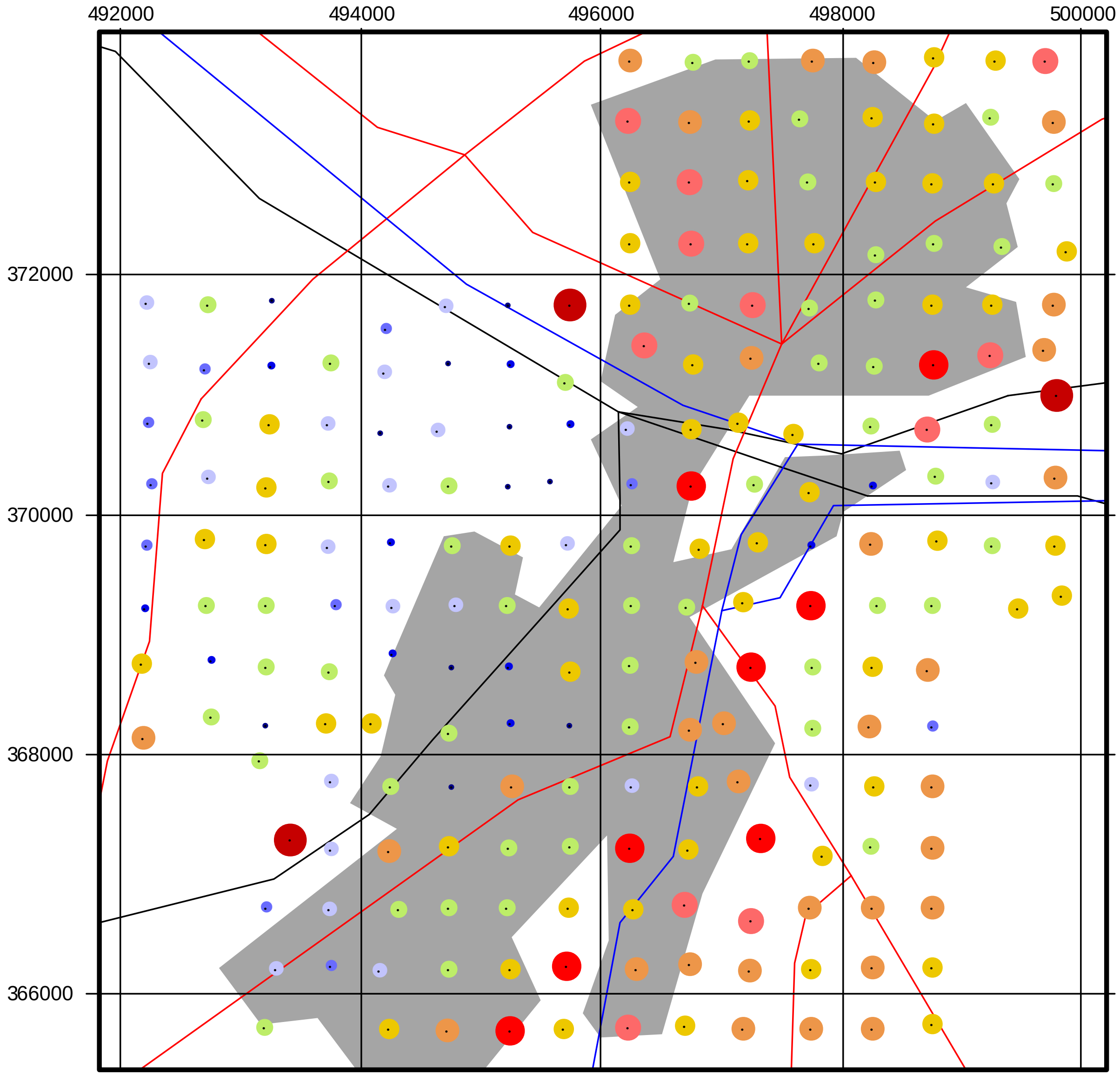
# Lincoln

## Surface Soils

## Iron



| surface soil | $Fe_2O_3$ (%) |
|---|---|
| number | 216 |
| minimum | 0.61 |
| maximum | 12.28 |
| median | 2.91 |
| mean | 3.33 |



# Lincoln

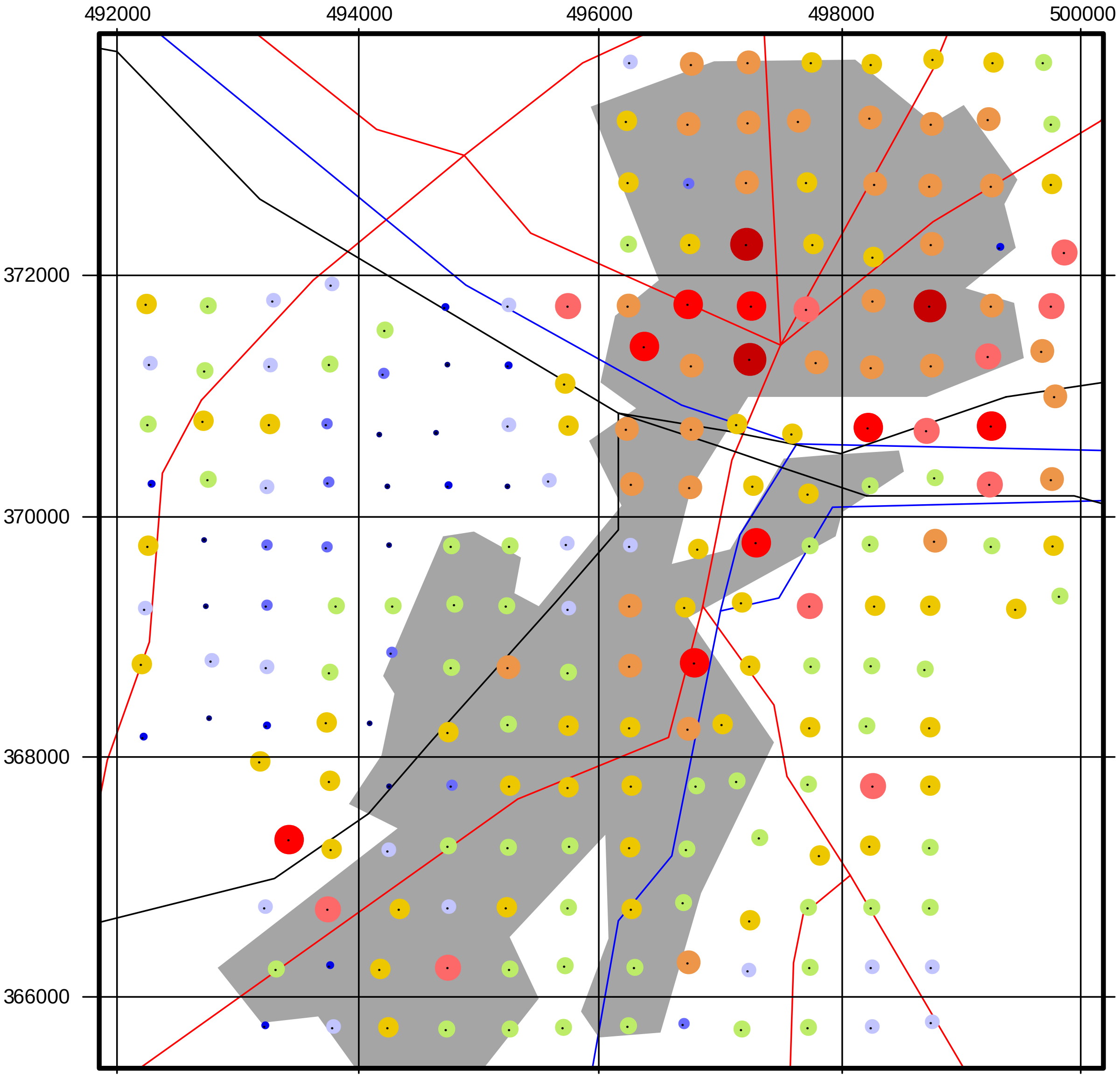
## Profile Soils

## Iron

| %ile | | WT% |
|---|---|---|
| | ● | |
| 99 | ● | 16.22 |
| 95 | ● | 9.76 |
| 90 | ● | 8.21 |
| 75 | ● | 5.49 |
| 50 | ● | 3.96 |
| 25 | ● | 2.81 |
| 15 | ● | 2.10 |
| 10 | ● | 1.66 |
| 5 | ● | 1.37 |

**Railway**
**Drainage**
**Roads**
▨ **Urban area**

| profile soil | $Fe_2O_3$ (%) |
|---|---|
| number | 214 |
| minimum | 0.63 |
| maximum | 22.88 |
| median | 3.96 |
| mean | 4.62 |



# Lincoln

## Surface Soils

## Lead

| %ile | | ppm |
|---|---|---|
| 99 | ● | 1174 |
| 95 | ● | 322 |
| 90 | ● | 232 |
| 75 | ● | 105 |
| 50 | ● | 55 |
| 25 | ● | 35 |
| 15 | ● | 29 |
| 10 | ● | 26 |
| 5 | ● | 23 |

— **Railway**

— **Drainage**

— **Roads**

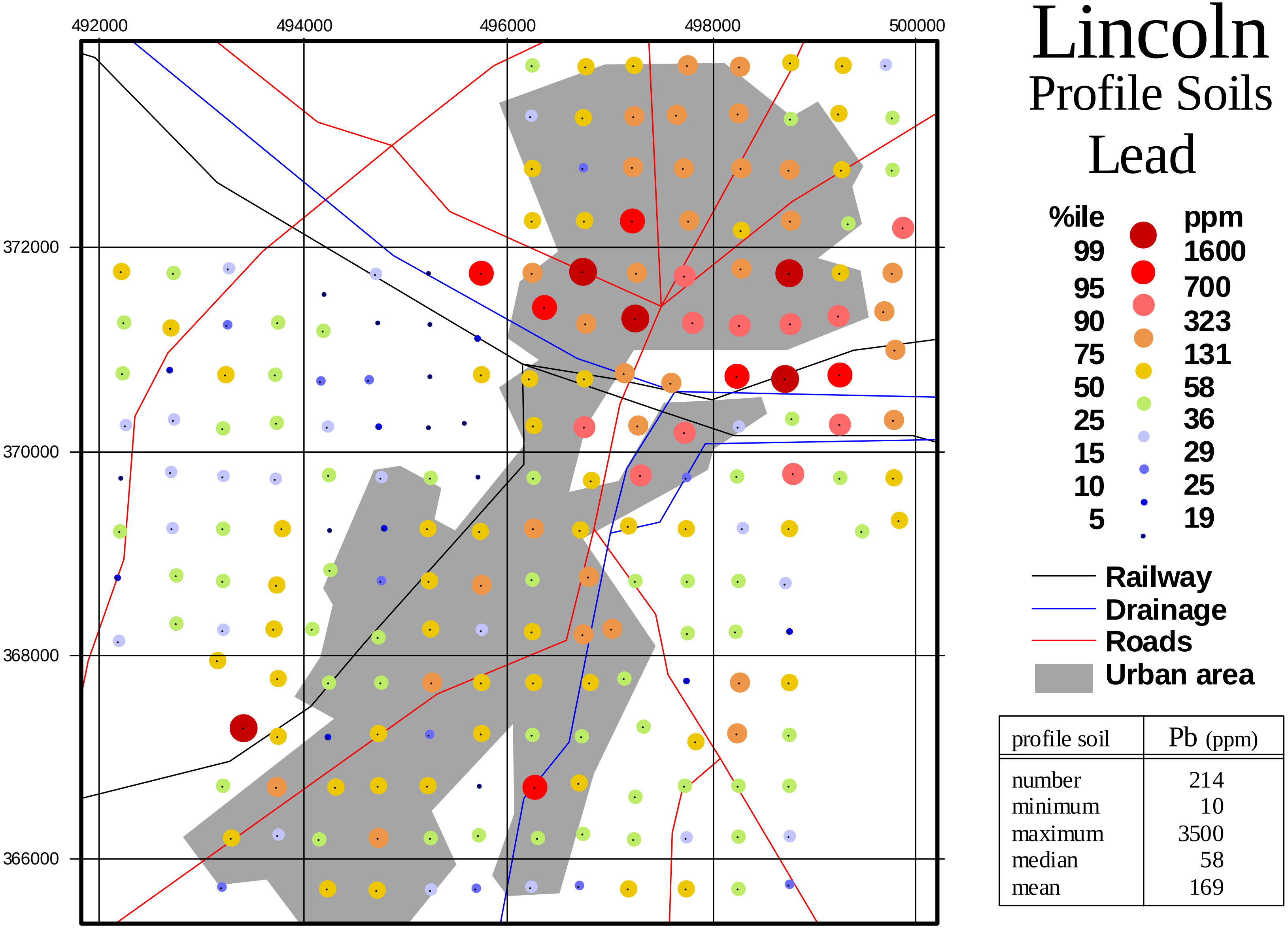
▨ **Urban area**

| surface soil | Pb (ppm) |
|---|---|
| number | 216 |
| minimum | 15 |
| maximum | 1400 |
| median | 55 |
| mean | 111 |

