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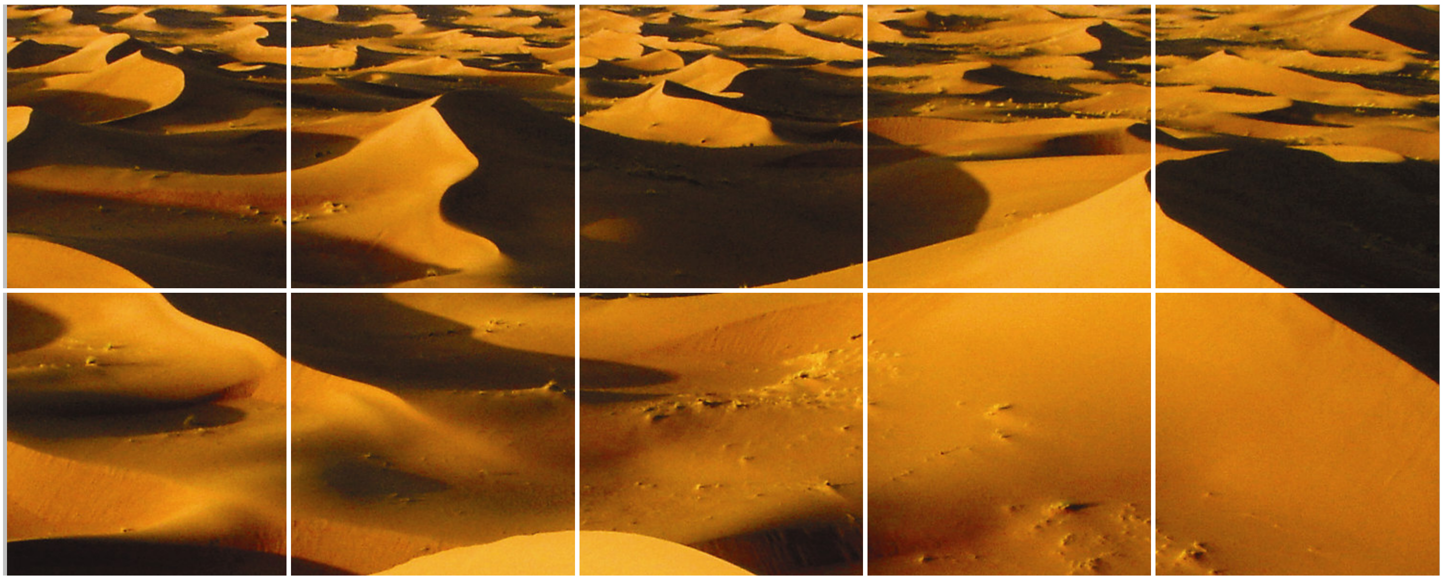

Modelling of PM_{10} at Santon

Report to Defra

ED48208
R3013 Issue 2
May 2010

Title	Modelling of PM10 at Santon
Customer	Defra
Customer reference	CPEA 15
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File reference	X:/admin/notes_to_and_from_defra/santon/report250510.doc
Reference number	ED48208/ENV/R/3013- Issue 2

AEA group
The Gemini Building
Harwell IBC
Didcot
Oxfordshire
OX11 0QR

t: 0870 190 6401
f: 0870 190 6318

Author	Name	John Abbott
Approved by	Name	John Stedman
	Signature	John Stedman.
	Date	25 May 2010

Executive summary

European Ambient Air Quality Directives are in place to ensure that Member States achieve specific standards for ambient air quality. The first Daughter Directive and the more recent CAFE Directive (EC/2008/50) set limit values for PM_{10} to be achieved from 2005 onwards. The limit values are:

40 µg m^{-3} as an annual mean;
50 µg m^{-3} as a daily mean not to be exceeded on more than 35 occasions in a year.

Measurements of PM_{10} concentrations at the Low Santon site indicate that the limit values for the annual mean concentration and the daily mean concentration were exceeded in 2007 and 2008. Various studies involving the analysis of monitoring data and dispersion modelling have previously been carried out by North Lincolnshire District Council, Corus, Lancaster University, AEA and Leeds University. These studies have attributed the high concentrations to emissions from the Corus steel works, fugitive emissions from the Tarmac slag handling operation and fugitive emissions from the unpaved haul road between the Corus works and the Tarmac slag handling operations.

Defra wish to assess the site's suitability for affiliation into the Automatic Urban and Rural Network (AURN). One consideration is whether the site meets the macroscale siting criterion set out in the Directive that the sampling site should be representative of an area of at least 250 m × 250 m (62,500 m^2) at industrial sites, where feasible.

This report describes a dispersion modelling study to estimate the area of exceedence of the limit values in the vicinity of the Low Santon site. The dispersion model ADMS4.1 was used to predict the contributions to ground level concentrations from the Corus plant and from fugitive emission sources, based on initial estimates of fugitive emissions derived using the methods described in the US Compilation of Air Pollutant Emission Factors, AP42. We adjusted the initial estimates of fugitive emissions to give "best" agreement with the monitoring results taking account the effects of wind direction and wind speed. The model performance compared to the measurements was acceptable when tested against a range of criteria:

- CAFÉ Directive data quality objective for the annual mean
- FAIRMODE Relative Directive Error for the daily mean values
- AEA Model Intercomparison Protocol Normalised Mean Bias
- AEA Model Intercomparison Protocol Factor of 2
- Scatter plots of measured vs modelled daily mean values
- Wind speed and direction dependence.

The model indicates that the following sources make the greatest contributions to annual mean concentrations in the vicinity of the Low Santon monitor:

- Corus steelworks
- Tarmac north aggregate handling
- Tarmac north wind erosion;
- Haul road
- Track out onto Dawes Lane

Taken together, the operations at the Tarmac site make the largest contributions to annual mean concentrations at the monitoring site. Emissions from the steel works and fugitive emissions associated with the Tarmac operation both add substantially to the modelled number of exceedences of the daily mean limit value.

The model indicates that the daily mean limit value of 50 µg m^{-3} will be exceeded more than 35 times in a year over an area greater than 150,000 m^2 outside of the boundaries of the Corus and Tarmac sites. The area can be compared with the macroscale siting criterion given in the CAFÉ Directive that the sampling site should be representative of an area of at least 250 m × 250 m (62,500 m^2) at industrial sites, where feasible.

The modelling also indicates that the annual mean limit value is exceeded at the Low Santon site. The area of exceedence is much smaller than that for the daily mean.

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1 Introduction

European Ambient Air Quality Directives are in place to ensure that Member States achieve specific standards for ambient air quality. The first Daughter Directive and the more recent CAFE Directive (EC/2008/50)[1] set limit values for PM_{10} to be achieved from 2005 onwards. The limit values are:

40 µg m^{-3} as an annual mean;
50 µg m^{-3} as a daily mean not to be exceeded on more than 35 occasions in a year.

The limit values have been adopted in the UK as air quality objectives for local authority review and assessment.

These have been exceeded at several sites in the Automatic Urban and Rural Network (AURN) as they have in many Member States, with the result that the UK has formally applied for a derogation of the legislation until the end of a formally approved time extension period. This application is based on the concentrations measured by the National networks only and does not include local authority monitoring sites. However, the Low Santon monitoring site, owned by North Lincolnshire District Council also exceeded both the annual and daily Limit Values in 2008 and Defra wish to assess the site's suitability for affiliation into the AURN. The location of the site is shown in Fig.1.

The principal issue in the site's suitability for affiliation lies in the micro and macro scale siting criteria specified in the Directive and in particular, whether the monitoring site is representative of an industrial source(s) exceeding 250m x 250m:

"Sampling points shall in general be sited in such a way as to avoid measuring very small micro-environments in their immediate vicinity, which means that a sampling point must be sited in such a way that the air sampled is representative of air quality for a street segment no less than 100 m length at traffic orientated sites and at least 250 m × 250 m at industrial sites, where feasible" **(CAFÉ directive, Annex III, B, 1b)**

A Partisol PM_{10} analyser ('High Santon', also owned by North Lincolnshire District Council) is located approximately 350 m away from the Low Santon Tapered Element Oscillating Microbalance (TEOM) instrument and this has reported significantly lower concentrations of PM_{10}. The annual mean concentration value was approximately 7 µg m^{-3} lower at the High Santon Partisol site.

This drop of 7 µg m^{-3} over 350 m represents a steeply declining concentration gradient with distance from the industrial sources and suggests that the high concentrations may be sufficiently localised to make the Low Santon site inappropriate for affiliation into the AURN based on the Directive siting criteria.

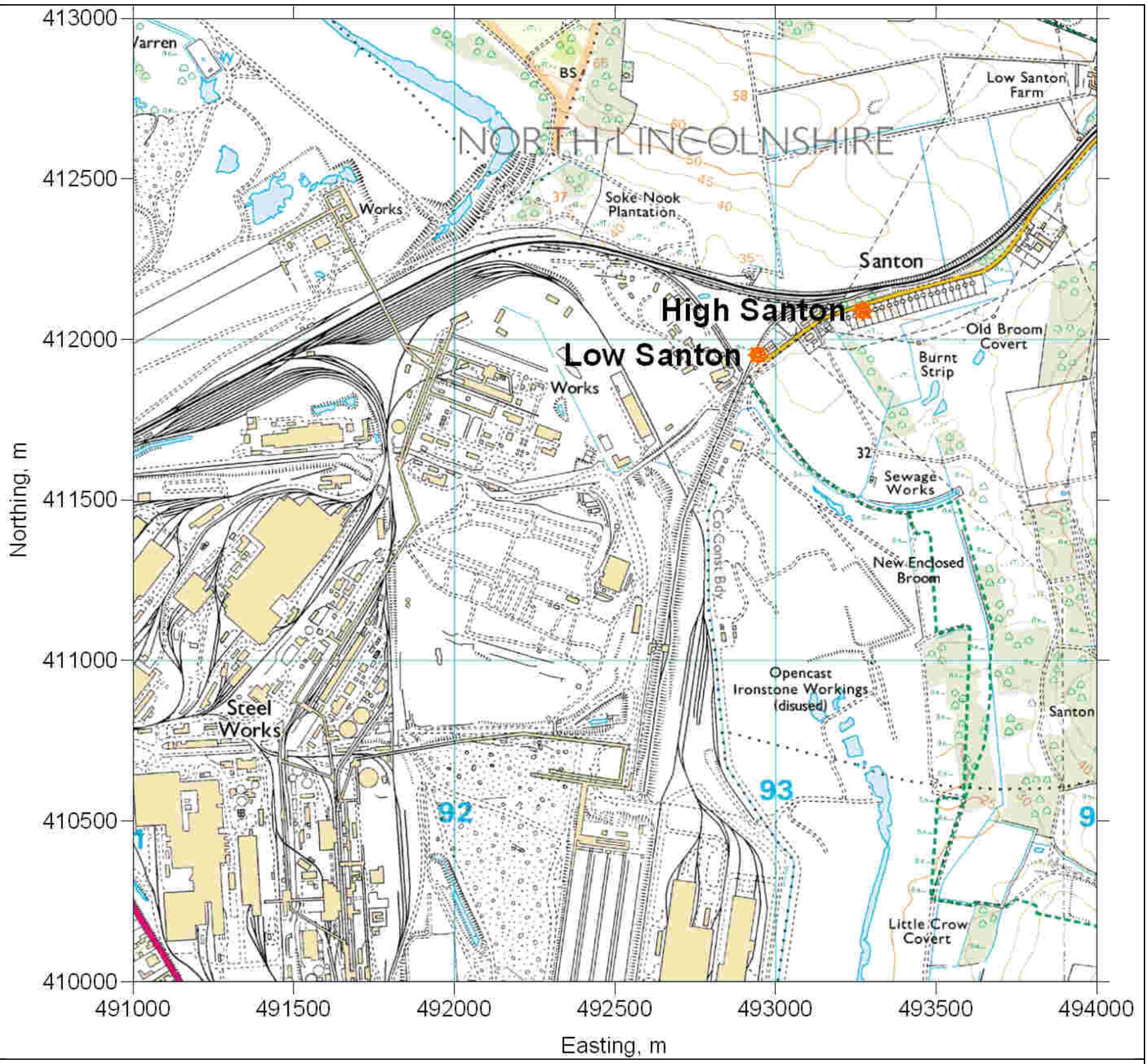
Additional work on analysis and attribution of these sources is continuing by the Environment Agency in their remit to appropriately permit and control these sources with support from the Scunthorpe Air Quality Technical Working Group (North Linconshire District Council, Environment Agency, Corus, Lancaster University, Leeds University, AEA, Defra). However, such analysis is likely to take a significant time before it can inform Defra's decisions regarding affiliation.

This report describes an assessment of PM_{10} concentrations in the vicinity of the Low Santon monitoring site. The main part of the work, described in Section 5, was a dispersion modelling study using the ADMS4.1 dispersion model. Section 2 of the report describes previous work to assess air quality in the area. Section 3 summarises measurements of PM_{10} concentrations at the monitoring sites. Section 4 identifies sources of emissions in the area of the monitoring sites and provides estimates of the quantities of particulate matter emitted. The results of the modelling are discussed in Section 6. Finally, Section 7 presents the conclusions based on the assessment.

The emission sources considered included the combustion and other emissions from the Corus steel works and fugitive emissions from the Multiserv and Tarmac slag handling operations.

[1] DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe.
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF

Fig. 1: Location of the Low Santon and High Santon monitors



2 Previous work

This section describes previous work by others to relevant to the assessment of the air quality in the vicinity of the Low Santon site.

2.1 Local authority review and assessment

Local authorities are required to review and assess the air quality in their areas from time to time. North Lincolnshire District Council has prepared a series of reports. The most relevant parts of the reports are described below.

2.1.1 Stage 2, 2001

North Lincolnshire District Council's Stage 2 air quality review and assessment report[2] in 2001 included details of PM_{10} monitoring at the Council Services Depot on Cottage Beck Road. The monitoring site was located to the west of Corus steelworks and was intended to quantify the effect of pollution generated by Corus and other industries. At that time, the annual mean was less than the limit value of 40 µg m^{-3} and there were fewer than 35 exceedences of the daily limit value of 50 µg m^{-3}.

The Stage 2 report also included a summary of monitoring carried out by Corus. The annual mean limit value was exceeded within the works boundary at the blast furnace and Broughton sites. The daily mean limit value was exceeded more than 35 times in a year at the blast furnace site. The annual mean limit value was met at the Corus Santon and A18 Gate sites on the works boundary. There were 2 exceedences of the daily limit value at the Corus Santon site.

North Lincolnshire District Council determined at that time that it was very unlikely that the air quality objectives would be exceeded.

2.1.2 Updating and Screening Assessment, 2003

North Lincolnshire District Council's Updating and Screening Assessment, 2003[3] included revised estimates of the concentration measured at the Cottage Beck Road site. The assessment reported more than 35 exceedences of the 24-hour mean limit of 50 µg m^{-3} in 1998,1999, 2001 and 2002. The Updating and Screening Assessment report also included summary of monitoring carried out by Corus. The annual mean limit value was exceeded at a monitoring station towards the southern end of the works.

North Lincolnshire District Council decided to carry out more detailed assessment of PM_{10} concentrations in Scunthorpe resulting from industrial emissions.

