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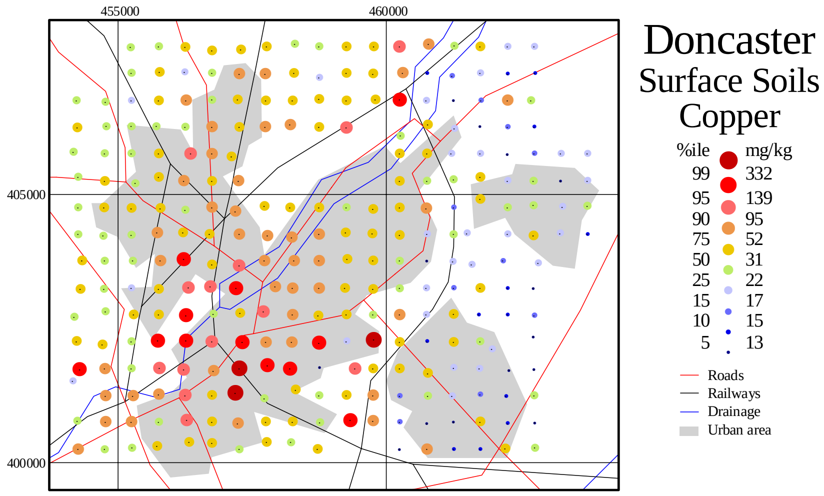
Geochemical baseline data for the urban area of Doncaster

Urban Geoscience and Geological Hazards Programme

Internal Report IR/02/079



BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/02/079

Geochemical baseline data for the urban area of Doncaster

K E O'Donnell

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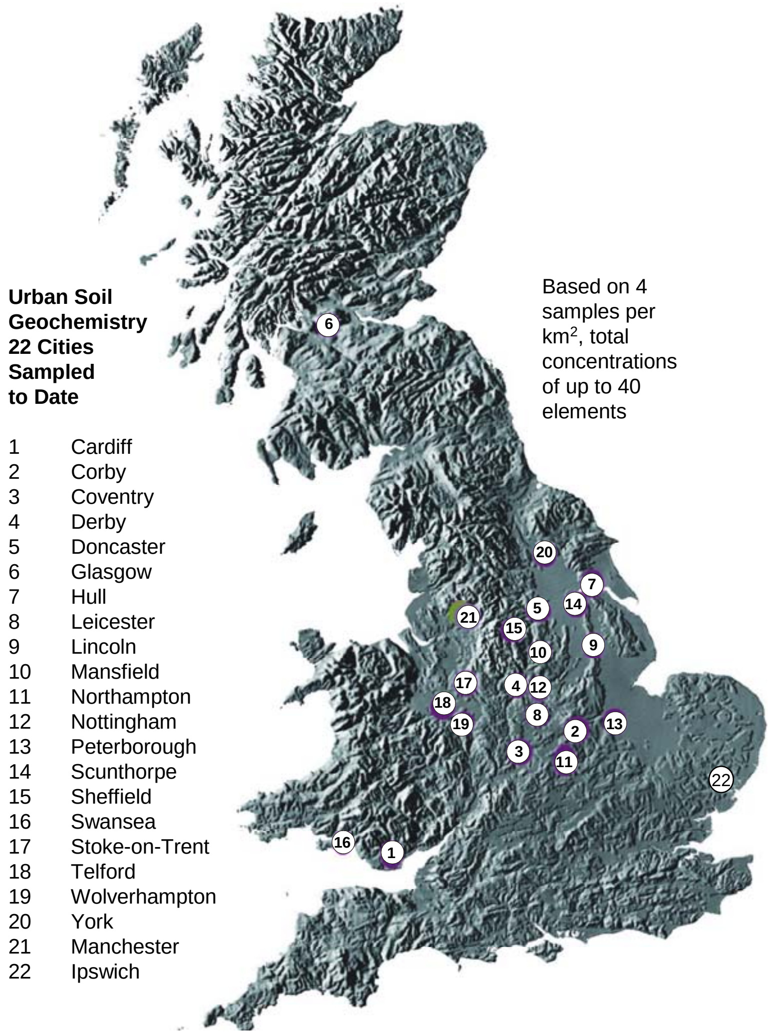
Foreword

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 Doncaster carried out by the British Geological Survey (BGS) during 1996. 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 Doncaster 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 Doncaster is presented in Table 1.

Preliminary interpretations of the data in relation to the underlying geology and to the industrial history of Doncaster are presented in this report and demonstrate that both of these factors have had significant influences on the soil geochemistry of Doncaster.

Table 1 Summary of the Doncaster soil sampling strategy

Date Sampled:	Summer 1996
Area Sampled:	70 km^2 (min E 454150; max E 463750; min N 400240; and max N 407800)
Sample Density:	1 per 0.25 km^2
Number of Samples:	279 surface (0.05 – 0.20 m) and 273 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, TiO_2,* Fe_2O_3, MnO, 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 Doncaster, undertaken by the British Geological Survey (BGS) during 1996 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 Doncaster (Figure 1).

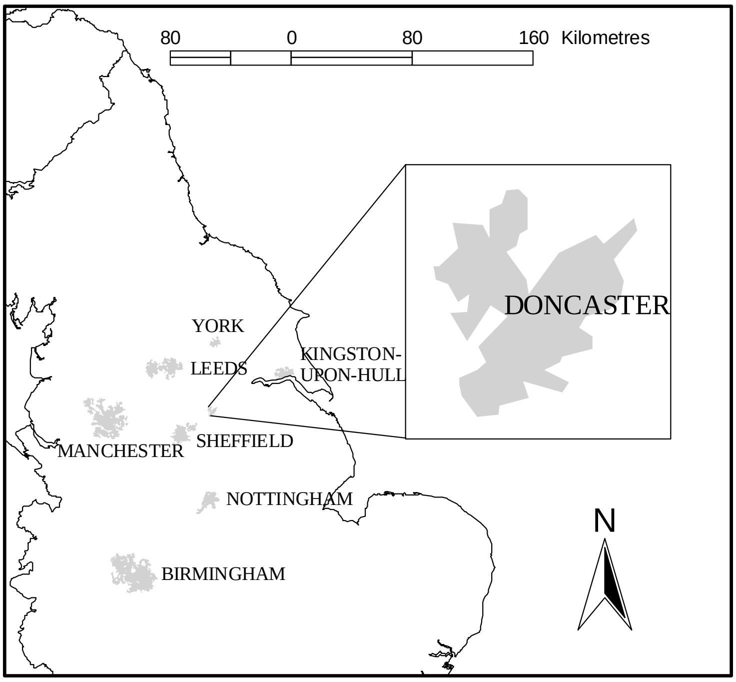

Figure 1 Location map for Doncaster

Doncaster became an important centre in West Yorkshire for engineering and for the coal mining industry. The city is particularly famous for the manufacturing of steam trains, which were used in the transportation of large volumes of coal. The distributions of approximately 23 major and trace elements including several PHE in the surface environment of Doncaster 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 70 km^2 was surveyed during the summer of 1996, in which a total of 279 surface soils (0.05 – 0.20 m depth) and 273 profile soils (0.35 – 0.50 m depth) were sampled. This extends from British National Grid references 454150 m east to 463750 m east and from 400240 m north to 407800 m north (Table 1). The survey area is shown in Figures 2 and 3.

2.2 HISTORICAL LAND USE

Engineering dominated industry in Doncaster in the late 19th and 20th centuries. The railway first arrived in Doncaster in 1849 and in 1853 the Great Northern Railway moved its engine building works to Doncaster, which became the cities biggest employer[1]. ‘The Plant’, as it is known locally, is still in operation, and in the last century and a half produced more than 2,500

[1] http://www.localhistories.org/doncaster.html

locomotives, with some of the most famous including 'The Flying Scotsman' and 'The Mallard', as well as thousands of carriages and wagons. During World War I and World War II, munitions manufacture dominated over the railway industry and Doncaster subsequently became an important coal-mining town, with this industry employing the highest proportion of the population. During the 1980s, many jobs were lost as pits were closed down, in common with many other areas of the UK, and the coal industry has virtually disappeared from Doncaster. Today, Doncaster is aiming towards commercial and leisure enterprises and the town is particularly famous for its horse-racing, which has been a well-known feature of the town for at least 4 centuries[2].

Industrial works are found alongside the Rivers Don and Dun Navigation as they pass through Doncaster (see Figure 3), predominately along the eastern banks, from the north-east corner of the district to Doncaster city. There are also industrial works and industrial estates in Bentley (to the west of the sampling area), Armthorpe (to the east of the sampling area) and to the south of Doncaster city centre, in proximity to the railway line. Sewage works are located on the eastern side of the Bentley area, and at the northern edge of Doncaster district (see Figure 3). There are also a number of mine tips and (mainly) disused quarries within and surrounding the sample area.

2.3 BEDROCK AND SUPERFICIAL GEOLOGY

Geological information for the Doncaster area was obtained from the BGS 1:63 360 series maps for the area (Institute of Geological Sciences, 1969) and the BGS digital DigmapGB® database (1:50 000 scale).

The bedrock geology underlying Doncaster is Permo-Triassic in age. In the southwest corner of the sample area, the Cadeby Formation (a dolomite) and the Edlington Formation (a calcareous mudstone) are found. These beds underlie the Brotherton Formation (a dolomitic limestone), which is the main parent material type along the western margin, where Quaternary deposits are absent (Figure 4). This is likely to be related to an increase in altitude towards the west of the area. The Roxby Formation (a calcareous mudstone) overlies the Brotherton Formation. The Nottingham Castle Sandstone Formation (also known as the Bunter Sandstone) underlies much of the sample area, through the central and eastern regions and extending into the southwest corner of the area (see Figure 5). This formation is part of the Sherwood Sandstone Group, an extremely important aquifer in the Midlands area, comprised of reddish medium-fine grained porous sandstone (Institute of Geological Sciences, 1980).

Quaternary deposits overlie much of the bedrock geology in the Doncaster area (Figure 4). The deposits trend largely northeast – southwest through the centre of the sample area, in line with the rivers that pass through Doncaster (see Figure 2). There are till deposits in the southwest part of Doncaster, with smaller exposures in the centre and northeast of the sample area, around the river valley. River terrace deposits underlie the western half of the Bentley area, the northern part of Doncaster city, extending into the southern part of Doncaster district and also underlie much of the eastern margin of the sample area. Glaciolacustrine deposits are found to the northeast of Bentley and to the east of Doncaster district. Glaciofluvial deposits (sand and gravel) are found to the southeast of the river valley and alluvial deposits underlie the northwest side of the river valley, widening into the Bentley area. The former are also found in the southeast corner of the sample area, while a large deposit of alluvium underlies much of Doncaster city centre.

The superficial deposits and bedrock geology are shown in Figure 4 and Figure 5, respectively.

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[2] http://www.nationmaster.com/encyclopedia/Doncaster

2.4 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 Doncaster, although limited data are available for the outskirts of the urban area (Carroll *et al.*, 1979).

The main soil type to the west of Doncaster is a brown calcareous earth. Soils in this group are fine-coarse loamy in texture and occur over dolomitic limestone. This soil type may therefore be present in the western part of Doncaster, which is underlain by the Brotherton Formation (Figure 5). North of Doncaster, there is an extensive region of stagnogley soils, mainly pelostagnogleys formed over glaciolacustrine deposits. This soil type is clayey in texture and is likely to occur over the glaciolacustrine deposits observed in the northern part of Doncaster (Figure 4). On the northern margin of the Bentley district, there are cambic stagnogley soils, which are fine loamy or clayey soils formed over till or head. South of Doncaster, there is largely a mixture of brown calcareous earth and pelostagnogley soils.

Directly to the east of Doncaster, the main soil types are brown sands and cambic gley soils. Both these soil groups are sandy or coarse loamy in texture and occur over glaciofluvial drift. Other notable soil types are an earthy peat soil, to the southeast of Doncaster, developed over Fen-carr peat and sandy gley soils, which occur over glaciofluvial drift in areas to the south, north and north-east of Doncaster.

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 Doncaster 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 in the BGS corporate geochemistry database.

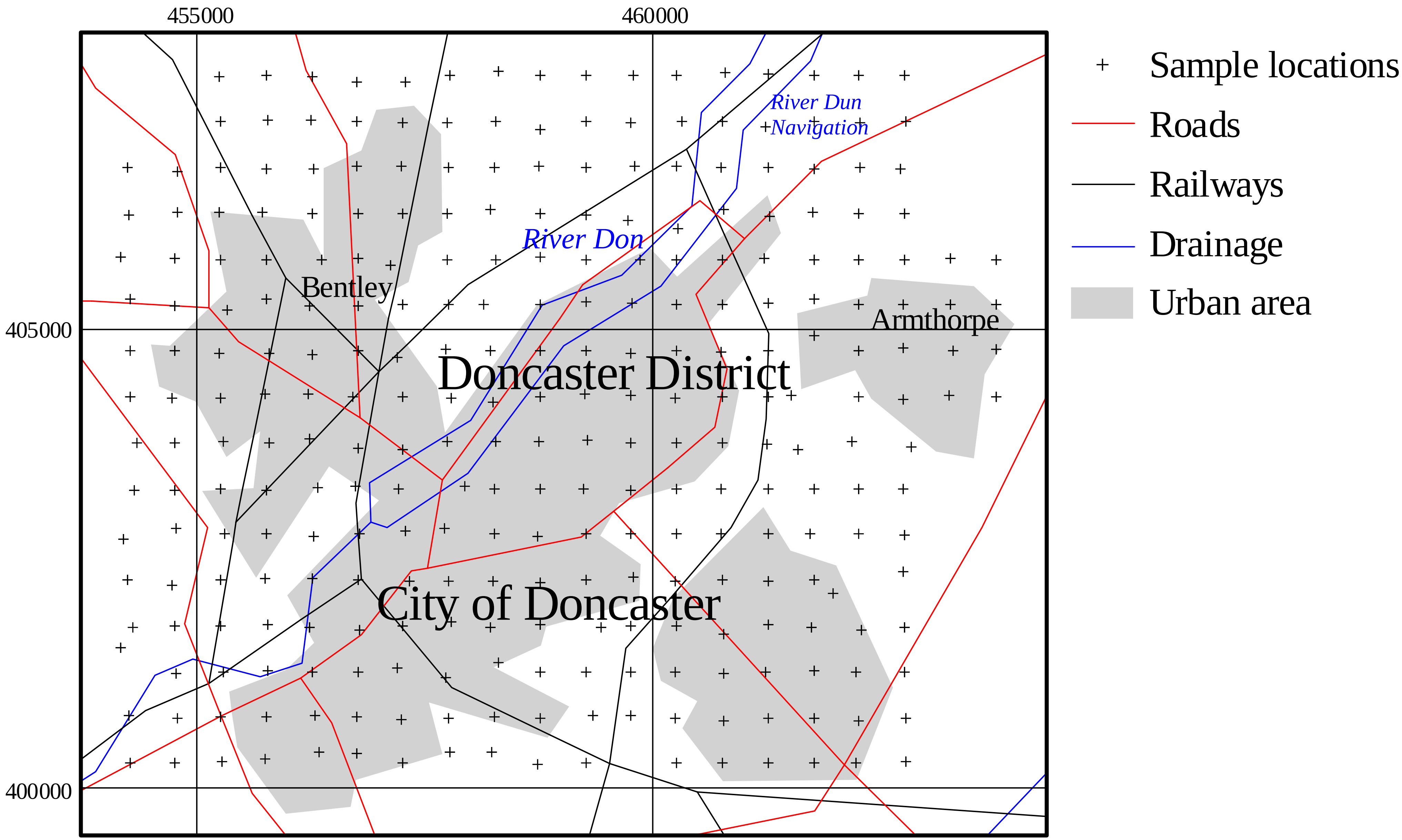

Figure 2 Map of the sampling area (Grid squares shown at 5 km intervals)

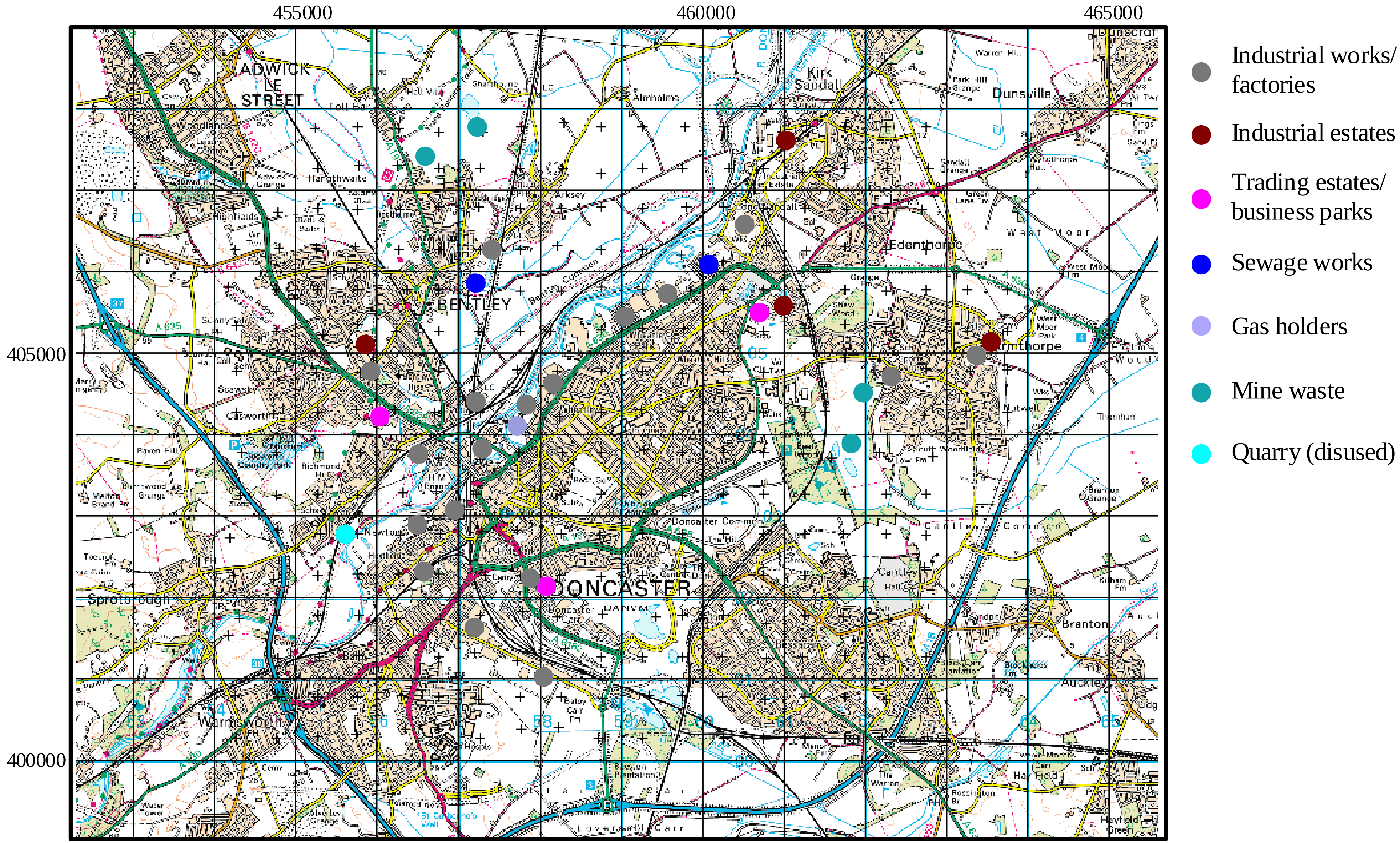

Figure 3 Topographical map of the sampling area (Grid squares shown at 1 km intervals)

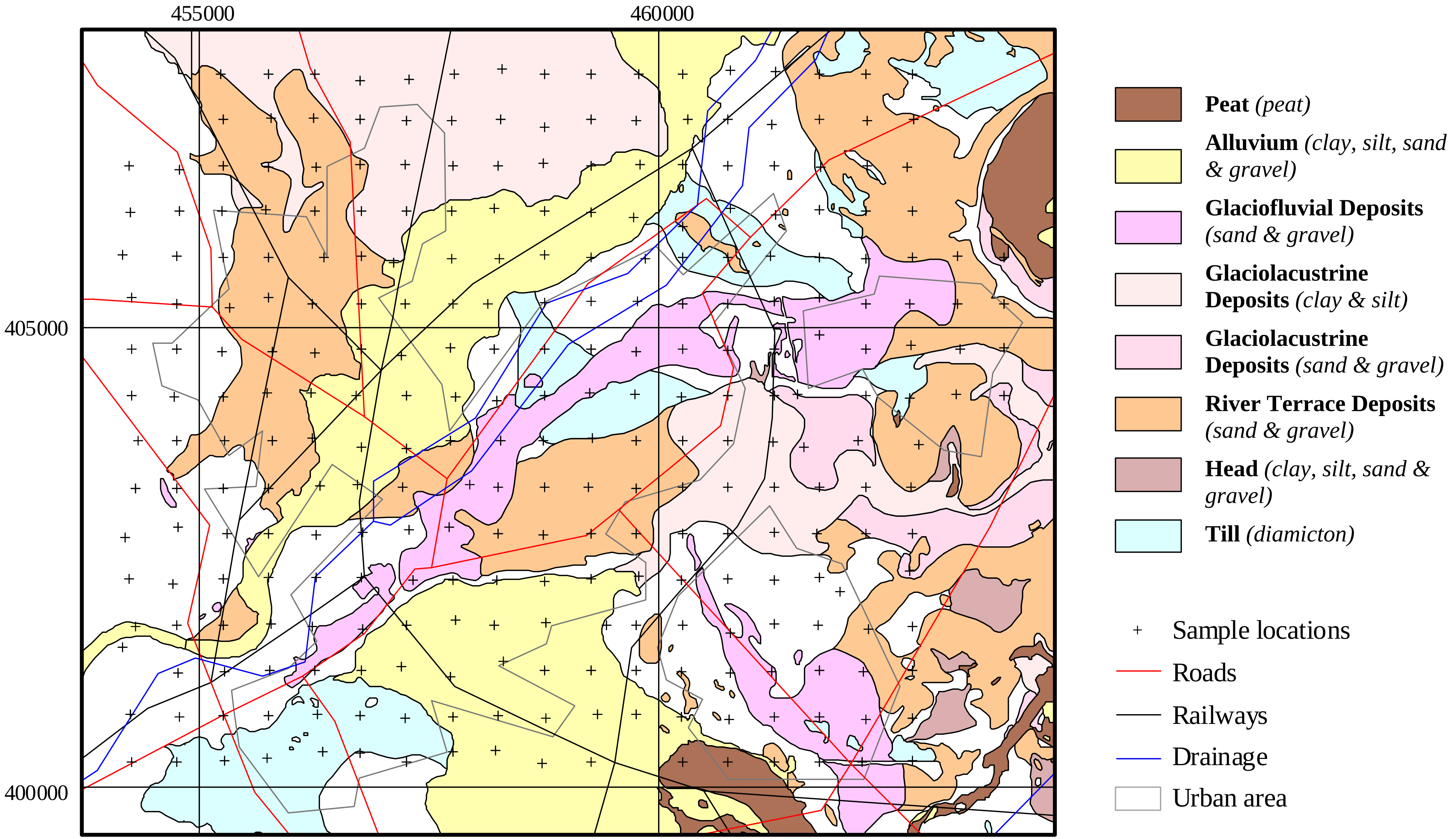

Figure 4 Superficial deposit map of Doncaster and the surrounding area (based on 1:50 000 scale geological map; BNG shown at 5 km intervals) BGS DigmapGB®

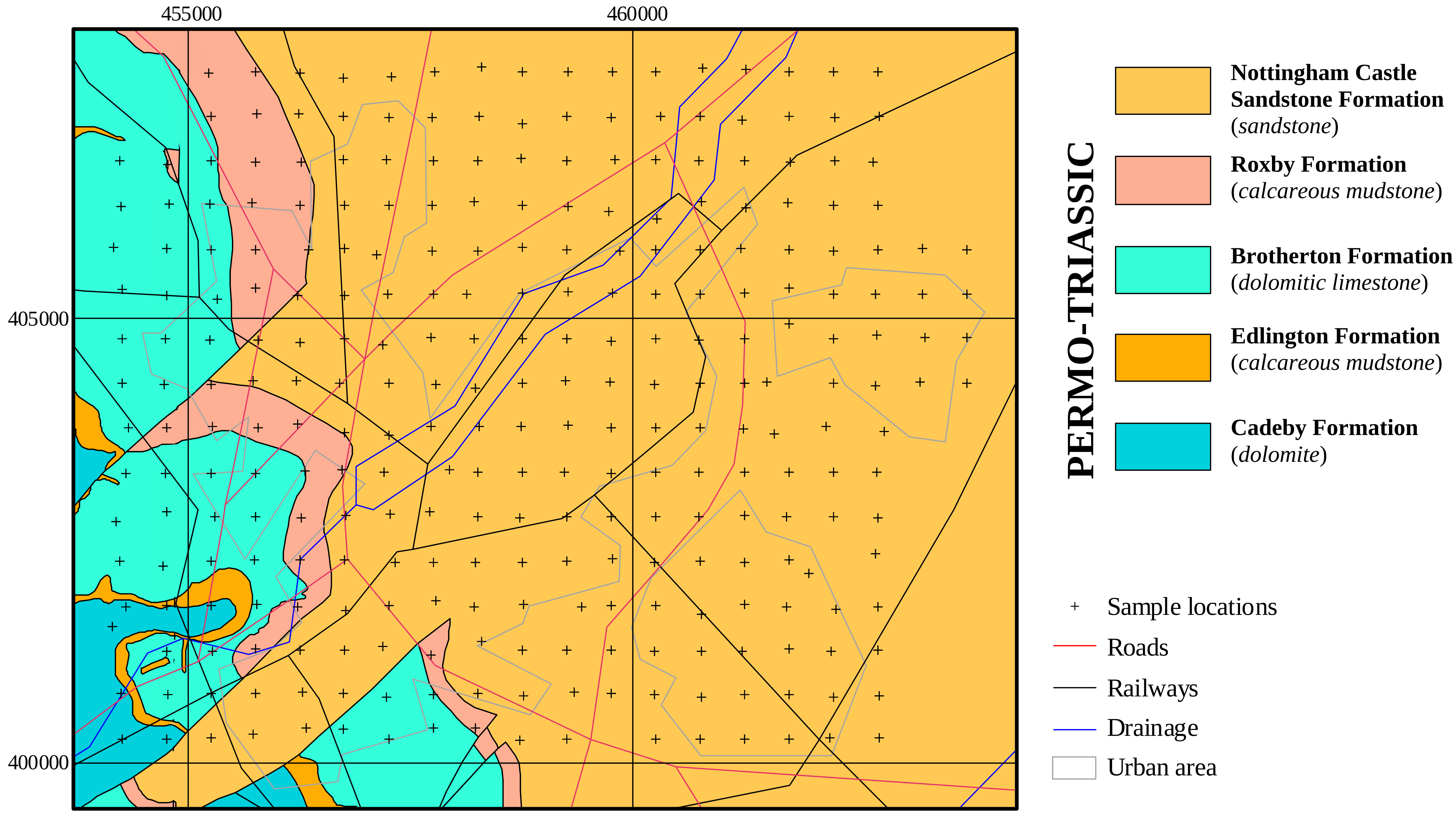

Figure 5 Bedrock geology map of Doncaster and the surrounding area (based on 1:50 000 scale geological map; BNG shown at 5 km intervals) BGS DigmapGB®

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 were made up of a three point composite 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 40ºC 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™. 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.

The ANOVA analysis was not carried out on Al_2O_3, CaO, MgO, K_2O, P_2O_5 or SiO_2 as these major elements were not analysed routinely in the urban sampling programme.

