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Air quality assessment for Cycle Enfield A1010 North proposals

Final Report

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Author(s):	Matthew Williams
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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 A1010 North using the ADMS-Urban model. 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.

The modelling used traffic flow and queuing data for the A1010 North supplied by the Council, with data for the rest of London taken from the London Atmospheric Emissions Inventory.

With the introduction of the proposals and a 2.5% reduction in traffic, annual average NO_2 concentrations are predicted to reduce by up to 0.5 $\mu g/m^3$ at roadside locations. The introduction of the scheme is predicted to 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 along the rest of the 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 A1010 are predicted to bring about only small decreases in PM_{10} and $PM_{2.5}$ concentrations. The effect of the increased queuing on PM_{10} and $PM_{2.5}$ concentrations is not as noticeable as for NO_2 because there are no emissions from queuing traffic 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. This report describes the assessment for the A1010 North. 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 ($\mu g/m^3$)	**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 ($\mu g/m^3$)	**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 18$\mu g/m^3$	

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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 A1010 North were provided for the junctions of the A1010 with the A1055, Ordnance Road, Carterhatch Lane, and Green Street. The data were am and pm peak total flows; these were converted to AADT flows using the profile described in Section 4.1.4. The split by vehicle type for each road was calculated using the equivalent data for each road in the LAEI. Table 4.1 gives a summary of the baseline traffic data.

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 4.1: Baseline A1010 North traffic data

Road	Direction	Speed (km/h)	AADT							
			Total	M'cycle	Car	Taxi	LGV	Bus	Rigid HGV	Artic. HGV
Hertford Rd (North of A1055)	Northbound	24-25	16922	258	13668	163	1991	454	339	50
Hertford Rd (North of A1055)	Southbound	5-25	17946	274	14495	173	2111	481	359	53
Bullsmoor Ln	Westbound	27-28	11133	103	8206	129	1436	147	601	406
Bullsmoor Ln	Eastbound	5-28	14003	130	10321	162	1806	185	889	511
Mollison Ave	Westbound	5-33	13991	191	10893	170	1351	132	829	425
Mollison Ave	Eastbound	37-55	15552	213	12109	189	1502	146	921	473
Hertford Rd (South of A1055)	Northbound	5-31	8255	126	6667	80	971	221	165	24
Hertford Rd (South of A1055)	Southbound	22-31	9235	141	7459	89	1086	248	185	27
Hertford Rd (North of Ordnance Rd)	Northbound	20-37	10924	167	8823	105	1285	293	219	32
Hertford Rd (North of Ordnance Rd)	Southbound	20-37	12560	191	10144	121	1478	337	251	37
Ordnance Rd	Two-way	34	15087	140	12710	199	1385	411	239	2
Hertford Rd (South of Ordnance Rd)	Northbound	8-33	13577	207	10966	131	1597	364	272	40
Hertford Rd (South of Ordnance Rd)	Southbound	8-33	16087	246	12993	155	1893	432	322	47
Hertford Rd (South of Carterhatch Ln)	Northbound	18-41	17991	274	14531	173	2117	482	360	53
Hertford Rd (South of Carterhatch Ln)	Southbound	18-41	14431	220	11656	139	1698	387	289	42
Carterhatch Ln	Two-way	9	22413	306	19290	381	1913	233	634	35
Hertford Rd (South of Carterhatch Ln)	Northbound	17-28	11739	179	9481	113	1381	315	235	35
Hertford Rd (South of Carterhatch Ln)	Southbound	17-28	13514	206	10915	130	1590	363	270	40
Hertford Rd (North of Green St)	Northbound	15-17	10270	156	8295	99	1208	276	205	30
Hertford Rd (North of Green St)	Southbound	15-17	14072	215	11366	136	1656	377	282	41
Green St	Two-way	20	9826	0	9108	0	254	464	0	0
Hertford Rd (South of Green St)	Northbound	5-35	8688	133	7017	84	1022	233	174	26
Hertford Rd (South of Green St)	Southbound	5-35	12766	195	10311	123	1502	342	255	38

Table 4.2: Traffic reductions due to scheme

Road	**Direction**	**Baseline**		**2.5% reduction in total traffic**		**5% reduction in total traffic**		**10% reduction in total traffic**	
		Total	**Car**	**Total**	**Car**	**Total**	**Car**	**Total**	**Car**
Hertford Rd (North of A1055)	Northbound	16922	13668	16499	13245	16076	12822	15230	11976
Hertford Rd (North of A1055)	Southbound	17946	14495	17497	14046	17049	13598	16151	12700
Bullsmoor Ln	Westbound	11133	8206	10855	7928	10576	7649	10020	7093
Bullsmoor Ln	Eastbound	14003	10321	13653	9971	13303	9621	12603	8921
Mollison Ave	Westbound	13991	10893	13641	10543	13291	10193	12592	9494
Mollison Ave	Eastbound	15552	12109	15163	11720	14774	11331	13997	10554
Hertford Rd (South of A1055)	Northbound	8255	6667	8049	6461	7842	6254	7430	5842
Hertford Rd (South of A1055)	Southbound	9235	7459	9004	7228	8773	6997	8312	6536
Hertford Rd (North of Ordnance Rd)	Northbound	10924	8823	10651	8550	10378	8277	9832	7731
Hertford Rd (North of Ordnance Rd)	Southbound	12560	10144	12246	9830	11932	9516	11304	8888
Ordnance Rd	Two-way	15087	12710	14710	12333	14333	11956	13578	11201
Hertford Rd (South of Ordnance Rd)	Northbound	13577	10966	13238	10627	12898	10287	12219	9608
Hertford Rd (South of Ordnance Rd)	Southbound	16087	12993	15685	12591	15283	12189	14478	11384
Hertford Rd (South of Carterhatch Ln)	Northbound	17991	14531	17541	14081	17091	13631	16192	12732
Hertford Rd (South of Carterhatch Ln)	Southbound	14431	11656	14070	11295	13709	10934	12988	10213
Carterhatch Ln	Two-way	22413	19290	21853	18730	21292	18169	20172	17049
Hertford Rd (South of Carterhatch Ln)	Northbound	11739	9481	11446	9188	11152	8894	10565	8307
Hertford Rd (South of Carterhatch Ln)	Southbound	13514	10915	13176	10577	12838	10239	12163	9564
Hertford Rd (North of Green St)	Northbound	10270	8295	10013	8038	9757	7782	9243	7268
Hertford Rd (North of Green St)	Southbound	14072	11366	13720	11014	13368	10662	12665	9959
Green St	Two-way	9826	9108	9580	8862	9335	8617	8843	8125
Hertford Rd (South of Green St)	Northbound	8688	7017	8471	6800	8254	6583	7819	6148
Hertford Rd (South of Green St)	Southbound	12766	10311	12447	9992	12128	9673	11489	9034

4.1.2 Traffic queues

Queuing was modelled at peak hours for a number of junctions along the A1010, 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 four major junctions along the A1010 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).

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

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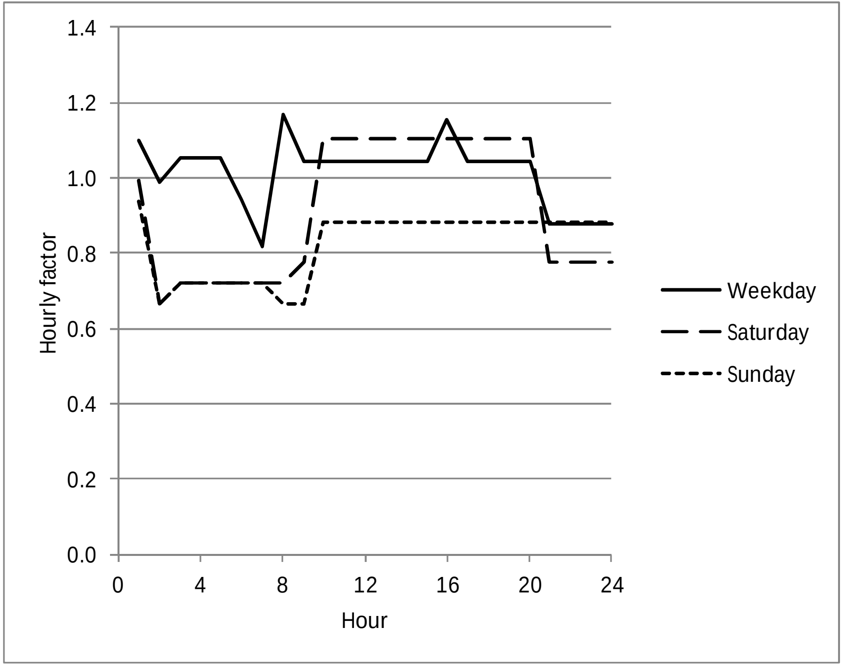
[2] Transport for London, *Traffic Directorate, Model Auditing Process: Traffic Scehemes in London Urban Networks, Design Engineer Guide Version 3.0*, March 2011

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. These 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 4.2.

