# AN INVESTIGATION OF INTERVENTIONS FOR THE REDUCTION OF TRAFFIC-RELATED AIR POLLUTION AT SCHOOLS IN ENGLAND

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# Abstract

Children are particularly vulnerable to the negative effects of air pollution exposure due to their developing lungs and their greater respiratory rate than adults. The school commute presents a period of particular threat because children are exposed to higher levels of air pollution due to increased road traffic. This can lead to a range of health problems, including asthma, respiratory infections, and long-term lung damage. This research fills a gap in the literature by identifying relevant, effective interventions to reduce potential child exposure to harmful pollutants during the school commute, based on comprehensive academic reviews, stakeholder opinion, and dispersion modelling.

This thesis aims to investigate interventions to reduce and mitigate potential child exposure to traffic-related air pollution (TRAP) in the vicinity of schools in England and on the school commute. A literature review was combined with the findings of a systematic review to determine suitable reduction and exposure mitigation interventions and to provide an academic basis for constructing a stakeholder survey distributed to English schools. The results of the survey were compiled by teacher and parent respondents. A geographical information system (GIS) was constructed to identify pollution levels at schools in England. Several highly polluted school environments were identified, and these were used as case study areas for dispersion modelling.

A set of interventions, popular with the participants in the stakeholder survey and shown to be demonstrably effective by the literature, were applied to the school environments using dispersion modelling to determine their overall effectiveness. The GIS showed that urban environments throughout the UK had the most polluted schools. Schools in England were significantly more polluted than schools in other UK countries. London had a greater number of polluted schools than any other UK region. Dispersion modelling showed the greatest reductions from all selected interventions were found on travel routes rather than by school buildings. At all travel routes, dispersion modelling showed reductions of $NO_2$ concentrations resulting from low emission zones (-15.85%), mode shifts to active travel (-12.97%), improved travel routes (-16.02%), ridesharing (-13.16%), and anti-idling (-8.27%).

The investigation outcomes provided the basis for policy recommendations at the national, local authority, and parent/teacher levels. The recommendations centre on reducing TRAP in the vicinity of schools and on the school commute, emphasising improved monitoring, greater communication between stakeholder groups, and immediate action.

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**Word Count:** 77,053

# Contents

## List of Abbreviations

| | |
|---|---|
| AADF | Annual Average Daily Flow |
| AADT | Annual Average Daily Traffic |
| ADMS | Atmospheric Dispersion Modelling Software |
| ADT | Average Daily Traffic |
| AIRMEX | European Indoor Air Monitoring and Exposure |
| AMSTAR | A MeaSurement Tool to Assess systematic Reviews |
| AQE | Air Quality England |
| AQEG | Air Quality Expert Group |
| AQMA | Air Quality Management Area |
| ASR | Annual Status report |
| AURN | Automatic Urban & Rural Network |
| BAU | Business As Usual |
| BC | Black Carbon |
| BMI | Body Mass Index |
| BREATHE | Brain dEvelopment and Air pollution ultrafine particles in scHool childrEn |
| BRT | Bus Rapid Transit |
| BVOC | Biogenic Volatile Organic Compound |
| CCS | Congestion Charging Scheme |
| CEDA | Centre for Environmental Data Analysis |
| CFD | Computational Fluid Dynamics |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| COMEAP | Committee on the Medical Effects of Air Pollutants |
| EBSCO | Elton B. Stephens Company |
| EFT | Emission Factors Toolkit |
| EC | European Commission |
| EU | European Union |
| FPN | Fixed Penalty Notice |
| FEV | Forced Expiratory Volume |
| GIS | Geographical Information System |
| GPS | Global Positioning System |
| HC | Hydrocarbon |

| | |
|---|---|
| HIA | Health Impact Assessment |
| HV | Heavy Vehicle |
| IDW | Inverse Distance Weighting |
| IMD | Index of Multiple Deprivation |
| IP | Internet Protocol |
| JB | Jarque-Bera |
| JBI | Joanna Briggs Institute |
| LA | Local Authority |
| LAI | Leaf Area Index |
| LAQ | Local Air Quality |
| LAQM | Local Air Quality Management |
| LDSA | Lung Deposited Surface Area |
| LEZ | Low Emission Zone |
| LSOA | Lower-layer Super Output Area |
| LTN | Low-Traffic Neighbourhood |
| MAAQ | Modelling of Ambient Air Quality |
| MDM | Multiple Deprivation Measure |
| MHCLG | Ministry of Housing, Communities and Local Government |
| MMEF | Maximal Mid-Expiratory Flow |
| NHS | National Health Service |
| NI | Northern Ireland |
| NIMDM | Northern Ireland Multiple Deprivation Measure |
| NISRA | Northern Ireland Statistics & Research Agency |
| NO | Nitrogen Oxide |
| $NO_2$ | Nitrogen Dioxide |
| NOS | Newcastle-Ottawa Scale |
| $NO_X$ | Nitrogen Oxides |
| $O_3$ | Ozone |
| OA | Output Area |
| ONS | Office for National Statistics |
| OpenFOAM | Open-Source Field Operation and Manipulation |
| OS | Ordinance Survey |
| OSGB | Ordinance Survey of Great Britain |

| | |
|---|---|
| PAH | Polycyclic Aromatic Hydrocarbons |
| PCM | Pollution Climate Mapping |
| PCN | Penalty Charge Notice |
| PICO | Patient/Problem, Intervention/Exposure, Comparison/Control, Outcome |
| PM | Particulate Matter |
| $PM_1$ | Particulate Matter < 1 µm |
| $PM_{10}$ | Particulate Matter < 10 µm |
| $PM_{2.5}$ | Particulate Matter < 2.5 µm |
| $PM_X$ | Particulate Matters |
| PNC | Particle Number Concentration |
| PRISMA | Preferred Reporting Items for Systematic Reviews & Meta-Analyses |
| PROSPERO | International Prospective Register of Systematic Reviews |
| QUOROM | Quality of Reporting of Meta-Analyses |
| RAC | Royal Automobile Club |
| RCPCH | Royal College of Paediatrics and Child Health |
| RDE | Real Driving Emissions |
| ROBINS | Risk Of Bias In Non-randomised Studies of Interventions |
| SD | Standard Deviation |
| SIMD | Scottish Index of Multiple Deprivation |
| $SO_2$ | Sulphur Dioxide |
| SOA | Super Output Area |
| SoCAB | South Coast Air Basin |
| SPICE | Setting - Population (or Perspective) - Intervention - Comparator - Evaluation |
| SPIDER | Sample, Phenomenon of Interest, Design, Evaluation, Research Type |
| TAPM | The Air Pollution Model |
| TMS | Traffic Management Strategies |
| TRAP | Traffic-Related Air Pollution |
| UFP | Ultrafine Particles |
| URN | Unique Reference Number |
| VOC | Volatile Organic Compounds |
| WHO | World Health Organisation |
| WIMD | Welsh Index of Multiple Deprivation |

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# 1.0 Introduction

Air quality is a complex and topical issue, and poor air quality is responsible for approximately 9 million premature annual deaths worldwide (Fuller et al., 2022). Approximately 1.8 billion, or 93%, of the world's children are exposed to toxic air daily, and estimates maintain that 600,000 children died in 2016 from acute respiratory tract infections due to air pollution exposure (World health Organization, 2018a). In the UK, anthropogenic air pollution is responsible for up to 36,000 annual deaths (GOV.UK, 2022a). Air pollution caused by traffic and other sources is also disproportionately detrimental to children's health due to their developing organs, making them an at-risk group (World Health Organization, 2018). Whilst much of the literature addresses health effects, traffic reduction, and air pollution at schools, relatively fewer studies address child exposure to air pollution at peak daily traffic times on the school commute.

School areas present zones that are particularly polluted during congregative times and travel associated with the school commute, such as the morning when children are dropped off and, in the afternoon, when they are collected (Whitehouse & Edwards, 2018; Whitehouse & Grigg, 2018; BLF, 2017). Children are exposed to harmful pollutants daily when travelling to and from school, presenting a direct and immediate concern for child health. These times coincide with daily peak traffic, so mitigating child exposure to high concentrations of air pollution at these times is of great importance.

Increasing evidence of the health crisis is becoming available, including child exposure to air pollution linked to asthma, low birth weight, heart disease, and poor neurodevelopment (World Health Organization, 2018b). As the severity of traffic-related air pollution (TRAP) on child health becomes increasingly evident, it is ever more important to ensure that effective, practical strategies and interventions for mitigating and reducing potential child exposure to these harmful pollutants are identified and researched.

### 1.1 Aims & Objectives

The aim of the current study can be summarised in the following statement:

- To investigate interventions suitable to the UK context for the reduction of TRAP on the school commute, to minimise potential child exposure to these pollutants, and to provide policy recommendations for key stakeholders.

The research questions and corresponding objectives are as follows:

Q1 What are effective TRAP and exposure reduction interventions supported by evidence that are suitable for the school commute?

Objective 1: Research suitable interventions from academic and grey literature.

