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Air quality assessment for Cycle Enfield A105 proposals

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1 Summary

Cycle Enfield is proposing to introduce segregated cycle lanes along the A1010, A105 and A110, including changes to the road layout in Enfield Town. Currently 0.7% of journeys in Enfield are by bike. As well as the introduction of safe cycle routes, Cycle Enfield is also providing free cycle training for anyone that lives, works or studies in Enfield, installing more cycle parking and introducing a £10 bike loan scheme. These are expected to increase the modal share to 5% by 2020.

The whole of the Borough of Enfield is declared an Air Quality Management Area due to concentrations of nitrogen dioxide (NO_2) and particulate matter (PM_{10}) exceeding the UK air quality objectives.

Air quality modelling was carried out for the area around the A105 using the ADMS-Urban model. Modelling was carried out for a base case, with no changes to the road, and for predicted reductions to the traffic flow of 2.5%, 5% and 10%. The modelling used traffic flow and queuing data for the A105 supplied by the Council, with data for the rest of London taken from the London Atmospheric Emissions Inventory.

Model verification was carried out to check that the model input data and assumptions were suitable for the area. Pollutant concentrations were calculated for the locations of the nearest monitoring sites and compared with measured data. The modelled concentrations showed good agreement with measured data giving confidence to the modelling for the different scenarios.

Without implementation of any of the Cycle Enfield proposals, the air quality objective for annual average NO_2 is predicted to be exceeded along the A105, although exceedences are limited to roadside locations. Concentrations of PM_{10} and $PM_{2.5}$ are not predicted to exceed the air quality objectives.

With the introduction of the proposals, and assuming a 2.5% reduction in traffic, annual average NO_2 concentrations are predicted to reduce by between 0.25 $\mu g/m^3$ and 0.5 $\mu g/m^3$ at roadside locations. The scheme will result in some increases in queue length and delay time, leading to increases in concentrations at junctions, however, the area of these increases will be much smaller than the area of air quality improvements resulting from reduced traffic flows. As a result, the majority of residents along this road will experience an improvement in air quality and corresponding health benefits.

With greater reductions in traffic flows, the increases in concentrations at queues generally become smaller and the decreases in concentrations along the rest of road become greater. With a traffic reduction of 10%, roadside annual average NO_2 concentrations are predicted to decrease by up to 1.5 $\mu g/m^3$.

The changes to the traffic flows along the A105 are predicted to bring about only small decreases in PM_{10} and $PM_{2.5}$ concentrations. The effect of the increased queuing on particulate concentrations is not as noticeable as for NO_2 because queuing emissions were assumed to consist only of exhaust emissions without any contribution from brake wear, tyre wear, road wear or resuspension.

2 Introduction

Cycle Enfield is proposing to introduce segregated cycle lanes along the A1010, A105 and A110, including changes to the road layout in Enfield Town. Currently 0.7% of journeys in Enfield are by bike. As well as the introduction of safe cycle routes, Cycle Enfield is also providing free cycle training for anyone that lives, works or studies in Enfield, installing more cycle parking and introducing a £10 bike loan scheme. These are expected to increase the modal share to 5% by 2020.

Changes to the road layout, traffic flows and speeds and levels of congestion could all have an impact on air quality.

Cambridge Environmental Research Consultants Ltd (CERC) was commissioned by Enfield Council to carry out air dispersion modelling to assess the impact of the proposed changes on nitrogen dioxide (NO_2) and particulate matter (PM_{10} and $PM_{2.5}$) concentrations in the area surrounding these roads. Four scenarios were modelled for 2016:

- a baseline scenario without the proposed scheme; and
- three scenarios with the scheme in place representing 2.5%, 5% and 10% reductions in traffic flows with corresponding changes to traffic queues.

This report describes the data and assumptions used in the modelling, and presents the model results. Section 3 sets out the air quality standards, with which the calculated concentrations are compared. The traffic and emissions data and model set-up are summarised in Sections 4 and 5, respectively. Model verification was carried out to check the data and assumptions are valid and this is described in Section 6. The results of the modelling for each of the scenarios are presented in Section 7. A discussion of the results is presented in Section 8.

3 Air quality standards

The EU *ambient air quality directive* (2008/50/EC) sets binding limits for concentrations of air pollutants, which take into account the effects of each pollutant on the health of those who are most sensitive to air quality. The directive has been transposed into English legislation as the *Air Quality Standards Regulations 2010*[1], which also incorporates the provisions of the *4th air quality daughter directive* (2004/107/EC).

The Air Quality Standards Regulations 2010 include limit values and target values. Local authorities are required to work towards air quality objectives. In doing so, they assist the Government in meeting the limit values. The limit values are presented in Table 3.1.

Table 3.1: Air quality limit values

	Value (µg/m^3)	Description of standard
NO_2	200	Hourly mean not to be exceeded more than 18 times a calendar year (modelled as 99.79th percentile)
	40	Annual average
PM_{10}	50	24-hour mean not to be exceeded more than 35 times a calendar year (modelled as 90.41st percentile)
	40	Annual average
$PM_{2.5}$	25	Annual average

The regulations also include national exposure reduction targets for $PM_{2.5}$, as set out in Table 3.2. These are based on the average exposure indicator (AEI) which is calculated as the three-year average of all measured $PM_{2.5}$ concentrations at urban background locations, e.g. the AEI for 2010 must be based on measurements for the years 2009, 2010 and 2011.

Table 3.2: Exposure reduction target for $PM_{2.5}$ relative to the AEI in 2010

Initial concentration (µg/m³)	Reduction target (%)	Year by which exposure reduction target should be met
Less than or equal to 8.5	0	2020
More than 8.5 but less than 13	10	
13 to less than 18	15	
18 to less than 22	20	
22 or more	All appropriate measures to reach 18µg/m³	

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[1] http://www.legislation.gov.uk/uksi/2010/1001/contents/made

The short-term objectives, i.e. those measured hourly or over 24 hours, are specified in terms of the number of times during a year that a concentration measured over a short period of time is permitted to exceed a specified value. For example, the concentration of NO_2 measured as the average value recorded over a one-hour period is permitted to exceed the concentration of 200 $\mu g/m^3$ up to 18 times per year. Any more exceedences than this during a one-year period would represent a breach of the objective.

It is convenient to model objectives of this form in terms of the equivalent percentile concentration value. A percentile is the concentration below which lie a specified percentage of concentration measurements. For example, consider the 98th percentile of one-hour concentrations over a year. Taking all of the 8760 one-hour concentration values that occur in a year, the 98th percentile value is the concentration below which 98% of those concentrations lie. Or, in other words, it is the concentration exceeded by 2% (100 – 98) of those hours, that is, 175 hours per year. Taking the NO_2 objective considered above, allowing 18 exceedences per year is equivalent to not exceeding for 8742 hours or for 99.79% of the year. This is therefore equivalent to the 99.79th percentile value. It is important to note that modelling exceedences of short term averages is generally not as accurate as modelling annual averages.

4 Emissions data

Modelling was carried out for four scenarios for 2016:

- a baseline scenario without the proposed scheme; and
- three scenarios with the scheme in place representing 2.5%, 5% and 10% reductions in traffic flows with corresponding changes to traffic queues.

4.1 Traffic emissions

4.1.1 Traffic flows

Traffic data for the roads affected by the scheme were provided by the Council. Data for all other roads in London were taken from the LAEI (London Atmospheric Emissions Inventory) 2010.

Traffic count data for the A105 were provided for four traffic count sites. The data included hourly traffic counts for sixteen days recorded in July 2014. The data included counts for 10 vehicle categories; these were mapped to the categories required for emissions calculations using the equivalent data for each road in the LAEI. Table 4.1 gives a summary of the baseline traffic data.

Table 4.1: Baseline A105 traffic data

Count ID	Speed (mph)	AADT							
		Total	M'cycle	Car	Taxi	LGV	Bus	Rigid HGV	Artic. HGV
5814-004-NB	23	10939	113	8707	134	1212	339	404	31
5814-004-SB	27	9474	137	7516	115	1046	333	306	20
5814-005-EB	23	10412	131	8289	127	1154	298	393	19
5814-005-WB	23	10196	93	8248	127	1148	236	326	19
5814-006-NB	27	9695	179	7628	117	1062	252	421	36
5814-006-SB	26	10360	121	8282	127	1152	297	354	26
5814-007-NB	24	9381	221	7383	182	788	520	246	41
5814-007-SB	23	9884	187	7839	193	837	531	269	28

The assessment considered reductions in traffic flows of 2.5%, 5% and 10%. It was assumed that these reductions would be brought about through reductions in car trips only. Reductions in car flows were therefore applied to reduce the total flow to the required level, while keeping the flows of all other vehicle categories unchanged. Table 4.2 shows the AADTs for the total traffic and cars only used in the assessment.

Table 4.2: Traffic reductions due to scheme

Count ID	Baseline		2.5% reduction		5% reduction		10% reduction	
	Total	Car	Total	Car	Total	Car	Total	Car
5814-004-NB	10939	8707	10666	8434	10392	8160	9845	7613
5814-004-SB	9474	7516	9237	7279	9000	7042	8526	6569
5814-005-EB	10412	8289	10152	8029	9891	7769	9371	7248
5814-005-WB	10196	8248	9941	7993	9686	7738	9177	7228
5814-006-NB	9695	7628	9452	7386	9210	7144	8725	6659
5814-006-SB	10360	8282	10101	8023	9842	7764	9324	7246
5814-007-NB	9381	7383	9147	7149	8912	6914	8443	6445
5814-007-SB	9884	7839	9637	7592	9390	7345	8896	6851

4.1.2 Traffic queues

Queuing was modelled at peak hours for a number of junctions along the A105, based on traffic modelling data for the current and future scenarios provided by the Council. Queuing was assumed to take place from 07:00 to 09:00 and from 17:00 to 19:00 on weekdays.

Mean maximum queue lengths, in Passenger Car Units (PCUs), were provided for seven major junctions along the A105 for the base case scenario. An average queue length of 5.75m per PCU was used[2]. The average queue length was assumed to be equal to half the mean maximum queue length for each junction for each modelled scenario, assuming that the queue is fully cleared in each cycle.

The total vehicle idling time per peak hour for each queue was calculated from the average delay time using the traffic flow data described in Sections 4.1.1, using the assumption that all traffic on the link joined a queue (i.e. that no traffic was free-flowing).

In cases for which the vehicle idling seconds calculated in this way represent a surplus of traffic relative to a continuous queue of the observed queue length, the total vehicle idling seconds were scaled to the measured queue length in order to account for free-flowing traffic.

Idling emission factors were derived from emissions for the lowest available speed in the published emission factors described in Section 4.1.5.

Table 4.3 and Table 4.4 present the modelled AM and PM peak queue lengths, traffic flows, and emissions for the modelled queues for each of the scenarios under consideration. NO_x emissions are also presented for each of the modelled scenarios. At many modelled junctions, the proposed development is expected to significantly increase queue lengths and delay times, an effect which will counteract the expected reduction in traffic around junctions.

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[2] Transport for London, *Traffic Directorate, Model Auditing Process: Traffic Scehemes in London Urban Networks, Design Engineer Guide Version 3.0*, March 2011

Table 4.3: Modelled AM peak queue data

Location	Baseline			2.5% reduction			5% reduction			10% reduction		
	Queue Length (m)	Delay time (s)	NO_x (g/s)	Queue Length (m)	Delay time (s)	NO_x (g/s)	Queue Length (m)	Delay time (s)	NO_x (g/s)	Queue Length (m)	Delay time (s)	NO_x (g/s)
Ridge Avenue Ahead & Left	54.6	60.5	0.025	41.1	50.6	0.021	37.1	46	0.019	31.1	40	0.016
Ridge Avenue Right	0.0	0	0.000	0.0	0	0.000	0.0	0	0.000	0.0	0	0.000
Village Road Ahead & Left	45.1	50.7	0.017	67.3	69	0.024	60.7	62.5	0.021	50.0	53.8	0.018
Church Street	31.6	41.7	0.014	33.1	43.1	0.015	30.8	40.6	0.014	27.6	37.6	0.012
Green Lanes N/bound Ah & Rt	3.7	7.6	0.002	25.9	18.9	0.004	25.6	18.5	0.004	22.7	17.3	0.004
Green Lanes S/bound	14.1	23.7	0.006	69.3	34.9	0.009	64.1	33.1	0.008	57.5	29.8	0.007
Fords Grove	3.5	9.1	0.001	33.4	58.4	0.009	31.6	55.8	0.008	27.9	52.5	0.007
Station Road	2.6	10.6	0.001	37.1	86.7	0.008	32.8	72.1	0.007	29.6	66.8	0.006
Green Lanes N/bound	0.0	0	0.000	31.6	17.7	0.000	29.6	17	0.000	27.3	15.9	0.000
Green Lanes S/bound	1.2	10.2	0.001	27.6	12	0.001	25.9	11.5	0.001	23.3	10.6	0.001
Green Lanes N/bound	21.9	29	0.011	40.5	39.4	0.014	38.2	37	0.013	32.8	31.3	0.011
Green Lanes S/bound Ah & Rt	18.1	31.7	0.008	70.2	62.3	0.015	62.1	53.6	0.013	47.2	37.2	0.009
Green Lanes S/bound Ah & Lt	33.1	41.6	0.015	0.0	0	0.000	0.0	0	0.000	0.0	0	0.000
Bourne Hill	38.8	44.9	0.014	36.5	53.1	0.016	33.1	50.1	0.015	31.1	50	0.015
Hedge Lane	53.5	72.8	0.020	60.7	63.9	0.017	59.2	62.5	0.016	26.2	35.2	0.009
Green Lanes N/bound	9.5	8.2	0.004	56.4	40.7	0.021	50.3	34.9	0.017	46.0	32.8	0.016
Green Lanes S/bound	4.0	8.8	0.002	34.5	44.5	0.010	32.8	42.9	0.010	27.6	34.6	0.008
Fox Lane	3.7	16.2	0.001	32.2	77.3	0.006	30.5	72.5	0.006	29.0	74.3	0.006
Green Lanes N/bound Ahead & Left	14.1	22.9	0.007	22.4	24.2	0.007	21.0	22.6	0.007	19.3	21.8	0.006
Green Lanes S/bound Ahead	33.6	60.4	0.017	14.1	16.5	0.005	14.1	16.8	0.005	14.1	17.6	0.005
Green Lane S/bound Right	33.6	74	0.017	14.1	0	0.000	14.1	0	0.000	14.1	0	0.000
Alderman's Hill	25.6	71.4	0.010	17.5	43	0.006	17.0	42.3	0.006	15.0	38.2	0.005
Green Lanes N/bound	31.6	30.6	0.016	45.4	30.1	0.015	43.4	29.2	0.014	39.7	27.7	0.013
Green Lanes S/bound	48.3	109	0.024	25.3	25	0.006	24.2	24.6	0.005	22.4	23.7	0.005
Broomfield Lane	12.7	45.9	0.006	14.1	62.5	0.008	13.5	61.2	0.008	12.1	57.9	0.007
Oakthorpe Road	3.2	38.5	0.002	4.0	54.6	0.002	4.0	54.1	0.002	3.7	52.9	0.002

