Bath Clean Air Plan

Bath and North East Somerset Council

AQ3 Air Quality Modelling Report

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March 2019

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Contents

Acronyms and Abbreviations

ADMS	Atmospheric Dispersion Modelling System
ANPR	Automatic Number Plate Recognition
AQMA	Air Quality Management Area
ATC	Automatic Traffic Counters
BANES	Bath and North East Somerset Council
CAZ	Clean Air Zone
COPERT	COmputer Programme to calculate Emissions from Road Transport
Defra	Department for Environment, Food & Rural Affairs
DfT	Department for Transport
EFT	Emission Factor Toolkit
fNO_2	Primary Nitrogen Dioxide
GBATH	Greater Bath Area Transport Model
HGV	Heavy Goods Vehicle
JAQU	Joint Air Quality Unit (Defra and the Department for Transport)
LGV	Light Goods Vehicle
LSOA	Lower Super Output Area
$\mu g/m^3$	Microgrammes per cubic metre
NO_2	Nitrogen dioxide
NO	Nitrogen oxide
NOx	Nitrogen oxides (taken to be NO_2 + NO)
PCM	Pollution Climate Mapping
PM_{10}	Small airborne particles less than 10 micrometres in aerodynamic diameter
$PM_{2.5}$	Small airborne particles less than 2.5 micrometres in aerodynamic diameter

1. Introduction

Poor air quality is the largest known environmental risk to public health in the UK[1]. Investing in cleaner air and doing more to tackle air pollution are priorities for the EU and UK governments, as well as for Bath and North East Somerset Council (B&NES). B&NES has monitored and endeavoured to address air quality in Bath, and wider B&NES, since 2002. Despite this, Bath has ongoing exceedances of the legal limits for Nitrogen Dioxide (NO_2) and these are predicted to continue until 2025 without intervention.

In 2017 the government published a UK Air Quality Plan for NO_2[2] setting out how compliance with the EU Limit Value for annual mean NO_2 will be reached across the UK in the shortest possible time. Due to forecast air quality exceedances, B&NES, along with 27 other Local Authorities, was directed by Minister Therese Coffey (Defra) and Minister Jesse Norman (DfT) in 2017 to produce a Clean Air Plan (CAP). The Plan must set out how B&NES will achieve sufficient air quality improvements in the shortest possible time. In line with Government guidance B&NES is considering implementation of a Clean Air Zone (CAZ), including both charging and non-charging measures, in order to achieve sufficient improvement in air quality and public health.

Jacobs has been commissioned by B&NES to produce an Outline Business Case (OBC) for the delivery of the CAP; a package of measures which will bring about compliance with the Limit Value for annual mean NO_2 in the shortest time possible in Bath. The OBC assesses the shortlist of options set out in the Strategic Outline Case[3], and proposes a preferred option including details of delivery. The OBC forms a bid to central government for funding to implement the CAP.

This document is written to support the OBC.

1.1 Purpose of Report

This report presents the outcomes of the air quality modelling for the BANES CAZ Feasibility study. This version of the report presents the results of the baseline modelling and the ‘with scheme’ results.

[1] Public Health England (2014) Estimating local mortality burdens associated with particular air pollution. https://www.gov.uk/government/publications/estimating-local-mortality-burdens-associated-with-particulate-air-pollution
[2] https://www.gov.uk/government/publications/air-quality-plan-for-nitrogen-dioxide-no2-in-uk-2017
[3] Bath and North East Somerset Council Clean Air Plan: Strategic Outline Case, March 2018 (http://www.bathnes.gov.uk/sites/default/files/siteimages/Environment/Pollution/strategic_outline_case_bath_28.03.2018_with_annexes.pdf)

2. Methodology

2.1 Overview

Air quality dispersion modelling has been undertaken using ADMS-Roads version 4.1 using vehicle emission factors from the EFT version 8.0.1a. A detailed model has been set up for Bath, incorporating detail on street canyons and gradients. The model has been verified and adjusted on the basis of year 2017 measurements from 44 nitrogen dioxide (NO_2) monitoring locations situated across Bath.

The model has been run at receptors representing both locations relevant for the air quality objectives (façades of residential buildings, schools, hospitals etc.) and locations designed to be comparable to the Government's PCM model, which is used to report compliance with the Limit Values. These receptors have been presented separately as there are important differences.

The model uses a variety of input data. Importantly the traffic data have been derived from the G-BATH transport model, using local fleet composition as described in OBC-13 'T3 Transport Modelling Methodology Report' in Appendix E of the OBC. Inputs and assumptions used are described in OBC-10 'AQ2 Local Plan Air Quality Modelling Methodology Report' in Appendix D of the OBC, which also includes the full methodology.

All modelling undertaken follows relevant guidance issued by JAQU, and has been subject to discussion with JAQU as the process has progressed.

Although Defra's Air Quality Plan sets out to tackle roadside NO_2 concentrations in the UK (Defra, 2017a), there are also Limit Values and Air Quality Objectives for particulate matter (PM), specifically PM_{10} and $PM_{2.5}$ which need some consideration as the UK has both a national and international obligation to regulate PM concentrations. The health effects and associated costs of PM are also interlinked with those of NO_2 and therefore require assessment.

3. Base Year Model Verification

3.1 Introduction

In order to ensure that ADMS-Roads accurately predicts local concentrations, it is necessary to verify the model against local measurements.

Background concentrations of nitrogen dioxide for the verification sites have been derived from the national maps, having been calculated using the approach as described in AQ2 Local Plan Air Quality Modelling Methodology Report. The background concentrations have then been adjusted based on a comparison with local monitoring (again described in detail in AQ2).

AADT flows, and the proportions of HDVs, for the roads adjacent to the monitoring sites, have been determined from the traffic model utilised for this feasibility study. The specifics of the vehicle fleet have been derived from ANPR (Automatic Number Plate Recognition) data collected around Bath. For full details see OBC-13 'T3 Transport Modelling Methodology report' in Appendix E of the OBC.

3.2 Nitrogen Dioxide

Most nitrogen dioxide (NO_2) is produced in the atmosphere by reaction of nitric oxide (NO) with ozone. It is therefore most appropriate to verify the model in terms of primary pollutant emissions of nitrogen oxides (NOx = NO + NO_2). It is also important to only verify that part of the total concentration which is predicted by the dispersion model (the background component has been verified and adjusted separately). This is because the alternative (i.e. verifying against the total concentrations only) risks hiding poor performance in the dispersion model. Because the model is unlikely to perform equally well at all locations, verifying the model at a large number of sites is preferable to only using a small number of sites; even when this means using diffusion tube monitors. While measurements made with diffusion tubes are generally of lower quality than those from automatic monitors, they are still considered to be more reliable than the results from a dispersion model; particularly one which is only verified for a small number of monitoring sites. The model has thus been run to predict the annual mean NOx concentrations during 2017 at 41 diffusion tube monitoring sites and 3 automatic monitoring sites. Concentrations have been modelled at the inlet height of the monitors.

The model output of road-NOx has been compared with the 'measured' road-NOx. Measured road-NOx has been calculated from the measured NO_2 concentrations and the predicted background NO_2 concentration using the NOx from NO_2 calculator (Version 6.1) available on the Defra LAQM Support website (Defra, 2018b). The results of this comparison showed that the model consistently under-predicted road-NOx concentrations at the monitoring sites. This is a very common experience when predicting NOx concentrations in urban environments using a dispersion model and emissions from Defra's EFT; which is the method recommended by JAQU and thus followed here. The accepted approach to addressing this under-prediction, following both Defra and JAQU guidance, is to uplift the model outputs to match the measurements. In practice there is a linear relationship between NOx emissions and road-NOx concentrations and it is thus often more convenient to apply the uplift to the model inputs (emissions) rather than to the model outputs (concentrations). Bias in the predicted emissions from future vehicle fleets may be different from that in the current fleet, but there is no way, within the methodology recommended by JAQU, to take account of this.

Further investigation showed a clear relationship between the extent to which road-NOx concentrations were under-predicted and the proportion of emissions coming from Light Goods Vehicles (LGV) and Heavy Duty Vehicles (HDV) (i.e. the sum of Heavy Goods Vehicles (HGVs), buses and coaches) on uphill lanes of gradient roads (see Technical Note on Gradient Emissions in Appendix B). This analysis suggests that NOx emissions from these vehicle types, on uphill lanes of gradient roads, were being under-predicted more than other NOx emissions. It was thus determined that the model predictions are improved if emissions from LGVs and HDVs on uphill lanes of gradient roads are uplifted independently from all other modelled emissions. Following this analysis, an adjustment factor of 7.392 has been applied to LGV and HDV NOx emissions on uphill lanes of gradient roads and an adjustment factor of 1.575 has been applied to all other NOx emissions. Subsequently, the model output of road-NOx has been re-compared with the 'measured' road-NOx and has zero bias (see Figure 1).

The EFT has been used to obtain both NOx and NO_2 emissions. Both uplifted NOx and NO_2 have been included within the air quality model to calculate location-specific primary NO_2[4] (f-NO_2) values for each receptor. These location specific values have then been used within the conversion of NOx to NO_2 (using the NOx to NO_2 calculator supplied by Defra). This is the approach recommended by JAQU.

The total nitrogen dioxide concentrations have then been determined by combining the adjusted modelled road-NOx concentrations with the predicted background NO_2 concentrations and f-NO_2 values within the NOx to NO_2 calculator. Figure 2 compares final adjusted modelled total NO_2 at each of the monitoring sites to measured total NO_2.

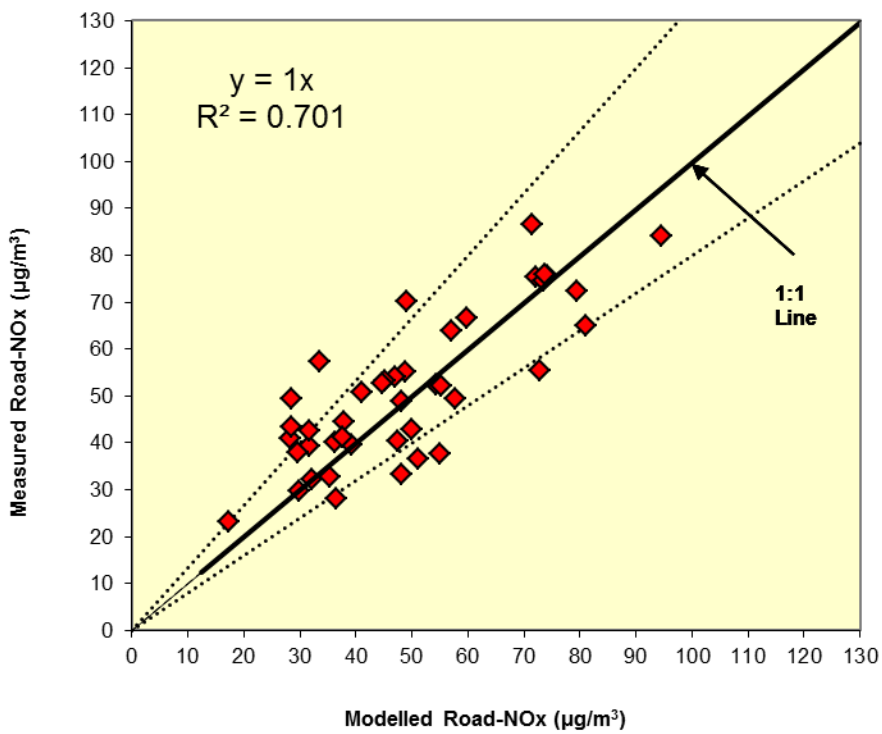

Figure 1: Comparison of Measured and Modelled Road-NOx Concentrations (following adjustments to emissions). The dashed lines show ± 25%.

[4] Emissions of NO_2 emitted directly to the atmosphere

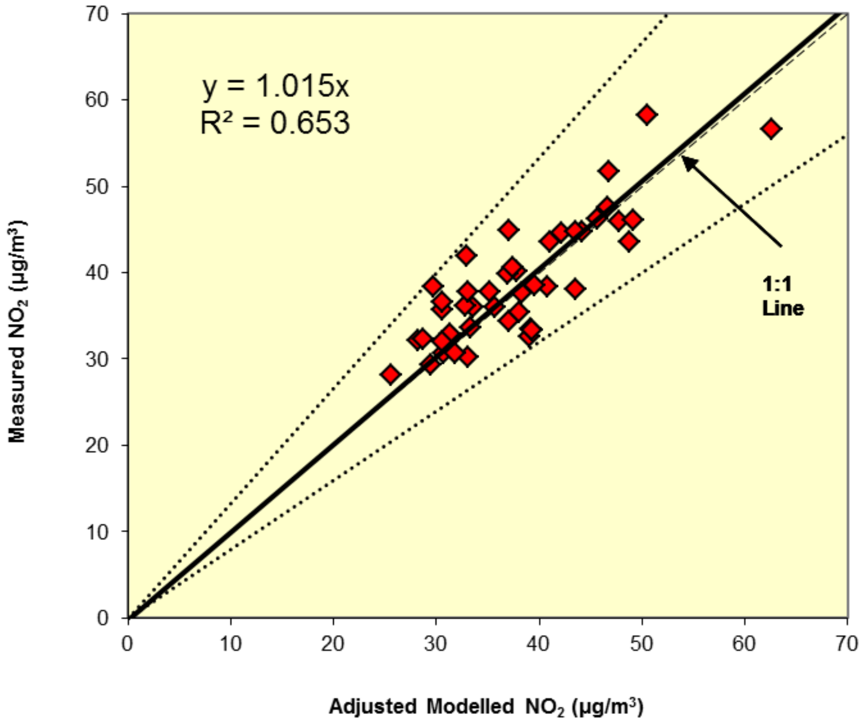

Figure 2: Comparison of Measured Total NO_2 to Final Adjusted Modelled Total NO_2 Concentrations. The dashed lines show ± 25%.

Table 1 shows the statistical parameters relating to the performance of the model, as well as 'ideal' values (Defra, 2018b). The values calculated for the model demonstrate that it is performing acceptably.

Table 1: Statistical Model Performance

Statistical Parameter	Model-Specific Value	'Ideal' Value
Correlation Coefficient [a]	0.85	1
Root Mean Square Error (RMSE) [b]	4.08	0
Fractional Bias [c]	-0.02	0

[a] Used to measure the linear relationship between predicted and observed data. A value of zero means no relationship and a value of 1 means absolute relationship.

[b] Used to define the average error or uncertainty of the model. The units of RMSE are the same as the quantities compared (i.e. µg/m^3). TG16 (Defra, 2018b) outlines that, ideally, a RMSE value within 10% of the air quality objective (4 µg/m^3) would be derived. If RMSE values are higher than 25% of the objective (10 µg/m^3) it is recommended that the model is revisited.

[c] Used to identify if the model shows a systematic tendency to over or under predict. Negative values suggest a model over-prediction and positive values suggest a model under-prediction.

3.3 PM_{10} and $PM_{2.5}$

It was only possible to verify the model performance for particulate matter (PM) at one monitoring site. Modelled road-PM_{10} concentrations have been compared to measured road-PM_{10} concentrations at the Windsor Bridge automatic monitoring station (CM3), in order to derive an adjustment factor to verify the model for PM_{10} concentrations. The data used to calculate the adjustment factor are provided below and have been based on unrounded values:

- Measured PM_{10}: 23.8 μg/m^3
- Background PM_{10} : 12.8 μg/m^3
- 'Measured' road-PM_{10} (measured – background): 23.8 –12.8 = 10.9 μg/m^3
- Modelled road-PM_{10} = 1.6 μg/m^3
- Road-PM_{10} adjustment factor: 10.9/1.6 = 6.938

Thus, the model under-predicts local PM_{10} concentrations significantly at this site. There is a possibility that this site was affected by local non-traffic emissions, but an analysis of measurements over a number of years has shown that measurements have not varied appreciably from one year to the next. It is also possible that the wider-scale background PM_{10} concentration, as taken from Defra maps, is incorrect and thus driving this high adjustment, but there is no way to test this. The predicted PM_{10} concentrations are thus considered to be less reliable than the NO_2 predictions.

There are no appropriate $PM_{2.5}$ monitoring stations. It has therefore not been possible to verify the model for $PM_{2.5}$. The model outputs of road-$PM_{2.5}$ have therefore been adjusted by applying the adjustment factor calculated for road-PM_{10}.

It should be noted that the Chelsea House automatic monitoring station (CM4) does measure concentrations of both PM_{10} and $PM_{2.5}$, but is not considered an appropriate site to use for model verification due to it being set back from main roads by approximately 15 m and the adjacent road (Snow Hill) not being included in the model (due to insufficient data available).

As the model predictions of PM could only be verified at a single monitoring site in Bath on a non-gradient road, there is no way to determine whether PM emissions should be further adjusted on gradient roads. The approach to gradient-uplifts therefore does not apply any additional adjustment to PM emissions beyond the uplifts applied from Defra's guidance.

4. Baseline Forecasts

4.1 Background Concentrations

Estimated background concentrations in the study area have been determined for 2017 and the future year 2021 using Defra's background maps (Defra, 2018b), with the NO_2 values adjusted based on a comparison with local measurements. The background concentrations are set out in Table 2 and have been derived as described in the Air Quality Modelling Methodology Report (AQ2). The background concentrations are all well below the objectives.

Table 2: Estimated Annual Mean Background Pollutant Concentrations in 2017 and 2021 (µg/m3)

Year	NO_2	PM_{10}	$PM_{2.5}$
2017	8.8 – 18.9	11.3 – 13.4	7.4 – 8.6
2021	7.6 – 16.3	11.0 – 13.1	7.2 – 8.3
Objectives	**40**	**40**	**25** [a]

The range of values is for the different 1x1 km grid squares covering the study area.

[a] The $PM_{2.5}$ objective, which is to be met by 2020, is not in Regulations and there is no requirement for local authorities to meet it.

4.2 Baseline Dispersion Model Results: Nitrogen Dioxide

4.2.1 Local Air Quality Baseline

Baseline concentrations of nitrogen dioxide have been modelled at existing receptor locations, as well as at 4 m from the kerb, 2 m in height, for comparison with PCM outputs. The results, which cover both the existing (2017) and future year (2021) baseline (Without Scheme), are set out in Figure 3 and

Figure 4 for receptor locations (i.e. relevant for the air quality objectives).