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 Doncaster, 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. Doncaster lies within the Humber-Trent regional geochemical atlas area, and it is therefore essential that data for the urban centre of Doncaster 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 Doncaster 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	Doncaster A S13	Doncaster S S13	Humber-Trent S15	Doncaster A S15	Doncaster S S15
Sb	mg/kg	<1	<1	<1	1	<1	<1
Al_2O_3	wt%	-	17.9	-	-	6.6	-
As	mg/kg	15	15	15	9	8	8
Ba	mg/kg	1704	1771	1835	291	376	372
CaO	wt%	0.35	0.33	-	0.20	0.18	-
Cd	mg/kg	<1	<1	<1	<1	1	1
Cr	mg/kg	98	96	98	41	35	40
Co	mg/kg	29	22	24	9	5	6
Cu	mg/kg	17	14	14	6	4	3
Fe_2O_3	wt%	6.88	6.95	7.07	1.88	1.92	2.02
Pb	mg/kg	109	110	110	24	24	23
MgO	wt%	1.2	1.1	-	0.6	0.5	-
MnO	wt%	0.128	0.107	0.123	0.082	0.061	0.071
Mo	mg/kg	1.6	1.6	0.5	0.7	1.4	0.2
Ni	mg/kg	36	36	36	12	10	11
K_2O	wt%	2.17	2.17	-	2.27	2.18	-
P_2O_5	wt%	0.13	0.13	-	0.09	0.09	-
SiO_2	wt%	-	56.3	-	-	74.7	-
Sn	mg/kg	3	2	2	5	4	4
TiO_2	wt%	0.817	0.888	-	0.392	0.432	-
U	mg/kg	2.5	2.6	3.2	1.2	1.7	2.1
V	mg/kg	97	84	93.7	35	23	31.3
Zn	mg/kg	113	113	112	30	28	29

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
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	1.1	-	10000	-
Sb	1.2	-	10000	-
Ba	2.9	-	600000	-
Pb	1.2	-	10000	-
U	0.5	-	650	-
TiO_2*	-	0.01	-	100.0
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 Doncaster 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 Doncaster, 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 Doncaster 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 influenced to some degree by diffuse pollution.

Table 5 Comparison of median concentrations in regional surface soil samples from the Humber-Trent atlas area (6561 samples) with Doncaster surface soil samples (279 samples)

Analyte	Units	Median Regional	Median Doncaster
Al_2O_3	wt%	11.5	8.4
Sb	mg/kg	0.5	2
As	mg/kg	13	13
Ba	mg/kg	376	398
Cd	mg/kg	1	1
CaO	wt%	2.12	0.73
Cr	mg/kg	71	64
Co	mg/kg	19	18
Cu	mg/kg	18	31
Fe_2O_3	wt%	4.66	5.48
Pb	mg/kg	43	78
MgO	wt%	1.1	0.8
MnO	wt%	0.08	0.130
Mo	mg/kg	2.2	2.4
Ni	mg/kg	22	19
K_2O	wt%	-	1.61
P_2O_5	wt%	0.29	0.26
SiO_2	wt%	-	60.5
Sn	mg/kg	4	5
TiO_2	wt%	0.680	0.462
U	mg/kg	2.1	1.9
V	mg/kg	83	63
Zn	mg/kg	72	105

Table 6 Comparison of median concentrations in regional profile soil samples from the Humber-Trent atlas area (6877 samples) with Doncaster profile soil samples (273 samples)

Analyte	Units	Median Regional	Median Doncaster
Al_2O_3	wt%	-	-
Sb	mg/kg	3	1
As	mg/kg	12	12
Ba	mg/kg	388	423
Cd	mg/kg	0.45	1
CaO	wt%	2.89	-
Cr	mg/kg	83	75
Co	mg/kg	21	22
Cu	mg/kg	20	30
Fe_2O_3	wt%	5.04	5.80
Pb	mg/kg	38	69
MgO	wt%	1.3	-
MnO	wt%	0.10	0.159
Mo	mg/kg	1.8	2.0
Ni	mg/kg	27	24
K_2O	wt%	1.98	-
P_2O_5	wt%	0.25	-
SiO_2	wt%	-	-
Sn	mg/kg	4	5
TiO_2	wt%	0.735	-
U	mg/kg	2.5	2.1
V	mg/kg	88	72
Zn	mg/kg	77	103

The concentrations of most major elements are lower at the median value in the urban soils from Doncaster, than on a regional scale (where data are available for comparison). The exceptions are Fe_2O_3 and MnO, which are higher in the Doncaster soils at both depths, although the difference is more significant for Fe_2O_3. The median concentrations of the elements Sb, Ba, Cu, Pb, Mo and Zn are higher in the Doncaster surface soils than the regional Humber-Trent surface soils, whilst Ba, Cd, Cu, Pb and Zn have higher median concentrations in the Doncaster profile soils than the regional profile soils. The median concentrations of Cr, Ni and V are lower in the urban surface soils, than in the regional soils and Sb, Cr and Ni concentrations are lower at the median in the urban profile soils. The median concentrations of As are exactly the same in the urban and regional surface soils (13 mg/kg) and in the urban and regional profile soils (12 mg/kg). Cobalt, Sn and U concentrations in the urban surface and profile soils are within 1 mg/kg of the corresponding regional soils at the median value.

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 horizons 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 heavy metal ions (Brady and Weil, 1999)) and this may affect the geochemical results.

A total of 23 major and trace elements were measured in Doncaster 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, SiO_2 and TiO_2 were additionally measured in the profile soils.

In the urban environment, elevated levels of potentially harmful elements, such as As, Cr and Pb, would normally be expected in the surface soils, as a result of diffuse pollution across the soil surface and/or direct loading of contamination onto the ground (from, for example industrial waste). Of the elements analysed at both sample depths, only Sb, As, Cu, Pb, Mo and Zn are higher in concentration at the median in the surface soils. The differences are however extremely small, with the exception of Pb, which is still only 9 mg/kg higher in concentration in the surface soils. The remaining elements (Ba, Cd, Cr, Co, Fe_2O_3, MnO, Ni, Sn, U and V) have equal or higher median values in the profile soils. 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 some areas, fresh topsoil may have been imported to cover more contaminated soils or made ground underneath (in back-gardens, for example). In the case of Doncaster, 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 more finely-sieved profile soils. It is, however, likely that the levels of diffuse pollution across the urban area of Doncaster are not particularly high, 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 across the soil surface.

4.3 GEOCHEMICAL DISTRIBUTION IN THE DONCASTER SOILS

There seem to be two main influences over the geochemical distribution in the soils of Doncaster, the first being anthropogenic, related to the location of industry and the city centre, and the second being geological.

The concentrations of the elements As, Cu, Pb, Mo, Sn and Zn are particularly high in the top and profile soils around the city centre. The levels seem to be more significantly elevated around the main industrial areas of the city centre, particularly the riverside and in the region of the train lines, where industrial works are also located (although diffuse urban contamination is likely to have an influence on the high concentrations). Levels of Sb are more dispersed across the sampling area, but higher values do occur around the city centre in the surface soils.

A number of elements are elevated in concentration in soils overlying alluvial deposits (Figure 4) in the area (including Ba, Cr, Co, MnO and Ni). With the exception of MnO, this includes high concentrations over a large part of the city centre, which is underlain by alluvium. A number of industrial sites within the city centre and alongside the river and canal are also located on or near alluvium. It is therefore difficult to separate the anthropogenic signature from the geological signature over this parent material type; although it is likely that the alluvium is naturally enriched in a number of major and trace elements, leading to higher concentrations of these elements in the overlying soils, which are further elevated by the effects of urban and industrial contamination.

The bedrock geology of the western part of the sample area is predominantly limestone and dolomite, while the remaining area is underlain by sandstone, which is most significantly exposed through the overlying drift towards the eastern side of the area. This difference in geology is reflected by the distribution of the major geochemical constituents of these rock types, with high levels of CaO and MgO on the western side of the area and high levels of SiO_2 on the eastern side of the area (particularly in the southeast corner).

Concentrations of most elements measured are in general lower over the eastern part of the sample area, and some elements are particularly low over the southeast corner of the area (As (surface), Cr, Co, Fe_2O_3, MnO, Mo (surface), Ni, TiO_2, U, V). This may be related to the absence of alluvium towards the east of the area and to the sandier nature of the parent materials (mainly sandstone and Quaternary sand and gravel). The elevated concentrations of many elements analysed in the more finely-sieved profile soils (section 4.2) suggest that they have a stronger affinity to finer soil particles (largely clay minerals) than to the coarser sand-sized fractions, which make up a more significant component of the soils in this area (see section 2.4). The southeast corner of the sample area is largely residential, with no obvious signs of industrial activity. This may explain the particularly low levels of some elements, although due to the heterogeneous nature of drift deposits, a geological signature may also significantly influence the soil geochemistry of this region. This is supported by the high levels of SiO_2 reported in this area, which is likely to reflect an especially high sand content in the soils.

There is an apparent geochemical association between Al_2O_3, TiO_2, U and V, with high concentrations to the north of the urban area (between Bentley and the rest of Doncaster district). This may be related to the glaciolacustrine deposits that are found in this area and possibly the alluvium. The overlying soils are likely to be clay-rich (section 2.4) and may therefore accumulate certain elements. Aluminium is a major component of clay minerals. High values are also found for these elements in proximity to the main railway lines.

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

The results for selected elements from surface soils in Doncaster are presented in Figure 6 in the context of six other urban areas from the Humber-Trent region (Lincoln, 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. In 75 % of the surface soil samples, Cd levels are at or above the threshold for soils with a pH of 6, however, only outlying samples have Cd concentrations of 2 mg/kg or more (the threshold for pH 7 soils). The concentrations of As in Doncaster are similar to the levels of As found in the soils of Lincoln, Mansfield, York and the regional Humber-Trent soils, only exceeding the 20 mg/kg SGV in outlying samples.

The distributions of Cu, Pb, Zn and Sn are fairly skewed, with high mean values, compared to the median values. This is the likely to represent the effects of urban contamination, particularly around the city centre and industrial areas. The ranges are elevated with respect to the regional distributions, especially in the upper quartiles; however, they are not high in relation to most of the other Humber-Trent urban areas. The distribution range for Mo is very similar to the regional distribution and is also comparable with most of the other urban centres. The levels of Sb are elevated with respect to the regional data, as well as to Lincoln, Mansfield and Scunthorpe, but the distribution is very similar to that of York, and is lower in the upper quartile in comparison to Hull and Sheffield.

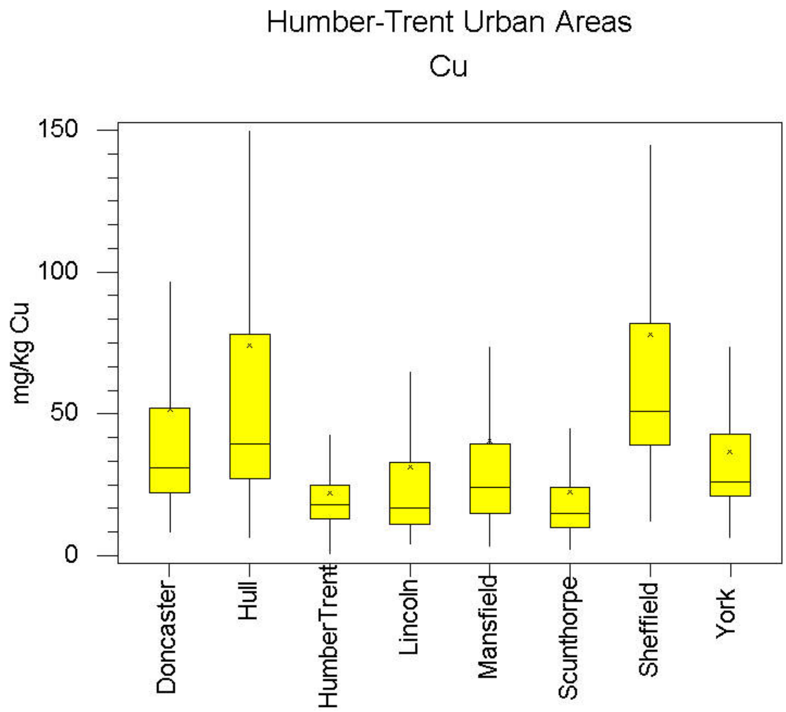

Figure 6: (a) Copper in surface soil

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)

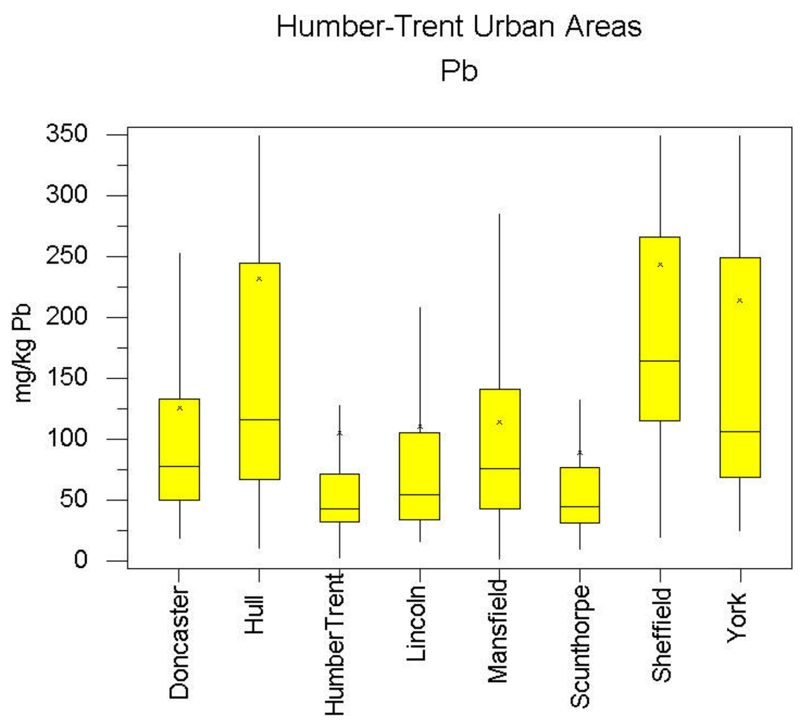

Figure 6: (b) Lead in surface soil

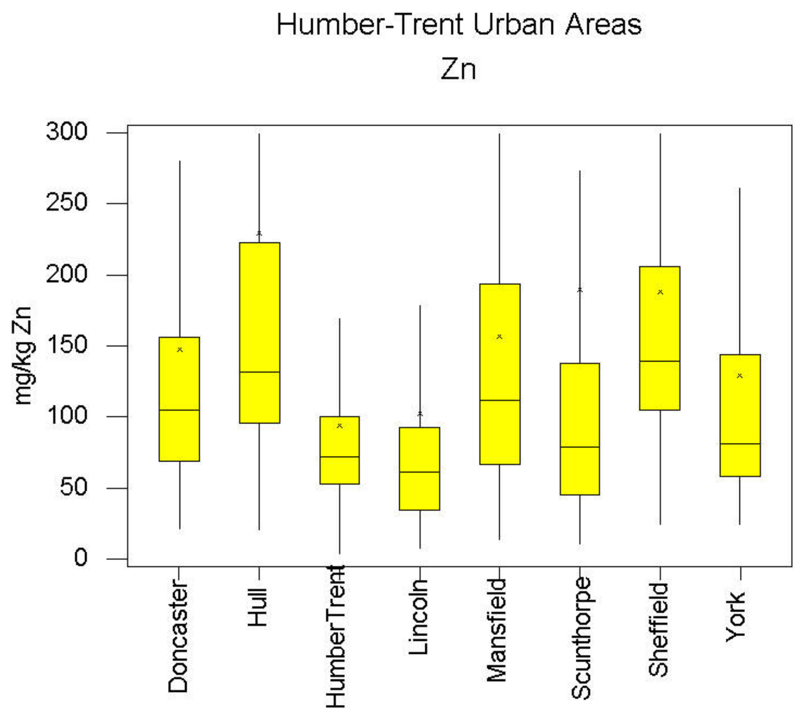

Figure 6: (c) Zinc in surface soil

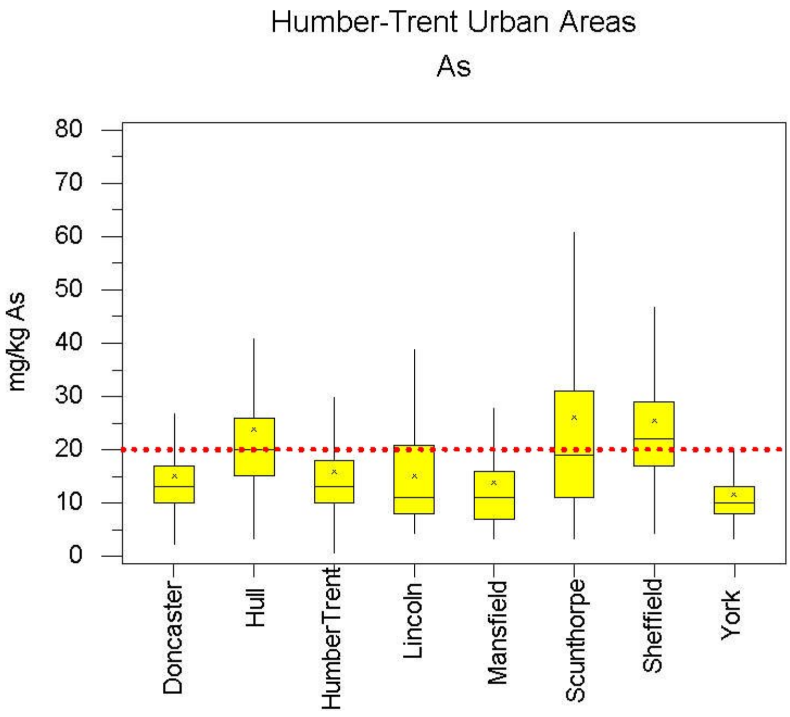

Figure 6: (d) Arsenic in surface soil

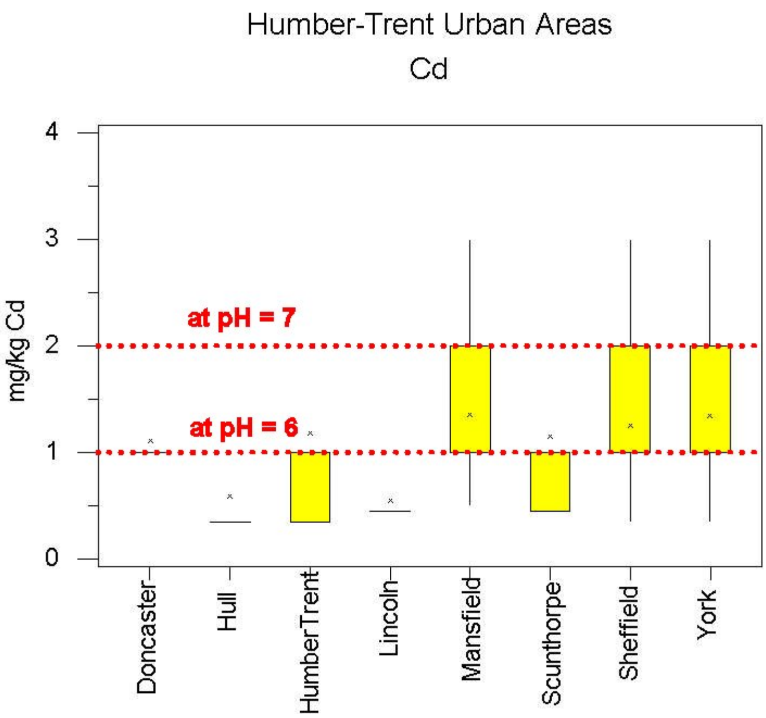

Figure 6: (e) Cadmium in surface soil

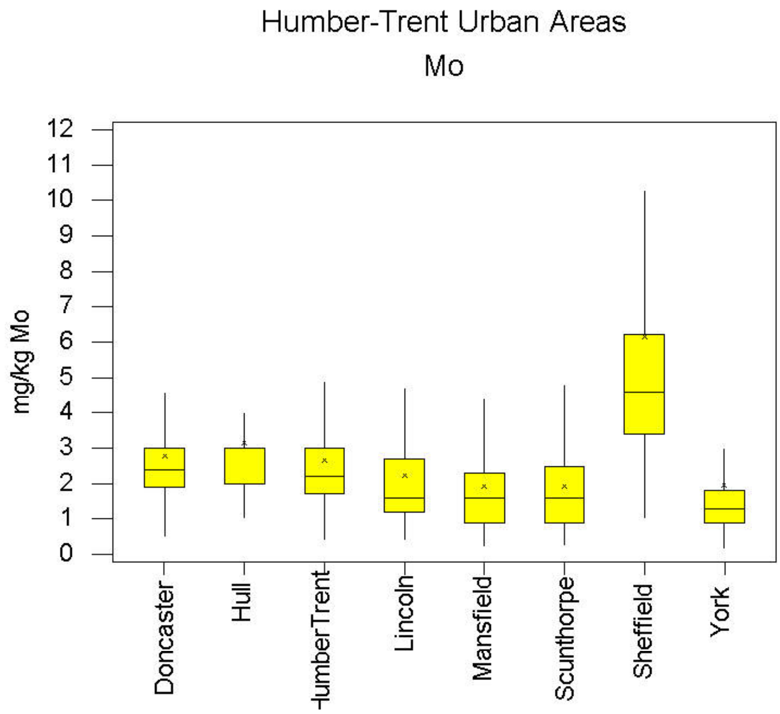

Figure 6: (f) Molybdenum in surface soil

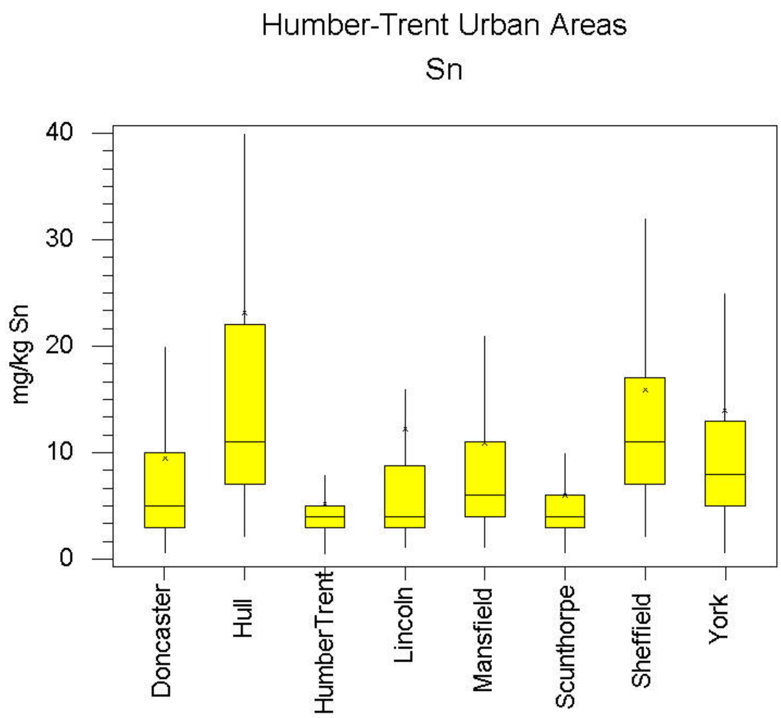

Figure 6: (g) Tin in surface soil

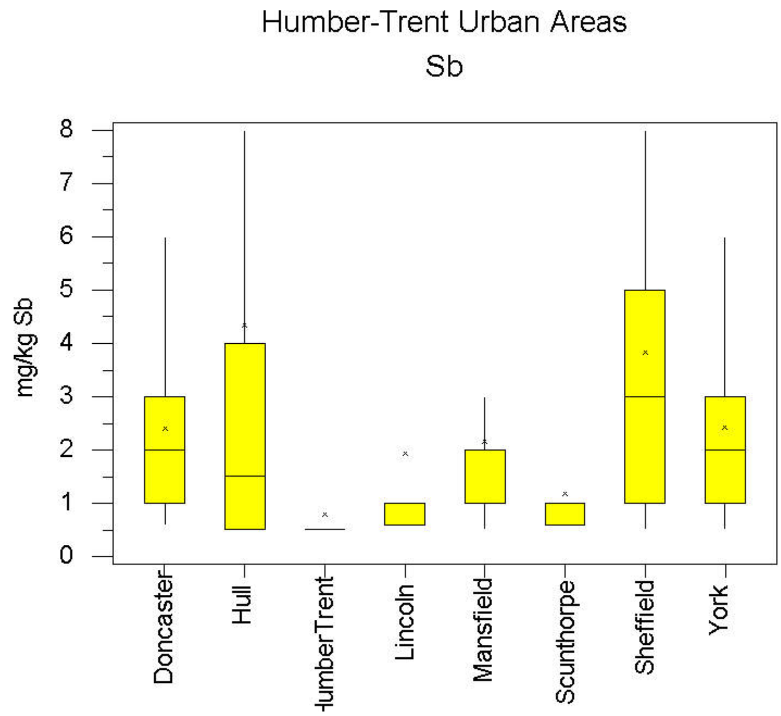

Figure 6: (h) Antimony in surface soil

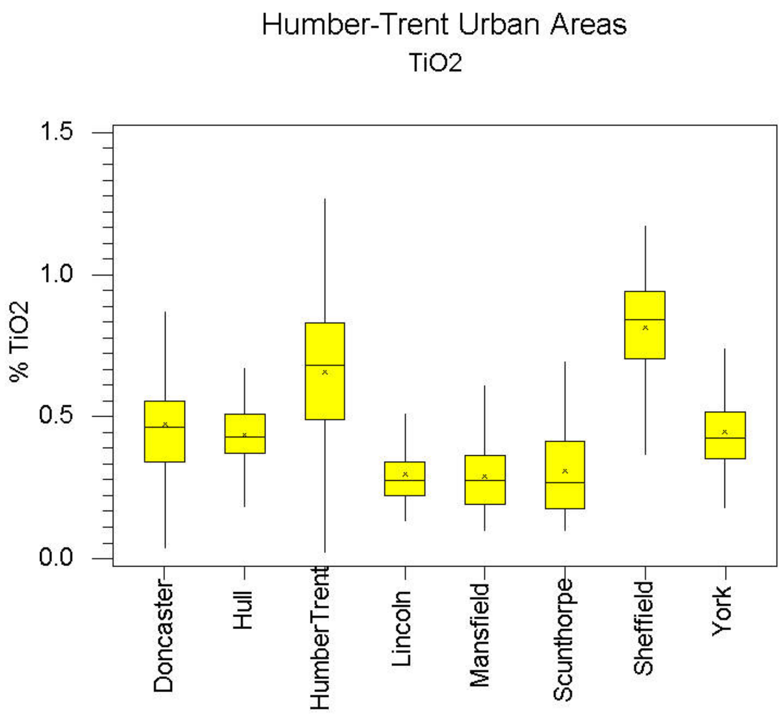

Figure 6: (i) Titanium oxide in surface soil

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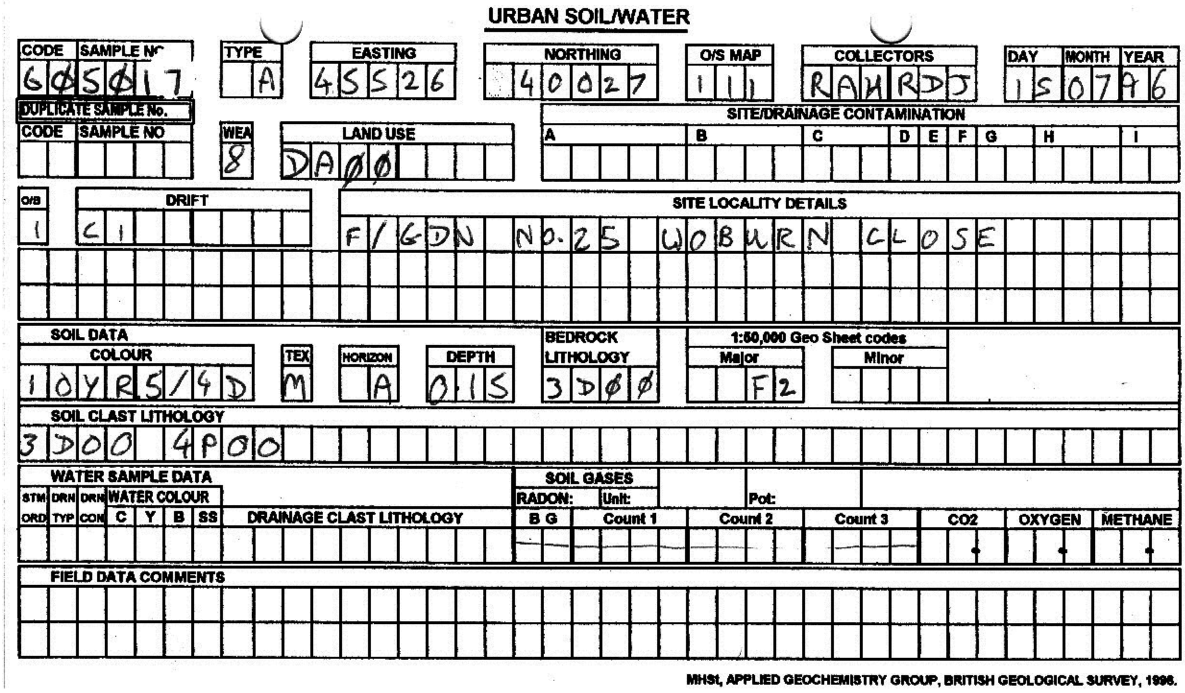
Appendix A: Examples of urban surface and profile soil field cards from Doncaster.