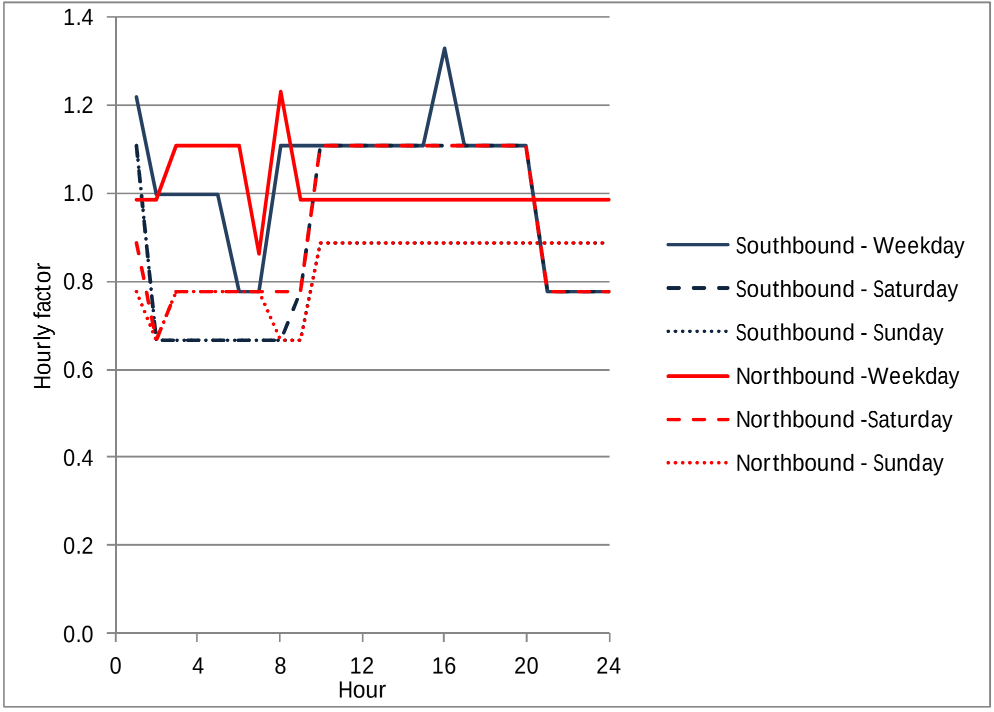
Table 4.4: Modelled PM peak queue data

Location	Baseline			2.5% reduction			5% reduction			10% reduction		
	Queue Length (m)	Delay time (s)	NO_x (g/s)	Queue Length (m)	Delay time (s)	NO_x (g/s)	Queue Length (m)	Delay time (s)	NO_x (g/s)	Queue Length (m)	Delay time (s)	NO_x (g/s)
Ridge Avenue Ahead & Left	43.4	46.4	0.023	44.9	55.8	0.027	40.3	49.7	0.024	33.1	42.1	0.020
Ridge Avenue Right	0.0	0	0.000	0.0	0	0.000	0.0	0	0.000	0.0	0	0.000
Village Road Ahead & Left	54.6	69	0.027	69.0	69.1	0.027	62.1	62.3	0.024	51.8	53.6	0.020
Church Street	25.3	33.6	0.013	22.7	32.8	0.013	21.9	32.2	0.013	20.1	31.3	0.012
Green Lanes N/bound Ah & Rt	15.8	16.3	0.008	69.0	33.4	0.017	64.4	31	0.015	55.5	27.4	0.013
Green Lanes S/bound	2.0	25.3	0.001	59.5	54.6	0.002	55.2	49.9	0.002	48.9	44	0.002
Fords Grove	11.5	6.8	0.004	21.9	50	0.029	20.1	48.6	0.028	18.1	46.5	0.026
Station Road	3.7	16.2	0.002	34.8	73.4	0.007	31.9	66.5	0.007	28.5	60.1	0.006
Green Lanes N/bound	0.0	0	0.000	56.9	24.3	0.000	52.6	22.2	0.000	46.0	19.4	0.000
Green Lanes S/bound	2.0	13.2	0.001	17.8	12	0.001	17.3	11.5	0.001	15.8	10.7	0.001
Green Lanes N/bound	65.6	54.4	0.032	81.9	74	0.043	71.6	61.8	0.035	53.2	39.8	0.022
Green Lanes S/bound Ah & Rt	15.2	45.5	0.008	41.1	35.9	0.006	38.2	34.6	0.006	32.2	29.2	0.005
Green Lanes S/bound Ah & Lt	18.4	19.7	0.009	0.0	0	0.000	0.0	0	0.000	0.0	0	0.000
Bourne Hill	38.8	46.8	0.016	32.5	50.9	0.017	30.5	48.6	0.016	29.6	49.6	0.016
Hedge Lane	66.7	76.1	0.028	68.4	77	0.028	66.4	75.7	0.027	27.3	37.5	0.013
Green Lanes N/bound	17.3	28.1	0.010	84.8	59.9	0.021	77.1	52.1	0.018	61.5	37.1	0.012
Green Lanes S/bound	4.9	8.8	0.003	43.4	61	0.019	39.7	55	0.017	32.5	43.4	0.013
Fox Lane	2.9	16.2	0.001	39.7	140.5	0.010	31.9	105	0.007	28.8	99.2	0.007
Green Lanes N/bound Ah & Lt	30.2	35.1	0.017	54.6	38	0.018	49.7	34.3	0.016	41.7	29.4	0.014
Green Lanes S/bound Ahead	19.8	23.7	0.012	19.0	30	0.014	17.3	26.7	0.013	15.0	22.7	0.011
Green Lane S/bound Right	19.8	46	0.012	19.0	0	0.000	17.3	0	0.000	15.0	0	0.000
Alderman's Hill	28.8	71	0.013	28.2	72	0.014	24.2	65.7	0.012	21.6	56.7	0.010
Green Lanes N/bound	75.0	76.8	0.042	74.2	50.4	0.027	67.6	44.3	0.024	58.7	37.5	0.020
Green Lanes S/bound	38.2	83.5	0.022	26.7	30.1	0.008	25.6	28.9	0.008	23.6	26	0.007
Broomfield Lane	35.9	137.6	0.019	22.4	87	0.012	20.7	81.5	0.011	17.5	71.7	0.010
Oakthorpe Road	8.3	52	0.005	13.5	105.5	0.010	12.9	102.7	0.009	11.5	94.2	0.008

4.1.3 Bus stops

Each bus stop was modelled as a 30-metre long road source. The total emission rate for each source was calculated based on the daily average bus flow, assuming that each bus waited at each stop for 60 seconds. Emissions from the bus stops were varied according to timetable information, as shown in Figure 4.1.

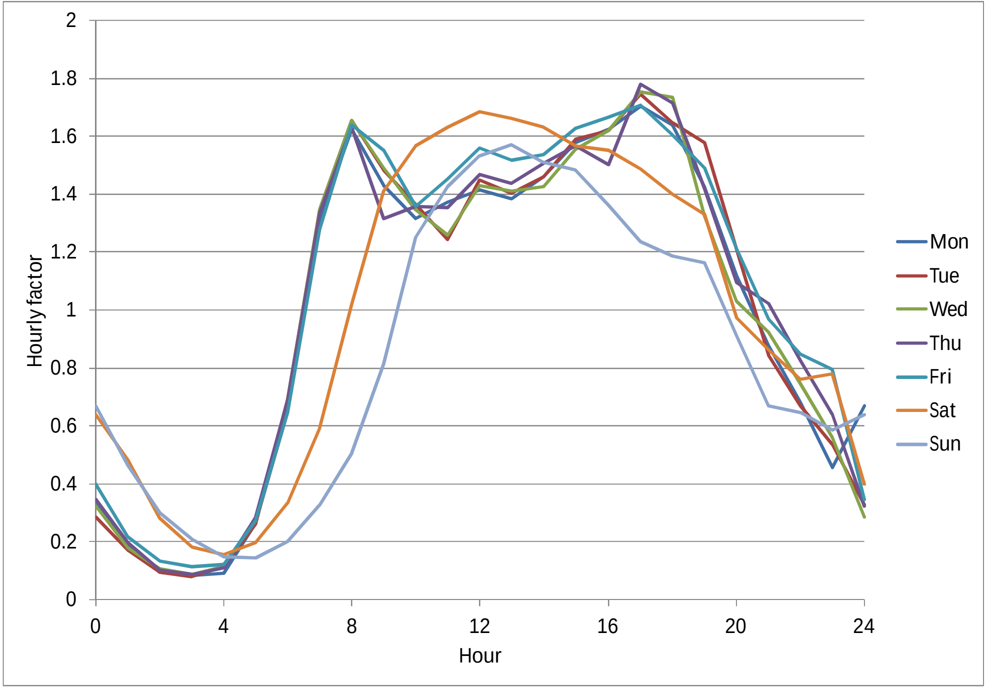
Figure 4.1: Bus stop emission profile



4.1.4 Time varying profiles

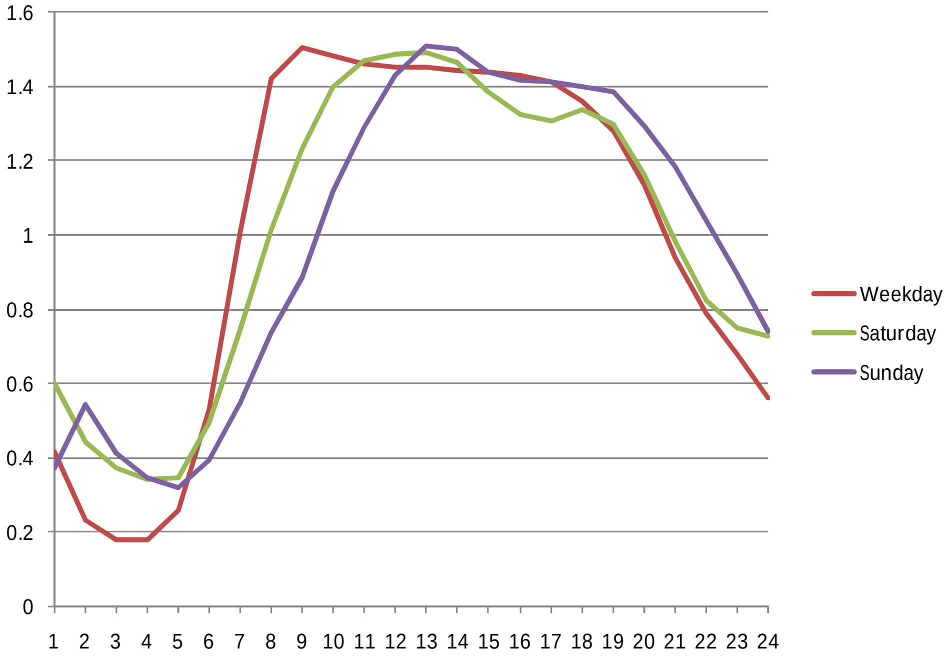
The variation of traffic flow during the day has been taken into account by applying a set of diurnal profiles to the road emissions. Road-specific profiles for the A105 were calculated from the traffic count data; average profiles for all the A105 road links are shown in Figure 4.2.

Figure 4.2: A105 traffic profiles



Hourly profiles for roads in the rest of London were taken from the report *Air pollution and emissions trends in London*[3] used in the compilation of the LAEI, and are shown in Figure 4.3.

Figure 4.3: LAEI traffic profiles



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[3] *Air pollution and emissions trends in London*, King's College London, Environmental Research Group and Leeds University, Institute for Transport studies http://www.airquality.co.uk/reports/cat05/1004010934_MeasurementvsEmissionsTrends.pdf

4.1.5 Traffic emission factors

Traffic emissions were calculated from this traffic flow data using DfT emission factors released in 2012. Note that there is large uncertainty surrounding the current emissions estimates of NO_x from all vehicle types, in particular diesel vehicles, in these factors; refer to for example an AQEG report from 2007[4] and a Defra report from 2011[5]. In order to address this discrepancy, the NO_x emission factors were modified based on recently published Remote Sensing Data (RSD)[6] for vehicle NO_x emissions. Scaling factors were applied to each vehicle category and Euro standard in order to better represent emissions from vehicles in London.

Road traffic PM_{10} and $PM_{2.5}$ emissions include contributions from brake, tyre and road wear, as well as resuspension.

4.2 Other emissions

Emission rates for all other sources were taken from the LAEI and modelled as aggregated 1-kilometre resolution grid sources covering the whole of London.

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[4] Trends in primary nitrogen dioxide in the UK

[5] Trends in NOx and NO2 emissions and ambient measurements in the UK

[6] Carslaw, D and Rhys-Tyler, G 2013: New insights from comprehensive on-road measurements of NO_x, NO_2 and NH_3 from vehicle emission remote sensing in London, UK. *Atmos. Env.* **81** pp 339–347.

5 Model set-up

Modelling was carried out using the ADMS-Urban[7] model (version 3.4.5). The model uses the detailed emissions data described in Section 4 together with a range of other input data to calculate the dispersion of pollutants. This section summarises the data and assumptions used in the modelling.

5.1 Surface roughness

A length scale parameter called the surface roughness length is used in the model to characterise the study area in terms of the effects it will have on wind speed and turbulence, which are key factors in the modelling. A value of 1.0 m was used to represent the modelled area, representing the built-up nature of the area.