# Lincoln

## Profile Soils

## Lead

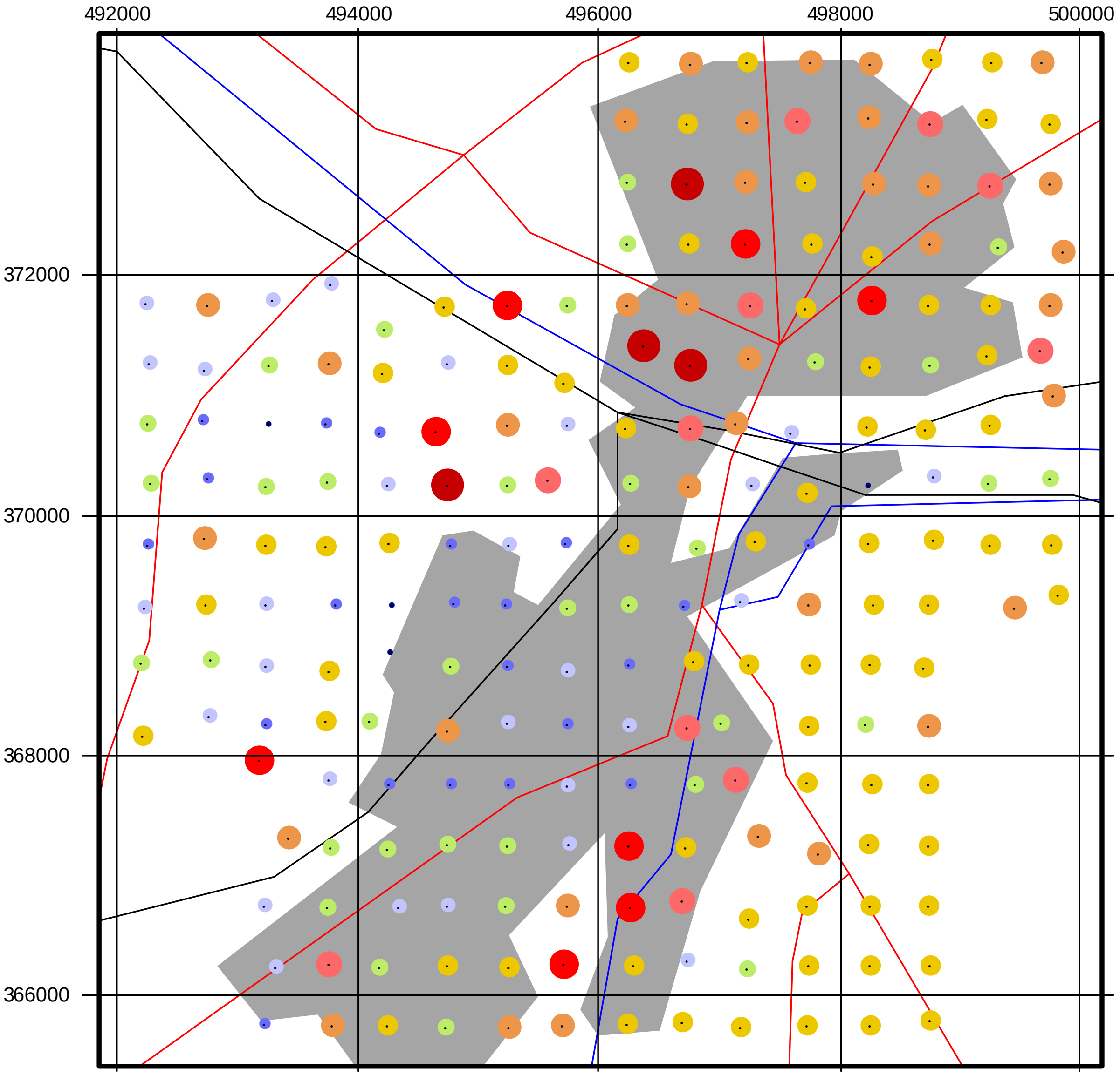


| profile soil | Pb (ppm) |
|---|---|
| number | 214 |
| minimum | 10 |
| maximum | 3500 |
| median | 58 |
| mean | 169 |

# Lincoln

## Surface Soils

## Magnesium



| %ile | | WT% |
|---|---|---|
| 99 | ● | 1.6 |
| 95 | ● | 1.1 |
| 90 | ● | 0.9 |
| 75 | ● | 0.7 |
| 50 | ● | 0.5 |
| 25 | ● | 0.4 |
| 15 | ● | 0.3 |
| 10 | ● | 0.2 |

— Railway
— Drainage
— Roads
▨ Urban area

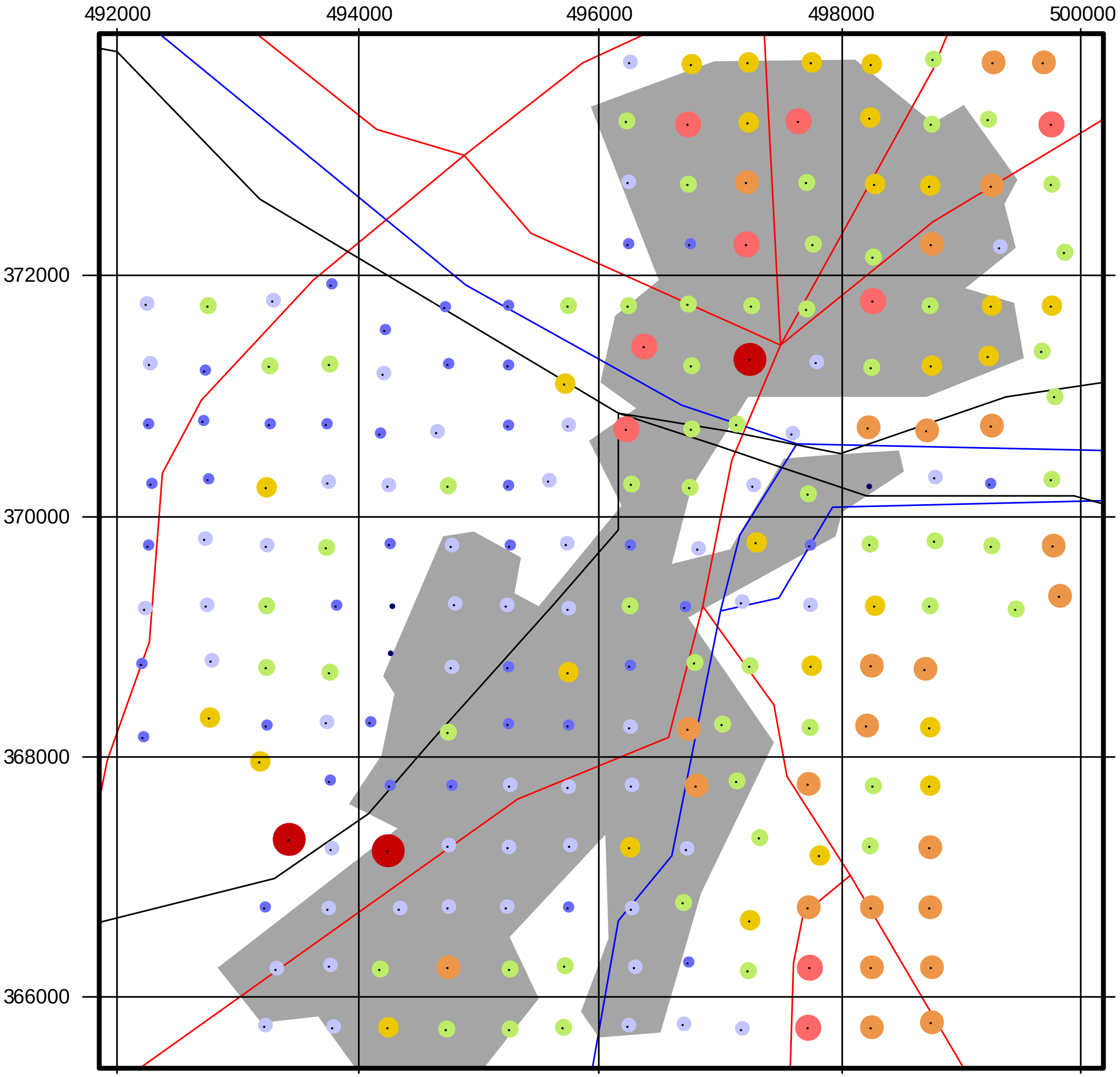
| surface soil | $MgO_2$ (%) |
|---|---|
| number | 216 |
| minimum | 0.1 |
| maximum | 3.5 |
| median | 0.5 |
| mean | 0.6 |

Magnesium was not determined in the profile soils

# Lincoln

## Surface Soils

## Manganese



| %ile |   | WT% |
|---|---|---|
| 99 | ● | 0.16 |
| 95 | ● | 0.12 |
| 90 | ● | 0.10 |
| 75 | ● | 0.09 |
| 50 | ● | 0.06 |
| 25 | ● | 0.04 |
| 15 | ● | 0.03 |

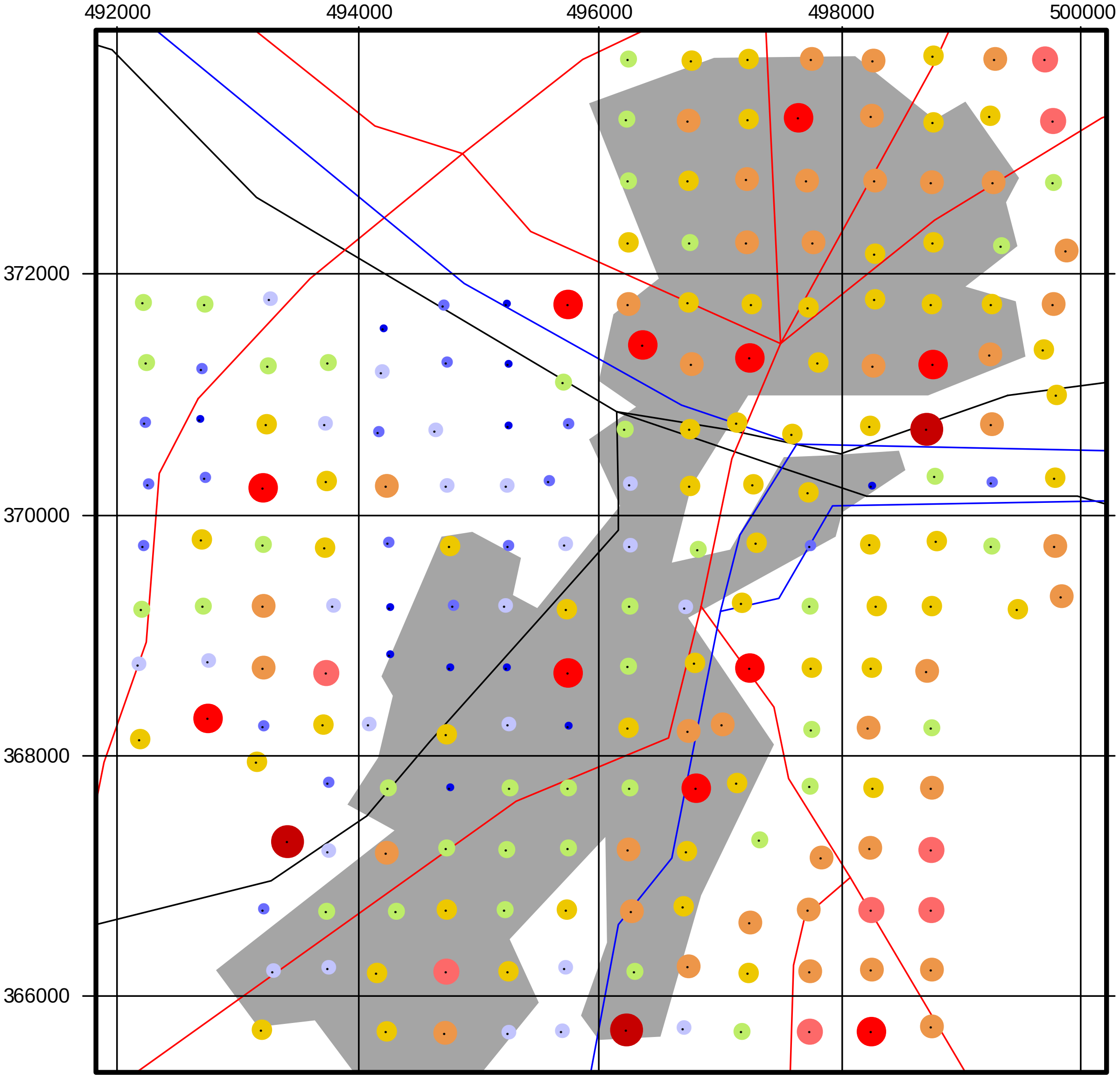
**Railway**
**Drainage**
**Roads**
▨ **Urban area**

| surface soil | MnO (%) |
|---|---|
| number | 216 |
| minimum | 0.02 |
| maximum | 1.06 |
| median | 0.06 |
| mean | 0.07 |