Objective 2: Identify solutions and strategies for the mitigation of TRAP or the reduction of potential child exposure on the school commute based on a systematic literature review and ratification from key stakeholders.

Q2 What are the current levels of TRAP in the vicinity of UK schools?

Objective 3: Identify TRAP concentrations in the vicinity of UK schools.

Q3 What is the effectiveness of the interventions on air quality and potential child exposure on school commutes?

Objective 4: Model the interventions on school case study locations.

Objective 5: Produce a series of recommendations based on the study findings.

The current research defines the ‘school commute’ as the daily period within which children travel to school during peak morning traffic. The research acknowledges that whilst a child’s commute technically begins at their own homes, an assessment of each child’s exposure to air pollution on their own commute is problematic. Accordingly, the only constant in the journey is temporal, given that all children generally arrive at the school destination at the same time, and this coincides with the busiest traffic period of each day. Due to practical limitations, the research does not assess the commute of each child beginning from their homes, nor does it assess individual exposure due to different transport modes. Rather, the research provides informed recommendations for the reduction of potential child exposure to harmful pollutants during their travel to school. The recommendations are based on the combined findings from a literature review, systematic review, stakeholder input, and dispersion modelling assessing data within the vicinity (500 metres) of the school building during the peak traffic period.

## 1.2 Novel Contribution to Knowledge

Based on the outcome of the literature review, there is currently no research that uses the findings of a systematic review of mitigation and reduction interventions in combination with comprehensive stakeholder opinion for the purposes of dispersion modelling interventions. Accordingly, the current research fills this gap by generating relevant, effective interventions with key stakeholder input to reduce potential child exposure to harmful pollutants during the school commute.

The interventions were identified based on their capacity for pollution reduction and selected using key stakeholder participation. Modelling these interventions across different school environments has value because it provides useful information regarding the application and suitability of interventions to authentic scenarios. The dispersion modelling process affirms the effectiveness of the selected interventions, already shown to be desirable by key stakeholders, to those who must implement the measures to mitigate risks to child health.

## 1.3 Methodology

### 1.3.1 Overview

The epistemological position of the research encompasses a mixed-methods approach, combining positivism and interpretivism in its methodology. The quantitative component of the current research would be traditionally considered within the context of positivism, and the qualitative element within interpretivism (Alharahsheh & Pius, 2020). The current research combines these approaches to assess the tangible effectiveness of air pollution and exposure reduction interventions within the context of key stakeholder attitudes and experiences relating to the school commute. Following an initial review of the literature, the practical methodology comprises a systematic review, stakeholder survey, case study selection, and modelling of interventions, each of which informs the subsequent research phase and overall study outcomes (see Figure 1).

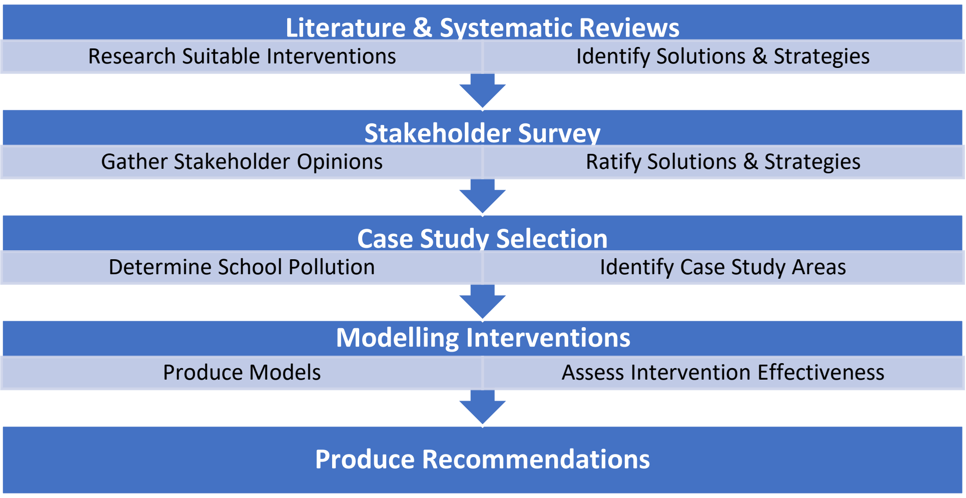

*Figure 1 Methodology overview flow diagram.*

The findings from the literature review and the systematic review provided a set of demonstrably effective interventions[1] for the reduction of air pollution or the mitigation of potential child exposure to these harmful pollutants. These findings informed the construction of a survey delivered to UK schools to assess key stakeholder attitudes and experiences of the school commute. The survey was disseminated to schools and encouraged participation from school governors, school staff members, teachers, parents, and other key stakeholders associated with schools, ultimately to determine suitable and popular air pollution reduction and mitigation strategies. The survey outcome provided a series of ratified air pollution reduction interventions suitable for the school environment. As part of the case study selection process, air pollution in the vicinity of schools in the UK was initially determined using a geographical information system (GIS). Several schools were then selected based on their suitability for the modelling process, which included data availability and appropriate geographical context. The interventions were then modelled on each area to determine the consequent air pollution reduction. The findings from all stages of the methodology have informed the construction of a series of practical recommendations for parents, teachers, and policymakers.

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[1] In the current thesis, interventions that are described as ‘demonstrably effective’ are those that have been shown in the literature to be effective in reducing TRAP concentrations or exposure to these pollutants against an established baseline.

### 1.3.2 Critical Review of Methodologies

#### 1.3.2.1 Literature & Systematic Reviews

The aim of the literature and systematic reviews was to identify research detailing effective interventions for reducing potential child exposure to TRAP, either by reducing sources of pollution or by mitigating child exposure. Additionally, the systematic review aimed to evaluate interventions in the literature based on their suitability to the school environment and to summarise the findings of the studies. The common purpose of systematic reviews is to utilise this structural process to make available research accessible to policymakers and academia (Page et al., 2021). A key strength of the systematic review is the narrow question focus with which to conduct a comprehensive and methodical evidence search. In addition, systematic reviews are characterised by their rigour of validity appraisal and objective summaries (Cook, Mulrow & Haynes, 1997). With these criteria, inferences are evidence-based, and the methodology is reproducible. For these reasons, the systematic review was appropriate for the current research to determine effective TRAP mitigation interventions for modelling in the school environment to assess their usefulness in reducing potential TRAP exposure on the school commute. Some drawbacks of the systematic review include the time commitment, which typically takes between 12 and 18 months. Other drawbacks include the typical requirement for multiple researchers to mitigate bias and the capability to assess research in other languages. The latter was considered unnecessary for the current research as the desirable research should apply to the UK environment, and it was expected that most of these studies would be written in English. Other methods were considered, including a narrative review, which would have taken less time but would not have provided the data desired for modelling the interventions.

Similarly, a meta-analysis was initially considered and would have provided a statistical combination of quantitative research results, highlighting effects with greater precision. However, it was desirable for the scope of the review to identify multiple interventions that would not be suited to this form of comparison, so the meta-analysis approach was abandoned. Whilst these other forms of review were considered, the systematic review fulfilled the criteria for the current research. However, to ensure that the time commitment was not a hindrance, the review was conducted to a strict timeline within which each stage was completed. In addition, work on the systematic review started in the early stages of the research to provide sufficient time to complete all phases. The issue of bias was a significant concern and was mitigated by adhering to a strict set of guidelines and specifications to ensure against any selection impartiality. These included the use of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) reporting framework as the widely accepted academic standard for systematic review reporting (Moher et al., 2009) and the SPICE (Setting - Population (or Perspective) - Intervention - Comparator – Evaluation) framework for research assessment (Booth, 2006). Other frameworks were considered for adaptation to the current research, such as SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, Research Type), but this is more commonly used for mixed-method research for the evaluation of outcomes relating to experiential situations of a population (Cooke, Smith & Booth, 2012). PICO (Patient/Problem, Intervention/Exposure, Comparison/Control, Outcome) was another consideration, although this is commonly used within the context of aetiology and is more suited to research questions intended to determine associations between exposures and outcomes (Schardt et al., 2007). SPICE was selected because of its usefulness in devising review questions that intend to evaluate the outcome of an intervention, making it ideal for the current review (Booth, 2006). The review methodology was registered for approval on the international prospective register of systematic reviews (PROSPERO) (Sideri, Papageorgiou & Eliades, 2018), and the ROBINS-I (Risk Of Bias In Non-randomised Studies of Interventions) tool was employed (Sterne et al., 2016) to check the study selection for bias. These tools were selected based on their association with the Cochrane review protocols. They were deemed appropriate because they are commonly used for systematic reviews and meta-analyses for health-outcome-based intervention research and provide a widely accepted standard in academia (Moher et al., 2010). Reviews of this type have been used extensively and effectively for assessing air pollution and health impacts (Yang et al., 2020; Quarato et al., 2017), child health (Parasin, Amnuaylojaroen & Saokaew, 2021; Bekkar et al., 2020), effective cognitive function (Chandra et al., 2022; Lu et al., 2020), and mitigation interventions (Chaudhuri & Kumar, 2022; Diener & Mudu, 2021).