5.2 Street canyons

Tall buildings lining the edges of roads have the effect of trapping and recirculating pollutants emitted by traffic and therefore increasing roadside pollutant concentrations. This street canyon effect has been modelled using the ADMS-Urban Advanced Street Canyon option.

The advanced street canyon modelling option in ADMS-Urban modifies the dispersion of pollutants from a road source according to the presence and properties of canyon walls on one or both sides of the road. It takes into account the following effects:

- Pollutants channelled along street canyons;
- Pollutants dispersed across street canyons by circulating flow at road height;
- Pollutants trapped in recirculation regions;
- Pollutants leaving the canyon through gaps between buildings as if there was no canyon; and
- Pollutants leaving the canyon from the canyon top.

Building geometry from OpenStreetMap and Ordnance Survey were used to calculate canyon data for each side of each road including:

- Whether there is a canyon wall, the minimum height and building length;
- The average, minimum and maximum height;
- The distance of the canyon wall from the road; and
- The canyon wall porosity, i.e. the proportion of canyon wall without buildings

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[7] http://www.cerc.co.uk/environmental-software/ADMS-Urban-model.html

5.3 Monin-Obukhov length

In urban and suburban areas a significant amount of heat is emitted by buildings and traffic, which warms the air within and above a city. This is known as the urban heat island and its effect is to prevent the atmosphere from becoming very stable. In general, the larger the urban area the more heat is generated and the stronger the effect becomes.

In the ADMS-Urban model, the stability of the atmosphere is represented by the Monin-Obukhov parameter, which has the dimension of length. In very stable conditions it has a positive value of between 2 metres and 20 metres. In near neutral conditions its magnitude is very large, and it has either a positive or negative value depending on whether the surface is being heated or cooled by the air above it. In very convective conditions it is negative with a magnitude of typically less than 20 metres.

The effect of the urban heat island is that, in stable conditions, the Monin-Obukhov length will never fall below some minimum value; the larger the city, the larger the minimum value. A value of 75 metres was used in the modelling.

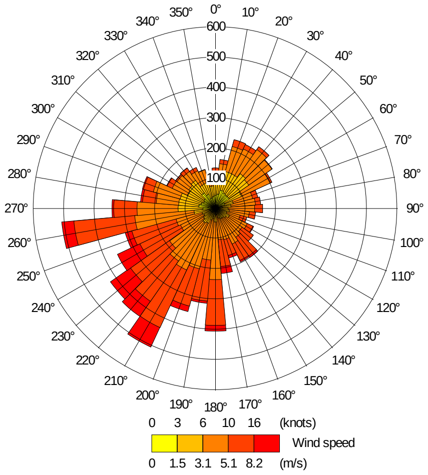
5.4 Meteorological data

Meteorological data from Heathrow for the year 2014 were used in the modelling. A summary of the data is given in Table 5.1. Figure 6.1 shows a wind rose giving the frequency of occurrence of wind from different directions for a number of wind speed ranges.

Table 5.1: Summary of meteorological data

	Minimum	Maximum	Mean
Temperature (°C)	-3.5	29.7	11.5
Wind speed (m/s)	0	17.5	4.2
Cloud cover (oktas)	0	8.0	3.9

Figure 5.1: Wind rose for Heathrow, 2014



5.5 Background concentrations

Nitrogen dioxide (NO_2) results from direct emissions from combustion sources together with chemical reactions in the atmosphere involving NO_2, nitric oxide (NO) and ozone (O_3). The combination of NO and NO_2 is referred to as nitrogen oxides (NO_x).

The chemical reactions taking place in the atmosphere were taken into account in the modelling using the Generic Reaction Set (GRS) of equations. These use hourly average background concentrations of NO_x, NO_2 and O_3, together with meteorological and modelled emissions data to calculate the NO_2 concentration at a given point.

Hourly background data for these pollutants and ozone were input to the model to represent the concentrations in the air being blown into the city.

NO_x, NO_2 and O_3 concentrations from Rochester, Harwell, Lullington Heath and Wicken Fen were input to the model, the monitored concentration used for each hour depending upon the wind direction for that hour, as shown in Figure 5.1.

Two sources of PM_{10}, $PM_{2.5}$, and SO_2 background data were used for the modelling. For hours for which the wind direction was from the west, rural data from Harwell were used, and for hours for which the wind direction was from the east, rural measurements from Rochester were used.

Figure 5.2: Wind direction segments used to calculate background concentrations for NO_x, NO_2 and O_3 (left) and PM_{10}, $PM_{2.5}$ and SO_2 (right)

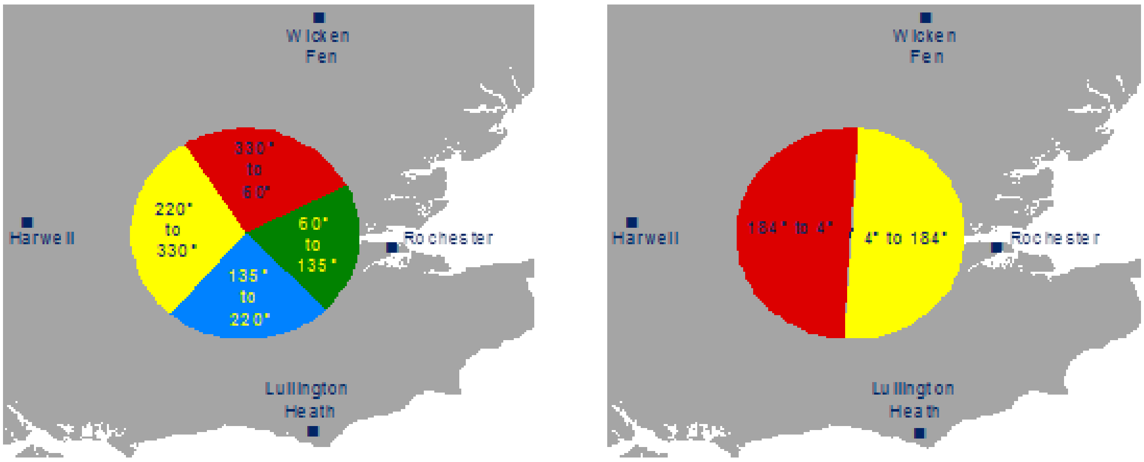


Table 5.2 summarises the annual statistics of the resulting background concentrations used in the modelling for 2014. It was assumed that background concentrations would not change significantly between 2014 and 2016.

Table 5.2: Background concentrations for 2014 (µg/m3)

	NO_x	NO_2	O_3	PM_{10}	$PM_{2.5}$	SO_2
Annual average	9.8	7.5	54.6	15.4	10.7	1.3
99.79th percentile of hourly average	103.8	59.4	112.9	-	-	-
90.41st percentile of 24-hour average	-	-	-	26.5	25.6	2.2

6 Model verification

The first stage of a modelling study is to model a current case in order to verify that the input data and model set-up are representative for the area. This was carried out by calculating hourly average concentrations of NO_2 and PM_{10} at the three monitoring sites located closest to the model area, and comparing the measured and modelled concentrations. Concentrations were calculated at these monitoring locations for 2014. Table 6.1 summarises these locations. Figure 6.1 shows the locations of the monitoring sites.

Table 6.1: Monitoring sites

Description	Site type	Site type	Location	Distance to kerb (m)
Bowes Road	Automatic	Roadside	529893, 192224	3
Enfield 9	Diffusion tube	Roadside	529893, 192224	3
Enfield 4	Diffusion tube	Urban Background	530349, 193283	24

Figure 6.1: Monitoring locations used for verification

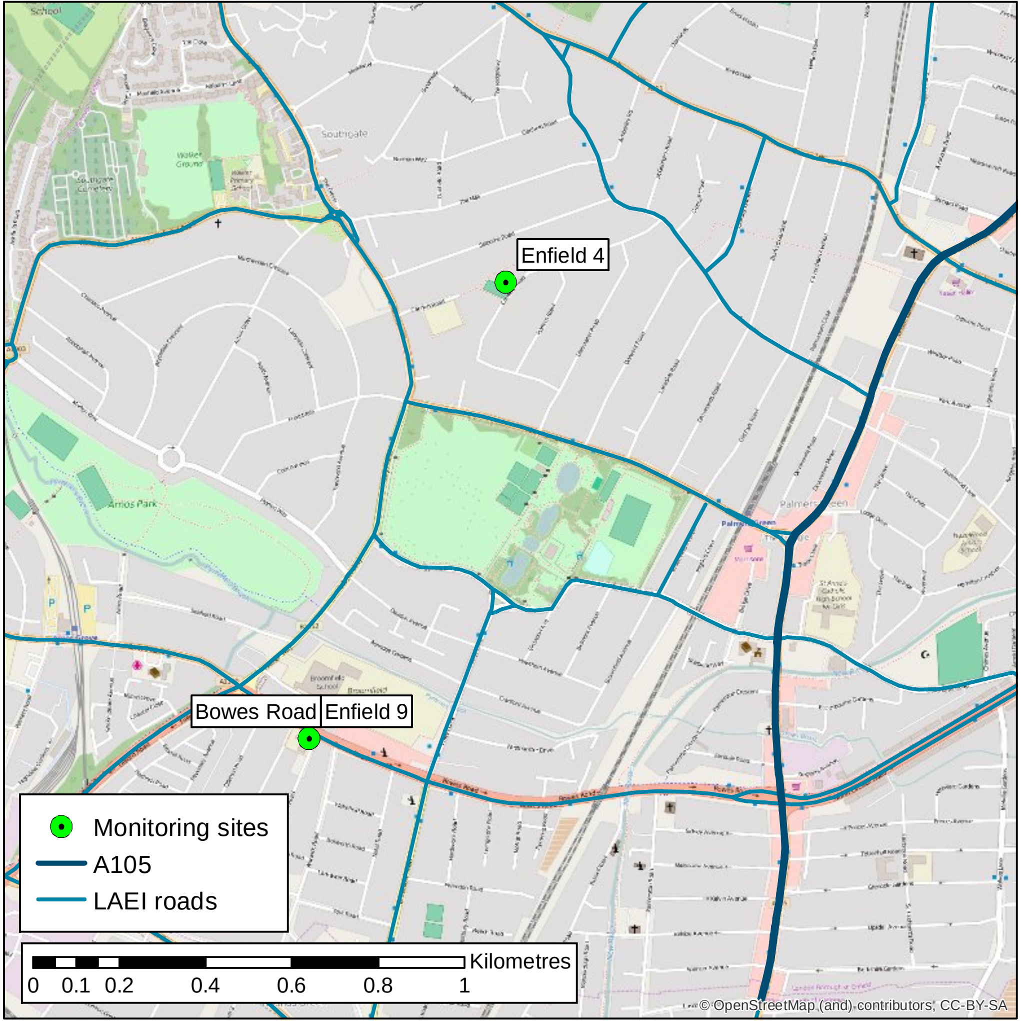


Table 6.2 presents the measured and modelled concentrations of NO_2 at the monitoring locations for 2014. Note that the Bowes Road automatic monitoring station had poor data capture for 2014, with only 15% of the year having valid data.

The modelled annual average NO_2 concentrations show good agreement for both the urban background location and the roadside location.

Table 6.2: Measured and modelled NO_x and NO_2 concentrations, 2014, µg/m^3

Site name	**Annual average NO_x**		**Annual average NO_2**		**99.79th percentile of hourly-average NO_2 concentrations**	
	Measured	**Modelled**	**Measured**	**Modelled**	**Measured**	**Modelled**
Bowes Road	99.0	73.1	41.1	36.8	133.0	174.9
Enfield 9	-	100.9	43.1	46.1	-	159.6
Enfield 4	-	31.9	21.6	24.0	-	94.7

Table 6.3 presents the monitored and modelled concentrations of PM_{10} at the monitoring locations for 2014. Both the predicted annual average PM_{10} concentration and predicted 90.41st percentile of 24-hourly average PM_{10} concentrations shows good agreement with the monitored values.

Table 6.3: Modelled and monitored PM_{10} concentrations, 2014, µg/m^3

Site name	**Site type**	**Annual average PM_{10}**		**90.41st percentile of 24-hour average PM_{10} concentrations**	
		Measured	**Modelled**	**Measured**	**Modelled**
Bowes Road	Roadside	21.4	20.4	36.8	37.8

These results show that the model setup accurately predicts concentrations at urban background and roadside locations in Enfield, and provides confidence in model results for future scenarios.

7 2016 scenario modelling

Ground level concentrations of NO_2 and PM_{10} were calculated on a grid of receptor points for the area around the A105 and other affected roads, with a resolution of 10m close to the roads, with additional points added along the roads where the concentration gradients are steepest. Concentrations were predicted to allow comparison against the air quality standards presented in Section 3, and presented in the form of coloured contour maps.

7.1 NO_2 air quality maps

Figure 7.1 and Figure 7.2 show contour plots of the annual average and 99.79th percentile of hourly average NO_2 concentrations for 2016 without the Cycle Enfield proposals. The plots show the air quality objective for annual average NO_2 concentrations of 40 µg/m³ is predicted to be exceeded along the A105, although exceedences are expected to be confined to very close to the road. The air quality objective for hourly average concentrations is predicted to be exceeded along sections of the A105, particularly where queues have been modelled, and along the North Circular.

Figure 7.3 to Figure 7.5 show the predicted annual average NO_2 concentrations for 2016 with the proposed scheme in place, taking into account the traffic reductions of 2.5%, 5% and 10% and the corresponding changes to traffic queues. Also shown are difference plots, showing the change in concentrations from the base case.

With the introduction of the proposals, and assuming a 2.5% reduction in traffic, annual average NO_2 concentrations are predicted to reduce by between 0.2 µg/m³ and 0.5 µg/m³ at roadside locations. The introduction of the scheme is predicted to result in an increase in queue length and delay time, leading to increases in concentrations of similar magnitude at junctions.

With greater reductions in traffic flows, the increases in concentrations at queues generally become smaller and the decreases in concentrations along the rest of road become greater. With a 10% reduction in traffic, annual average NO_2 concentrations at roadside locations are predicted to decrease by up to 1.5 µg/m³. However, none of the scenarios considered is predicted to eliminate exceedences of the air quality objectives along the A105.