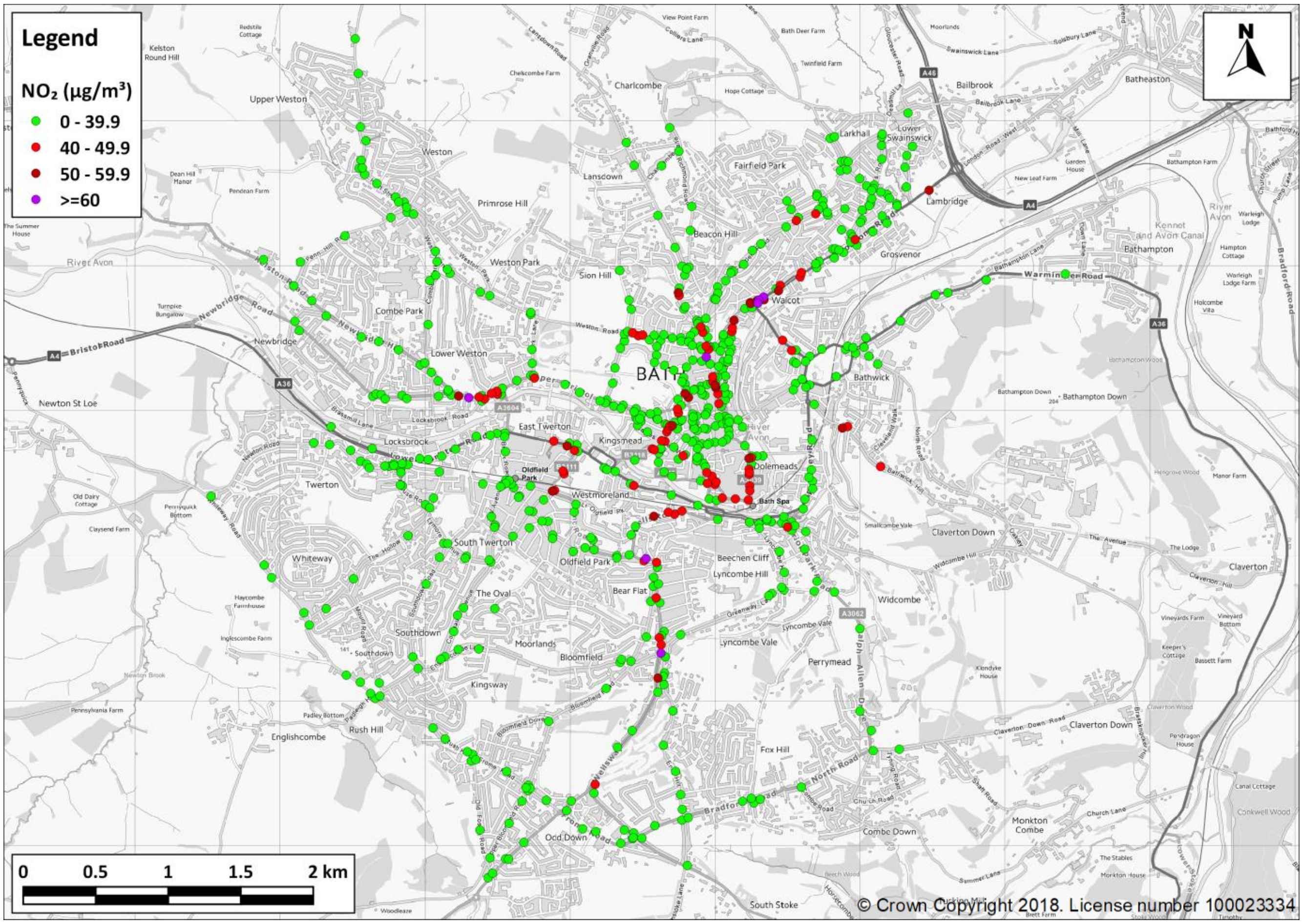

Figure 3: Predicted NO_2 concentrations in 2017 at receptor locations relevant to the national air quality objective (annual mean)

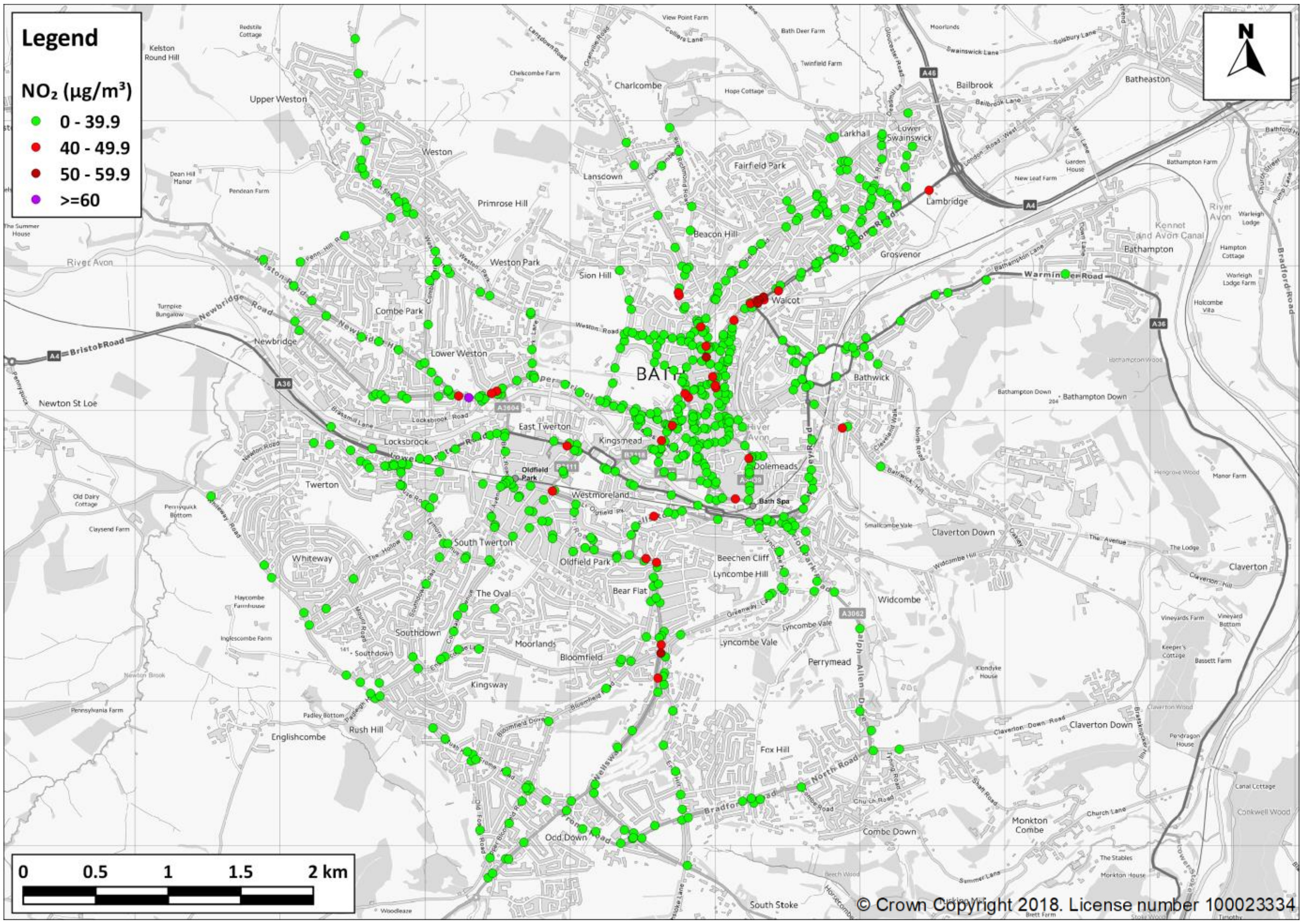

Figure 4: Predicted NO_2 concentrations in 2021 at receptor locations relevant to the national air quality objective (annual mean*)*

The predicted annual mean concentrations of nitrogen dioxide show exceedances in 2017 at locations relevant to the air quality objectives. The exceedances are all along busy roads, particularly within street canyons and close to junctions. These exceedances are consistent with the conclusions of Bath and North East Somerset Council in the outcome of its air quality review and assessment work and declared AQMA for exceedances of the annual mean nitrogen dioxide objective.

The predicted annual mean concentrations of nitrogen dioxide still show exceedances in 2021 at locations relevant to the air quality objectives, although these are fewer in number than in 2017. The exceedances are all along busy roads, particularly within street canyons and close to junctions. The predicted concentrations at the locations with exceedances are presented in Appendix A.

4.2.2 Baseline for Comparison with the PCM

Concentrations of nitrogen dioxide have also been modelled at relevant receptor locations adjacent to roads within the PCM model. The results, which cover both the 2017 and 2021 years, are set out in

Figure 5 and

Figure **6** for locations modelled at 4 m from the kerb and 2 m in height (i.e. relevant for comparison with the PCM model). These model outputs have then been simplified to only report the maximum value for each census ID of the PCM model. These results are reported in spreadsheet TD1.

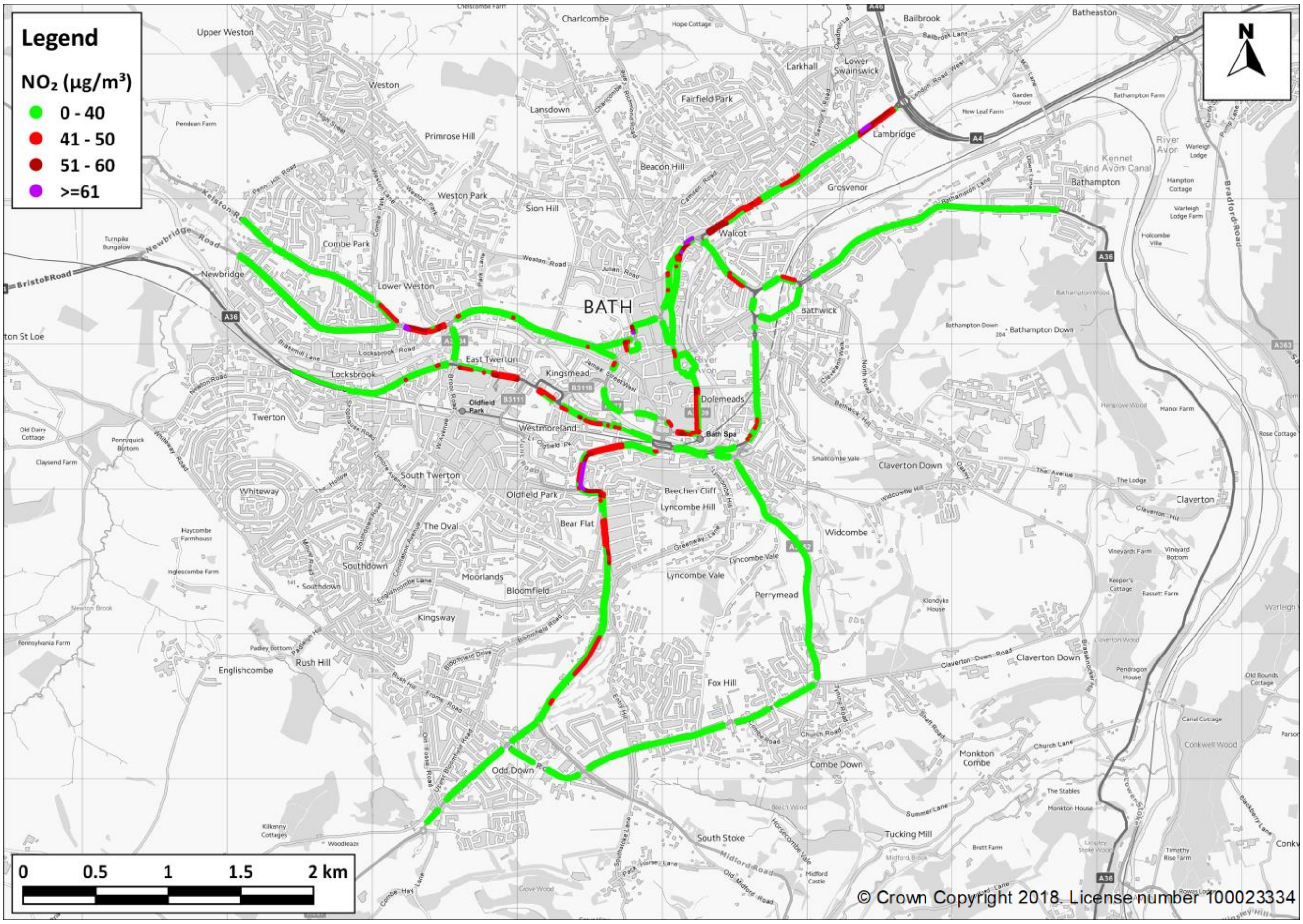

Figure 5: Predicted NO_2 concentrations in 2017 at PCM-equivalent receptor locations (annual mean)

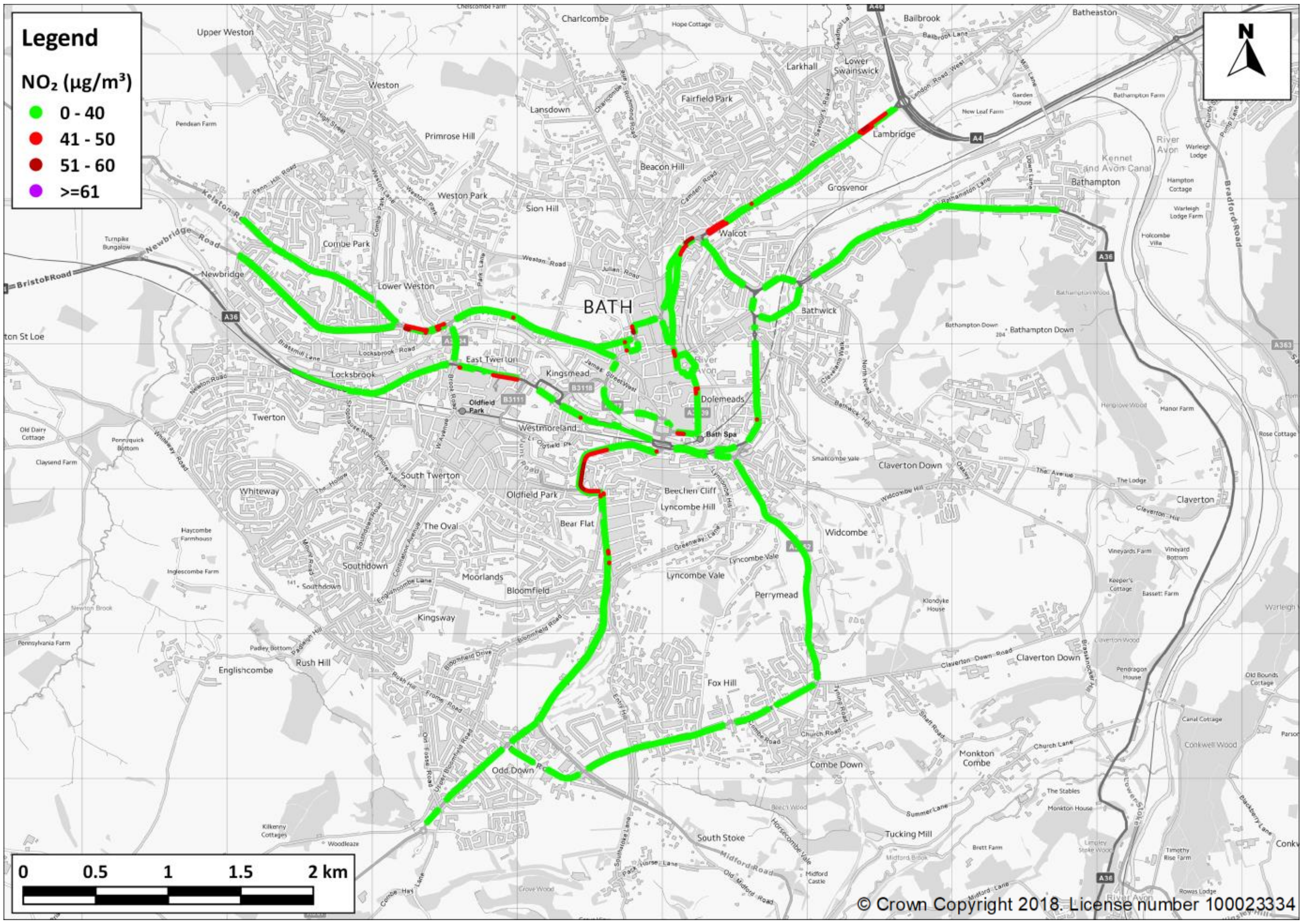

Figure 6: Predicted NO_2 concentrations in 2021 at PCM-equivalent receptor locations (annual mean)

The predicted annual mean concentrations of nitrogen dioxide at PCM-equivalent receptors show exceedances of the annual mean Limit Value in 2017 in central Bath.

The predicted annual mean concentrations of nitrogen dioxide at PCM-equivalent receptors still show exceedances of the annual mean Limit Value in 2021, although these are fewer in number than in 2017. The predicted concentrations at the locations with exceedances are presented in Appendix A.

4.3 Baseline Dispersion Model Results: PM_{10} and $PM_{2.5}$

4.3.1 Local Air Quality Baseline

Baseline concentrations of PM_{10} and $PM_{2.5}$ have been modelled at existing receptor locations, representing locations with exposure relevant to the national air quality objectives (40mg/m^2 for PM_{10} and 25mg/m^2 for $PM_{2.5}$). The results, which cover both the existing (2017) and future year (2021) baseline (Without Scheme) for PM_{10} and $PM_{2.5}$, are set out in are set out in

Figure 7,

Figure 8,

Figure 9, and

Figure 10 for receptor locations (i.e. those relevant for the air quality objectives).

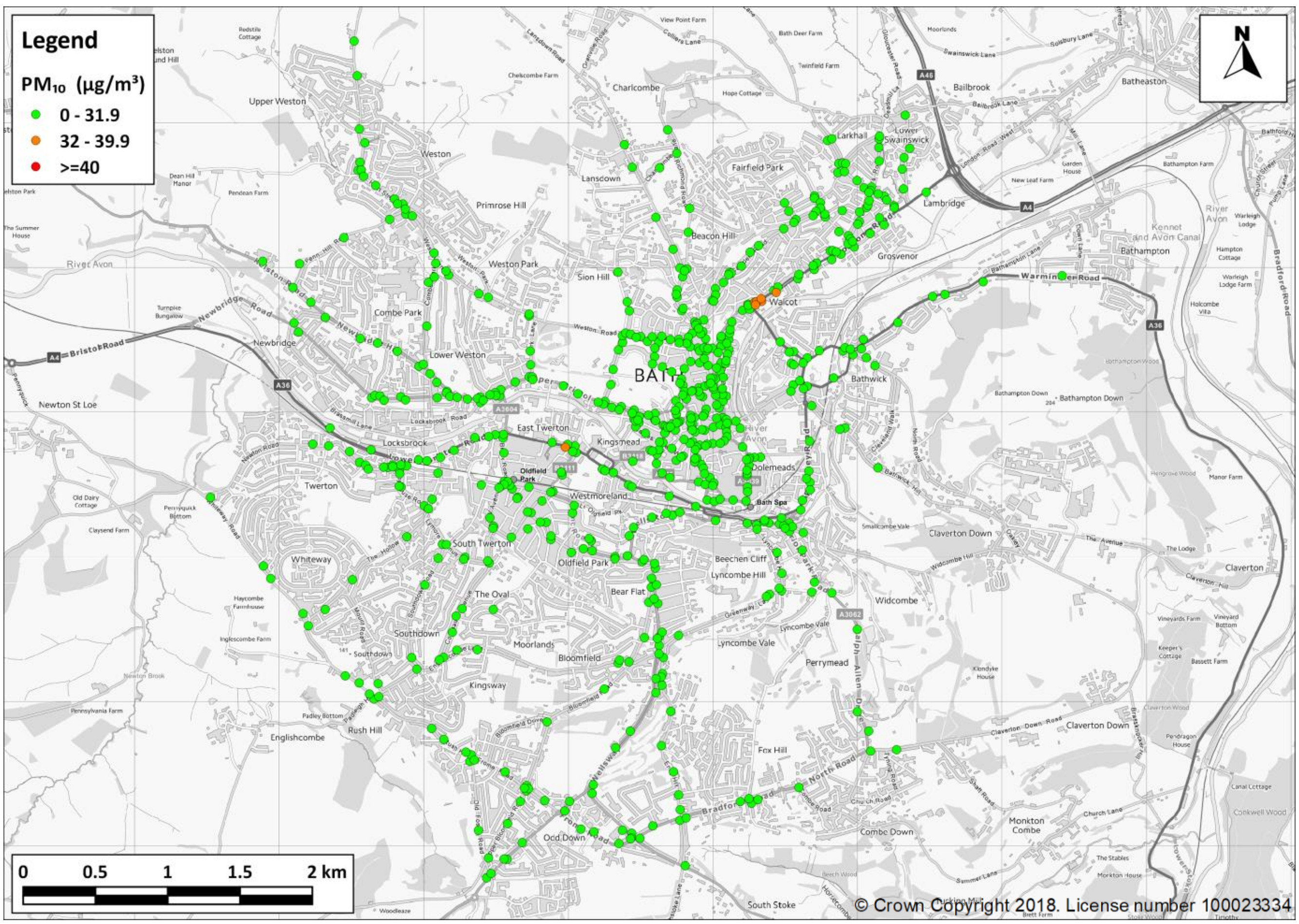

Figure 7: Predicted PM_{10} concentrations in 2017 at receptor locations relevant to the national air quality objective (annual mean)