#### 1.3.2.2 Stakeholder Survey

The findings of the literature and systematic reviews informed the development of a stakeholder survey. The aim of the survey was to gain information to determine a set of suitable air pollution reduction and mitigation interventions that were shown to be effective by the literature and systematic reviews but were also popular amongst the key stakeholders who had to implement them. The survey was delivered to UK schools via their publicly available email contacts to assess stakeholder attitudes and experiences towards air pollution at their schools and on the school commute.

It was important to ensure that the stakeholders were suitably cohesive in their experiences and roles for the justification of the study (Lam et al., 2019; Totlandsdal et al., 2007; Sanderson et al., 2006; Darnall & Jolley. 2004). The survey was sent to schools in England, encouraging them to disseminate the questionnaire link via their channels. The participants were requested to contribute based on their proximity to the issues at hand and included members of school governor boards, parents, teachers, local council representatives, and parent/teacher associations. As is the case in similar studies (Cori et al., 2020; Bloomberg et al., 2011; Gauderman et al., 2004; Stevens, Cullinan & Colvile, 2004; Chai et al., 2001), schoolchildren were not included in the survey as the study considered the parental viewpoint suitably representative of the children and their involvement with associated issues, such as the selection of transport modes to school.

Stakeholder surveys have been used effectively in this manner for similar research aims in the literature, including determining the respiratory health effects of air pollution (Laumbach & Kipen, 2012), understanding stakeholder needs to improve understanding of the health effects of air pollution (Brunekreef & van Bree, 2004), to gather stakeholder opinions for end-user needs regarding air pollution and health (Amann et al., 2002), to conduct broad stakeholder consultation to identify interventions for improving noise pollution and health impacts (Black & Black, 2009), and to probe policymakers and environmental organisations to identify health and air pollution requirements (Downs et al., 2006).

Due to the volume of responses, the survey data were categorised into parents and teachers for the analysis, which provided a more manageable assessment method but was also representative of the main groups involved in the school commute. Opinions and experiences from the participating stakeholders were used to identify interventions for mitigating and reducing child exposure to harmful pollutants on the school run. The resultant interventions were identifiably effective in the literature and deemed suitable for implementation in the school environment or the school commute by the key stakeholders.

#### 1.3.2.3 GIS & Case Study Selection

To provide a foundation upon which to select school areas as case studies for dispersion modelling of interventions, a GIS was constructed. The GIS comprised a database of TRAP and deprivation at UK schools. GIS facilitates the generation of maps using a variety of data sources for visualisation and interrogation of the data, making it an ideal tool for this phase of the current research. GIS has been used effectively in research concerning air pollution modelling (Hoek et al., 2008; Gulliver & Briggs, 2005; Pummakarnchana, Tripathi & Dutta, 2005), and to determine locations (Guttikunda & Calori, 2013; Gulliver & Briggs, 2011) and identify demographics (Vienneau, De Hoogh & Briggs, 2009) that are at a greater risk of exposure. Pollution Climate Mapping (PCM) data provided by Defra was used to populate the GIS with background air pollution concentrations. PCM data has been used effectively for the assessment of potential air pollution exposure (Hannam et al., 2014; Rushworth, Lee & Mitchell, 2014) and modelling scenarios for air quality strategies (Miranda et al., 2015; Oxley et al., 2013; Oxley, Apsimon & Valiantis, 2011).

#### 1.3.2.4 Dispersion Modelling of Interventions

Once case study regions were selected, the most popular and effective interventions, based on the findings of the literature review, the systematic review and the stakeholder survey, were modelled using proprietary atmospheric dispersion modelling software (ADMS-Roads version 5.0) to determine their effectiveness. ADMS-Roads dispersion modelling software was considered appropriate for the current research based on its position as an industry standard due to its effectiveness for modelling road traffic pollution. In addition, its traffic volume parameterisation makes it particularly suitable for modelling pollution reduction interventions. Similar modelling approaches have been used effectively to determine TRAP, commonly considering spatiality with respect to monitoring sources (Vardoulakis et al., 2005; McHugh, Carruthers & Edmunds, 1997), topography (Jeanjean et al., 2016; Crouse, Goldberg & Ross, 2009), and source apportionment (Liu et al., 2015b; Lawrence et al., 2013).

## 1.4 Thesis Outline

The thesis chapters reflect the sequence of each research stage detailed in the flow diagram (Figure 1). This non-traditional thesis structure permits the presentation of methods and results of each section in turn. Adopting this sequential approach is preferable to the more traditional thesis structure because it facilitates the summary and development of the findings from each distinct methodological undertaking (Figure 1).

### Chapter 1: Introduction.

The current chapter introduces the issue of TRAP on the school commute and potential child exposure to these harmful pollutants. The research objectives are stated with the project aim and corresponding research questions, and the forthcoming thesis content is summarised. Some background literature is presented with a focus on TRAP and child health and its relation to the thesis methodologies.

### Chapter 2: Literature Review.

The review of literature is presented in Chapter 2, which outlines the existing research context of the current research, detailing the nature of TRAP, its effects on child health, the susceptibility of children as an at-risk group to air pollution, policy contexts, and monitoring networks and practices. A review of determining exposure is expounded, followed by salient research on exposure mitigation, prevention interventions, and pollution reduction strategies.

### Chapter 3: Systematic Review.

A systematic literature review was constructed using the PRISMA evidence-based minimum requirements for reporting systematic reviews (Moher et al., 2009). This targeted literature review researched academic and grey literature to find suitable interventions for reducing traffic or mitigating potential TRAP exposure. Chapter 3 describes the systematic review in terms of its methodology and findings.

The review identified salient research on demonstrably effective interventions that can be applied to the school commute context. The findings are described, and a synthesis of the primary studies is presented. Based on the systematic review findings, a survey was subsequently administered to key stakeholders.

### Chapter 4: Stakeholder Survey.

The stakeholder survey is described in terms of its methodology and findings. The survey was developed based on the literature review and systematic review findings and then disseminated to key stakeholders throughout UK schools. The survey gathered evidence of opinions and experiences from those involved with the school commute. The questionnaire responses were used to determine what were considered to be the most effective or appropriate mitigation strategies and interventions to reduce potential child exposure to TRAP on the school commute.

The survey findings are presented in the categories of teachers and parents, representing the two key affected groups involved in the school commute. Interventions identified as effective in the findings of the literature and systematic reviews were assessed for their popularity among the stakeholders. The interventions that were both popular among the stakeholders and were suitable for the dispersion modelling process are identified.

### Chapter 5: Case Study Selection.

Determination of pollution in the vicinity of UK schools is conducted and the findings are described. A GIS (Geographical Information System) was produced to identify TRAP in the UK and the concentrations of $NO_2$ at all schools.

The GIS used PCM data provided by Defra. The mapped PCM data in the GIS provided a searchable system through which school locations suitable for intervention modelling in England were identified. This approach has been justified in similar studies which assessed pollutant exposure (Forbes et al., 2009) and modelled air quality limit values (Oxley et al., 2009). $NO_2$ concentrations can be used as an indicator of traffic emissions (Janhäll, 2015; Tonne et al., 2008), and were used for the identification of suitable schools. A series of conditional criteria was applied to the areas with the greatest numbers of affected schools to filter the results, producing several schools that matched the requirements for modelling the interventions identified by the questionnaire. The selection process for suitable school locations and interventions for modelling is described. The interventions for modelling are described based on the findings from Chapters 2 and 3.

The method for the selection of school locations is explained and uses a filtration process based on the generated GIS dataset.

### Chapter 6: Intervention Modelling.

The identified interventions were modelled on the case study schools selected in the previous phase (detailed in Chapter 5) using dispersion modelling. A 500-metre area surrounding each school was initially modelled and verified. Upon satisfactory verification of each model, interventions were modelled in each case study region. The modelling and verification process is described, and the findings are detailed.

### Chapter 7: Discussion & Conclusion.

A discussion of the research is presented in Chapter 7. The research questions and objectives are restated in the context of the findings, which are summarised, and the results are interpreted within the context of their application. The limitations of the research are acknowledged, and recommendations are made for parents, teachers, and policymakers to implement interventions. Opportunities for future research based on the findings are described.

The thesis closes with a restatement of the research and a reiteration of its key points. The work’s relevance and significance are then expounded upon with some concluding comments on future directions.

## 1.5 Covid-19 Impact Statement

Given the onset of the Covid-19 pandemic of 2020, the current statement forms a summary of research activities that were initially planned but have changed as a consequence of these events and the extent to which it has been necessary for the work to be adapted under these circumstances. The main methodological facets of the current research affected by the pandemic are (1) the adoption of a Delphi approach for the survey and (2) the dissemination of the questionnaire in the autumn term of 2020.