Figure 7.1: Annual average NO_2 concentration for baseline scenario

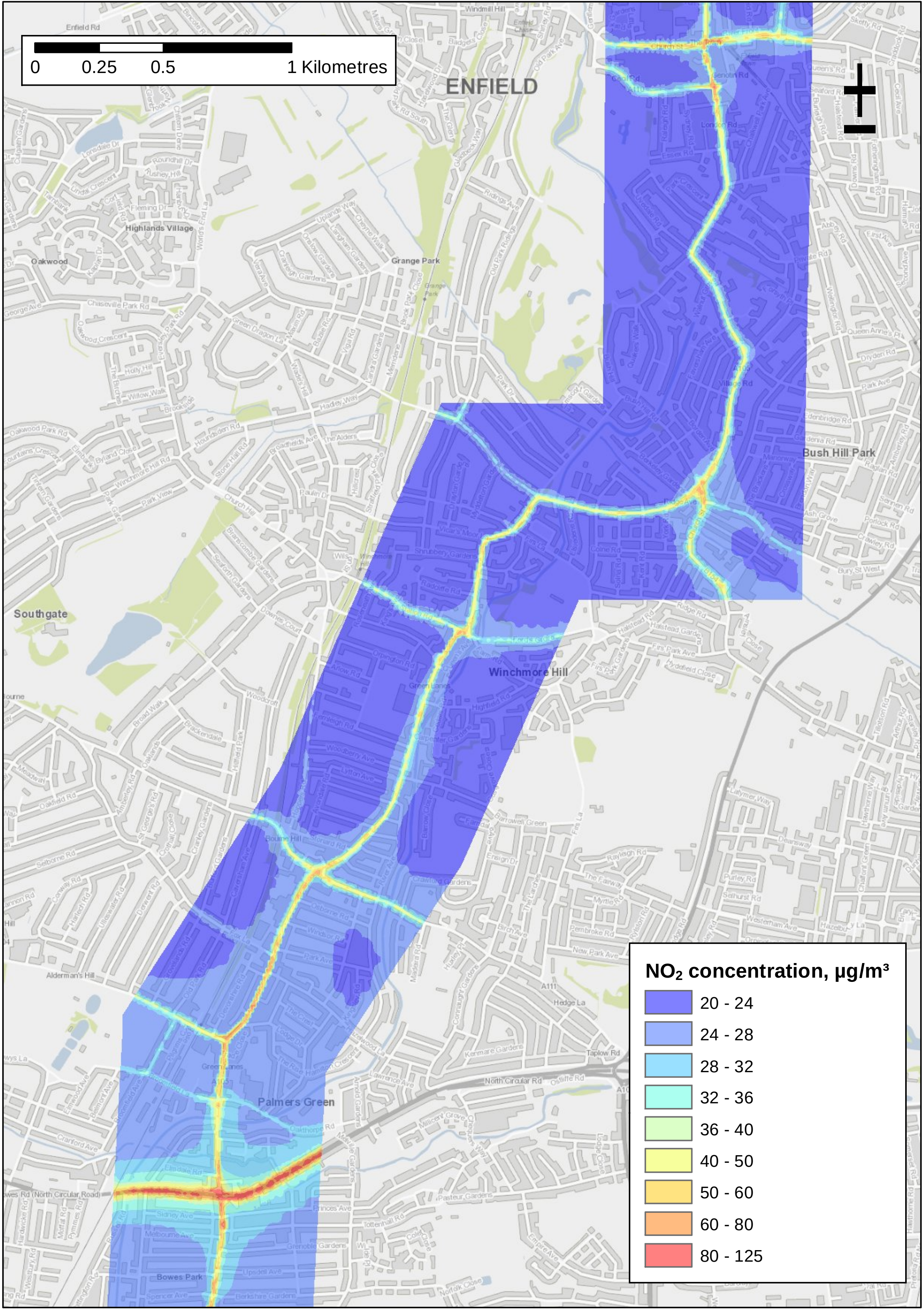


Figure 7.2: 99.79th percentile of hourly average NO_2 concentrations for baseline scenario

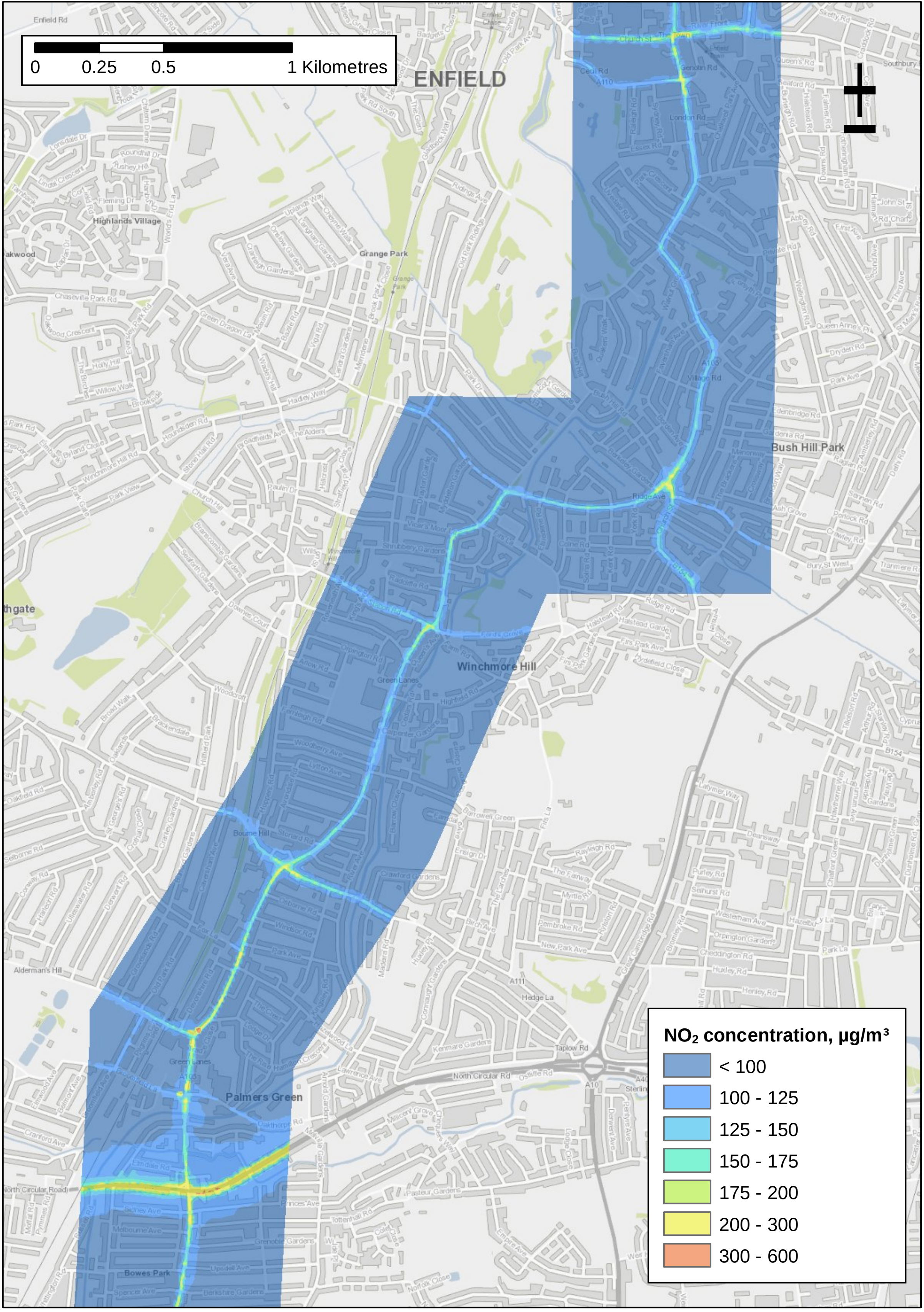


Figure 7.3: Annual average NO_2 concentrations for 2.5% traffic reduction scenario (left) and difference plot (right)

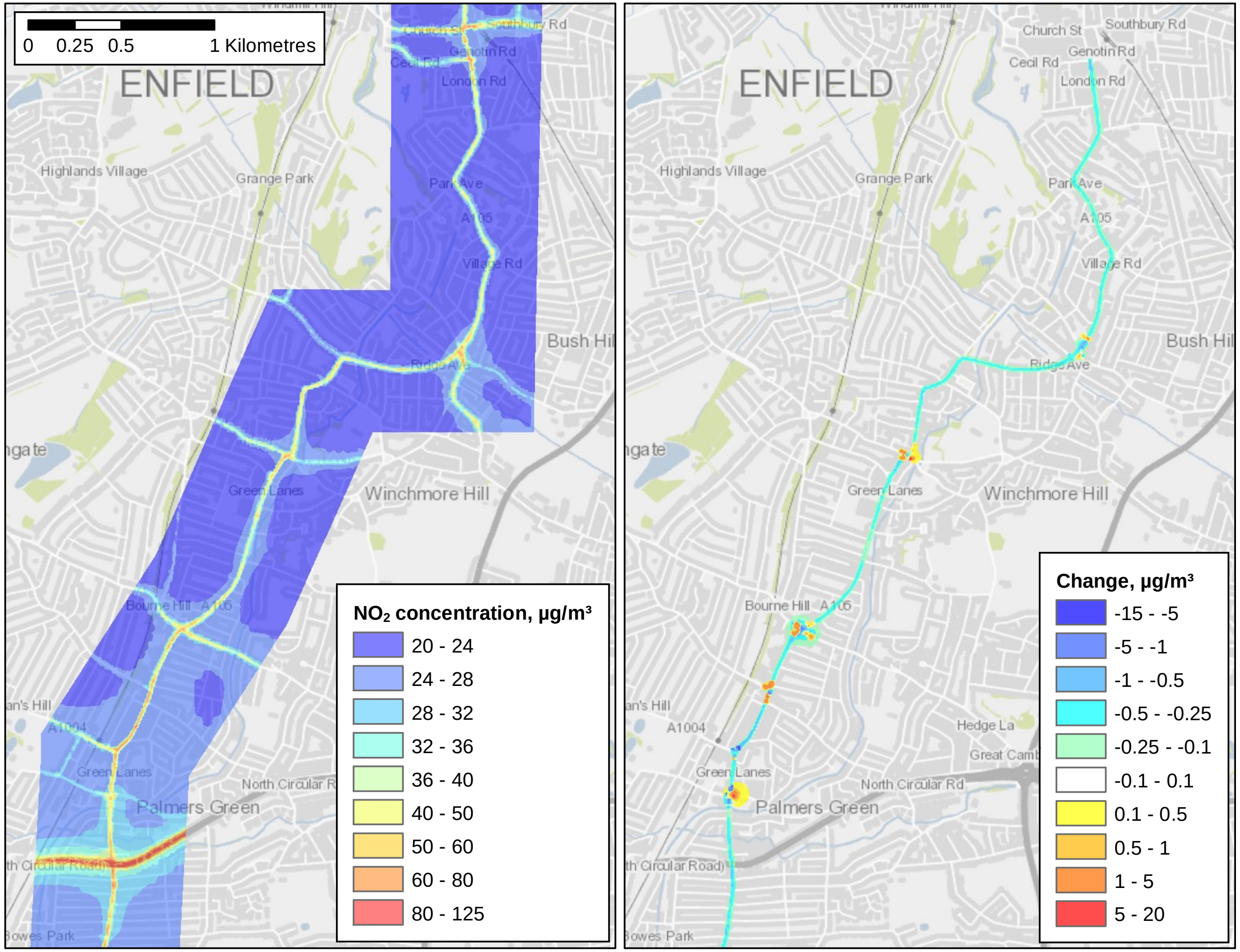


Figure 7.4: Annual average NO_2 concentrations for 5% traffic reduction scenario (left) and difference plot (right)