2.1.3 Detailed Assessment, 2004

The Detailed Assessment report, 2004[4] includes a summary of dispersion modelling carried out by Corus as part of their application for an IPPC Permit. The modelling was carried out using the dispersion model ADMS3.1. The Corus report was included as an Appendix to the Detailed Assessment report. The model results indicated that 24-hour mean PM_{10} objective would be exceeded at a number of relevant residential receptors surrounding the integrated steelworks, particularly those residential areas along the eastern fringe of Scunthorpe town and isolated dwellings to the south and

[2] http://www.nlincs.aeat.com/documents/reports/36070525_NorthLincolnshireCouncilStage2AirQualityReviewandAssessment.pdf

[3] http://www.nlincs.aeat.com/documents/reports/40070618_USAFinalReport2.pdf

[4] http://www.nlincs.aeat.com/documents/reports/40070618_DetailedAssessment2.pdf

west of the integrated steelworks. The modelling indicated that the objective would be met in the vicinity of the Low Santon monitoring site.

The Detailed Assessment recommended that an Air Quality Management Area (AQMA) shall be defined and then designated for the Scunthorpe area where there is likely exceedence of the Air Quality Objectives.

North Lincolnshire District Council declared an AQMA for the daily mean objective for PM_{10} on 26 October 2005. The area covered the area of the steel works and associated processes. It included the area surrounding the Low Santon and High Santon monitors.

2.1.4 Further Assessment, 2008

The Further Assessment of PM_{10} in the Scunthorpe Area[5] presents the results from additional monitoring work carried out to support the declaration of the AQMA. It includes detailed analysis of monitoring data for 2006 from the Low Santon site.

Detailed analysis of the results fro the Low Santon site indicated that:

- The mean concentration is greatest when the wind direction is between 200^o and 300^o. This area covers most of the steelworks site and Tarmac operations.
- The largest concentrations occur more frequently during the day than at night.
- Large concentrations are observed more frequently on weekdays than at weekends.
- The daily average concentration exceeds 50 µg m^{-3} most frequently during the summer months.
- There was little correlation between train times passing to the north of the monitoring site and PM_{10} concentrations.
- Resuspension of dust from Dawes Lane may contribute to high PM_{10} concentrations.

2.1.5 Detailed Assessment, 2008

The Detailed Assessment of PM_{10}, 2008[6] presents the results of monitoring at the Low Santon and High Santon sites over the period from installation to the end of 2007.

The Low Santon monitoring site uses a TEOM device to monitor PM_{10} concentrations. The TEOM device is not equivalent to the gravimetric reference method specified in the EC Directive. The TEOM measurements can be converted to be equivalent measurements using the Volatile Correction Model[7]. However, the Volatile Correction Model had not been adopted for Review and Assessment purposes at the time of the Detailed Assessment. The TEOM measurements reported in the Detailed Assessment were converted approximately to equivalent values by multiplying by a factor of 1.3 as recommended at the time. The use of the 1.3 factor can overestimate concentrations where the PM_{10} fraction contains a large fraction of coarse dust.

The TEOM measurements, as corrected, indicated that neither the annual mean nor the daily mean limit value would be met at the Low Santon site. The Detailed Assessment recommended that an AQMA should be declared for the annual mean objective for PM_{10} in the vicinity of the Low Santon monitoring site.

PM_{10} concentrations were measured at the High Santon site using a Partisol device. These measurements are equivalent to the gravimetric reference method. However, the data capture was slightly less than required by the Directive. Nevertheless, the Detailed Assessment indicated that the limit values were met at the High Santon site.

[5] http://www.nlincsair.info/documents/reports/105080603_Final_Further_Assessment.pdf

[6] http://www.nlincsair.info/documents/reports/99080214_Detailed_Assessment_PM10_2008.pdf

[7] http://www.volatile-correction-model.info/

2.2 Corus Permit Improvement Requirements

Corus prepared an air quality impact assessment as part of the application for a Permit to operate under the Integrated Pollution Prevention and Control Regulations (now replaced by the Environmental Permitting Regulations). The air quality impact assessment was included in North Lincolnshire District Council's Detailed Assessment, 2004. The Permit was issued in 2004 and contained several improvement requirements. Improvement Programme Requirement 37 requires Corus to review the air quality impact assessment annually and amend it where necessary. Corus prepared a revised assessment in 2009[8]. The revised assessment used the ADMS4 dispersion model to predict the contribution to ground level concentrations from the Corus emission sources. The modelling used meteorological data from Waddington for 1999 and assumed constant rate of emissions. The modelled process contribution to annual mean PM_{10} concentrations was 8.7 µg m^{-3} at Low Santon and 7.5 µg m^{-3} at High Santon.

2.3 Andrew Malby, Lancaster University

Andrew Malby carried out an assessment of the monitoring data from Low Santon and dispersion modelling as a case study as part of his PhD thesis to Lancaster University.

He analysed monitoring data from the Low Santon site for 2006 using a series of bi-polar plots of average concentration by wind direction and by wind speed and/or time of day. The analysis indicated that high concentrations generally arise during working hours and increased notably with strong winds.

He used the dispersion models ADMS-Urban and ADMS4 to predict ground level concentrations at the Low Santon site. The model used meteorological data from Waddington for 2006. He considered using meteorological data from the Rowland Road (Scunthorpe Town) air quality monitoring site. However, he considered Rowland Road site data to be unsatisfactory because the wind speeds measured at Rowland Road were much lower than those at Waddington because of the sheltered nature of the site.

He considered the following emission sources:

- Corus emissions, based on the emissions inventory prepared by the company for its Permit application;
- Road traffic emissions from major roads;
- Emissions from minor sources such as agriculture and domestic emissions;
- Fugitive emissions from the Corus coal beds and the Tarmac site;
- Fugitive emissions from an upaved haul road between the Corus works and the Tarmac site.

He used an estimate of the annual average background concentration of 27 µg m^{-3} taken from the air quality archive for all hours of the year.

Andrew Malby used empirical equations provided by the US Compilation of Air Pollutant Emission Factors AP42 to provide initial estimates of fugitive emissions from aggregate handling, wind erosion and from unpaved roads. The modelled results were then assessed against the measured concentrations. He demonstrated that the modelled contributions from the fugitive emissions had broadly the correct dependence on wind direction, wind speed and time of day compared with the measurements. He also showed that the modelled and measured concentrations were in reasonable agreement at the 100^{th}, 99^{th}, 90^{th} and 50th percentiles of hourly values.

He concluded that fugitive impacts at Low Santon are dominated by vehicle-raised emissions from the unpaved haul road carrying slag between the steel works and the Tarmac site.

[8] Neil Haines. Revised dispersion modelling-Corus Scunthorpe works. Reference source 109616. January 2009.

2.4 Andrew Kent, AEA and David Carslaw, Leeds University

Andrew Kent and David Carslaw[9] used the `openair` statistical package to analyse monitoring data from the Low Santon monitoring site for a period from the end of 2005 through 2007. The main purpose of the study was to show how the `openair` package can be applied to a complex source location.

They compared the variation in measured average PM_{10} and sulphur dioxide concentrations with wind direction and wind speed or time of day using bivariate polar plots provided by the `openair` package. They concluded that the pollutants had similar dependence on wind direction, wind speed and time of day. They commented that taken together, the analysis shows that for westerly winds at Santon the concentrations of sulphur dioxide and PM_{10} are likely to be dominated by the same combustion source. They further note that there are three distinct PM_{10} signatures when wind speeds are in the range 5-10 m s^{-1} from the west.

[9] Andrew Kent and David Caslaw. Analysis of air pollution in North Lincolnshire. AEA and University of Leeds. September 2008 http://www.nlincsair.info/documents/reports/128090223_NorthLincs_R_Project_Report.pdf

3 Summary of monitoring data

3.1 Introduction

Monitoring data from the Low Santon and High Santon monitoring sites provides the basis for the assessment of PM_{10} concentrations in the vicinity of the Low Santon site. In addition, measurements from monitoring sites at Rowland Road (Scunthorpe Town), Allanby Street, Appleby and Broughton have been used to provide a composite estimate of background concentrations. This section summarises measurements at these sites.

3.2 Low Santon

The Low Santon monitoring station is located (OS grid reference 492947, 411937) to the north east of Scunthorpe, on the eastern boundary of the steelworks. Dawes Lane is 5 m to the south of the monitoring station, running from a rural location in the east through the steelworks and into Scunthorpe. A raised embankment 5 m north of the site carries freight traffic along one of the major rail lines into the steelworks. The surrounding area consists of arable fields with a number of trees and to the east, a small residential area. Fig. 1 shows the location of the site on a map of the area.

PM_{10} concentrations are measured using a Rupprecht & Patterschnick TEOM 1400a analyser. The measurements commenced in October 2005 and are continuing.

Measurements made using the TEOM device are not equivalent to the gravimetric reference measurement specified in the European Directive. However, the measurements may be corrected using the Volatile Correction Model so that they are equivalent. Table 1 summarises the corrected measurements for 2007 and 2008. Data to support the use of the Volatile Correction Model is not available for earlier years.

Table 1: Summary of PM_{10} concentrations measured at the Low Santon site: Volatile Correction Model applied

	2008	2007
Annual mean, µg m^{-3}	38.0	42.5
Number of 24-hour exceedences of 50 µg m^{-3}	71	88
Days with valid daily mean	308	281
Data capture, %	84%	77%

TEOM measurements were corrected approximately by multiplying the measurements by a factor of 1.3 before the Volatile Correction Model became available. North Lincolnshire District Council's air quality review and assessment reports present results corrected using the 1.3 factor. Table 3 (below) includes data reported by the council using the 1.3 factor.

3.3 High Santon

The monitor at High Santon is located (OS grid reference 493271, 412089) in the front garden of a property in the collection of properties known as High Santon Villas, approximately 350 m to the east of the Santon TEOM site. Fig. 1 shows the location of the site on a map of the area. The site began operation in High Santon on the 5th January 2007.

Particulate matter PM_{10} concentrations are sampled using a Partisol sampler at this site. The Partisol measurements are equivalent to the gravimetric reference method. Table 2 summarises the measurements for 2007 and 2008.

Table 2: Summary of concentrations measured at the High Santon site

	2008	2007
Annual mean	31.0	30.5
Number of 24-hour exceedences of 50 µg m^{-3}	34	34
Days with valid daily mean	318	304
Data capture, %	87%	83%

3.4 Background sites

Measurements from monitoring sites at Rowland Road (Scunthorpe Town AURN), Allanby Street, Appleby and Broughton have been used to provide a composite estimate of background concentrations. All of these sites measure PM_{10} using TEOM devices. The application of the Volatile Correction Model to the composite background concentration is described in Section 5.

The Scunthorpe Town AURN site was commissioned in July 2004. The site is located adjacent to the residential properties on Rowland Road at the north- eastern end of the Scunthorpe steelworks. It is approximately 3 km WSW of the Low Santon monitor.

The Broughton site commenced operation on the 10th March 2006. The site is located within an Anglian Water enclosure within a residential area in the village of Broughton. It is approximately three km east of the steelworks site. The B1207 is 500 m west of the site and the area between this road and the steelworks is comprised of woods and fields. It is approximately 4 km south-east of the Low Santon monitor.

On the 8th February 2007 a TEOM commenced operation in Appleby Village. This site is located on a playing field in the village of Appleby. Arable fields and open field surround the village. It is 6 km northeast of Scunthorpe and 4 km north-east of the Low Santon monitor.

The Allanby Street monitoring station is located on a small patch of grass, adjacent to a local car park and close to Scunthorpe Town Centre. PM10 is monitored at this site using a TEOM 1400a. The high street is 105 m from the site and Britannia Corner; a busy road junction is 153 m away. It is approximately 1 km northwest of the steelworks site boundary and 4 km west of the Low Santon monitor.

Table 3 lists the concentrations for 2007 reported in North Lincolnshire District Council's Air Quality Progress Report, 2008.[10] The TEOM measurements were corrected using the approximate factor of 1.3.

Table 3: Summary of PM_{10} concentrations measured by TEOM: correction factor of 1.3 applied

Site	Grid reference	Annual mean	Number of exceedences of the daily limit	Hourly data capture, %
Low Santon	492947, 411937	51.1	133	90
Scunthorpe Town	490315, 410830	25.0	18	98
Broughton	496048, 409411	23.0	5	99
Appleby village	495079, 414767	24.0	8	87
Allanby Street	489273, 411446	24.1	11	100

The annual mean concentration and number of exceedences at Low Santon are substantially lower when the Volatile Correction Model is applied.

[10] http://www.nlincsair.info/documents/reports/116090223_Final_Progress_Report_2008.pdf

4 Emission sources

4.1 Introduction

This assessment considered emissions from the main sources of particulate matter emissions in the vicinity of the Santon monitoring stations. The main sources were the Corus steel works and various slag handling operations carried out by Multiserv and Tarmac.

Most of the emissions from the Corus steel works are discharged through individual chimney stacks. The modelling has represented these as point sources. The emissions from the slag handling operations and from coal handling and iron ore handling operations within the Corus plant occur over a wider area as the result of:

- Aggregate handling operations;
- Wind erosion from stockpiles;
- Movement of vehicles on unpaved roads.

The modelling represented these sources as area sources or volume sources.

This section describes how the rates of emission from each source were estimated.

4.2 Corus steel works

Corus carried out a detailed assessment of the impact on air quality of operations at the Scunthorpe plant as part of the application process for EPR Permit BL3838. The permit contains Improvement Programme Requirement 37, which requires Corus to review the air quality impact assessment on an annual basis and amend it where necessary. A revised air quality impact assessment was prepared in 2008 to take account of changes to the plant since the Permit was issued. Defra supplied AEA with a copy of a short report[11] that summarised the assessment. The assessment used a dispersion model ADMS4 to predict the contribution from the Corus plant to ground level concentrations of a range of pollutants including PM_{10}. Defra also provided AEA with copies of the input files used in the modelling study. This assessment has used the same model inputs to represent the emissions from the Corus plant, with the following exceptions:

1. The Corus coal beds and iron ore beds were treated as fugitive dust sources, below.
2. The emissions from the Queen Anne and Queen Victoria stove stacks A16-A20 with total emissions 0.088 g s^{-1} were omitted.
3. The emissions from the BBM stoking pits, A101-A125 with total emissions 0.14 g s^{-1} were omitted.
4. Other minor emissions sources, emitting less than 0.01 g s^{-1} were omitted.

Table 4 lists the point sources included in the model. It shows the height and diameter of each point source, its OS grid coordinates, discharge volumetric flow or velocity, the temperature of discharge and the average rate of emission of PM_{10} particulate matter.

Table 5 lists the Corus emissions treated as area sources. The table shows the OS coordinates of the vertices of the areas and the rate of emission. The discharge temperature and velocity were set to 15^{o}C and zero respectively.

[11] Neil Haines. Revised dispersion modelling-Corus Scunthope Works. Corus Swinden Technology Centre Reference 109616. January 2009.