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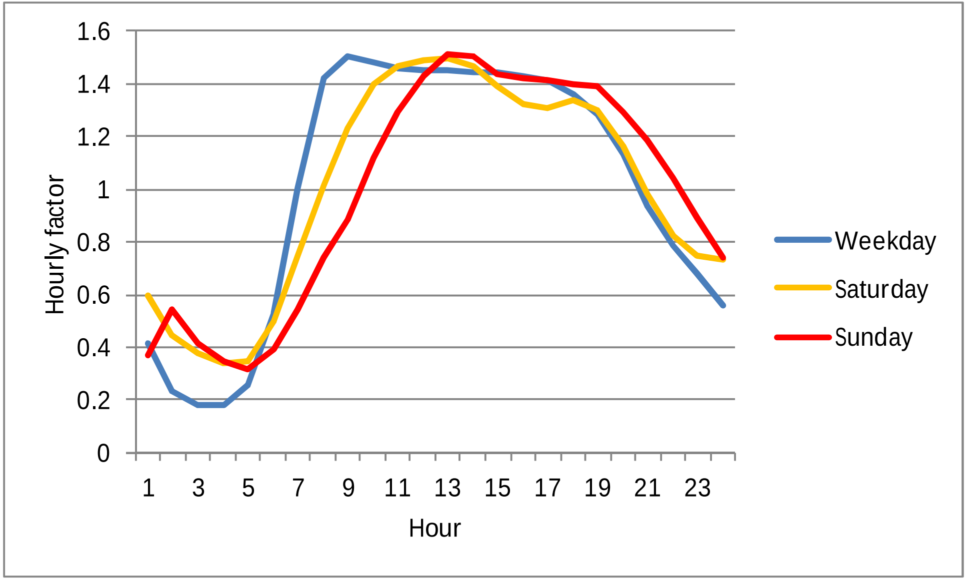
[3] *Air pollution and emissions trends in London*, King's College London, Environmental Research Group and Leeds University, Institute for Transport studies http://www.airquality.co.uk/reports/cat05/1004010934_MeasurementvsEmissionsTrends.pdf

Figure 4.2: LAEI traffic profiles



4.1.5 Traffic emission factors

Traffic emissions were calculated from the traffic flow data using DfT emission factors released in 2014. 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 for 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.

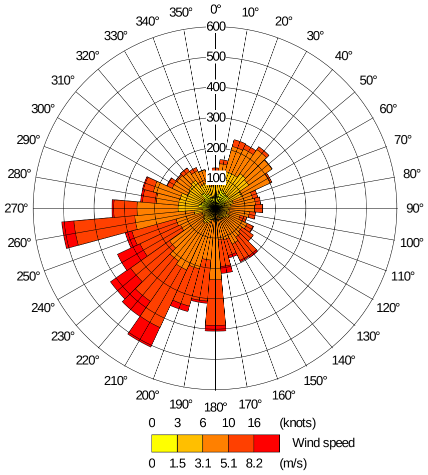
5.4 Meteorological data

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 5.1 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)

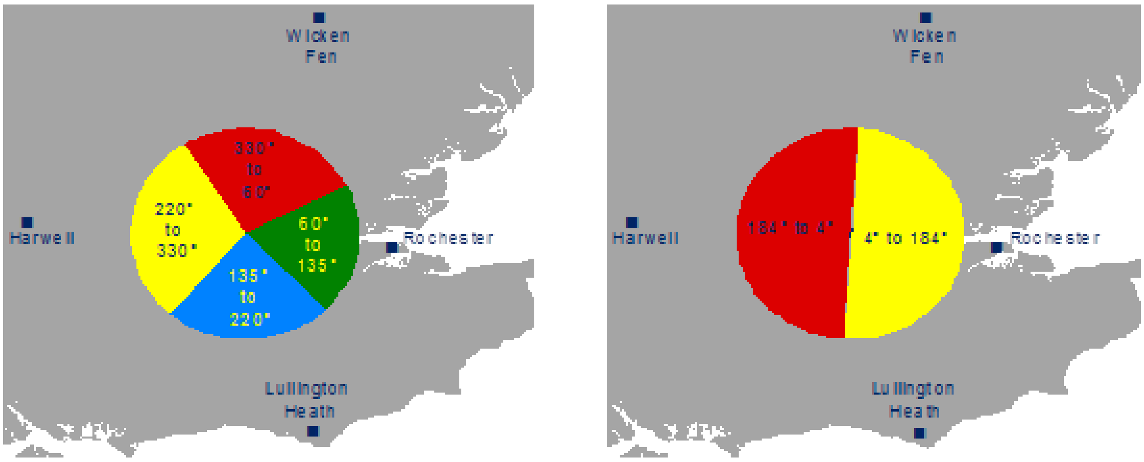


Table 5.2 summarises the annual statistics of the resulting background concentrations used in the modelling for 2014. It was assumed that background concentrations would not change significantly between 2014 and 2016.

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 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)
Prince of Wales	Automatic	Urban Background	536886, 198497	N/A
Enfield 2	Diffusion tube	Industrial	536634, 196356	N/A
Enfield 3	Diffusion tube	Urban Background	533881, 195832	8
Enfield 5	Diffusion tube	Urban Background	535126, 196295	5
Enfield 7	Diffusion tube	Roadside	535460, 199849	2

Figure 6.1: Monitoring locations used for verification

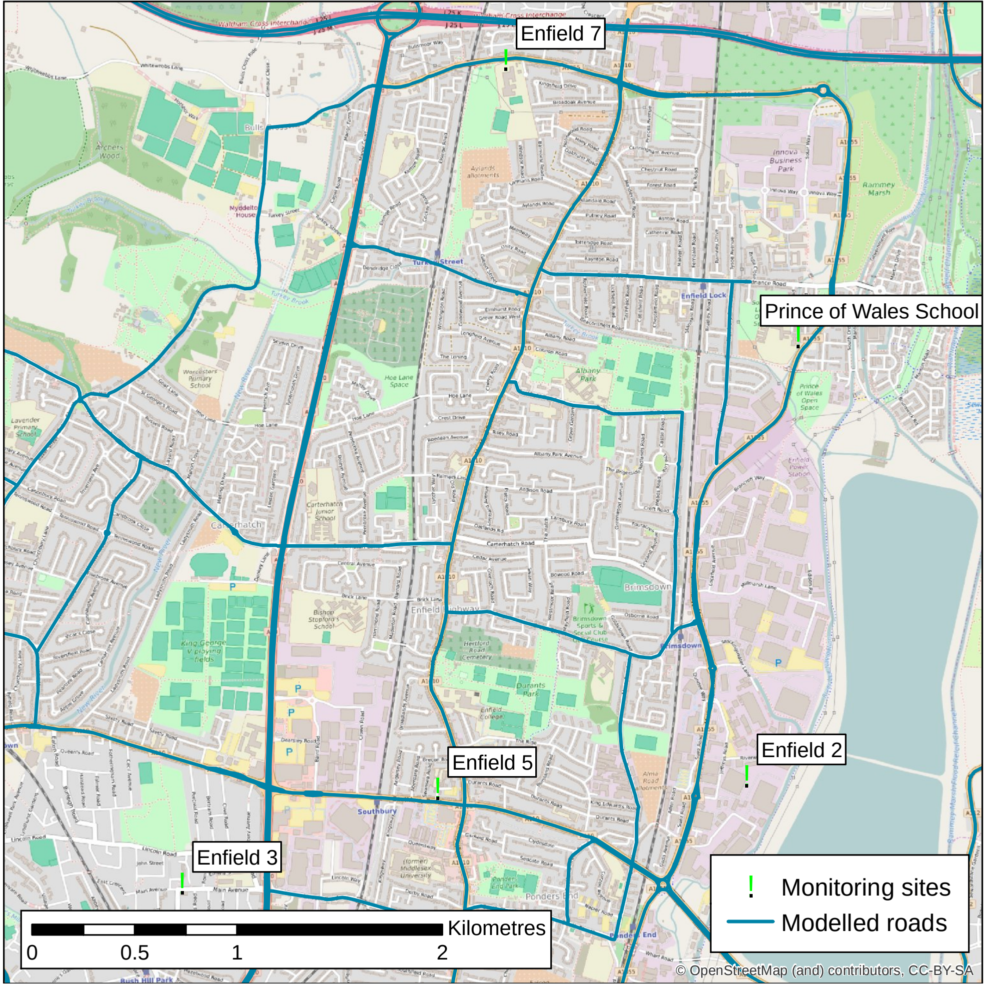


Table 6.2 presents the measured and modelled concentrations of NO_2 at the monitoring locations for 2014. The modelled annual average NO_2 concentrations show generally good agreement. There is no consistent over or underprediction of concentrations with two of the sites showing agreement within 5% and two more showing agreement within 25%.