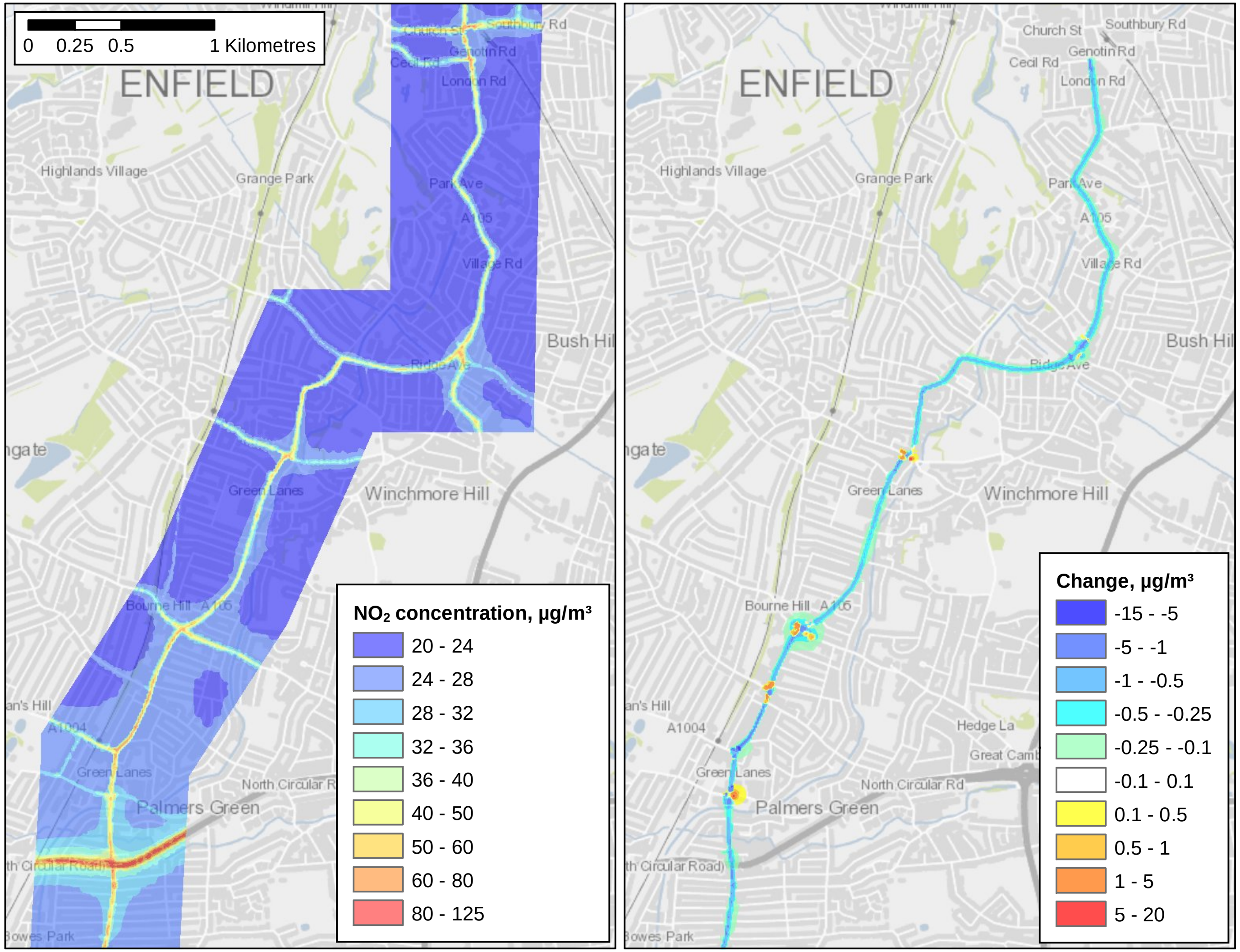
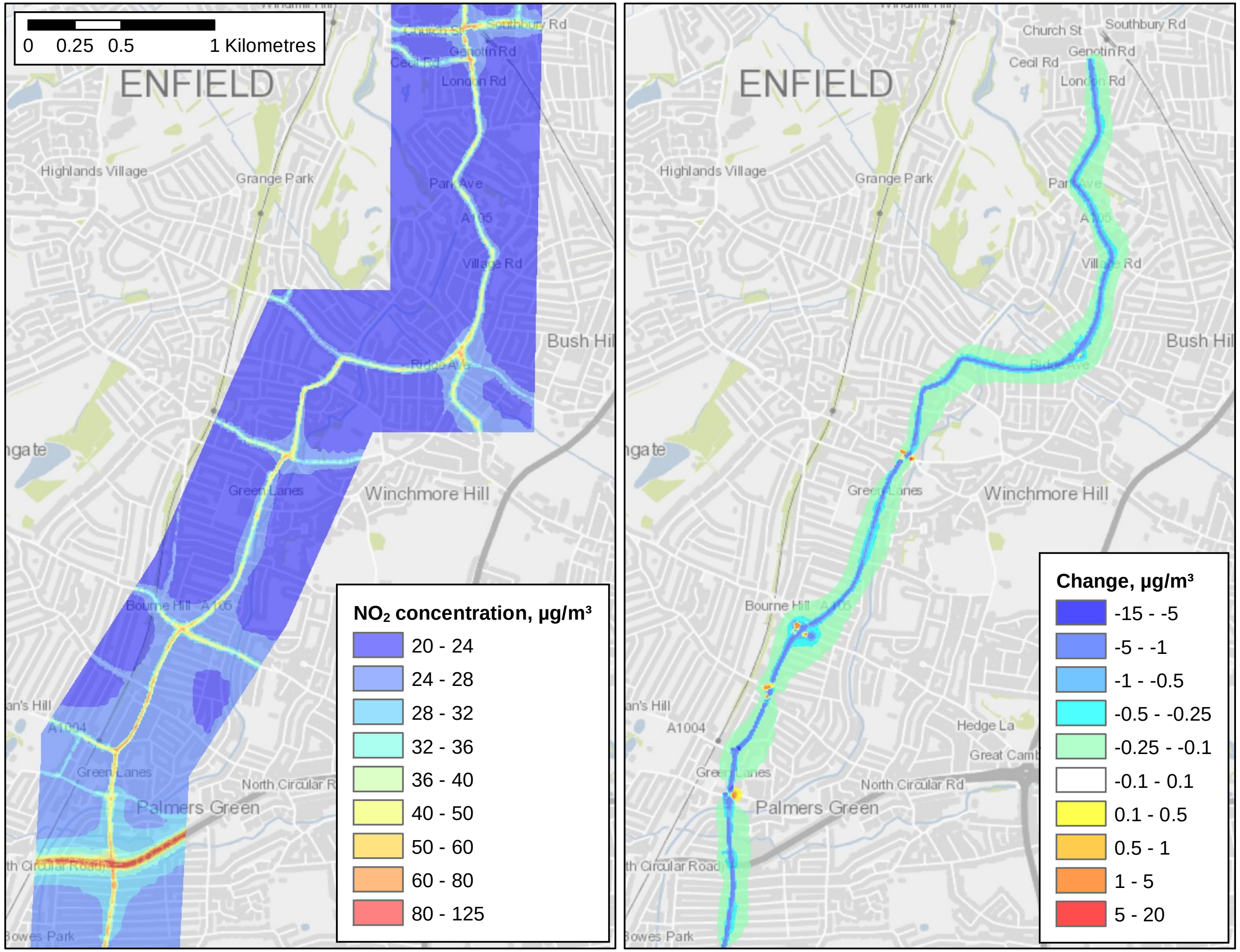


Figure 7.5: Annual average NO_2 concentrations for 10% traffic reduction scenario (left) and difference plot (right)



7.2 PM_{10} air quality maps

Figure 7.6 and Figure 7.7 show contour plots of the annual average and 90.41st percentile of 24-hour average PM_{10} concentrations for 2016 without the Cycle Enfield proposals. The plots show that the air quality objective for annual average PM_{10} concentrations of 40 µg/m³ is not predicted to be exceeded along the A105. The air quality objective for 24-hourly average concentrations is only predicted to be exceeded along the North Circular.

Figure 7.7 to Figure 7.10 show the predicted 90.41st percentiles of 24-hour average PM_{10} concentrations for 2016 taking into account the traffic reductions of 2.5%, 5% and 10% and the corresponding changes to traffic queues. Also shown are difference plots, showing the change in concentrations from the base case.

The changes to the traffic flows along the A105 are predicted to bring about only small decreases in PM_{10} concentrations. The effect of the increased queuing on PM_{10} concentrations is not as noticeable as for NO_2 because queuing emissions were assumed to only consist of exhaust emissions without any contribution from brake wear, tyre wear, road wear or resuspension.

Figure 7.6: Annual average PM_{10} concentration for baseline scenario

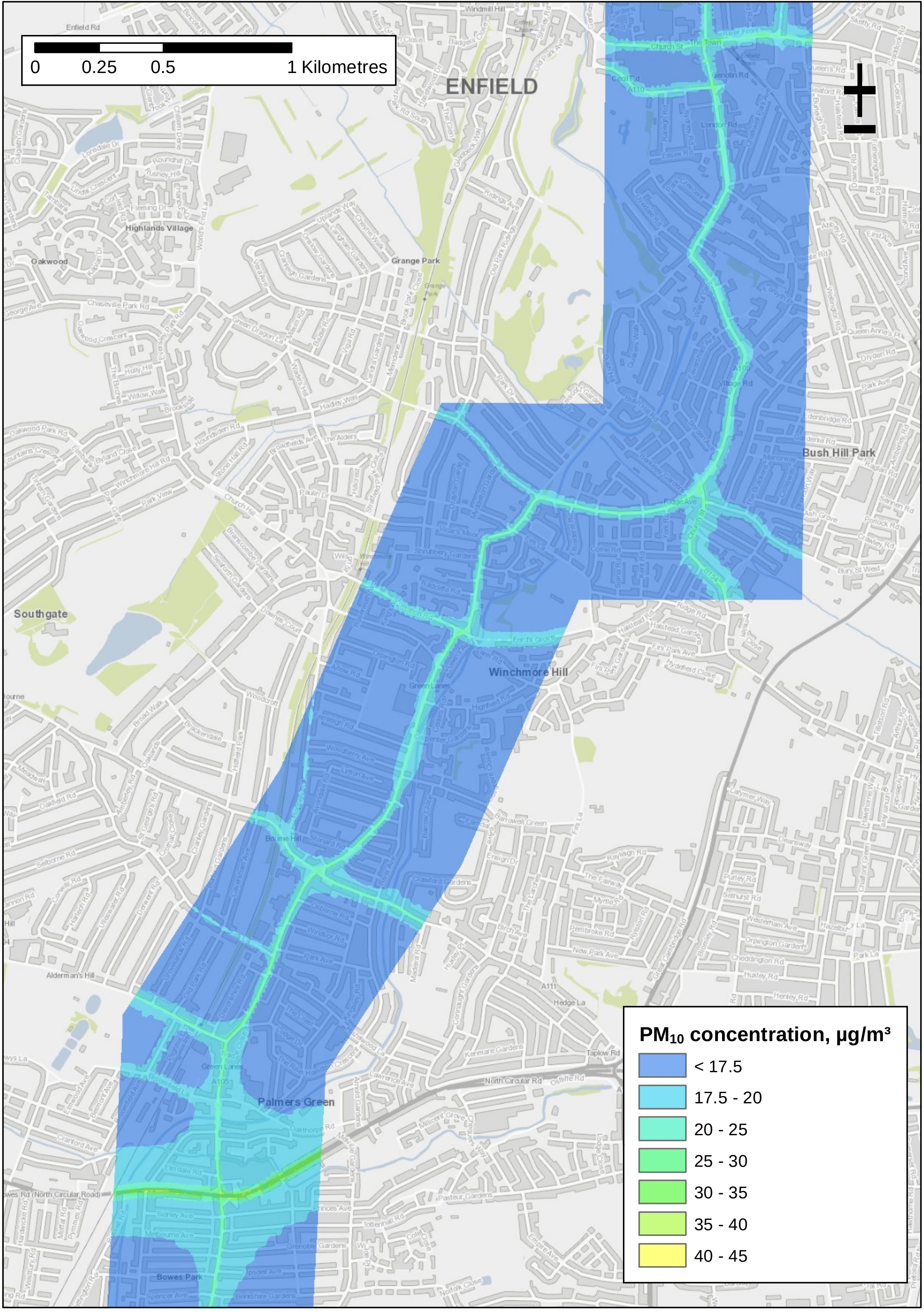


Figure 7.7: 90.41st percentile of 24-hour average PM_{10} concentrations for baseline scenario

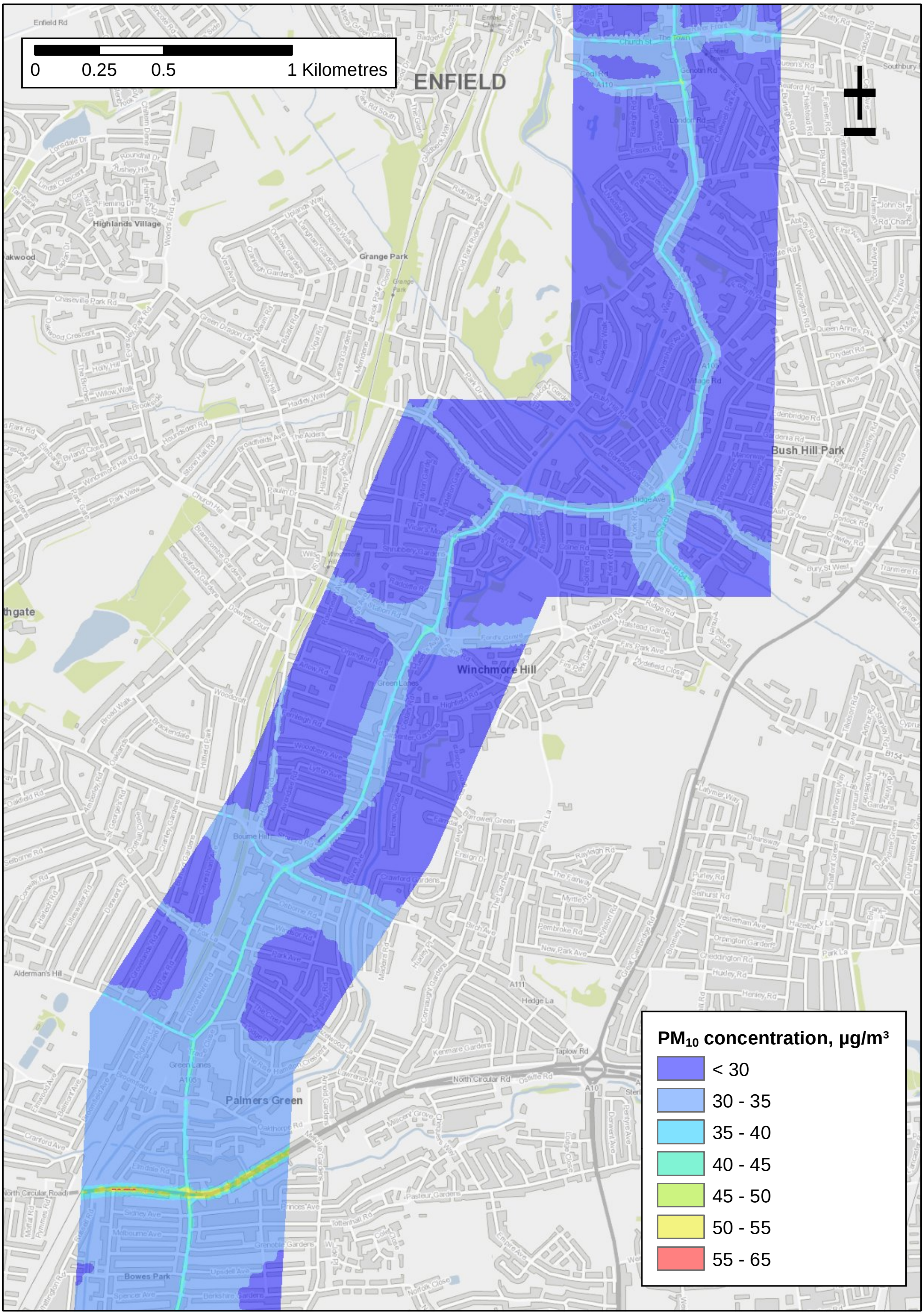


Figure 7.8: Annual average PM_{10} concentrations for 2.5% traffic reduction scenario (left) and difference plot (right)