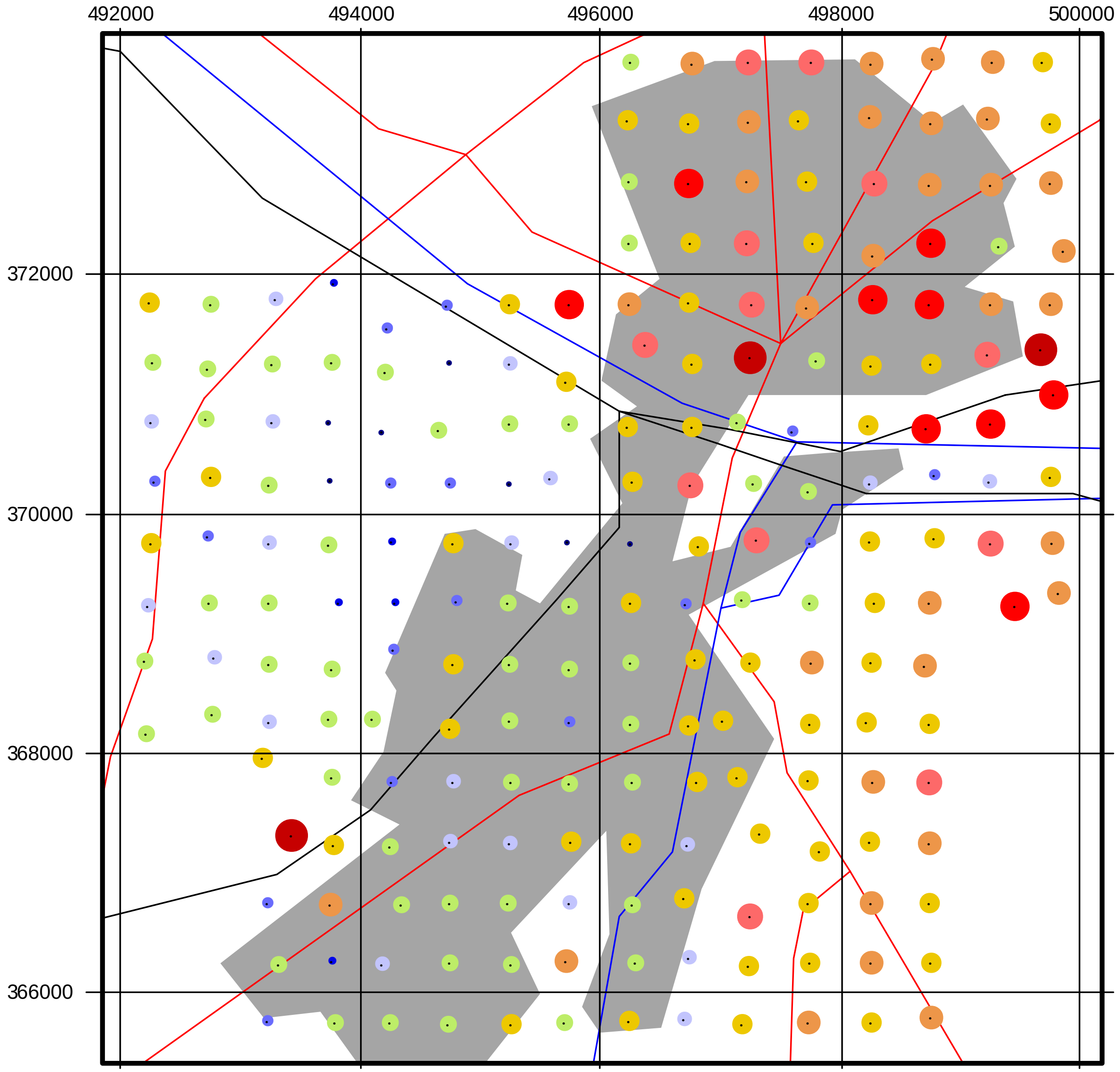
# Lincoln

## Profile Soils

## Manganese



| profile soil | MnO (%) |
|---|---|
| number | 214 |
| minimum | 0.02 |
| maximum | 0.52 |
| median | 0.07 |
| mean | 0.08 |



# Lincoln

## Surface Soils

## Molybdenum

| %ile | ppm |
|---|---|
| 99 | 10.8 |
| 95 | 4.7 |
| 90 | 3.9 |
| 75 | 2.7 |
| 50 | 1.6 |
| 25 | 1.2 |
| 15 | 1.0 |
| 10 | 0.8 |
| 5 | 0.7 |

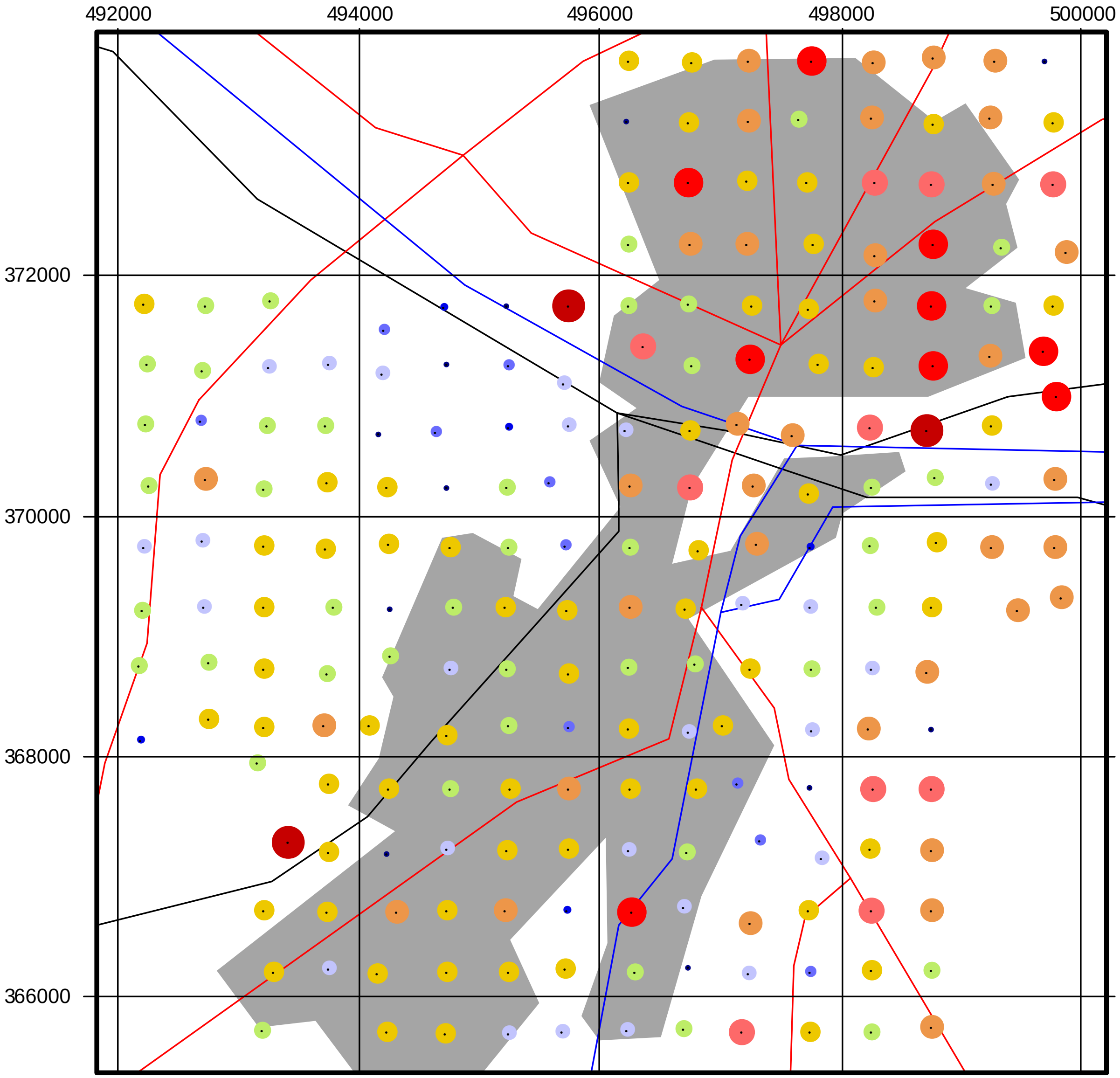
— Railway
— Drainage
— Roads
▨ Urban area

| surface soil | Mo (ppm) |
|---|---|
| number | 216 |
| minimum | 21.1 |
| maximum | 0.4 |
| median | 1.6 |
| mean | 2.2 |

# Lincoln

## Profile Soils

## Molybdenum



| %ile | | ppm |
|---|---|---|
| 99 | ● | 19.3 |
| 95 | ● | 5.0 |
| 90 | ● | 4.2 |
| 75 | ● | 3.1 |
| 50 | ● | 2.3 |
| 25 | ● | 1.8 |
| 15 | ● | 1.4 |
| 10 | ● | 1.2 |
| 5 | ● | 1.0 |