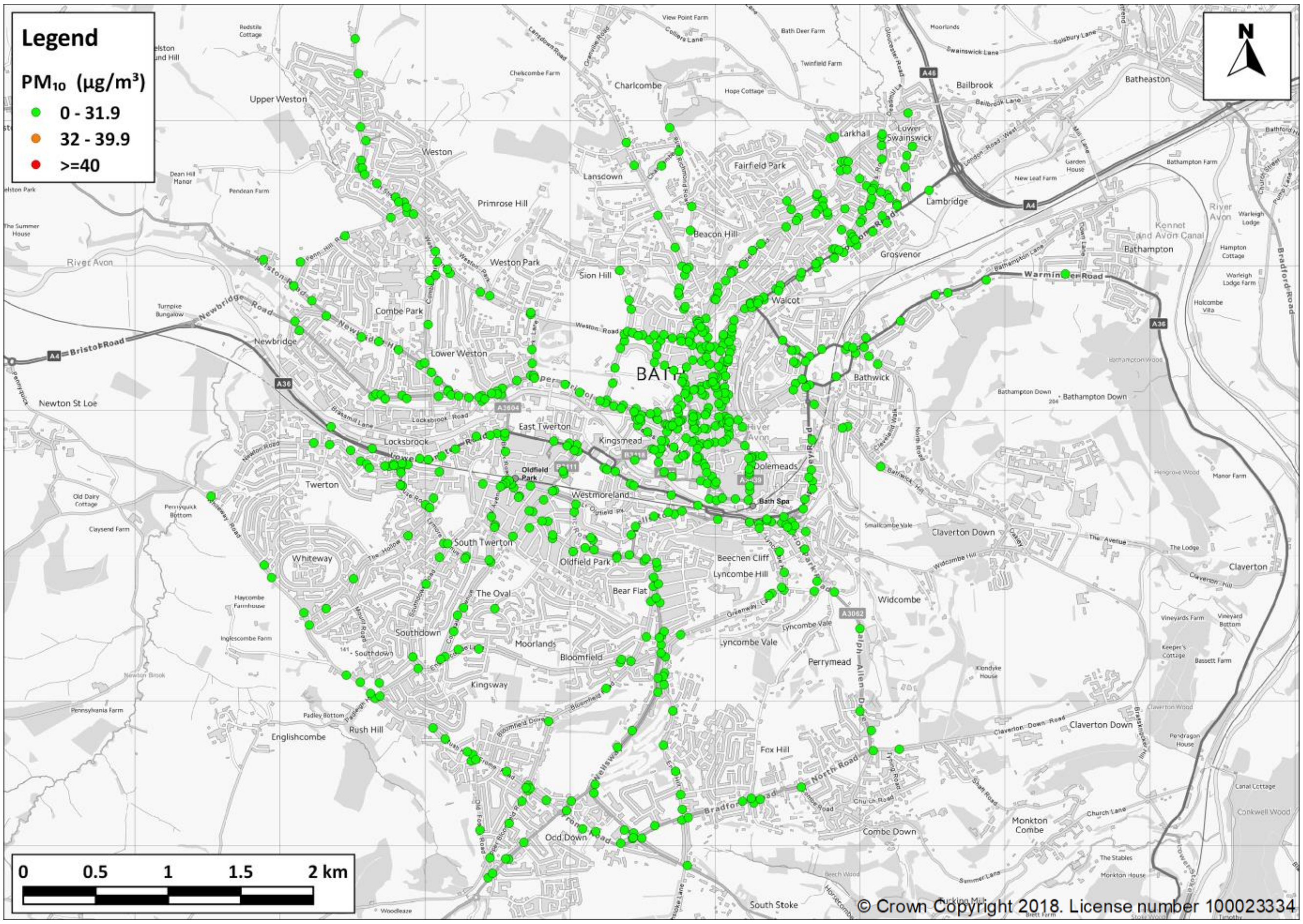

Figure 8: Predicted PM_{10} concentrations in 2021 at receptor locations relevant to the national air quality objective (annual mean)

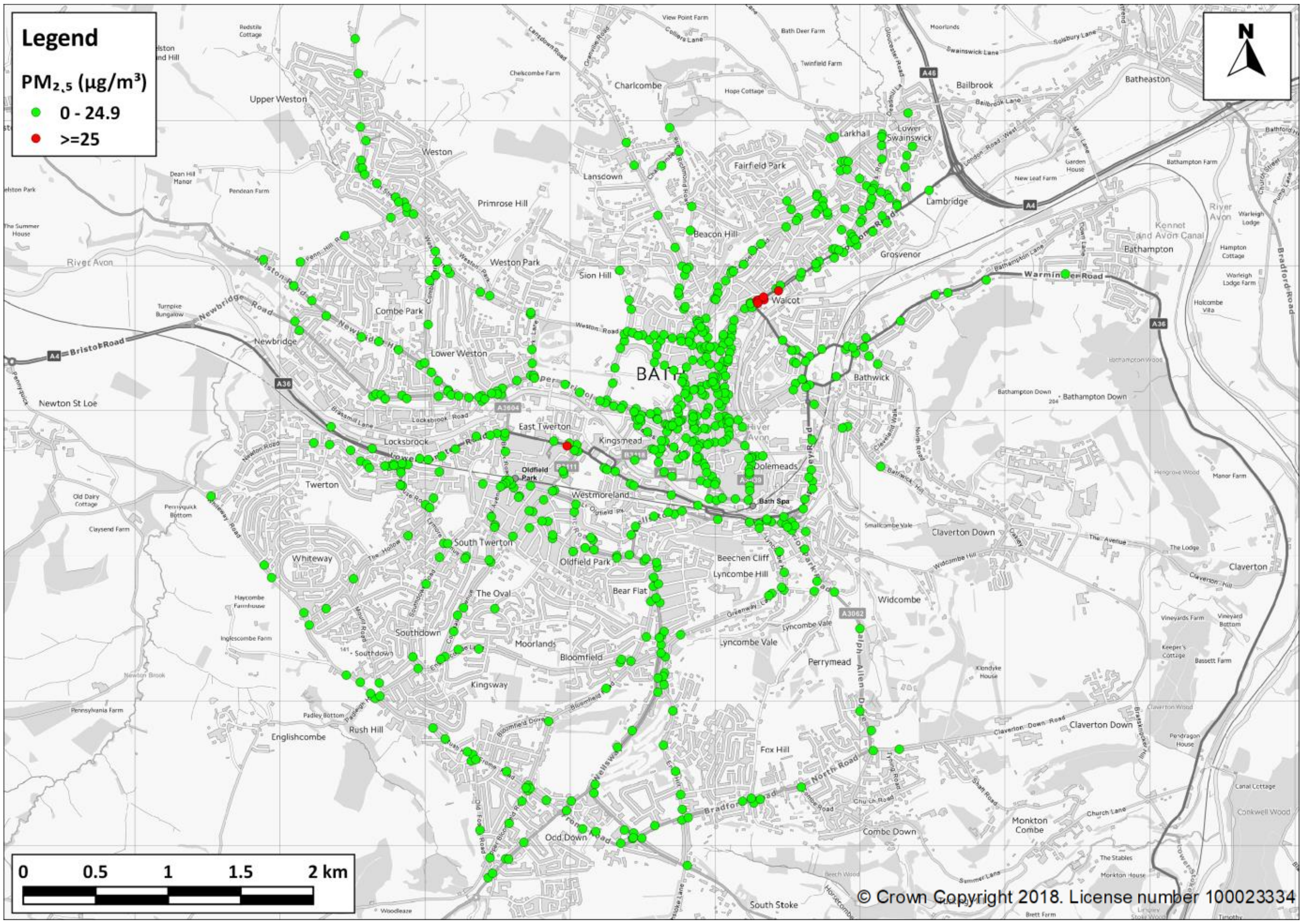

Figure 9: Predicted $PM_{2.5}$ concentrations in 2017 at receptor locations relevant to the national air quality objective (annual mean)

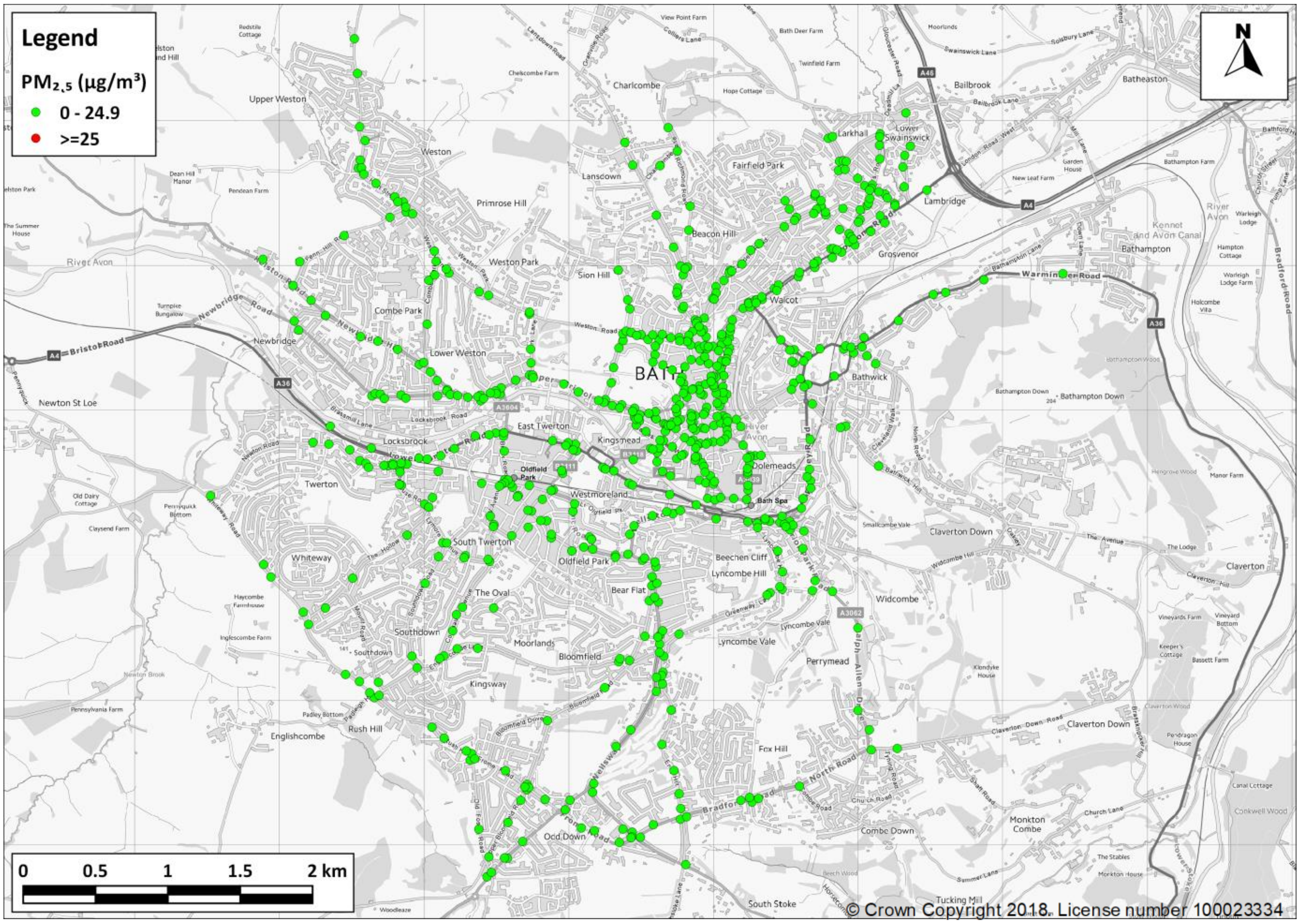

Figure 10: Predicted $PM_{2.5}$ concentrations in 2021 at receptor locations relevant to the national air quality objective (annual mean)

The predicted annual mean concentrations of PM_{10} show no exceedances in 2017 at locations relevant to the air quality objectives, while the predicted annual mean concentrations of $PM_{2.5}$ show an exceedance in 2017 at two locations relevant to the air quality objectives. The exceedances are located along the busy London Road, within a street canyon and close to the junction with Cleveland Place, and along Lower Bristol Road within a street canyon. This location represents approximately 60 residential properties that lie particularly close to the kerb. There are other locations in close proximity along these roads where there are no exceedances predicted; these locations lie slightly further away from the kerb, where concentrations are expected to be lower.

The predicted annual mean concentrations of PM_{10} and $PM_{2.5}$ show no exceedances in 2021 at locations relevant to the air quality objectives. For PM_{10} there is also an air quality objective based on the 24-hour average. Using a dispersion model to predict exceedances of the 24 hour mean objective is challenging and, as outlined in TG16, an analysis of measured concentrations at sites across the UK shows that there is a risk of exceeding the 24 hour air quality objective when the annual mean concentration is above 32 µg/m^3. Based on this relationship, there is a risk that the 24 hour air quality objective was exceeded in 2017, but by 2021 there will be no risk of an exceedance. The modelling for PM_{10} has been verified and adjusted based on measurements at a single location and these results are thus considered to be uncertain.

4.3.2 Baseline for comparison with the PCM

Concentrations of PM_{10} and $PM_{2.5}$ have also been modelled at each of the relevant receptor locations adjacent to roads within the PCM model. The results, which cover both the 2017 and 2021 years for PM_{10} and $PM_{2.5}$, are set out in Figure 11,

Figure 12,

Figure **13** and

Figure **14** for locations modelled at 4 m from the kerb and 2 m in height (i.e. relevant for comparison with the PCM model). These model outputs have then been simplified to only report the maximum value for each census ID of the PCM model. These results are reported in spreadsheet TD1.

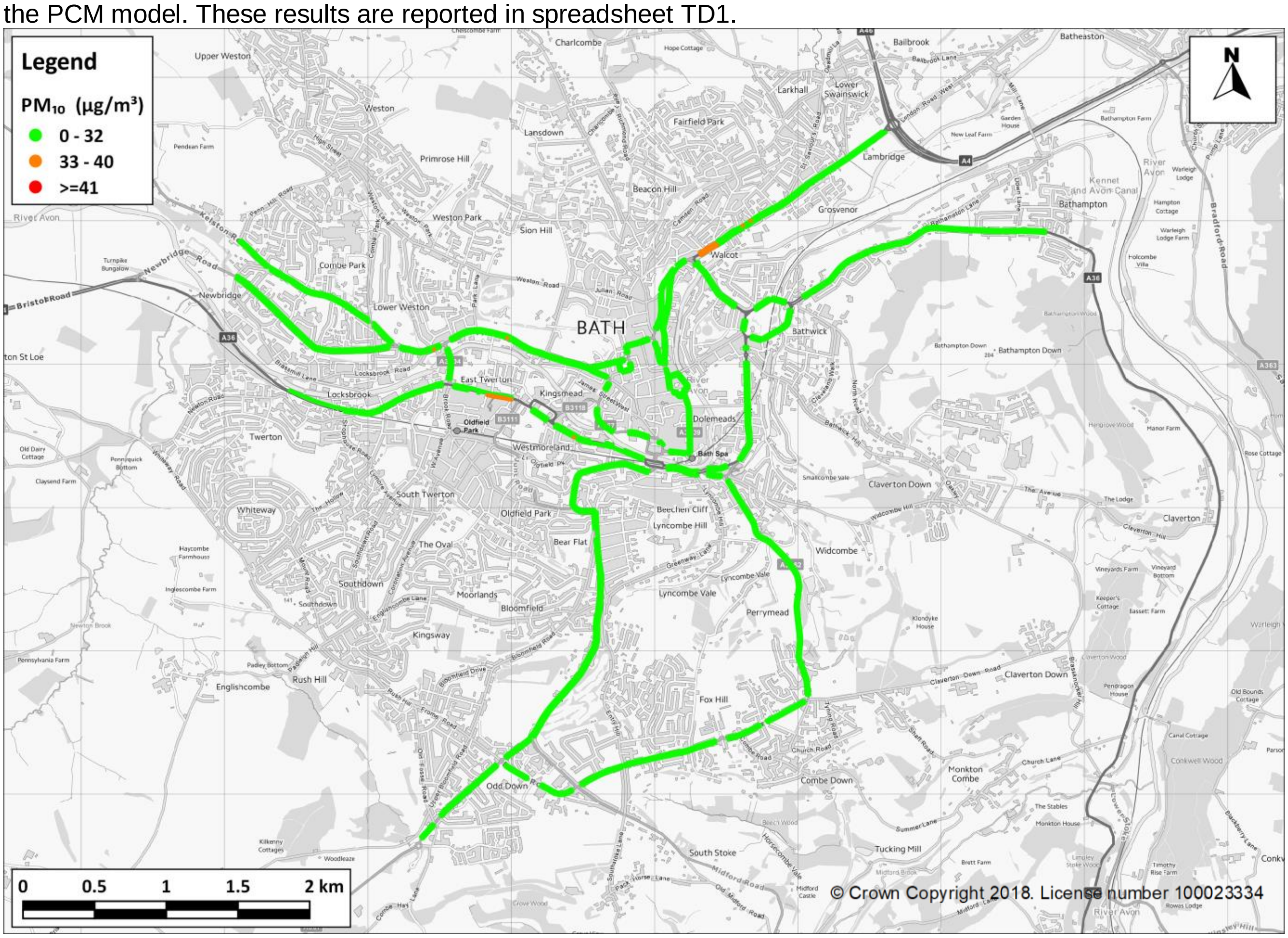

Figure 11: Predicted PM_{10} concentrations in 2017 at PCM-equivalent receptor locations

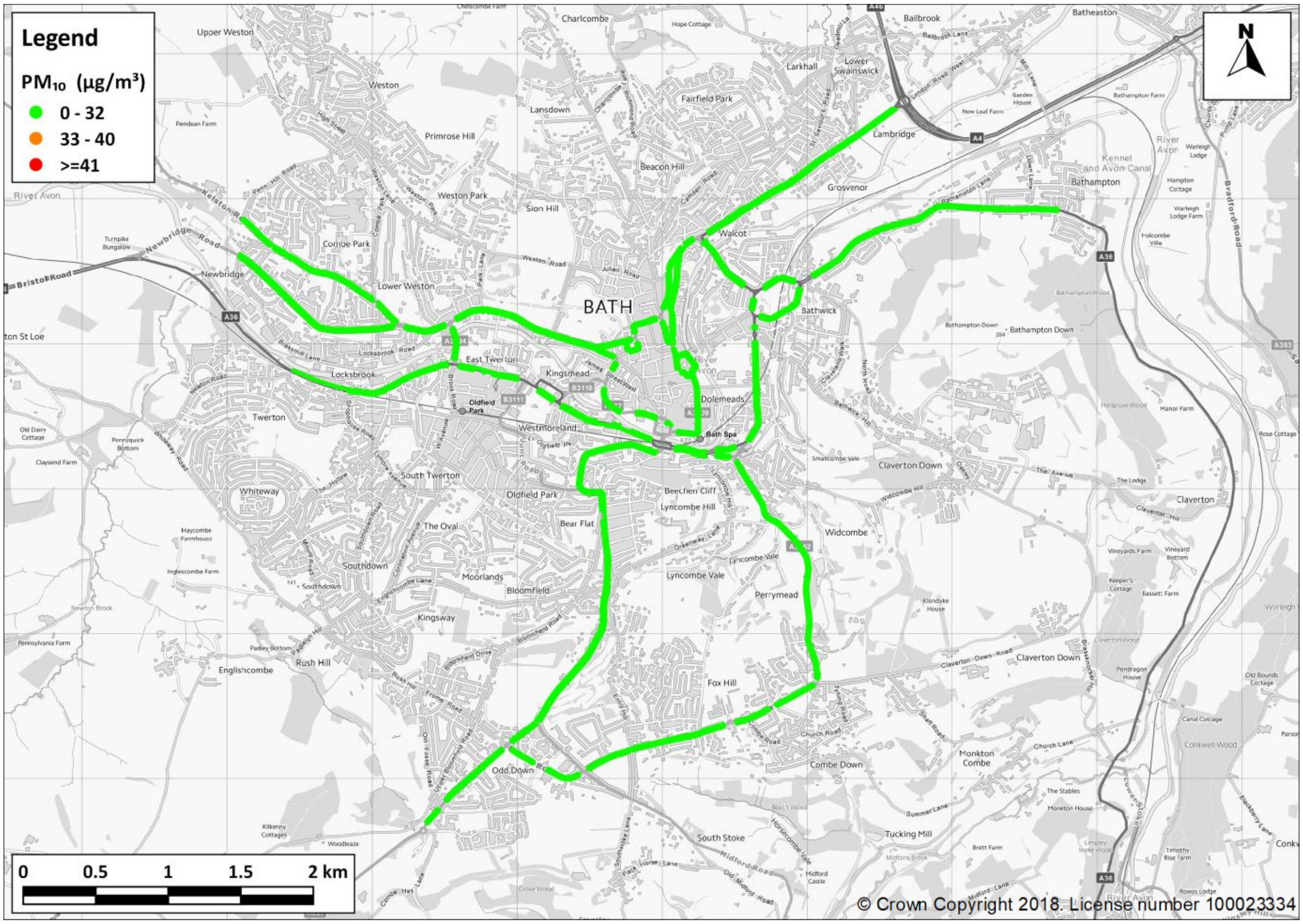

Figure 12: Predicted PM_{10} concentrations in 2021 at PCM-equivalent receptor locations