The originally planned Delphi approach would have ratified the design of strategies for the provision of effective mitigation interventions for potential child exposure to air pollution supported by stakeholders via a focus group followed by an iterative process of no fewer than three rounds of questionnaires, working towards achieving consensus (Beretta, 1996). However, given the disruption to schools and educational services as a consequence of the pandemic and related measures, it was considered that a single questionnaire delivered to a broader number of potential respondents would be more appropriate. In addition, the delivery of the questionnaire to individual key stakeholders was replaced with a broader approach, which delivered the questionnaire to all schools in England via their public email addresses. This approach was considered preferable to the Delphi, which would have required a more significant time commitment at a point when people were unusually busy and preoccupied by the pandemic. The revised approach provided the opportunity for gatekeepers to disseminate the questionnaire to interested parties and parents through their own usual and trusted channels. It was anticipated that this method could achieve a larger uptake, and the adapted approach could match the contribution of the Delphi method given its maximisation of uptake and dissemination to a broader catchment of stakeholders. The volume of data accrued from the survey is considered to have achieved this aim. The adjusted approach received ethical approval.

The circumstances of the pandemic and its effects on the operation of schools, and uncertainties around their opening, also led to a later than anticipated delivery of the survey and the gathering of primary data for the current research. This situation was mitigated by the delivery of a single questionnaire. The delivery time period of the questionnaire also had to acknowledge the circumstances of the respondents and the uncertainties they faced.

In addition to the initially planned methodology adjustments, a case study was constructed to highlight the nature of the Covid-19 pandemic measures and their effects on air pollution around schools in England. In order to demonstrate what was achievable if public behaviours shifted towards a greater reduction of non-essential travel, a study was carried out to identify the reduction of TRAP around schools in England as a consequence of the national stay-at-home order of 2020 (also termed “lockdown”) in response to the Covid-19 pandemic (Brown, Barnes & Hayes, 2021). This research article has been included as an addition to the existing methodology to provide the context within which the research has been carried out and to acknowledge the effects of the stay-at-home orders, reductions in non-essential travel and closure of schools (see Appendix A).

# 2.0 Literature Review

## 2.1 Traffic-Related Air Pollution

### 2.1.1 Overview

As is the case with other forms of air pollution, traffic-related pollution can be considered in terms of gaseous pollutants and particles. Traffic exhaust fumes can contain many pollutants, including carbon monoxide (CO), carbon dioxide ($CO_2$), sulphur dioxide ($SO_2$), nitrogen oxides ($NO_X$ and $NO_2$), particulate matter ($PM_{10}$ and $PM_{2.5}$), and others (Amaral et al., 2021). These pollutants are produced by combustion, so they can be found in the exhaust fumes of vehicular traffic. Particulate matter can also comprise non-exhaust pollution, such as brake and tyre wear and resuspended road dust (Grantz, Garner & Johnson, 2003).

Arguably the most important of these components are nitrogen oxides ($NO_X$ and $NO_2$) and particulate matter ($PM_{10}$ and $PM_{2.5}$). Oxides of nitrogen and particulate matter are both pollutants that are harmful to human health (Kim, Kabir & Kabir, 2015). In cities where traffic levels are high, concentrations of these pollutants can be elevated (Karagulian et al., 2015).

Within the UK context, a report by the Committee on the Medical Effects of Air Pollutants (COMEAP) (Harrison, 2018) maintains that due to exceedances in urban areas of the UK, residents are exposed to illegal concentrations of $NO_2$. The report also cites evidence that links exposure to $NO_2$ to a range of severe health effects, concluding that this evidence has strengthened over recent years. In addition, the report argues that whilst $NO_2$ can perform to some extent as an indicator of the effects of other traffic-related pollutants, given the extent of the epidemiological evidence now available, it is pertinent to regard $NO_2$ as causative of some of the health impacts that have been associated with it in related research (Harrison, 2018).

Air pollution in the UK has also been highlighted as a significant threat to child and adolescent health (Clark, Coll-Seck & Banerjee, 2020). The inquest into the 2013 death of 9-year-old Ella Adoo-Kissi-Debrah concluded that her death was caused by ‘asthma contributed to by exposure to excessive air pollution’ (Barlow, 2021). Ella was exposed to high levels of pollution near her London home and became the first person in the UK to have air pollution listed as a cause of death on her death certificate (Renshaw et al., 2022). Nearly a decade later, children living on or near busy main roads are still exposed to toxic air pollution. Among many other adverse health effects, these children can experience stunted lung growth of up to 14% and a 10% increased risk of lung cancer (Williams et al., 2019).

### 2.1.2 Nitrogen Oxides

Nitrogen oxides ($NO_X$) are a class of highly reactive gases that are produced when fuel is burned at high temperatures (Hill & Smoot, 2000). $NO_X$ emissions can come from both natural and human-made sources, but they are most associated with fossil fuel combustion activities such as power generation, industrial furnaces, and vehicle engines. While small amounts of $NO_X$ are necessary for the proper functioning of the atmosphere, high concentrations of these gases can be harmful to human health and the environment. $NO_X$ emissions can contribute to the formation of smog and acid rain and exacerbate respiratory conditions such as asthma (Beamer, 2019; Boningari & Smirniotis, 2016). Various vehicular control technologies have been developed to reduce the negative impacts of $NO_X$ emissions, including low-$NO_X$ burners and catalytic converters (Javed, Irfan & Gibbs, 2007).

Nitric oxide (NO) is an important pollutant of the nitrogen species emitted from fossil fuel combustion. NO rapidly reacts with ground-level ozone to form nitrogen dioxide ($NO_2$), nitric acid, and nitrate particles (Boningari & Smirniotis, 2016). Because of these ongoing and often continuous reactions, $NO_X$ is used as a term to represent all oxides of nitrogen. $NO_2$ is one of several reactive gases that make up $NO_X$ and is primarily produced by industrial processes and vehicular emissions. Elevated urban $NO_2$ is a consequence of road traffic and other fossil-fuel combustion sources, and the road transport sector provides a significant contribution to UK emissions (Brown, Barnes & Hayes, 2021). For this reason, when there are no nearby prominent industrial sources, it is common for $NO_2$ to be used as a proxy in the identification of vehicular emissions due to the constant state of reaction associated with these chemicals (Hamra et al., 2015).

Inhalation of elevated concentrations of $NO_2$ can lead to a range of adverse health effects. Short-term exposure can aggravate existing respiratory problems, like asthma (Hwang et al., 2005) and can lead to increased hospitalisation cases (Kampa & Castanas, 2008). Longer-term exposure has been linked to a greater susceptibility to respiratory system infections (Ryan et al., 2013). As is the case with particulate matter (PM), children, the elderly, and people with existing respiratory illnesses have been identified as groups at the greatest risk (Guarnieri & Balmes, 2014).

### 2.1.3 Particulate Matter

Major fossil fuel constituents from which PM is derived include nitrate, sulphate, chloride, ammonium, and elemental and organic carbon (Moreno, Jones & Richards, 2004). Smaller particles can become deposited in the lower respiratory tract, often leading to more severe health consequences (Asri et al., 2021). Accordingly, the focus of related regulation is on the aerodynamic diameter of PM, which is classed as less than 10µm ($PM_{10}$), or less than 2.5µm ($PM_{2.5}$). $PM_{10}$ and $PM_{2.5}$ concentrations are commonly reported as micrograms per cubic metre of air ($\mu g/m^3$). PM that is not fossil-fuel-derived, such as dust blown by winds, usually falls above the $PM_{10}$ criterion and is consequently filtered in the upper airway (Ebi & McGregor, 2008).

Human exposure to PM can cause short-term health problems, including irritation of the eyes, nose and throat, respiratory issues, and shortness of breath (Kim, Kabir & Kabir, 2015). Longer-term issues associated with exposure include the worsening of pre-existing conditions such as heart disease and asthma, and can negatively affect heart, lung, and brain function (Ebi & McGregor, 2008).

### 2.1.4 Traffic Contributions to Air Pollution

Many studies worldwide have focused on determining traffic contributions to background air pollution concentrations. Urban $NO_2$ and PM levels are heavily comprised of background concentrations (Laumbach & Kipen, 2012; Hoek et al., 2002; Künzli et al., 2000). Local sources of air pollution are often a relatively small component of measured concentrations (De Nazelle et al., 2012; Beleen et al., 2009; Zhou & Levy, 2007).

In urban areas, traffic-related air pollution (TRAP) is a major source of air pollution. Studies have demonstrated that pollution is greater during hours of commuting to and from work and school (Wong et al., 2021; Engström & Forsberg, 2019; Liang et al., 2019; Alvarez-Pedrerol et al., 2017; Liu et al., 2015a; Ragettli et al., 2015; Zuurbier et al., 2011; Zuurbier et al., 2010).

Proximity to major road sources is also an important factor in concentration exposure, with an inverse relationship between distance from traffic and concentration levels (Zou et al., 2020; Fecht et al., 2016; Puett et al., 2014; Su et al., 2009; Su, Jerrett & Beckerman, 2009; Bignal et al., 2007; Schikowski et al., 2005; Roorda-Knape et al., 1999).