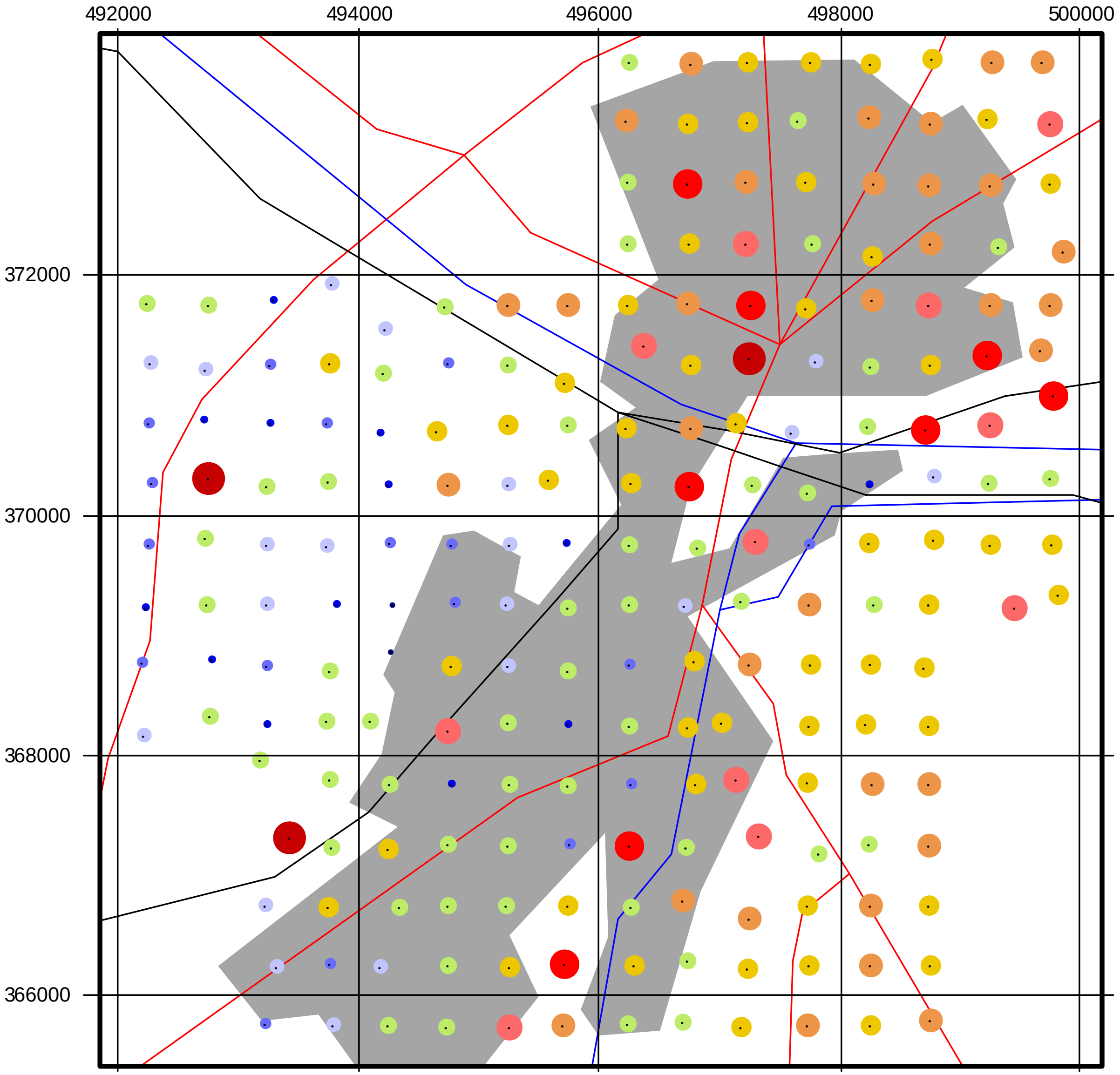
**Railway**

**Drainage**

**Roads**

▨ **Urban area**

| profile soil | Mo (ppm) |
|---|---|
| number | 214 |
| minimum | 0.6 |
| maximum | 52.0 |
| median | 2.3 |
| mean | 3.0 |



# Lincoln

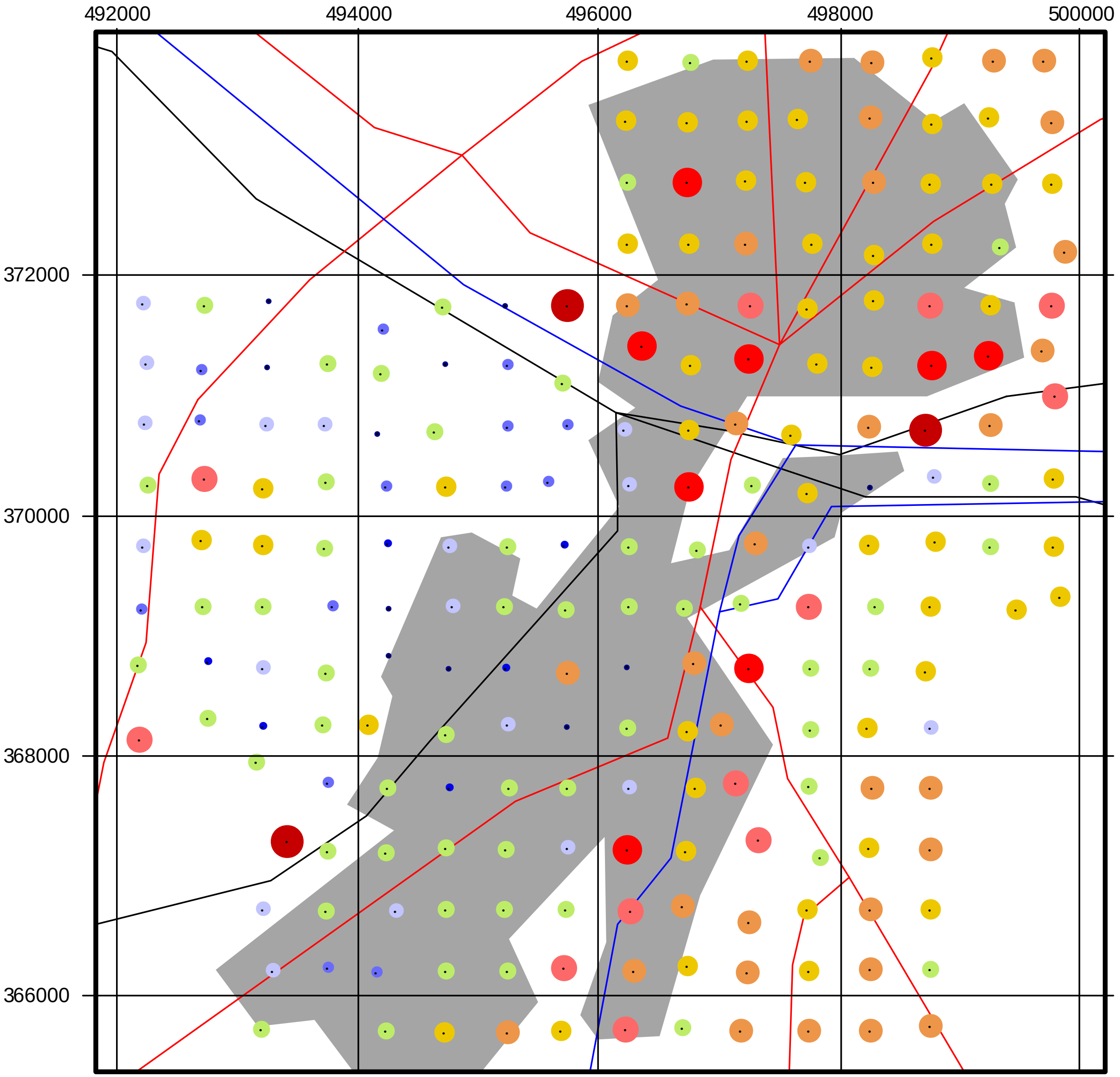
## Surface Soils

## Nickel

| %ile | ppm |
|---|---|
| 99 | 60 |
| 95 | 34 |
| 90 | 28 |
| 75 | 19 |
| 50 | 14 |
| 25 | 8 |
| 15 | 6 |
| 10 | 5 |
| 5 | 4 |

— **Railway**
— **Drainage**
— **Roads**
▨ **Urban area**

| surface soil | Ni (ppm) |
|---|---|
| number | 216 |
| minimum | 2 |
| maximum | 101 |
| median | 14 |
| mean | 15 |



# Lincoln

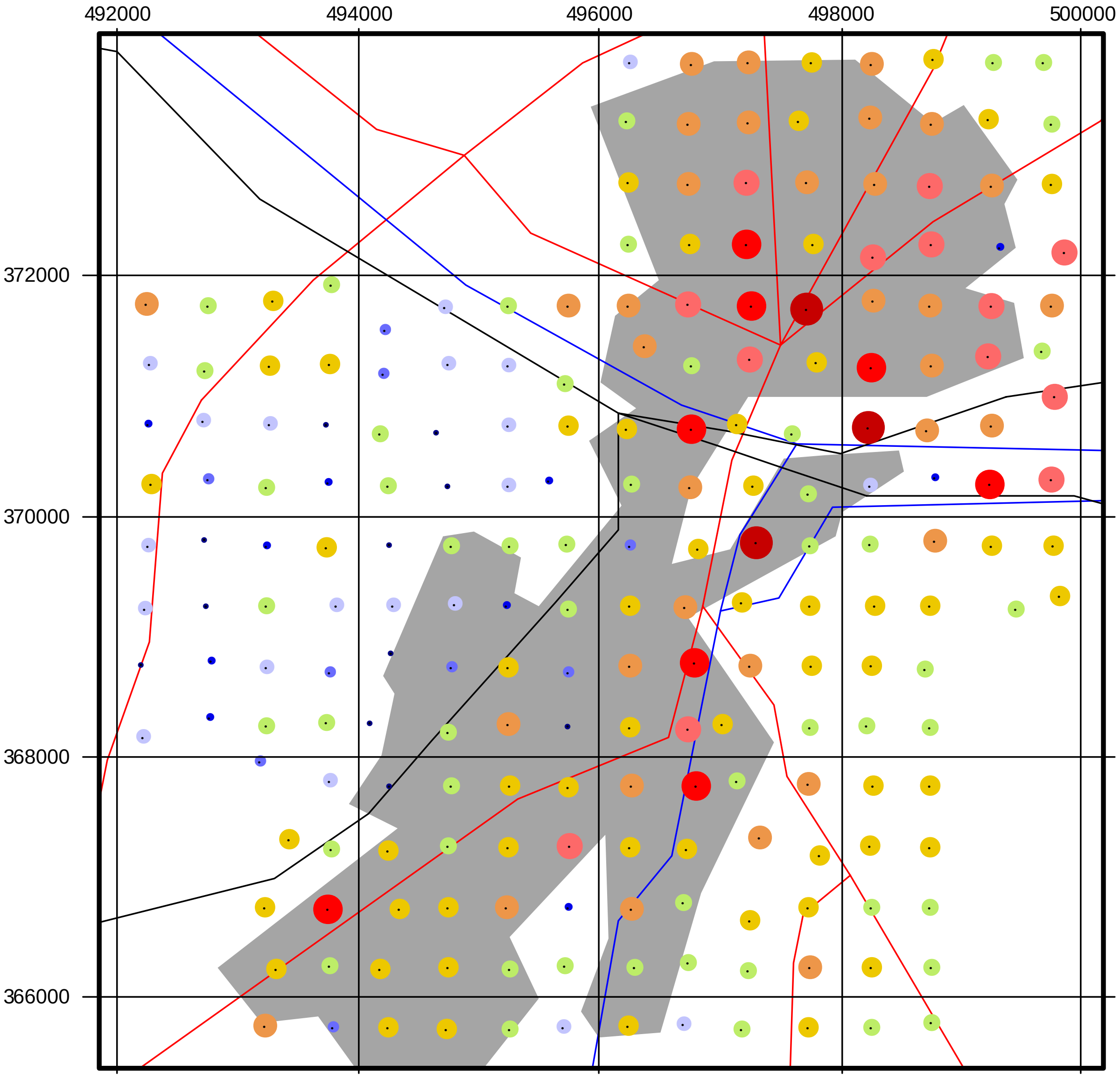
## Profile Soils

## Nickel

| %ile | | ppm |
|---|---|---|
| 99 | ● | 136 |
| 95 | ● | 54 |
| 90 | ● | 41 |
| 75 | ● | 30 |
| 50 | ● | 22 |
| 25 | ● | 14 |
| 15 | ● | 11 |
| 10 | ● | 9 |
| 5 | ● | 8 |

| | |
|---|---|
| — | **Railway** |
| — | **Drainage** |
| — | **Roads** |
| ▨ | **Urban area** |

| profile soil | Ni (ppm) |
|---|---|
| number | 214 |
| minimum | 6 |
| maximum | 335 |
| median | 22 |
| mean | 26 |



# Lincoln
## Surface Soils
## Phosphorus

| %ile | | WT% |
|---|---|---|
| 99 | ● | 1.19 |
| 95 | ● | 0.88 |
| 90 | ● | 0.61 |
| 75 | ● | 0.45 |
| 50 | ● | 0.32 |
| 25 | ● | 0.24 |
| 15 | ● | 0.20 |
| 10 | ● | 0.18 |
| 5 | ● | 0.14 |