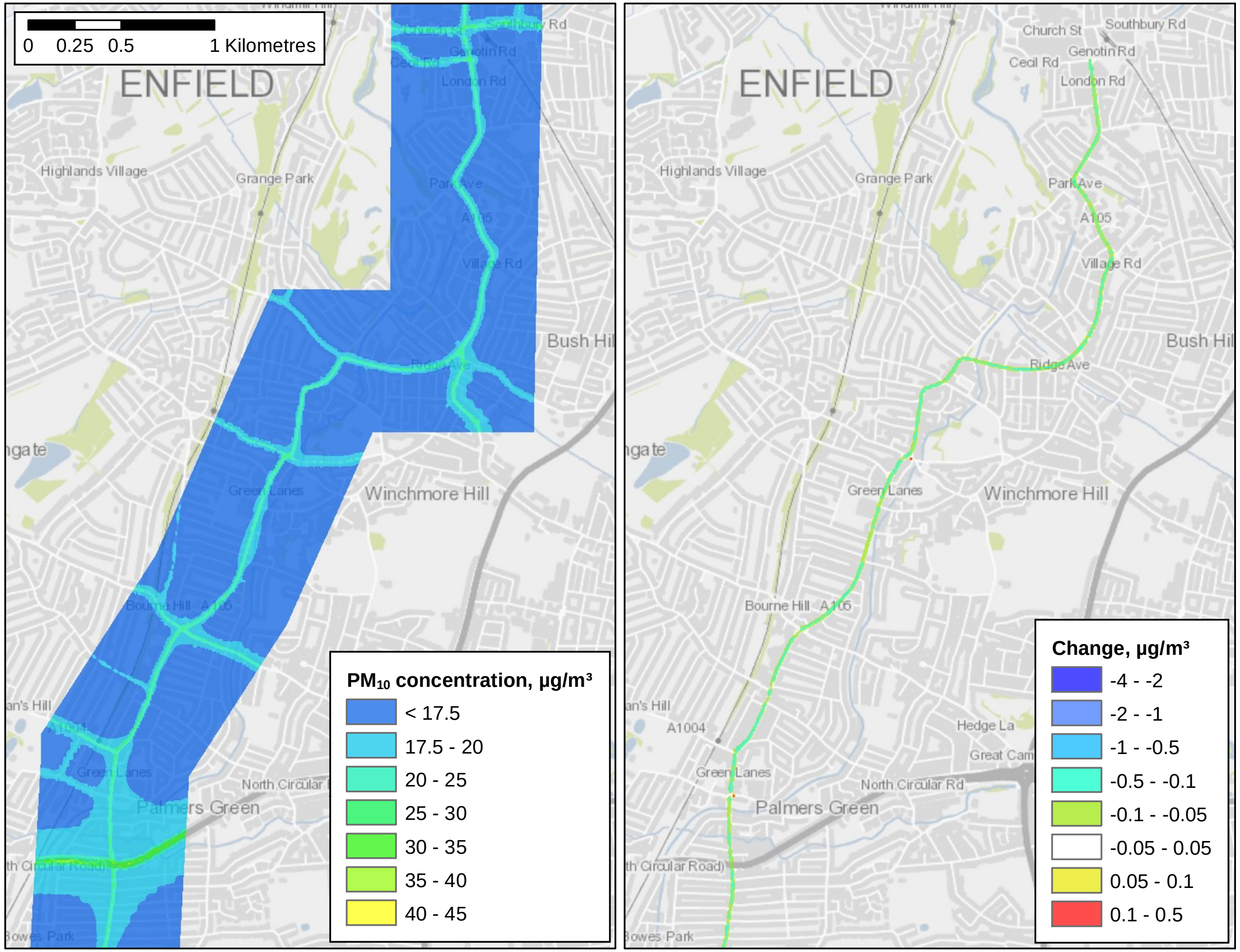


Figure 7.9: Annual average PM_{10} concentrations for 5% traffic reduction scenario (left) and difference plot (right)

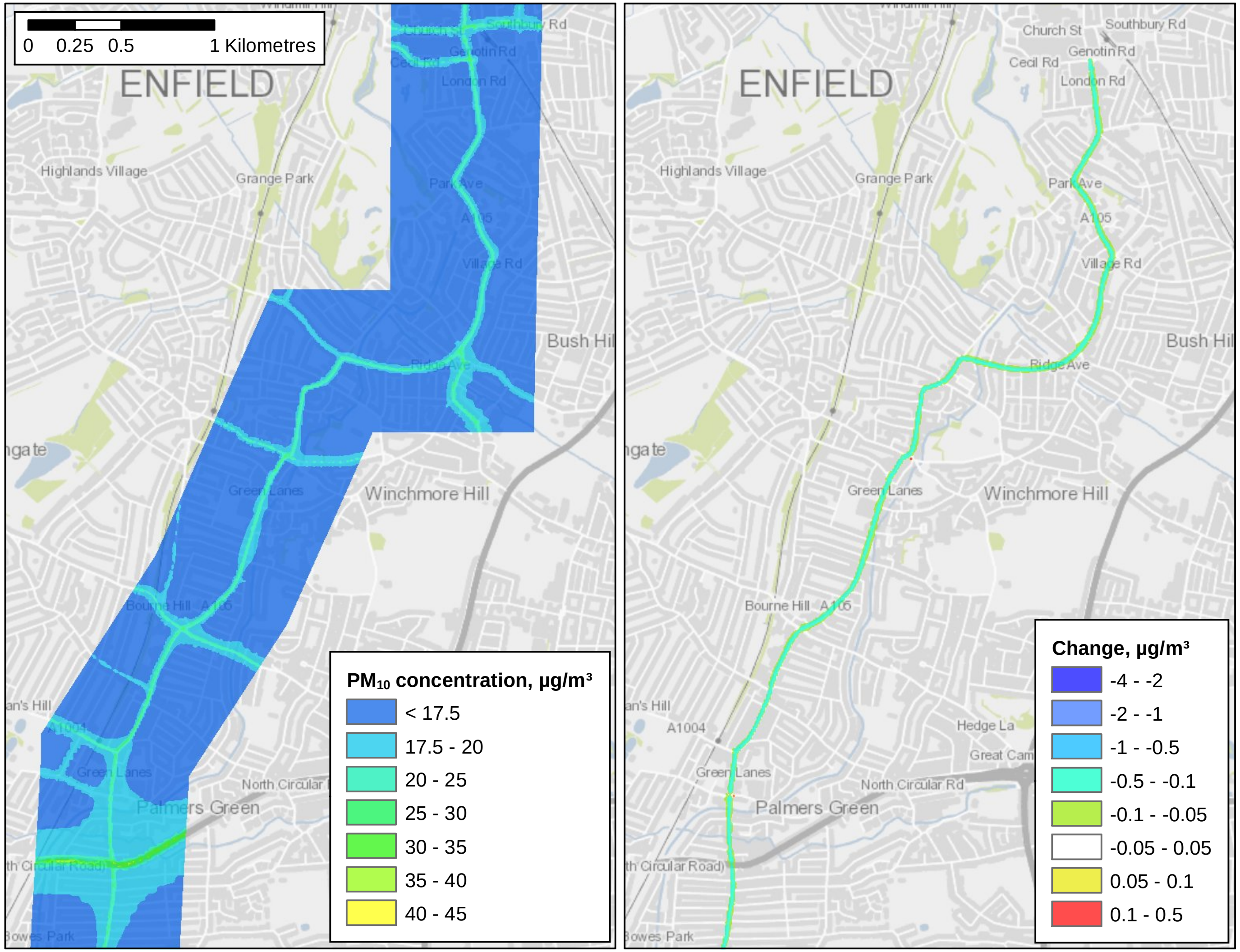
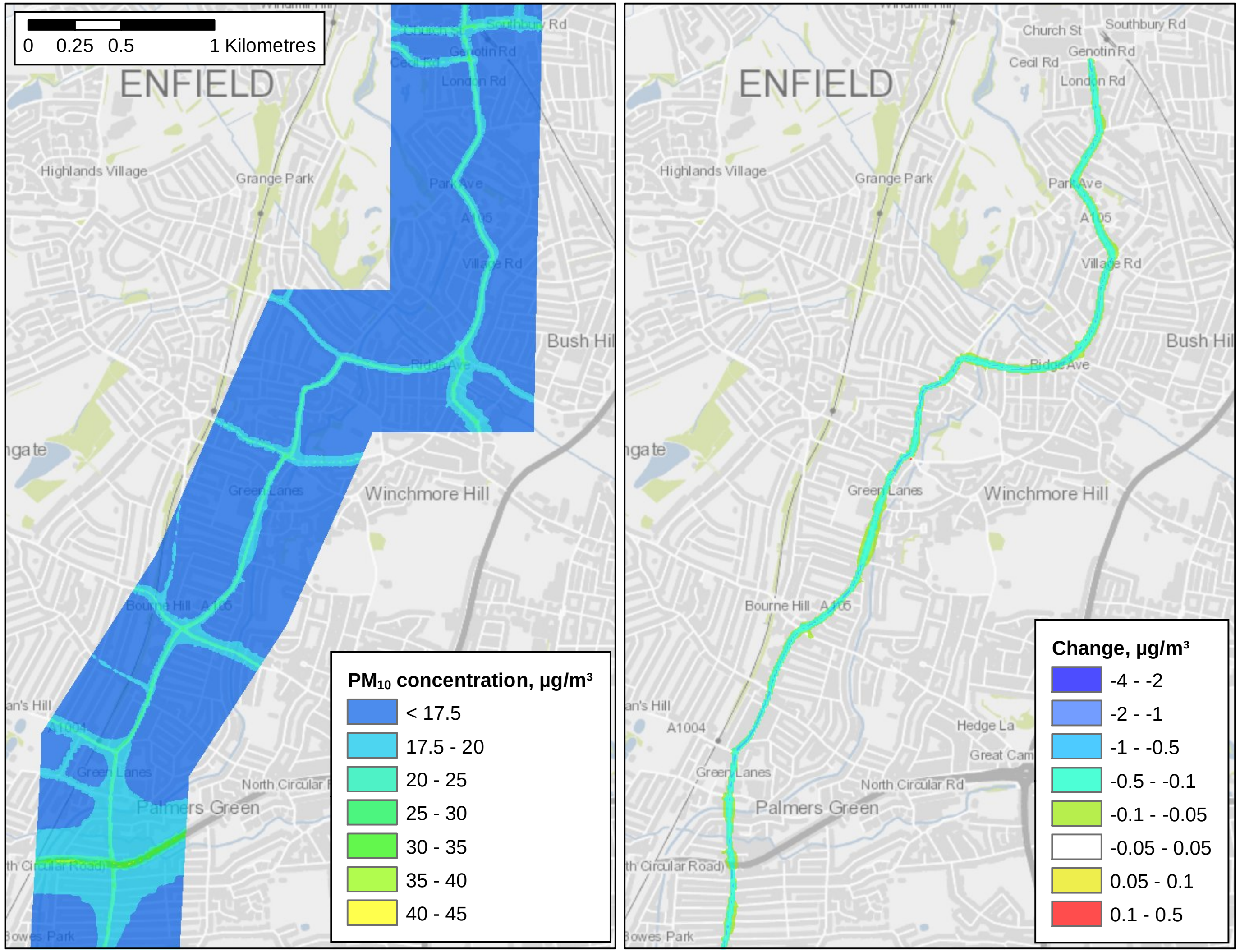


Figure 7.10: Annual average PM_{10} concentrations for 10% traffic reduction scenario (left) and difference plot (right)



7.3 $PM_{2.5}$ concentrations

Figure 7.11 shows a contour plot of the annual average PM_{10} concentrations for 2016 without the Cycle Enfield proposals. The plots show that the air quality objective for annual average $PM_{2.5}$ concentrations of 25 $\mu g/m^3$ is not predicted to be exceeded along the A105.

Figure 7.12 to Figure 7.14 show the predicted annual average $PM_{2.5}$ concentrations for 2016 taking into account the traffic reductions of 2.5%, 5% and 10% and the corresponding changes to traffic queues. Also shown are difference plots, showing the change in concentrations from the base case.

The traffic reductions are only predicted to result in small reductions in $PM_{2.5}$ concentrations.

Figure 7.11: Annual average $PM_{2.5}$ concentration for baseline scenario

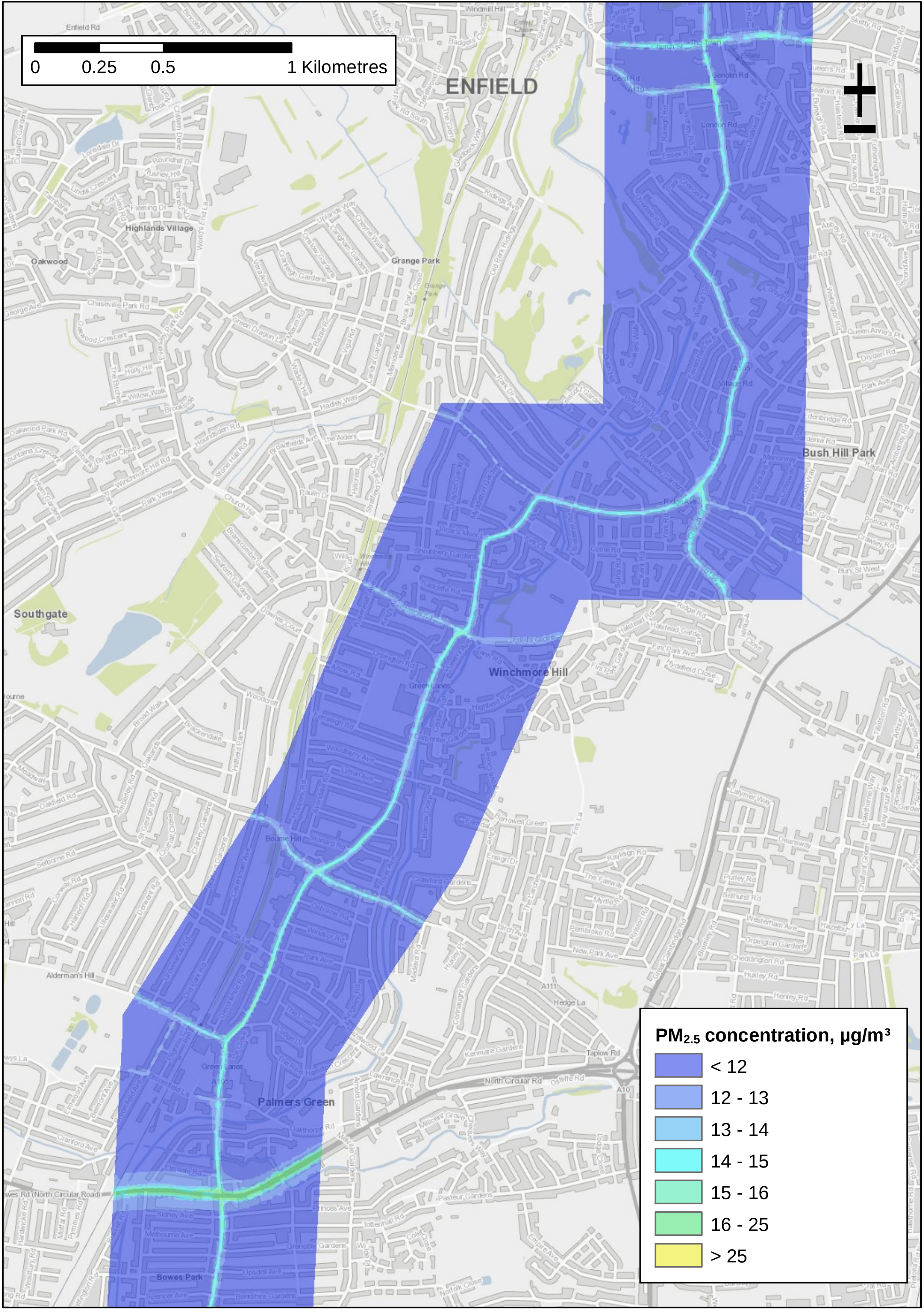


Figure 7.12: Annual average $PM_{2.5}$ concentrations for 2.5% traffic reduction scenario (left) and difference plot (right)