## 2.2 Traffic-Related Air Pollution & Child Health

### 2.2.1 Overview

As an at-risk group, children are more susceptible to the harmful effects of air pollution and other adverse environmental exposures (Diapouli, Chaloulakou & Spyrellis, 2007; Salvi, 2007). The ways in which children and their developing physiologies interact with their environment mean that they generally receive a higher level of exposure (Goldizen, Sly & Knibbs, 2016). In this respect, the developmental stage of childhood has a profound effect on the consequences of air pollution exposure.

Determining which pollutants have specific adverse effects on human health is complicated in epidemiological studies due to the tendency of pollutants from the same source (such as such as road traffic) to be interrelated (Kulkarni & Grigg, 2008; Pekkanen & Pearce, 2001). When an intervention reduces all emission components, this is not a problem. Such interventions include traffic reduction measures, such as congestion charging or clean air zones (see Rashid et al., 2021). However, if only one component within the pollutant mix is targeted by an intervention (such as diesel particulate filters), then this poses an issue. Accordingly, data are required from a range of studies, including human exposures to specific pollutants, exposure markers to specific sources of emissions, and molecular and cellular responses to exposures in vitro (Kulkarni & Grigg, 2008).

Daily background pollutant concentration variations are often used in studies to determine the short-term effects of exposure (Ma et al., 2020). In these studies, children are commonly monitored intensively for a short period. This study design may attempt to identify a correlation between temporal changes in pollutant concentrations and changes in health. This correlation evidences short-term health effects due to pollutant exposure. However, this study design cannot determine long-term air pollution effects at a population level, such as the development of cancer or asthma.

To determine and assess the long-term effects of pollutant exposure, large epidemiological datasets are used in combination with long-term exposure data (Rojas-Martinez et al., 2007). A common method for the assessment of long-term exposure to TRAP is to use the distance from the home to main roads (Rushworth, Lee & Mitchell, 2014). Refinements to this procedure include the addition of traffic data and meteorological data such as wind speed and direction (Cesaroni et al., 2013). Drawbacks to measuring distances from homes to roads include disregarding personal exposure for the individuals. Another common method for the assessment of long-term exposure is to discount local exposure differences and only analyse the effect of background pollutant levels. This approach can also be achieved using data for individuals from geographically distinct populations that are representative of a range of background exposures (see Oxley et al., 2009).

### 2.2.2 Child Susceptibility to Air Pollutants

Children are commonly considered a susceptible population when setting air pollution exposure limits. Accordingly, children require additional uncertainty factors when assessing exposure, which is usually ascertained by dividing the safe limit for adult exposure by 10 or 100 (Kulkarni & Grigg, 2008). The greater metabolic rate of children presents the most apparent difference between the lungs of children and adults, resulting in a greater number of breaths per minute (Kelly, 2003). The increased respiration increases the airway exposure to inhaled pollutants, which can also vary the standard rate of lung function increase in children’s growing lungs. In addition, many air pollutants are oxidants. Accordingly, the pro-oxidant activity of particles and gases is also closely correlated with inflammatory activity in cell and animal studies (Salvi, 2007).

### 2.2.3 Infection

Comparatively less attention has been paid to the effects of air pollution on bacterial and infection vulnerability. Some of the existing research includes a study conducted by Fusco et al. (2001) in Rome, which identified a 4% increase in child (up to 14 years old) hospital admissions due to acute respiratory infections caused by $NO_2$ exposure. Another study by Barnett et al. (2005) reported that in Australia and New Zealand, increased hospital admissions for acute bronchitis and pneumonia in children under four years old were associated with high concentrations of $PM_{2.5}$ and $NO_2$.

Compelling data has been produced from developing world studies, where child exposure to high PM levels is more common due to a combination of exposures to the combustion of crude fossil fuels such as coal and biomass, and high TRAP concentrations (Romieu et al., 2002). At the turn of the century, air pollution exposure in the developing world was estimated to be responsible for over two million yearly deaths (Bruce et al., 2000), and a significant proportion of these fatalities were children under five years old (Smith et al., 2000). These deaths were predominantly due to exposure to acute lower respiratory tract infection as a consequence of particulate inhalation (Ezzati & Kammen, 2001). Innate immune defences to bacterial pathogens can be directly attenuated by TRAP exposure or indirectly by reducing anti-viral defences, increasing vulnerability to secondary bacterial infection (Grigg, 2007).

### 2.2.4 Lung Function

The adverse effects of air pollution exposure on child respiratory health are compelling, and study findings of the adverse effects on lung function are among the most robust. A broad range of longitudinal and cross-sectional epidemiological studies suggest that air pollutants as a consequence of fossil fuel combustion negatively affect the normal lung function of children (Schultz, Litonjua & Melén, 2017; Gauderman, et al., 2007; Gauderman, et al., 2004; Ward & Ayres, 2004; Horak et al., 2002).

Gauderman et al. (2007) examined data from a cohort of 1759 children for over eight years. The children were an average age of 10 years and were based in California, USA. Differences in background concentrations of $O_3$, $NO_2$, and PM in 12 communities were used as long-term exposure markers. Repeated spirometric measurements were taken to determine lung function growth. A reduction of forced expiratory volume in one second (FEV1)[2] was associated with inhalable PM (P=0.04) and $NO_2$ exposure, with no significant effects found for $O_3$. The identified reductions in lung function growth due to air pollution exposure also resulted in reduced attainment of lung function in adulthood. The estimated proportion of 18-year-olds with an observed-to-expected FEV1 ratio of <80% was 7.9% in communities with high exposure, compared with 1.6% in communities with low exposure. A similarly large cohort study conducted in Mexico City, Mexico, found significant associations between FEV1 deficits and forced vital capacity growth and $NO_2$, $PM_{10}$, and $O_3$ (Rojas-Martinez et al., 2007).

Whilst determining the most important components of pollution is problematic due to their inter-relation, PM is considered among the most toxic to human health, and the severity of health effects is inversely related to particle size (Kulkarni & Grigg, 2008). The long-term effects of lung function growth reduction remain largely undefined, but there are concerns that children who live in areas with high levels of pollution are more likely to suffer increased mortality and morbidity should they develop respiratory diseases (Kulkarni et al., 2006).

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[2] Forced expiratory volume, or the volume of air that can be forced from the lungs, in one second.

However, Avol et al. (2001) have asserted that a reduction of lung growth associated with air pollution appears to be partially reversible. Their community study based in Southern California found that children who moved into higher and lower air pollution areas demonstrated differing behaviours. Those who moved to areas with lower exposures to $PM_{10}$ showed a significant maximal mid-expiratory flow (MMEF) growth increase, particularly if they remained in the area for more than three years.

Mechanisms for the impairment of lung growth induced by pollution remain debated. An early systematic review of panel studies of children between 6 and 11 years old showed that short-term ambient PM increases were associated with significant changes in lung function (Ward & Ayres, 2004).

### 2.2.5 Respiratory Symptoms

Small but significant reductions of lung function in otherwise healthy children have been described in terms of limited clinical significance, but there remains substantial evidence from panel and cohort studies that air pollution is associated with increased levels of respiratory problems (Nazar & Niedoszytko, 2022; Manisalidis et al., 2020; D’amato et al., 2016; Mabahwi, Leh & Omar, 2014; Siddique, Ray & Lahiri, 2011; Cesaroni et al., 2008; Kumar et al., 2008). An early summary of available evidence for asthma and allergies in children concluded that there was sufficient evidence to link air pollution to increased incidences of coughs, exacerbated asthma, and reduced lung function (World Health Organization, 2005). Guarnieri & Balmes (2014) focused on epidemiological and experimental clinical studies and determined that from a mechanistic perspective, there is a strong likelihood that air pollution exposure leads to oxidative airway injury, which then leads to inflammation, remodelling, and increased sensitisation. Instances of asthma have also been linked to exposure to several pollutants (Yang et al., 2020). Whilst measures of individual exposure are comparatively lacking, these studies demonstrate consistent support for the association of fossil fuel pollutants with increased respiratory symptoms in children.

Pierse et al. (2006) studied a cohort of 4400 preschool children and reported a higher prevalence of coughs without colds with increased PM pollution exposure. The PM was locally generated and predominantly from nearby roads. Venn et al. (2001) conducted a similar study in the UK and found that children who lived within 150 metres of a main road had a greater risk of wheeze (1.08), with the most significant risk localised to those within 90 metres of the road. In earlier studies, some inconsistencies were found concerning the adverse effects of living near a road (Wilkinson et al., 1999; Livingstone et al., 1996). These inconsistencies were considered to be due to the inadequacy of using distance from roads as a marker for exposure to local air pollution sources, particularly among schoolchildren who spend significant periods of time away from their homes. Later studies combined modelled exposure to local air pollution sources at home and school addresses with measured background levels to clarify these early inconsistencies (Kulkarni & Grigg, 2008).

Another method to assess air pollution exposure and health effects is to identify an association between temporal changes in background air pollution levels and changes in health variables. An early study found that daily fluctuations of background $PM_{10}$ levels were associated with acute respiratory child hospital admissions, school absences, and increased asthma medication usage (Bascom et al., 1996). Similarly, Lee et al. (2006) correlated daily mean pollutant concentrations ($PM_{2.5}$, $PM_{10}$, $NO_2$, $O_3$, and $SO_2$) with asthma hospital admissions in children under 18 years old. The study found a significant increase in asthma admission rates with all pollutants except $SO_2$.