Table 6.2: Measured and modelled NO_x and NO_2 concentrations, 2014, $\mu g/m^3$

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**
Prince of Wales	50.2	36.1	24.2	25.1	82.8	102.7
Enfield 2	-	-	29.9	31.4	-	-
Enfield 3	-	-	27.9	22.3	-	-
Enfield 5	-	-	36.7	26.6	-	-
Enfield 7	-	-	32.4	39.8	-	-

There are no PM_{10} monitors within the modelling area; Table 6.3 presents the monitored and modelled concentrations of PM_{10} at the nearest site, Bowes Road, for 2014. The predicted annual average PM_{10} concentration and 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, $\mu g/m^3$

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 A1010 North 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 air quality standard for annual average NO_2 concentrations is likely to be exceeded along the length of the A1010, although exceedences are likely to be restricted to roadside building facades with the highest concentrations at major junctions. The air quality standard for hourly average NO_2 concentrations is only predicted to be exceeded at roadside at the busiest junctions.

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 relative to the base case.

With the introduction of the proposals and a 2.5% reduction in traffic, annual average NO_2 concentrations are predicted to reduce by up to 0.5 $\mu g/m^3$ at roadside locations. The introduction of the scheme is predicted to result in some increases in queue length and delay time leading to increases in concentrations 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 the 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 $\mu g/m^3$. None of the scenarios considered is predicted to eliminate exceedences of the air quality objectives in the area.

Figure 7.1: Annual average NO_2 concentration for baseline scenario

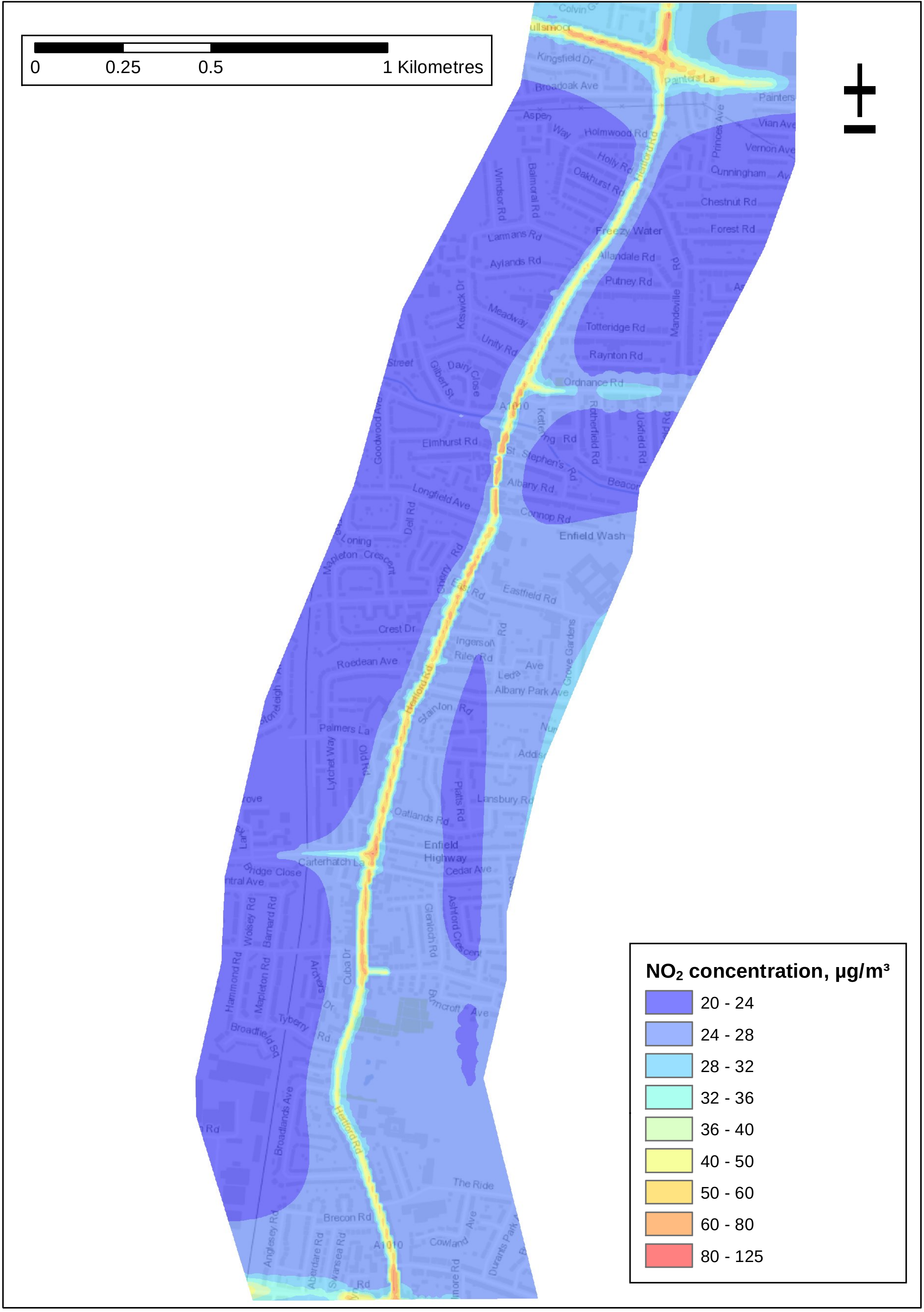


Figure 7.2: 99.79th percentile of hourly average NO_2 concentrations for baseline scenario