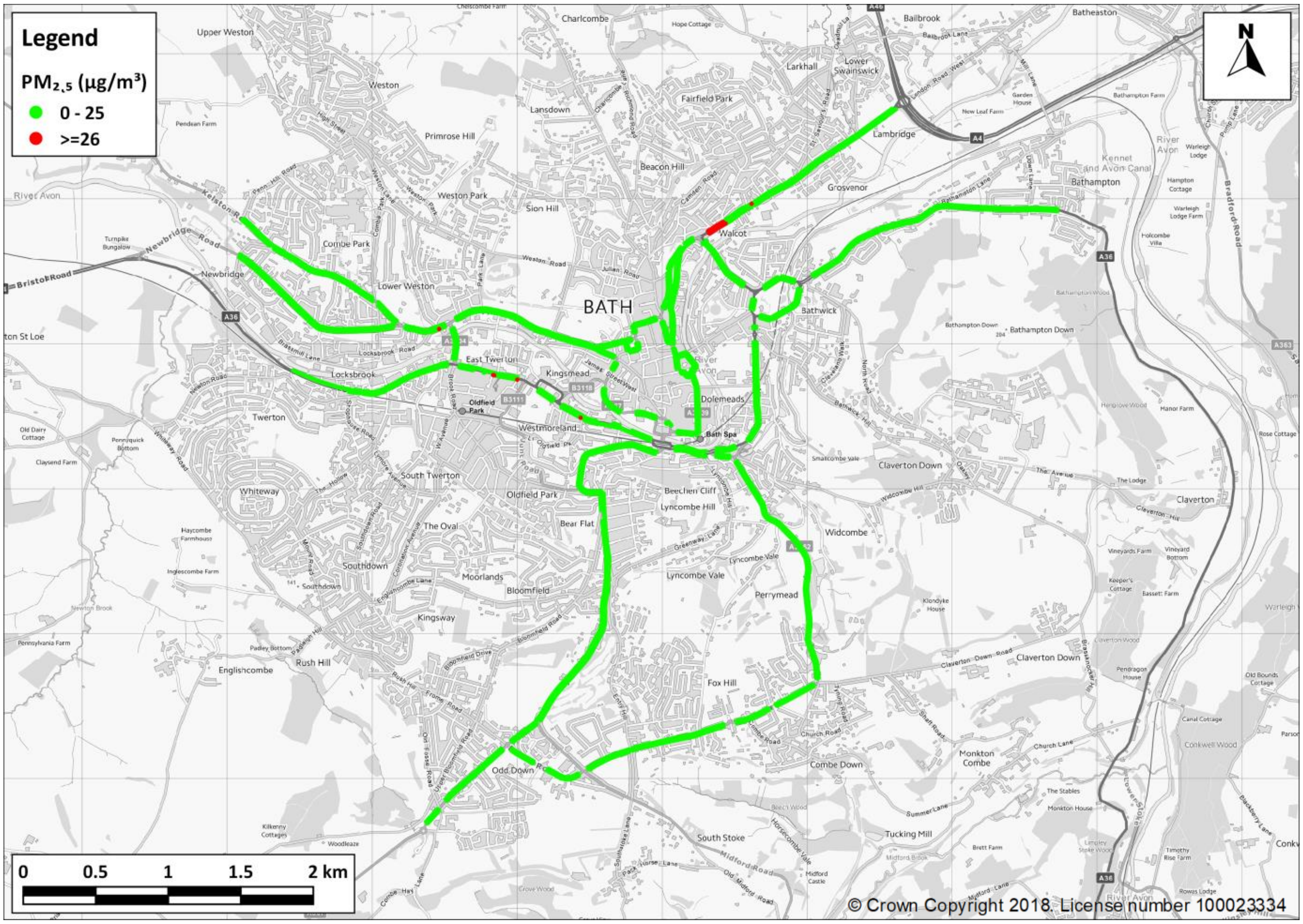

Figure 13: Predicted $PM_{2.5}$ concentrations in 2017 at PCM-equivalent receptor locations

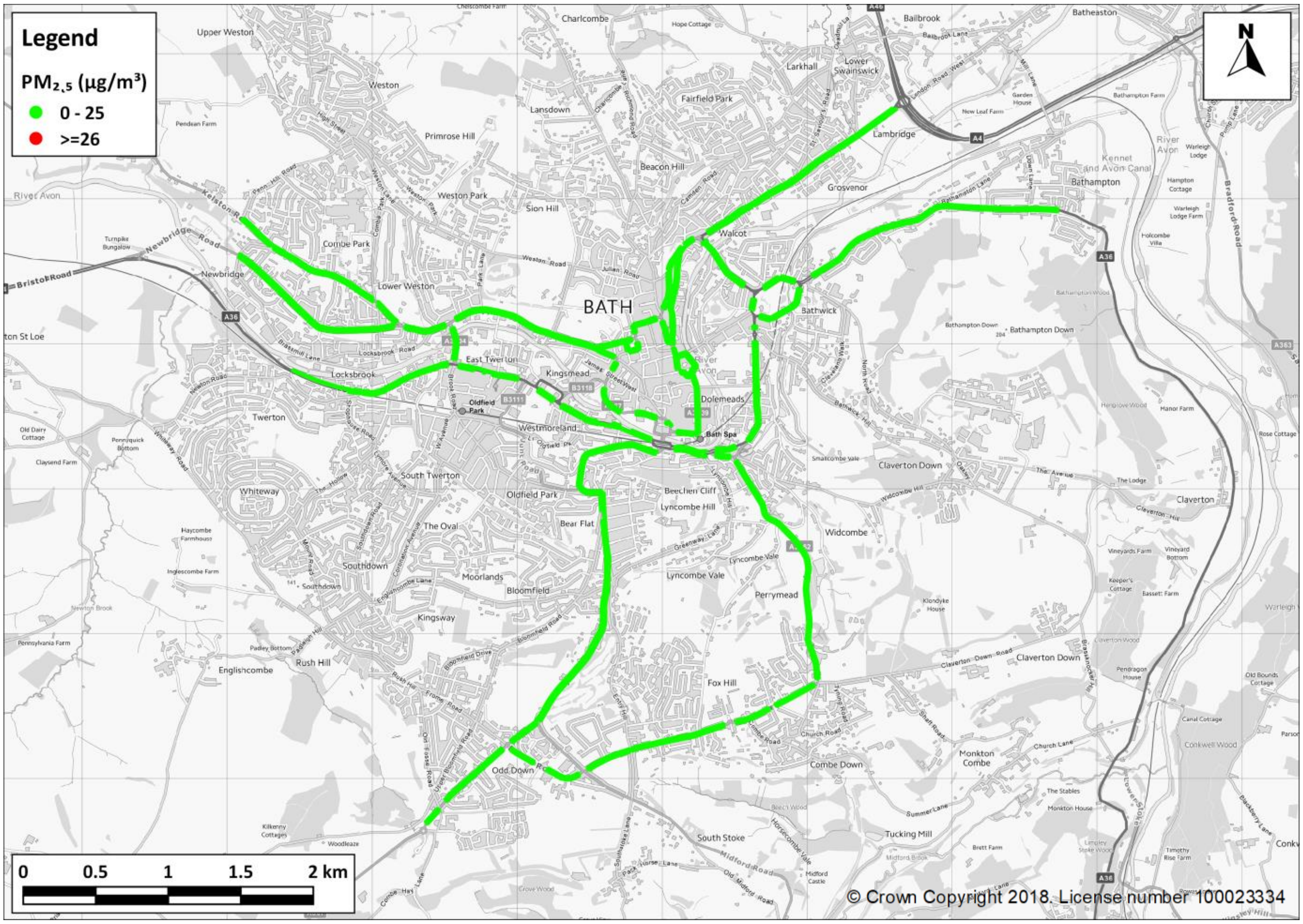

Figure 14: Predicted $PM_{2.5}$ concentrations in 2021 at PCM-equivalent receptor locations

The predicted annual mean concentrations of PM_{10} show no exceedances of the annual mean Limit Value in 2017, while the predicted annual mean concentrations of $PM_{2.5}$ show exceedances in 2017 along three roads. These exceedances are located along the busy London Road, within a street canyon and close to the junction with Cleveland Place, and along Lower Bristol Road within a street canyon, and along Upper Bristol Road, close to the busy junction with Windsor Bridge Road. These locations represent approximately 40 residential properties that lie particularly close to the kerb. There are other locations in close proximity along these roads where there are no exceedances predicted; these locations lie slightly further away from the kerb, where concentrations are expected to be lower. The predicted annual mean concentrations of PM_{10} and $PM_{2.5}$ show no exceedances of the annual mean Limit Values in 2021.

For PM_{10} there is also a Limit Value based on the 24-hour average. As described earlier, using a dispersion model to predict exceedances of the 24 hour mean Limit Value can be inaccurate, but the outcomes of the model suggest there is a risk that the 24 hour Limit Value is exceeded in 2017. By 2021, there is no risk of the 24 hour Limit Value being exceeded.

5. Assessment of Scheme Impacts

5.1.1 Schemes assessed

The Strategic Outline Case indicated that a CAZ B, C or D scheme might achieve compliance in 2021. Initially a CAZ C scheme was tested and found to not achieve compliance. Since a CAZ D scheme is more stringent than a CAZ C scheme, this was tested next, with a £7.50/£100 charge (which related to the outcomes of the stated preference survey). A CAZ B scheme was not tested as this is less stringent than a CAZ C scheme and would therefore be non-compliant. The CAZ D scheme (£7.50/£100 charge) was found to also be non-compliant, but with concentrations only marginally in exceedance of the Limit Values. A CAZ D scheme with a higher charge (£9/£100) was thus tested next, the predicted concentrations of which were found to be compliant. The addition of location specific traffic management being applied to both CAZ C (£9/£100 charge) and CAZ D (£9/£100 charge) schemes was then subsequently tested, with both amended schemes also found to be compliant. The results of these schemes are provided below.

5.1.2 2021 CAZ C (£9/£100 charge)

Predicted annual mean concentrations of nitrogen dioxide 2021 for a CAZ C (£9 charge for Light Duty Vehicles, £100 for Heavy Duty Vehicles) for both subsets of receptors (those which are comparable to PCM outputs and those which are relevant for the air quality objectives) are presented in Figure 15 and

Figure **16**.

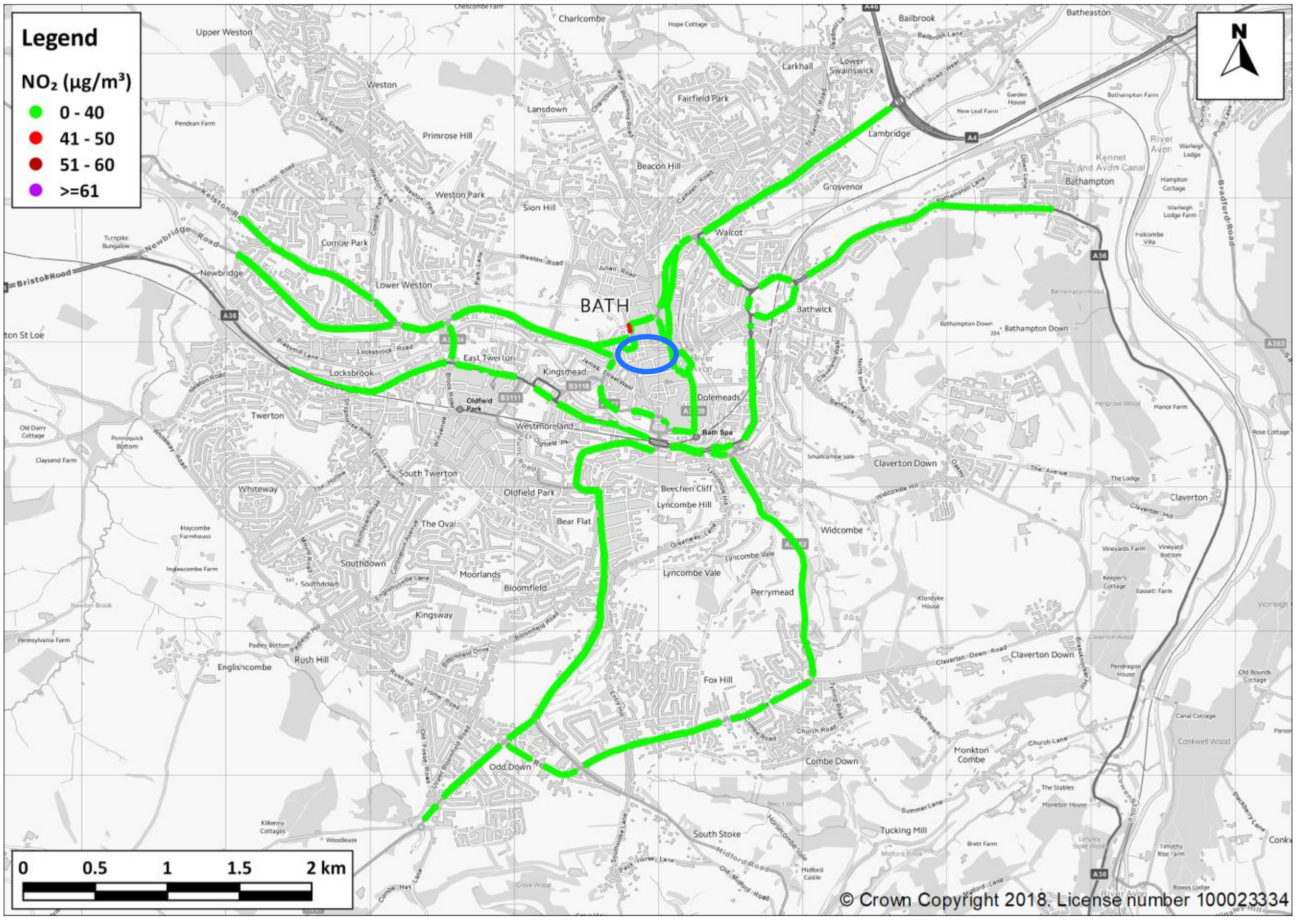

Figure 15: Predicted NO_2 concentrations in 2021 with a CAZ C (£9/£100 charge) at PCM-equivalent receptor locations (exceedance location shown within blue oval)

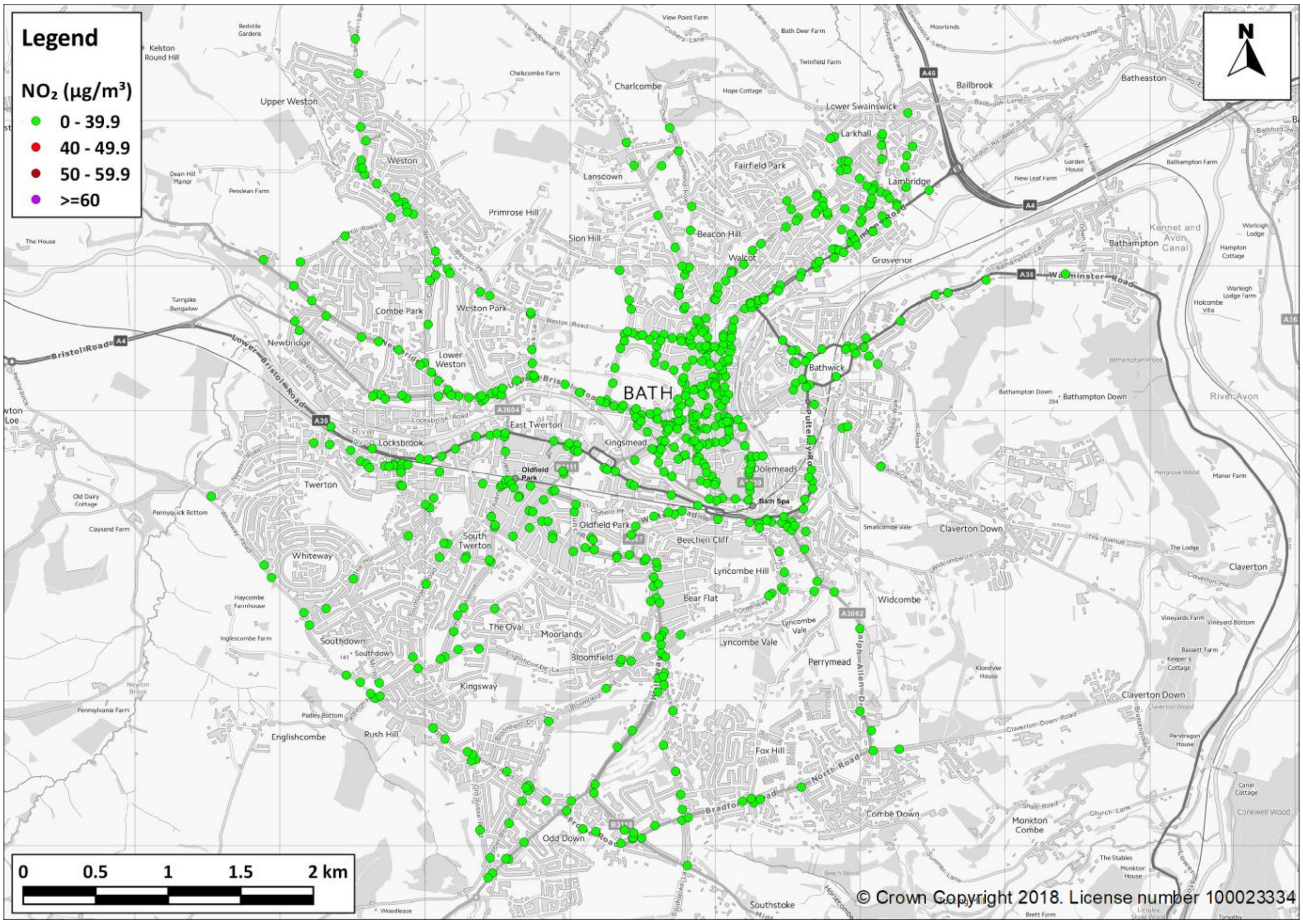

Figure 16: Predicted NO_2 concentrations in 2021 with a CAZ C (£9/£100 charge) at receptor locations relevant to the national air quality objective (annual mean)

There are still exceedances of the annual mean nitrogen dioxide Limit Value at PCM-equivalent receptors with a CAZ C on Gay Street. Hence a CAZ C would not achieve compliance in the shortest time possible. There are no exceedances at locations relevant to the air quality objectives with a CAZ C implemented in 2021.

5.1.3 2021 CAZ D (£7.50/£100 charge)

Following the outcomes of the Stated Preference Survey, a £7.50 charge for light vehicles within a CAZ D was run through the traffic and air quality models. The outcomes for the CAZ D £7.50 charge are presented in

Figure **17** and

Figure **18** below.