— Railway
— Drainage
— Roads
▨ Urban area

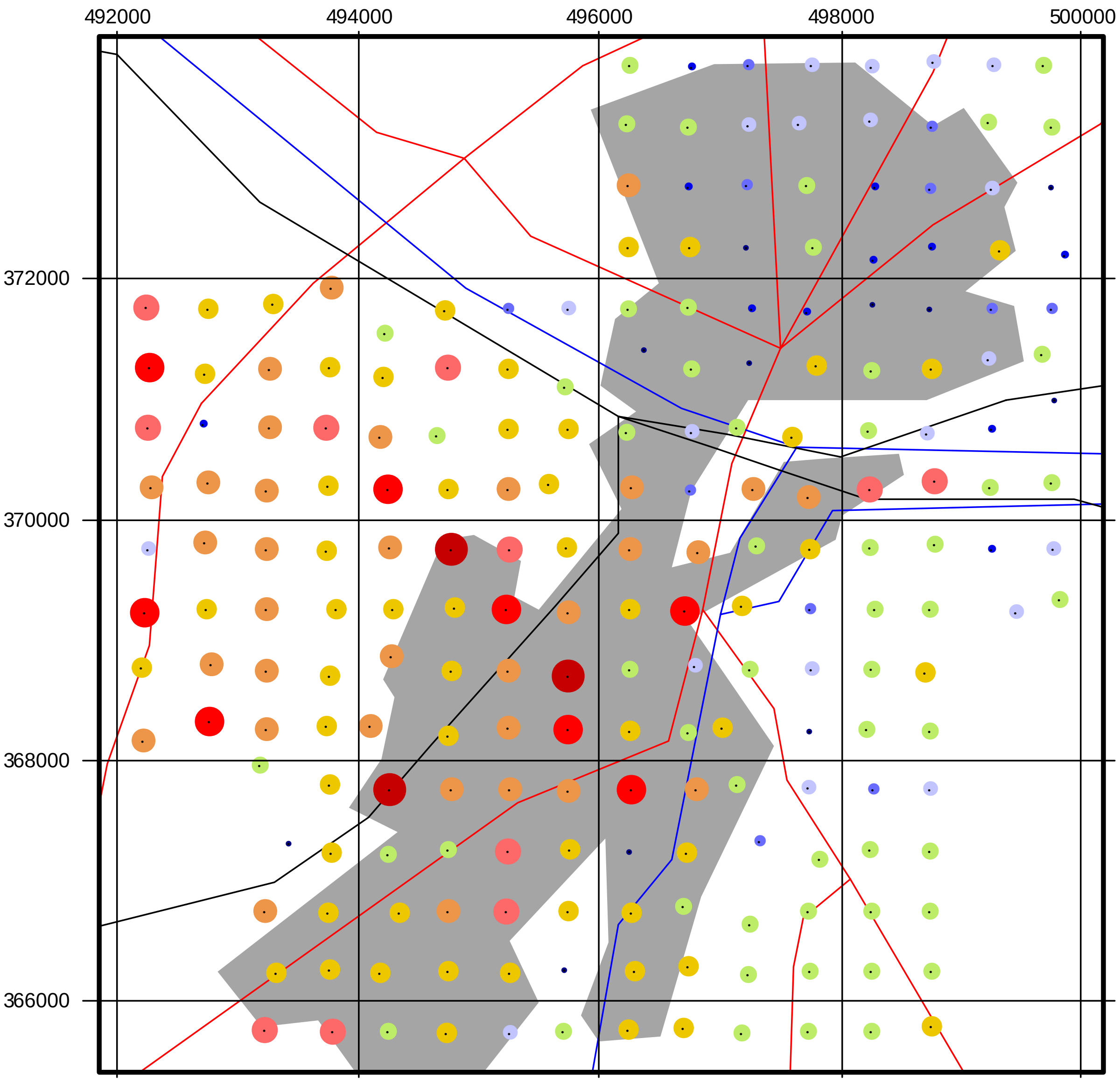
| surface soil | $P_2O_5$ (%) |
|---|---|
| number | 216 |
| minimum | 0.09 |
| maximum | 1.31 |
| median | 0.32 |
| mean | 0.38 |

Phosphorus was not determined in the profile soils

# Lincoln

## Surface Soils

## Silicon

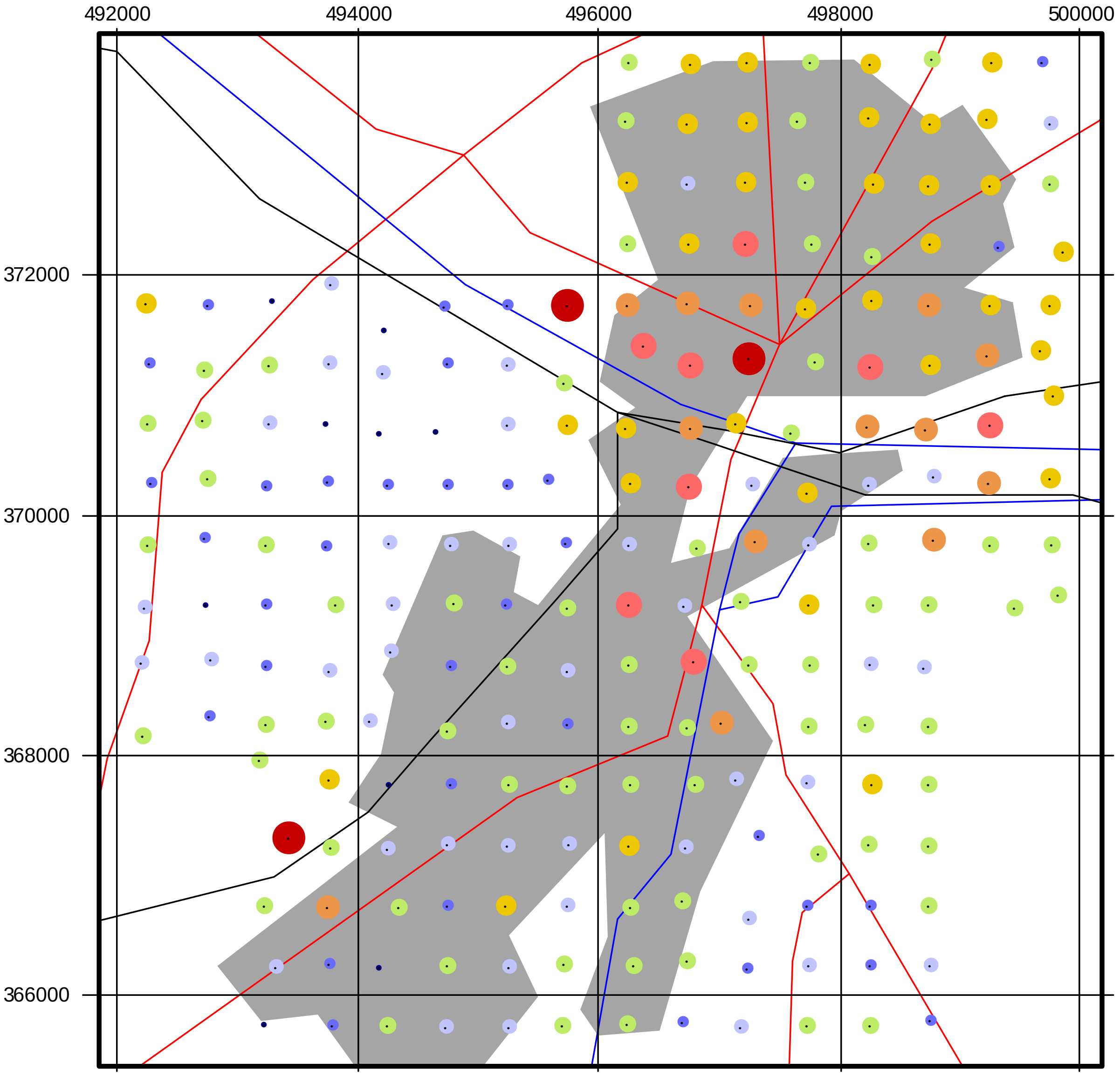


| %ile | | WT% |
|---|---|---|
| 99 | ● | 75.6 |
| 95 | ● | 73.4 |
| 90 | ● | 72.1 |
| 75 | ● | 68.4 |
| 50 | ● | 62.5 |
| 25 | ● | 54.0 |
| 15 | ● | 49.6 |
| 10 | ● | 47.1 |
| 5 | ● | 42.3 |

| | |
|---|---|
| — | Railway |
| — | Drainage |
| — | Roads |
| ▨ | Urban area |

| surface soil | Si $O_2$ (%) |
|---|---|
| number | 216 |
| minimum | 35.3 |
| maximum | 77.4 |
| median | 62.5 |
| mean | 60.8 |

Silicon was not determined in the profile soils



# Lincoln

## Surface Soils

## Tin

| %ile | | ppm |
|---|---|---|
| 99 | ● | 219 |
| 95 | ● | 37 |
| 90 | ● | 24 |
| 75 | ● | 8 |
| 50 | ● | 4 |
| 25 | ● | 3 |
| 15 | ● | 2 |
| | · | |

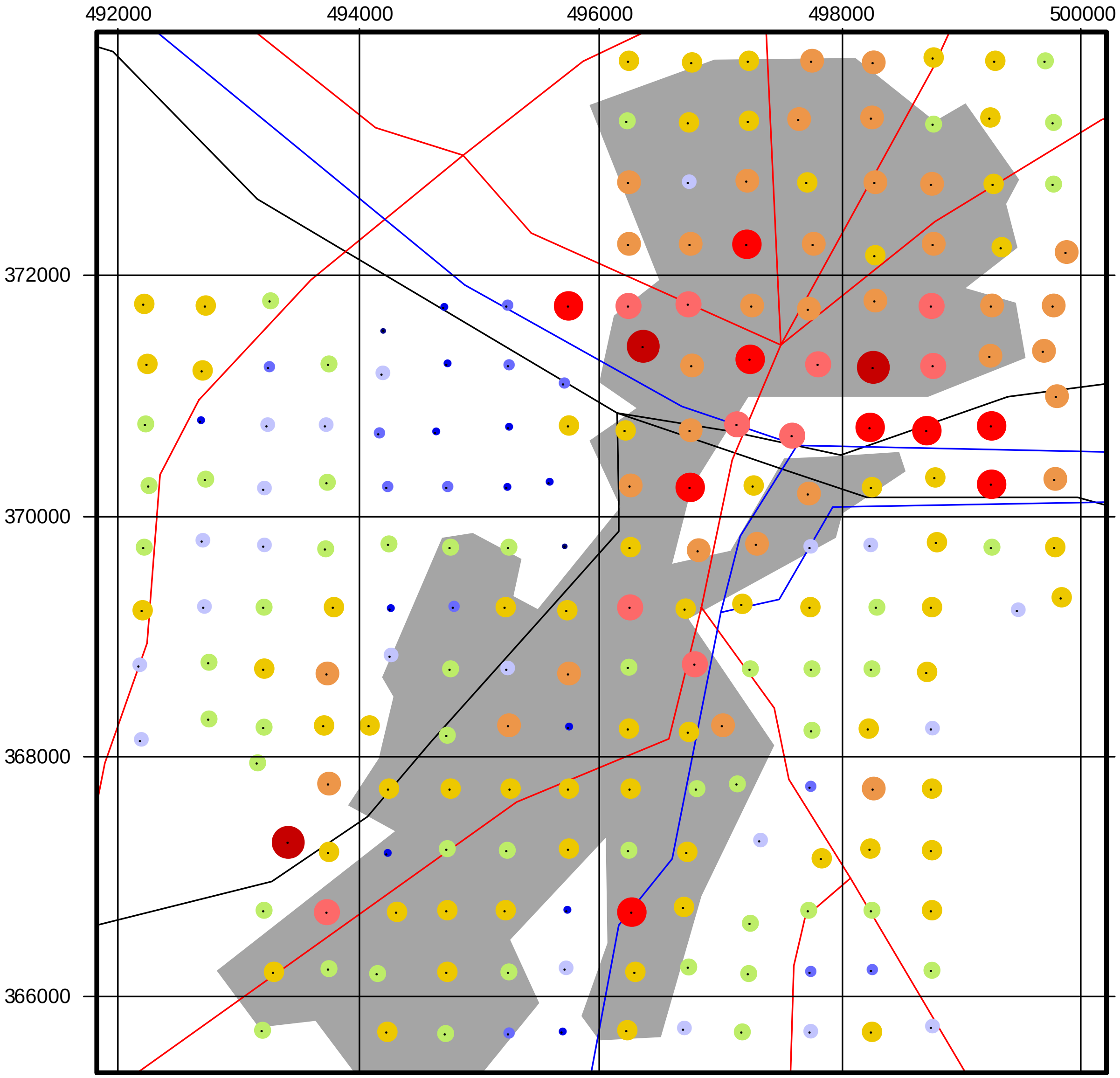
— **Railway**
— **Drainage**
— **Roads**
▨ **Urban area**

| surface soil | Sn (ppm) |
|---|---|
| number | 216 |
| minimum | 1 |
| maximum | 250 |
| median | 4 |
| mean | 12 |