URBAN SOIL/WATER

CODE	SAMPLE No	TYPE	EASTING	NORTHING	O/S MAP	COLLECTORS	DAY	MONTH	YEAR
6Ø	5Ø17	A	45526	40027	111	RAH RDJ	15	07	96

DUPLICATE SAMPLE No. CODE / SAMPLE NO

WEA: 8 | LAND USE: DAØØ | SITE/DRAINAGE CONTAMINATION: A B C D E F G H I

O/B: 1 | DRIFT: C1

SITE LOCALITY DETAILS: F/GDN NO.25 WOBURN CLOSE

SOIL DATA

COLOUR	TEX	HORIZON	DEPTH	BEDROCK LITHOLOGY	1:50,000 Geo Sheet codes Major	Minor
10YR5/4D	M	A	015	3DØØ	F2	

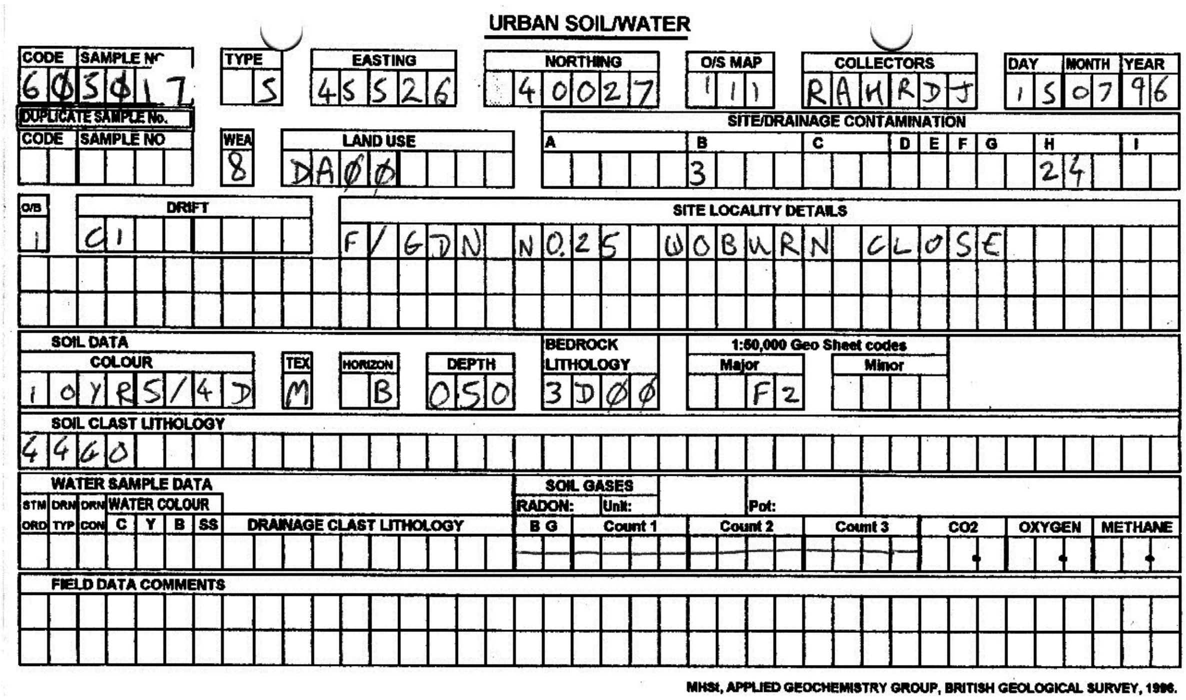
SOIL CLAST LITHOLOGY: 3D00 4P00

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

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



URBAN SOIL/WATER

CODE	SAMPLE No	TYPE	EASTING	NORTHING	O/S MAP	COLLECTORS	DAY	MONTH	YEAR
6Ø	5Ø17	S	45526	40027	111	RAH RDJ	15	07	96

DUPLICATE SAMPLE No. CODE / SAMPLE NO

WEA: 8 | LAND USE: DAØØ | SITE/DRAINAGE CONTAMINATION: A; B: 3; C; D E F G; H: 24; I

O/B: 1 | DRIFT: C1

SITE LOCALITY DETAILS: F/GDN NO25 WOBURN CLOSE

SOIL DATA

COLOUR	TEX	HORIZON	DEPTH	BEDROCK LITHOLOGY	1:50,000 Geo Sheet codes Major	Minor
10YR5/4D	M	B	050	3DØØ	F2	

SOIL CLAST LITHOLOGY: 4460

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

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

Appendix B: Percentile calculations for Doncaster soils (surface)

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%	0.4	45.1	5.6	0.12	1.04	0.17	0.222	0.049	1.89	35	34	7	6	13	39	7	0.9	277	33	0.9	0.45	2	0.6
10%	0.4	49.5	6.1	0.16	1.14	0.24	0.255	0.062	2.38	38	39	8	8	15	44	8	1.2	304	37	1.1	0.45	2	0.6
15%	0.5	50.9	6.4	0.18	1.19	0.29	0.280	0.072	2.92	41	42	10	9	17	50	9	1.5	325	41	1.3	0.45	3	1
25%	0.5	55.2	6.9	0.19	1.31	0.40	0.343	0.083	3.98	50	49	12	12	22	70	10	1.9	349	50	1.4	1	3	1
50%	0.8	60.5	8.4	0.26	1.61	0.73	0.462	0.130	5.48	63	64	18	19	31	105	13	2.4	398	78	1.9	1	5	2
75%	1.3	64.5	10.1	0.34	1.90	1.78	0.555	0.196	7.52	78	78	22	26	52	156	17	3.0	510	133	2.4	1	10	3
90%	2.0	68.9	13.6	0.51	2.16	3.51	0.735	0.237	9.22	106	110	29	39	95	277	23	4.0	682	271	2.9	2	20	4
95%	2.4	70.3	17.1	0.64	2.31	5.05	0.863	0.290	9.95	126	127	37	51	139	388	30	5.0	783	370	3.2	2	29	7
99%	5.4	72.8	20.2	0.91	2.90	8.61	0.985	0.436	12.14	153	341	47	120	332	977	58	14.0	1911	767	4.5	5	71	15
MAX	15.8	74.2	22.2	1.20	3.85	29.07	0.994	1.171	17.38	342	499	66	163	1228	1463	74	21.2	2580	1100	8.3	7	184	33
MIN	0.2	9.2	1.3	0.03	0.38	0.09	0.034	0.034	0.79	20	21	5	5	8	21	2	0.5	56	18	0.5	0.45	0.55	0.6
MEDIAN	0.8	60.5	8.4	0.26	1.61	0.73	0.462	0.130	5.48	63	64	18	19	31	105	13	2.4	398	78	1.9	1	5	2
MEAN	1.1	59.1	9.2	0.30	1.65	1.55	0.473	0.151	5.75	69	73	19	23	52	148	15	2.8	470	126	2.0	1	10	2

* minimum value reported as half detection limit

Appendix B: Percentile calculations for Doncaster soils (profile)

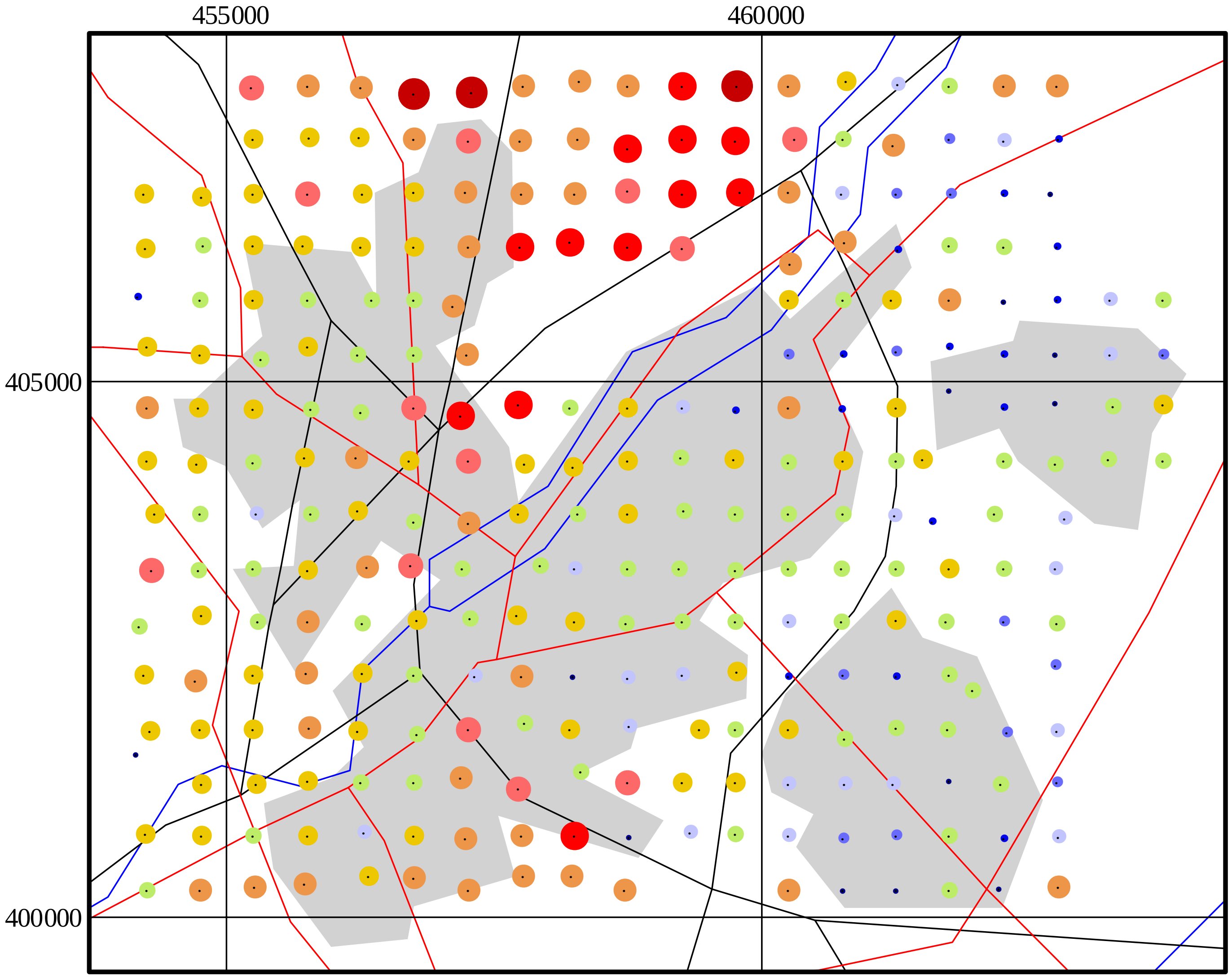
S-Soils:	MnO	Fe_2O_3	V	Cr	Co	Ba	Ni	Cu	Zn	As	Mo	Pb	U	Cd*	Sn*	Sb*
Percentiles	**%**	**%**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
5%	0.043	2.69	46	46	12	290	12	15	57	7	1.2	29	1.2	0.45	2	0.6
10%	0.058	3.31	49	50	13	314	14	18	66	8	1.3	32	1.3	0.45	2	0.6
15%	0.071	3.76	53	56	15	340	15	21	71	9	1.5	36	1.5	0.45	2	0.6
25%	0.087	4.42	59	64	17	368	18	23	80	10	1.6	43	1.7	1	3	0.6
50%	0.159	5.80	72	75	22	423	24	30	103	12	2.0	69	2.1	1	5	1
75%	0.224	7.59	90	90	26	534	33	48	148	16	2.5	118	2.5	2	8	2
90%	0.283	9.67	119	113	34	693	47	92	279	23	3.9	256	2.8	2	16	4
95%	0.324	11.19	137	121	40	866	59	203	440	32	5.1	405	3.0	3	25	7
99%	0.461	13.58	169	279	43	1741	131	576	969	75	15.0	1099	4.1	4	66	21
MAX	0.595	22.25	360	402	66	2212	202	2412	1778	105	23.4	3000	7.0	12	586	109
MIN	0.012	1.11	26	16	8	82	8	8	26	5	0.8	20	0.3	0.45	0.55	0.6
MEDIAN	0.159	5.80	72	75	22	423	24	30	103	12	2.0	69	2.1	1	5	1
MEAN	0.168	6.29	79	83	23	494	29	64	160	15	2.7	133	2.1	1	11	3

* minimum value reported as half detection limit

Appendix C: Graduated symbol geochemical maps for Doncaster 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 (surface soils only)
Uranium
Vanadium
Zinc

Doncaster
Surface Soils
Aluminium

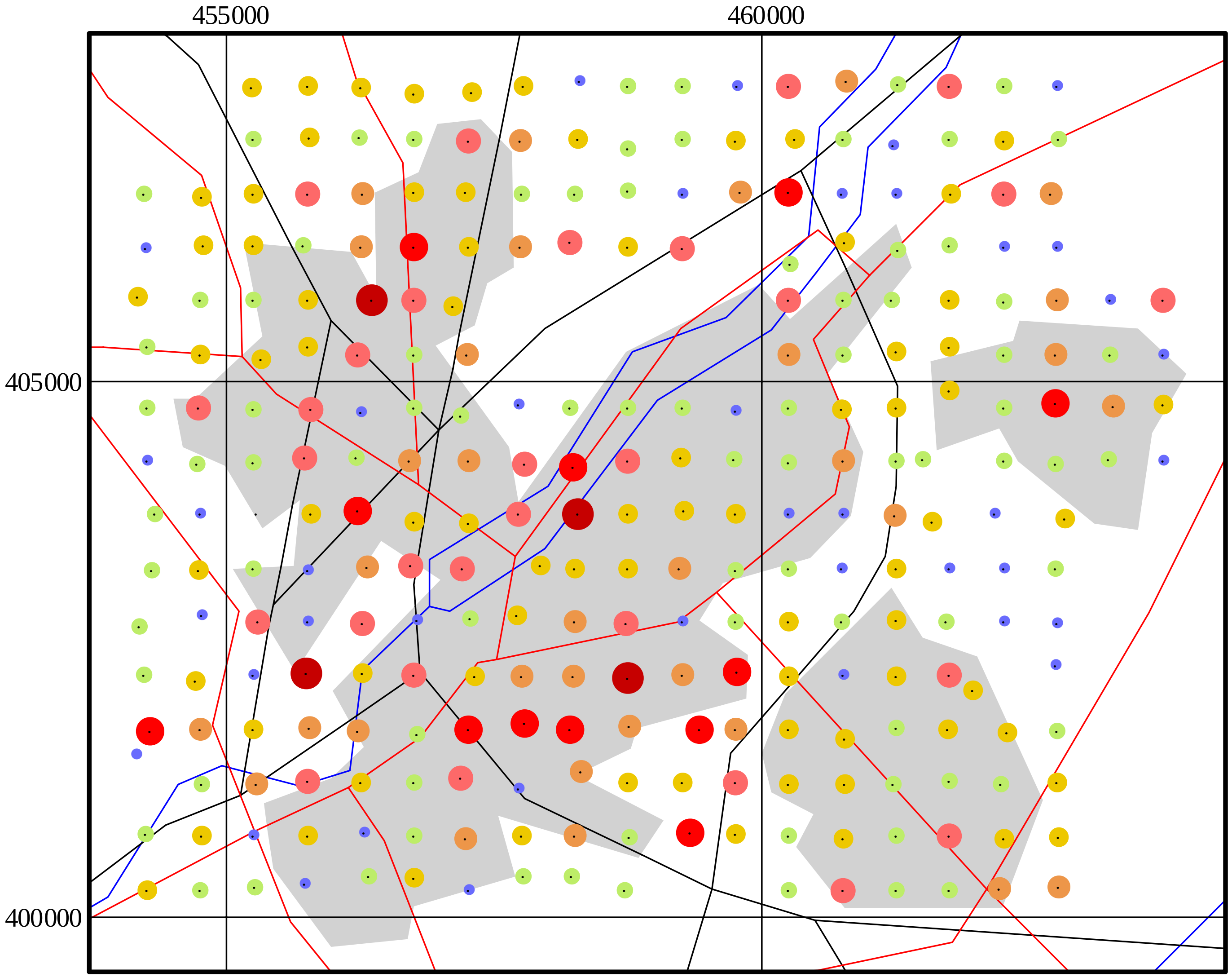


%ile	WT%
99	20.2
95	17.1
90	13.6
75	10.1
50	8.4
25	6.9
15	6.4
10	6.1
5	5.6

Roads
Railways
Drainage
Urban area

surface soil	Al_2O_3 (%)
number	279
minimum	1.3
maximum	22.2
median	8.4
mean	9.2

Aluminium was not determined in the profile soils



Doncaster
Surface Soils
Antimony

%ile	mg/kg
99	15
95	7
90	4
75	3
50	2
25	1
10	0.6

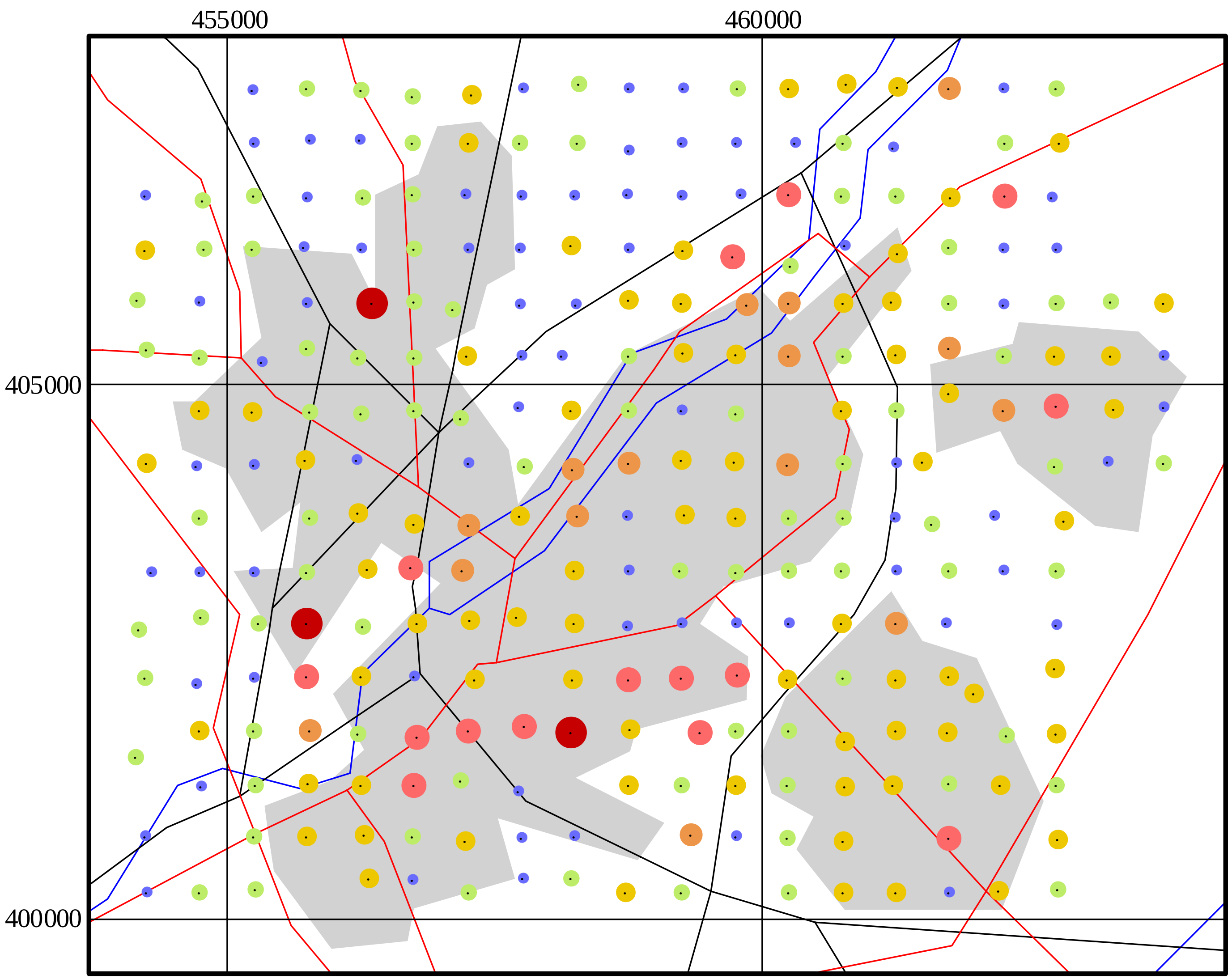
- Roads
- Railways
- Drainage
- Urban area