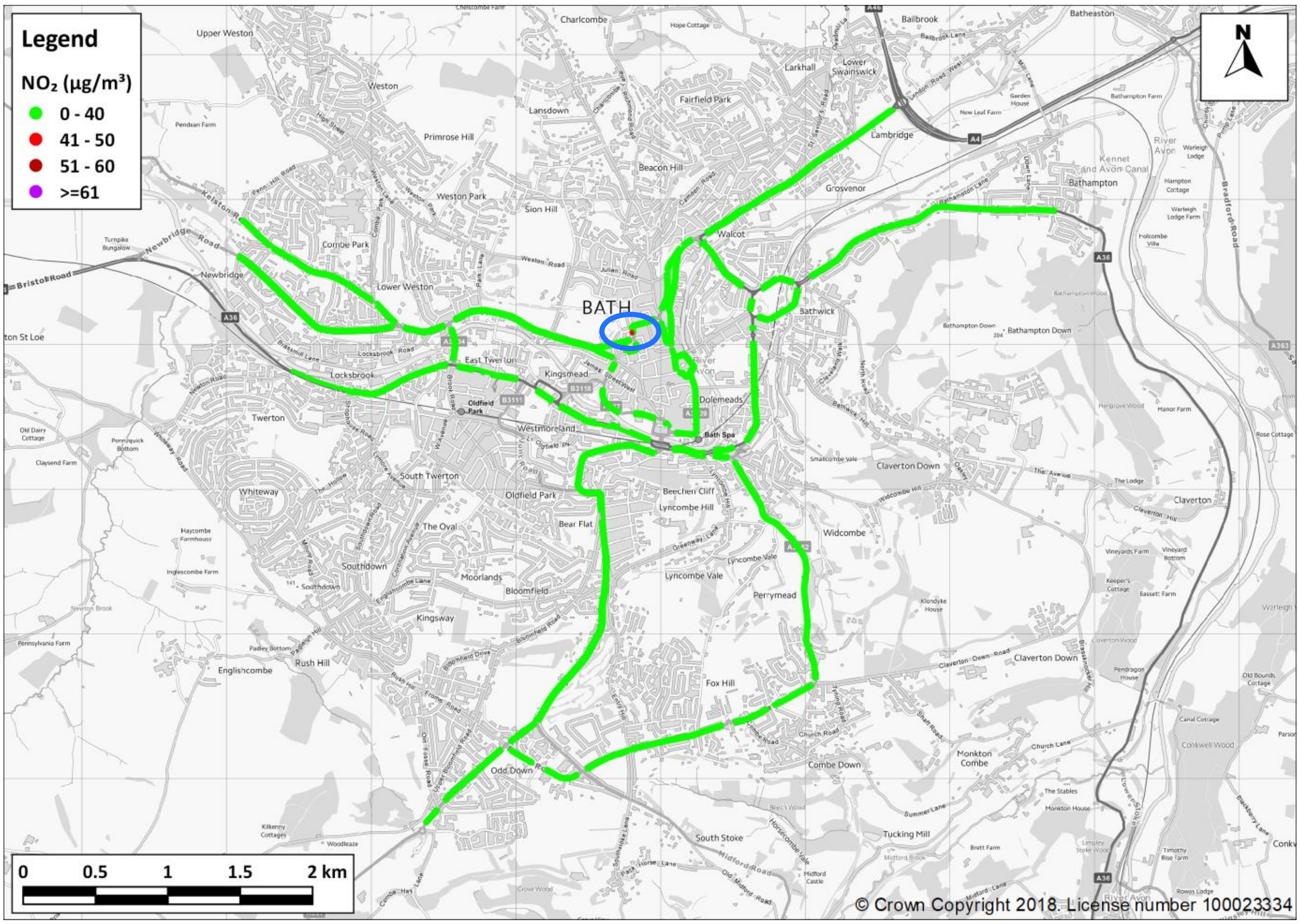

Figure 17: Predicted NO_2 concentrations in 2021 with a CAZ D (£7.50/£100 charge) at PCM-equivalent receptors (exceedance location shown within blue oval)

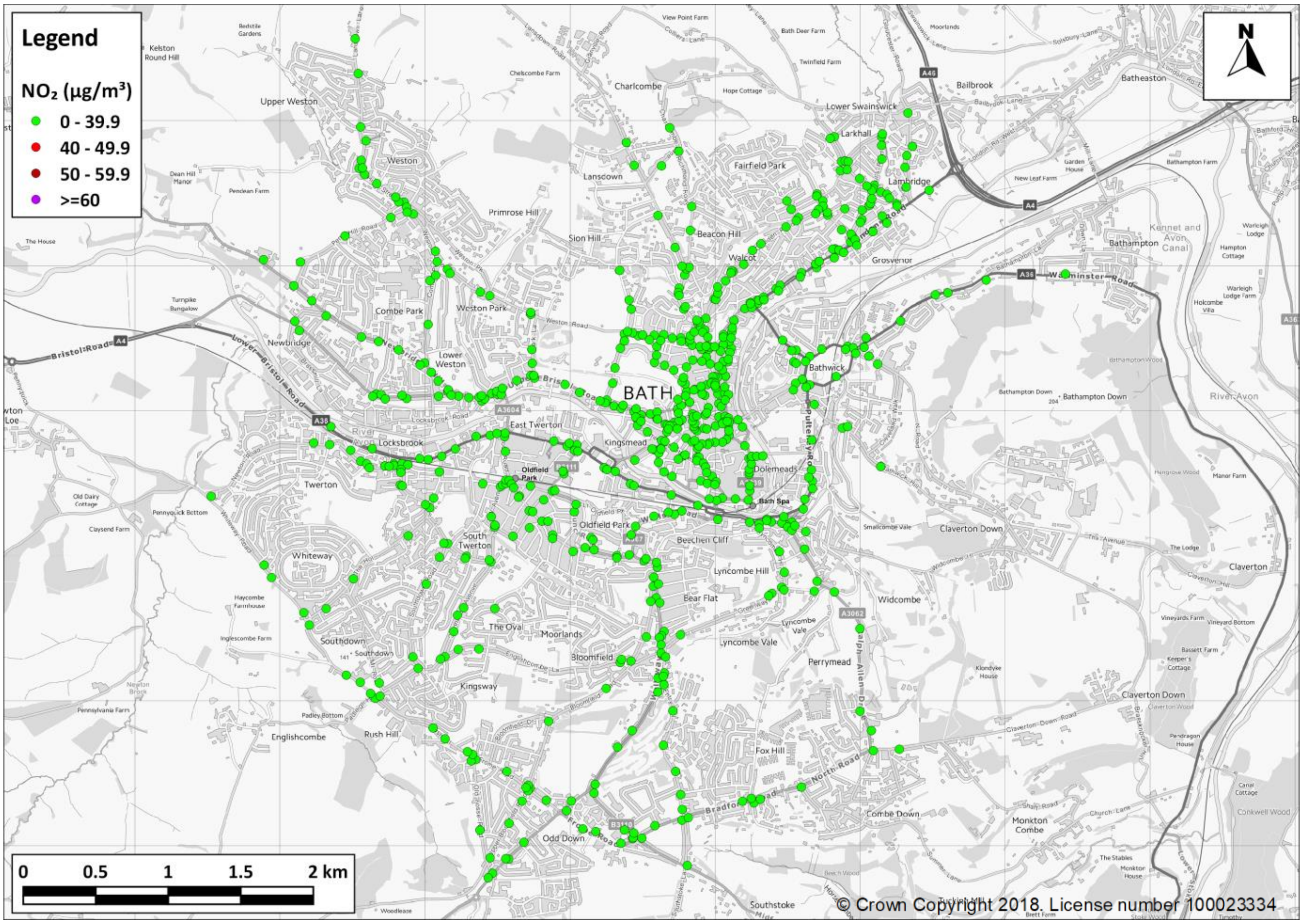

Figure 18: Predicted NO_2 concentrations in 2021 with a CAZ D (£7.50/£100 charge) at receptor locations relevant to the national air quality objective (annual mean)

There are still exceedances of the annual mean nitrogen dioxide Limit Value at the same PCM-equivalent location as for the CAZ C (on Gay Street). Hence a CAZ D £7.50 charge would not achieve compliance in the shortest time possible. There are no exceedances at receptors relevant to the air quality objectives with a CAZ D £7.50 charge implemented in 2021.

5.1.4 2021 CAZ D (£9/£100 Charge)

In order to ascertain whether a CAZ D would achieve compliance with a higher charge, a CAZ D (£9 charge for Light Duty Vehicles, £100 charge for Heavy Duty Vehicles) was also run through the air quality model. The outcomes for annual mean nitrogen dioxide are presented in

Figure **19** and Figure 20.

As PM_{10} and $PM_{2.5}$ are fully compliant in the 2021 baseline, outcomes for the CAZ D are not presented for PM_{10} or $PM_{2.5}$.

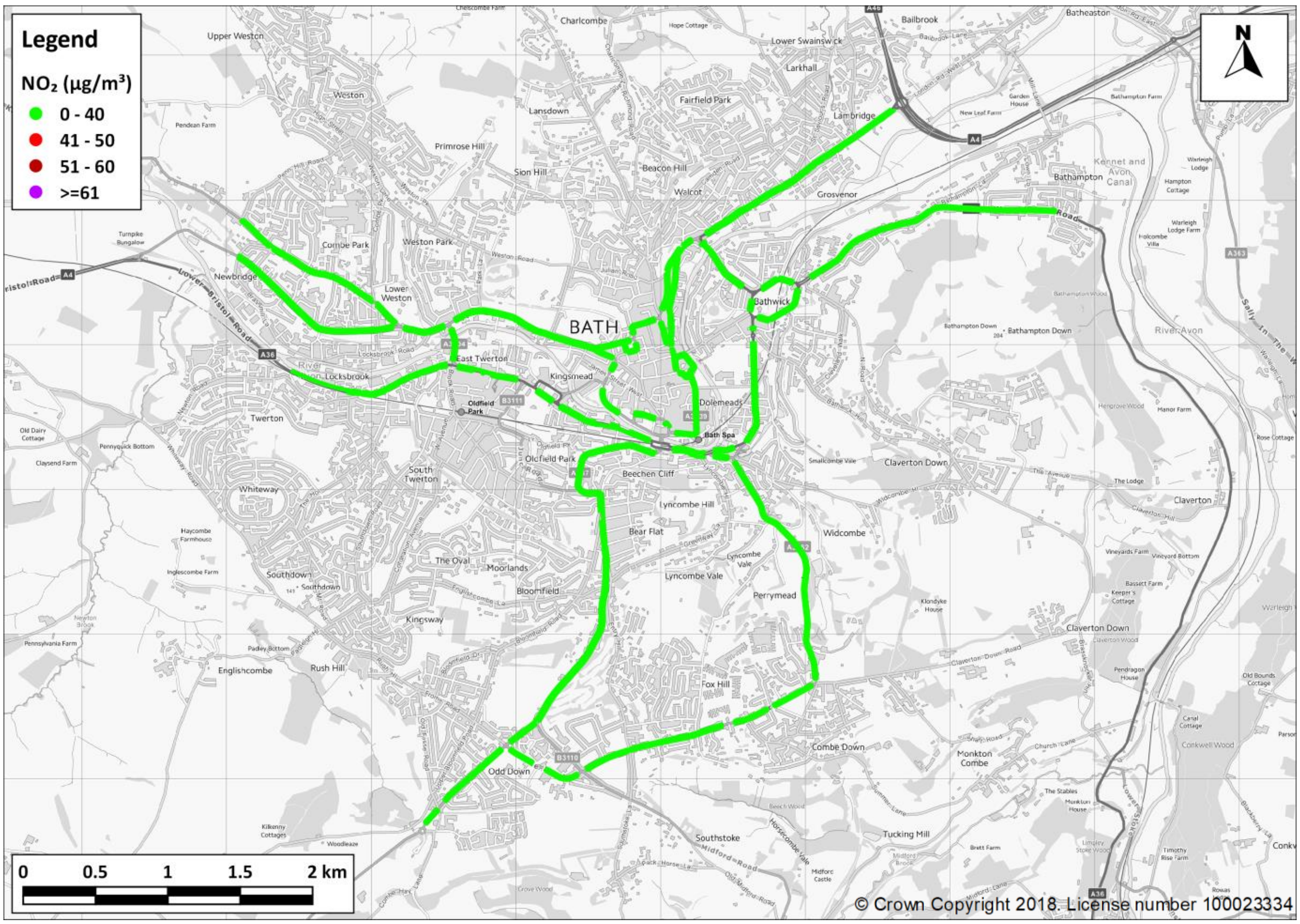

Figure 19: Predicted NO_2 concentrations in 2021 with a CAZ D (£9/£100 charge) at PCM-equivalent receptor locations (annual mean)

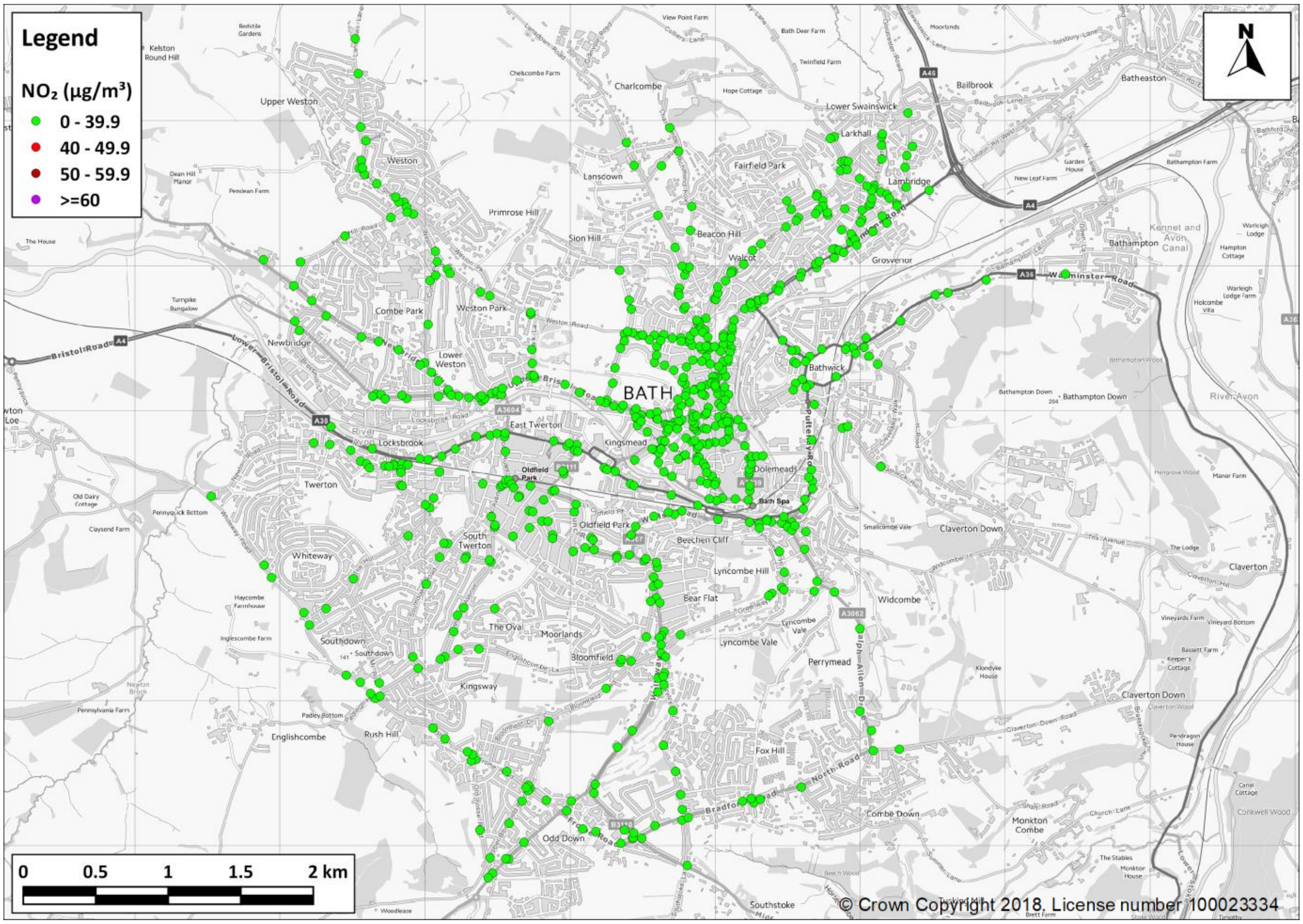

Figure 20: Predicted NO_2 concentrations in 2021 with a CAZ D (£9/£100 charge) at receptor locations relevant to the national air quality objective (annual mean)

The predicted annual mean concentrations of nitrogen dioxide show compliance with the limit values and air quality objectives for nitrogen dioxide at all locations in central Bath.

5.1.5 2021 CAZ C (£9/£100 Charge) With Traffic Management

In order to ascertain whether a CAZ C would achieve compliance with location specific traffic management included, a CAZ C (£9 charge for Light Duty Vehicles, £100 charge for Heavy Duty Vehicles) with traffic management at Queens Square was also run through the air quality model. The outcomes for annual mean nitrogen dioxide for PCM equivalent receptors, and receptors representing air quality objectives are presented in Figure 21 and Figure 22.

As PM_{10} and $PM_{2.5}$ are fully compliant in the 2021 baseline, outcomes for the CAZ C with traffic management scheme are not presented for PM_{10} or $PM_{2.5}$.

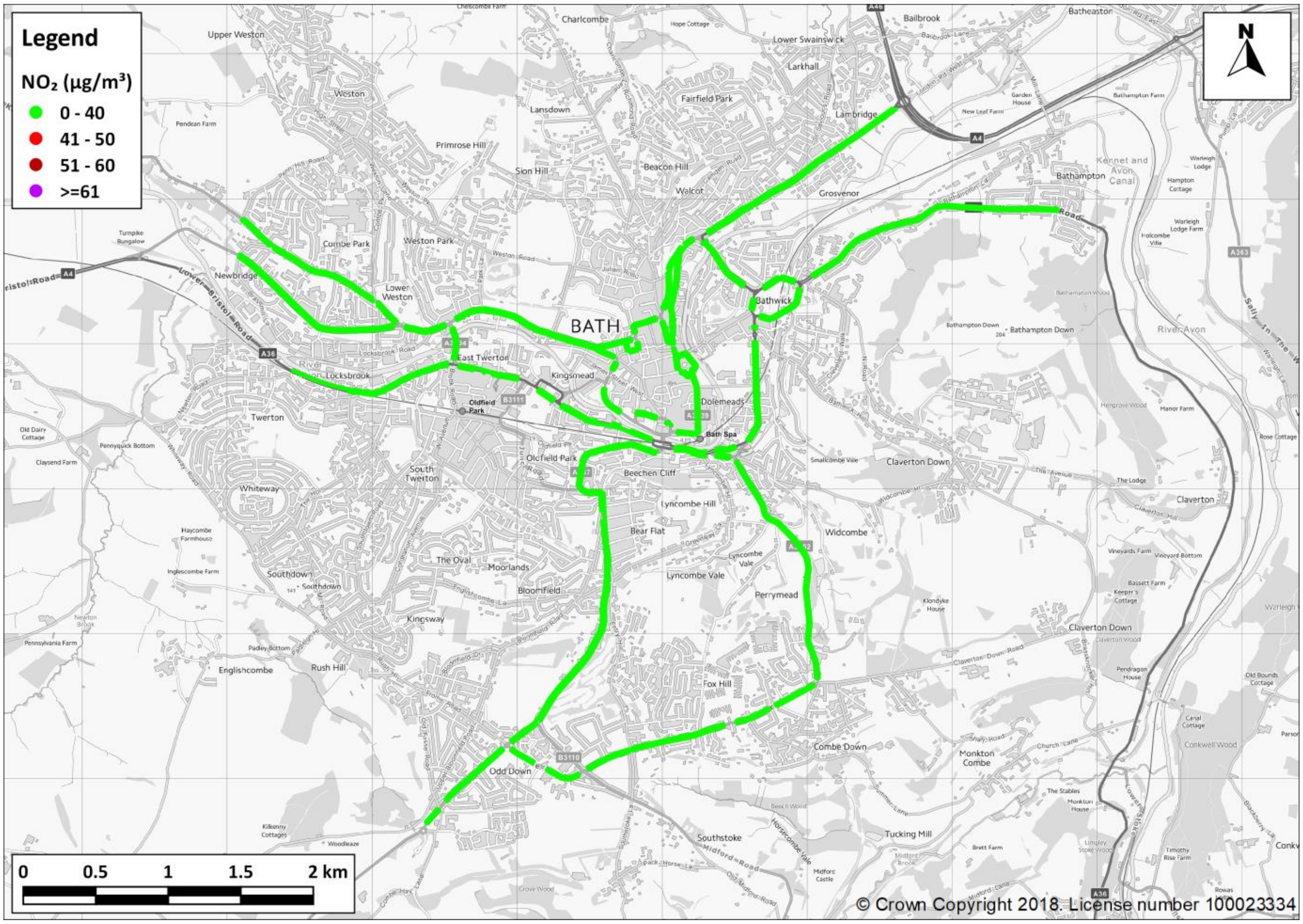

Figure 21: Predicted NO_2 concentrations in 2021 with a CAZ C (£9/£100 charge) with Traffic Management at PCM-equivalent receptor locations (annual mean)