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

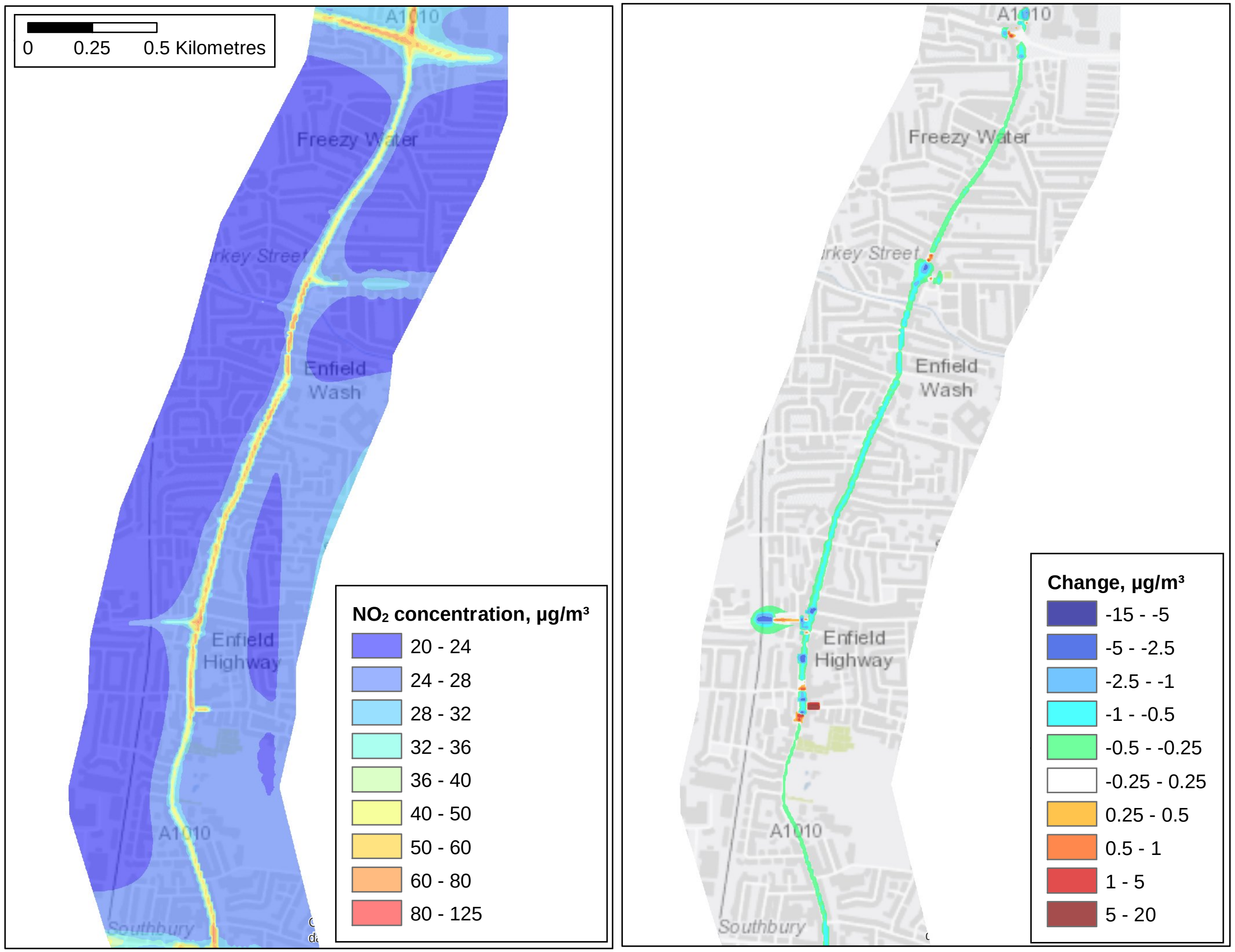


Figure 7.4: Annual average NO_2 concentrations for 5% traffic reduction scenario (left) and difference plot (right)

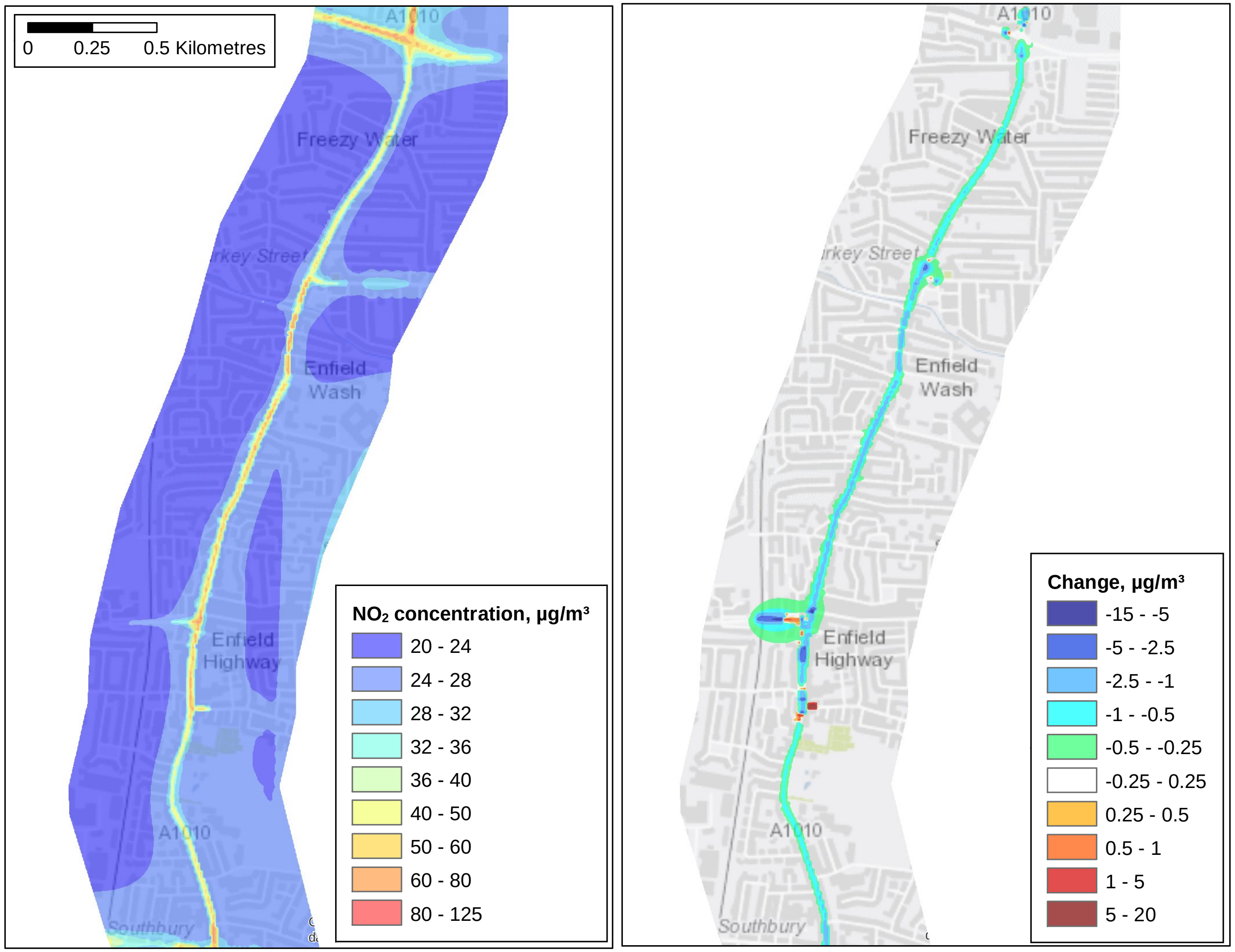
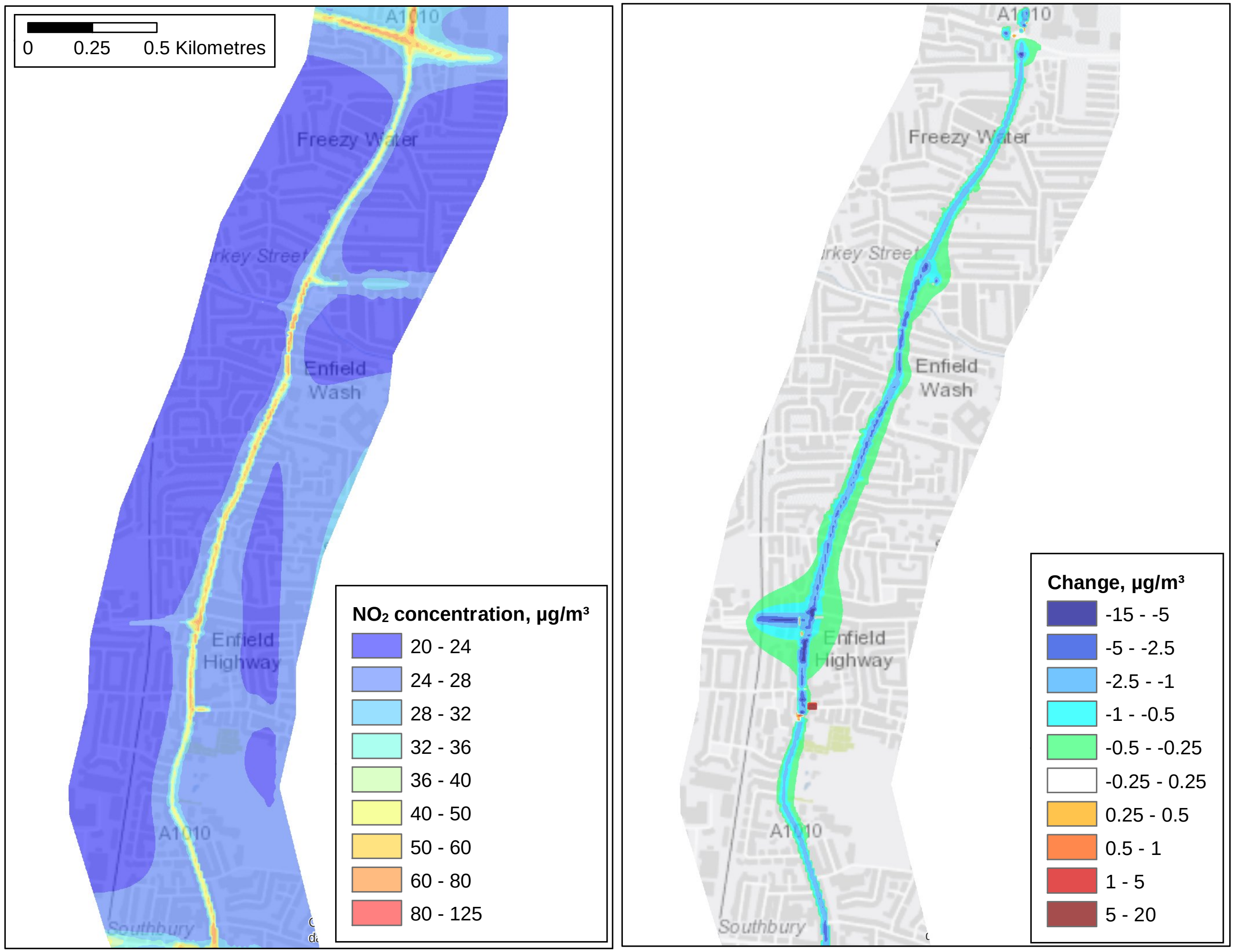


Figure 7.5: Annual average NO_2 concentrations for 10% traffic reduction scenario (left) and difference plot (right)



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 standard for annual average PM_{10} concentrations is not likely to be exceeded along the A1010.