surface soil	Sb (mg/kg)
number	278
minimum	0.6*
maximum	33
median	2
mean	2

*minimum value reported as half detection limit

Doncaster

Profile Soils Antimony

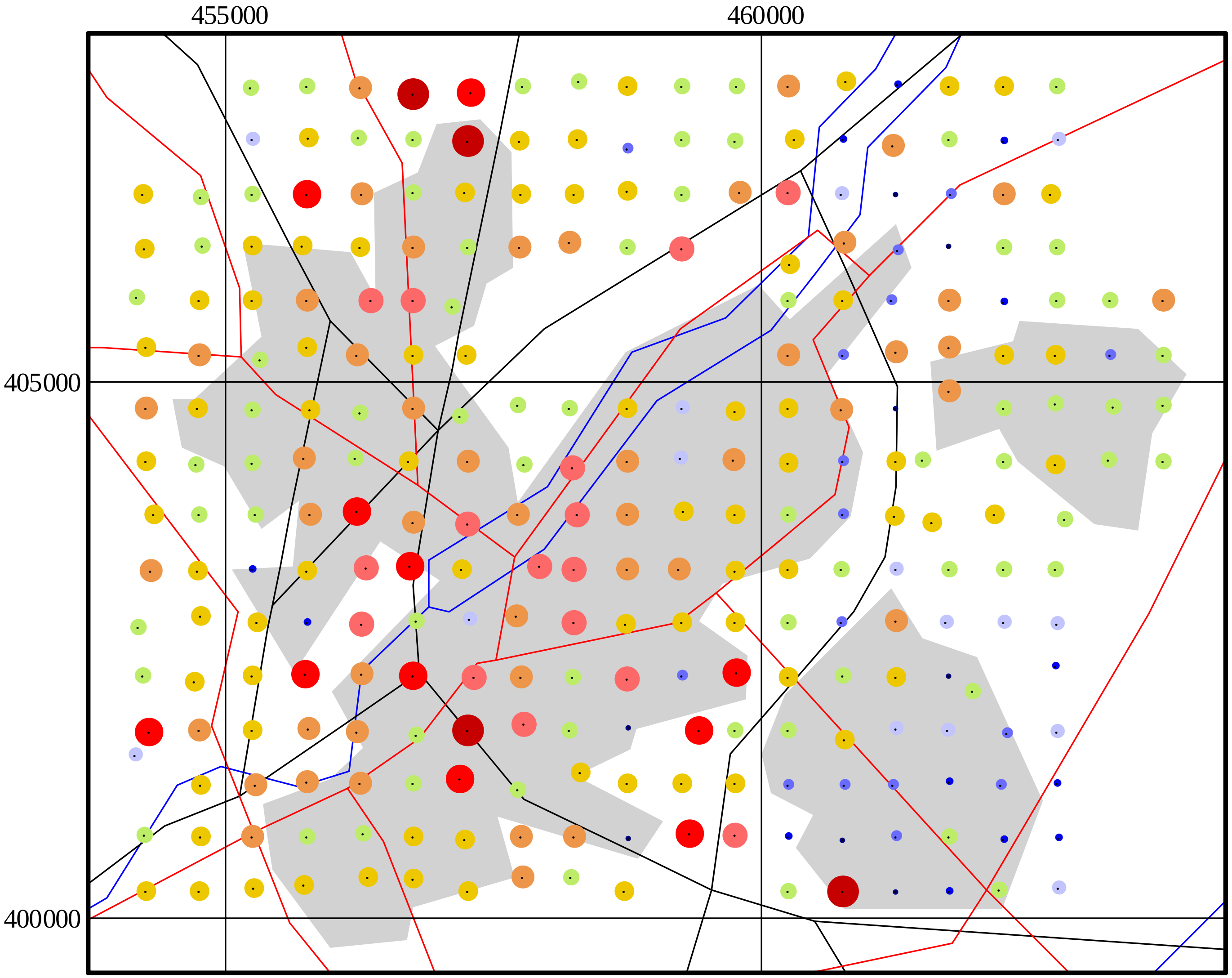


%ile	mg/kg
99	21
95	7
90	4
75	2
50	1
25	0.6

Roads
Railways
Drainage
Urban area

profile soil	Sb (mg/kg)
number	273
minimum	0.6*
maximum	109
median	1
mean	3

*minimum value reported as half detection limit

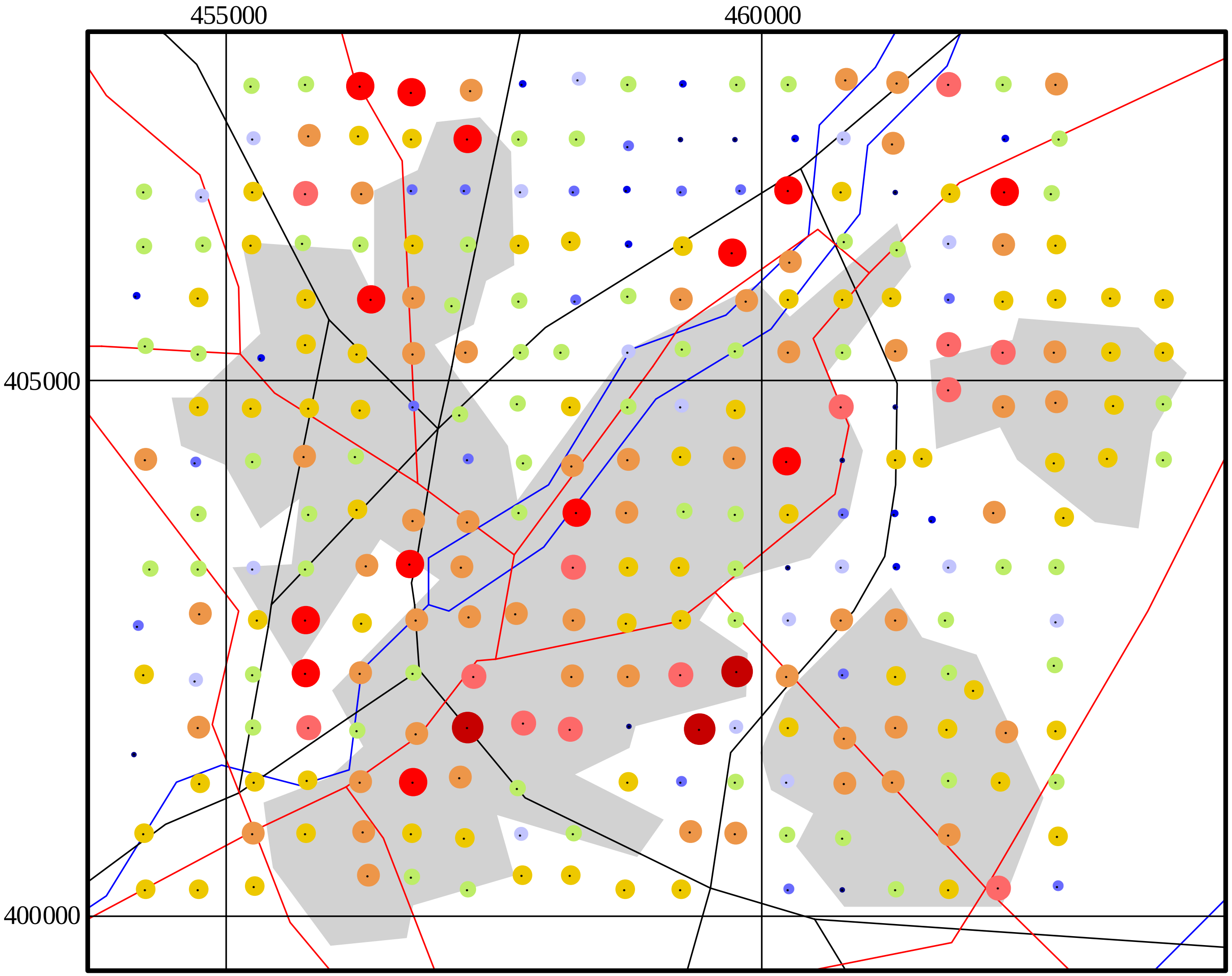


Doncaster
Surface Soils
Arsenic

%ile	mg/kg
99	58
95	30
90	23
75	17
50	13
25	10
15	9
10	8
5	7

Roads
Railways
Drainage
Urban area

surface soil	As (mg/kg)
number	279
minimum	2
maximum	74
median	13
mean	15



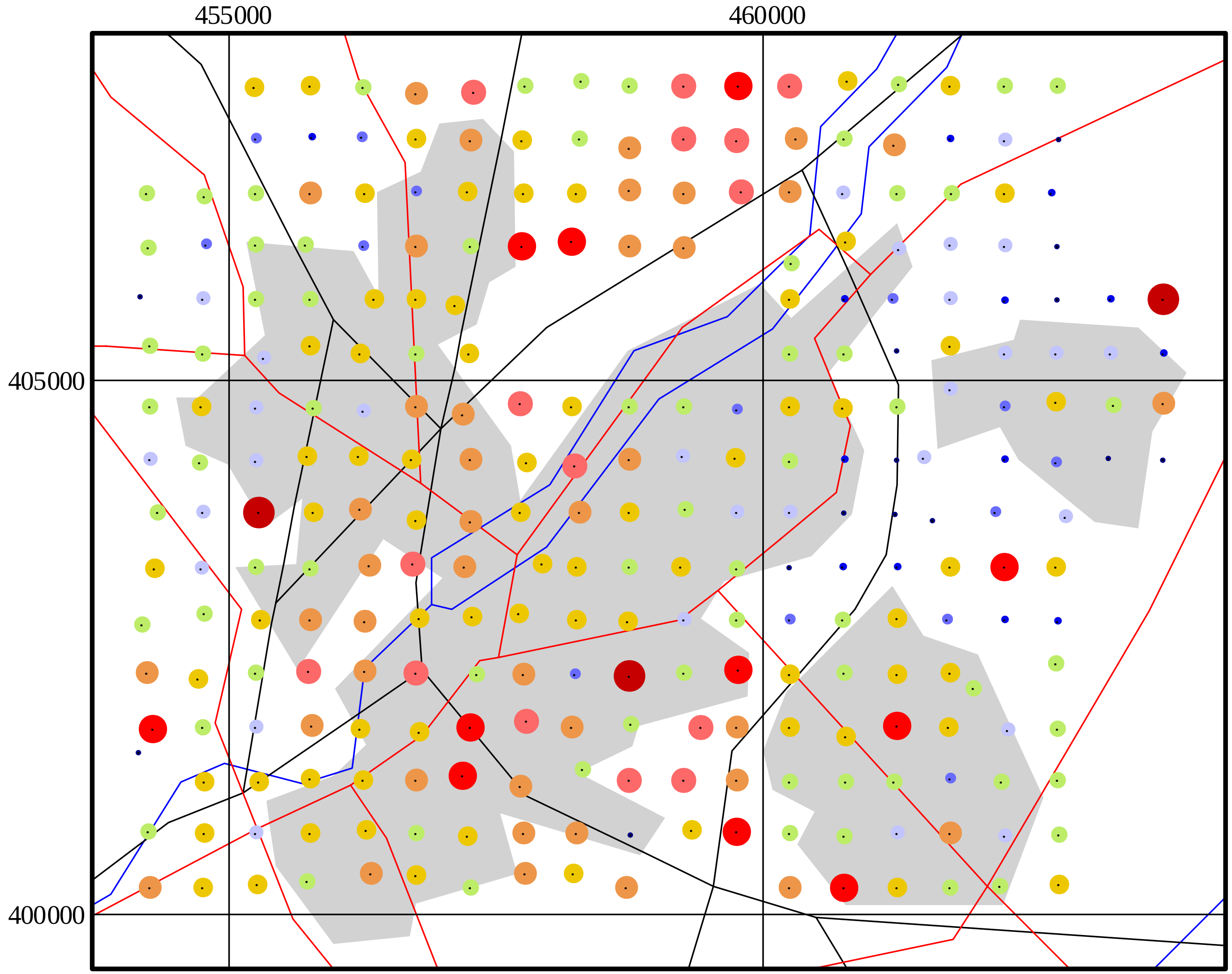
Doncaster
Profile Soils
Arsenic

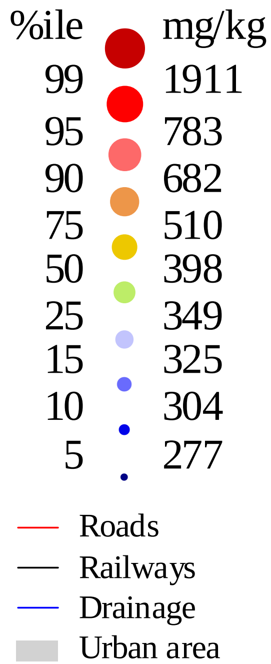
%ile	mg/kg
99	75
95	32
90	23
75	16
50	12
25	10
15	9
10	8
5	7