Air pollution as a cause of respiratory problems, including asthma, has also been assessed in the context of early years TRAP exposure. Brauer et al. (2007) studied a birth cohort of 4000 for the first four years of their life and assessed TRAP and respiratory symptom development, finding increased ratios for both wheeze (1.2) and diagnosed asthma cases (1.3). McConnell et al. (2002) conducted a similar study in California and found that of 3535 children followed up for five years, 265 reported new asthma diagnoses, and this was over three times greater for children who undertook regular sporting activities.

### 2.3 Determining Exposure

Determining TRAP concentrations in any given environment is an essential step for the development of effective interventions. Determining child exposure to these pollutants presents additional challenges. Epidemiological studies have faced common problems related to the measurement of multiple confounding factors and pollutant exposure. Exposure is dependent on patterns of activity, which can demonstrate significant variability between individuals who live in the same geographical area (Khan et al., 2018). In addition, it has been argued that indoor pollutants should be considered when exposure data are interpreted (Klepac et al., 2018). Due to ethical considerations, controlled studies of child exposure to pollutants cannot be conducted, so exposure biomarkers are required. Such biomarkers can be derived from a more comprehensive understanding of the molecular and cellular mechanisms for the disparate health effects of air pollution in children.

The substantial proportion of time spent by children at school is self-evident. Accordingly, determining the extent of child exposure to TRAP at and around schools has received increasing attention in the literature. Children are more vulnerable to air pollution than adults, and studies have accordingly focused on related health issues (Mejía et al., 2011; Bateson & Schwartz, 2004). Children are a vulnerable demographic due to their developing physiological traits and behaviour. For example, children tend to have higher rates of physical activity, resulting in greater levels of air pollution inhalation than adults (Trasande & Thurston, 2005). This factor could influence child exposure in playgrounds when compared to the classroom (Minguillón et al., 2015) or at different times of the school day (Rivas et al., 2014).

The importance of air pollution mitigation measures was also assessed by Sá et al. (2017), who argued that children were a priority given their status as an at-risk group and the time they spend at school. The research aim was to evaluate mitigation measures implemented in and around nursery and primary schools for the improvement of air quality. Continuous measurements of several pollutants, including particulate matter and $NO_2$, were performed in two campaigns before and after implementing low-cost mitigation measures in three schools in the Porto district of Portugal. The mitigation measures were evaluated by comparing concentration measurements in both mitigation campaigns. The most consistently effective measure was raising awareness among school coordinators, teachers, collaborators and students about the influence and importance of indoor air quality for children and schools. Education in this respect included good hygiene practices, ventilation and cleaning, and the characteristics of cleaning products and craftwork materials, such as paints and glues, for the improvement of health. The variability of air pollutants across cities has also been demonstrated, in addition to the variability of daily exposure, which is identified as a factor that should be accounted for in the study of human exposure (Minguillón et al., 2015). Elbayoumi et al. (2014) also assessed the distinction between indoor and outdoor pollutant concentrations at schools. The impact of CO concentrations on the health of children was monitored in 36 naturally ventilated classrooms throughout 12 schools in the Gaza Strip, Palestine. The study measured concentrations with electrochemical analysers over the autumn, winter, and spring of 2011 and 2012. The measured concentrations showed that levels of CO were lower indoors than outdoors and also demonstrated seasonal variation.

Indoor CO was 1.5 times greater than spring and three times greater than autumn. The levels recorded in the study were below WHO guidelines, although they were still identified as posing a risk to the health of students and their academic performance.

Whilst comparative assessments of pollutant concentrations may be more common in the literature, a relatively small number of UK studies attempt to understand potential child exposure to poor air quality on the school commute, during which children are exposed daily to peak traffic. Daily background pollutant concentration variations were used in early panel studies to determine the short-term effects of exposure (Brunekreef & Hoek, 1993). In these studies, children were monitored intensively for a short time period or periods. This study design attempts to identify a correlation between temporal changes in pollutant concentrations and changes in lung function. Such a correlation indicates a short-term health effect due to pollutant exposure. However, this study design cannot determine long-term air pollution effects at a population level, such as the development of cancer or asthma. A follow-up study by Gauderman et al. (2007) also highlighted the importance of air pollution generated from local sources. The study found that, independently of the background pollution levels, children who lived within 0.5 km of a major motorway had a reduction of annual growth of FEV1 and a decreased MMEF rate. Reduced lung growth was associated with background air pollution levels (affecting all children within the geographically determined region) and locally generated pollution (only affecting children living near the road sources).

### 2.4 Pollution at Schools

Concurrent research has supported the mitigation of potential child exposure to TRAP at school and on the school commute and includes efforts as diverse as summaries of evidence on exposure and academic performance (Stenson et al., 2021), providing an overview of concentrations at schools (Osborne et al., 2021b) and child protection against neurodevelopmental harms (Rivas et al., 2018). The adverse effects of road traffic on air quality in cities throughout the UK and Europe have been well-documented. Many studies have assessed the quality of air around and within school buildings (Crilley et al., 2013; Raysoni et al., 2013; Wichmann et al., 2009) and the inequalities associated with childhood exposure to air pollution have also been highlighted (Stuart & Zeager, 2011).

The influence of road traffic volume is also significant when considering potential child exposure (Jain et al., 2020; Korsavi, Montazami & Mumovic, 2020; Smart et al., 2020;

Roberts et al., 2019). Traffic volume is higher during weekdays than on weekends and higher in central urban regions than in suburban areas (Rangel et al., 2022), and the distance of school buildings to major roads can also determine emission influence (Suhaimi, Jalaludin & Abu Bakar, 2021). Factors such as these are essential to consider when planning or improving urban areas or developing effective pollution reduction and mitigation interventions. Other possible determining factors include the impact of private car use for child transportation to school, although the quantification of this is often problematic due to the simultaneity of this event and the general daily rush hour periods (Jain et al., 2020). This coincidence was explored in Brown, Barnes & Hayes (2021), which examined the effects of non-essential travel reduction as a consequence of the UK stay-at-home order (or lockdown). Significant $NO_2$ reductions were identified during the first month of the lockdown around schools at both background and traffic sites (-35.13% and −40.82%, respectively).

Geographical and meteorological contexts are also meaningful, such as the influence of sandy or dusty school playgrounds and their effect at congregative times. During these times, hourly PM concentrations can be many times higher than average nightly concentrations, with the influence of sandy playgrounds diminishing with increasing distance (Minguillón et al., 2015).

Additionally, children can carry mineral particles indoors, increasing ambient concentrations (Burtscher & Schüepp, 2012). Child activity can also readily resuspend particles due to their size and profusion in playground sands. These factors, whilst arguably more relevant to cities with a Mediterranean climate, are indicative of the requirement for a broader outlook in the current research regarding the development of suitable mitigation and reduction interventions based on comprehensive, contextual data. For example, a study by Geiss et al. (2011) involved the measurement of VOCs between 2003 and 2008 in schools, kindergartens, and other public buildings throughout Europe. The geographic locations of the buildings were all within the European Indoor Air Monitoring and Exposure (AIRMEX) study frame. Analysis of over 1000 measurements demonstrated that indoor sources prevailed for the majority of the VOCs in question. Concentration ratios of indoor and outdoor sources indicated that outdoor air penetration was characterised by significantly higher pollution levels for the south of Europe when compared to the north.

Whilst child exposure to pollution at school requires local-level interventions, it remains an issue of global concern. Concentrations of TRAP at schools have been identified worldwide utilising a broad range of methods. For example, research conducted by Raysoni et al. (2013) investigated spatial and temporal heterogeneity of TRAP at schools within the El Paso area of Texas, USA. The research was undertaken as part of a study of TRAP's impact and health effects on children with asthma. All the schools studied were located in high-traffic areas apart from one control school. Concentrations of $PM_{2.5}$ and $NO_2$ are commonly used as indicators of traffic emissions (see Janhäll, 2015) and were measured for 13 weeks at each location. Outdoor measurements were simultaneously taken from within classrooms and from elevated positions, such as fences or walls near open spaces. The data was primarily used for comparison between indoor and outdoor concentrations, so limitations associated with the positioning of monitors and the monitoring period were alleviated. Problems arising from data collection or availability are common in the literature (Cheng & Phillips, 2014; Gopalakrishnan & Ganeshkumar, 2013). The BREATHE (BRain dEvelopment and Air polluTion ultrafine particles in scHool childrEn) project was a dedicated initiative funded by the European Union (EU) to address this issue. The project provided a comprehensive dataset for the study of urban air pollution impacts on child cognitive development. The data collection focused on school exposure, and a vital element of the study involved an extensive campaign to measure aerosols at 39 primary schools in metropolitan Barcelona. The concentration collection attempted to characterise the exposure of children to TRAPs. Nitrogen Dioxide ($NO_2$), Ultrafine Particles (UFP), $PM_{2.5}$, and Polycyclic Aromatic Hydrocarbons (PAHs) were selected as representative of TRAPs and were measured during two week-long campaigns. Measurements were taken simultaneously in school courtyards and classrooms. A study conducted within the framework was conducted by Minguillón et al. (2015), who assessed the impact of road traffic and sandy playgrounds on the air quality around 39 schools in Barcelona, Spain. An intensive campaign over one month took place in four schools around which $PM_1$, $PM_{2.5}$, $PM_{10}$, BC (Black Carbon), and NO concentrations were recorded daily. The findings indicated that NO, BC, and $PM_X$ concentrations were more significant in schools in closer proximity to traffic, with daily patterns reflecting peak traffic times. NO concentrations decreased as the distance from the road increased. The study also found that the influence of road traffic on ambient pollutants was reduced at weekends.