Figure 7.8 to Figure 7.10 show the predicted annual 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 air quality objectives for PM_{10} concentrations are not predicted to be exceeded anywhere along the A1010 North.

The changes to the traffic flows along the A1010 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 there are no emissions from queuing traffic 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

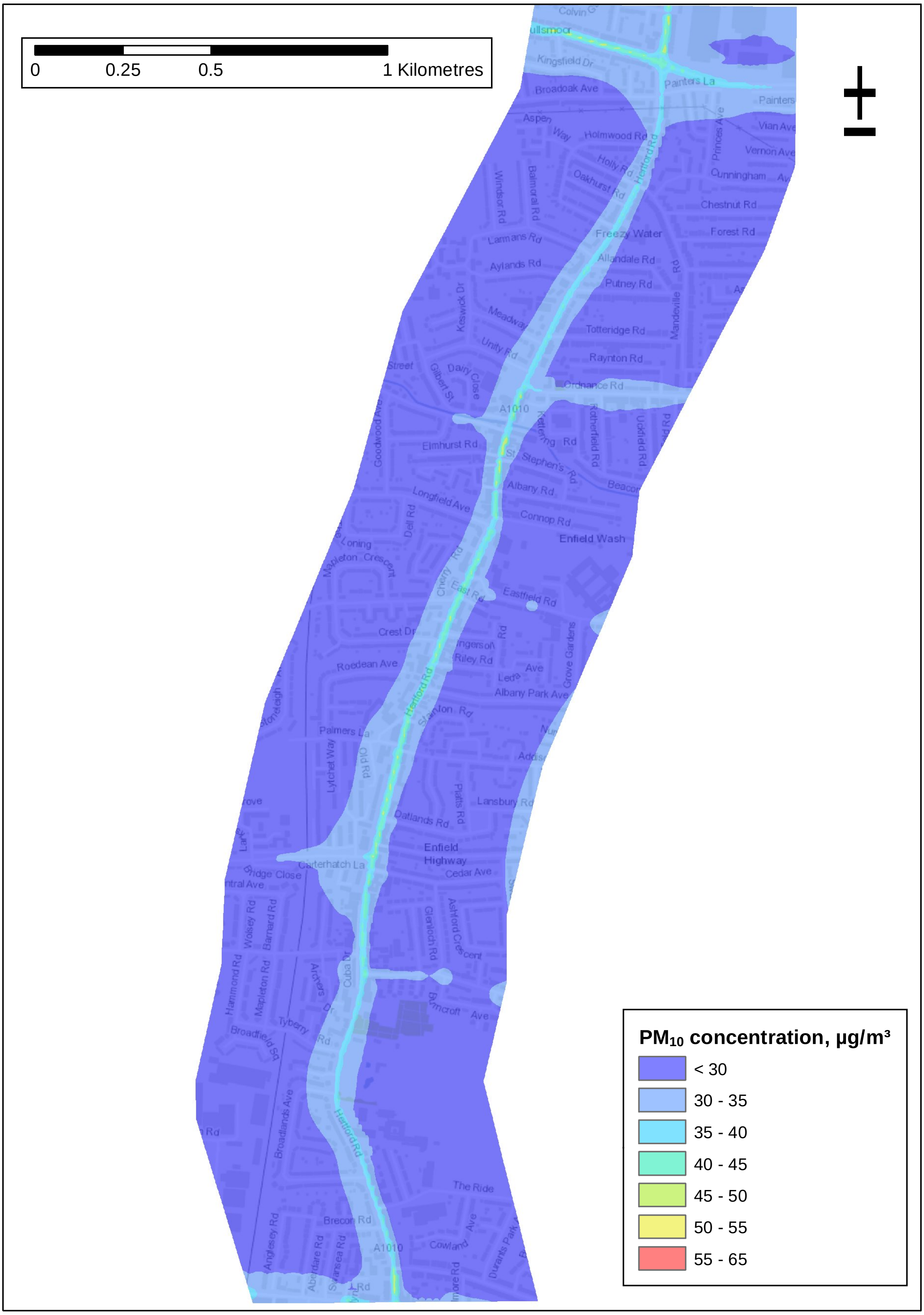


Figure 7.8: Annual average PM$_{10}$ concentrations for 2.5% traffic reduction scenario (left) and difference plot (right)

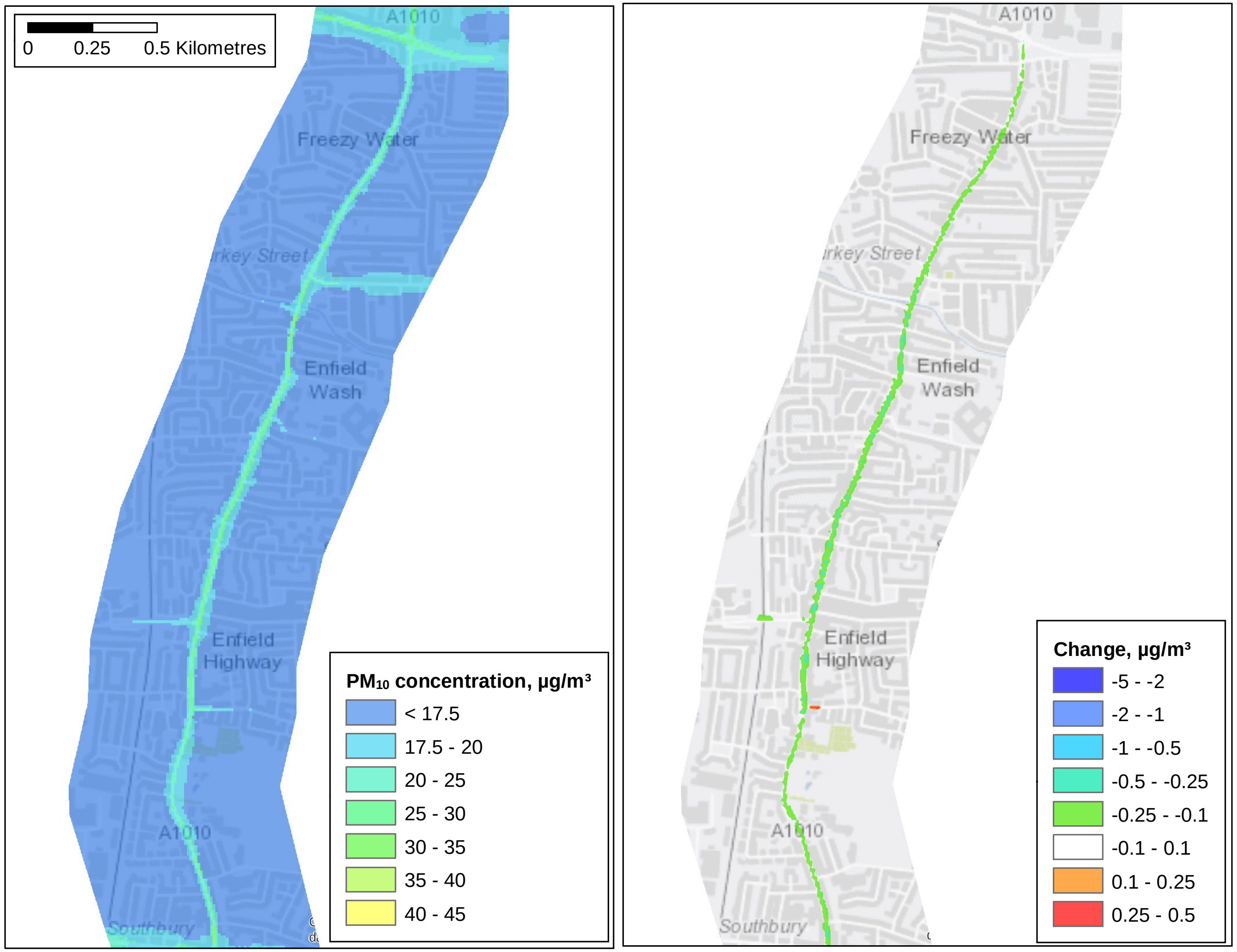


Figure 7.9: Annual average PM_{10} concentrations for 5% traffic reduction scenario (left) and difference plot (right)