Roads
Railways
Drainage
Urban area

profile soil	As (mg/kg)
number	273
minimum	5
maximum	105
median	12
mean	15

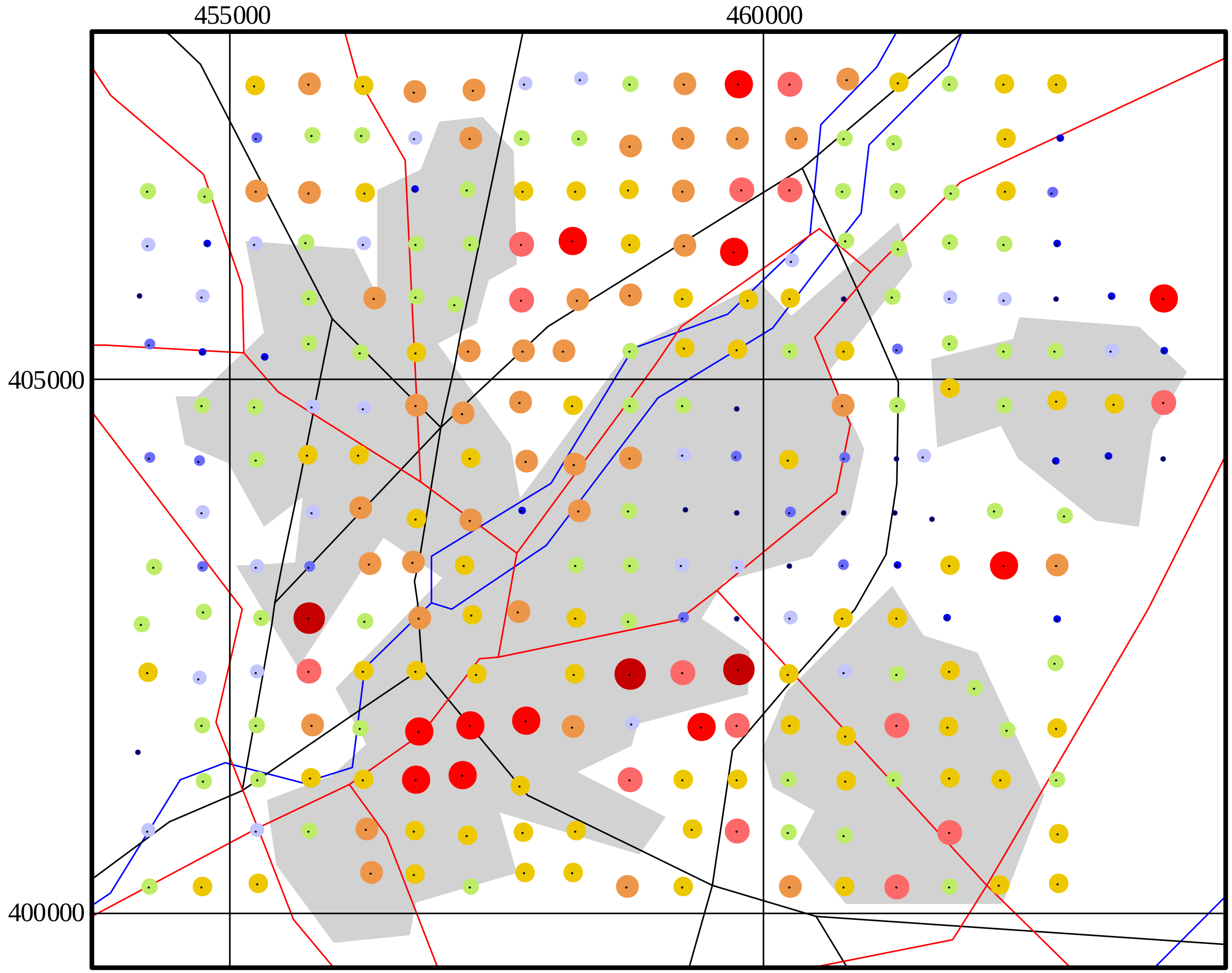
Doncaster
Surface Soils
Barium

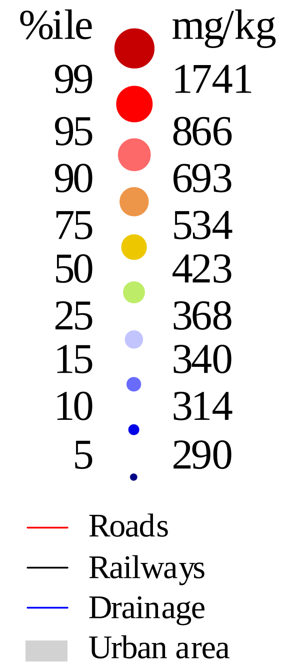




surface soil	Ba (mg/kg)
number	279
minimum	56
maximum	2580
median	398
mean	470

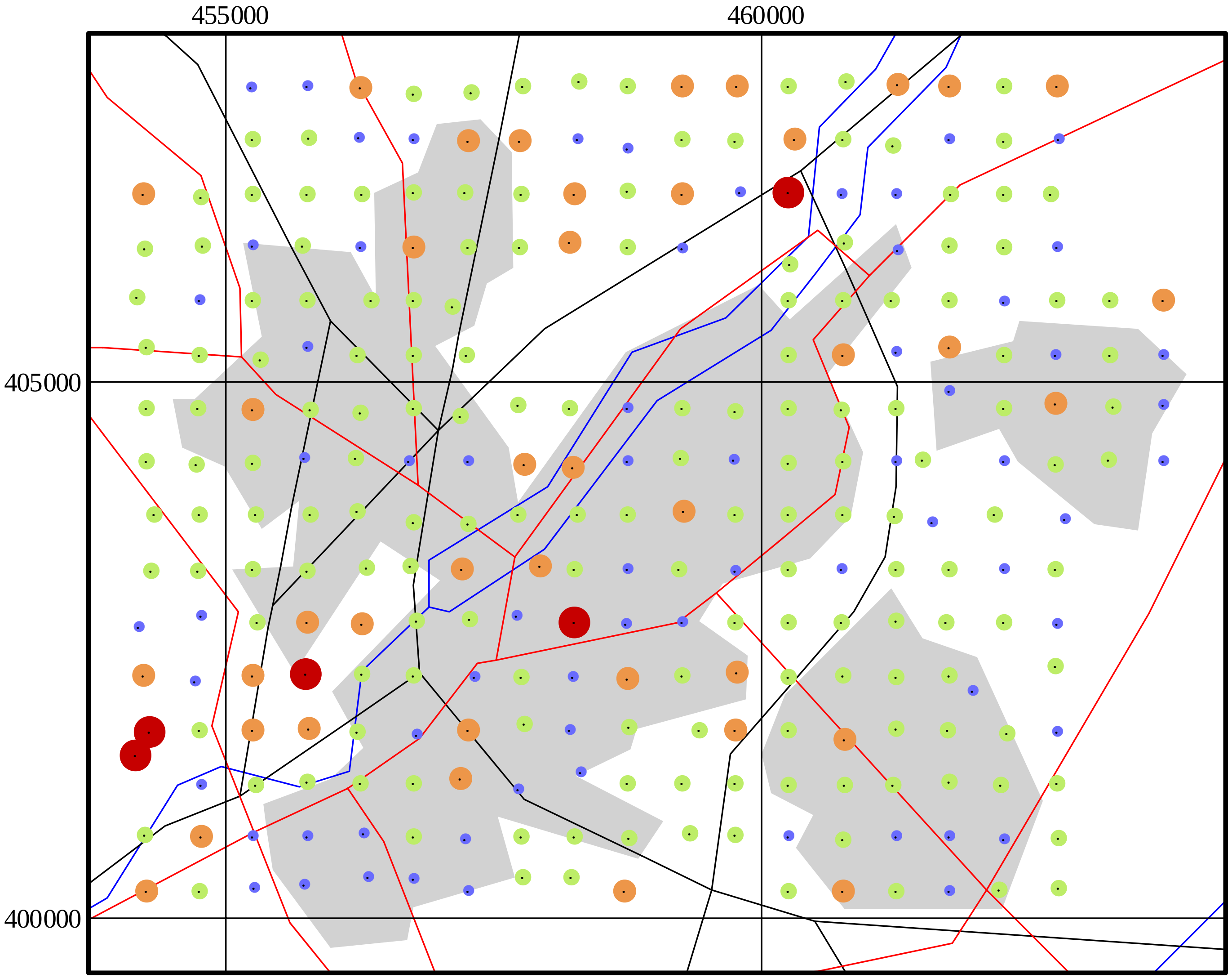
Doncaster
Profile Soils
Barium





profile soil	Ba (mg/kg)
number	273
minimum	82
maximum	2212
median	423
mean	494

Doncaster
Surface Soils
Cadmium



%ile	mg/kg
99	5
95	2
75	1
15	0.45

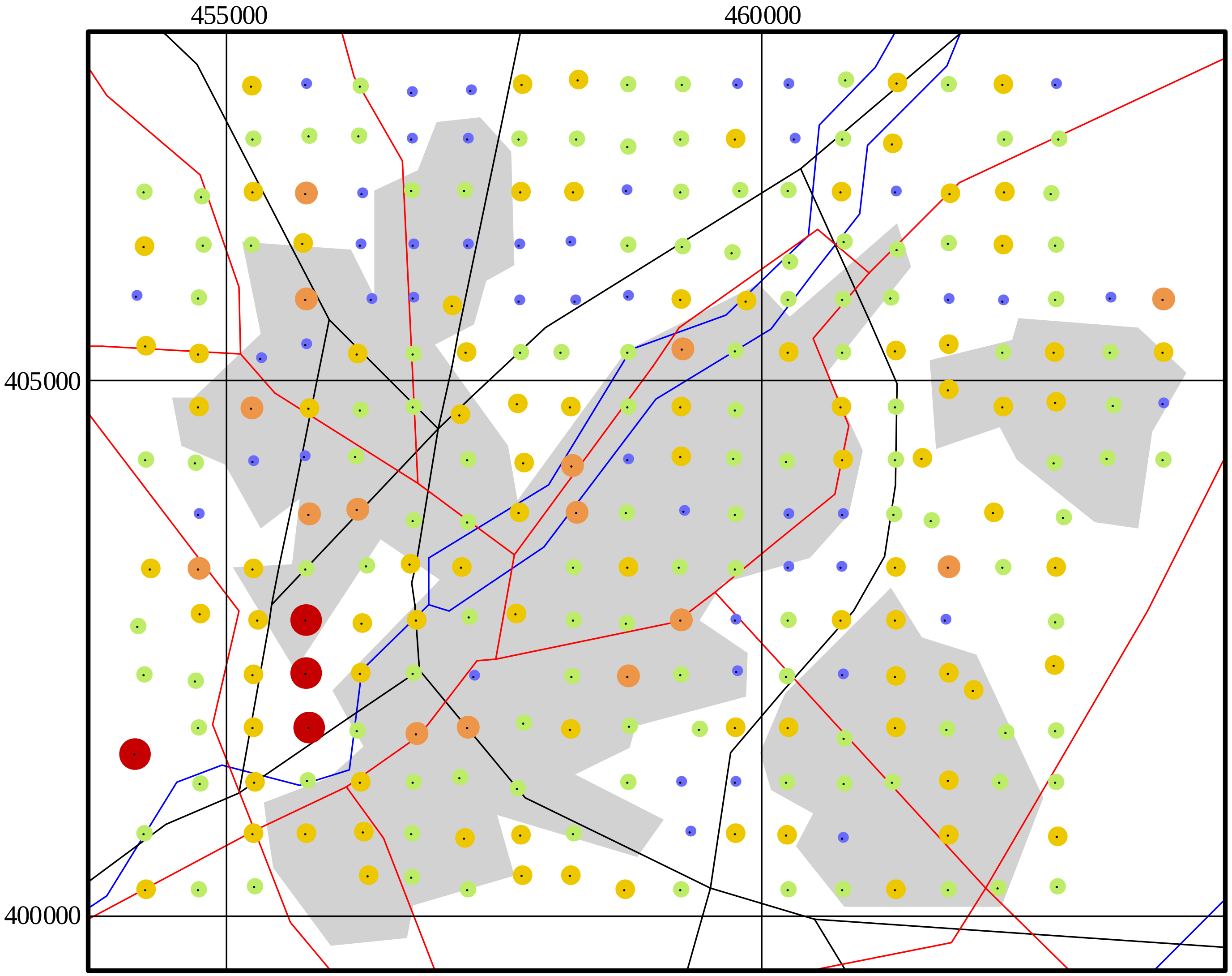
Roads
Railways
Drainage
Urban area

surface soil	Cd (mg/kg)
number	279
minimum	0.45*
maximum	7
median	1
mean	1

*minimum value reported as half detection limit

Doncaster

Profile Soils
Cadmium



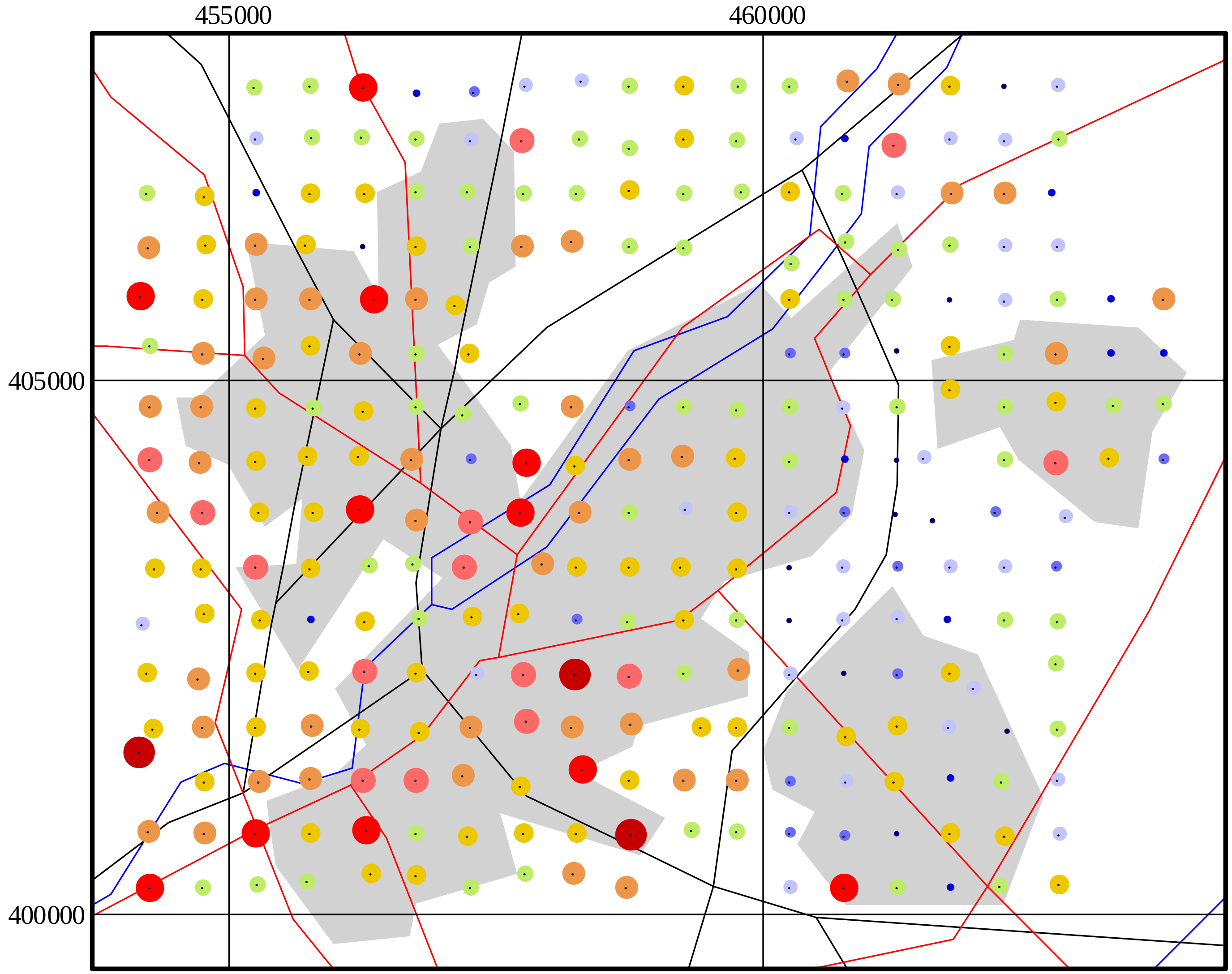
%ile	mg/kg
99	4
95	3
90	2
75	1
50	0.45

Roads
Railways
Drainage
Urban area

profile soil	Cd (mg/kg)
number	273
minimum	0.45*
maximum	12
median	1
mean	1

*minimum value reported as half detection limit

Doncaster
Surface Soils
Calcium

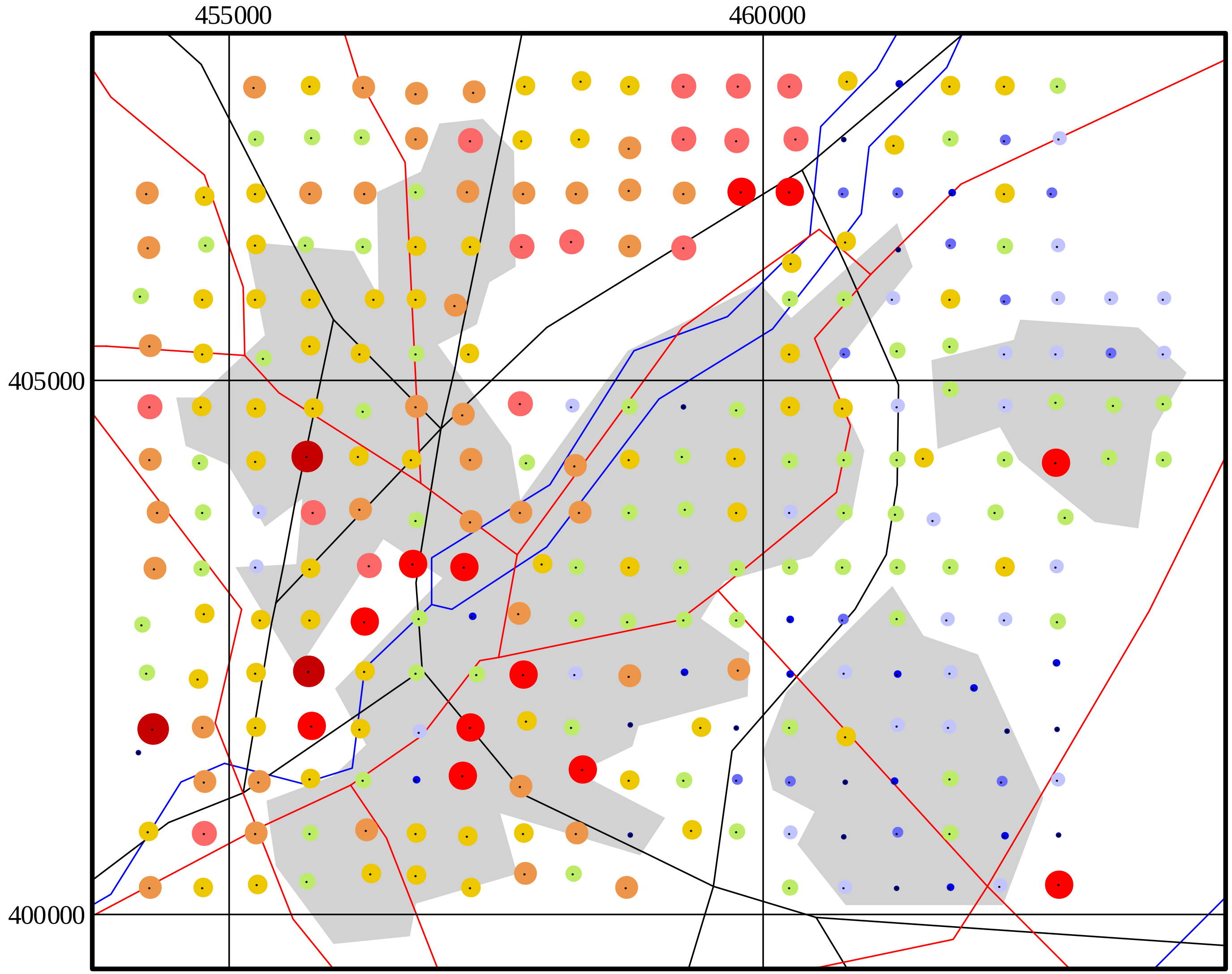


%ile	WT%
	8.61
99	5.05
95	3.51
90	1.78
75	0.73
50	0.40
25	0.29
15	0.24
10	0.17
5	

Roads
Railways
Drainage
Urban area

surface soil	CaO (%)
number	279
minimum	0.09
maximum	29.07
median	0.73
mean	1.55

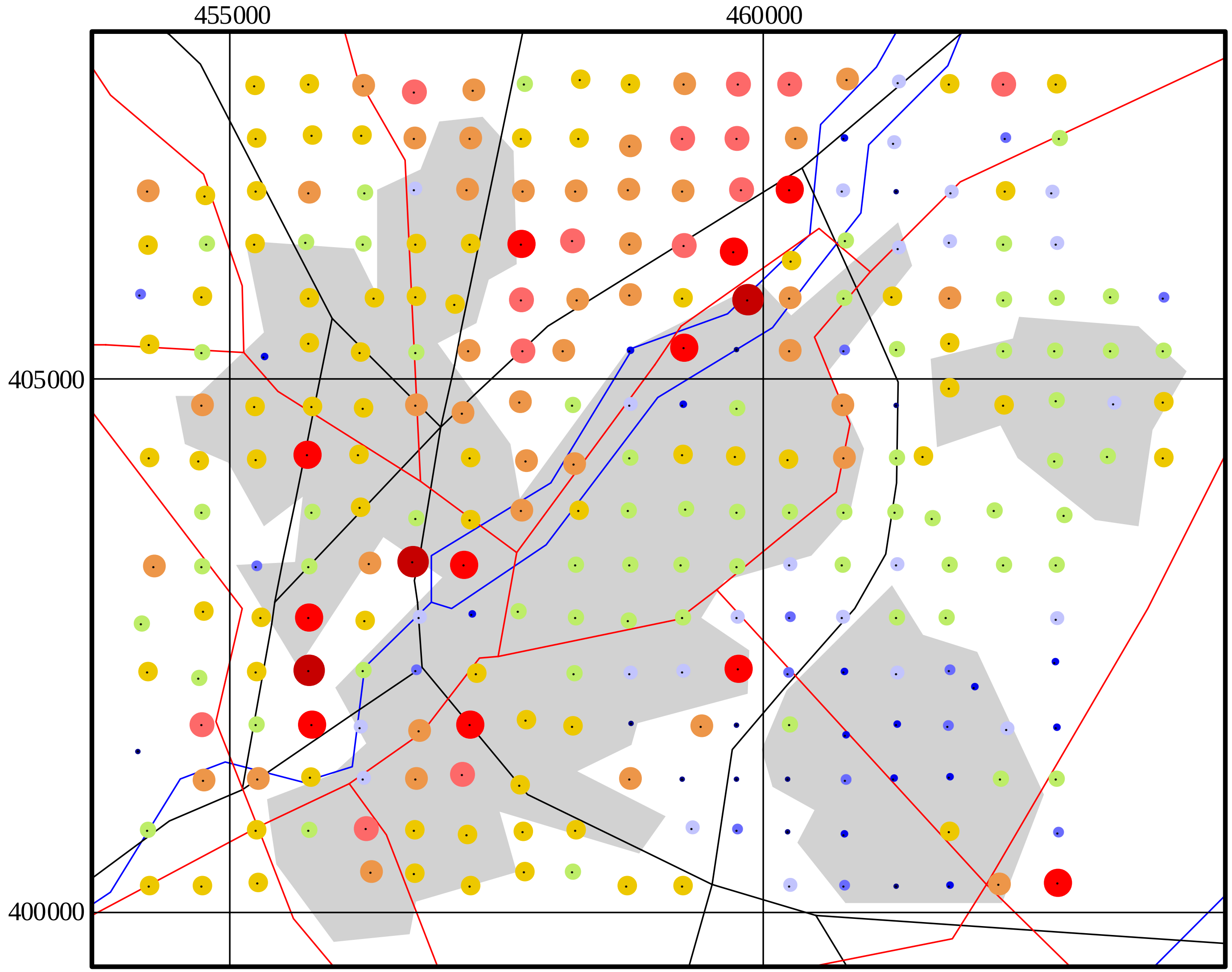
Calcium was not determined in the profile soils