Table 4: Corus point source emissions

Source	Height, m	Diameter, m	Easting, m	Northing, m	Efflux volumetric flow or velocity		Temperature, ^oC	PM_{10} emission rate, g s^{-1}
A1	107	6.7	492050	409660	607.17	m^3 s	163	24.7
A2	41	3.95	492010	409790	191.37	m^3 s	75	2.12
A3	39.8	1.37	491950	409740	7.9	m^3 s	67	0.158
A9	39.8	1.37	491980	409740	7.88	m^3 s	80	0.036
A16	61.4	2.67	491610	410380	84.59	m^3 s	248	0.044
A30	71.5	0.44	491630	410430	3.51	m^3 s	125	0.198
A32	77.8	0.39	491630	410290	5.25	m^3 s	125	0.163
A33	77.8	0.39	491630	410220	5.25	m^3 s	125	0.138
A46	20	5	491560	410390	224.76	m^3 s	43	0.339
A47	22	3	491510	410370	137.07	m^3 s	47	0.075
A48	54.9	3	491600	410250	62.66	m^3 s	69	1.92
A48b	19.5	1.2	491520	410420	3.7	m^3 s	31	0.011
A49	7.4	1.8	492350	408740	13.6	m^3 s	16	0.08
A50	7.6	0.9	492440	408810	3.23	m^3 s	19	0.019
A51	61	1.9	493060	408620	21.38	m^3 s	33	0.093
A52	45.7	1.98	492940	408650	43.13	m^3 s	32	0.835
A53	61	2.3	492860	408640	34.8	m^3 s	35	0.843
A54	76.2	2.13	492990	408610	59.57	m^3 s	57	0.191
A55	76.2	2.13	492990	408610	58.22	m^3 s	58	0.233
A56	76.2	2.13	492990	408610	54.04	m^3 s	58	0.189
A57	55	6.22	493050	408650	473	m^3 s	38	0.777
A58	45.7	3.58	492920	408640	38.47	m^3 s	28	0.978
A59	33	2.5	493190	408770	34.35	m^3 s	52	1.47
A69	27.8	2.1	492890	409010	24.85	m^3 s	51	0.046
A70	25	2.1	492810	408910	68.24	m^3 s	34	0.014
A71	38	1.83	492500	409290	28.29	m^3 s	35	0.534
A78	20	3	493300	408700	141	m^3 s	20	0.016
A81	33	4.25	493190	408770	75.9	m^3 s	100	0.091
A83	41	2.21	493190	408770	59.72	m^3 s	15	0.6
A127	54.5	2.8	492850	409400	6.35	m^3 s	284	0.049
A129	47.3	2.3	491350	411210	7	m^3 s	374	0.065
A130	54.9	2.3	491350	411210	7.2	m^3 s	435	0.067
A137	60	2.74	492850	409400	18.52	m^3 s	400	0.084
A201	96	3.8	491360	410920	133.96	m^3 s	196	0.111
A202	76.5	4.2	491580	410160	111.98	m^3 s	161	3.36
A203	76.5	4.2	491580	410080	121.3	m^3 s	171	0.061
A301	76	3.35	492060	411910	90.15	m^3 s	280	0.342
A302	74.2	3	491590	410870	77.62	m^3 s	246	1.56
A303	74.2	3	491720	411080	78.31	m^3 s	201	2.48
A308	56	1.75	492250	411600	20	m^3 s	760	---
A316	18.2	0.68	491640	410870	0.71	m^3 s	47	0.076
AFCO Pushing	0	1	491660	410970	3	m s^{-1}	200	1.2
DLCO Pushing	0	1	492100	411820	3	m s^{-1}	200	1.2

Source	Height, m	Diameter, m	Easting, m	Northing, m	Efflux volumetric flow or velocity		Temperature, ^{o}C	PM_{10} emission rate, g s^{-1}
Quench1	30.5	7.67	491980	411870	1	m^3 s	58	0.454
Quench2	34.5	6.3	491590	410850	1	m^3 s	58	0.603
Quench3	18.3	10.91	491720	411100	1	m^3 s	58	1.31

Table 5: Corus area source emissions

Source	Height, m	Easting, m	Northing, m	Area m^2	PM_{10} emission rate, g s^{-1}
DLCO Diffuse	10	492028 492034 492184 492180	411860 411882 411825 411802	3649.87	0.38
AFCO Diffuse	10	491705 491721 491593 491578	411082 411071 410871 410882	4487.67	0.41
QM/QB Diffuse	20	491578 491621 491626 491581	410500 410500 410412 410409	3960.49	2.16
QA/QV Diffuse	20	491590 491634 491641 491598	410291 410294 410196 410195	4217.04	2.52
BOS Diffuse	73	492862 493192 493176 492848	408814 408765 408670 408718	32177.06	18.73

4.3 Fugitive emission sources

Fig. 2 shows the locations of the fugitive emission sources taken into consideration in this assessment.

The coal supplied to the Corus steel plant is initially stored in stockpiles in an area to the north of the Corus plant. Typically, 2,530,000 tonnes of coal pass through the coal beds per year[12]. The coal is loaded into the stockpiles using mobile conveyor elevators. It is removed using tracked reclaimers that discharge onto conveyors feeding the coking plants. Particulate emissions arise from the loading and unloading operations and from wind erosion from the stockpiles and from cleared areas,

The ore beds handle typically 5,840,000 tonnes of material per annum. The ore is loaded into the stockpiles using tracked conveyor elevators. It is removed using tracked reclaimers that discharge onto conveyors feeding the steel works. Particulate emissions arise from the loading and unloading operations and from wind erosion from the stockpiles and from cleared areas,

The Multiserv metal recovery plant reprocesses up to 700 tonnes per hour of slag and other debris from the Corus steel works. The plant consists of a reception facility, magnetic separators, screens for product sizing and a number of troughed belt conveyors and outloading bunkers. Slag is delivered to a stockpile at the north of the site. From there it is transferred by front end loader into a partially enclosed process feed hopper. The processing operations and conveyors are enclosed. The recovered products are transferred to trucks via the outloading bunkers.

The principal sources of dust emission on site are from:

- Unloading raw material from trucks;

[12] Corus UK Limited Permit number 3838 Improvement programme reference 34 Emission source terms. July 2004.

- Loading of products into trucks;
- Wind erosion from the feed stockpile;
- Wind erosion from cleared parts of the stockpile area;
- Wind erosion from the working area of the stockpile;
- Trucks on unpaved roads.

Slag used for hot mix asphalt production is usually weathered for several months to allow for the hydration of free lime that would otherwise weaken the road coating. Part of the slag produced by the Multiserv plant (~20%) is stored in windrows in an area approximately 300 x 300 m immediately to the east of the plant. Dust emissions will occur from:

- Transfer of raw material from trucks into stockpile conveyors;
- Discharge of raw material from stockpile conveyors;
- Discharge of weathered material from front end loaders into trucks;
- Wind erosion from the stockpile;
- Wind erosion from cleared parts of the stockpile area;
- Trucks on unpaved roads.

Tarmac also stores large quantities of slag in areas north (Tarmac north) and south (Tarmac south) of Dawes Lane. Dust emissions will occur from:

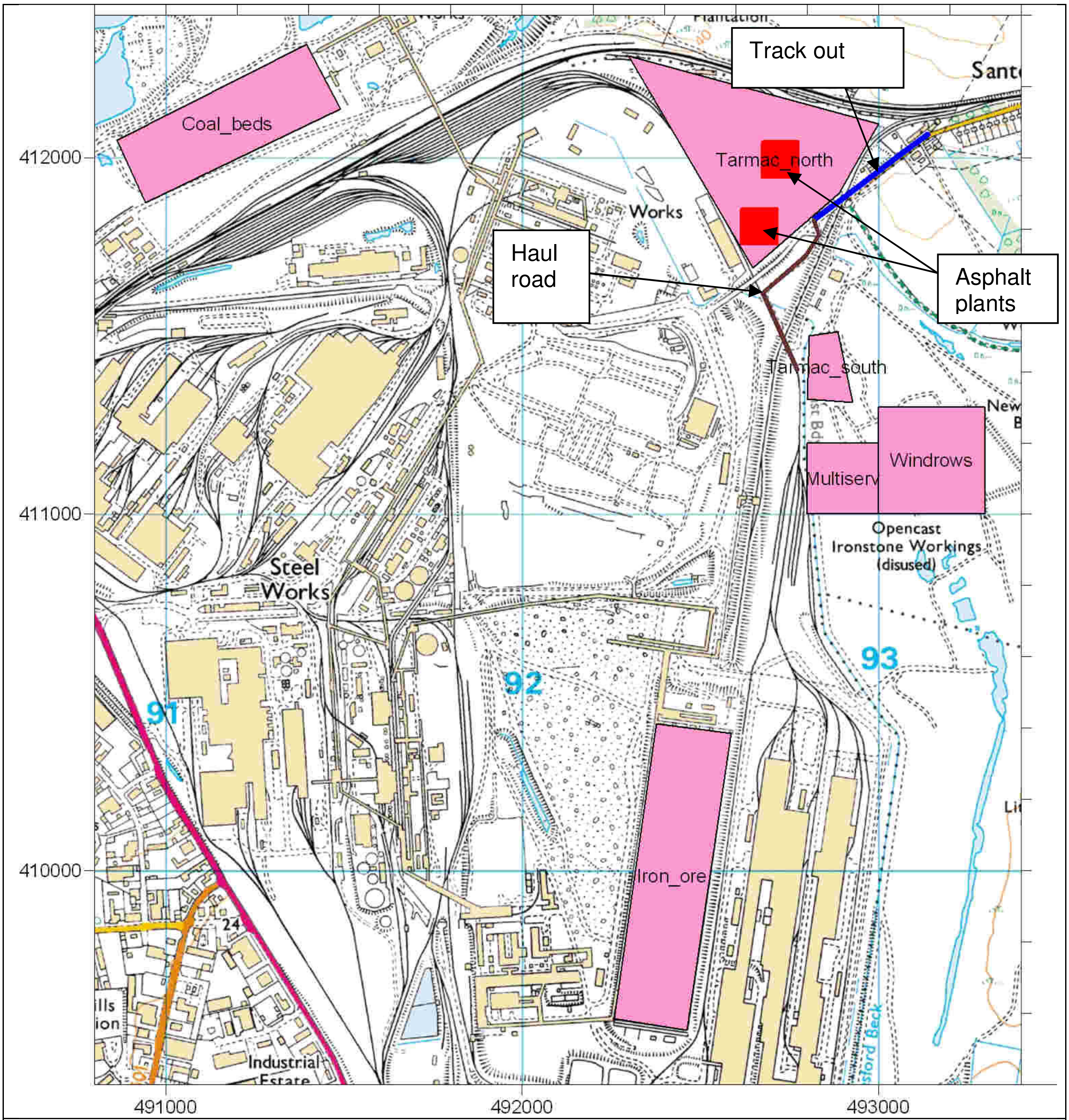
- Transfer of raw material from trucks into stockpile conveyors;
- Discharge of raw material from stockpile conveyors;
- Discharge of weathered material from front end loaders into trucks;
- Wind erosion from the stockpile;
- Wind erosion from cleared parts of the stockpile area;
- Trucks on unpaved roads.

Tarmac operates two asphalt coating plants north of Dawes Lane. Graded slag is stored in small stockpiles close to each plant. Front end loaders transfer the material into the plant feed hopper. Dust emissions will occur from:

- Transfer of raw material from trucks into stockpile conveyors;
- Discharge of raw material from stockpile conveyors;
- Discharge of weathered material from front end loaders into trucks;
- Wind erosion from the stockpile;
- Wind erosion from cleared parts of the stockpile area;

Slag from the steel works is carried in 40 tonne lorries on unpaved roads to the Tarmac site north of Dawes Lane. The lorries then cross Dawes Lane to the Tarmac site. Some of the road material is tracked out onto Dawes Lane on the tyres and as the result of spillage. Other traffic then carries this tracked out material along Dawes Lane.

Fig. 2: Fugitive emission sources considered in this assessment



4.4 Emissions from aggregate handling

The estimation of emissions from aggregate handling operations such conveyor loading and unloading is rather uncertain. The approach taken here was to use an empirical formula from AP42 to provide an initial estimate for input into the dispersion model. The initial estimate was then adjusted as described in Section to obtain near optimum agreement between the modelled and measured concentrations.

AP42 provides the following empirical formula for estimating the rate of dust emissions from aggregate handling operations[13]:

$$E = 0.0016k \frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \quad (1)$$

where E is the emission of particulate matter in kg per tonne of material handled;
k is a numerical factor dependent on particle size-0.35 for PM_{10};
U is the wind speed, m s^{-1};
M is the percentage moisture content of the feed material. AP42 provides estimates of the moisture content of coal, iron ore and slag.

The emission rate was estimated for each hour of the year, using meteorological data from Waddington. Table 6 shows the values used to evaluate the AP42 formula for each of the aggregate handling operations. It also shows the calculated total emissions based on 2008 meteorological data.

Table 6: Parameters used to estimate emissions from aggregate handling operations

Source	Throughput, tonnes h^{-1}	Hours operation per week	No. of handling operations	Moisture content, %	Annual PM_{10} emission, kg
Multiserv	700	10 hrs x 6 days	2	0.92	18029
Windrows	140	10 hrs x 6 days	3	0.92	5408
Tarmac south	140	10 hrs x 6 days	2	0.92	3606
Tarmac north	420	10 hrs x 6 days	2	0.92	10817
Asphalt east	210	10 hrs x 6 days	2	0.92	5408
Asphalt west	210	10 hrs x 6 days	2	0.92	5408
Coal beds	289	24 hrs x 7 days	4	4.8	3509
Iron ore	667	24 hrs x 7 days	4	2.2	24146

Each of the emission sources was treated as an area source with dimensions shown in Fig.2, The emissions for each hour of the year were distributed uniformly across the surface area.

4.5 Emissions from wind erosion from stockpiles

The estimation of emissions resulting from wind erosion from stockpiles is rather uncertain. The approach taken here was to use an empirical formula from AP42 to provide an initial estimate for input into the dispersion model. The initial estimate was then adjusted as described in Section 5 to obtain near optimum agreement between the modelled and measured concentrations.

[13] http://www.epa.gov/ttn/chief/ap42/ch13/final/c13s0204.pdf

AP42 provides the following empirical formula for estimating the emission of dust for wind erosion from mixtures of erodible and non-erodible surfaces subject to disturbances:

$$E_a = k \sum_{i=1}^{N} P_i \quad (2)$$

where E_a is the annual emission per unit area, g m^{-2} a^{-1};
k is a particle size multiplier, 0.5 for PM_{10};
N is the number of disturbances per year;
P_i is the erosion potential corresponding to the observed (or probable) fastest mile of wind for the ith period between disturbances, g m^{-2}.

The erosion potential function for a dry, exposed surface is:

$$P_i = 58(u^* - u_t^*)^2 - 25(u^* - u_t^*)$$
$$P_i = 0 \Leftarrow u^* \le u_t^* \quad (3)$$

where u^* is the friction velocity, m s^{-1}; and
u_t^* is the threshold friction velocity, m s^{-1}

The capacity of the stockpile areas corresponds to a few days up to a few months consumption. The stockpiles are continuously replenished so that different parts of the stockpile may have gone less than one, two, three, up to, say, 90 days since the surface was disturbed. The area of each stockpile was therefore divided into several equal parts and each part treated separately with times since disturbance of one, two, three, etc. days since disturbance.