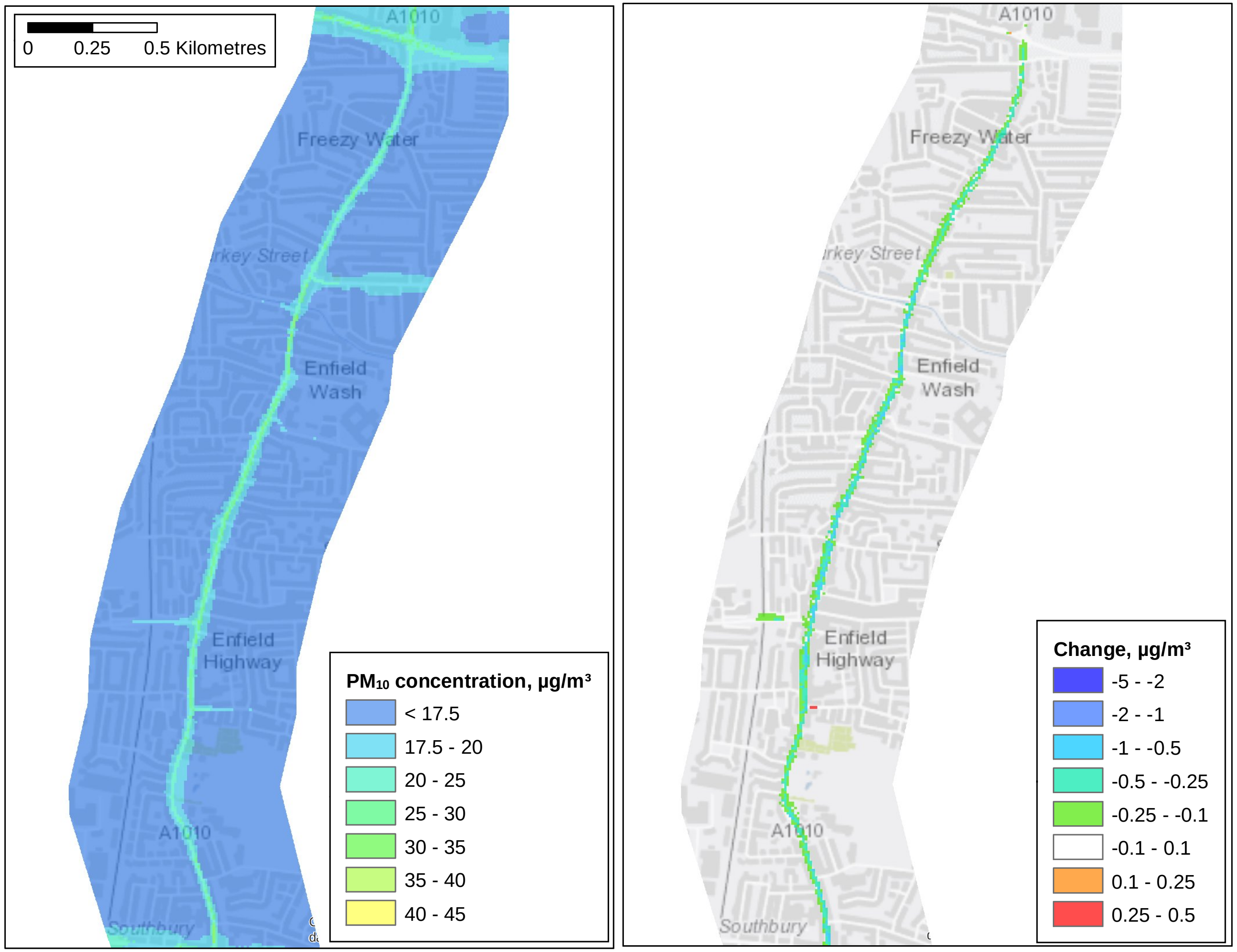
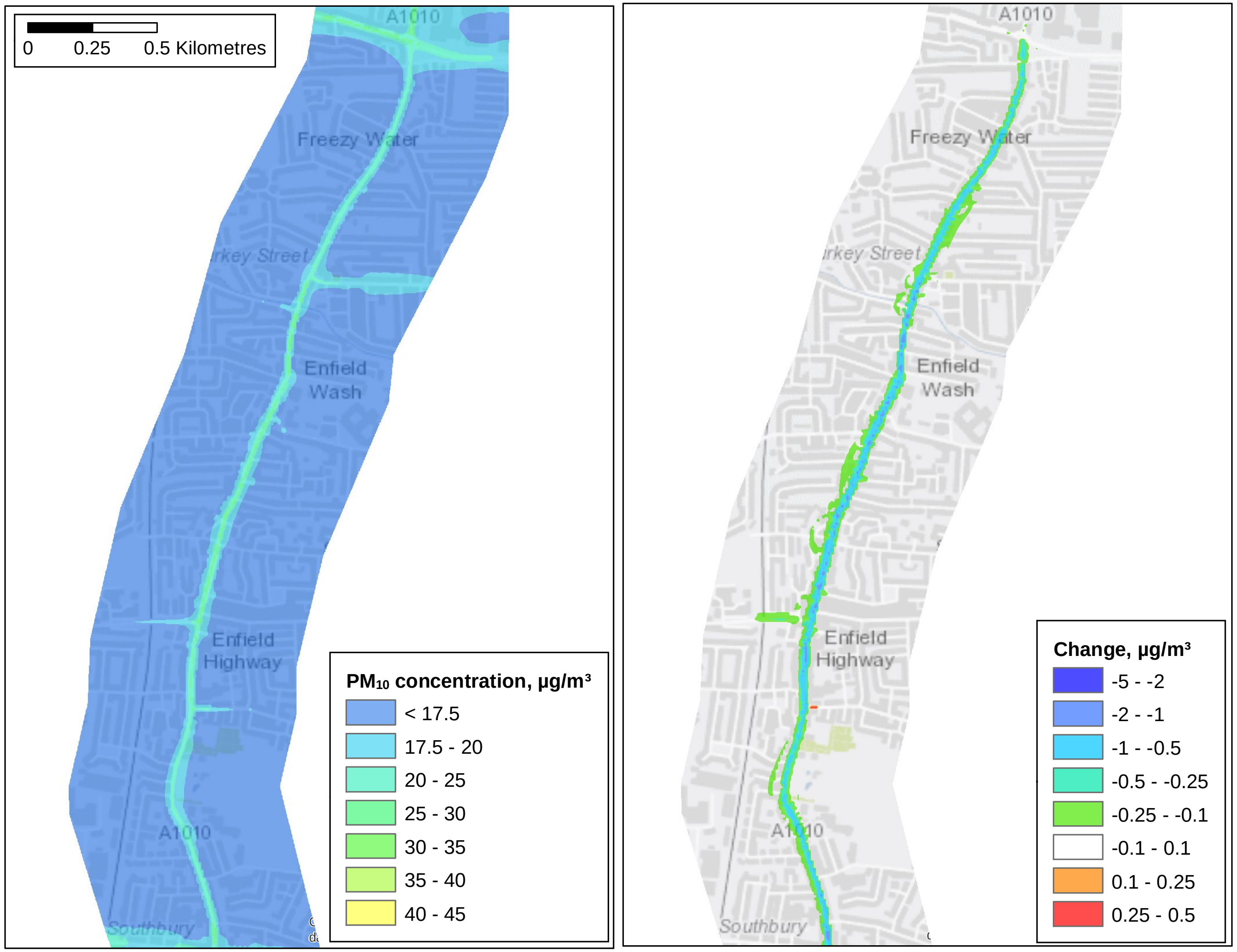


Figure 7.10: Annual average PM_{10} concentrations for 10% traffic reduction scenario (left) and difference plot (right)



7.3 PM$_{2.5}$ concentrations

Figure 7.11 shows a contour plot of the annual average PM$_{2.5}$ concentrations for 2016 without the Cycle Enfield proposals. The plots show that the air quality standard for annual average PM$_{2.5}$ concentrations is not likely to be exceeded along the A1010.