Doncaster
Surface Soils
Chromium

%ile	mg/kg
	341
99	127
95	110
90	78
75	64
50	49
25	42
15	39
10	34
5	

surface soil	Cr (mg/kg)
number	279
minimum	21
maximum	499
median	64
mean	73



Doncaster

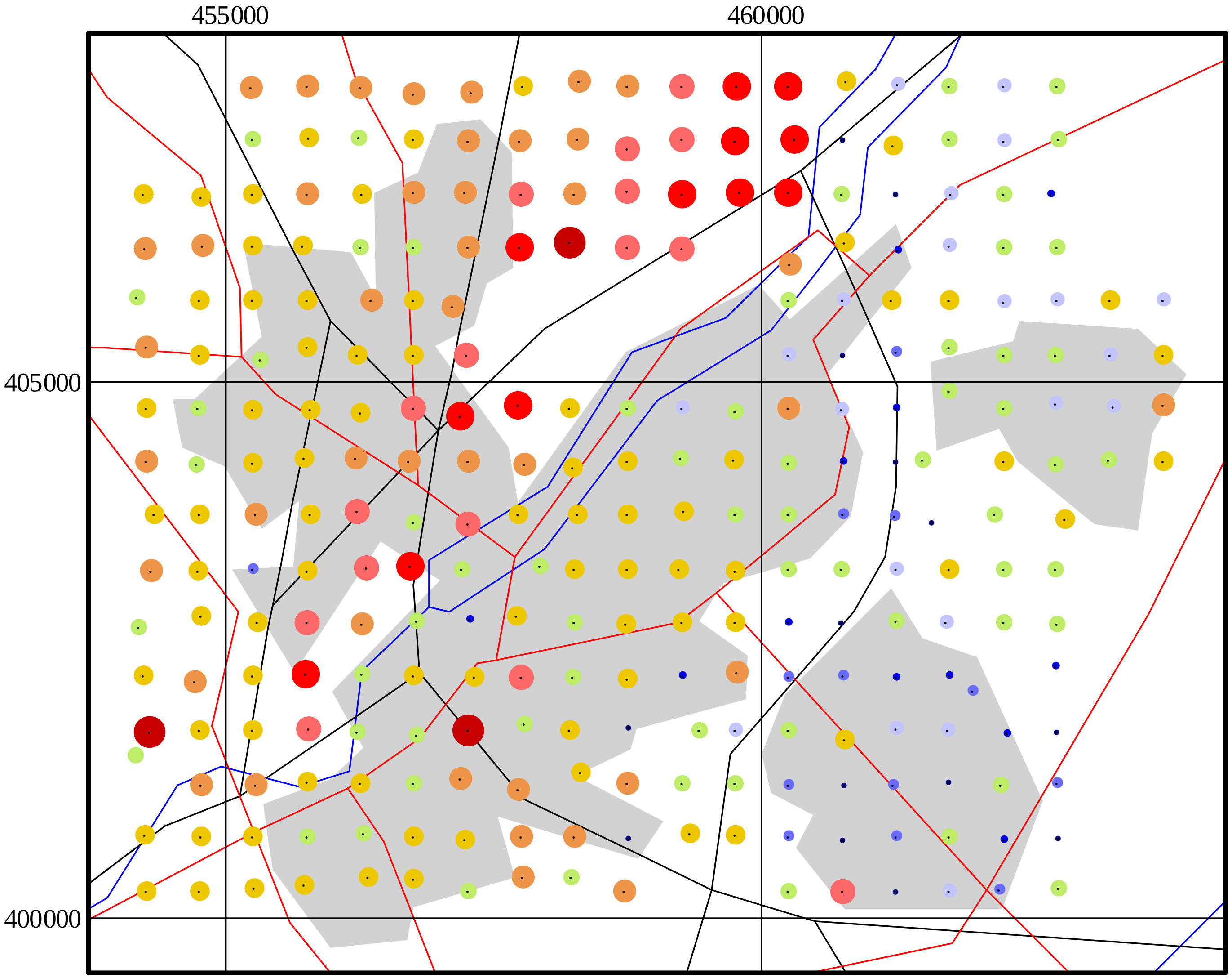
Profile Soils

Chromium

%ile	mg/kg
99	279
95	121
90	113
75	90
50	75
25	64
15	56
10	50
5	46

Roads
Railways
Drainage
Urban area

profile soil	Cr (mg/kg)
number	273
minimum	16
maximum	402
median	75
mean	83



Doncaster
Surface Soils
Cobalt

%ile	mg/kg
99	47
95	37
90	29
75	22
50	18
25	12
15	10
10	8
5	7

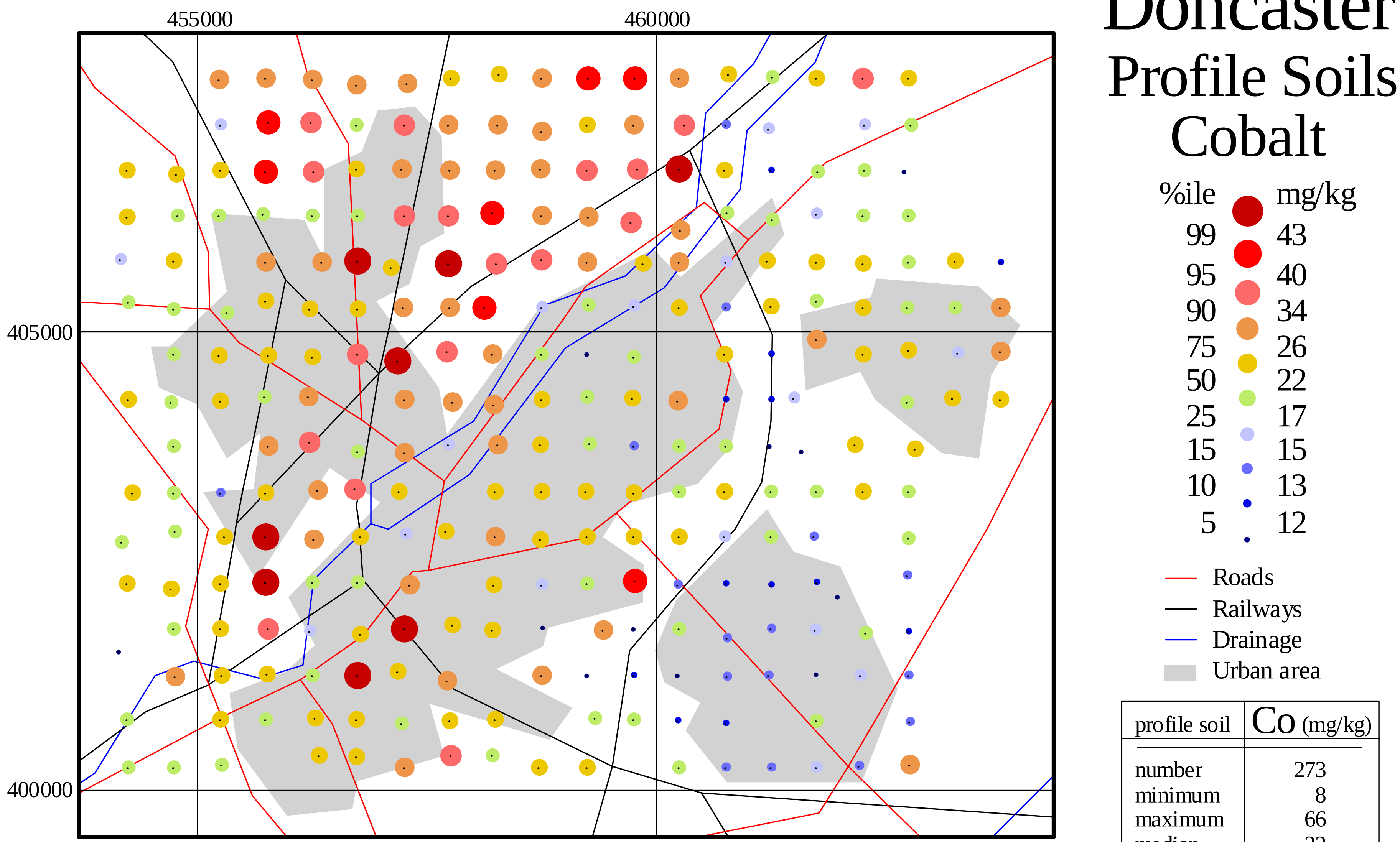
Roads
Railways
Drainage
Urban area

surface soil	Co (mg/kg)
number	279
minimum	5
maximum	66
median	18
mean	19

Doncaster

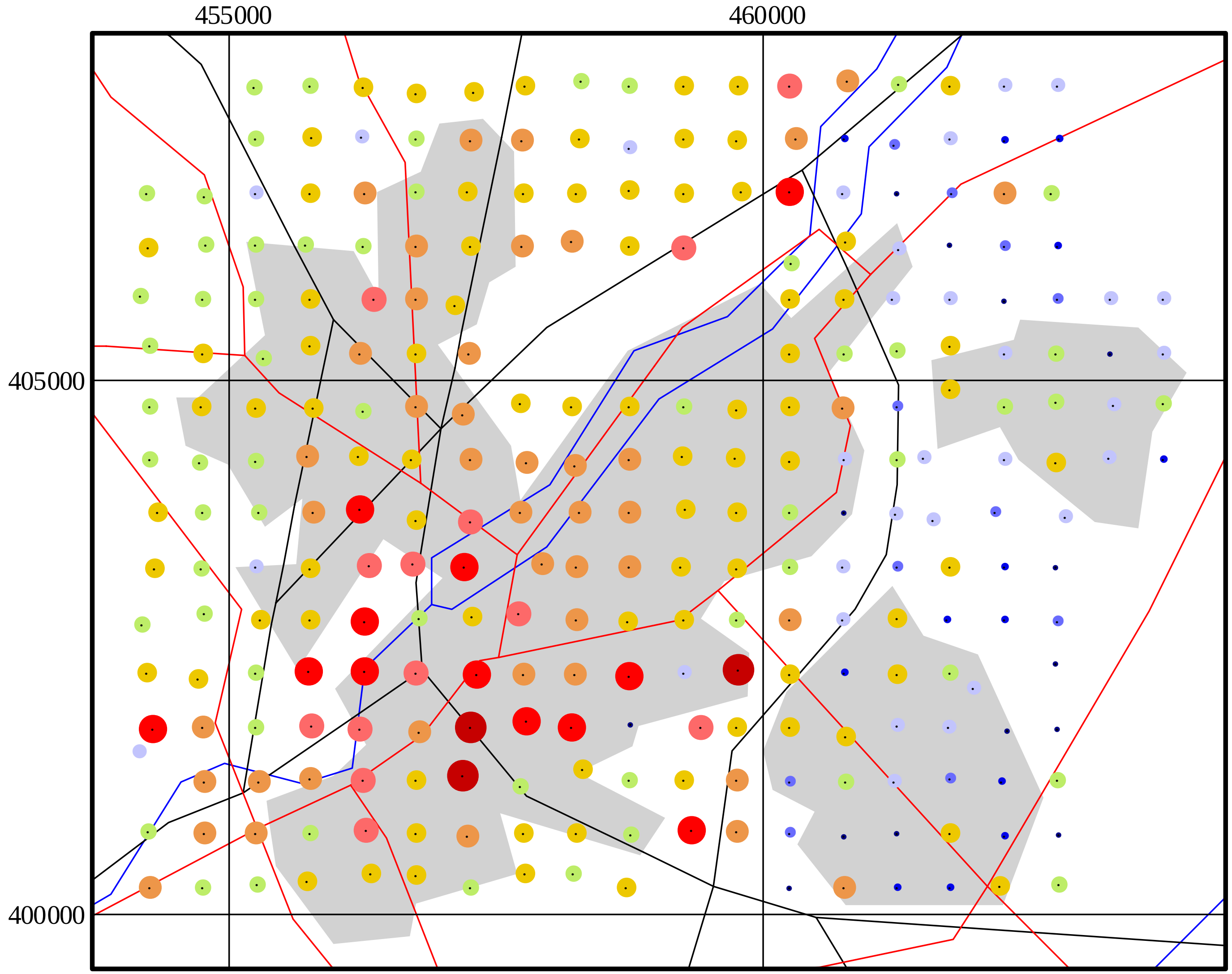
Profile Soils

Cobalt



profile soil	Co (mg/kg)
number	273
minimum	8
maximum	66
median	22
mean	23

Doncaster
Surface Soils
Copper



%ile	mg/kg
99	332
95	139
90	95
75	52
50	31
25	22
15	17
10	15
5	13

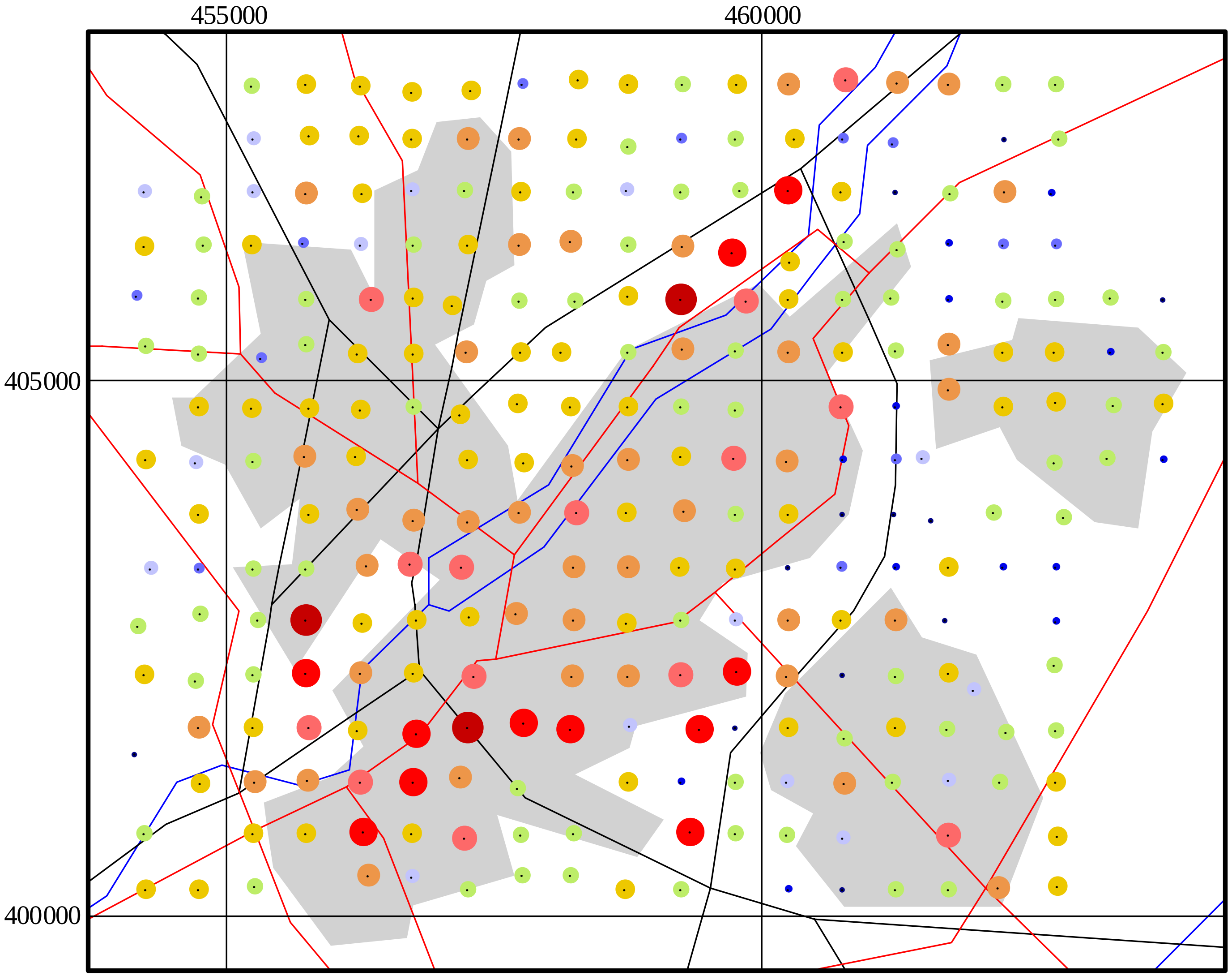
Roads
Railways
Drainage
Urban area

surface soil	Cu (mg/kg)
number	279
minimum	8
maximum	1228
median	31
mean	52

Doncaster

Profile Soils

Copper

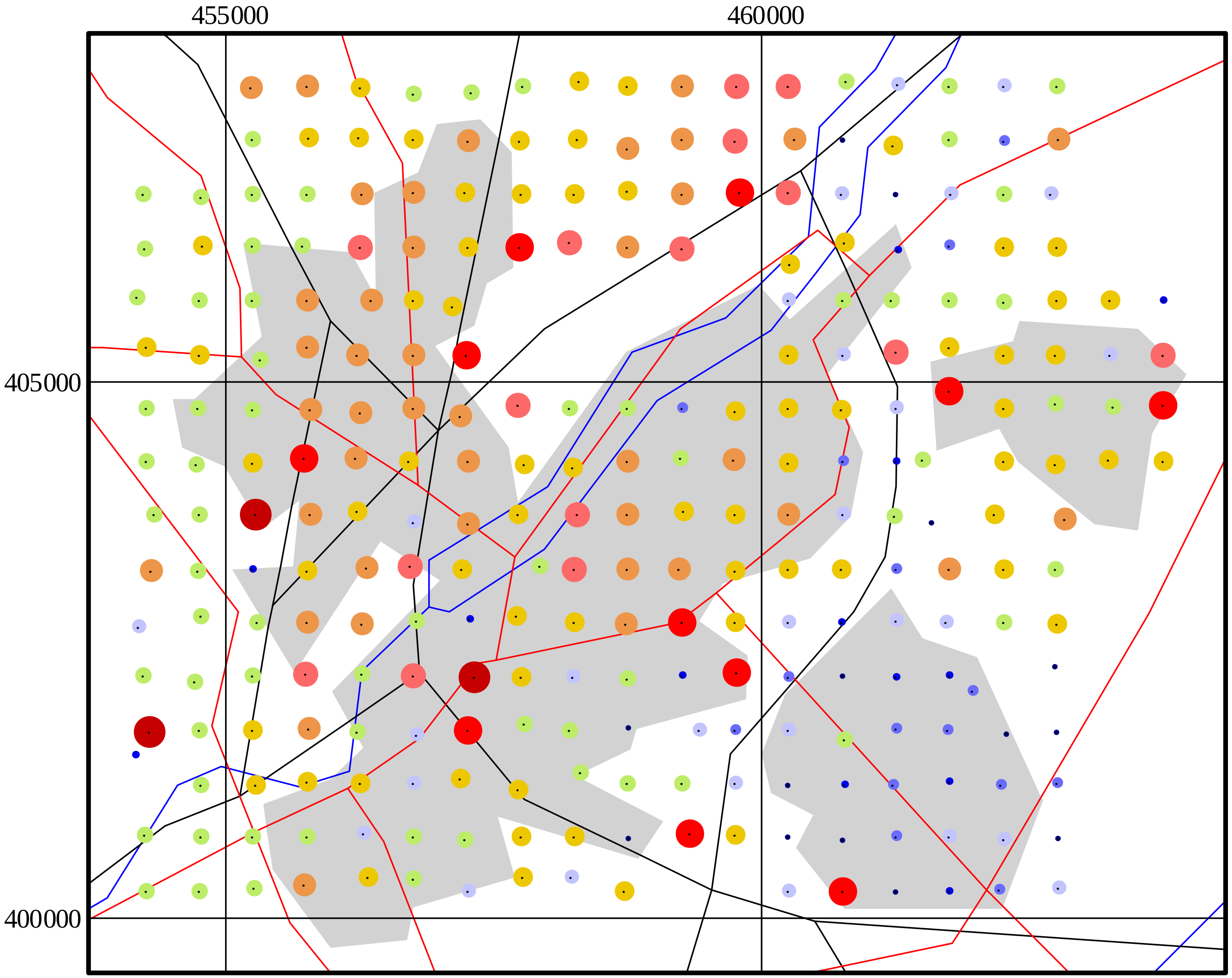


%ile	mg/kg
99	576
95	203
90	92
75	48
50	30
25	23
15	21
10	18
5	15

Roads
Railways
Drainage
Urban area

profile soil	Cu (mg/kg)
number	273
minimum	8
maximum	2412
median	30
mean	64

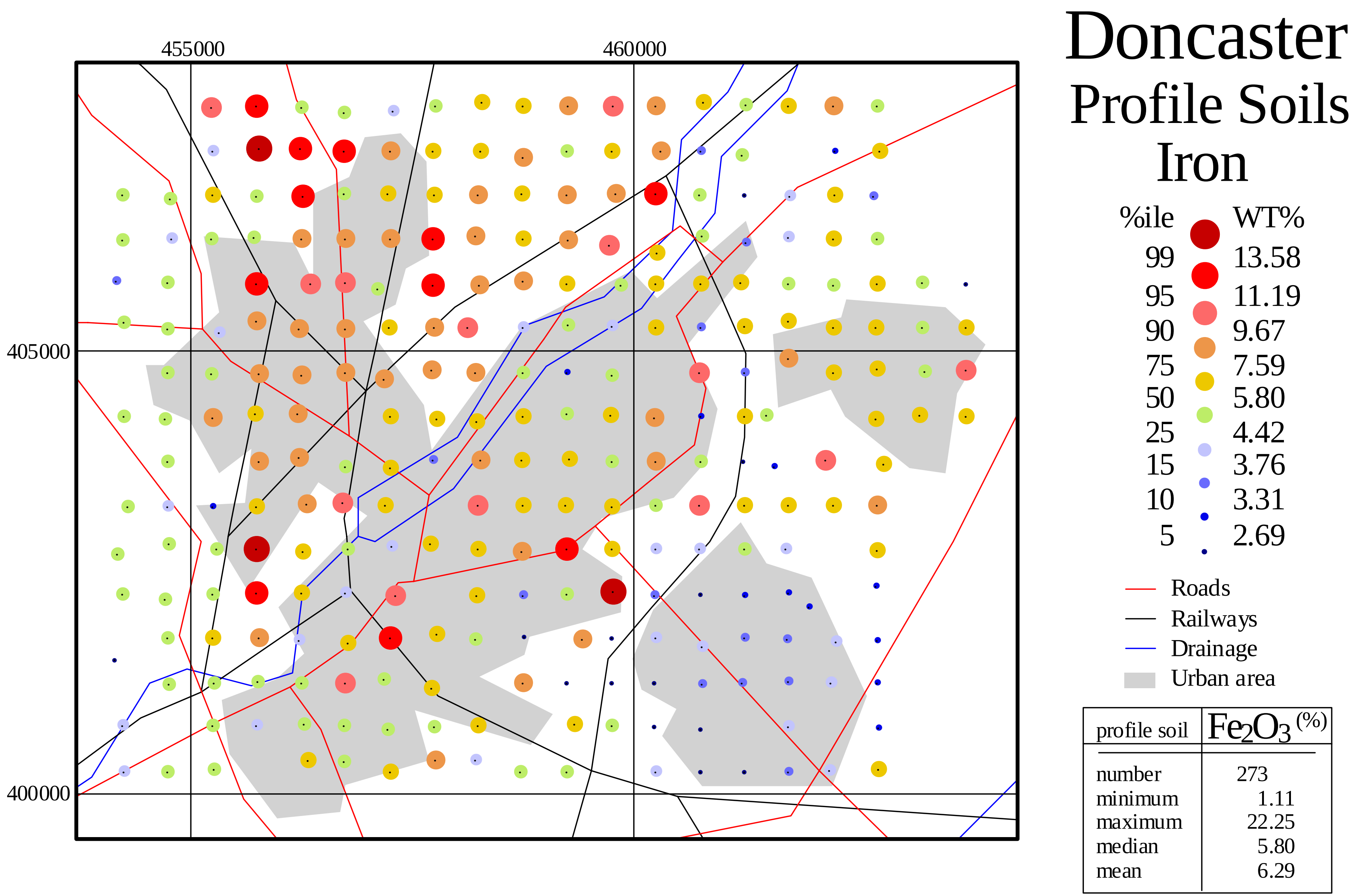
Doncaster
Surface Soils
Iron



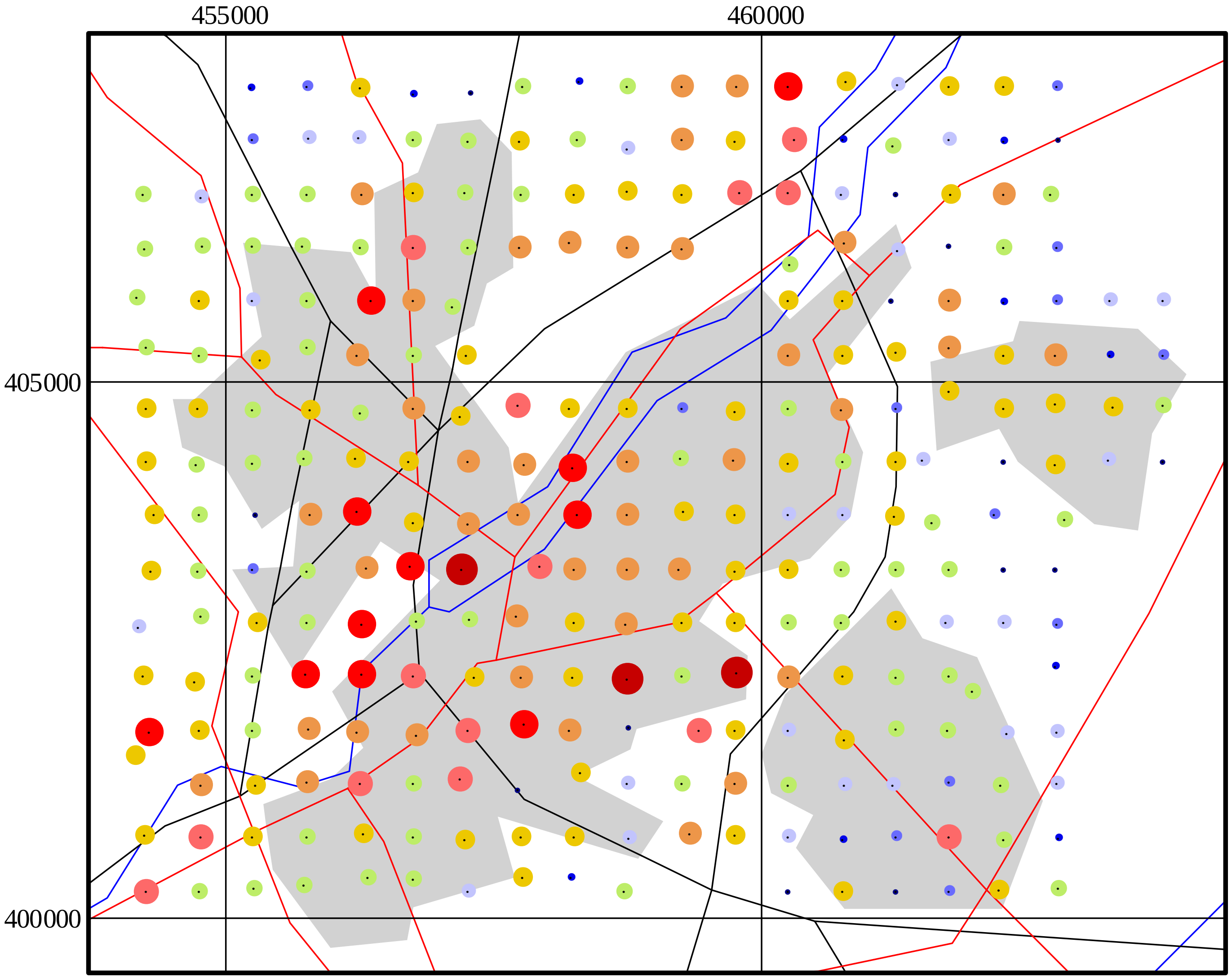
%ile	WT%
99	12.14
95	9.95
90	9.22
75	7.52
50	5.48
25	3.98
15	2.92
10	2.38
5	1.89

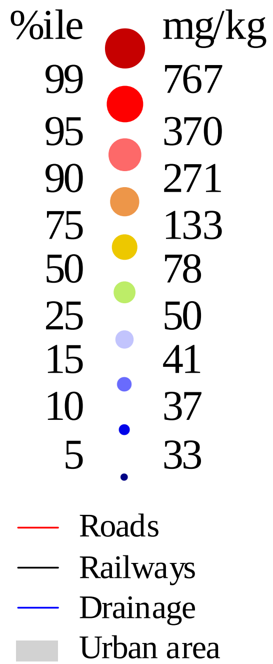
Roads
Railways
Drainage
Urban area

surface soil	Fe_2O_3(%)
number	279
minimum	0.79
maximum	17.38
median	5.48
mean	5.75


Doncaster
Profile Soils
Iron
455000
460000
405000
400000
%ile
WT%
99 13.58
95 11.19
90 9.67
75 7.59
50 5.80
25 4.42
15 3.76
10 3.31
5 2.69
Roads
Railways
Drainage
Urban area
profile soil
Fe2O3 (%)
number 273
minimum 1.11
maximum 22.25
median 5.80
mean 6.29

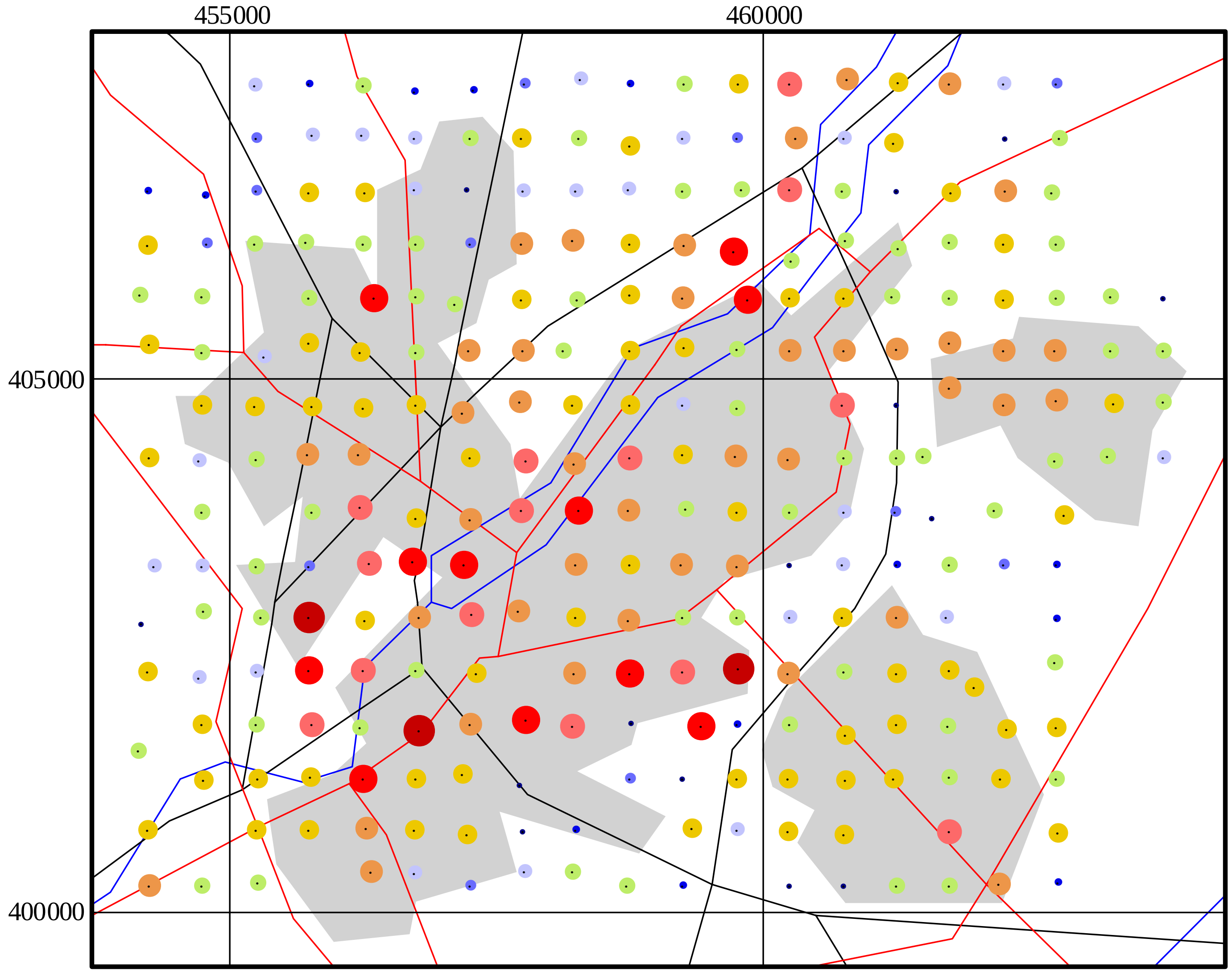
Doncaster
Surface Soils
Lead





surface soil	Pb (mg/kg)
number	279
minimum	18
maximum	1100
median	78
mean	126

Doncaster
Profile Soils
Lead

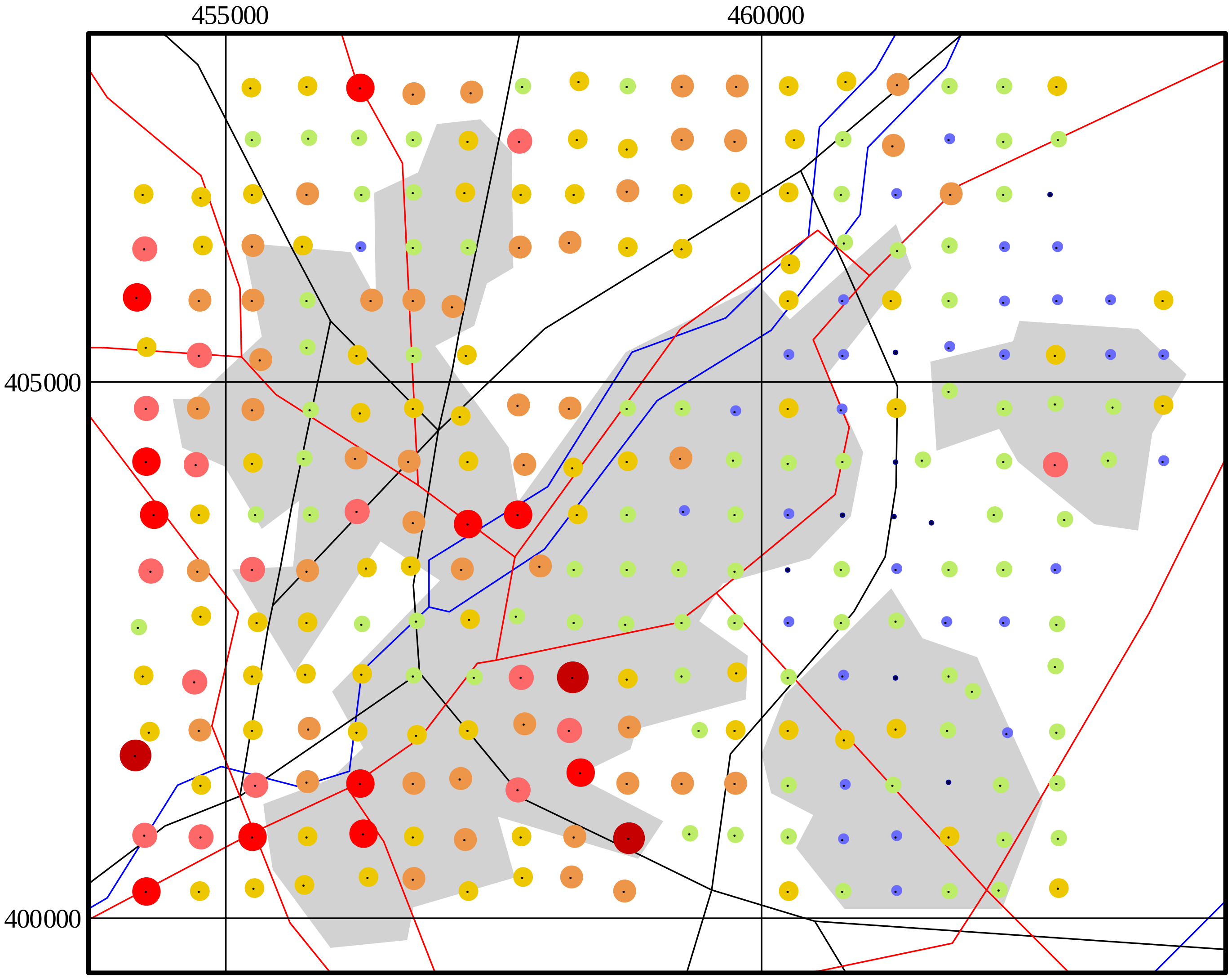


%ile	mg/kg
99	1099
95	405
90	256
75	118
50	69
25	43
15	36
10	32
5	29

Roads
Railways
Drainage
Urban area

profile soil	Pb (mg/kg)
number	273
minimum	20
maximum	3000
median	69
mean	133

Doncaster
Surface Soils
Magnesium



%ile	WT%
99	5.4
95	2.4
90	2.0
75	1.3
50	0.8
25	0.5
10	0.4

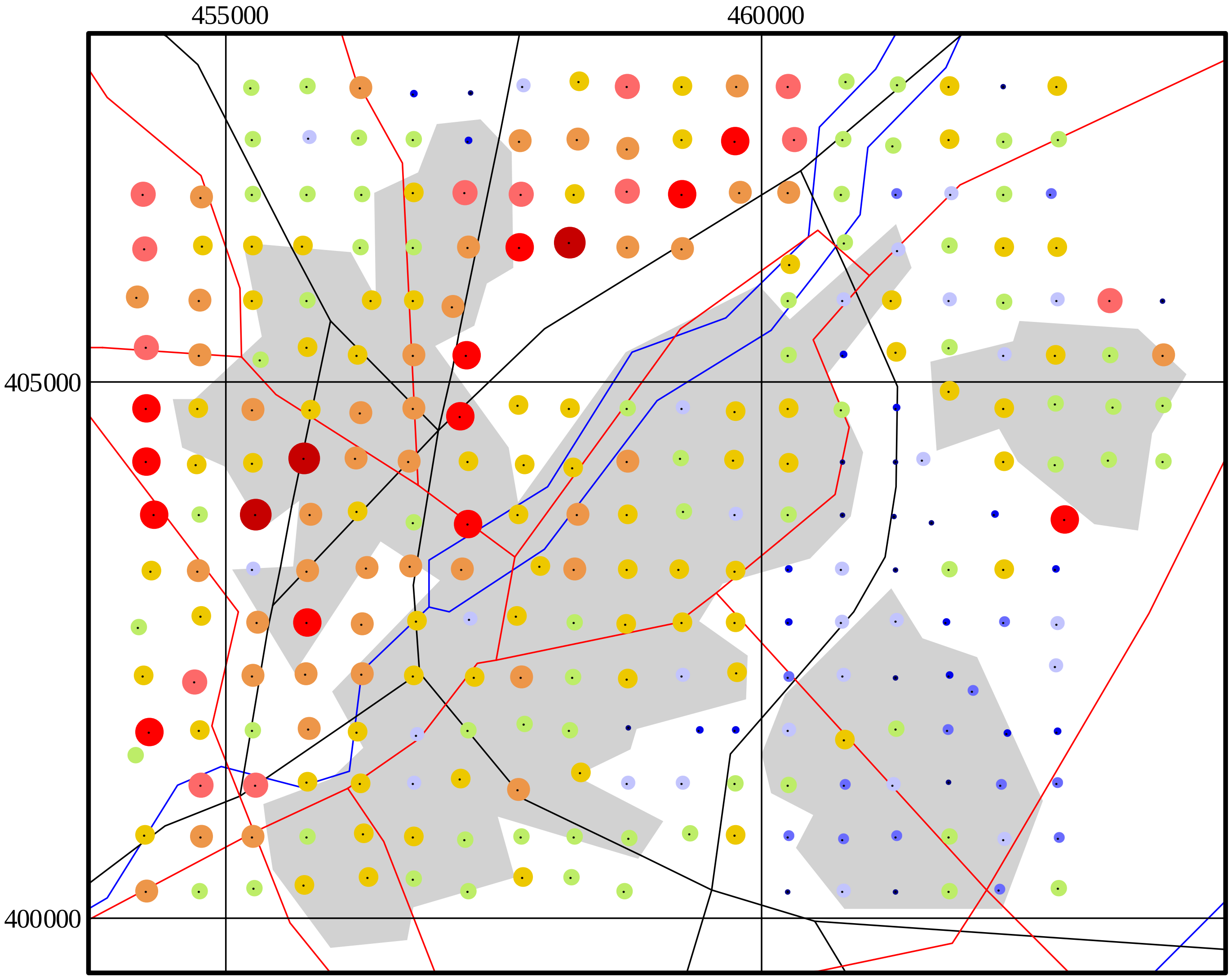
Roads
Railways
Drainage
Urban area

surface soil	MgO (%)
number	279
minimum	0.2
maximum	15.8
median	0.8
mean	1.1

Magnesium was not determined in the profile soils

Doncaster

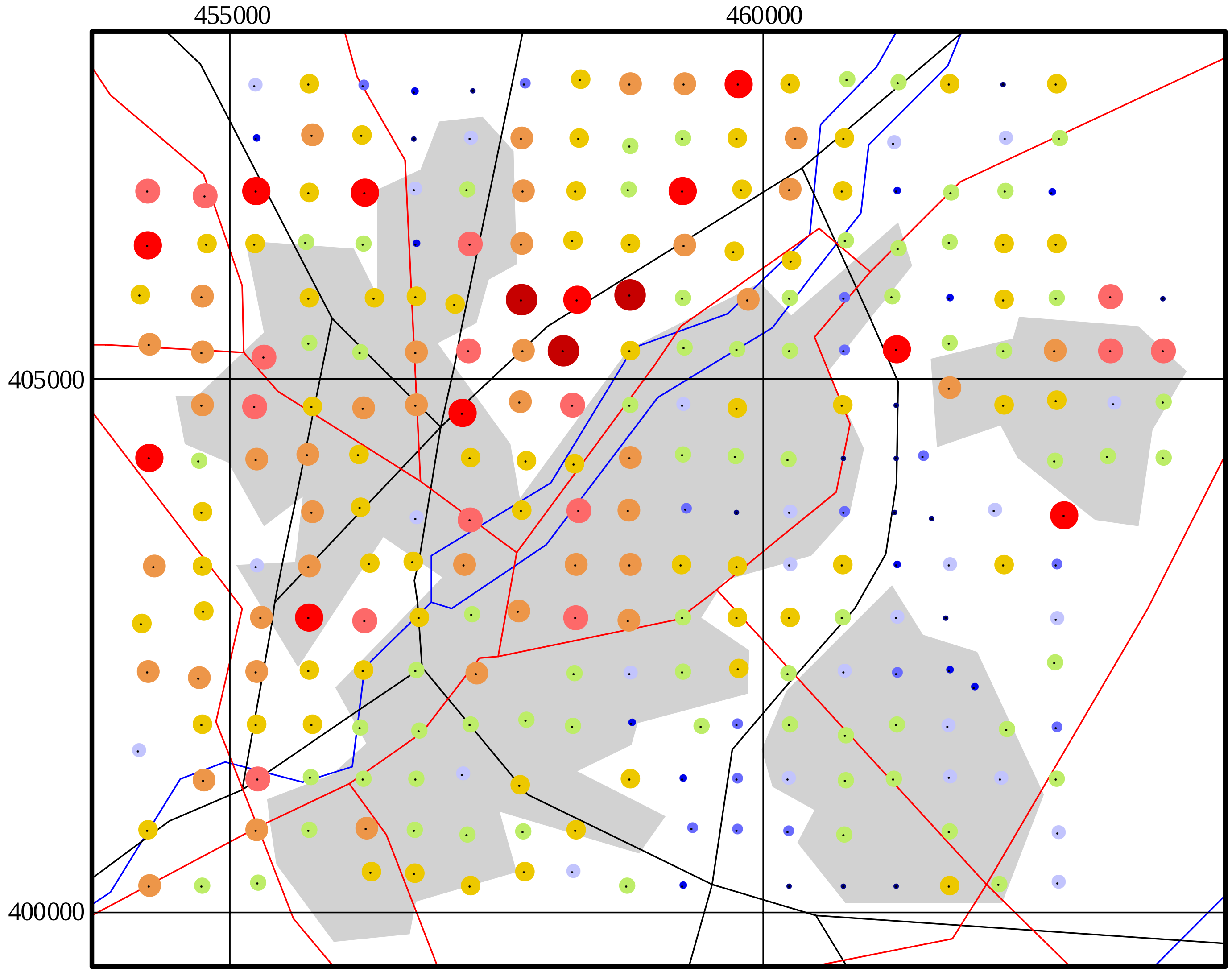
Surface Soils Manganese



%ile	WT%
99	0.436
95	0.290
90	0.237
75	0.196
50	0.130
25	0.083
15	0.072
10	0.062
5	0.049

Roads
Railways
Drainage
Urban area

surface soil	MnO (%)
number	279
minimum	0.034
maximum	1.171
median	0.130
mean	0.151



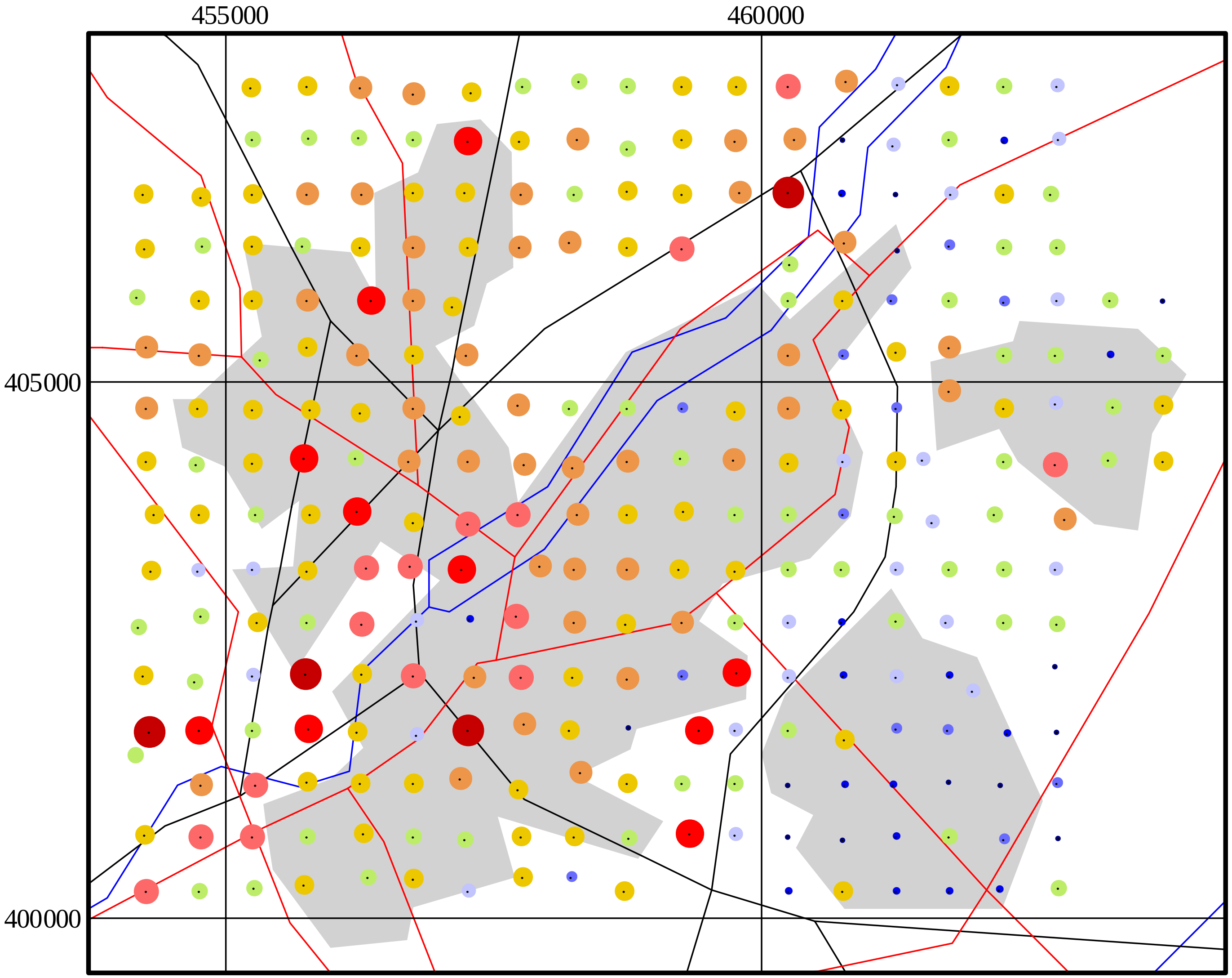
Doncaster
Profile Soils
Manganese

%ile	WT%
99	0.461
95	0.324
90	0.283
75	0.224
50	0.159
25	0.087
15	0.071
10	0.058
5	0.043

Roads
Railways
Drainage
Urban area

profile soil	MnO (%)
number	273
minimum	0.012
maximum	0.595
median	0.159
mean	0.168