## 2.5 Policy Context

Concentrations of key outdoor air pollutants in the UK are controlled by a set of regulations that control human exposure by legislating that concentrations must not exceed specific limit values (Defra, 2010).

At the local level, local authorities (LA) in the UK are required to review their air quality and designate air quality management areas when improvements are considered necessary (Defra, 2021a). This is commonly achieved using the national Automatic Urban and Rural Network (AURN) (Defra, 2022a).

It is important for the current research to consider contemporary national policy to identify areas in which improvements can be made for the protection of child health against harmful TRAPs within environments they frequently occupy, such as the school commute.

### 2.5.1 Monitoring Networks

#### 2.5.1.1 Automatic Urban & Rural Network

The Automatic Urban and Rural Network (AURN) is the most extensive monitoring network in the UK (Defra, 2022a). The network comprises automatic air quality monitoring stations that provide high resolution data made freely available to the public through Defra and includes hourly measurements of particulate matter ($PM_{10}$ and $PM_{2.5}$), oxides of nitrogen ($NO_X$), nitrogen dioxide ($NO_2$), ozone ($O_3$), and carbon monoxide (CO). The network is used for compliance reporting against the Ambient Air Quality Directives. Some of the critical purposes of the AURN network are to ensure that air quality targets are met, to provide data for UK Air Quality Strategy reviews and assessments, to assess policy effectiveness, and to identify air pollution concentration trends.

#### 2.5.1.2 Diffusion Tubes

Diffusion tubes, or diffusive samplers, are $NO_2$ monitors that are relatively inexpensive and small in size, comprising a plastic tube with an open end and a gauzed end. The gauze contains a chemical that absorbs $NO_2$, allowing the determination of average air pollution over approximately one month (Defra, 2022b). Diffusion tubes are commonly used by LAs when simple indicative methods of air quality data capture are sufficient. The purposes may be to provide longer-term averaged data on $NO_2$ concentrations in a particular area or to determine an annual mean objective of less than 40 µg/m$^3$ to compare with Air Quality Strategy Objectives (ibid.).

### 2.5.2 Local Air Quality Management

Local Air Quality Management (LAQM) in the UK is undertaken by LAs using prescribed processes under Part IV of the Environment Act 1995. Authorities are obliged to monitor, review, and assess local air quality (LAQ) and report on it in an Annual Status Report (ASR). These monitoring results and reports are made publicly available online or by request. If the LA identifies areas which exceed UK air quality objectives, they must carry out additional assessments and declare an Air Quality Management Area (AQMA). The size of the AQMA can range from one street to an entire city or larger. The LA must try to minimise and reduce concentrations within AQMAs by producing an Air Quality Action Plan (Defra, 2021a).

Under the Modelling of Ambient Air Quality (MAAQ) contract, background pollution concentrations are modelled annually by Defra. The background concentrations are visualised in maps published by Defra as Pollution Climate Mapping (PCM) data to assist LAQM. The maps are produced with a resolution of 1x1 km and are made available to the public for study purposes with acknowledgement. The fundamental purpose of the maps is the provision of background concentration estimates for specific pollutants. These estimates can then be used to assess air quality to better understand local source contribution to total pollutant concentrations. The maps are calibrated using data from the Automatic Urban and Rural Network (AURN) and provide information on how pollutant concentrations change across a wide area over time (Defra, 2021b).

As discussed, throughout the country, monitoring equipment is located to provide outputs which reflect the variation in exposure of people within a single location. However, they do not capture personal exposures from minor local exposure variations, such as children travelling to school during rush hour.

### 2.5.3 Policy for Schools

There remains no statutory UK guidance relating to the siting of schools to sources of pollution, such as main roads. Studies have made recommendations regarding school proximity to busy roadways, although this is yet to become legislation (Wolfe et al., 2021). However, school pollution concentrations can be influenced by local authority decisions. For example, should they be deemed to have a detrimental impact on local air quality, planning applications can be rejected by councils (Osborne et al., 2021a; Osborne et al., 2021b).

Several local programmes in the UK have prioritised the reduction of TRAP around schools, including the School Streets Initiative (Hopkinson et al., 2021) and the introduction of green barriers (Barwise & Kumar, 2020). Other efforts include the publication of clean air toolkits by some LAs (Castell et al., 2021; Commodore et al., 2017), which commonly detail strategies that can be undertaken to reduce or mitigate potential child exposure to TRAP. As the technology becomes less expensive, personal exposure studies have become increasingly popular (Oh et al., 2019; Usemann et al., 2019; Zhang et al., 2018; Spira-Cohen et al., 2011; Ashmore & Dimitroulopoulou, 2009; Van Roosbroeck et al., 2006). In these projects, children record real-time pollution exposure with personal monitors carried or worn on the school run and across different modes of travel.

## 2.6 Exposure Mitigation Interventions & Reduction Strategies

### 2.6.1 Overview

Given the vulnerability of children to air pollution, interventions to reduce or mitigate their contact with air pollution at school are recognised as essential for a range of health issues and also for academic performance (Requia et al., 2022; Stenson et al., 2021; Banerjee, 2016; Burtscher & Schüepp, 2012; Dwyer et al., 2001). However, given the contribution of traffic to poor air quality around schools, many interventions can be considered in terms of relating to the reduction of TRAP (Reche et al., 2014) or the mitigation of exposure (Mazaheri et al., 2018).

### 2.6.2 Anti-Idling

Campaigns and technologies associated with anti-idling are prevalent in the literature, including research by Ryan et al. (2013) and Paton-Walsh et al. (2019), who assessed the effectiveness of anti-idling campaigns, and Xu et al. (2013), who developed and implemented an anti-idling detection and warning system. The region immediately surrounding schools are often regarded as areas of high traffic concentrations at peak times (Osborne et al., 2021b) and are accordingly sources of elevated pollution. Living near these traffic sources is also associated with the development of asthma and the worsening of existing respiratory illnesses (Burgess, 2019). Child microenvironments commonly include schools and travel to and from schools, sometimes in vehicles. These environments have been argued as particularly relevant when considering TRAP exposure, especially when considering the number of schools in close proximity to major roads in the UK (Kumar et al., 2020). Paton-Walsh et al. (2019) identified limiting motor vehicle idling as an effective measure for the reduction of air pollution, in addition to possessing co-benefits such as reduced fuel costs. Idling vehicle emissions contribute to student exposure to air pollution (Spira-Cohen et al., 2010), and rush hour peaks in exposure have also been identified (Mazaheri et al., 2018). Anti-idling is considered to be an effective measure for improving air quality, as most idling occurs at exposure hotspots such as road junctions, car parks, and schools. The researchers recommended the introduction of anti-idling zones, particularly around at-risk populations, such as child-care centres, care homes, schools, and hospitals.

Anti-idling is argued to be most effective for air quality improvement in areas where traffic associated with drop-off and pick-up is a significant contributor to the local air pollution mix (Kim et al., 2014; Ryan et al., 2013). However, the intervention is not as effective when schools are near major roadways (Xu et al., 2013; Spira-Cohen et al., 2011). Appropriate education must also accompany anti-idling efforts to ensure that drivers are fully informed about the health impacts of poor air quality and vehicular emissions and are then more likely to show compliance and less likely to resent the intervention (Eghbalnia et al., 2013).