We calculated the erosion potential for each hour of the year. Emissions were allowed if the emission potential for an hour exceeded the accumulated emissions for previous hours since disturbance: the hour's emission was then the difference between the emission potential and the accumulated emission.

AP42 provides estimates of the threshold friction velocity for coal, overburden and roadbed material. AP42 does not provide estimates of the threshold friction velocity for the slag. Taking account of the AP42 measurements and other data for soils[14], we estimate that the threshold friction velocity for the slag is likely to be approximately 1 m s^{-1} or greater.

The friction velocity at the surface of the stockpile depends on the wind speed and the shape of the stockpile. For relatively flat stockpiles, with height /length ratio < 0.2, AP42 gives $u^*=0.053U_{10}$ where U_{10} is the windspeed at 10 m above ground. AP42 divides steeper- sided stockpiles into separate parts corresponding to the level of turbulence. The top 14% of the area of the stockpile is the most exposed: AP42 gives $u^*=0.09U_{10}$ for this part of the stockpile. AP42 allocates a value of $u^*=0.06U_{10}$ for the middle 50% of the area of the stockpile part of the stockpile. The remaining part of the stockpile is allocated a value of $u^*=0.02U_{10}$.

The calculation of the erosion potential requires an estimate of the wind speed during gusts (i.e. the fastest mile of wind): we estimated this to be 1.5 times the hourly average wind speed.

On average, the area of each stockpile was assumed to correspond to 50% of the available area: i.e the stockpile corresponds to half of the available capacity. The remaining area was assumed to correspond to cleared areas of the stockpile. Materials are continuously extracted from the stockpiles so that different parts of the cleared area may have gone less than one, two, three, up to, say, 90 days since the surface was disturbed. The area of each cleared area was therefore divided into several equal parts and each part treated separately with times since disturbance of one, two, three, etc. days since disturbance.

Material is added to and extracted from the stockpiles over relatively small areas. These working areas move over the stockpile area as the material is added and removed. The time since disturbance in these areas is shorter, typically an hour or a day.

[14] http://www.wrapair.org/forums/dejf/documents/WRAP_WBD_PhaseII_Final_Report_050506.pdf

The area of the stockpiles and the working areas were estimated from aerial photographs. Table 7 lists the estimated stockpile areas and the assumed storage capacity/ time between loading operations. It also lists the values of the threshold friction velocity and the values of $u^*/U_{10.}$ Finally it lists the calculated annual emission for wind erosion from each component of the stockpiles, based on 2008 meteorology for Waddington.

Each of the emission sources was treated as an area source with dimensions shown in Fig.2, The emissions for each hour of the year were distributed uniformly across the surface area.

Table 7; Parameters used to estimate emissions from wind erosion

Stockpile	Part	Area, m^2	Threshold friction velocity, m s^{-1}	u^*/U_{10}	Storage capacity/ time since clearance, days	Annual PM_{10} emission, kg
Multiserv	Stockpile	2000	1	0.053	6	29
	Cleared	2000	0.55	0.053	6	787
	Working	600	0.55	0.053	1/24	1397
Windrows	Top	3150	1	0.09	90	422
	Middle	11250	1	0.06	90	150
	Bottom	8100	1	0.02	90	0
	Cleared	9000	0.55	0.053	30	1877
	Working	600	0.55	0.053	1/24	1397
Tarmac south	Top	3150	1	0.09	90	422
	Middle	11250	1	0.06	90	150
	Bottom	8100	1	0.02	90	0
	Cleared	9000	0.55	0.053	30	1877
	Working	600	0.55	0.053	1/24	1397
Tarmac north	Top	9450	1	0.09	90	1266
	Middle	33750	1	0.06	90	450
	Bottom	24300	1	0.02	90	0
	Cleared	27000	0.55	0.053	30	5535
	Working	1800	0.55	0.053	1/24	4191
Asphalt east	Top	84	1	0.09	7	58
	Middle	300	1	0.06	7	17
	Bottom	216	1	0.02	7	0
	Cleared	600	0.55	0.053	6	236
	Working	200	0.55	0.053	1/24	505
Asphalt west	Top	84	1	0.09	7	58
	Middle	300	1	0.06	7	17
	Bottom	216	1	0.02	7	0
	Cleared	600	0.55	0.053	6	236
	Working	200	0.55	0.053	1/24	505
Coal beds	Top	8400	1.12	0.09	30	2418
	Middle	30000	1.12	0.06	30	452
	Bottom	21600	1.12	0.02	30	0
	Cleared	60000	0.54	0.053	30	13017
	Working	4000	0.54	0.053	1	2524
Iron ore	Top	11200	1	0.09	30	4497
	Middle	40000	1	0.06	30	1603
	Bottom	28800	1	0.02	30	0
	Cleared	80000	0.55	0.053	30	16681
	Working	6000	0.55	0.053	1	2278

4.6 Trucks on unpaved roads

Slag is delivered to and collected from the Multiserv plant, the windrow area and the Tarmac stockpiles by truck. The trucks travel on unpaved roads throughout these areas. In addition trucks bring slag material to the Tarmac north along an unpaved haul road.

The estimation of emissions resulting from unpaved roads is uncertain. The approach taken here was to use an empirical formula from AP42 to provide an initial estimate for input into the dispersion model. The initial estimate was then adjusted as described in Section to obtain near optimum agreement between the modelled and measured concentrations.

AP42 provides the following empirical formula for estimating the emission of dust from vehicle traffic along unpaved roads:

$$E_k = 422.9\left(\frac{s}{12}\right)^{0.9}\left(\frac{W}{3}\right)^{0.45} \quad (4)$$

where E_k is the emission factor for PM_{10}, g veh-km^{-1};
s is the percentage silt content of the road surface material;
W is the weight of the truck in tons.

AP42 provides a range of 0.2-19% silt for unpaved roads associated with iron and steel processing, with mean of 6%. It has been assumed that the average weight of the loaded trucks is 40 tonnes and that the transport operations continue for 10 hours per day, 6 days per week.

Dust emissions from unpaved roads are suppressed by water, either as the result of rain or following watering of the road. We have assumed that dust will be suppressed if there is more than 0.254 mm rain in the preceding 24 hours. We have also assumed that the roadway is watered because this is generally accepted as best practice. AP42 indicates that the efficiency of water suppression depends on the quantities of water used. The amount of water required to obtain efficiencies above 75% increases substantially: we assumed 75% reduction in emissions.

Table 8 lists the numbers of trucks using haul roads in each area and the distance travelled. It also lists the annual emission calculated using 2008 meteorology.

Table 8; Parameters used to estimate emissions from unpaved roads

Area	Trucks per hour	Distance travelled, m	Annual emission, kg
Multiserv	20	300	2026
Windrows	4	500	675
Tarmac south	4	300	405
Tarmac north	12	800	3241
Haul road	20	500	3369

The emissions from the Multiserv, Windrow, Tarmac south and Tarmac north areas were treated as an area source distributed evenly over the area shown in Fig.2. The haul road was treated as 4 volume sources each 6 m wide and 3 m deep as shown in Fig.2 with the emissions uniformly spread along the road.

The trucks using the haul road cross Dawes Lane to get into the Tarmac north site. Dust is deposited on to the road from the truck tyres and as the result of spillage. Other vehicles travelling onto Dawes Lane then spread the dust along the road. For this assessment, we have assumed that each truck crossing the road results in an emission of 10 g of PM_{10} based on discussion by Muleski et al.[15] It was also assumed that the rate of emission decreased linearly to zero over a distance of 400 m from the crossing point, again following Muleski et al. The track out emission was represented as four 100m long volume sources, each 3 m high and 8 m wide, shown in Fig.2. The total annual track out emissions was initially estimated to be 624 kg.

[15] Muleski, G.E.; Cowherd, C; Kinsey, JS. Particulate emissions form construction activities. J Air and Waste Management Association, 55. 772-763, 2005.

5 Dispersion modelling

5.1 Introduction

We used the dispersion model ADMS4.1 to predict ground level concentrations of PM_{10} particulate matter in the vicinity of the Low Santon and High Santon monitoring sites.

ADMS4.1 is a PC-based model of the dispersion in the atmosphere of passive, buoyant or slightly dense continuous or finite duration releases from single or multiple sources. It is a state of the art dispersion model in which the boundary layer structure is characterised by the height of the boundary layer and the Monin-Obukhov length, a length scale dependent on the friction velocity and heat flux at the surface. Concentration distributions are Gaussian in stable and neutral conditions, but the vertical distribution is non-Gaussian in convective conditions to take account of the skewed structure of the vertical component of turbulence. The model contains a meteorological preprocessor that calculates the required boundary layer parameters from a variety of meteorological input data. The model can be used to calculate mean concentrations and concentration percentiles for averaging times ranging from seconds to a year.

The general approach taken was to model the contribution to ground level concentrations at the Low Santon and High Santon monitoring sites from each of the identified emissions sources based on the initial estimates of emissions described in Section 4. The contributions were then scaled to provide a good fit to the measurement data. We then ran the model with scaled emissions to predict concentrations at a grid of receptors. The predicted concentrations were then interpolated to provide contour plots (isopleths) superimposed on a map of the area. This section describes how the model was set up and adjusted and also presents the results of the modelling.

5.2 Model set up

The model used hourly sequential meteorological data for Waddington for 2007 and 2008 to represent weather conditions. The data set included measurements of wind speed and direction, temperature, cloud cover and rainfall for each hour. Waddington is approximately 50 km south of Scunthorpe.

The model used a surface roughness of 0.4 m to represent the terrain in the area of the steel works and a surface roughness of 0.1 m to represent the conditions in the vicinity of the meteorological station.

Large industrial operations such as the Corus steel works generate heat which can prevent the development of the most stable atmospheric conditions. The model took this into account by setting a lower limit for the Monin-Obkhov length of 30 m.

The emissions from aggregate handling operations and wind erosion depend on the wind speed. The emissions also depend on the hours of plant operation. Time-varying input files were prepared for the fugitive emission sources to take account of the variations in emissions. The emissions from point sources and area sources in the Corus plant (other than the coal beds and iron ore beds) were assumed to be constant with time.

The model was initially run to predict the contribution from the following sources to hourly concentrations at the Santon and High Santon monitoring sites:

- Corus steel works (excluding the coal and iron ore beds);
- Aggregate handling operations:
  - Multiserv
  - Windrows
  - Tarmac south
  - Tarmac north
  - Asphalt plant

- Coal beds
- Iron ore beds

- Wind erosion
  - Multiserv
  - Windrows
  - Tarmac south
  - Tarmac north
  - Asphalt plant
  - Coal beds
  - Iron ore beds
- Unpaved roads
  - Multiserv
  - Windrows
  - Tarmac south
  - Tarmac north
  - Haulage road, in 4 sections
- Track out along Dawes Lane, in 4 sections.

The final model runs were carried out to predict ground level concentrations at a rectangular grid of receptors at 40 m intervals over a 4 km x 4 km domain centred approximately on the Low Santon monitoring site. In addition concentrations were predicted at 10 m resolution in a 1 km x 1 km area centred on the monitoring site. The model was used to predict annual average concentrations and the number of exceedences of the 24 hour limit value of 50 µg m^{-3}. This required an estimate of background concentrations for each hour of the year. This was prepared as follows.

Monitoring data were obtained from the NorthLincsair internet site[16]. The background concentration was set to the concentration at the monitoring site depending on the wind direction and the availability of data as shown in Table 9.

Table 9: Criteria for selecting background sites

Wind direction	First choice background site	Second choice background site
0≤θ<90	Appleby Village	Broughton
90≤θ<180	Broughton	Appleby Village
180≤θ<270	Scunthorpe Town	Allanby Street
270≤θ≤360	Appleby Village	Broughton

All these monitoring stations use TEOM devices to measure PM_{10} concentrations. The TEOM device does not provide measurements that are comparable with the gravimetric reference standard. However, the measurements may be adjusted using the Volatile Correction Method to provide measurements that comply with the gravimetric reference standard. Daily average concentrations were calculated from the hourly values where there were more than 17 measurements in the day. Daily average values were then corrected using the Volatile Correction for Scunthorpe Town, taking account of the 1.3 approximate adjustment factor already applied to the reported TEOM measurements. The daily background concentrations were then compared to the Partisol measurements from High Santon. The background values were replaced by the High Santon value for wind directions 0-180 degrees, where there was a valid Partisol measurement. These values were used in the model adjustment described below. For the final model runs, the background values were replaced by the annual mean background value for those days when there was no valid measurement. Finally, all the background concentrations for all the hours in each day were set to the daily average value.

5.3 Model adjustment

This section describes the method used to adjust the model to provide a good fit with the measured concentrations.

16 http://www.nlincsair.info/

Daily average concentrations for the Low Santon monitoring site were calculated from the hourly values where there were more than 17 measurements in the day. Daily average values were then corrected using the Volatile Correction Model, taking account of the 1.3 approximate adjustment factor already applied to the reported TEOM measurements.

The background concentrations for each day were then subtracted from the Low Santon values to provide a “non-background” concentration. The background concentrations were similarly subtracted from the High Santon Partisol measurements to provide “non-background” concentrations for that site.

The “non-background” concentrations were then allocated to 18 “bins” according to the median wind direction on each day (30-90degrees, 90-150 degrees, 150-210 degrees, etc.) and the maximum daily wind speed (<4 m s^{-1}, 4-7 m s^{-1}, >7 m s^{-1}). High concentrations are expected in the low wind speed category for fugitive emission sources that are independent of wind speed (unpaved roads); high concentrations are expected in the high wind speed category from wind erosion sources.

The modelled contributions from the following source groups were then summed for each hour:

- Corus plant (excluding the coal and ore beds);
- Aggregate handling operations, excluding the asphalt plants;
- Aggregate handling operations at the asphalt plants;
- Wind erosion;
- Unpaved roads, excluding the haul road;
- The haul road;
- Track out.

Daily average contributions were then calculated for each source group provided that there were more than 17 valid hourly model predictions. The contribution from each source group was then multiplied by a calibration factor, initially set to unity. The total contribution was then calculated as the sum of the modelled contributions multiplied by the appropriate calibration factors. The modelled contributions were then allocated to the same “bins”. “Non-background” and modelled contributions were only allocated to “bins” where there was both a non-background value and a modelled value for the same day.

The total modelled concentrations were also calculated as the modelled contribution plus the background value. The number of measured exceedences, n, of the 24 hour limit value was then calculated for those days when both measured and modelled estimate were available. The nth largest total modelled concentration was then calculated.

The mean concentrations were then calculated for each of the “bins” for both the modelled contribution and the “non-background” concentration. The number of days in each bin was also counted.

These calculations were carried out for the monitoring data for Low Santon and for High Santon for 2007 and 2008. There was not adequate data for earlier years because the High Santon site was not operating and no Volatile Correction data were available.