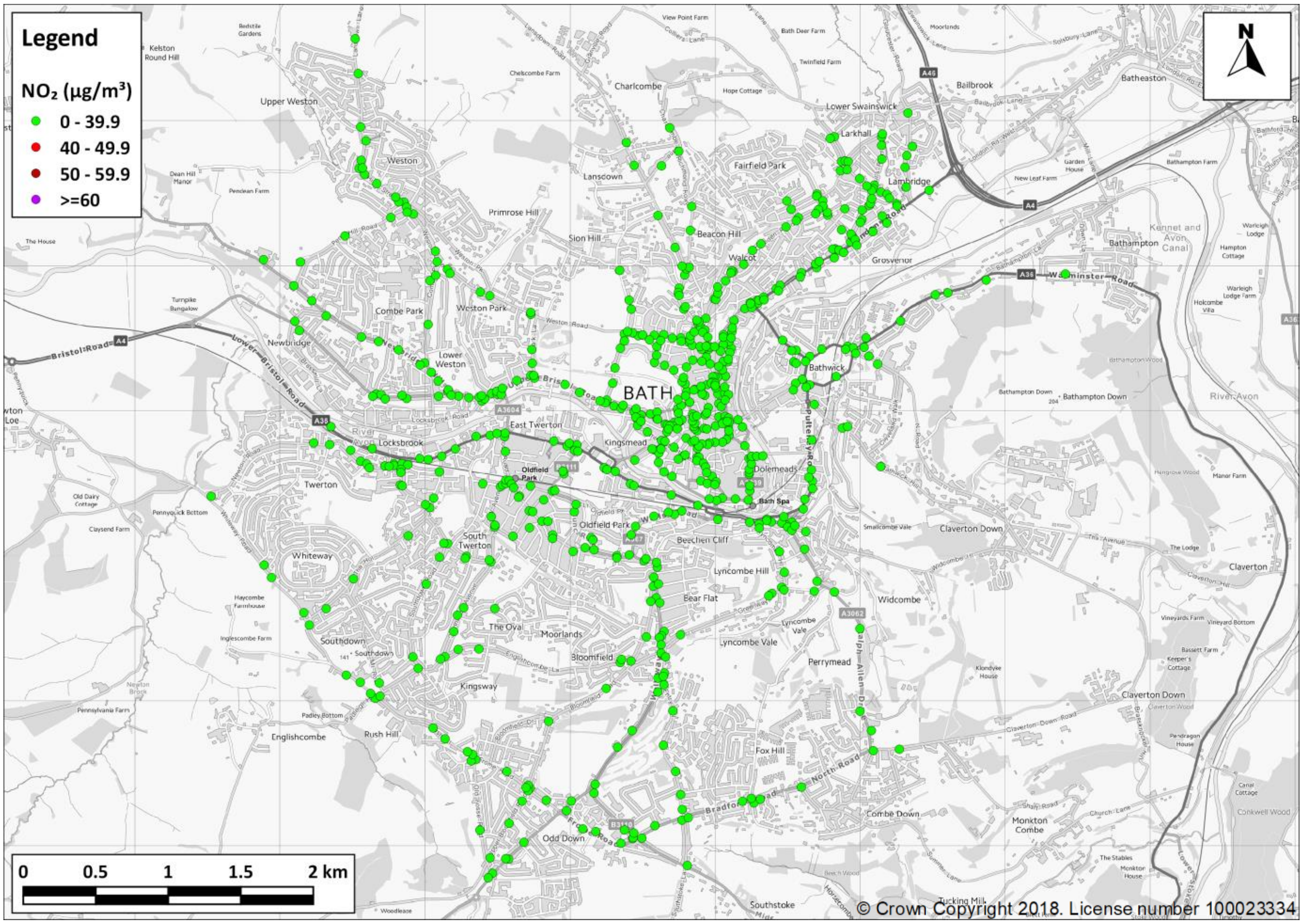

Figure 22: Predicted NO_2 concentrations in 2021 with a CAZ C (£9/£100 charge) with Traffic Management at receptor locations relevant to the national air quality objective (annual mean)

The predicted annual mean concentrations of nitrogen dioxide show compliance with the limit values and air quality objectives for nitrogen dioxide at all locations in central Bath.

5.1.6 2021 CAZ D (£9/£100 Charge) With Traffic Management and Concessions

In order to ascertain whether a CAZ D with a concession for Euro 4 or 5 diesel cars would achieve compliance with traffic management included, a CAZ D (£9 charge for Light Duty Vehicles, £100 charge for Heavy Duty Vehicles) was also run through the air quality model assuming Euro 4 and 5 diesel cars are not charged for the first year and traffic management is included at Queens Square. The outcomes for annual mean nitrogen dioxide for PCM equivalent receptors, and receptors representing air quality objectives are presented in presented in Figure 23 and Figure 24.

As PM_{10} and $PM_{2.5}$ are fully compliant in the 2021 baseline, outcomes for the CAZ D scheme are not presented for PM_{10} or $PM_{2.5}$.

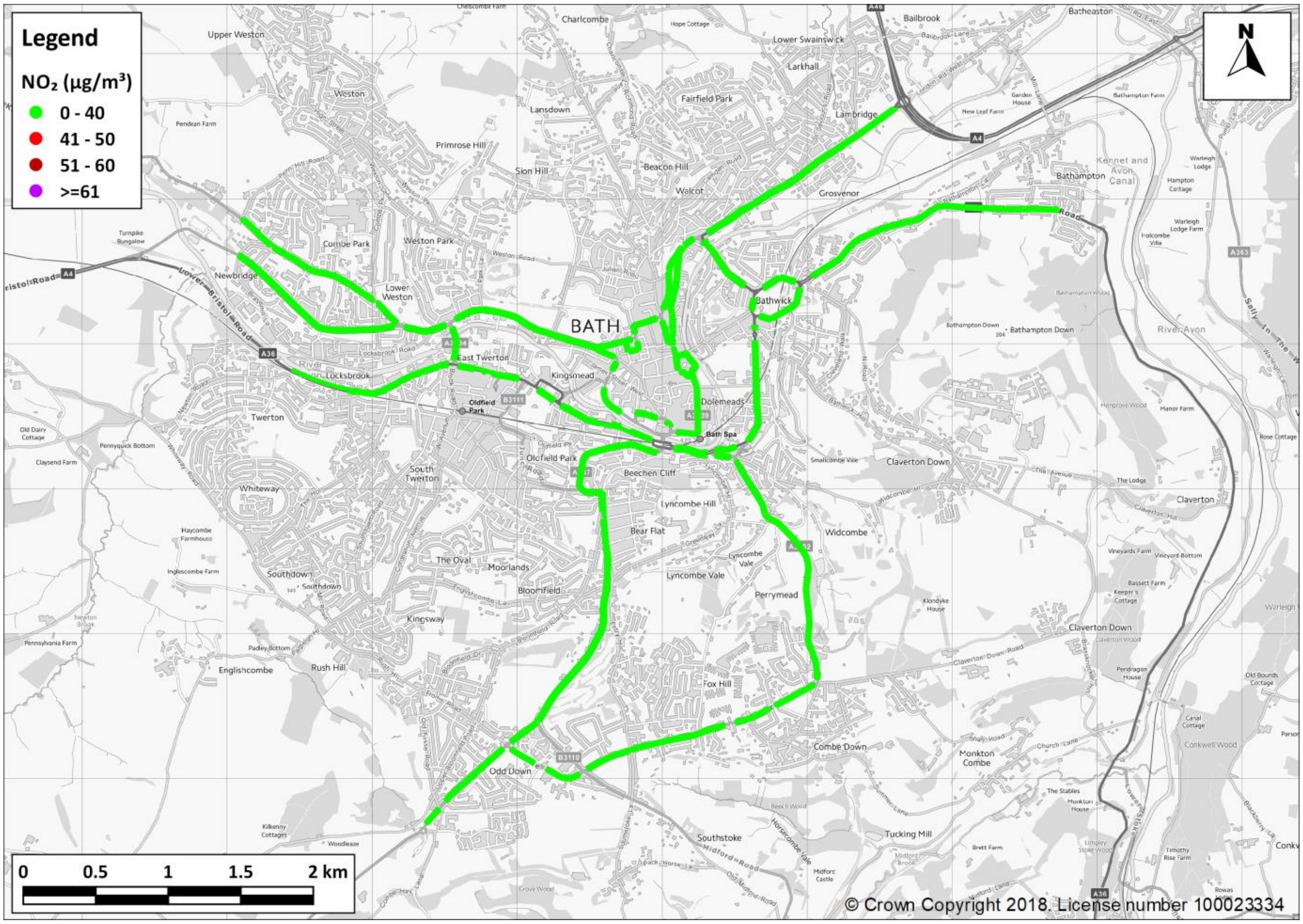

Figure 23: Predicted NO_2 concentrations in 2021 with a CAZ D (£9/£100 charge) With Traffic Management and Concessions at PCM-equivalent receptor locations (annual mean)

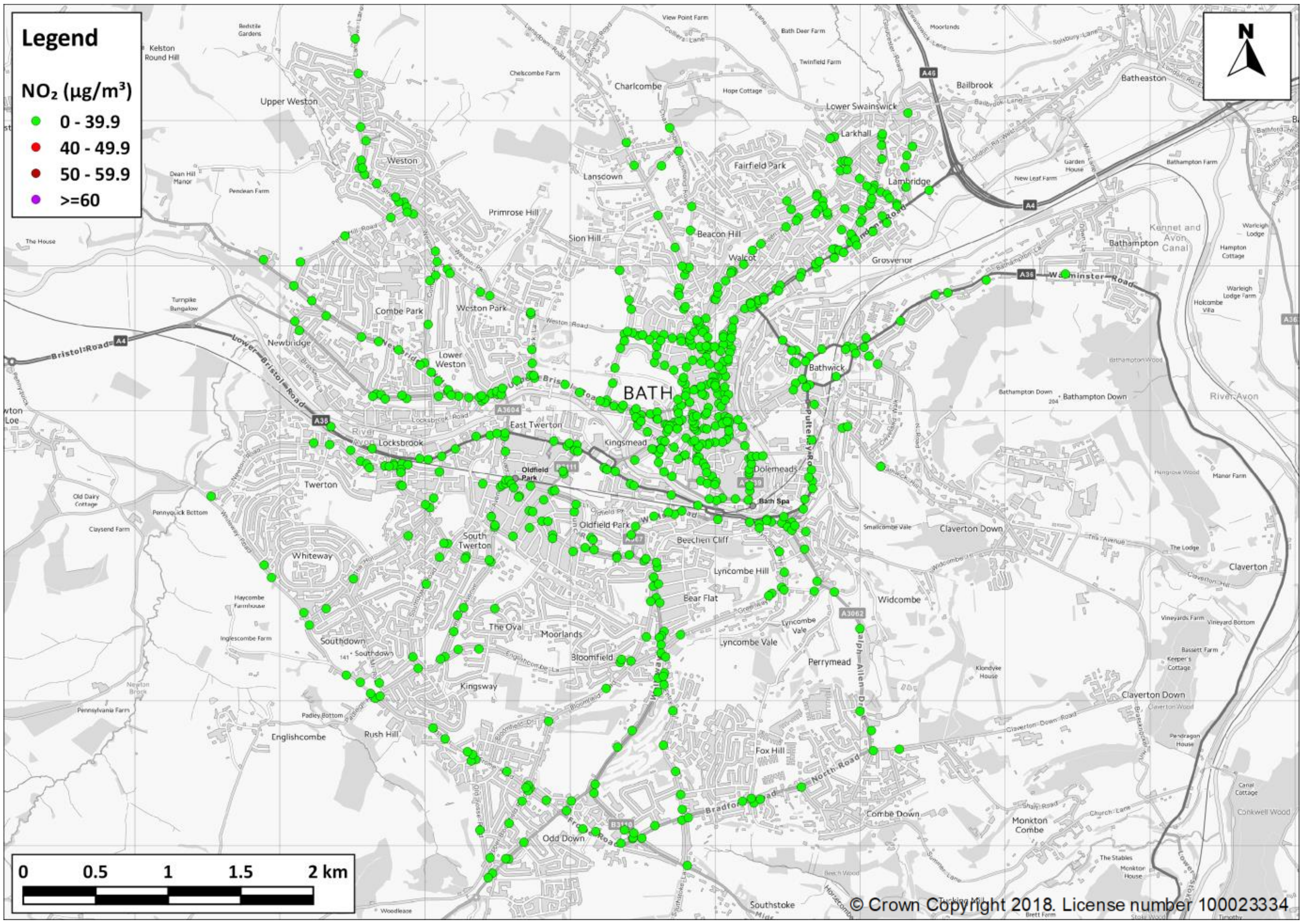

Figure 24: Predicted NO_2 concentrations in 2021 with a CAZ D (£9/£100 charge) With Traffic Management and Concessions at receptor locations relevant to the national air quality objective (annual mean)

The predicted annual mean concentrations of nitrogen dioxide show compliance with the limit values and air quality objectives for nitrogen dioxide at all locations in central Bath.

6. Health Impact Assessment

Population weighted mean concentrations to follow as part of Full Business Case. However, the health impacts have been monetised within the economic assessment using emissions, as part of the Outline Business Case.

7. References

Defra. (2017a). *Air quality plan for nitrogen dioxide (NO2) in the UK.* Retrieved from https://www.gov.uk/government/publications/air-quality-plan-for-nitrogen-dioxide-no2-in-uk-2017

Defra. (2018b). *Local Air Quality Management (LAQM) Support Website*. Retrieved from http://laqm.defra.gov.uk/

Defra. (2018b). *Review & Assessment: Technical Guidance LAQM.TG16 February 2018 Version.* Defra. Retrieved from https://laqm.defra.gov.uk/documents/LAQM-TG16-February-18-v1.pdf

Defra. (2018b). *Review & Assessment: Technical Guidance LAQM.TG16 February 2018 Version.* Defra. Retrieved from https://laqm.defra.gov.uk/documents/LAQM-TG16-February-18-v1.pdf

Appendix A. Predicted Concentrations

Table 3: Predicted NO_2 Concentrations at Existing Locations of Non-Compliance ($\mu g/m^3$) [a]

Location	2017 Base	2021 Baseline	2021 With CAZ C (£9/£100)	2021 With CAZ D (£7.50/£100)	2021 With CAZ D (£9/£100)	2021 With CAZ C (£9/£100) & Traffic Management	2021 With CAZ D (£9/£100), Traffic Management & Concessions
LAQM Receptors							
Residential property at the corner of Bennett Street & Lansdown Road	**62**	**52**	38	36	36	38	37
Residential property at Lansdown Road (near Guinea Lane)	**46**	38	28	27	27	28	28
Residential property at Crescent Lane	**44**	37	32	30	30	33	33
Residential property at James Street West	**47**	**42**	34	32	32	34	34
Residential property at Charles Street	**45**	40	33	31	31	32	32
Residential property at Charles Street	**45**	38	32	30	30	30	30
Residential property at corner of Chapel Row & Monmouth Street	**54**	**46**	38	37	37	35	35
Residential property at corner of Queen Square & Queen Square Place	**46**	39	33	32	32	29	28
Residential property at Queen Square	**45**	37	31	30	30	28	28
Residential property at Broad Street	**41**	34	26	25	25	26	26
Residential property at Broad Street	**45**	37	23	23	22	23	23
Residential property at Broad Street (near The Paragon)	**58**	**50**	35	35	34	35	35
Residential property at Walcot Street	**45**	37	24	23	23	24	23
Residential property at Lansdown Road (near The Paragon)	**50**	**41**	26	25	25	26	26
Residential property at Crescent Lane	**46**	38	32	30	30	33	33
Residential property at Gay Street	**52**	**44**	37	36	35	33	33
Residential property at Gay Street	**57**	**48**	40	39	38	35	35
Residential property at Green Park (near Midland Bridge Road)	**43**	36	28	26	26	27	27
Residential property at James Street West (near Milk Street)	**42**	36	27	26	26	27	27
Residential property at Corn Street	**43**	35	24	23	23	24	24
Residential property at corner of Charles Street & Monmouth Street	**47**	40	33	31	31	33	32

Location	2017 Base	2021 Baseline	2021 With CAZ C (£9/£100)	2021 With CAZ D (£7.50/£100)	2021 With CAZ D (£9/£100)	2021 With CAZ C (£9/£100) & Traffic Management	2021 With CAZ D (£9/£100), Traffic Management & Concessions
Residential property at Charles Street	**45**	38	32	30	30	30	30
Residential property at St James's Parade	**43**	37	29	27	27	29	28
Residential property at the junction of London Road, Walcot Street & The Paragon	**56**	**46**	31	29	29	30	30
Residential property at the corner of Lansdown Road & George Street	**41**	36	30	29	29	29	29
Residential property at Walcot Street	**49**	40	25	24	24	25	25
Residential property at Broad Street (near The Paragon)	**58**	**50**	35	35	35	35	35
Residential property at Crescent Lane	**45**	38	31	30	30	33	33
Residential property at St James's Parade	**42**	36	28	26	26	27	27
Residential property at the corner of St James's Parade & Corn Street	**41**	34	26	25	25	26	26
Residential property at St James's Parade (opposite Dorchester Street)	**45**	38	29	27	27	29	28
Residential property at Wells Road	**46**	40	32	31	30	32	32
Residential property at Wells Road	**51**	**43**	28	28	28	28	28
Residential property at Dorchester Street (near Manvers Street)	**46**	40	31	31	31	32	32
Residential property at Dorchester Street (opposite bus station)	**49**	**42**	31	30	30	32	32
Residential property at Manvers Street (south of Railway Street)	**46**	38	27	26	26	27	27
Residential property at Manvers Street (north of Railway Street)	**44**	37	26	25	25	26	26
Residential property at Manvers Street (north of Railway Street)	**42**	35	25	24	24	25	25
Residential property at Manvers Street (north of Railway Street)	**44**	37	25	25	25	26	25
Residential property at Manvers Street (north of Henry Street)	**42**	35	25	24	24	25	25
Residential property at Manvers Street (near Terrace Walk)	**51**	**43**	31	30	30	31	31
Residential property at Manvers Street (near North Parade)	**42**	36	26	25	25	26	26

Location	2017 Base	2021 Baseline	2021 With CAZ C (£9/£100)	2021 With CAZ D (£7.50/£100)	2021 With CAZ D (£9/£100)	2021 With CAZ C (£9/£100) & Traffic Management	2021 With CAZ D (£9/£100), Traffic Management & Concessions
Residential property at Green Park (near Midland Bridge Road)	**43**	36	27	26	26	27	27
Residential property at Lansdown Road (near Morford Street)	**48**	40	28	27	26	27	27
Residential property at Lansdown Road (between Morford Street and Julian Road)	**47**	39	27	26	26	27	26
Residential property at the corner of Lansdown Road and Brunswick Place	**49**	**41**	30	28	28	29	29
Residential property at Lansdown Road (south of Lansdown Place East)	**59**	**49**	31	30	30	30	30
Residential property at Lansdown Road (north of Lansdown Grove)	**50**	**41**	28	27	27	27	27
Residential property at Eastbourne Avenue (between Fairfield Road and Claremont Road)	**42**	31	25	24	24	25	25
Residential property at the corner of Camden Road and Fairfield Road	**43**	33	28	27	27	28	28
Residential property at London Road (opposite Cleveland Place)	**42**	35	28	27	26	27	27
Residential property at London Road (between Cleveland Place and Thomas Street)	**60**	**50**	38	36	36	38	37
Residential property at London Road (between Cleveland Place and Thomas Street)	**62**	**52**	40	37	37	40	39
Residential property at London Road (between Cleveland Place and Thomas Street)	**61**	**51**	39	37	36	39	38
Residential property at London Road (between Cleveland Place and Thomas Street)	**61**	**51**	39	36	36	39	38
Residential property at London Road (between Cleveland Place and Thomas Street)	**56**	**47**	35	33	33	35	35
Residential property at London Road (near Snow Hill)	**42**	34	27	25	25	27	26
Residential property at London Road (near Snow Hill)	**56**	**47**	35	33	33	35	35