# Lincoln

## Profile Soils

## Tin



| %ile | | ppm |
|---|---|---|
| 99 | ● | 318 |
| 95 | ● | 46 |
| 90 | ● | 31 |
| 75 | ● | 12 |
| 50 | ● | 7 |
| 25 | ● | 5 |
| 15 | ● | 4 |
| 10 | ● | 3 |
| 5 | • | 2 |

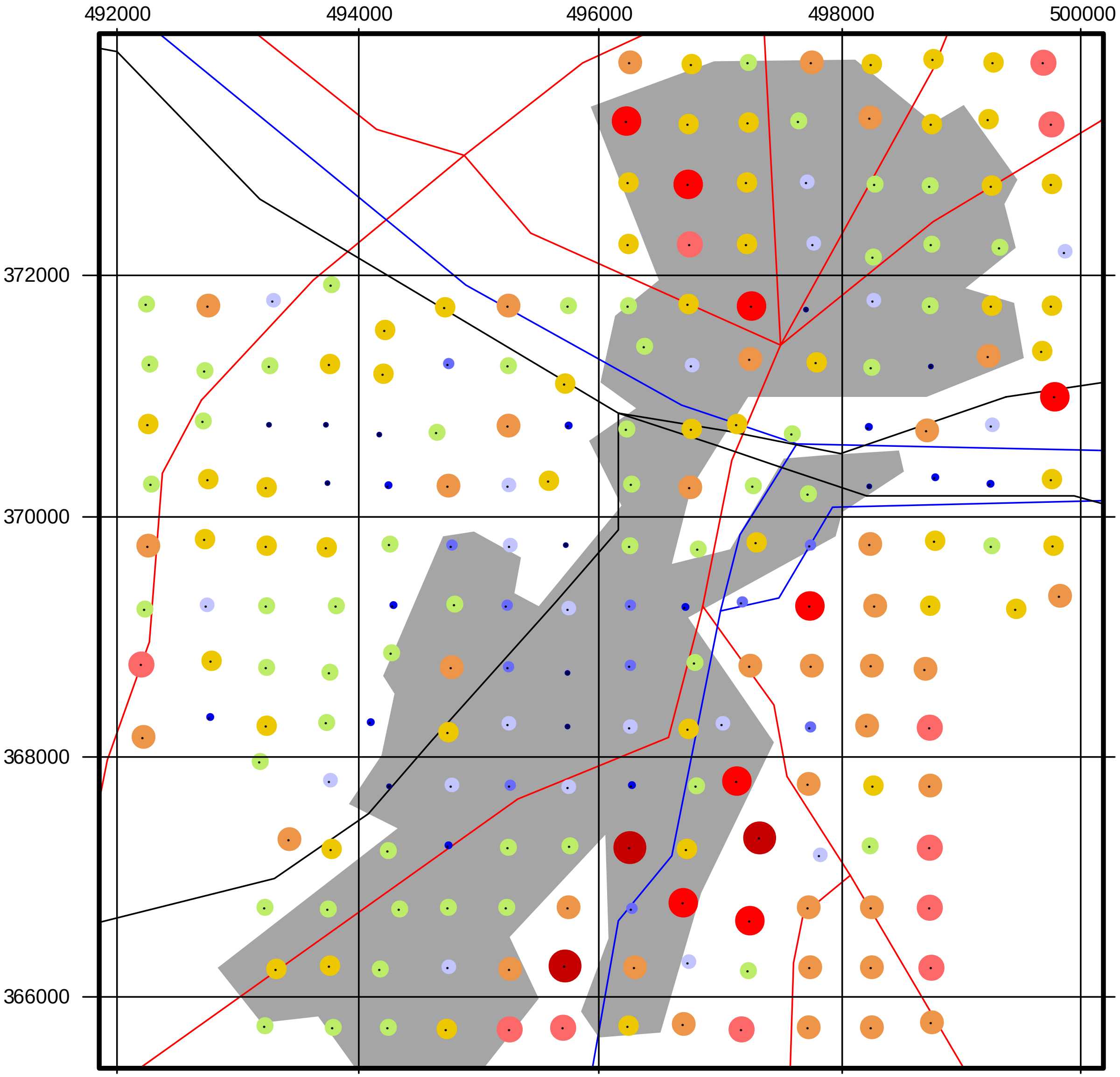
— Railway
— Drainage
— Roads
▨ Urban area

| profile soil | Sn (ppm) |
|---|---|
| number | 214 |
| minimum | 1 |
| maximum | 1360 |
| median | 7 |
| mean | 25 |

# Lincoln

## Surface Soils

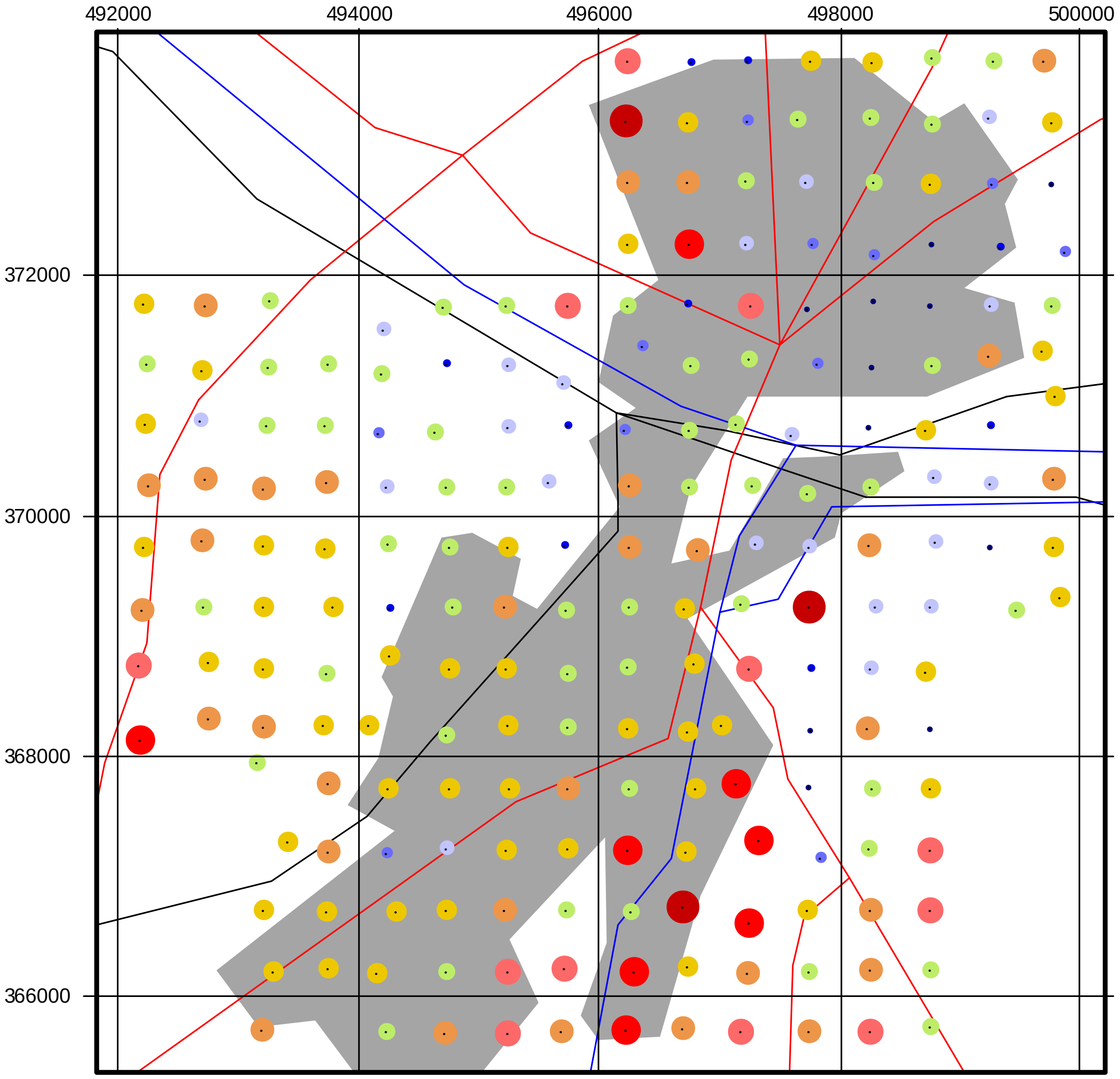
## Titanium



| %ile | | WT% |
|---|---|---|
| 99 | ● | 0.716 |
| 95 | ● | 0.506 |
| 90 | ● | 0.441 |
| 75 | ● | 0.339 |
| 50 | ● | 0.275 |
| 25 | ● | 0.222 |
| 15 | ● | 0.202 |
| 10 | ● | 0.186 |
| 5 | ● | 0.161 |
| | · | |

| | |
|---|---|
| — | Railway |
| — | Drainage |
| — | Roads |
| ▨ | Urban area |

| surface soil | $TiO_2$ (%) |
|---|---|
| number | 216 |
| minimum | 0.130 |
| maximum | 0.774 |
| median | 0.275 |
| mean | 0.297 |



# Lincoln

## Profile Soils

## Titanium

| %ile | | WT% |
|---|---|---|
| 99 | ● | 0.914 |
| 95 | ● | 0.751 |
| 90 | ● | 0.702 |
| 75 | ● | 0.561 |
| 50 | ● | 0.495 |
| 25 | ● | 0.393 |
| 15 | ● | 0.357 |
| 10 | ● | 0.338 |
| 5 | ● | 0.284 |
| | · | |

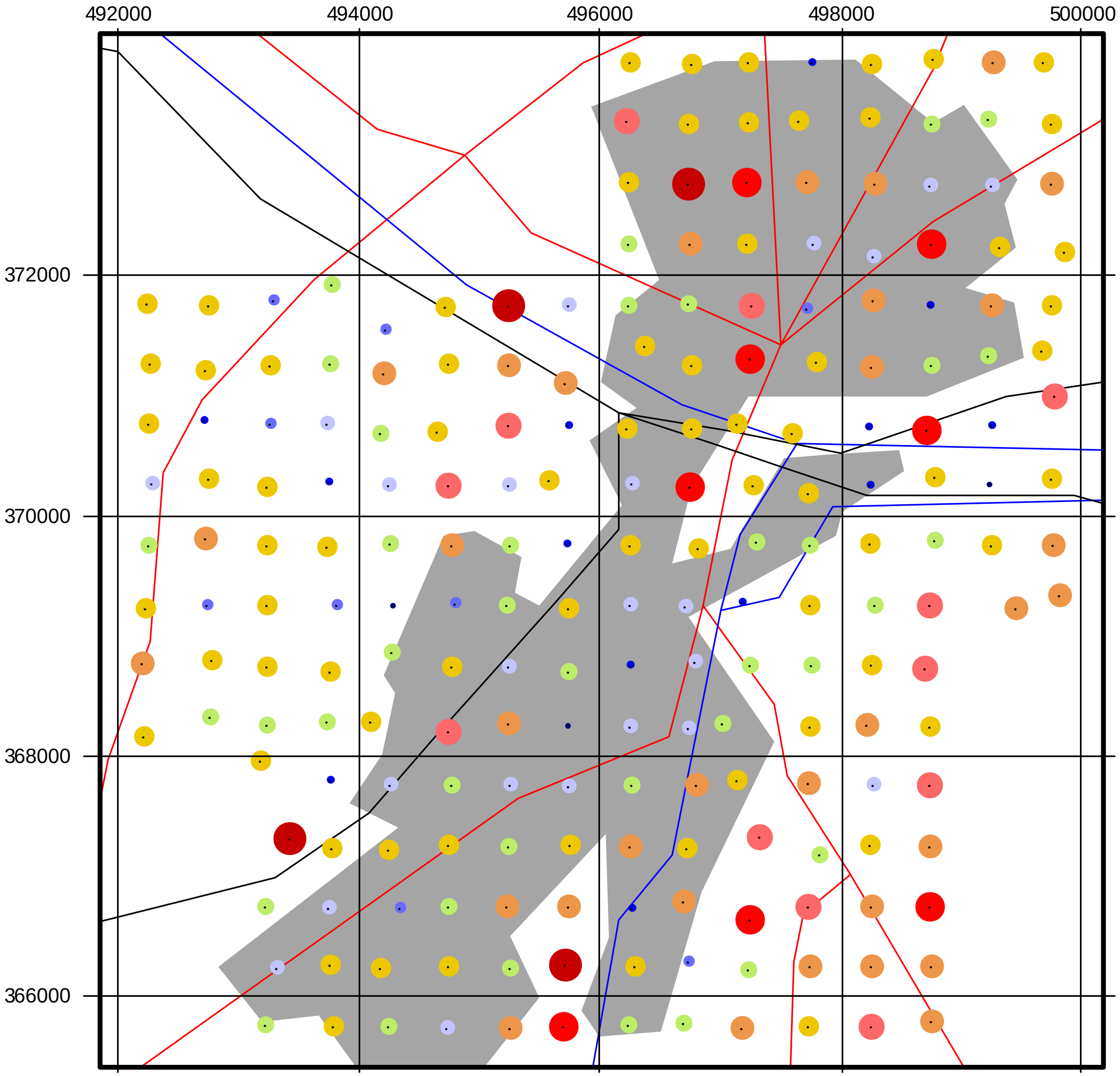
— Railway
— Drainage
— Roads
▨ Urban area