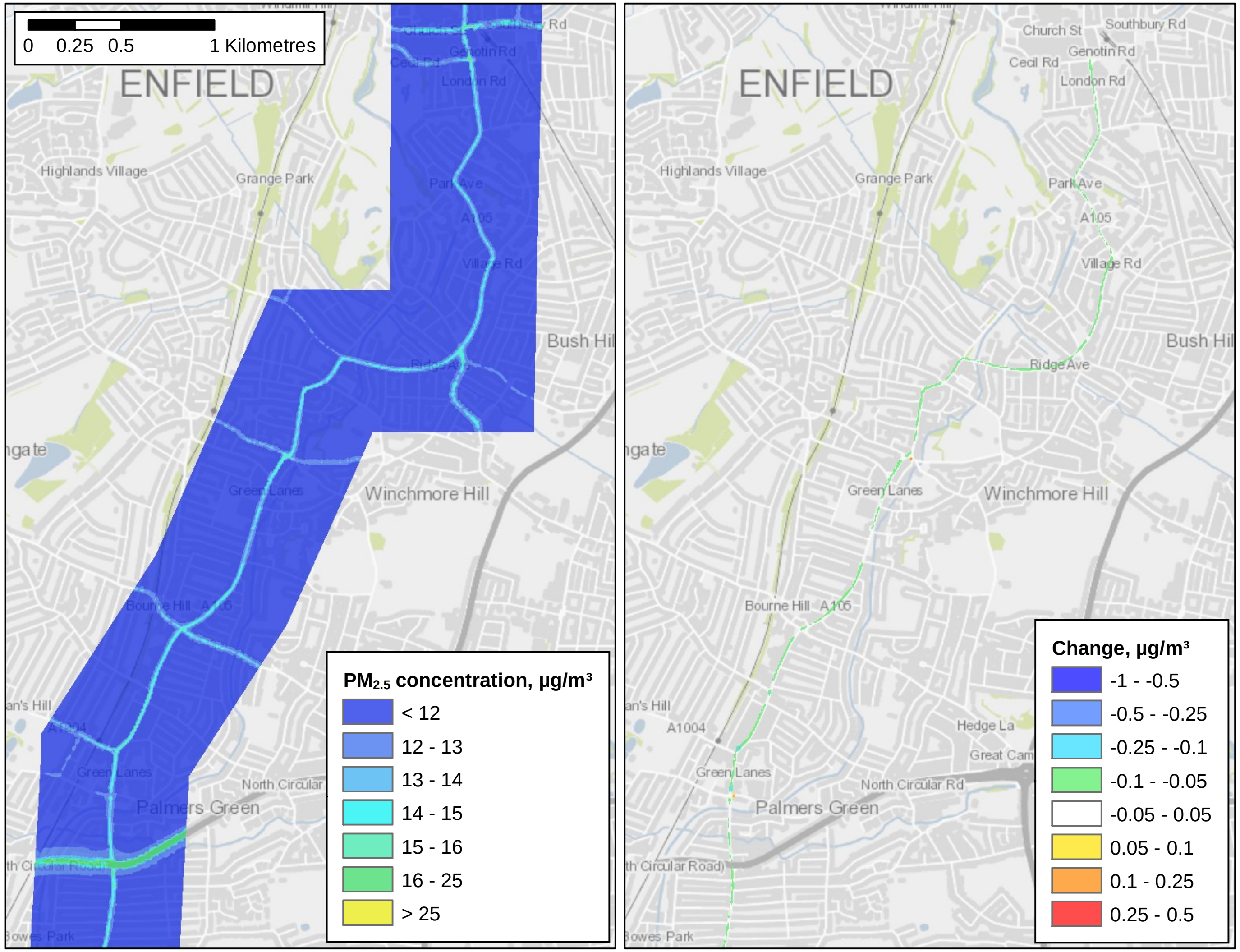


Figure 7.13: Annual average $PM_{2.5}$ concentrations for 5% traffic reduction scenario (left) and difference plot (right)

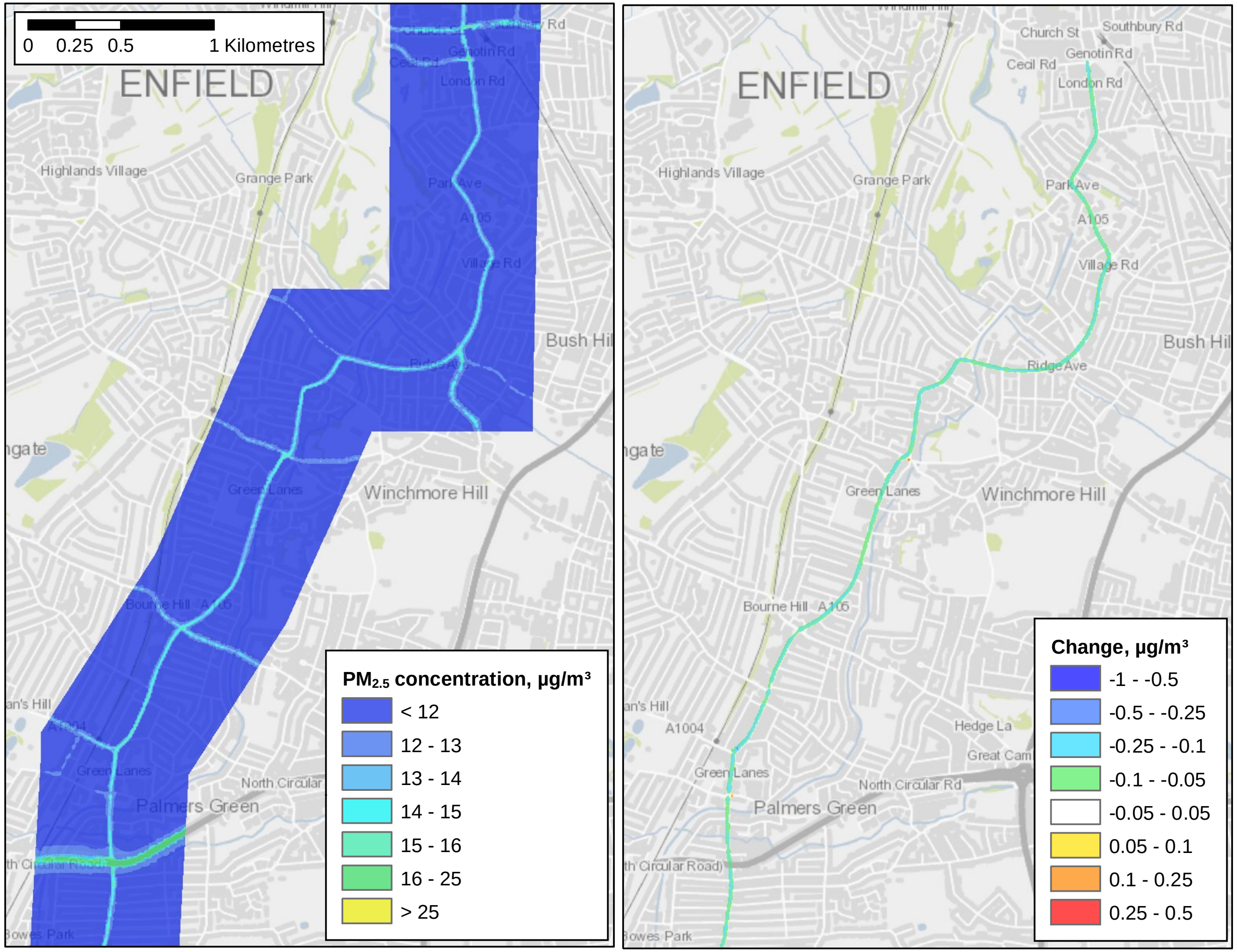
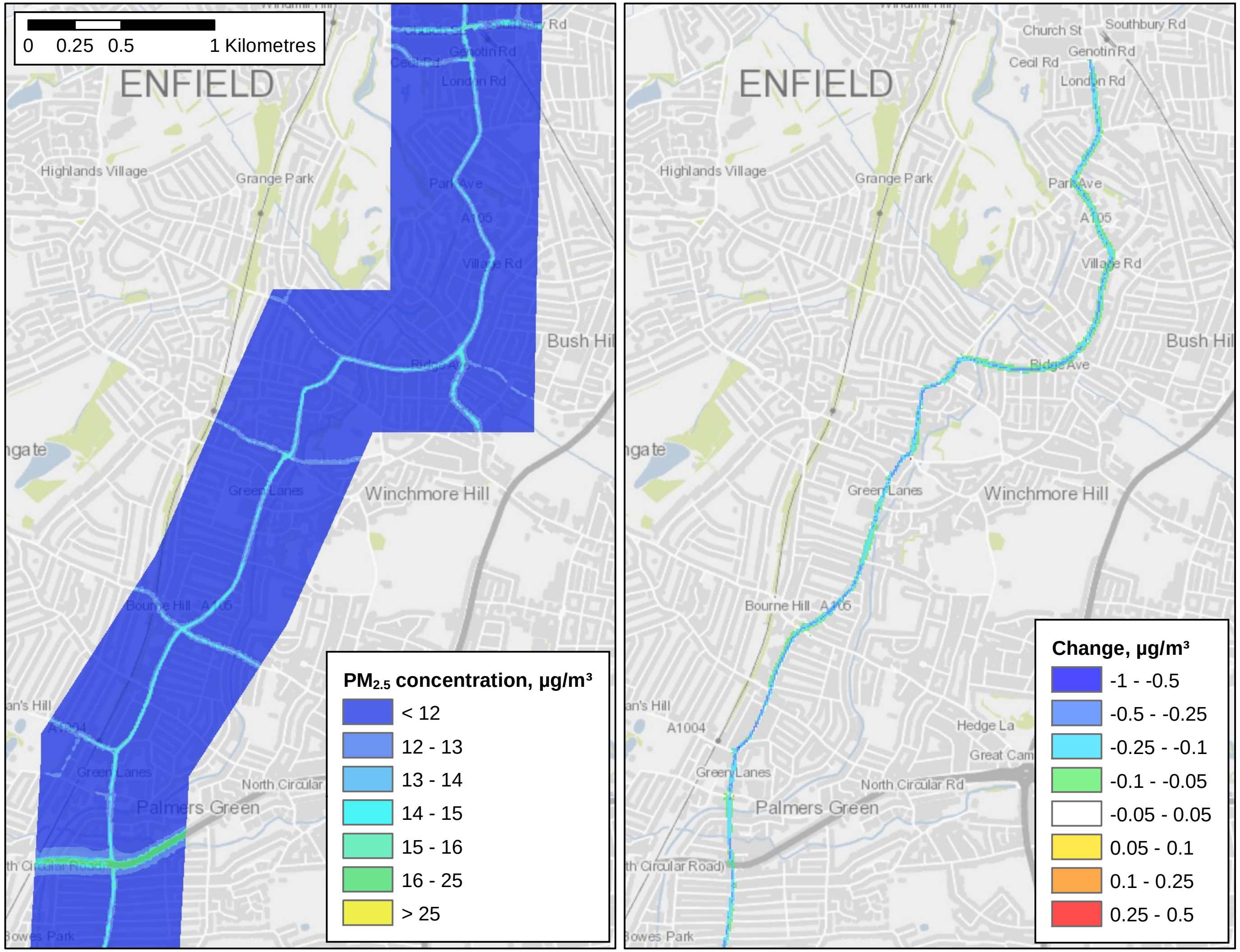


Figure 7.14: Annual average $PM_{2.5}$ concentrations for 10% traffic reduction scenario (left) and difference plot (right)



8 Discussion

Air quality modelling was carried out using ADMS-Urban to assess the impact of a proposal to introduce a segregated cycle way to the A105, including projected traffic reductions associated with the scheme. Currently 0.7% of journeys in Enfield are by bike. As well as the introduction of safe cycle routes, Cycle Enfield is also providing free cycle training for anyone that lives, works or studies in Enfield, installing more cycle parking and introducing a £10 bike loan scheme. These are expected to increase the modal share to 5% by 2020.

The modelling took into account the effect of emissions from free-flowing traffic, queuing traffic and idling buses using bus timetable data and traffic flow and queue data supplied by the Council.

There are no air quality monitoring sites on this section of the A105 so model verification was carried out by comparing measured and modelled concentrations at three nearby monitors: two co-located roadside monitors, and one urban background site. The modelled concentrations showed good agreement with the measured data giving confidence to the modelling of the traffic reduction scenarios.

Without any of the Cycle Enfield proposals, the air quality objective for annual average NO_2 is predicted to be exceeded along the A105, although exceedences are limited to roadside locations. Concentrations of PM_{10} and $PM_{2.5}$ are not predicted to exceed the air quality objectives.