Location	2017 Base	2021 Baseline	2021 With CAZ C (£9/£100)	2021 With CAZ D (£7.50/£100)	2021 With CAZ D (£9/£100)	2021 With CAZ C (£9/£100) & Traffic Management	2021 With CAZ D (£9/£100), Traffic Management & Concessions
Residential property at London Road (near Brunswick Street)	**46**	38	29	28	28	29	29
Residential property at London Road (near Brunswick Street)	**44**	36	28	27	27	28	28
Residential property at London Road (east of St Saviour's Road)	**44**	36	28	27	27	28	28
Residential property at London Road West	**54**	**43**	29	28	28	29	29
Residential property at Wells Road	**42**	35	23	23	23	23	23
Residential property at Wells Road	**43**	36	24	24	24	24	24
Residential property at Bathwick Street (opposite Henrietta Road)	**43**	36	30	28	28	31	30
Residential property at Bathwick Street (south of Henrietta Road)	**45**	38	32	30	30	32	32
Residential property at Bathwick Hill (near Sydney Buildings)	**54**	**43**	23	23	23	23	23
Residential property at Bathwick Hill (opposite Darlington Place)	**43**	35	20	19	19	20	19
Residential property at Prior Park Road (near Claverton Street)	**41**	34	28	27	27	28	28
Residential property at Wellsway (west of Hayesfield Park)	**43**	35	23	23	23	23	23
Residential property at Wellsway (west of Hayesfield Park)	**61**	**50**	28	28	27	28	28
Residential property at Wellsway (east of Holloway)	**48**	**41**	34	33	33	34	34
Residential property at Wellsway (opposite Milton Avenue)	**42**	35	24	24	24	24	24
Residential property at Wellsway (north of St Luke's Road)	**47**	39	27	26	26	27	27
Residential property at Wellsway (south of St Luke's Road)	**49**	40	26	25	25	26	26
Residential property at Wellsway (near Greenway Lane)	**61**	**50**	27	27	27	27	27
Residential property at Wellsway (south of Greenway Lane)	**59**	**48**	25	25	24	25	25

Location	2017 Base	2021 Baseline	2021 With CAZ C (£9/£100)	2021 With CAZ D (£7.50/£100)	2021 With CAZ D (£9/£100)	2021 With CAZ C (£9/£100) & Traffic Management	2021 With CAZ D (£9/£100), Traffic Management & Concessions
Residential property at Wellsway (near Midford Road)	**44**	36	21	21	21	21	21
Residential property at Upper Bristol Road (near Ashley Avenue)	**55**	**45**	27	27	26	27	27
Residential property at Upper Bristol Road (near Shaftesbury Avenue)	**75**	**62**	36	36	36	36	36
Residential property at Upper Bristol Road (opposite Locksbrook Road)	**47**	39	27	27	27	27	27
Residential property at Upper Bristol Road (near Hungerford Road)	**49**	**41**	33	32	32	33	33
Residential property at Upper Bristol Road (between Hungerford Road and Windsor Bridge Road)	**47**	40	33	32	32	33	33
Residential property at Upper Bristol Road (between Hungerford Road and Windsor Bridge Road)	**47**	40	33	32	32	33	33
Residential property at Upper Bristol Road (opposite Park Lane)	**42**	36	31	30	30	32	31
Residential property at Bathwick Hill (south of Cleveland Walk)	**49**	39	20	20	20	20	20
Residential property at Lower Bristol Road (near Westmoreland Road)	**41**	35	30	28	28	30	29
Residential property at Brougham Hayes	**44**	36	22	21	21	22	22
Residential property at Brougham Hayes	**48**	40	24	24	24	24	24
Residential property at Brougham Hayes (near Livingstone Road)	**53**	**45**	29	27	27	29	28
Residential property at Lower Bristol Road (near Midland Road)	**41**	36	30	28	28	30	29
Residential property at Lower Bristol Road (near Lorne Road)	**51**	**44**	37	34	34	37	36
Residential property at Brougham Hayes (near Livingstone Road)	**42**	35	22	22	22	22	22
Residential property at London Road (opposite Cleveland Place)	**52**	**44**	35	33	33	35	34
PCM Links [b]							
A4 (PCM Census ID 6133)	44	38	31	0	30	29	29
A36 (PCM Census ID 6990)	50	44	37	36	36	38	37

Location	2017 Base	2021 Baseline	2021 With CAZ C (£9/£100)	2021 With CAZ D (£7.50/£100)	2021 With CAZ D (£9/£100)	2021 With CAZ C (£9/£100) & Traffic Management	2021 With CAZ D (£9/£100), Traffic Management & Concessions
A367 (PCM Census ID 7128)	44	37	31	30	29	30	30
A36 (PCM Census ID 17920)	47	39	33	31	31	33	33
A4 (PCM Census ID 26126)	64	51	37	35	35	37	37
A4 (PCM Census ID 27156)	53	45	37	36	36	37	37
A36 (PCM Census ID 28320)	44	32	28	27	27	28	27
A4 (PCM Census ID 36131)	**60**	**51**	**42**	**41**	40	37	36
A367 (PCM Census ID 37050)	**69**	**58**	35	34	34	35	35
A3039 (PCM Census ID 38015)	**52**	**45**	32	31	31	32	32
A4 (PCM Census ID 56445)	**63**	**51**	32	31	31	32	31
A4 (PCM Census ID 57772)	**70**	**58**	38	37	36	38	38
A3039 (PCM Census ID 57774)	**55**	**45**	29	28	27	29	28
A367 (PCM Census ID 75361)	**43**	37	30	29	29	30	30
A367 (PCM Census ID 77949)	**41**	34	20	20	20	20	20
A36 (PCM Census ID 77950)	**51**	**44**	37	34	34	37	36
A431 (PCM Census ID 77954)	**46**	37	25	24	24	25	25

[a] Exceedances of the national Objective and EU Limit Value are shown in bold.

[b] The maximum predicted concentration of all PCM-equivalent receptor locations along each PCM Link (with non-compliance in 2017).

Appendix B. Technical Note on Gradient Emissions

Technical Note:
Gradient Emissions

December 2018

Experts in air quality
management & assessment

Document Control

Client	Jacobs	**Principal Contact**	Becky Lloyd

Job Number	J3145

Report Prepared By:	Dr Austin Cogan

Document Status and Review Schedule

Report No.	Date	Status	Reviewed by
J3145A/N2/F3	7 December 2018	Final	Dr Ben Marner (Technical Director)

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1 Introduction

1.1 Previous air quality modelling undertaken for the Bath Clean Air Zone (CAZ) feasibility work takes into account the effects of gradients on vehicle emissions following the Joint Air Quality Unit (JAQU) Air Quality and Transport guidance. This guidance also states that *"details of the modelling technique used to consider gradient effects should be shared with JAQU"*. After following the approach set out in the guidance, the model appears to be behaving differently at roads with gradients, such that nitrogen oxides (NOx) concentrations are underestimated significantly more than at non-gradient locations. The approach previously used was to adjust NOx concentrations separately for locations at gradient and non-gradient roads. Further analysis has since been carried out, which has found a relationship between the NOx underestimation and Light Goods Vehicle (LGV) plus Heavy Duty Vehicle (HDV) emissions on uphill lanes of gradient roads. This analysis has determined that model predictions are improved if emissions from LGVs and HDVs on uphill lanes of gradient roads are uplifted independently from all other modelled emissions.

2 Previous Approach for Gradient Effects

2.1 The previous modelling followed the approach set out in the JAQU guidance, which is based upon Defra's Local Air Quality Management (LAQM) guidance (Defra, 2018b). This includes deriving vehicle emissions from the Emission Factor Toolkit (EFT v8.01a) and then uplifting emissions from pre-2014 HDVs on gradient roads using equations defined by Defra. The Defra's LAQM guidance (Defra, 2018b) states *"the gradient dependence of vehicles fitted with SCR (Selective Catalytic Reduction) emission abatement, i.e. the 2014 and later HDVs, does not follow a simple relationship. This is likely to be because the amount of NOx reduction reagent added is actively controlled, depending on engine speed and load. This complex behaviour and the overall low EF for these vehicles mean that no gradient compensation is required".*

2.2 In order to ensure that the air quality model accurately predicts local concentrations, it is necessary to verify the model against local measurements. Most nitrogen dioxide (NO_2) is produced in the atmosphere by reaction of nitric oxide (NO) with ozone. It is therefore most appropriate to verify the model in terms of primary pollutant emissions of nitrogen oxides ($NOx = NO + NO_2$). The model has been run to predict the annual mean NOx concentrations during 2017 at 41 diffusion tube monitoring sites and three automatic monitoring sites. Concentrations have been modelled at the inlet height of the monitors.

2.3 The model output of road-NOx (i.e. the component of total NOx coming from road traffic) has been compared with the 'measured' road-NOx. Measured road-NOx has been calculated from the measured NO_2 concentrations and the predicted background NO_2 concentration using the NOx from NO_2 calculator (Version 6.1) available on the Defra LAQM Support website (Defra, 2018b).

2.4 The EFT has been used to obtain both NOx and primary NO_2[1] emissions. Both NOx and NO_2 have been included within the air quality model to calculate location-specific proportions of primary NO_2 (fNO_2) at each receptor. These values have then been used within the conversion of NOx to NO_2 (using the NOx to NO_2 calculator supplied by Defra).

2.5 An adjustment factor has been determined as the slope of the best-fit line between the 'measured' road contribution and the model derived road contribution, forced through zero (Figure 1). As the model appeared to behaving differently at those sites with gradients, and those which have been modelled without gradients, these have been verified separately. In addition, the model also appeared to be behaving differently at major (A- and B-Roads) and minor roads at those sites with gradients, and these have also been verified separately. At each receptor modelled, the calculated adjustment factors of 2.402 and 3.494 have been applied to the modelled gradient road-NOx concentration for minor and major roads respectively, and a factor of 1.637 has been applied to the modelled non-gradient road-NOx concentration. These adjusted road-NOx concentrations have then been combined to provide total adjusted modelled road-NOx concentrations at each receptor.

2.6 The total nitrogen dioxide concentrations have then been determined by combining the adjusted modelled road-NOx concentrations with the predicted background NO_2 concentration within the NOx to NO_2 calculator. Figure 2 compares final adjusted modelled total NO_2 at each of the monitoring sites to measured total NO_2 for gradients and non-gradients.

2.7 The results imply that the model has under-predicted the road-NOx contribution at both gradient and non-gradient roads, but significantly more for gradient roads (especially for major roads).

[1] Emissions of NO_2 emitted directly to the atmosphere

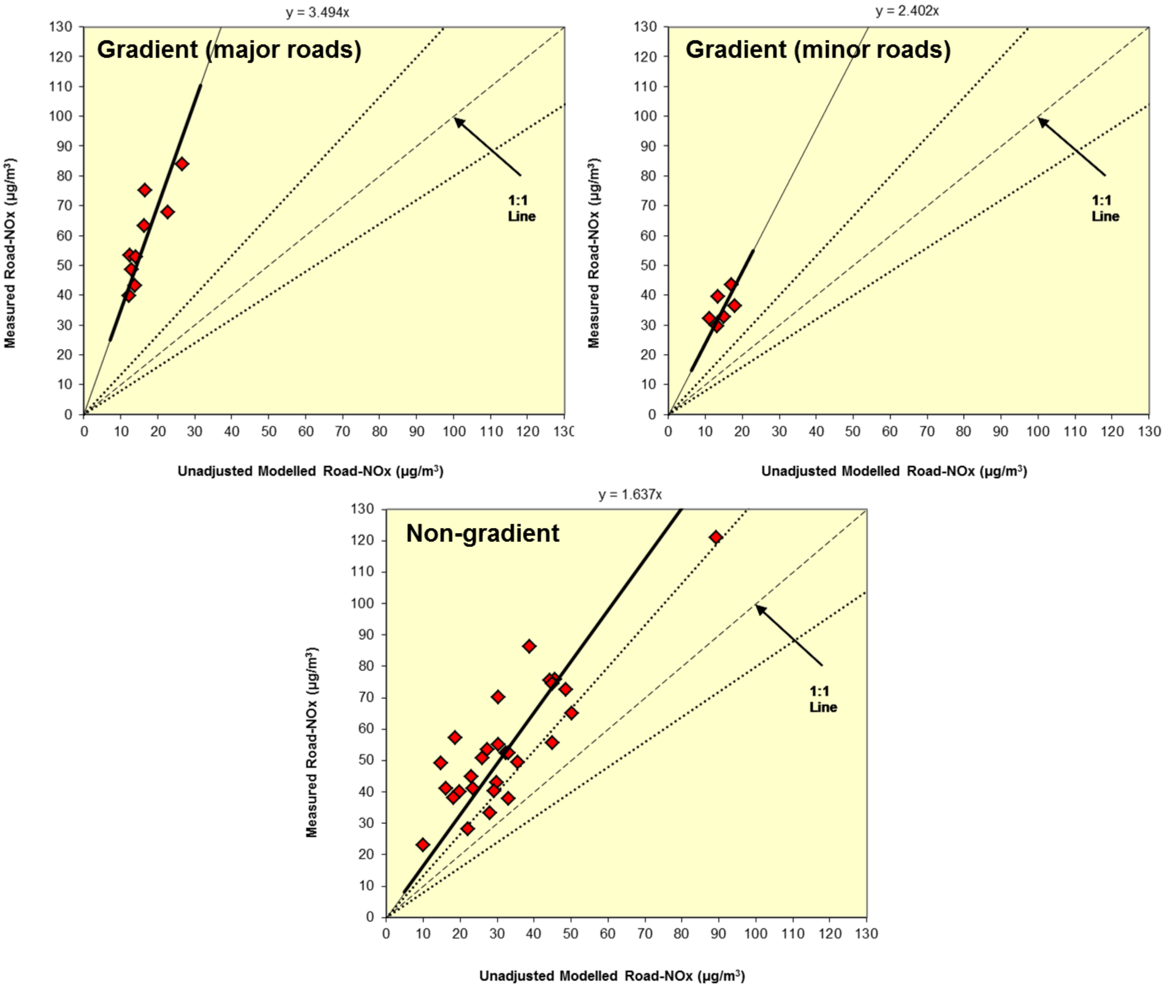

Figure 1: Comparison of Measured Road NOx to Unadjusted Modelled Road NOx Concentrations. The dashed lines show ± 25%.

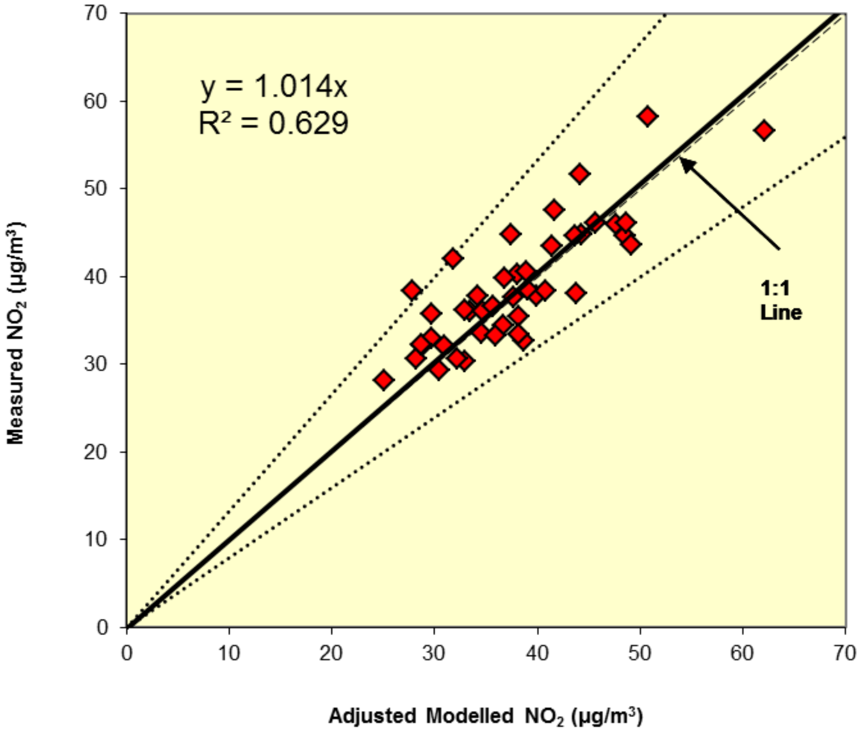

Figure 2: Comparison of Measured Total NO_2 to Final Adjusted Modelled Total NO_2 Concentrations. The dashed lines show ± 25%.

3 Analysis of Gradient Effects

3.1 An investigation was undertaken to understand why there was a difference in the model verification for major and minor gradient roads. During this investigation, a trend between the adjustment factor for each monitoring site at a gradient road (i.e. the difference in measured and modelled road-NOx at each site individually) and the percentage of emissions from LGVs and HDVs on uphill lanes was found (see Figure 3). This trend demonstrates that the air quality model is under-predicting NOx concentrations more where there are a greater proportion of LGV and HDV emissions. No clear trends were found with LGVs and rigid HDVs, artic HDVs or buses/coaches individually. Similarly, there was no positive correlation between emissions from cars and the required gradient adjustment factors (in fact, since the trend is a negative correlation since it is the inverse of the plot shown in Figure 3).

3.2 The results in Figure 3 indicate that the effects of uphill gradients on emissions from LGVs and HDVs in Bath are not being taken account of fully by Defra's approach. In particular, Defra's approach does not take account of increased emissions from LGVs, nor Euro 6 HDVs. Given that the EFT assumes the LGV and HDV fleets comprise of a large proportion of Euro 6 vehicles in 2017 (33% for LGVs, 55% for rigid HGVs, 72% for artic HDVs and 40% for buses and coaches) and the behaviour of NOx emissions from SCR-equipped vehicles is complex, it is considered highly possible that there could be some gradient effects from Euro 6 vehicles; particularly on short hills or in stop-start traffic, where the beneficial effect of increased exhaust temperature on SCR performance may not be fully realised. Nevertheless, this analysis cannot differentiate which vehicle models are driving the observed excess NOx concentrations on gradients.

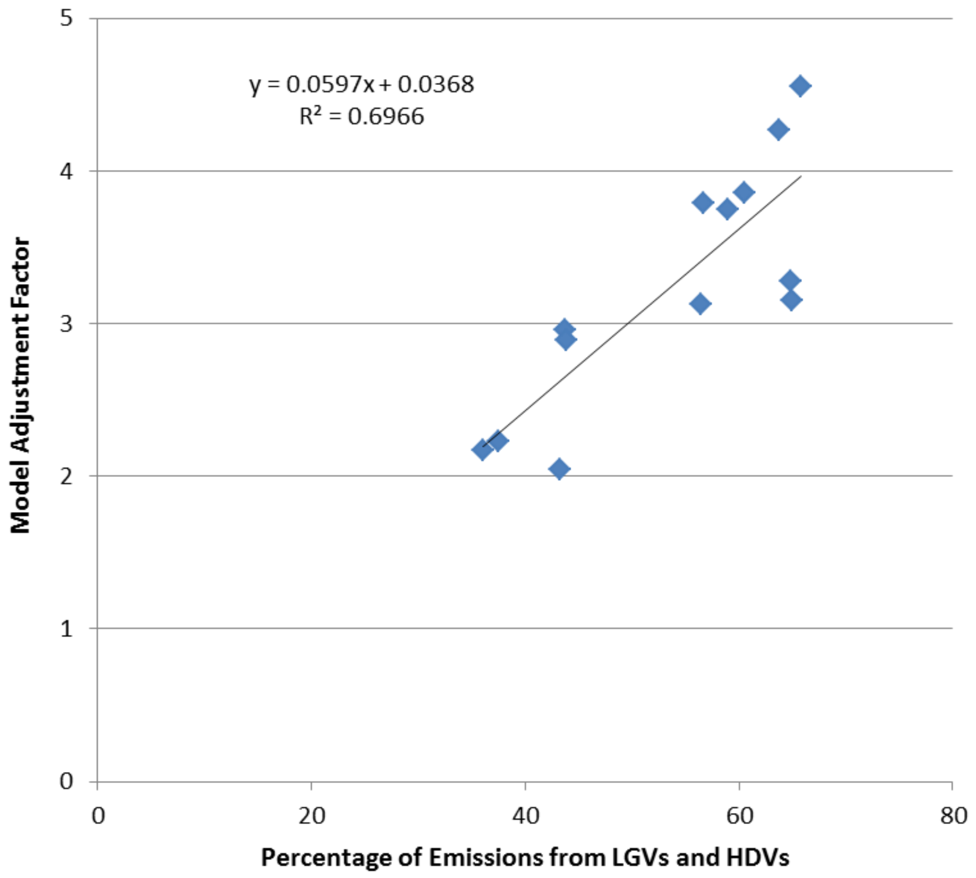

Figure 3: Measured Road-NOx divided by Modelled Road-NOx on Gradient Roads (Y Axis) vs Percentage of NOx Emissions from the Nearest Road which are Assumed to Come from LGVs and HDVs (X Axis)

4 Proposed Approach for Gradient Effects

4.1 To correct for the underestimation in LGV and HDV NOx emissions on uphill lanes of gradient roads, two adjustment factors have been derived; one for LGV and HDV emissions on uphill lanes of gradient roads (hereafter known as the 'gradient' adjustment factor) and one for all other emissions (i.e. emissions on non-gradient roads, downhill lanes of gradient roads, and car/motorcycle emissions on uphill lanes of gradient roads) (hereafter known as the 'non-gradient' adjustment factor). The precise value of each adjustment factor is affected by the other adjustment and so an iterative approach was necessary to obtain these adjustment factors. This approach is described below.