| profile soil | Ti $O_2$ (%) |
|---|---|
| number | 214 |
| minimum | 0.186 |
| maximum | 1.013 |
| median | 0.495 |
| mean | 0.497 |

# Lincoln

## Surface Soils

## Uranium



| %ile | | ppm |
|---|---|---|
| 99 | ● | 3.0 |
| 95 | ● | 2.1 |
| 90 | ● | 1.9 |
| 75 | ● | 1.5 |
| 50 | ● | 1.2 |
| 25 | ● | 1.0 |
| 15 | ● | 0.8 |
| 10 | ● | 0.7 |
| 5 | ● | 0.5 |

— **Railway**

— **Drainage**

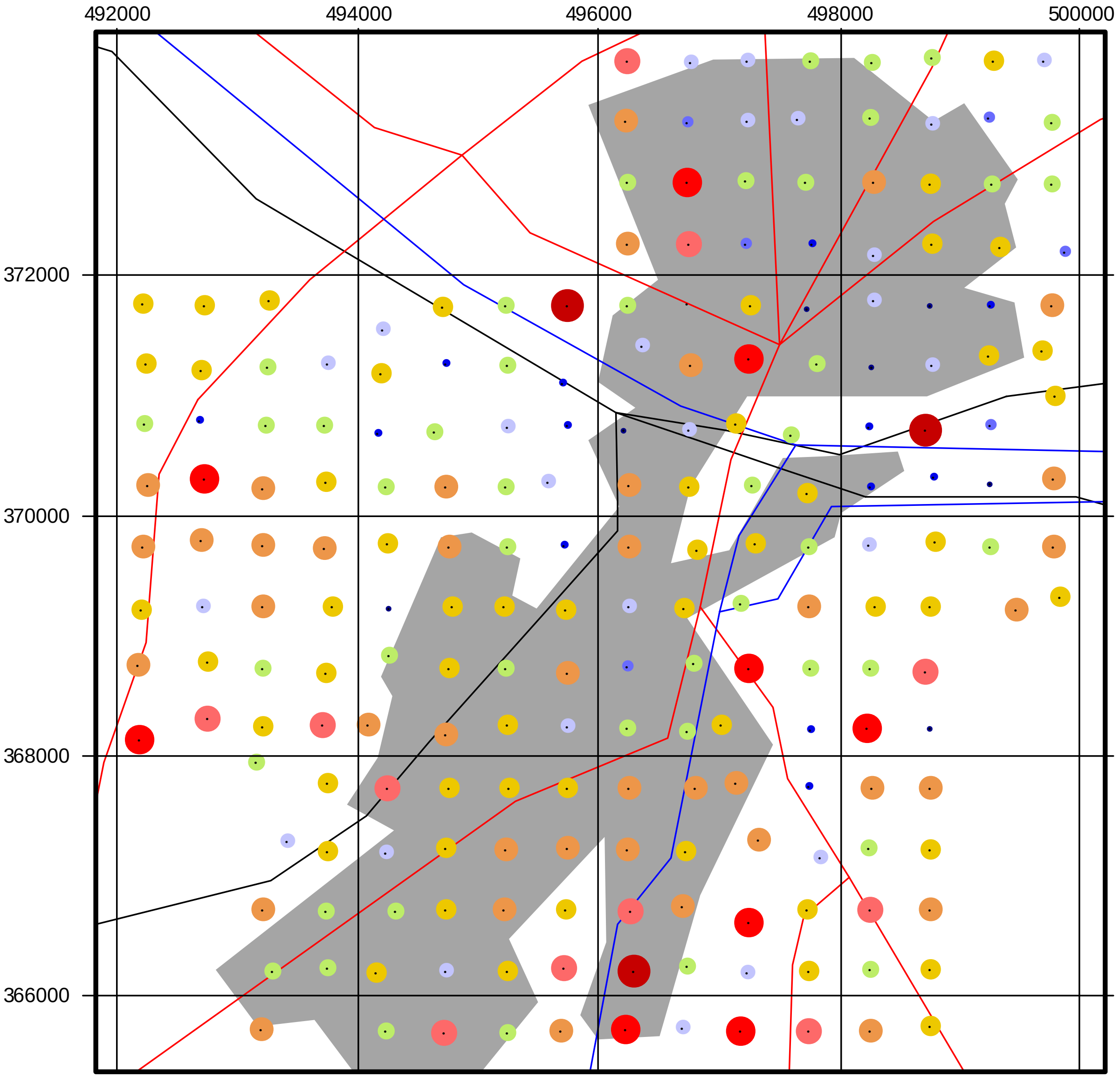
— **Roads**

▨ **Urban area**

| surface soil | U (ppm) |
|---|---|
| number | 216 |
| minimum | 0.25* |
| maximum | 3.6 |
| median | 1.2 |
| mean | 1.3 |

*minimum value reported as half detection limit

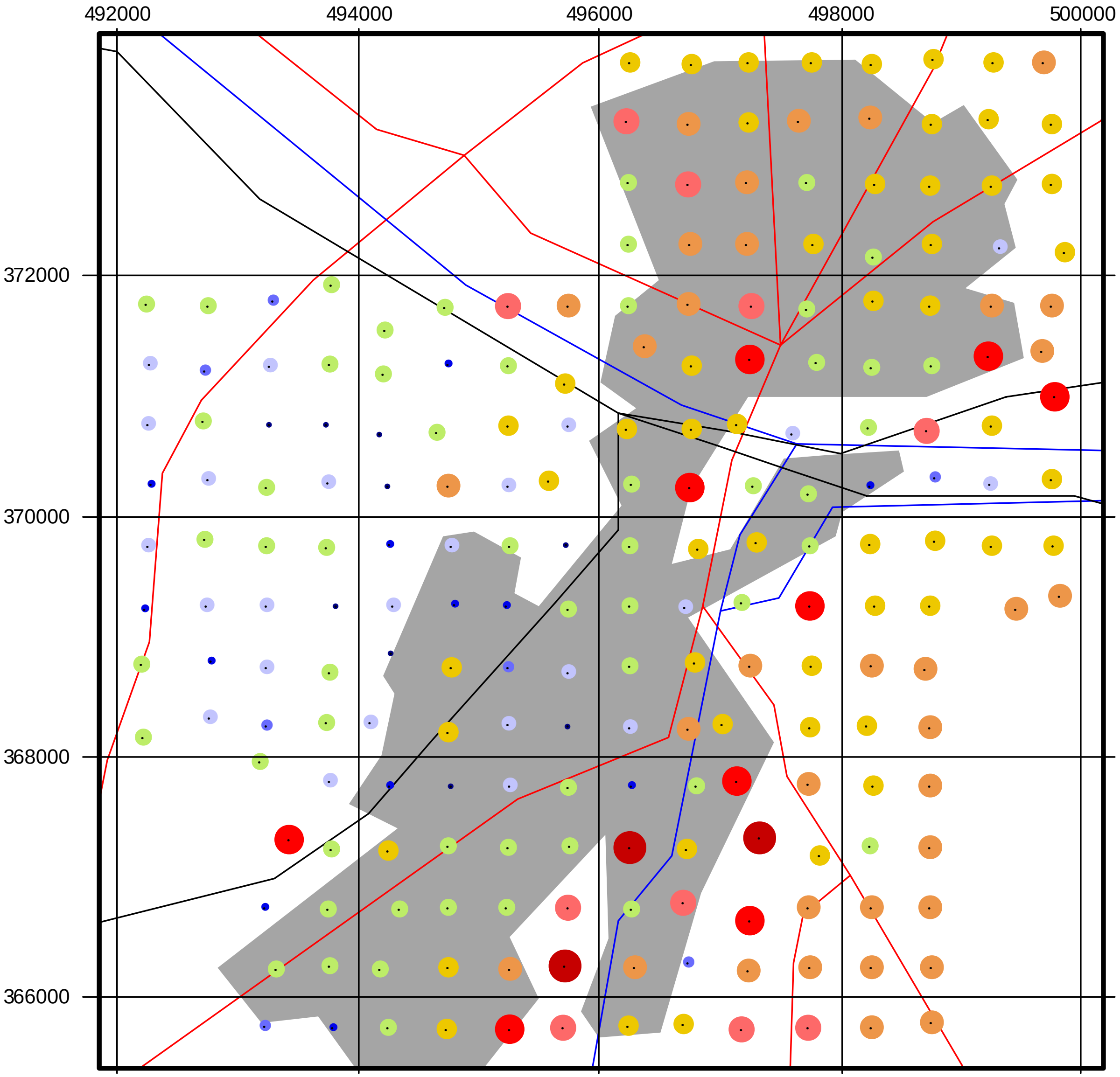
# Lincoln
## Profile Soils
## Uranium



| profile soil | U (ppm) |
|---|---|
| number | 214 |
| minimum | 0.25* |
| maximum | 4.9 |
| median | 2.3 |
| mean | 2.3 |

*minimum value reported as half detection limit

# Lincoln
## Surface Soils
## Vanadium



| %ile | | ppm |
|---|---|---|
| 99 | ● | 178 |
| 95 | ● | 119 |
| 90 | ● | 90 |
| 75 | ● | 71 |
| 50 | ● | 54 |
| 25 | ● | 37 |
| 15 | ● | 34 |
| 10 | ● | 33 |
| 5 | ● | 30 |