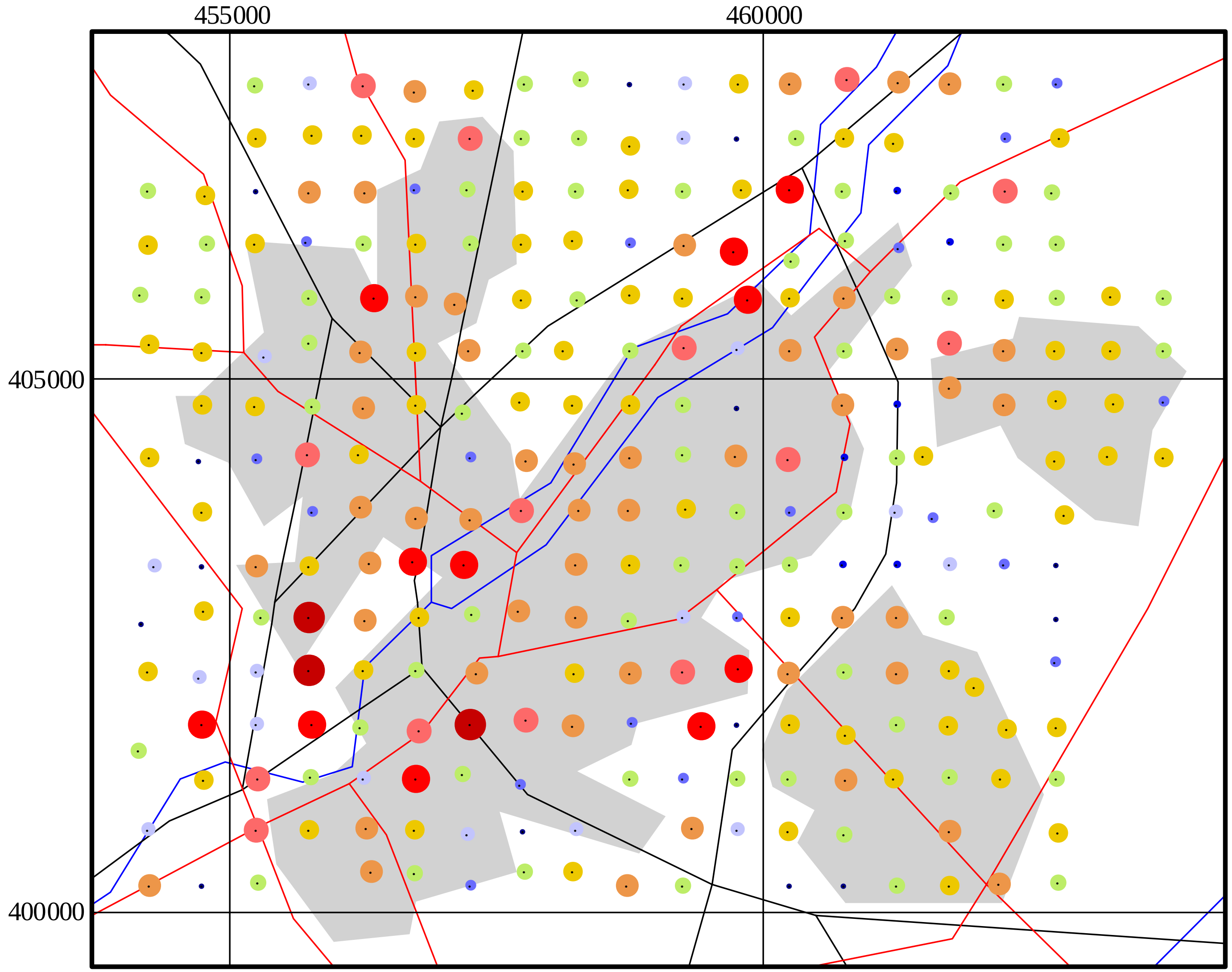
Doncaster
Surface Soils
Molybdenum



%ile	mg/kg
	14.0
99	5.0
95	4.0
90	3.0
75	2.4
50	1.9
25	1.5
15	1.2
10	0.9
5	

Roads
Railways
Drainage
Urban area

surface soil	Mo (mg/kg)
number	279
minimum	0.5
maximum	21.2
median	2.4
mean	2.8



Doncaster

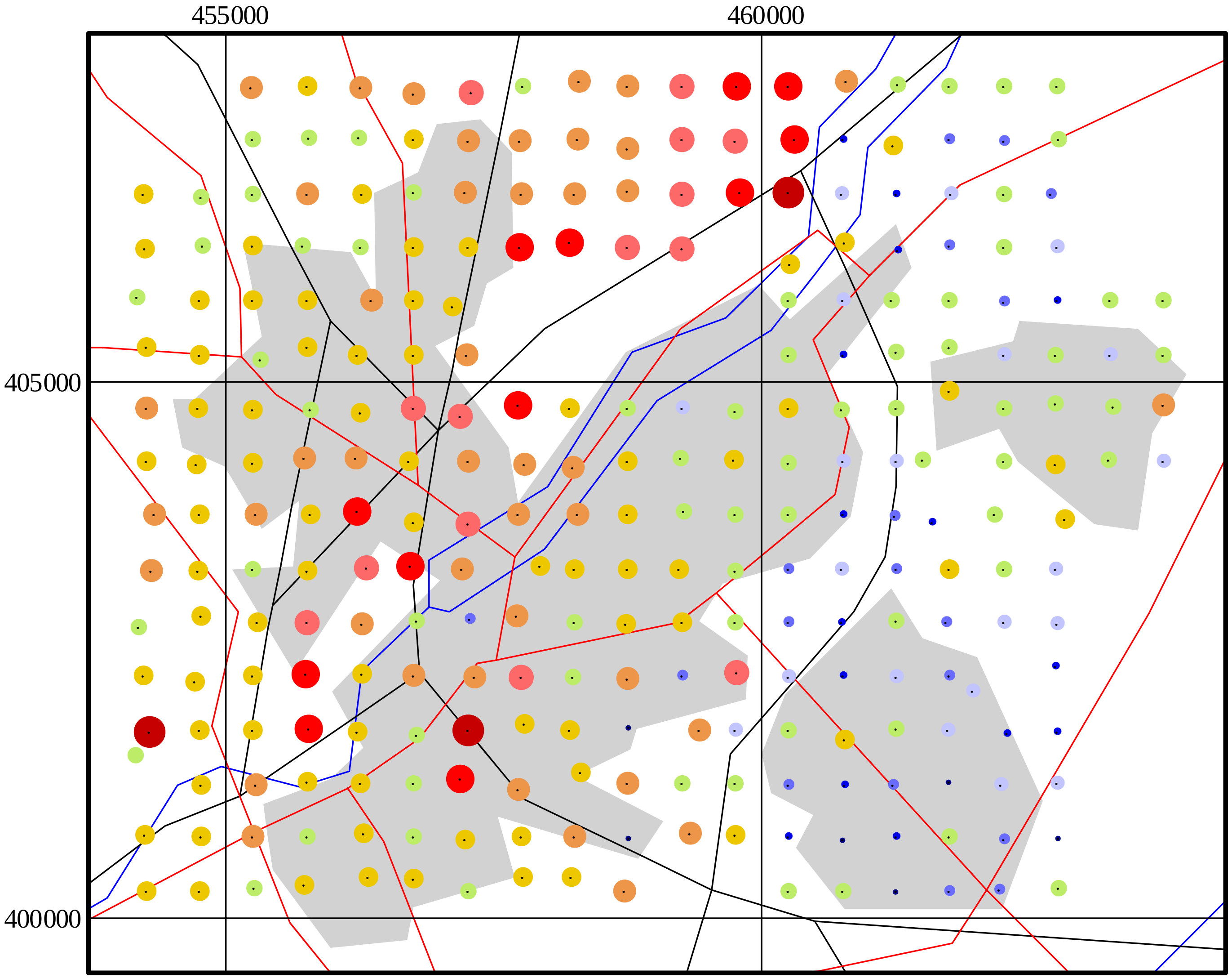
Profile Soils Molybdenum

%ile	mg/kg
99	15.0
95	5.1
90	3.9
75	2.5
50	2.0
25	1.6
15	1.5
10	1.3
5	1.2

Roads
Railways
Drainage
Urban area

profile soil	Mo (mg/kg)
number	273
minimum	0.8
maximum	23.4
median	2.0
mean	2.7

Doncaster
Surface Soils
Nickel

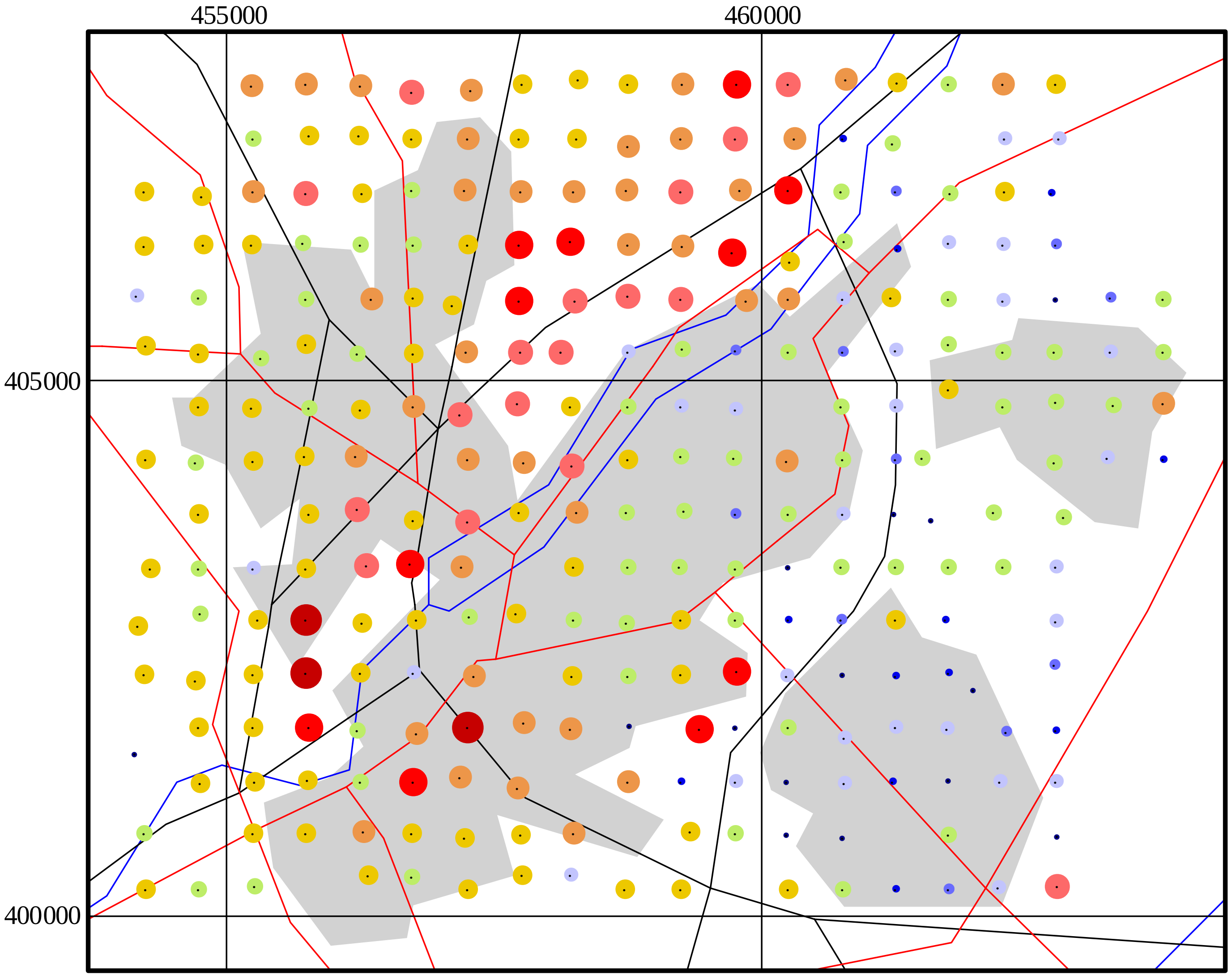


%ile	mg/kg
99	120
95	51
90	39
75	26
50	19
25	12
15	9
10	8
5	6

Roads
Railways
Drainage
Urban area

surface soil	Ni (mg/kg)
number	279
minimum	5
maximum	163
median	19
mean	23

Doncaster
Profile Soils
Nickel

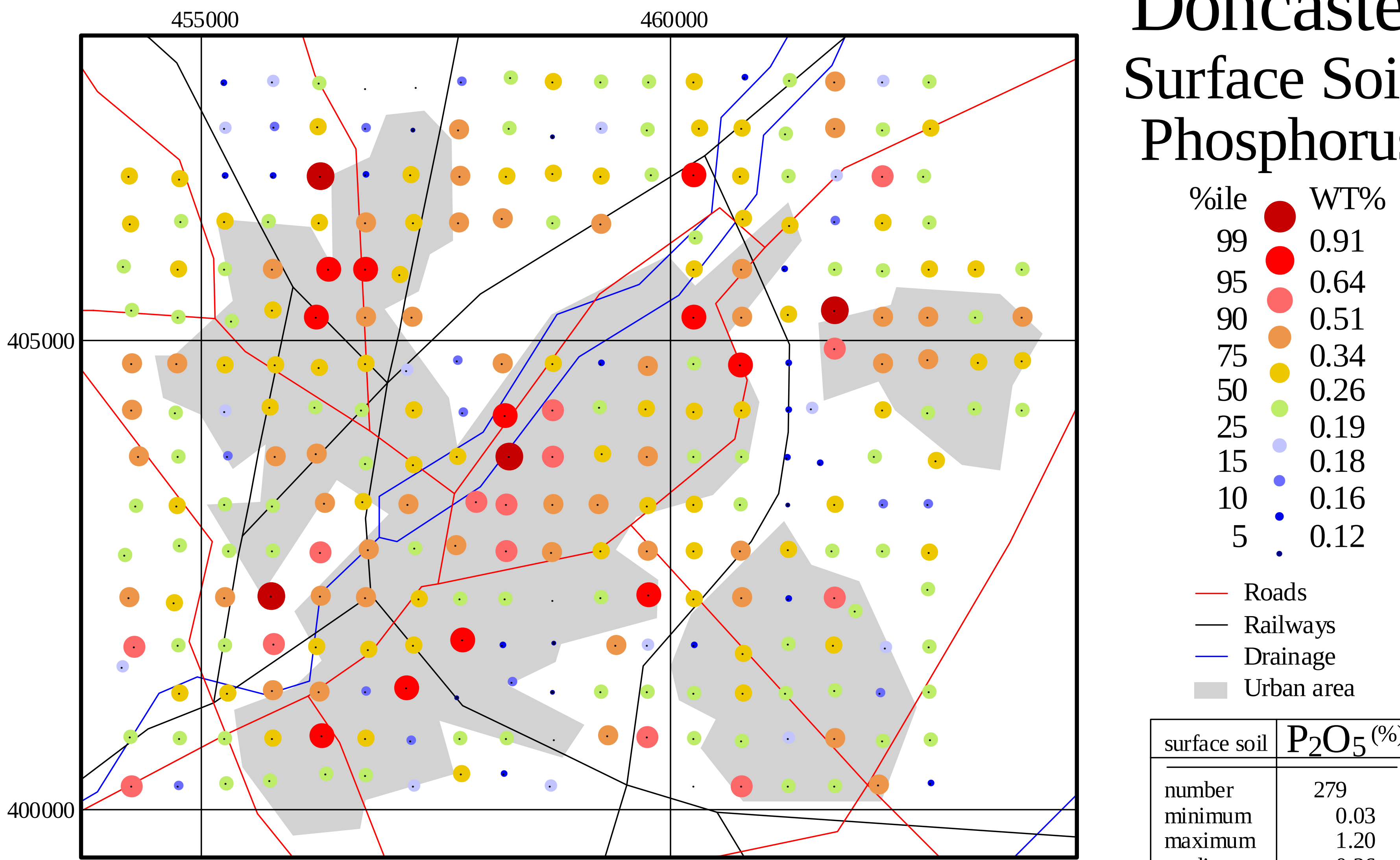


%ile	mg/kg
99	131
95	59
90	47
75	33
50	24
25	18
15	15
10	14
5	12

Roads
Railways
Drainage
Urban area

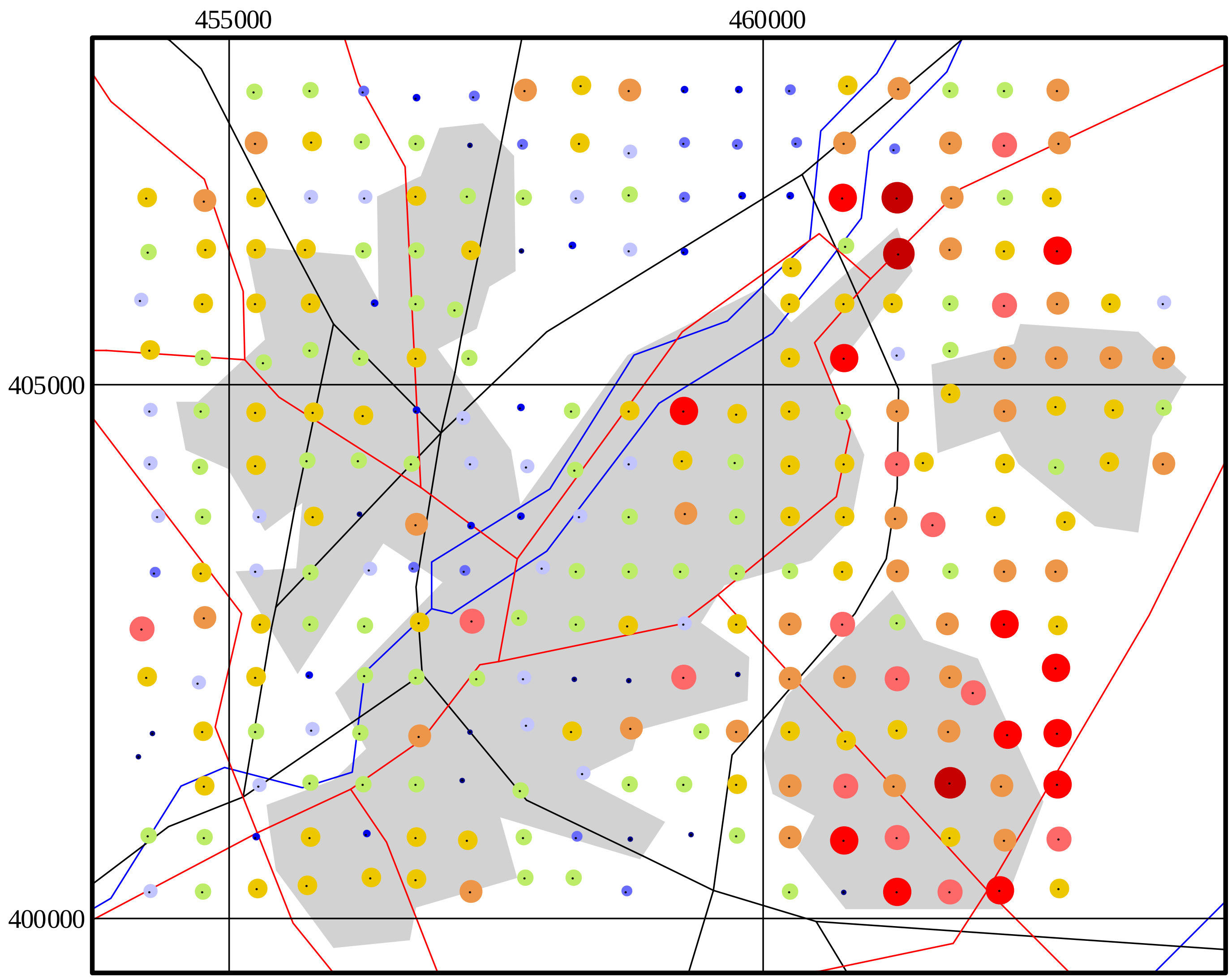
profile soil	Ni (mg/kg)
number	273
minimum	8
maximum	202
median	24
mean	29

Doncaster
Surface Soils
Phosphorus



surface soil	P_2O_5 (%)
number	279
minimum	0.03
maximum	1.20
median	0.26
mean	0.30

Phosphorus was not determined in the profile soils



Doncaster
Surface Soils
Silicon

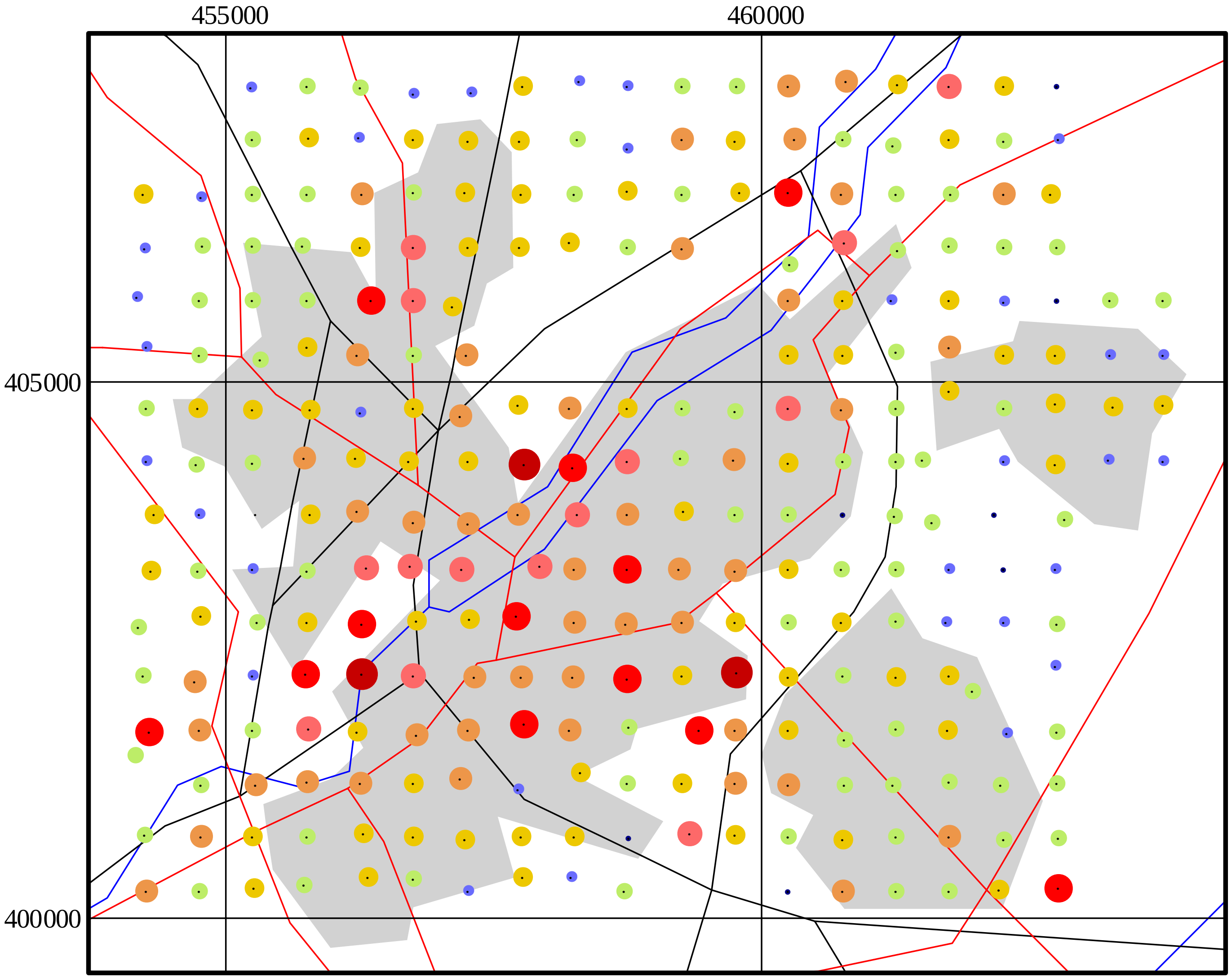
%ile	WT%
99	72.8
95	70.3
90	68.9
75	64.5
50	60.5
25	55.2
15	50.9
10	49.5
5	45.1

- Roads
- Railways
- Drainage
- Urban area

surface soil	SiO_2 (%)
number	279
minimum	9.2
maximum	74.2
median	60.5
mean	59.1

Silicon was not determined in the profile soils

Doncaster
Surface Soils
Tin



%ile	mg/kg
99	71
95	29
90	20
75	10
50	5
25	3
10	2

Roads
Railways
Drainage
Urban area

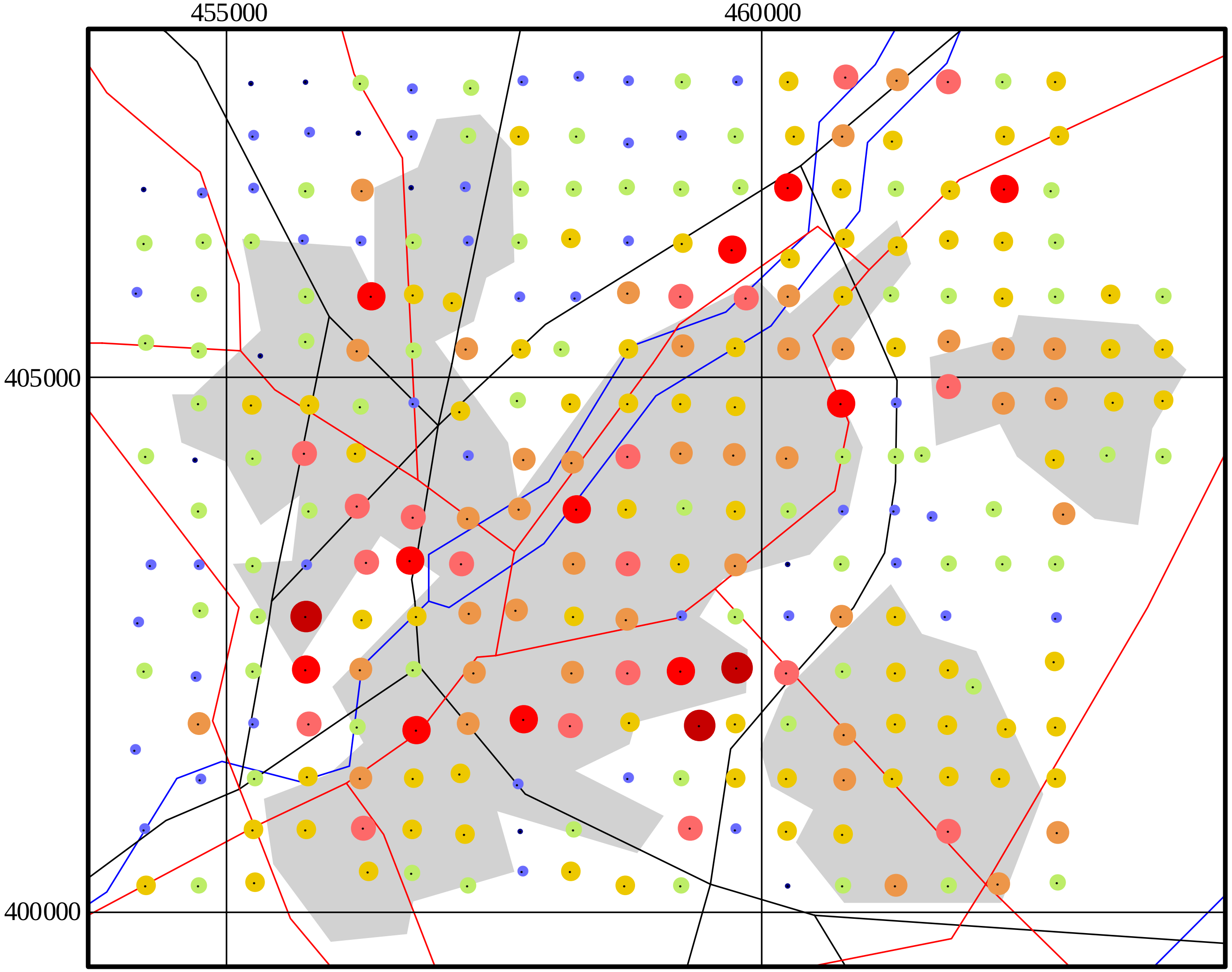
surface soil	Sn (mg/kg)
number	278
minimum	0.55*
maximum	184
median	5
mean	10