4.2 Initially, the ‘non-gradient’ adjustment factor has been calculated by comparing ‘measured’ and unadjusted modelled road-NOx concentrations at monitoring sites on non-gradient roads. This gave an adjustment factor of 1.660 (see Figure 4). Modelled road-NOx at all non-gradient sites, modelled road-NOx at all downhill lanes gradient sites, and modelled road-NOx from passenger cars at all gradient sites, was then multiplied by this adjustment factor.

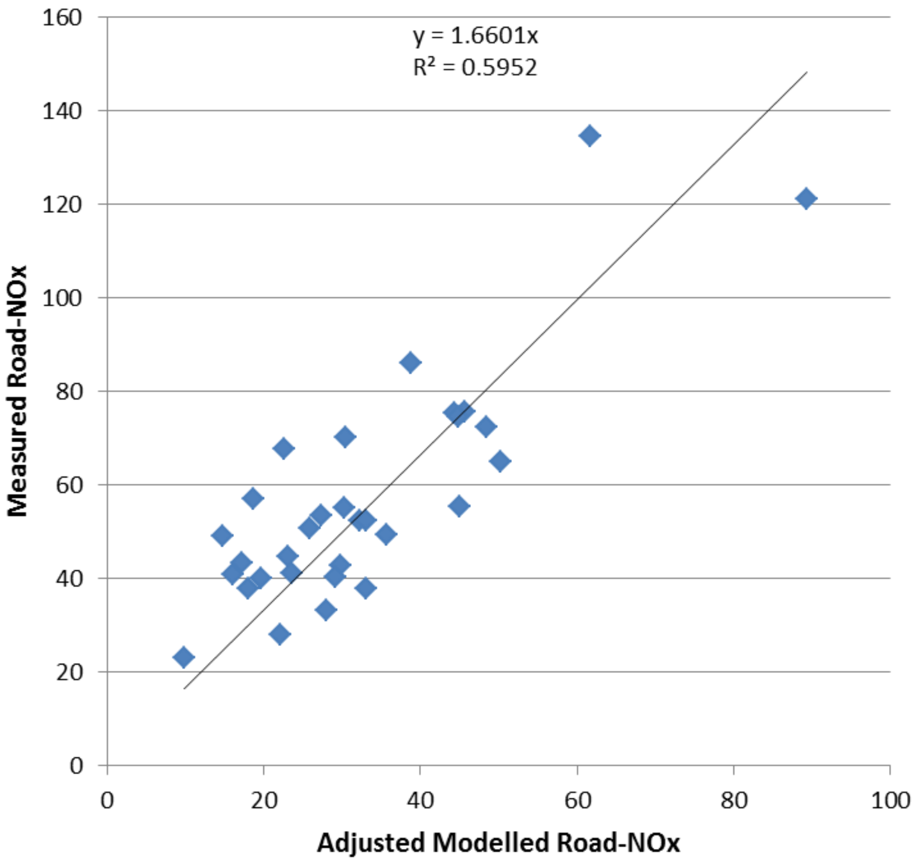

Figure 4: Comparison of Measured Road-NOx to Unadjusted Modelled Road-NOx Concentrations at Non-gradient Roads (µg/m^3)

4.3 The next step was to subtract the adjusted modelled NOx from passenger cars from the measured road-NOx on gradient roads. This gave a ‘residual road-NOx’ which it has been assumed comes from LGVs and HDVs on uphill lanes of gradient roads. Modelled LGV+HDV NOx was then plotted against this residual measured road-NOx (Figure 5). An adjustment factor which is specific to modelled LGV+HGV NOx on gradients was then determined as the slope of the best-fit line (forced through zero) shown in Figure 5. This adjustment factor (5.041) was then applied to all NOx emissions from LGVs and HDVs on uphill lanes of gradient roads.

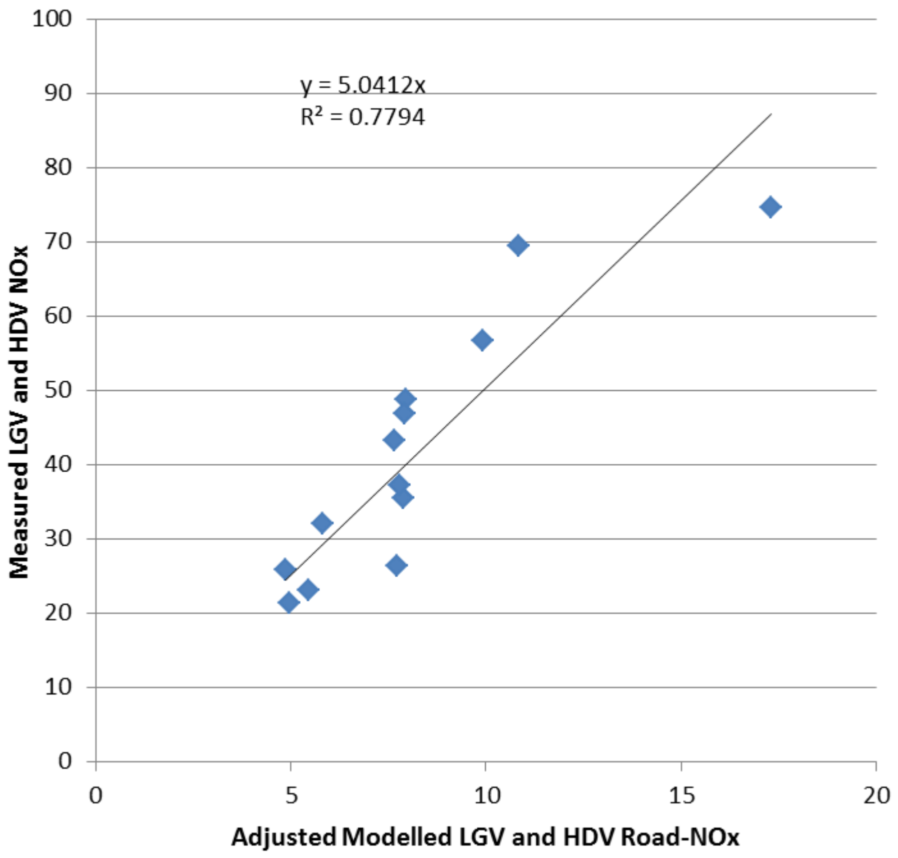

Figure 5: Comparison of Measured LGV+HDV NOx (i.e. the residual of the measured NOx) to Unadjusted Modelled LGV+HDV NOx Concentrations at Gradient Roads (μg/m^3)

4.4 Figure 6 shows the total measured road-NOx vs total modelled road-NOx at all of the monitoring sites (gradient and non-gradient) following these adjustments. This demonstrates that the adjusted road-NOx concentrations still have a bias of 2.2%. Both the gradient and non-gradient adjustment factors have thus been multiplied by 0.978. Following this adjustment, there is no overall bias in the model predictions when compared with these measurements (see Figure 7).

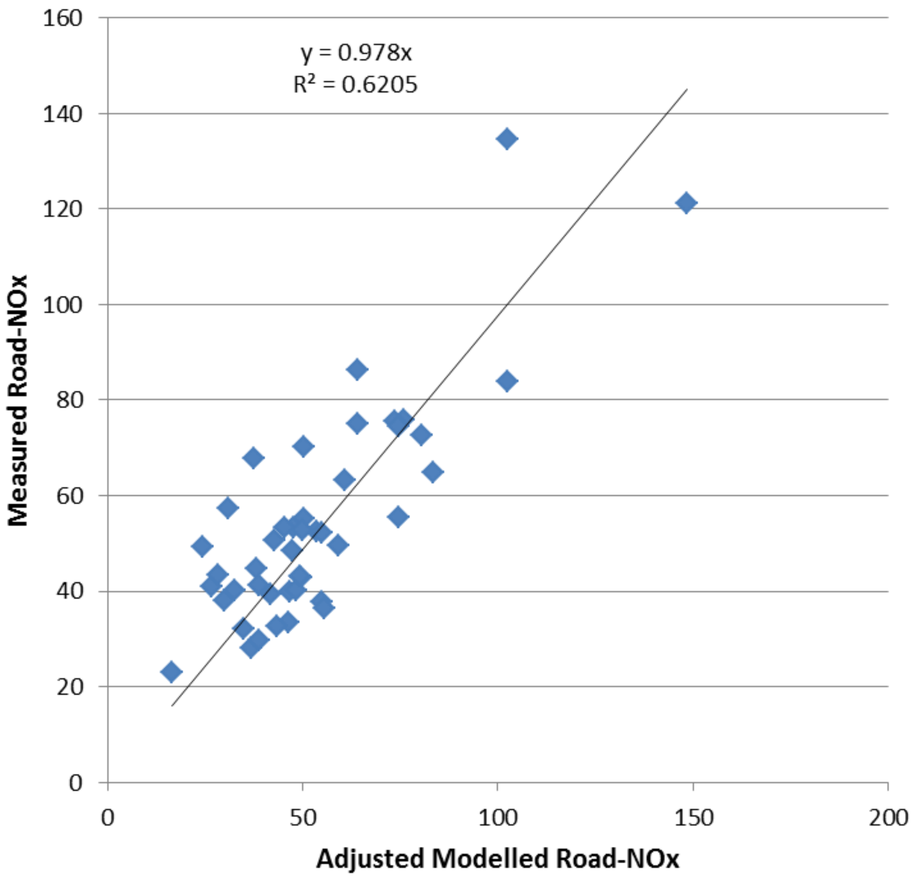

Figure 6: Comparison of Measured Road-NOx to Adjusted Modelled Road-NOx Concentrations at Gradient and Non-gradient Roads (µg/m^3)

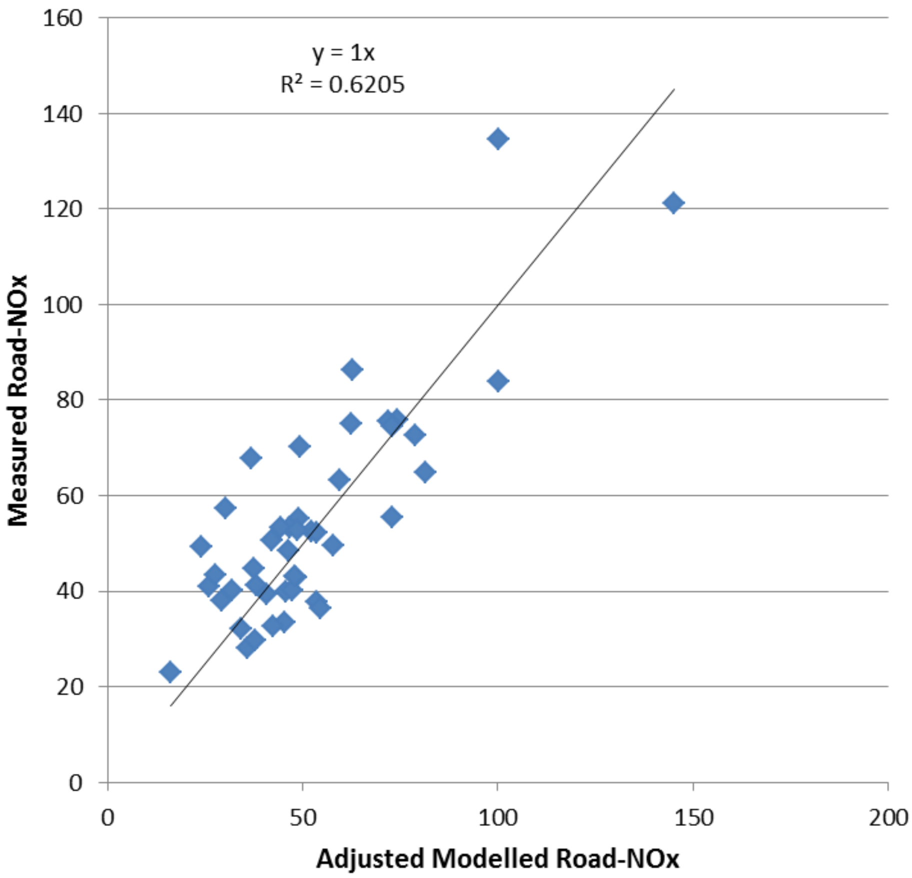

Figure 7: Comparison of Measured Road-NOx to Adjusted Modelled Road-NOx Concentrations at Gradient and Non-gradient Roads after Iterating (µg/m³)

4.5 This approach assumes that only those roads which are closest to each monitor will affect the measured concentrations; when in fact each predicted concentration will be affected by emissions from all roads in the study area. Furthermore, the measured road-NOx concentrations against which the model has been verified are, themselves, a function of the model predictions for primary NO_2. In order to take account of these factors, it is necessary to carry out further iterations; this time adjusting the emissions input to the dispersion model. The updated adjustment factors have thus been applied to the emissions, the air quality model re-run, measured road-NOx re-calculated using the re-defined fNO_2 values, and the adjustment factors updated iteratively again. This iterative approach has been repeated six times, until the unadjusted road-NOx achieved zero bias and no further updates to the adjustment factors were needed.

4.6 The final adjustment factors derived from this iterative approach are 7.392 and 1.575 for the 'gradient' and 'non-gradient' adjustment factors, respectively. Figure 8 presents the unadjusted road-NOx with zero bias. The total nitrogen dioxide concentrations have then been determined by combining the unadjusted modelled road-NOx concentrations with the predicted background NO_2

concentration within the NOx to NO_2 calculator. Figure 9 compares final adjusted modelled total NO_2 at each of the monitoring sites to measured total NO_2 for gradients and non-gradients.

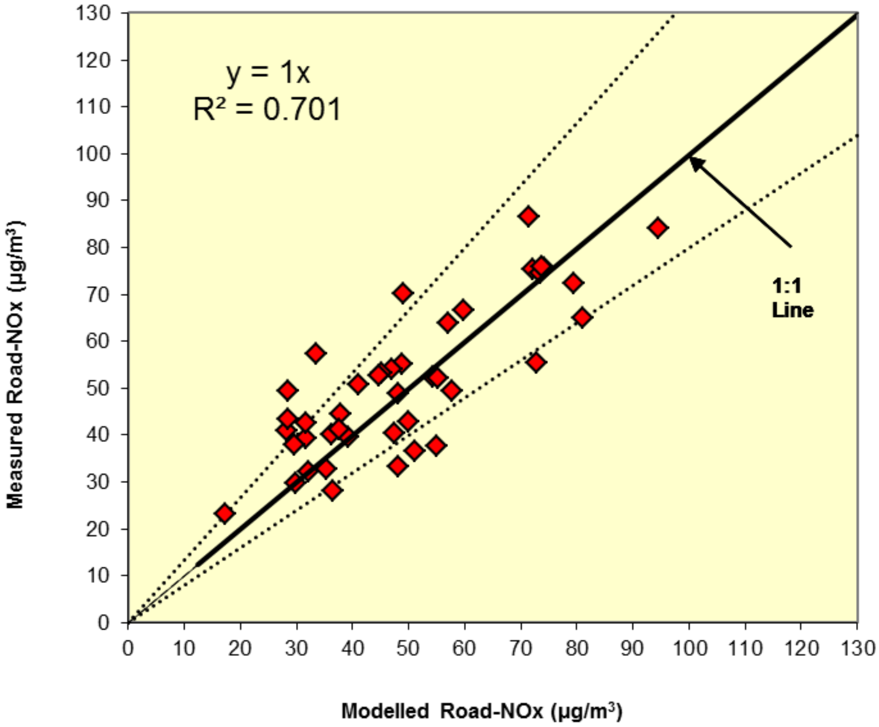

Figure 8: Comparison of Measured Road NOx to Modelled Road NOx Concentrations. The dashed lines show ± 25%.

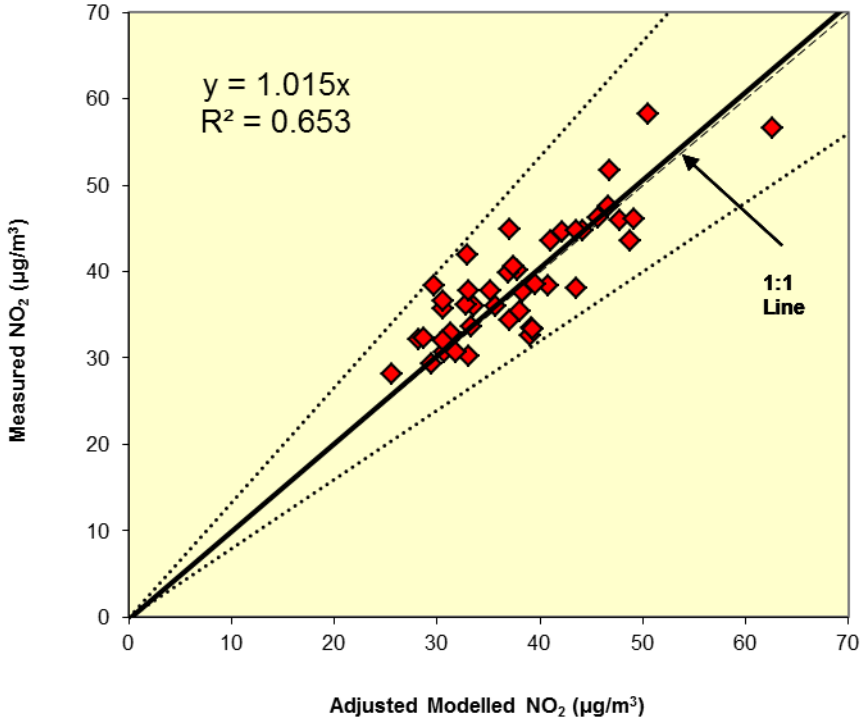

Figure 9: Comparison of Measured Total NO_2 to Final Adjusted Modelled Total NO_2 Concentrations. The dashed lines show ± 25%.

4.7 It must be recognised that as the composition of the vehicle fleet changes, the required uplifts to NOx emissions could also change, but there is no way to determine this effect. In any event, this issue is not specific to the revised approach of applying separate adjustments on gradients, and affects any study which uplifts either the model inputs or the model outputs based on a comparison with measurements.

4.8 It should also be noted that the adjustment factor applied to LGV and HDV emissions on uphill lanes of gradient roads is the same regardless of the specific gradient. There is insufficient information to derive uplift functions which are specific to different gradients and so it is possible that emissions may be over-predicted on shallow gradients and under-predicted on steep gradients. This was also the case in the previous modelling.

4.9 It is thus proposed that the air quality modelling for the Bath CAZ feasibility work includes the ‘gradient’ and ‘non-gradient’ emission adjustment factors described above, in addition to following the approach set out in the JAQU and Defra guidance. The NOx emissions will thus be derived using the EFT, adjusted using Defra’s approach to gradient effects, and then the NOx emissions will be uplifted using the adjusted factors.

4.10 As the model predictions of particulate matter (PM) could only be verified at a single monitoring site in Bath on a non-gradient road, there is no way to determine whether PM emissions should be further adjusted on gradient roads. The proposed approach therefore does not apply any additional adjustment to PM emissions beyond the uplifts applied from Defra's guidance.

4.11 The 'non-gradient' adjustment factor is marginally lower than previously calculated for non-gradient roads, indicating that the model may lead to predicted concentrations at non-gradient roads being marginally lower than previously modelled[2]. Figure 9 shows that concentrations in some locations will be slightly over-predicted; while in other locations concentrations will be under-predicted. This is, however, similar to the previous modelling approach and the bias and r^2 value for modelled NO_2 are similar[3] with the proposed approach.

5 Conclusion

5.1 The analysis of gradient effects has demonstrated that the previous approach does not adjust emissions sufficiently to take account of gradient effects on emissions of NOx from LGVs and HDVs. It is considered that the proposed approach takes account of gradient effects in a more robust way and should be adopted for the Bath CAZ feasibility work.

[2] NOx adjusted by 1.575 as opposed to 1.637 previously.

[3] Bias and r^2 value of the previous approach are 2.3% and 0.63, respectively, while for the proposed approach are 2.3% and 0.65, respectively.