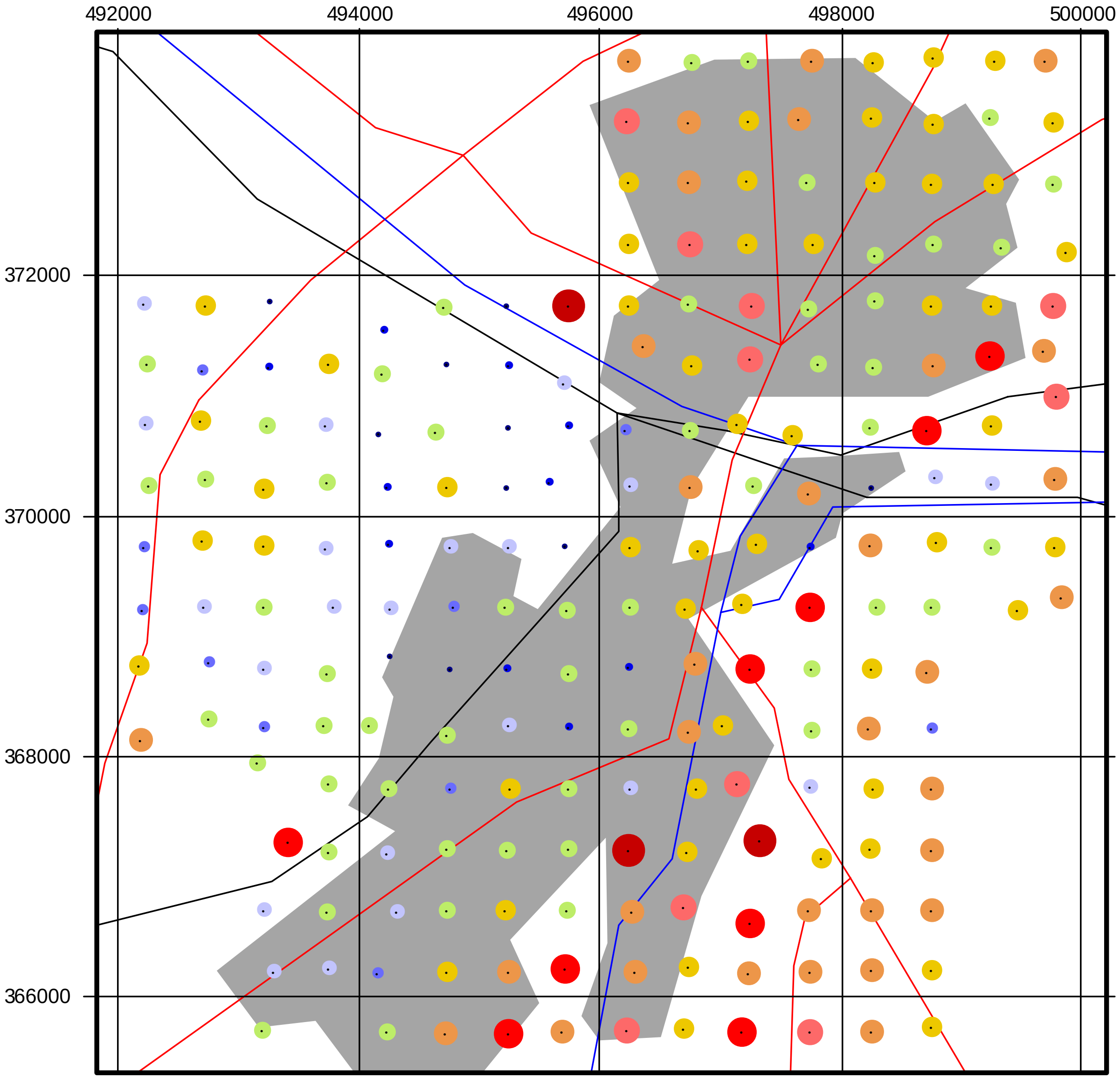
| | |
|---|---|
| — | **Railway** |
| — | **Drainage** |
| — | **Roads** |
| ▨ | **Urban area** |

| surface soil | V (ppm) |
|---|---|
| number | 216 |
| minimum | 23 |
| maximum | 215 |
| median | 54 |
| mean | 59 |

# Lincoln

## Profile Soils

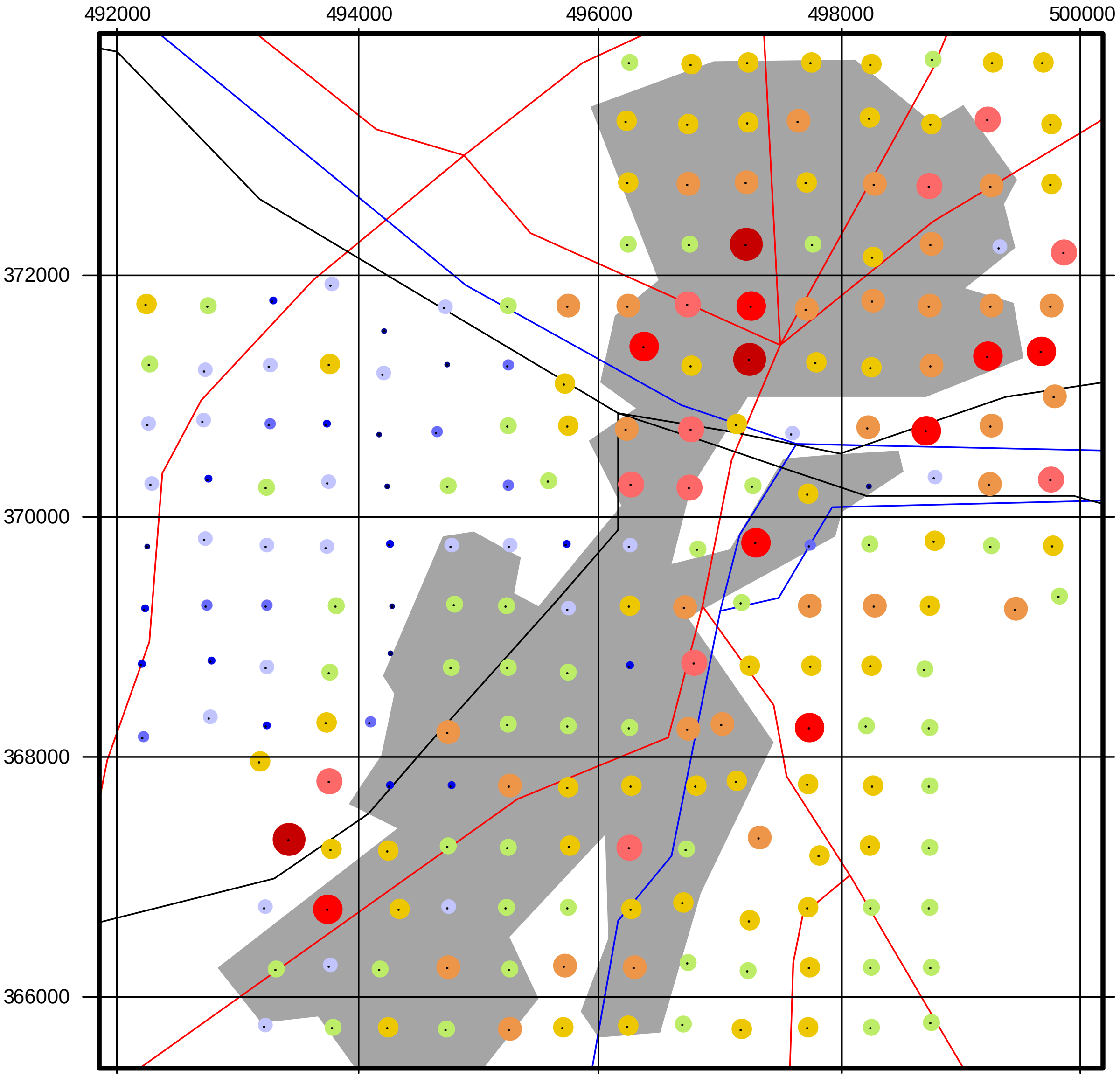
## Vanadium



| %ile | ppm |
|---|---|
| 99 | 219 |
| 95 | 167 |
| 90 | 128 |
| 75 | 89 |
| 50 | 66 |
| 25 | 51 |
| 15 | 46 |
| 10 | 41 |
| 5 | 37 |

- Railway
- Drainage
- Roads
- Urban area

| profile soil | V (ppm) |
|---|---|
| number | 214 |
| minimum | 28 |
| maximum | 259 |
| median | 66 |
| mean | 77 |



# Lincoln

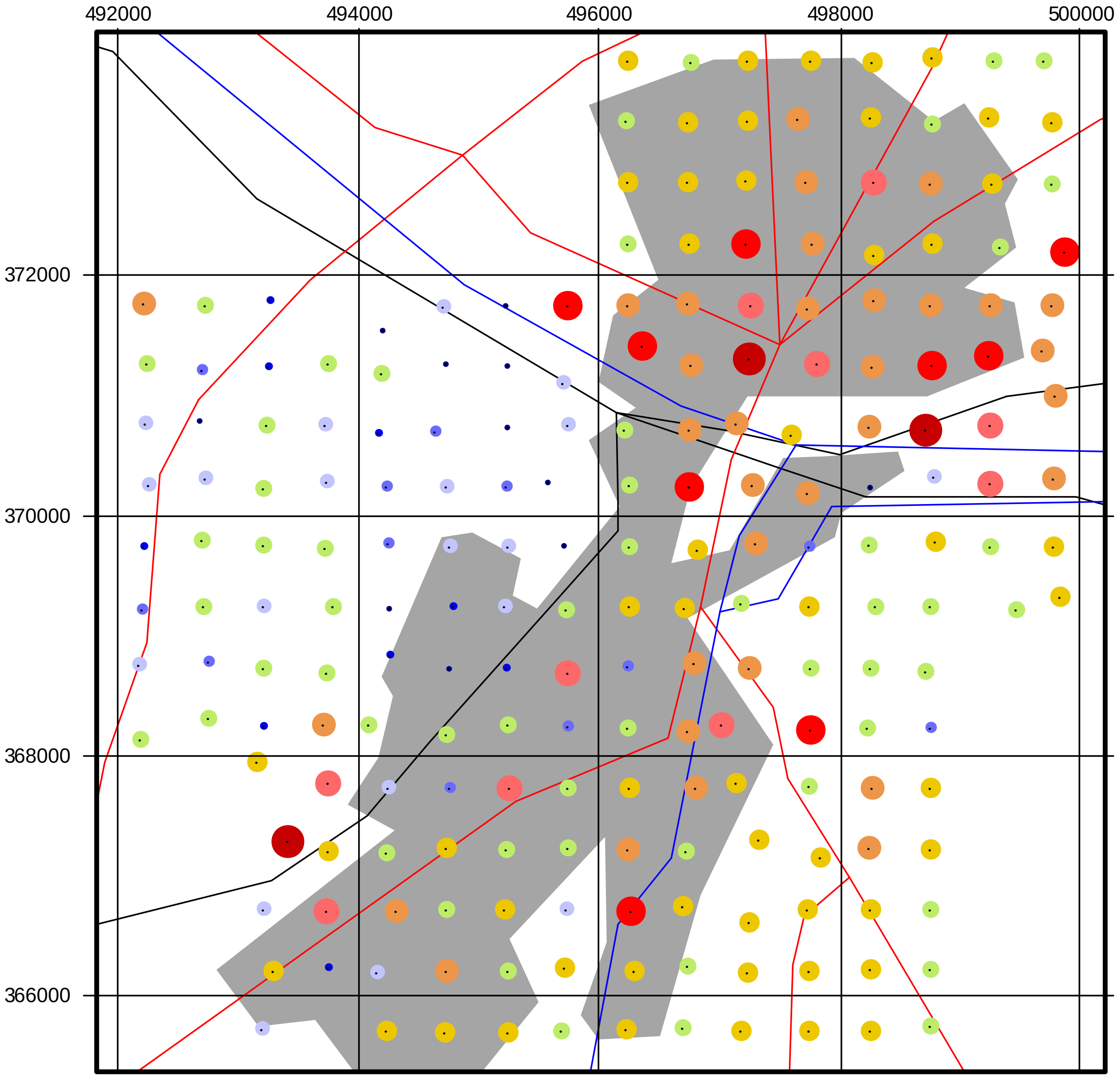
## Surface Soils

## Zinc

| %ile | | ppm |
|---|---|---|
| 99 | ● | 777 |
| 95 | ● | 269 |
| 90 | ● | 184 |
| 75 | ● | 92 |
| 50 | ● | 61 |
| 25 | ● | 35 |
| 15 | ● | 27 |
| 10 | ● | 25 |
| 5 | • | 20 |

— Railway
— Drainage
— Roads
▨ Urban area

| surface soil | Zn (ppm) |
|---|---|
| number | 216 |
| minimum | 7 |
| maximum | 2399 |
| median | 61 |
| mean | 102 |



# Lincoln

## Profile Soils

## Zinc

| %ile | ppm |
|---|---|
| 99 | 1041 |
| 95 | 367 |
| 90 | 221 |
| 75 | 119 |
| 50 | 79 |
| 25 | 47 |
| 15 | 35 |
| 10 | 29 |
| 5 | 21 |

— Railway
— Drainage
— Roads
▨ Urban area

| profile soil | Zn (ppm) |
|---|---|
| number | 214 |
| minimum | 9 |
| maximum | 7500 |
| median | 79 |
| mean | 152 |