The aim was then to select values for the calibration factors to minimise the scalar cost function:

$$J = \sum_k \left\{ \sum_i m_{ik}(x_{ik} - y_{ik})^2 + (r_k - s_k)^2 \sum_i m_{ik} \right\}$$

Where k is an element of the set, {Low Santon 2007, Low Santon 2008, High Santon 2007, High Santon 2008};
i is the “bin”;
m_{ik} is the number of valid days in bin i in data set k
x_{ik} the average of the measured non-background concentrations in bin i for data set k;
y_{ik} the average of the modelled contributions in bin i for data set k;

j_{ik} the average of the modelled contributions in bin i for data set k;
r_k is the n^{th} largest measured concentration;
s_k is the n^{th} largest total modelled concentration.

The minimisation was carried out using the Excel Solver function. Calibration factors less than zero were not permitted. The contribution from the Corus plant (except the coal ad iron ore beds) was not adjusted.

The model adjustment process was intended to take account the differences in the contribution from different sources associated with wind speed and wind direction. As such it can discriminate, to some extent, between sources. However, it is not always possible to discriminate in this way between sources that are close together or have similar dependency on wind speed. In practice, the algorithm allocates all the impacts to a single source where there are similar sources.

The chosen calibration factors were as follows:

Aggregate handling other than asphalt plant:	1.376
Aggregate handling at asphalt plant	0.002
Erosion	2.274
Unpaved roads, other than the haul road	0
Haul road	4.900
Track out onto Dawes Lane	0.730

This should not be interpreted that the unpaved roads and the asphalt plant aggregate handling do not contribute: their contributions just have similar patterns to other sources.

5.4 Model results

Table 10 lists the contributions from each of the modelled sources to annual mean concentrations at the Low Santon and High Santon monitoring sites. It lists the modelled concentrations with and without adjustment to fit the measured data. Emissions associated with Tarmac north site on Dawes Lane (from aggregate handling, wind erosion, unpaved haul roads and track out) together make the largest contribution. The Corus steel works also makes a substantial contribution.

Table 10: Modelled contributions to annual mean PM_{10} concentrations at the monitoring sites, $\mu g\ m^{-3}$

Source type	Location	Without adjustment				With adjustment			
		2008		2007		2008		2007	
		Low Santon	High Santon	Low Santon	High Santon	Low Santon	High Santon	Low Santon	High Santon
Corus steel works (sources listed in Tables 4 and 5)		6.97	5.36	7.13	5.37	6.97	5.36	7.13	5.37
Aggregate handling	Multiserv	0.27	0.36	0.19	0.29	0.37	0.50	0.26	0.39
	Windrows	0.06	0.08	0.05	0.06	0.08	0.11	0.07	0.08
	Tarmac south	0.17	0.16	0.13	0.13	0.23	0.22	0.18	0.18
	Tarmac north	4.03	0.73	4.50	0.66	5.55	1.00	6.19	0.90
	Asphalt east	1.23	0.37	0.22	0.05	0.00	0.00	0.00	0.00
	Asphalt west	1.30	0.32	0.18	0.04	0.00	0.00	0.00	0.00
	Coal beds	0.02	0.03	0.03	0.02	0.02	0.04	0.04	0.03
	Iron ore	0.17	0.23	0.15	0.16	0.24	0.31	0.20	0.23
Wind erosion	Multiserv	0.04	0.04	0.02	0.02	0.08	0.08	0.03	0.05
	Windrows	0.05	0.05	0.02	0.03	0.10	0.11	0.04	0.06
	Tarmac south	0.03	0.03	0.02	0.02	0.08	0.06	0.05	0.05
	Tarmac north	1.81	0.37	1.95	0.42	4.11	0.84	4.43	0.95
	Asphalt east	0.07	0.03	0.07	0.03	0.16	0.07	0.15	0.06
	Asphalt west	0.13	0.03	0.13	0.03	0.30	0.07	0.29	0.07
	Coal beds	0.01	0.01	0.00	0.00	0.02	0.02	0.01	0.01
	Iron ore	0.09	0.10	0.01	0.02	0.21	0.23	0.03	0.03
Unpaved roads	Multiserv	0.03	0.04	0.03	0.04	0.00	0.00	0.00	0.00
	Windrows	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
	Tarmac south	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00
	Tarmac north	1.47	0.21	2.10	0.28	0.00	0.00	0.00	0.00
Haul road S to N	1 (237 m)	0.17	0.08	0.16	0.07	0.82	0.41	0.78	0.34
	2 (160 m)	0.21	0.06	0.19	0.05	1.04	0.28	0.91	0.25
	3 (67 m)	0.16	0.03	0.15	0.03	0.80	0.15	0.72	0.14
	4 (50 m)	0.18	0.02	0.16	0.02	0.88	0.11	0.78	0.11
	Total	0.72	0.19	0.65	0.17	3.53	0.95	3.19	0.84
Track out E to W	1	0.62	0.04	0.56	0.04	0.45	0.03	0.41	0.03
	2	2.40	0.05	2.05	0.05	1.75	0.03	1.49	0.03
	3	0.30	0.05	0.29	0.06	0.22	0.04	0.21	0.04
	4	0.02	0.06	0.02	0.07	0.02	0.04	0.02	0.05
	Total	3.33	0.19	2.92	0.21	2.43	0.14	2.13	0.15

Table 11 shows the modelled number of exceedences at the Low Santon and High Santon sites. It shows the effect of removing the contributions from specified emission sources.

Table 11: The effect of removing emissions from sources on the number of exceedences of the PM_{10} daily limit value

Removed sources	2008		2007	
	Low Santon	High Santon	Low Santon	High Santon
None	73	10	70	20
Corus (sources listed in Tables 4 and 5)	41	8	37	10
Aggregate handling	49	9	42	13
Wind erosion	43	7	51	18
Haul road	38	9	43	17
Track out	64	9	65	19
All fugitive	4	6	12	9
All modelled	3	5	5	5
Number of days modelled	284	292	255	236

Fig.3 shows the modelled number of exceedences of the daily limit value of 50 µg m^{-3} for 2008 plotted as isometric lines on a map of the area based on modelled concentrations at 40 m spatial resolution. Fig.4 shows model predictions at the increased resolution of 10 m in the vicinity of the Santon monitoring site for 2008 meteorology. Fig. 5 shows model predictions for 2007 meteorology at 10 m resolution.

The modelled number of exceedences at Low Santon in Figs, 3-5 is greater than shown in Table 11 because when calculating exceedences, the ADMS4.1 model :

- requires the user to provide background concentrations for each hour of the year (see Section 5.2);
- calculates concentrations for each hour of the year for which meteorological data is available;
- increases the modelled number of exceedences pro-rata to take account of missing meteorological data.

Fig. 6 shows the modelled annual mean concentration for 2008 plotted as isopleths on a map of the area based on modelled concentrations at 40 m spatial resolution. Fig. 7 shows model predictions at 10 m resolution in the vicinity of the Santon monitoring site for 2008 meteorology. Fig. 8 shows model predictions for 2007 meteorology at 10 m resolution.

Fig. 3: Modelled number of exceedences of the 50 µg m^{-3} PM_{10} limit value, 2008 at 40 m resolution

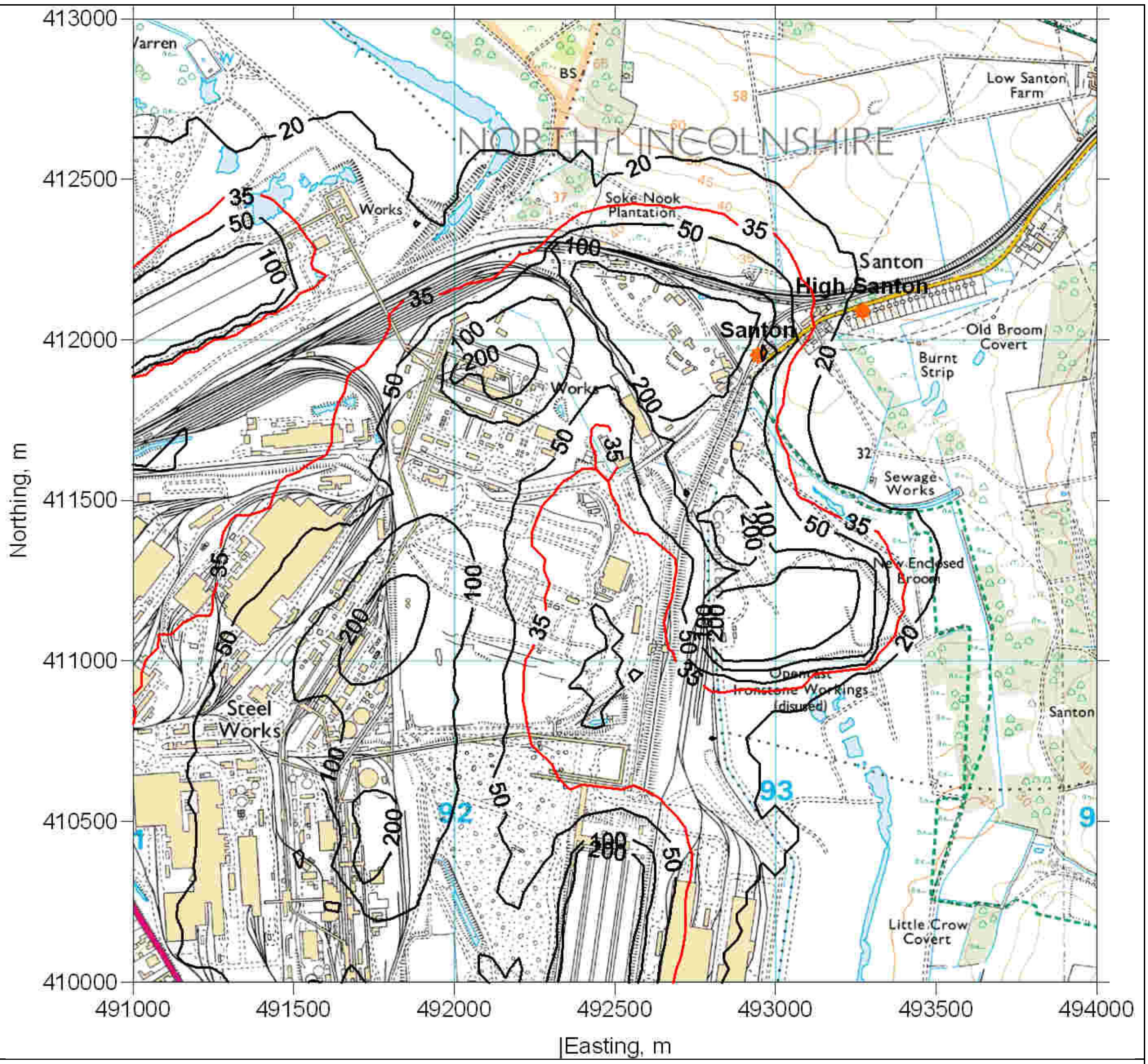


Fig. 4: Modelled number of exceedences of the 50 µg m^{-3} PM_{10} limit value, 2008 at 10 m resolution

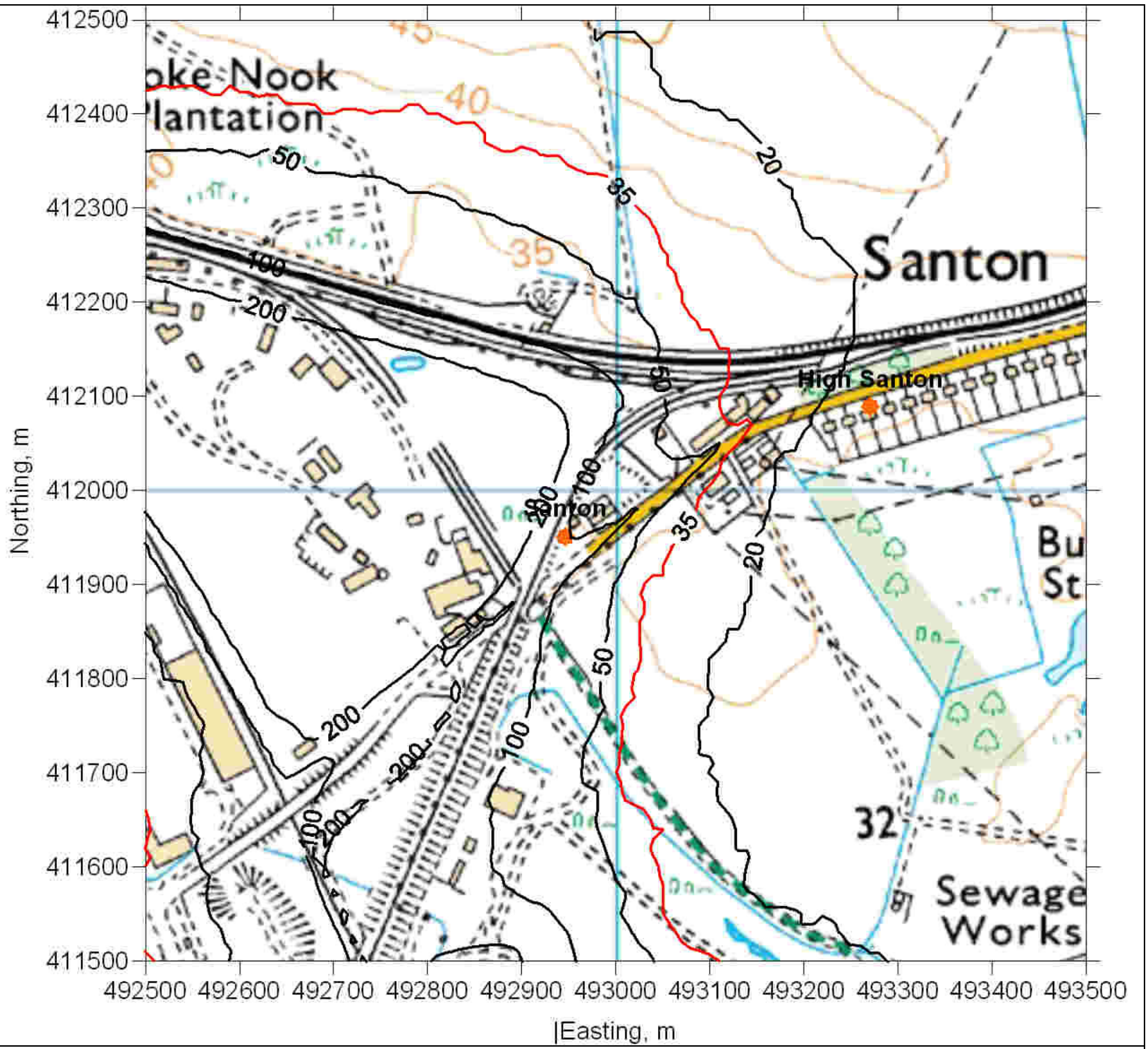


Fig. 5: Modelled number of exceedences of the 50 µg m^{-3} PM_{10} limit value, 2007 at 10 m resolution