*minimum value reported as half detection limit

Doncaster

Profile Soils

Tin



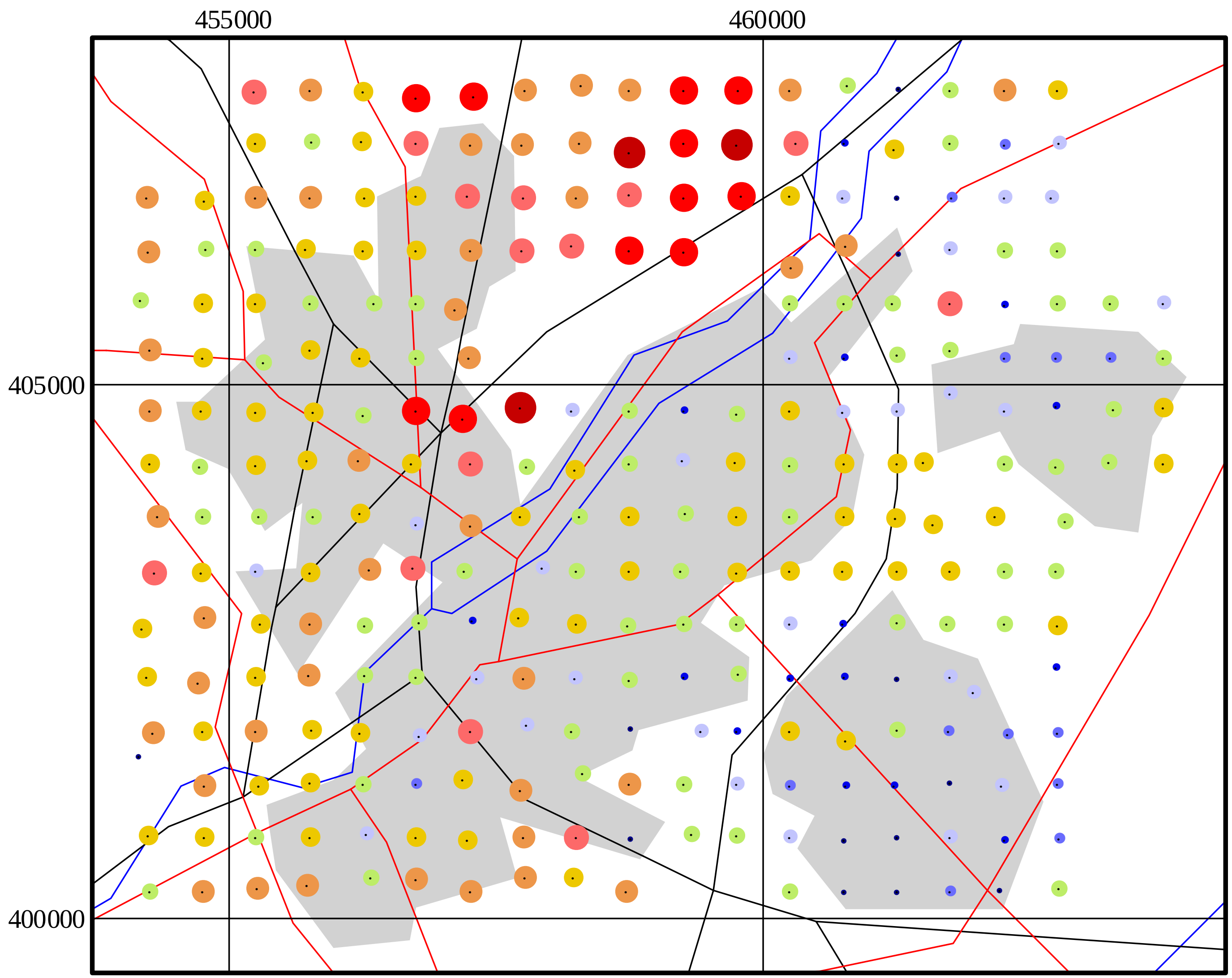
%ile	mg/kg
99	66
95	25
90	16
75	8
50	5
25	3
15	2

Roads
Railways
Drainage
Urban area

profile soil	Sn (mg/kg)
number	273
minimum	0.55*
maximum	586
median	5
mean	11

*minimum value reported as half detection limit

Doncaster
Surface Soils
Titanium



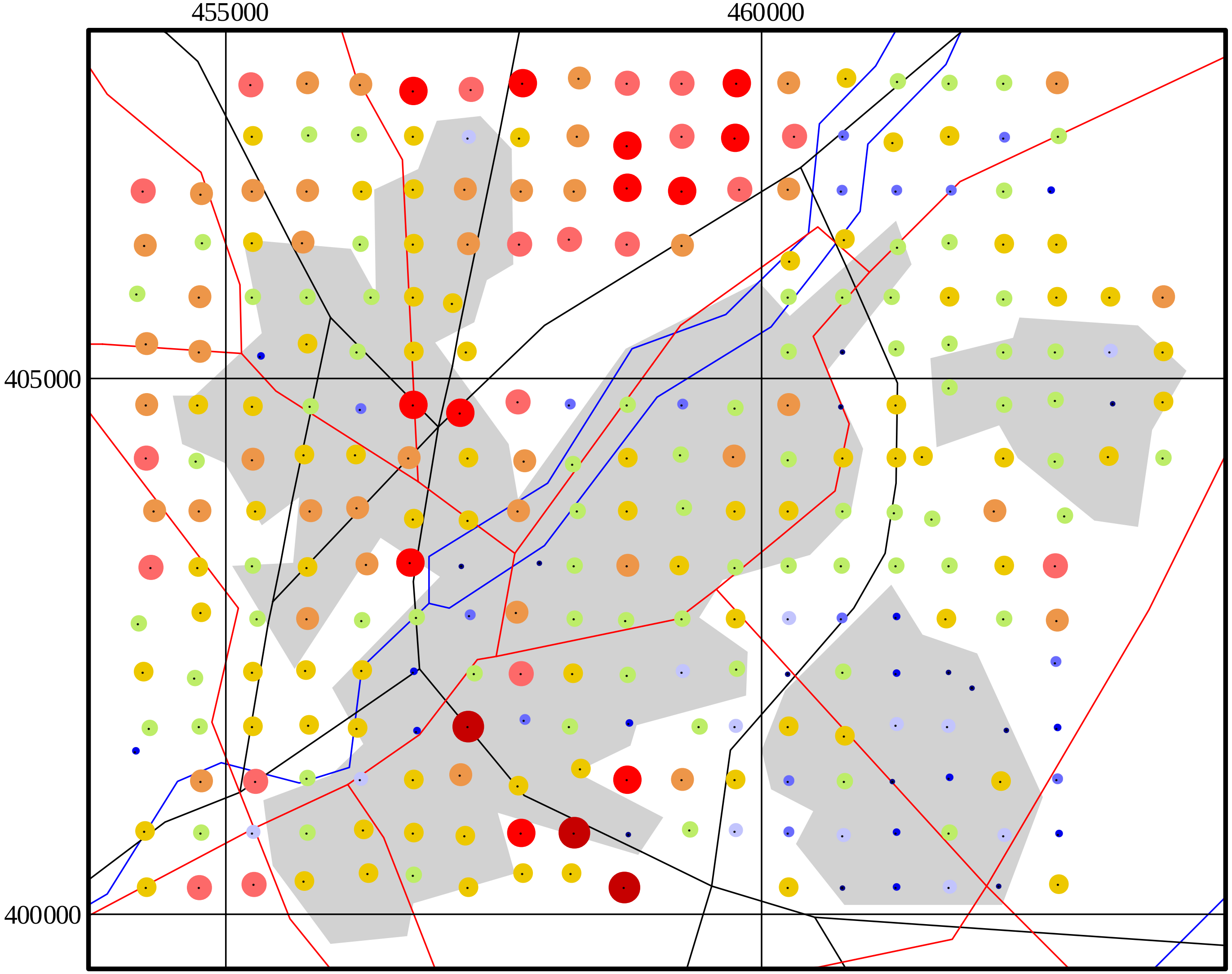
%ile	WT%
99	0.985
95	0.863
90	0.735
75	0.555
50	0.462
25	0.343
15	0.280
10	0.255
5	0.222

Roads
Railways
Drainage
Urban area

surface soil	TiO_2 (%)
number	279
minimum	0.034
maximum	0.994
median	0.462
mean	0.473

Titanium was not determined in the profile soils

Doncaster
Surface Soils
Uranium



%ile	mg/kg
99	4.5
95	3.2
90	2.9
75	2.4
50	1.9
25	1.4
15	1.3
10	1.1
5	0.9

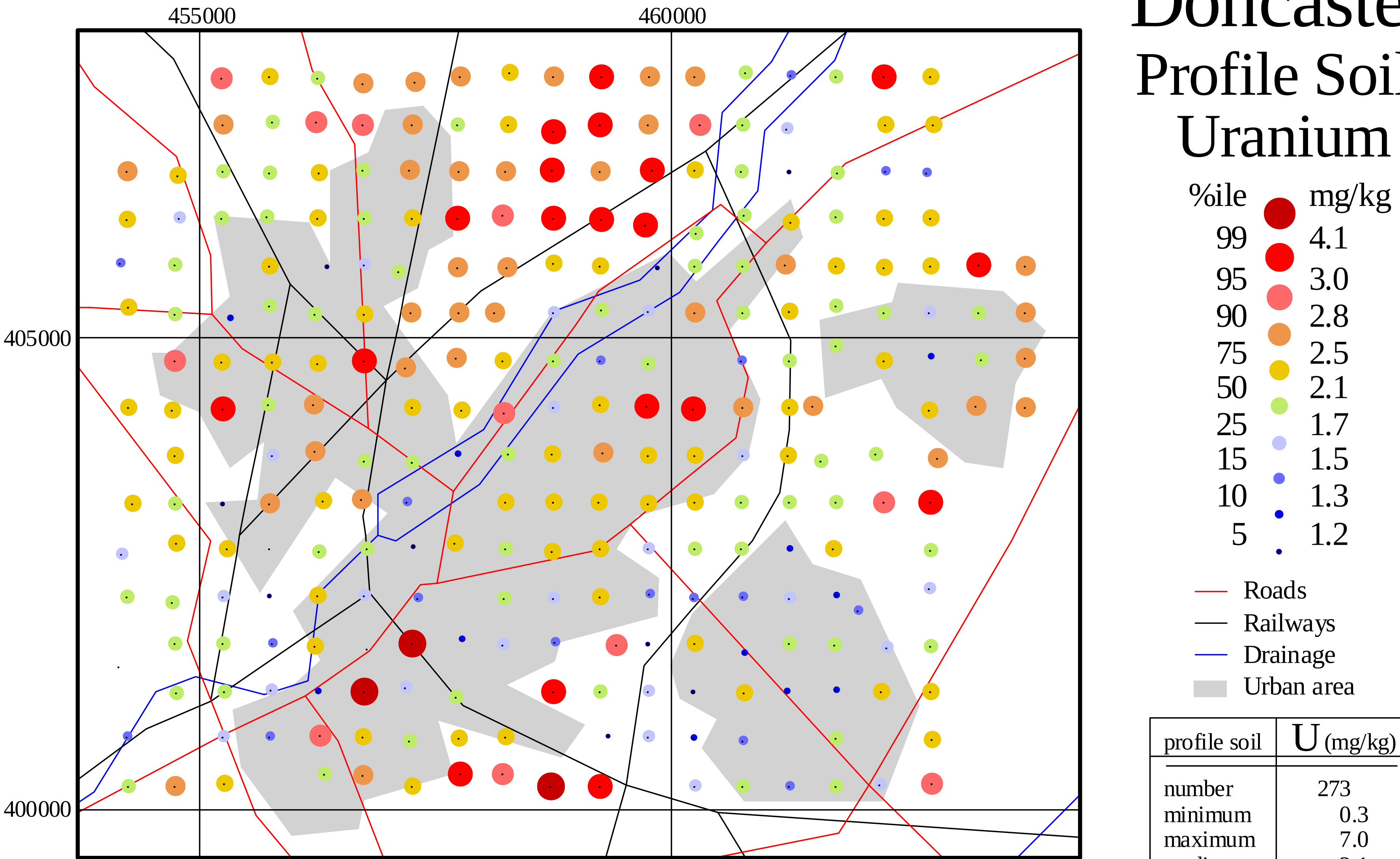
Roads
Railways
Drainage
Urban area

surface soil	U (mg/kg)
number	279
minimum	0.5
maximum	8.3
median	1.9
mean	2.0

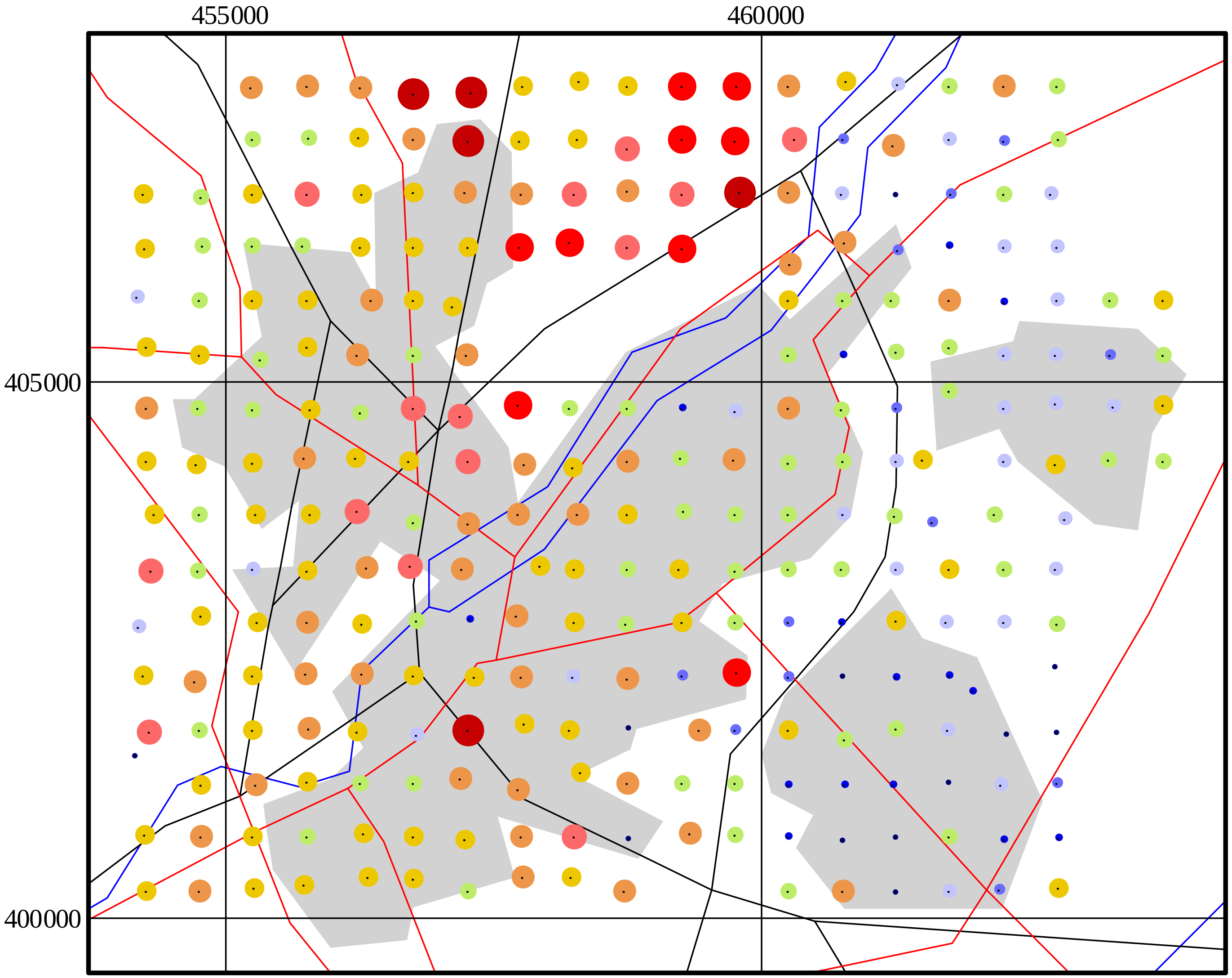
Doncaster

Profile Soils

Uranium



profile soil	U (mg/kg)
number	273
minimum	0.3
maximum	7.0
median	2.1
mean	2.1



Doncaster

Surface Soils

Vanadium

%ile	mg/kg
99	153
95	126
90	106
75	78
50	63
25	50
15	41
10	38
5	35

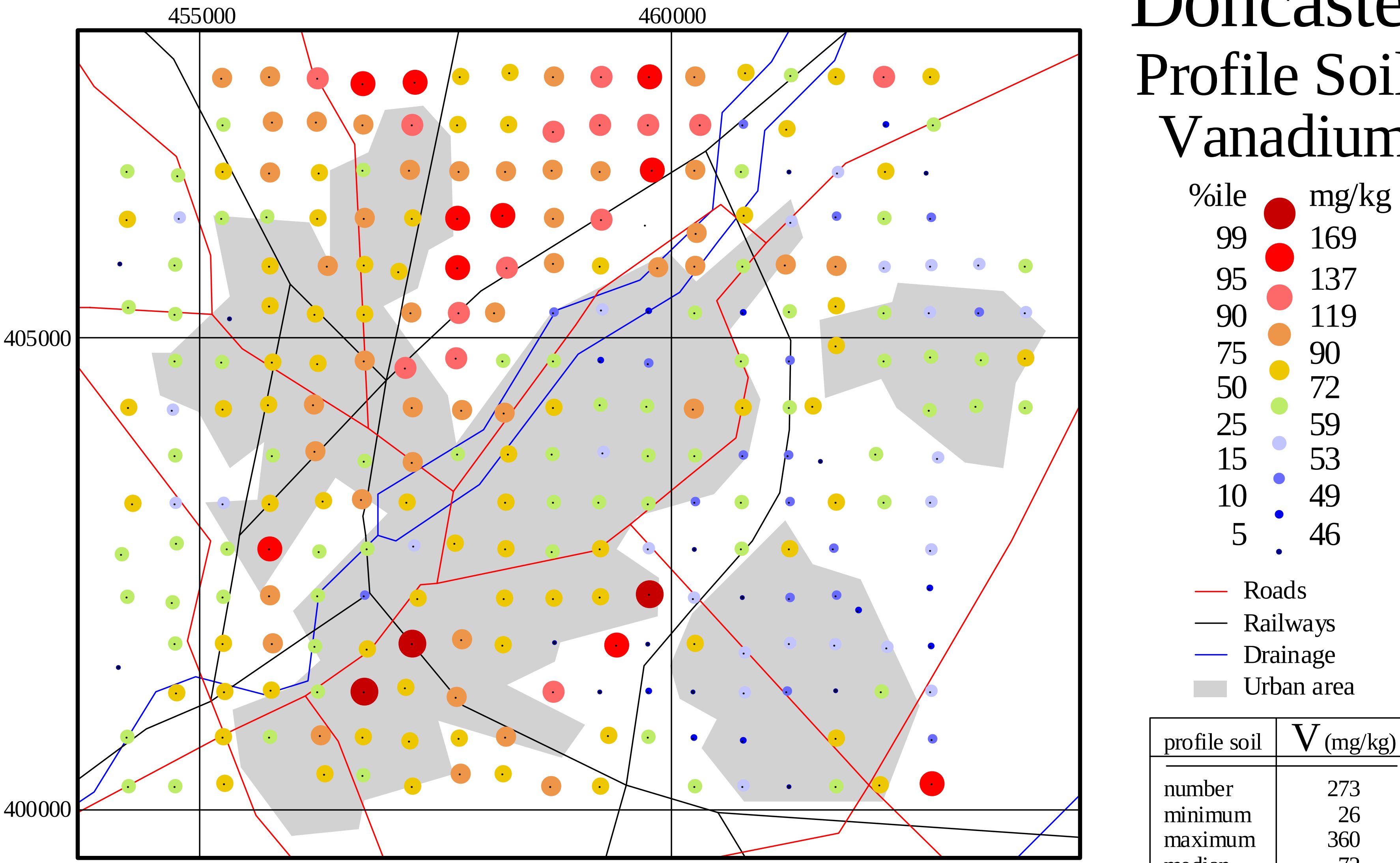
Roads
Railways
Drainage
Urban area

surface soil	V (mg/kg)
number	279
minimum	20
maximum	342
median	63
mean	69

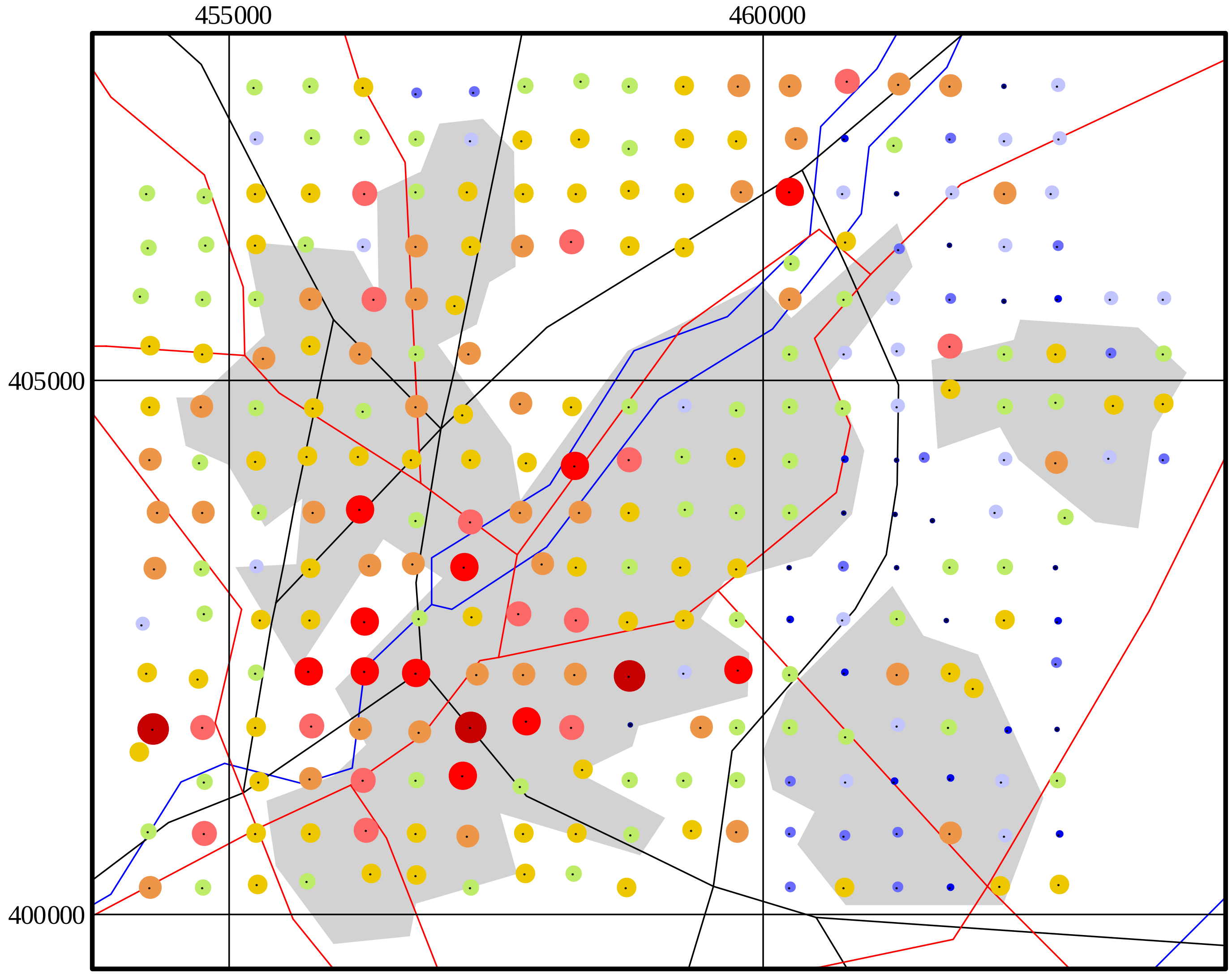
Doncaster

Profile Soils

Vanadium



profile soil	V (mg/kg)
number	273
minimum	26
maximum	360
median	72
mean	79



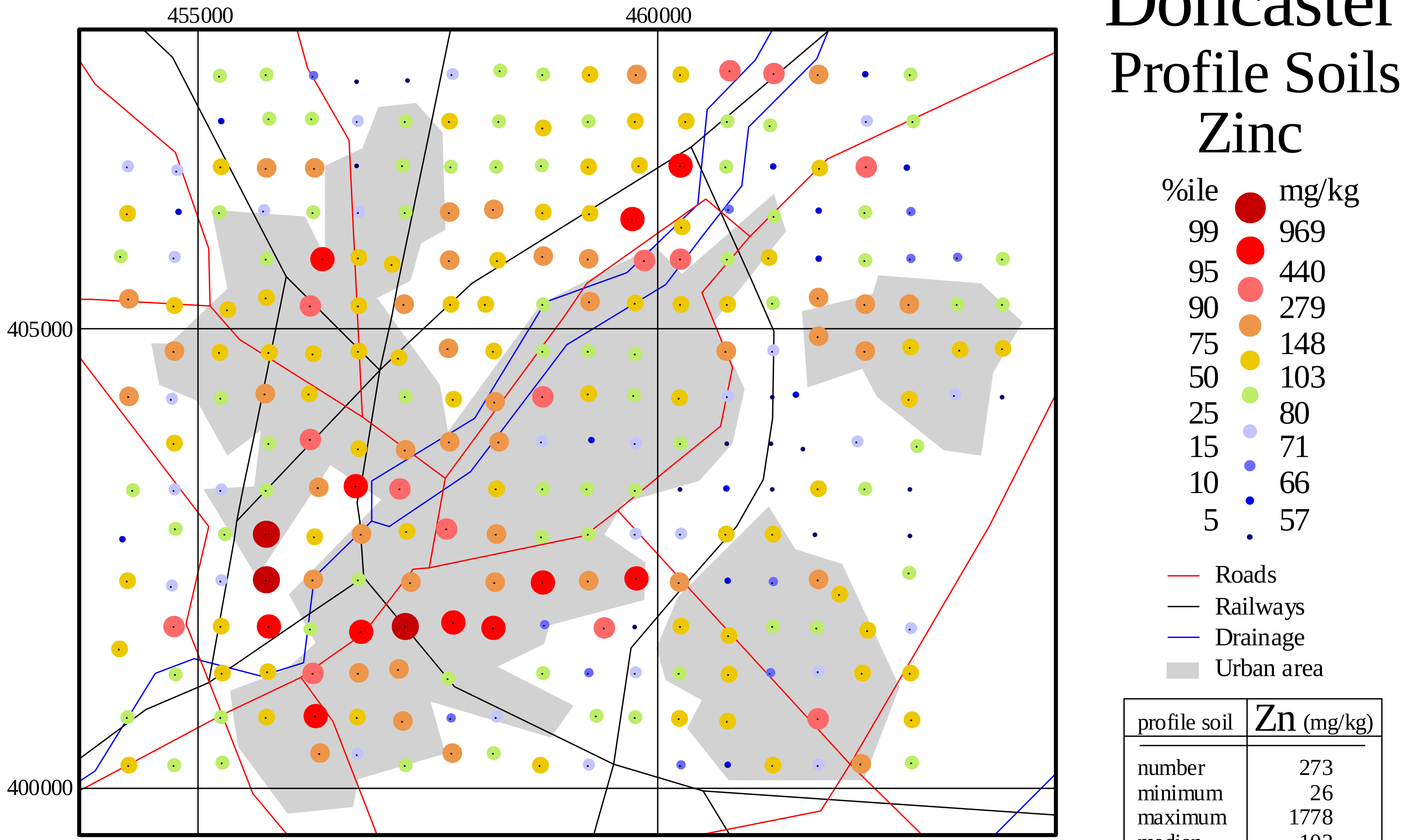
Doncaster
Surface Soils
Zinc

%ile	mg/kg
99	977
95	388
90	277
75	156
50	105
25	70
15	50
10	44
5	39

Roads
Railways
Drainage
Urban area

surface soil	Zn (mg/kg)
number	279
minimum	21
maximum	1463
median	105
mean	148

Doncaster
Profile Soils
Zinc



profile soil	Zn (mg/kg)
number	273
minimum	26
maximum	1778
median	103
mean	160