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)

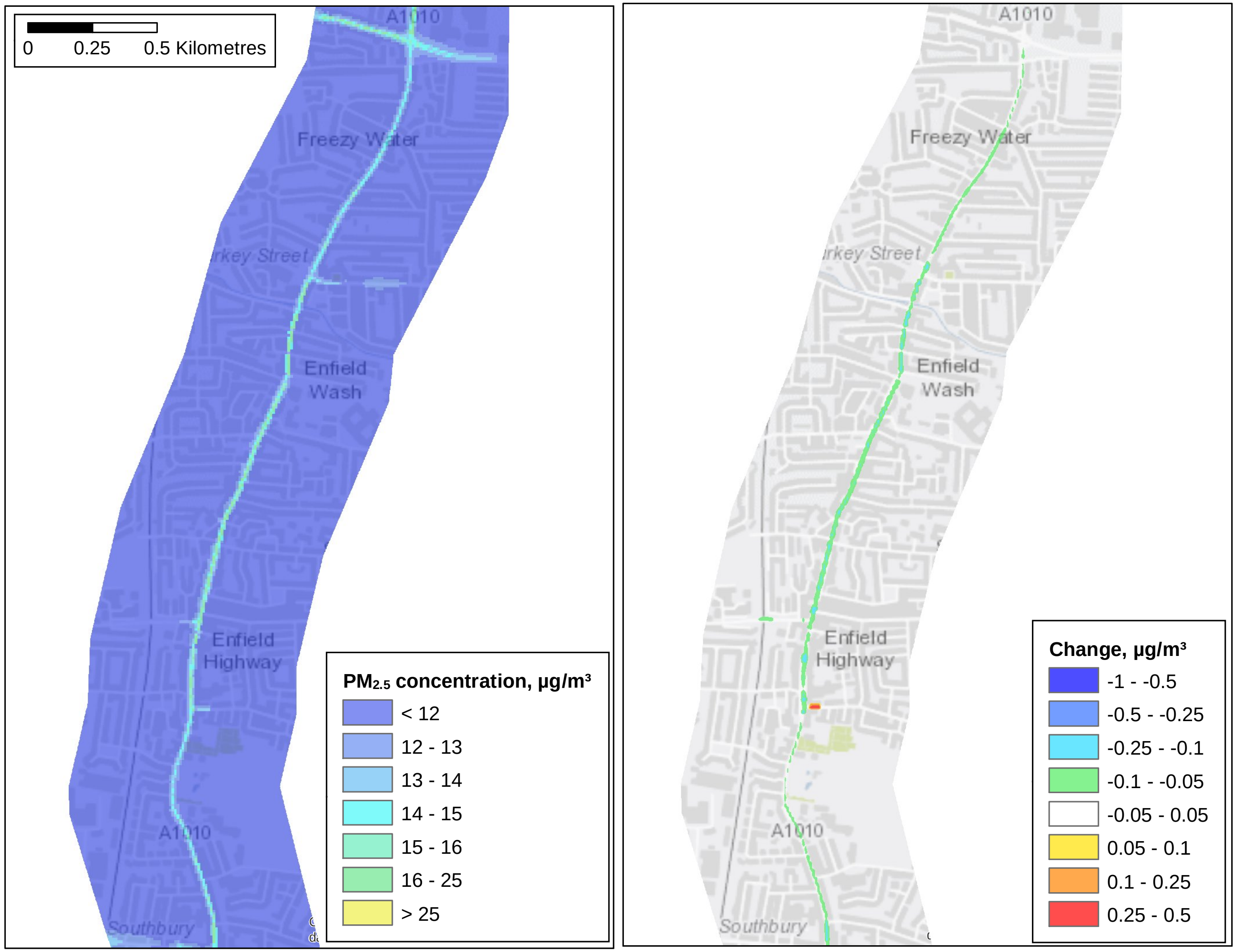


Figure 7.13: Annual average $PM_{2.5}$ concentrations for 5% traffic reduction scenario (left) and difference plot (right)

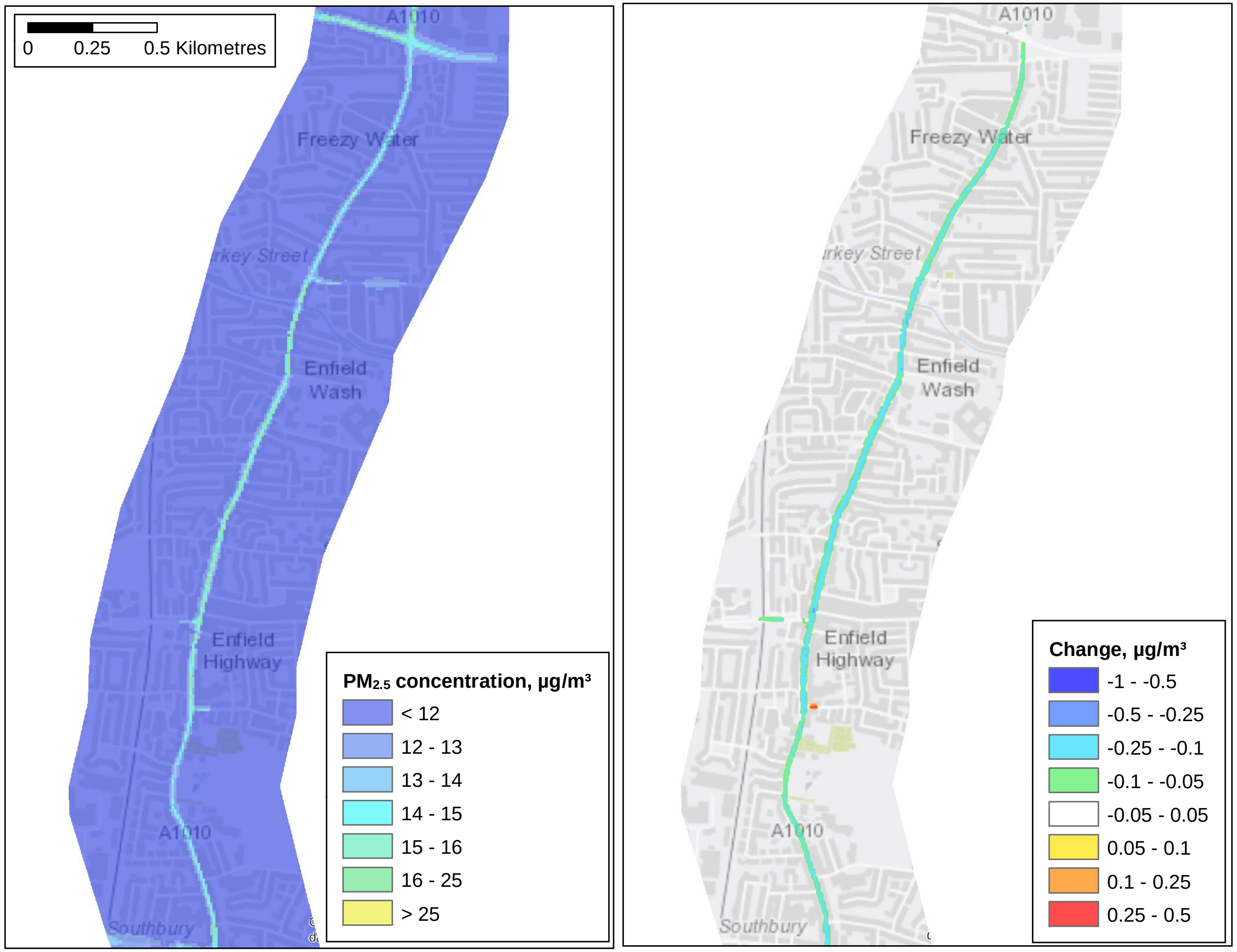
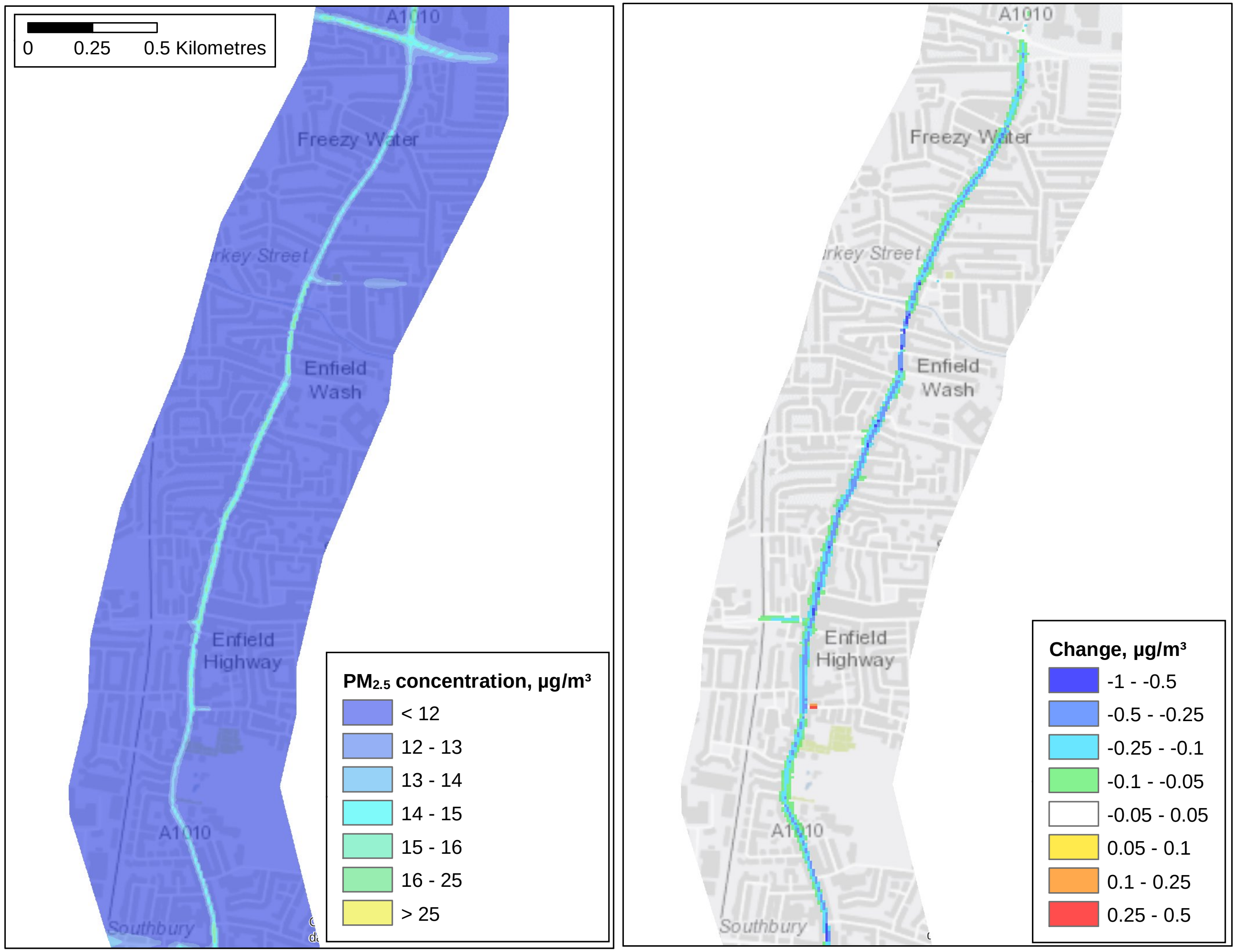