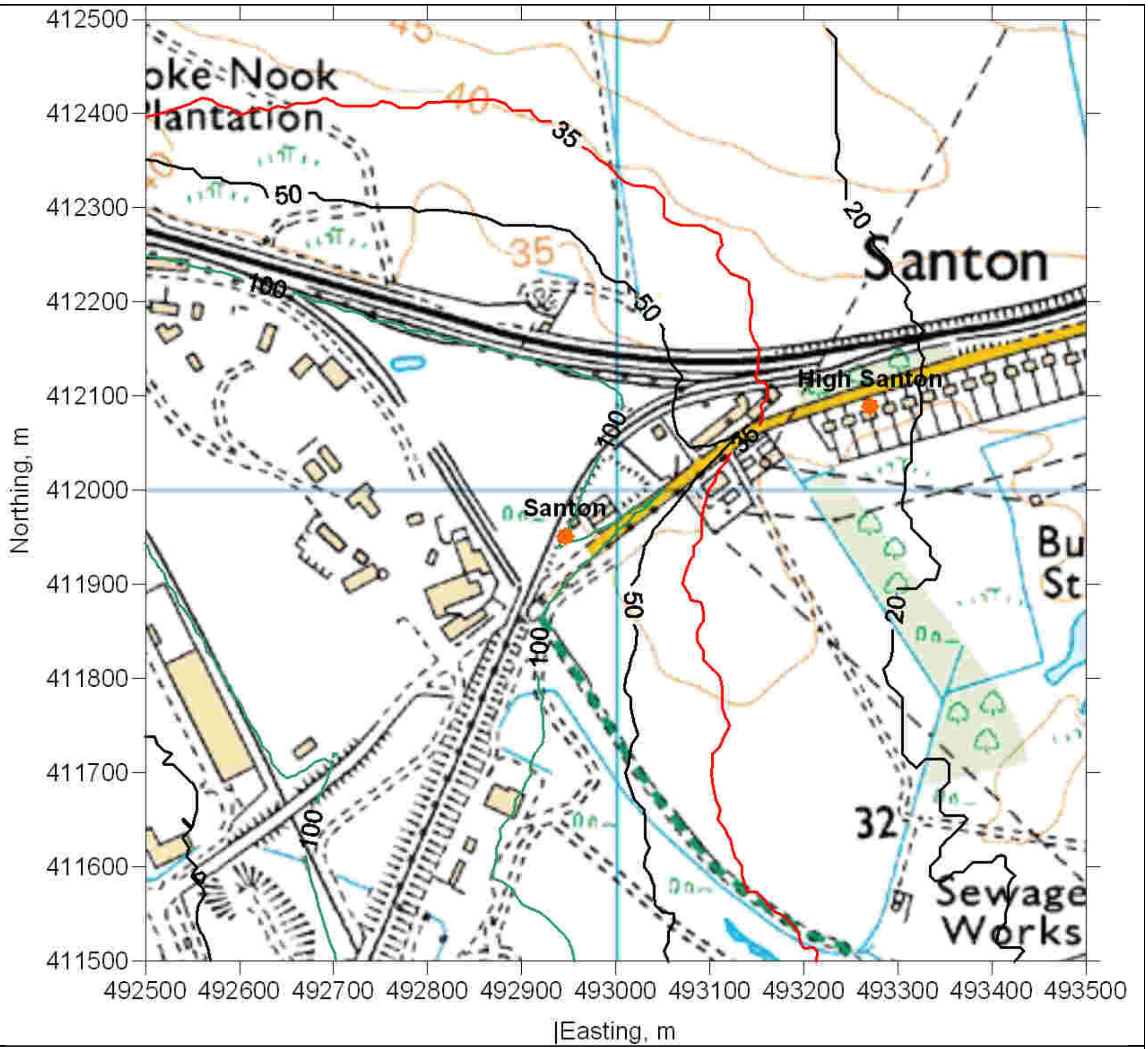


Fig. 6: Modelled annual mean PM_{10} ($\mu g\ m^{-3}$), 2008 at 40 m resolution

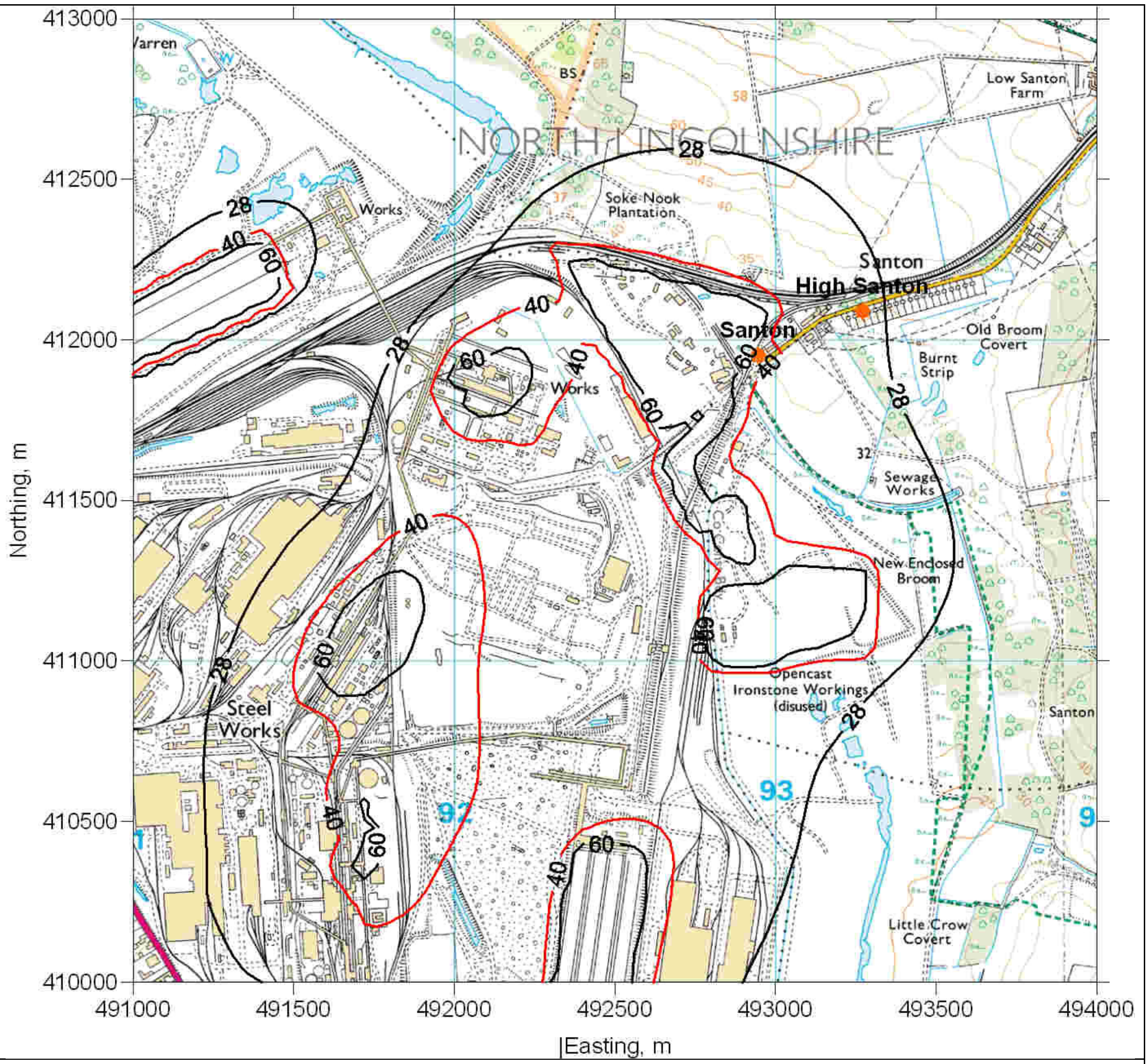


Fig. 7: Modelled annual mean PM_{10} (µg m^{-3}), 2008 at 10 m resolution

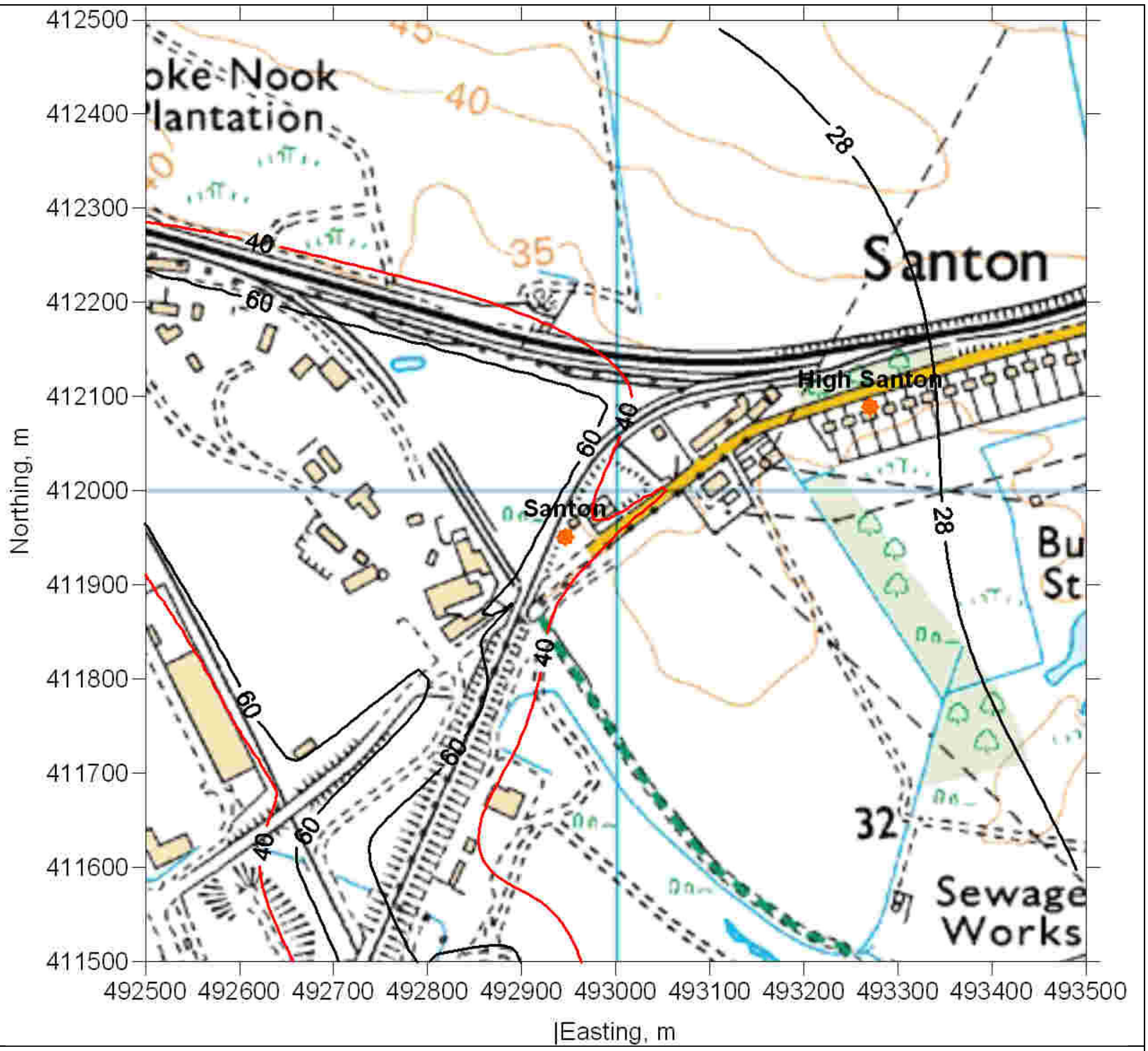
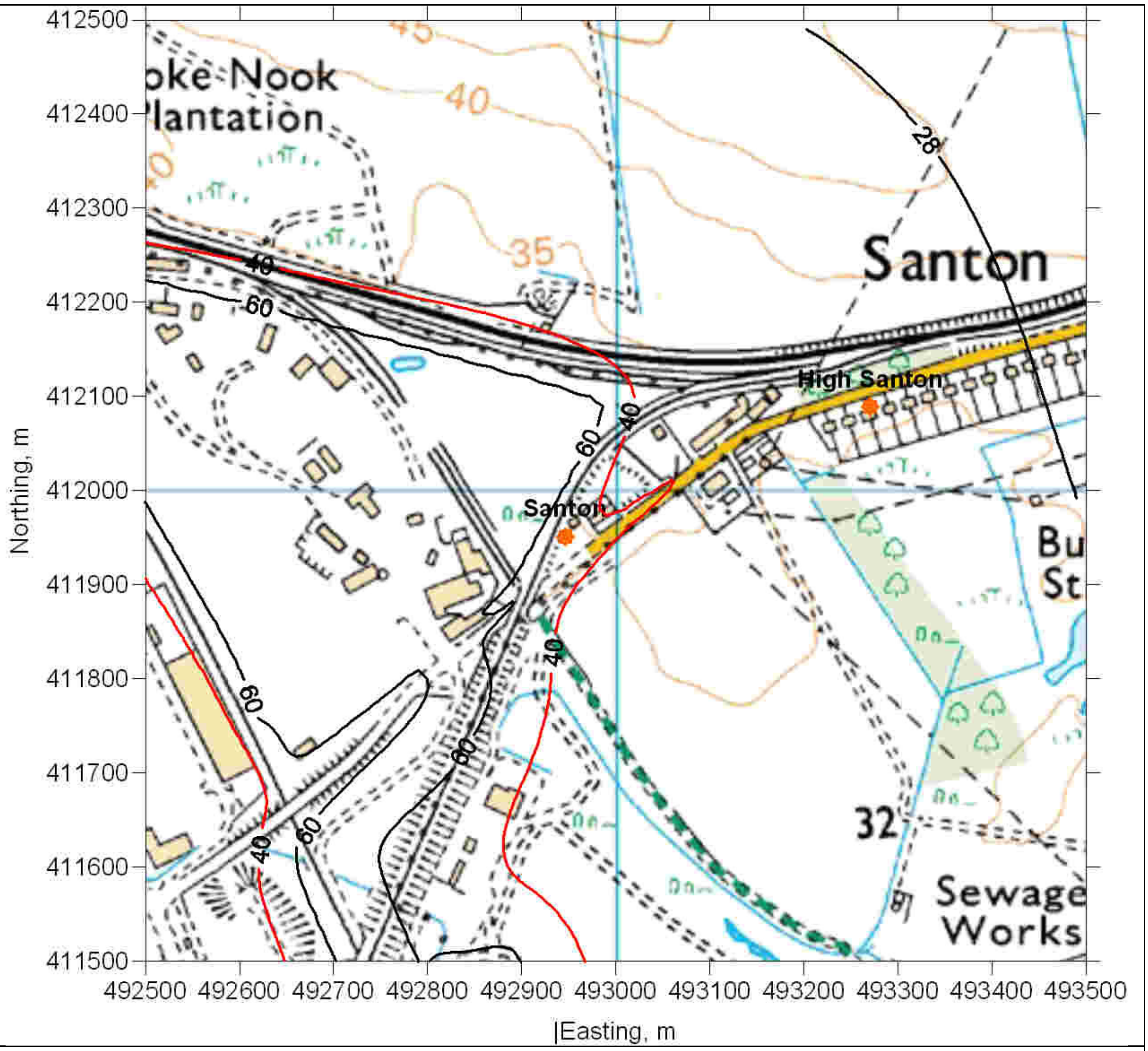


Fig. 8: Modelled annual mean PM_{10} (µg m^{-3}), 2007 at 10 m resolution



6 Discussion

6.1 Model uncertainty

Annex 1 of Directive 2008/50/EC on ambient air quality and cleaner air for Europe sets data quality objectives for modelling uncertainty. The Annex specifies that the difference between the observed and modelled annual mean should be less than 50% of the limit value at 90 % of measurement sites. Table lists the observed and modelled average concentrations. The difference between the observed and modelled concentrations was 11% or less at both monitoring stations in both years of the assessment. The model meets the annual mean data quality objective.