With the introduction of the proposals, and assuming a 2.5% reduction in traffic, annual average NO_2 concentrations are predicted to reduce by between 0.25 $\mu g/m^3$ and 0.5 $\mu g/m^3$ at roadside locations. The scheme will result in some increases in queue length and delay time, leading to increases in concentrations at junctions, however, the area of these increases will be much smaller than the area of air quality improvements resulting from reduced traffic flows. As a result, the majority of residents along this road will experience an improvement in air quality and corresponding health benefits.

With greater reductions in traffic flows, the increases in concentrations at queues generally become smaller and the decreases in concentrations along the rest of road become greater. With a traffic reduction of 10%, roadside annual average NO_2 concentrations are predicted to decrease by up to 1.5 $\mu g/m^3$.

The changes to the traffic flows along the A105 are predicted to bring about only small decreases in PM_{10} and $PM_{2.5}$ concentrations. The effect of the increased queuing on particulate concentrations is not as noticeable as for NO_2 because queuing emissions were assumed to only consist of exhaust emissions without any contribution from brake wear, tyre wear, road wear or resuspension.

APPENDIX A: Summary of ADMS-Urban

ADMS-Urban is a practical air pollution modelling tool, which has been developed to provide detailed predictions of pollution concentrations for all sizes of study area. The model can be used to look at concentrations near a single road junction or over a region extending across the whole of a major city. ADMS-Urban has therefore been extensively used for the Review and Assessment of Air Quality carried out by Local Authorities in the UK. The following is a summary of the capabilities and validation of ADMS-Urban. More details can be found on the CERC web site at www.cerc.co.uk.

ADMS-Urban is a development of the Atmospheric Dispersion Modelling System (ADMS), which has been developed to investigate the impacts of emissions from industrial facilities. ADMS-Urban allows full characterisation of the wide variety of emissions in urban areas, including an extensively validated road traffic emissions model. It also boasts a number of other features, which include consideration of:

- the effects of vehicle movement on the dispersion of traffic emissions;
- the behaviour of material released into street-canyons;
- the chemical reactions occurring between nitrogen oxides, ozone and Volatile Organic Compounds (VOCs);
- the pollution entering a study area from beyond its boundaries;
- the effects of complex terrain on the dispersion of pollutants; and
- the effects of a building on the dispersion of pollutants emitted nearby.

More details of these features are given below.

Studies of extensive urban areas are necessarily complex, requiring the manipulation of large amounts of data. To allow users to cope effectively with this requirement, ADMS-Urban has been designed to operate in the widely familiar PC environment, under Microsoft Windows 7, Windows Vista or XP. The manipulation of data is further facilitated by the possible integration of ADMS-Urban with a Geographical Information System (GIS) such as MapInfo or ArcGIS, and with the CERC Emissions Inventory Toolkit, EMIT.

Dispersion Modelling

ADMS-Urban uses boundary layer similarity profiles 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 the heat flux at the ground. This has significant advantages over earlier methods in which the dispersion parameters did not vary with height within the boundary layer.

In stable and neutral conditions, dispersion is represented by a Gaussian distribution. In convective conditions, the vertical distribution takes account of the skewed structure of the vertical component of turbulence. This is necessary to reflect the fact that, under convective conditions, rising air is typically of limited spatial extent but is balanced by descending air extending over a much larger area. This leads to higher ground-level concentrations than would be given by a simple Gaussian representation.

Emissions

Emissions into the atmosphere across an urban area typically come from a wide variety of sources. There are likely to be industrial emissions from chimneys as well as emissions from road traffic and domestic heating systems. To represent the full range of emissions configurations, the explicit source types available within ADMS-Urban are:

- **Industrial points**, for which plume rise and stack downwash are included in the modelling.
- **Roads**, for which emissions are specified in terms of vehicle flows and the additional initial dispersion caused by moving vehicles is also taken into account.
- **Areas**, where a source or sources is best represented as uniformly spread over an area.
- **Volumes**, where a source or sources is best represented as uniformly spread throughout a volume.

In addition, sources can also be modelled as a regular grid of emissions. This allows the contributions of large numbers of minor sources to be efficiently included in a study while the majority of the modelling effort is used for the relatively few significant sources.

ADMS-Urban can be used in conjunction with CERC's Emissions Inventory Toolkit, EMIT, which facilitates the management and manipulation of large and complex data sets into usable emissions inventories.

Presentation of Results

For most situations ADMS-Urban is used to model the fate of emissions for a large number of different meteorological conditions. Typically, meteorological data are input for every hour during a year or for a set of conditions representing all those occurring at a given location. ADMS-Urban uses these individual results to calculate statistics for the whole data set. These are usually average values, including rolling averages, percentiles and the number of hours for which specified concentration thresholds are exceeded. This allows ADMS-Urban to be used to calculate concentrations for direct comparison with existing air quality limits, guidelines and objectives, in whatever form they are specified.

ADMS-Urban can be integrated with the ArcGIS or MapInfo GIS to facilitate both the compilation and manipulation of the emissions information required as input to the model and the interpretation and presentation of the air quality results provided.

Complex Effects - Street Canyons

The *Operational Street Pollution Model (OSPM)*[8], developed by the Danish National Environmental Research Institute (NERI), has been incorporated within ADMS-Urban.

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[8] Hertel, O., Berkowicz, R. and Larssen, S., 1990, 'The Operational Street Pollution Model (OSPM).' *18th International meeting of NATO/CCMS on Air Pollution Modelling and its Applications.* Vancouver, Canada, pp741-749.

The OSPM uses a simplified flow and dispersion model to simulate the effects of the vortex that occurs within street canyons when the wind-flow above the buildings has a component perpendicular to the direction of the street. The model takes account of vehicle-induced turbulence. The model has been validated against Danish and Norwegian data.

Complex Effects - Chemistry

ADMS-Urban includes the *Generic Reaction Set (GRS)*[9] atmospheric chemistry scheme. The original scheme has seven reactions, including those occurring between nitrogen oxides and ozone. The remaining reactions are parameterisations of the large number of reactions involving a wide range of Volatile Organic Compounds (VOCs). In addition, an eighth reaction has been included within ADMS-Urban for the situation when high concentrations of nitric oxide (NO) can convert to nitrogen dioxide (NO_2) using molecular oxygen.

In addition to the basic GRS scheme, ADMS-Urban also includes a trajectory model[10] for use when modelling large areas. This permits the chemical conversions of the emissions and background concentrations upwind of each location to be properly taken into account.

Complex Effects – Terrain and Roughness

Complex terrain can have a significant impact on wind-flow and consequently on the fate of dispersing material. Primarily, terrain can deflect the wind and therefore change the route taken by dispersing material. Terrain can also increase the levels of turbulence in the atmosphere, resulting in increased dilution of material. This is of particular significance during stable conditions, under which a sharp change with height can exist between flows deflected over hills and those deflected around hills or through valleys. The height of dispersing material is therefore important in determining the route it takes. In addition areas of reverse flow, similar in form and effect to those occurring adjacent to buildings, can occur on the downwind side of a hill.

Changes in the surface roughness can also change the vertical structure of the boundary layer, affecting both the mean wind and levels of turbulence.

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[9] Venkatram, A., Karamchandani, P., Pai, P. and Goldstein, R., 1994, ‘The Development and Application of a Simplified Ozone Modelling System.’ *Atmospheric Environment,* Vol 28, No 22, pp3665-3678.

[10] Singles, R.J., Sutton, M.A. and Weston, K.J., 1997, ‘A multi-layer model to describe the atmospheric transport and deposition of ammonia in Great Britain.’ In: *International Conference on Atmospheric Ammonia: Emission, Deposition and Environmental Impacts. Atmospheric Environment*, Vol 32, No 3.

The ADMS-Urban Complex Terrain Module models these effects using the wind-flow model FLOWSTAR[11]. This model uses linearised analytical solutions of the momentum and continuity equations, and includes the effects of stratification on the flow. Ideally hills should have moderate slopes (up to 1 in 2 on upwind slopes and hill summits, up to 1 in 3 in hill wakes), but the model is useful even when these criteria are not met. The terrain height is specified at up to 16,500 points that are interpolated by the model onto a regular grid of up to 128 by 128 points. The best results are achieved if the specified data points are regularly spaced. FLOWSTAR has been extensively tested with laboratory and field data.

Regions of reverse flow are treated by assuming that any emissions into the region are uniformly mixed within it. Material then disperses away from the region as if it were a virtual point source. Material emitted elsewhere is not able to enter reverse flow regions.

Complex Effects - Buildings

A building or similar large obstruction can affect dispersion in three ways:

1. It deflects the wind flow and therefore the route followed by dispersing material;
2. This deflection increases levels of turbulence, possibly enhancing dispersion; and
3. Material can become entrained in a highly turbulent, recirculating flow region or cavity on the downwind side of the building.

The third effect is of particular importance because it can bring relatively concentrated material down to ground-level near to a source. From experience, this occurs to a significant extent in more than 95% of studies for industrial facilities.

The buildings effects module in ADMS-Urban has been developed using extensive published data from scale-model studies in wind-tunnels, CFD modelling and field experiments on the dispersion of pollution from sources near large structures. It operates out to a distance of about 30 building heights from the building and has the following stages:

(i) A complex of buildings is reduced to a single rectangular block with the height of the dominant building and representative streamwise and crosswind lengths.

(ii) The disturbed flow field consists of a recirculating flow region in the lee of the building with a diminishing turbulent wake downwind, as shown in Figure A1.

(iii) Concentrations within the well-mixed recirculating flow region are uniform and based upon the fraction of the release that is entrained.

(iv) Concentrations further downwind in the main wake are the sum of those from two plumes: a ground level plume from the recirculating flow region and an elevated plume from the non-entrained remainder.

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[11] Carruthers D.J., Hunt J.C.R. and Weng W-S. 1988. 'A computational model of stratified turbulent airflow over hills – FLOWSTAR I.' Proceedings of Envirosoft. In: *Computer Techniques in Environmental Studies,* P. Zanetti (Ed) pp 481-492. Springer-Verlag.

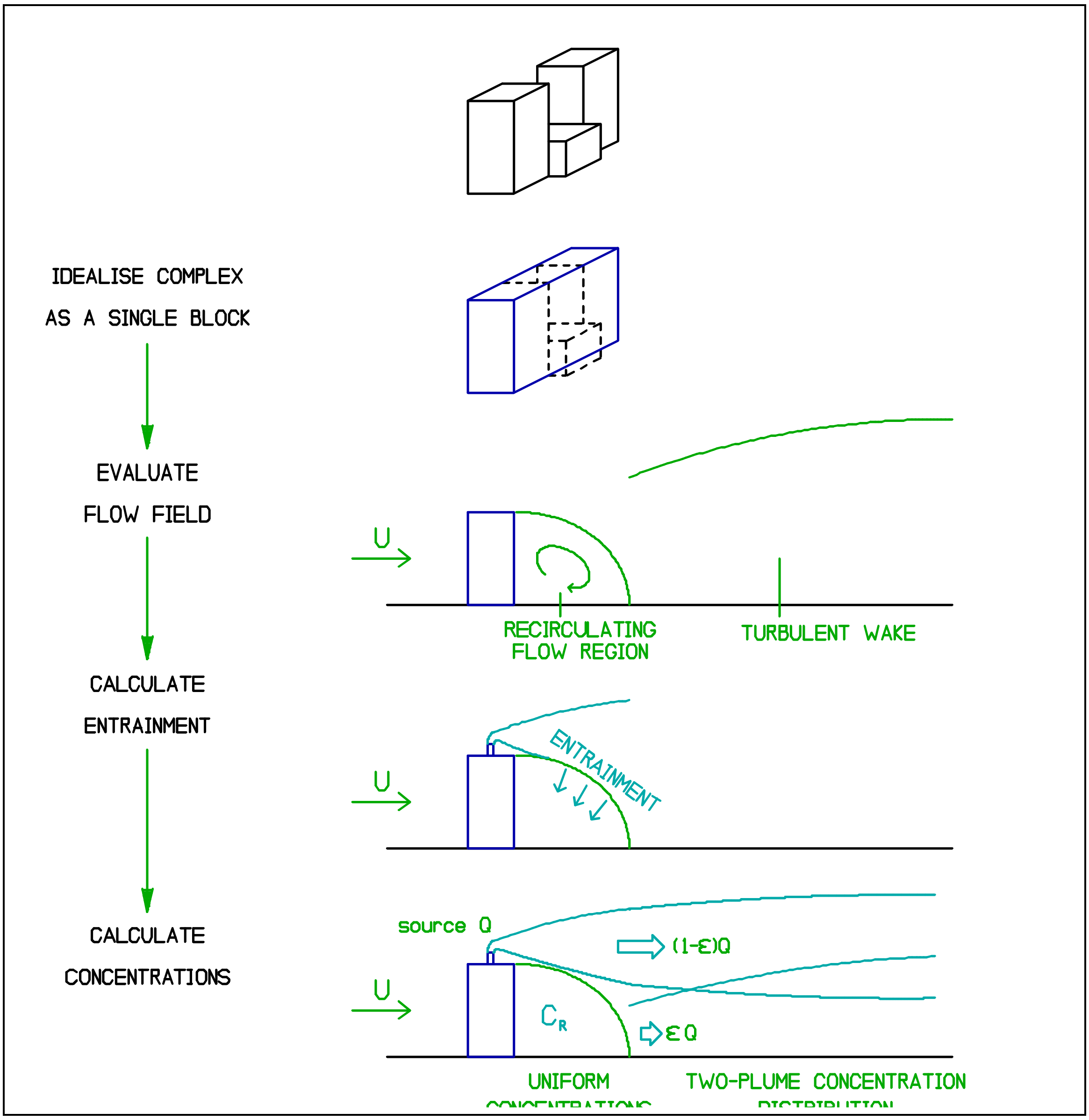

Figure A3.1: Stages in the modelling of building effects

Data Comparisons – Model Validation

ADMS-Urban is a development of the Atmospheric Dispersion Modelling System (ADMS), which is used throughout the UK by industry and the Environment Agency to model emissions from industrial sources. ADMS has been subject to extensive validation, both of individual components (e.g. point source, street canyon, building effects and meteorological pre-processor) and of its overall performance.

ADMS-Urban has been extensively tested and validated against monitoring data for large urban areas in the UK, including Central London and Birmingham, for which a large scale project was carried out on behalf of the DETR (now DEFRA).

Further details of ADMS-Urban and model validation, including a full list of references, are available from the CERC web site at www.cerc.co.uk.