Figure 7.14: Annual average $PM_{2.5}$ concentrations for 10% traffic reduction scenario (left) and difference plot (right)



8 Discussion

Air quality modelling was carried out using ADMS-Urban to assess the impact of a proposal to introduce a segregated cycle way along the A1010 North, 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. 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.

With the introduction of the proposals and a 2.5% reduction in traffic, annual average NO_2 concentrations are predicted to reduce by up to 0.5 $\mu g/m^3$ at roadside locations. The introduction of the scheme is predicted to 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 along the rest of the 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 A1010 are predicted to bring about only small decreases in PM_{10} and $PM_{2.5}$ concentrations. The effect of the increased queuing on PM_{10} and $PM_{2.5}$ concentrations is not as noticeable as for NO_2 because there are no emissions from queuing traffic 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.

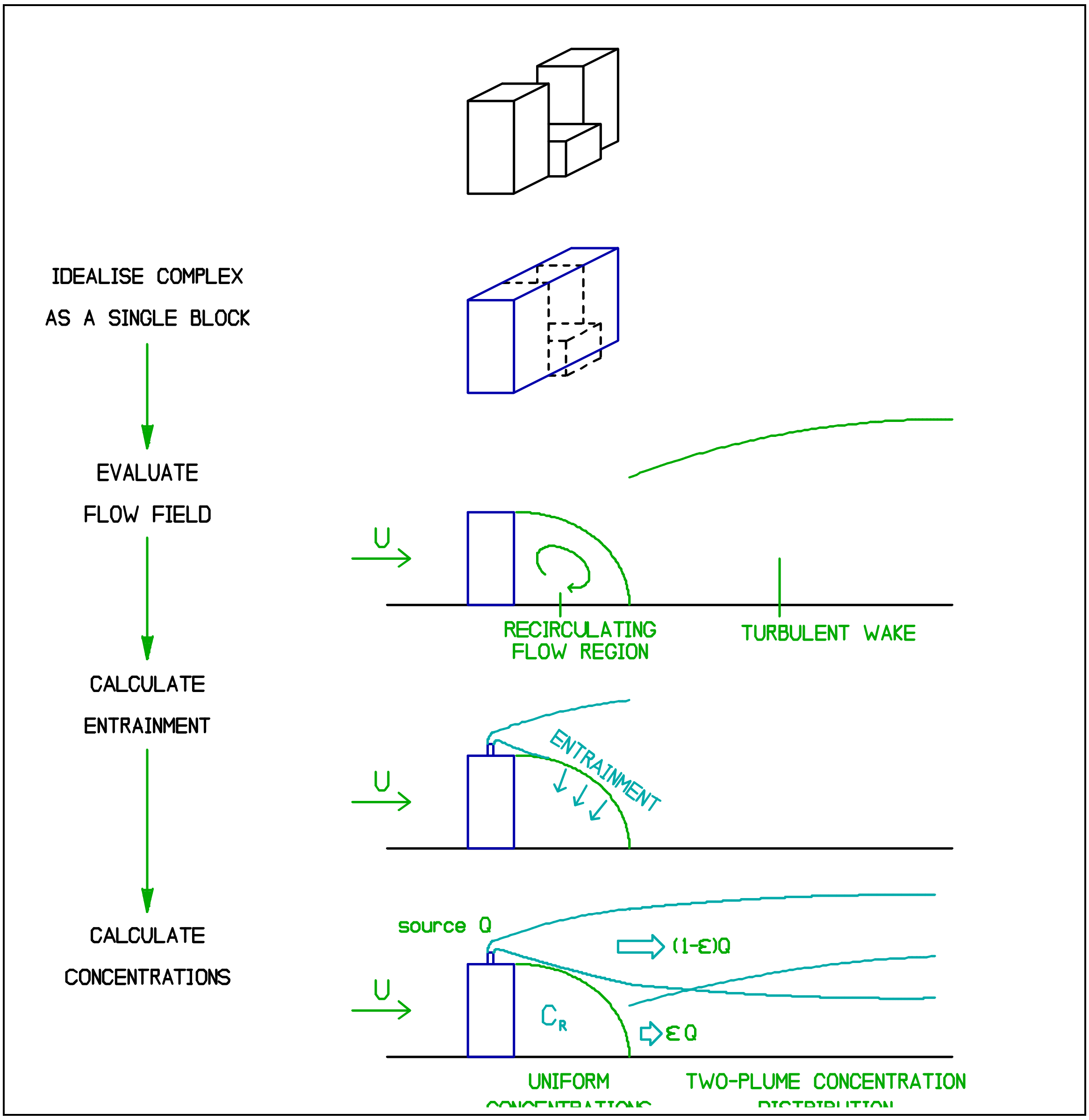

Figure A3.1: Stages in the modelling of building effects

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.