The definition for the data quality objective for modelling uncertainty for daily means provided by the Directive is ambiguous with respect to the daily mean objective. The Forum for Air Quality Modelling in Europe (FAIRMODE) Guidance on the use of models for the European Air Quality Directive defines a Relative Directive Error (RDE)[17]. Table12 lists the values of the RDE calculated for the Low Santon and High Santon monitoring sites. Annex 1 of the Directive has not yet defined a data quality objective for the daily mean PM_{10} concentration. The objective for several other pollutants is 50%. The model would meet a similar objective if it were applied to PM_{10}.

The Model Intercomparison Protocol developed by AEA for Defra indicates that a model would be considered unsatisfactory if more than 50% of modelled values were outside the range 50-200% of the measured values. It also indicates that the normalised mean bias[18] should lie within the range -0.2 to +0.2. The fraction within a factor of two and the normalised mean bias are also shown in Table 12. The model performance is acceptable according to these criteria.

Table 12: Summary of model performance

Data set	No. of days	Mean			No. of exceedences		Fraction of days within a factor of 2, %	Normalised mean bias	Relative Directive Error, %
		Measured	Modelled	Difference/ Limit value, %	Measured[19]	Modelled			
Low Santon 2008	284	38.0	42.3	11	63	73	87	0.10	6
High Santon 2008	292	30.4	28.8	4	27	10	91	-0.06	15
Low Santon 2007	255	42.9	42.7	1	82	70	80	-0.02	6
High Santon 2007	236	30.2	33.2	8	29	20	82	0.09	6

Figs. 9-12 show scatter plots of total modelled vs measured daily average concentrations at Low Santon 2008, High Santon 2008, Low Santon 2007 and High Santon 2007. Objective assessment of

[17] http://fairmode.ew.eea.europa.eu/fol404948/Model_guidance_document_v5_1a.pdf

$$RDE = \frac{|O_{LV} - M_{LV}|}{LV}$$

where O_{LV} is the closest observed daily measured concentration to the limit value (LV) and M_{LV} is the correspondingly ranked model concentration.

[18] Calculated as the sum of model differences from the observed values divided by the sum of the observed values

[19] The number of exceedences is less that shown in Table 1 because modelled concentrations were not available on all days because the meteorological data was unsatisfactory or background concentrations were not available. The number of exceedences shown here corresponds to days when both measured and modelled concentrations were available.

scatter plots is difficult: our subjective assessment is that the model performance in this respect is satisfactory.

Table 13 lists the numbers of days with concentrations in excess of 50 µg m^{-3} categorized by median wind direction and maximum hourly wind speed for modelled and measured concentrations at the Low Santon site.

Table 13: Comparison of the numbers of exceedences of the PM_{10} daily limit value at Low Santon categorized by wind direction and wind speed

Median wind direction, degrees	Maximum hourly wind speed, m	Total 2007-2008		2008		2007	
		Measured	Modelled	Measured	Modelled	Measured	Modelled
330-30	<4	0	0	0	0	0	0
30-90		0	0	0	0	0	0
90-150		1	2	1	2	0	0
150-210		0	1	0	0	0	1
210-270		6	6	0	2	6	4
270-330		3	1	1	0	2	1
330-30	4-7	0	1	0	0	0	1
30-90		1	3	0	2	1	1
90-150		1	3	0	1	1	2
150-210		10	4	3	2	7	2
210-270		40	42	18	20	22	22
270-330		4	2	1	0	3	2
330-30	>7	0	0	0	0	0	0
30-90		2	0	0	0	2	0
90-150		0	2	0	0	0	2
150-210		22	15	11	8	11	7
210-270		52	56	28	33	24	23
270-330		3	4	0	3	3	1

Fig. 9: Scatter plot of modelled vs measured daily mean concentrations –Low Santon 2008

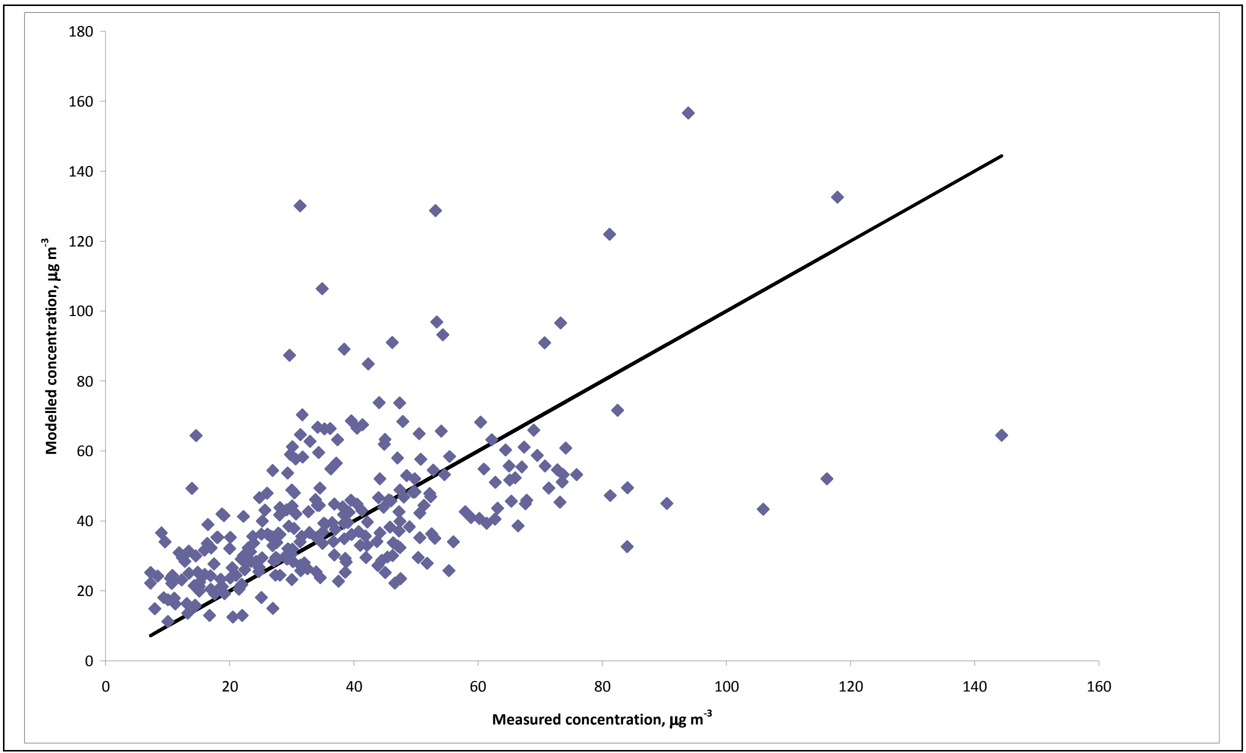


Fig. 10: Scatter plot of modelled vs measured daily mean concentrations –High Santon 2008

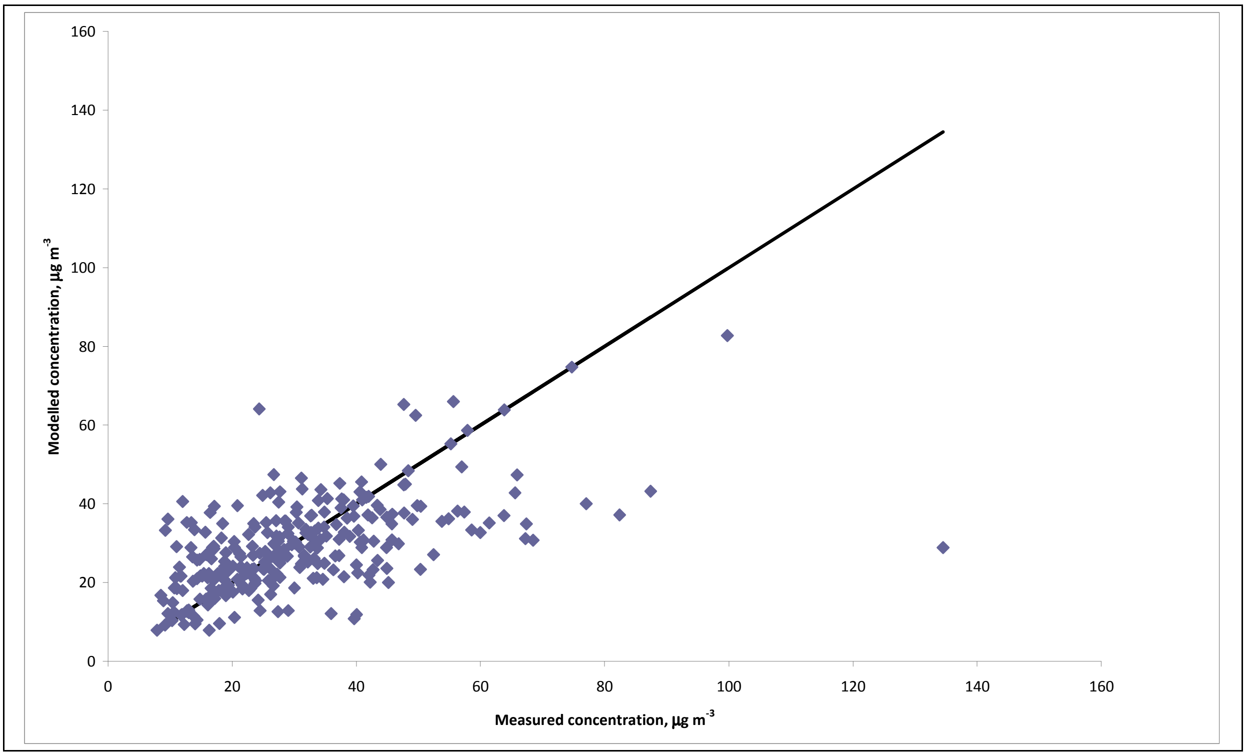


Fig. 11: Scatter plot of modelled vs measured daily mean concentrations –Low Santon 2007

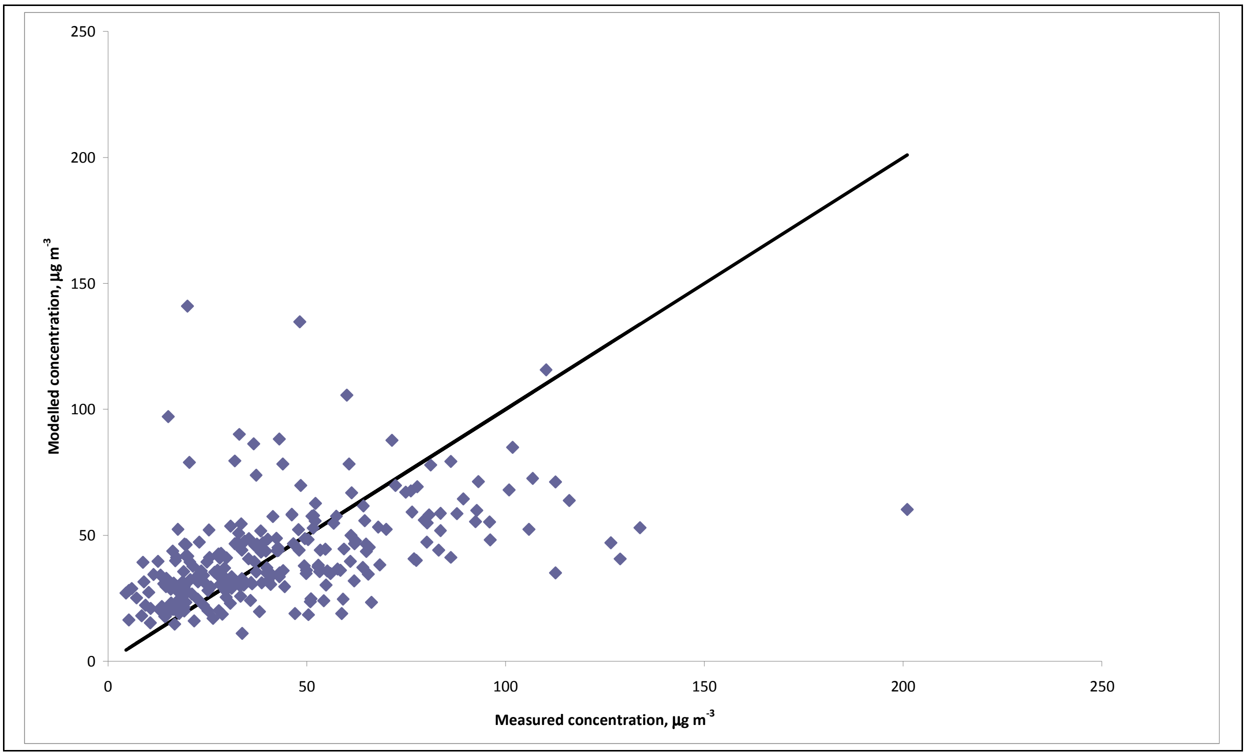
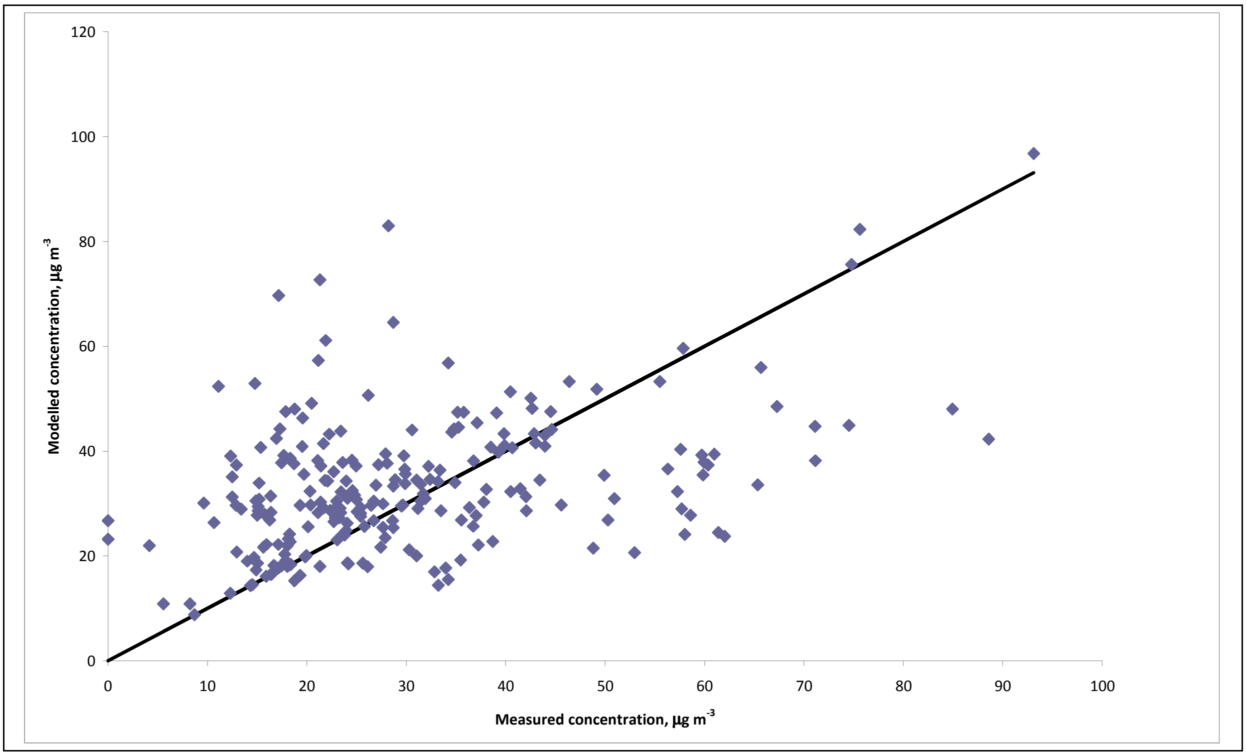


Fig. 12: Scatter plot of modelled vs measured daily mean concentrations –High Santon 2007



6.2 Source apportionment

Table 10 shows the modelled contributions to annual mean concentrations at the Low Santon and High Santon monitoring sites for both the unadjusted and adjusted model. The adjusted model indicates that the following sources make the greatest contributions:

- Corus steelworks
- Tarmac north aggregate handling
- Tarmac north wind erosion
- Haul road
- Track out onto Dawes Lane

All of these except the Corus steel works are associated with the Tarmac north site on Dawes Lane. Taken together, the operations at the Tarmac north site make the largest contributions to annual mean concentrations at the monitoring sites.

The model adjustment process was designed to take into account the differences in the contribution from different sources associated with wind speed and wind direction. As such it can discriminate, to some extent, between sources allowing the concentration to be apportioned between sources. However, the analysis is ill-conditioned for those sources that that are close together in direction from the monitors and have similar dependency on wind speed. Thus the contribution from unpaved roads, other than the haul road, has been allocated in the model adjustment process to other sources. Nevertheless, the unadjusted results in Table 10 indicate that the Tarmac north site is also the largest unpaved road contributor to concentrations at the monitoring sites.

Table 11 shows the effect of removing emissions from the main sources on the number of exceedences of the daily mean limit. Emissions from the steel works and fugitive emissions associated with the Tarmac operation both add substantially to the number of exceedences.

6.3 Area of exceedence of air quality objectives

The measurements of PM_{10} concentrations at the Santon monitoring site exceeded both the annual mean and daily mean objectives. The modelling results shown in Figs.3-8 provide the basis for assessing the area over which the objectives are exceeded.

Fig. 3 indicates that the daily mean limit value of 50 µg m^{-3} is exceeded more than 35 times in a year over much of the Corus site including near the coal beds and the iron ore beds and also near the Tarmac and Multiserv operations. Much of this area lies within industrial sites: members of the public should not have access and there is no fixed habitation. Annex III of Directive 2008/50/EC excludes areas where members of the public do not have access and there is no fixed habitation

Figs 4 and 5 provide greater detail of the area around the Low Santon monitor and show an area of exceedence outside the boundaries of the industrial works. The results for the two modelled years are similar, with the 2007 results indicating the greater area of exceedence.

Fig.13 shows the areas of exceedence based on the 2007 modelling results and bounded by the boundaries of the Corus site, the Tarmac site and the railways. The area to the north of the Tarmac site is 104,750 m^2. The area to the south of the Tarmac north site is 54,450 $m^{2.}$ The area to the north is agricultural and there is no public access by road or footpath. The area to the south includes residential properties, common land, Dawes Lane, agricultural areas, a public footpath, a haulage yard and part of an industrial estate. Fig .14 shows the main uses of the land within the southern area of exceedence. Table 14 lists the areas.

Table 14: Areas of exceedence of the PM_{10} daily limit value

Area	Use	Area, m^2
North of Tarmac site	Total	104,750
	Agricultural	104,750
South of Tarmac site	Total	54,450
	Agricultural	39,800
	Haulage yard	3,550
	Industrial estate yard	3,700
	Public access	7,400

Annex III of Directive 2008/50/EC states that sampling points shall in general be sited in such a way as to avoid measuring very small micro-environments in their immediate vicinity, which means that a sampling point must be sited in such a way that the air sampled is representative of air quality for a street segment no less than 100 m length at traffic-orientated sites and at least 250 m × 250 m (62,500 m^2) at industrial sites, where feasible. The area of non-agricultural land in the identified area of exceedence is less than the 250 x 250 m. The total area of exceedence is greater than 250 x 250 m.

Fig. 5 indicates that the annual mean limit value of 40 µg m^{-3} is exceeded over much of the Corus site including near the coal beds and the iron ore beds and also near the Tarmac and Multiserv operations. Figs 6 and 7 provide greater detail of the area around the Santon monitor and show a small area of exceedence outside the boundaries of the industrial works. The results for the two modelled years are similar, with the 2007 results indicating the greater area of exceedence. The area of exceedence is considerably less than the area of exceedence of the daily mean objective.

Fig. 13: Areas of exceedence of the daily limit value outside the Corus and Tarmac works, 2007

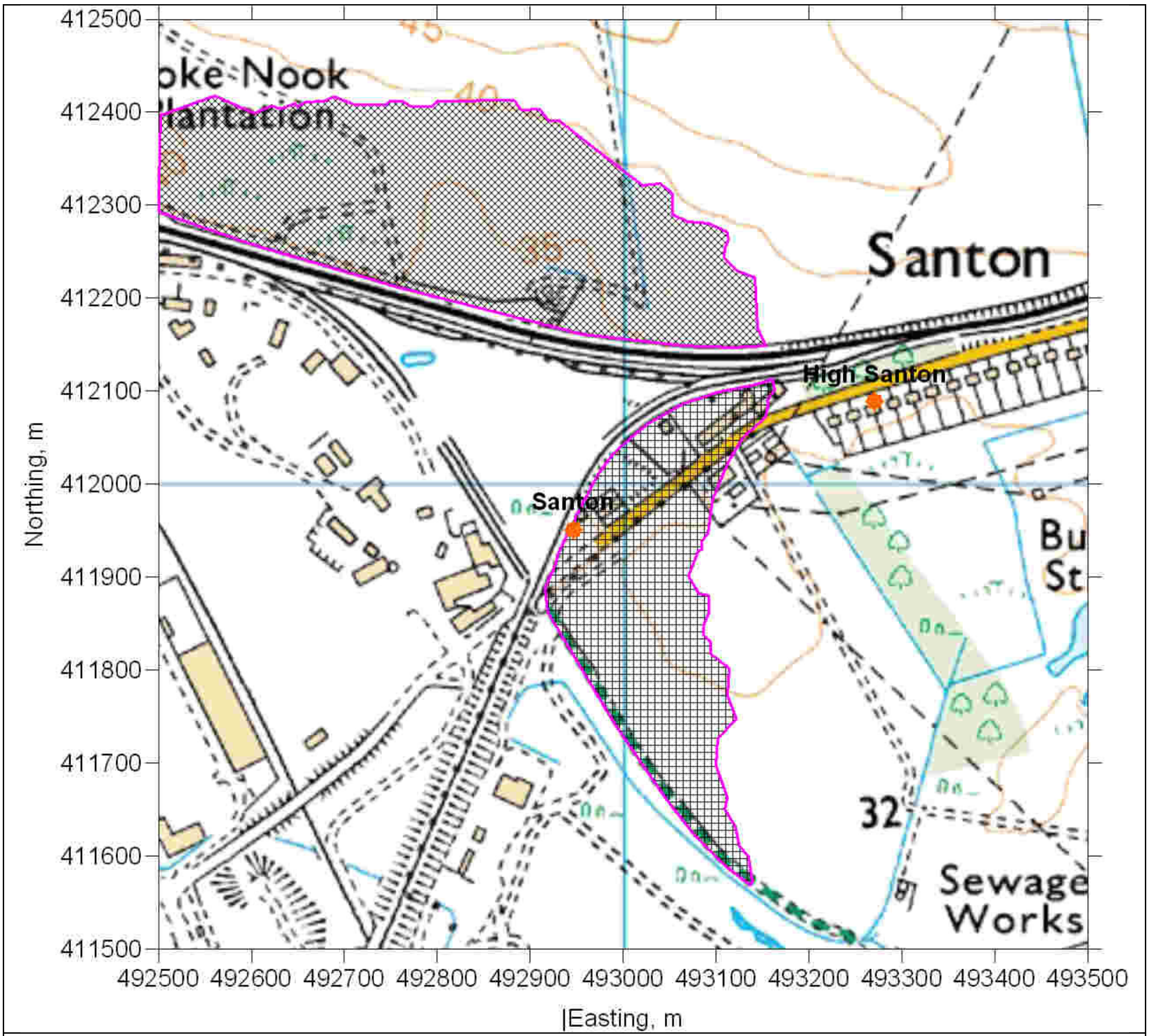
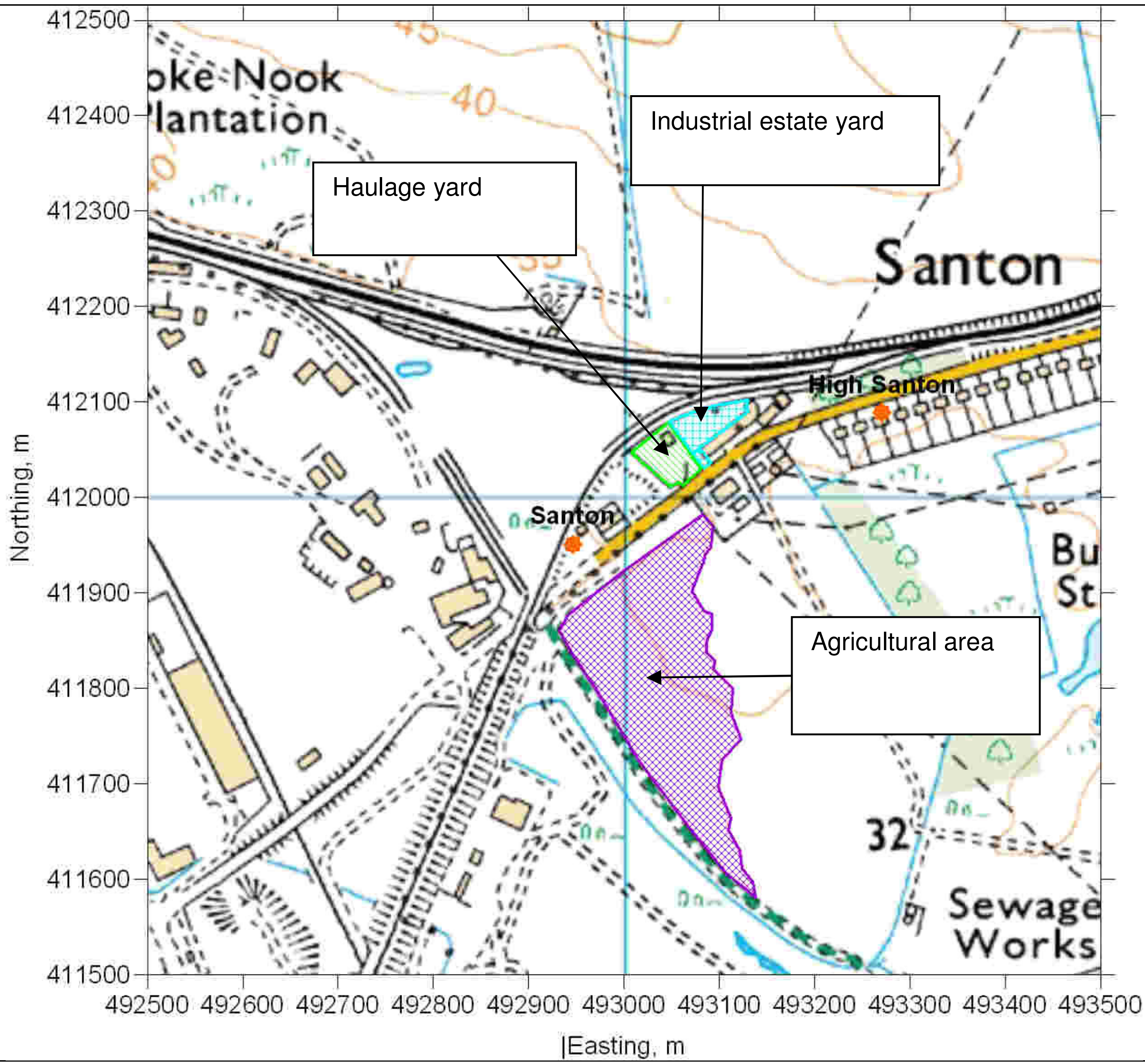


Fig. 14: Agricultural and industrial areas within the area of exceedence



7 Conclusions

Measurements of PM_{10} concentrations at the Low Santon site indicate that the Limit Values for the annual mean concentration and the daily mean concentration are exceeded. Various studies involving the analysis of monitoring data and dispersion modelling have previously been carried out by North Lincolnshire District Council, Corus, Lancaster University, AEA and Leeds University. These studies have attributed the high concentrations to emissions from the Corus steel works, fugitive emissions from the Tarmac slag handling operation and fugitive emissions from the unpaved haul road between the Corus works and the Tarmac slag handling operations.

The dispersion model ADMS4.1 was used to predict the contributions to ground level concentrations from the Corus plant and from fugitive emission sources, based on initial estimates of fugitive emissions derived using the methods described in the US Compilation of air pollutant emission factors, AP42. We adjusted the initial estimates of fugitive emissions to give “best” agreement with the monitoring results taking account the effects of wind direction and wind speed. The model performance compared to the measurements was acceptable when tested against a range of criteria:

CAFÉ Directive data quality objective for the annual mean
FAIRMODE Relative Directive Error for the daily mean values
AEA Model Intercomparison Protocol Normalised Mean Bias
AEA Model Intercomparison Protocol Factor of 2
Scatter plots of measured vs modelled daily mean values
Wind speed and direction dependence.

The model indicates that the following sources make the greatest contributions to annual mean concentrations in the vicinity of the Low Santon monitor:

Corus steelworks
Tarmac north aggregate handling;
Tarmac north wind erosion;
Haul road
Track out onto Dawes Lane

Taken together, the operations at the Tarmac site make the largest contributions to annual mean concentrations at the monitoring sites. Emissions from the steel works and fugitive emissions associated with the Tarmac operation both add substantially to the modelled number of exceedences of the daily mean limit.

The model indicates that the daily mean limit value of 50 µg m^{-3} will be exceeded more than 35 times in a year over an area greater than 150,000 m^2 outside of the boundaries of the Corus and Tarmac sites. The area can be compared with the macroscale siting criterion given in the CAFÉ Directive that the sampling site should be representative of an area of at least 250 m × 250 m (62,500 m^2) at industrial sites, where feasible.

The modelling also indicates that the annual mean limit value is exceeded at the Low Santon site. The area of exceedence is much smaller than that for the daily mean.

AEA group
The Gemini Building
Harwell IBC
Didcot
Oxfordshire
OX11 0QR

Tel: 0870 190 6401
Fax: 0870 190 6318