### 2.6.3 Low Emission Vehicle Promotion & Vehicle-Restricted Zones

Whilst the relationships between vehicle emissions and air quality are well established, comparatively limited and sometimes contradictory empirical evidence exists for the effectiveness of traffic management strategies (TMS) for emission reduction and the improvement of air quality (Bigazzi & Mohamed, 2018). Within this body of research, studies have also identified the effects of traffic control policies on urban air pollution. For example, several studies highlighted the benefits of low emission zone (LEZ) implementation (see Santos, Gómez-Losada & Pires, 2019; Bigazzi & Mohamed, 2018; Duque et al., 2016) and the benefits of the London LEZ (see Kelly et al., 2011a; Kelly et al., 2011b). Wood et al. (2015) also examined the introduction of the London LEZ and assessed its effects on air pollution and the health of East London schoolchildren. The study assessed associations between TRAP and respiratory or allergic symptoms among eight and nine-year-old schoolchildren residing within the LEZ. Parents completed questionnaires to provide data relating to respiratory and allergy symptom information. This information was linked to modelled annual air pollution concentrations and based on the residence location of each child. A multivariable mixed effects logistic regression analysis was used. TRAP ($NO_X$, $NO_2$, and $PM_{10}$) exposure was associated with rhinitis but no other symptoms. Critically, no significant improvement was found in air quality in London as a consequence of the LEZ during the first three years of implementation, and respiratory and allergic symptoms were also unaffected. However, several modelling studies support TMS implementation to reduce exhaust emissions, and it has been noted that the deficiency of empirical evidence should not be construed as a lack of benefits (Gulliver & De Hoogh, 2015; Van Erp et al. 2012). The most substantial evidence for benefits to air quality across 22 reviewed TMS exists for LEZ and area road pricing (Bigazzi & Rouleau, 2017). The most substantial evidence for emissions benefits across the same reviewed TMS is road pricing, vehicle operation restrictions, lower speed limits, traffic signal timing, intersection control devices, eco-driving, and employer-based programs. Bigazzi & Mohamed (2018) built upon their systematic literature review that evaluated empirical evidence for TMS and associated empirical evidence for the mitigation of air polluting emissions, human exposure, and the health impacts associated with TRAPs (Bigazzi & Rouleau, 2017).

It is important to highlight the distinction between LEZs and ‘School Streets’ initiatives. LEZs and School Streets initiatives are both aimed at reducing air pollution and promoting sustainable transport, but they have different objectives and approaches. LEZs are areas within cities or towns where access is restricted to vehicles, commonly based on whether they meet certain emissions standards (Wood et al., 2015). The purpose of LEZs is to reduce air pollution by encouraging the use of low-emission vehicles and promoting alternative forms of transportation, such as cycling and public transport. LEZs typically apply to all vehicles entering the zone, including cars, lorries, and buses. School Streets initiatives are LEZs specific to roads around schools and are aimed at improving road safety and reducing traffic congestion during school drop-off and collection times. In a School Streets initiative, adjacent roads are closed to through traffic during school hours, making it safer for children to walk or cycle to school. This also reduces traffic congestion, air pollution and noise levels in the area (Thomas, Furlong & Aldred 2022; Chivers, Wong & Preston, 2019). While conflicting evidence exists (see Mudway et al., 2019), some research shows that traffic can be reduced overall rather than displaced by implementing School Streets (Hopkinson et al., 2021).

Broad policies implemented from high government and industry levels can realise some sustainable transport strategies, including regulated vehicle and fuel standards, fuel pricing, and vehicular and fuel technologies. Local or regional governments typically implement other strategies, such as those related to traffic management and land use. The application scale is important because of the resources required for detailed modelling of the full impacts of policies and projects proposed (Grote et al., 2021). Accordingly, gaps in the knowledge of TMS effectiveness are particularly problematic for regional and local strategies. Bigazzi & Mohamed (2018) highlight a need to improve knowledge of real-world TMS effects to better inform sustainable transportation decision-making. There is also a need to better understand ways to improve the uptake of effective TMS implementation by regional and local governments.

Attempts towards the protection of human health and compliance with air quality limit values have seen many cities throughout Europe and the rest of the world introduce vehicle-restricted or low-emission zones. LEZs are now regarded as an important policy intervention for improving air quality in the urban environment (Cyrys et al., 2014). There are currently estimated to be over 200 LEZs in operation in Europe alone at the time of writing (Moral-Carcedo, 2022).

An LEZ can be considered as localised action undertaken in a specific geographic area to reduce vehicle emissions and improve local air quality (Tarrino-Ortiz et al., 2022). A variety of concepts exist within the model of LEZs. For example, an LEZ that is implemented to improve air quality may become active when air pollution exceedances occur or before they occur. A technology-based LEZ may restrict specific types of vehicles from entering a specified urban area. An LEZ that is transport-based could restrict or prioritise traffic to improve traffic flow for the reduction of emissions (Amundsen & Sundvor, 2018). Additionally, timescales are an essential consideration for LEZ implementation. Some urban centres produce forecasts for potential pollution and trigger action on the basis of these predictions (Holman, Harrison & Querol, 2015).

Given the large number of LEZs, many studies have attempted to use monitored data to quantify their air quality impact. Interventions related to large events have commonly provided important data for the assessment and evaluation of strategies (Mudway et al., 2019; Wood et al., 2015; Kelly et al., 2011a; Friedman et al., 2001). For example, Friedman et al. (2001) assessed the effectiveness of car use disincentives as a strategy for the minimisation of traffic congestion at the 1996 Summer Olympic games in Atlanta, Georgia. Low-emission vehicle promotion has additionally included the assessment of road transport policies

(Malmqvist et al., 2018; McKinstry & Chowdhury, 2015), TMS (Bigazzi & Mohamed, 2018; Lobdell et al., 2011), LEZs (Kelly et al., 2011a; Kelly et al., 2011b), a congestion charging scheme (CCS) (Tonne et al., 2008), and grade separation (Alvanchi, Rahimi & Alikhani, 2019).

A common aim for many LEZs is to achieve compliance with EU air quality limits, which are principally determined using monitored ambient air pollution concertation data. European LEZs often restrict vehicular access based on European emission standards and are used as a key element of strategies for emission control (Kelly et al., 2011b).

Evidence for the reduction of pollution due to the application of LEZs is rare when considering their extensive application (Mudway et al., 2019; Bigazzi & Mohamed, 2018; Wood et al., 2015). Mudway et al. (2019) argued that the effects of European LEZs on concentrations of $NO_2$ and $PM_{10}$ were largely inconsistent. A review conducted by Wang et al. (2016) to assess air quality strategies on public health in Europe found relatively few studies that addressed LEZ impacts on human health (see Cyrys et al., 2014; Johansson, Burman & Forsberg, 2009; Tonne et al., 2008; Hutchinson & Pearson, 2004). Only one study was found that sourced health data from people to assess the effects of LEZ introduction on respiratory symptoms, with negligible findings (Burr et al., 2004).

### 2.6.4 Facemasks

The awareness, and arguably acceptance, of facemask use in public has increased as a consequence of the Covid-19 pandemic (Greenhalgh et al., 2020). Over recent years, the increasing public awareness of air pollution and its associated risks has been accompanied by a growth in the production of non-occupational facemasks manufactured to filter gaseous pollutants and particulate matter (Zhang & Mu, 2018). Some manufacturers have also produced smaller protective facemasks for child use (Goh et al., 2019).

Facemasks are commonly considered unsuitable as a primary air pollution exposure mitigation measure for children for a number of reasons (Smart et al., 2020). The foremost concern is that the removal of emission sources in close proximity to schools and other places where children congregate should be the primary aim and carries greater benefits (Public Health England, 2019). Other reasons include the difficulty of correctly fitting the facemask to a child’s face when the mask has been originally designed for adults, and the likelihood of a child wearing a mask for prolonged periods of time, both of which reduce the effectiveness of the intervention (McDonald et al., 2020). It has also been argued that facemasks impact breathing efforts due to greater resistance, resulting in a reduction of air volume breathed, which could result in fatigue and discomfort (Johnson, 2016).

Whilst these reasons are buoyed by the literature, the emission reduction process is problematic and slow compared to the immediacy of air pollution exposure. Many children also have little choice regarding their exposure to air pollution on their school commute. Accordingly, facemasks and similar personal interventions present potentially viable solutions in the shorter term if they are suitably manufactured and worn properly (McDonald et al., 2020).

Some research has examined the efficacy of facemasks and their ability to fit the faces of children (Cherrie et al., 2018). The effectiveness of facemasks has also been explored as a barrier to air pollution inhalation. Pacitto et al. (2019) examined the effectiveness of commercially available facemasks for the reduction of PM exposure. Commercial facemask respirators are widely used throughout the world as an individual measure to protect against particulate pollution, but data are lacking on their effectiveness in reducing airborne particulate exposure (gaseous pollutants were not examined). The study developed a custom experimental method to measure respirator effectiveness under actual environmental conditions against $PM_{2.5}$, particle number concentration (PNC), lung deposited surface area (LDSA) and BC. In a price range of 1 to 44 Euros, the most effective mask was consistently the same, costing 20 Euros, and possessing a good fit on a dummy head and a filter on its entire surface with two one-way exhalation valves. The importance of a good fit to the face is highlighted in terms of application to children. The effectiveness of filters for reducing PM exposure depends not only on the filter itself but the tightness of the fit and the seal around the face of the individual. Limitations to the methodology include the test consideration of counting breathing as inhalation only. Exhalation generates positive pressure, so the respirator fit might be compromised, with unfiltered aerosol entering the breathing zone. This is particularly true for respirators lacking exhalation valves. Accordingly, an overestimation of the measured efficiency might have occurred. Also, intense exercise (like cycling) can increase inhalation and exhalation frequency and intensity. The mask fit might be compromised with heavy breathing, while high rates of simulated breathing might lead to improved fitting and filtration.

### 2.6.5 Public Transport Improvement

Car use accounts for the most significant share of polluting emissions in the transport sector, and approximately 76.3% of these trips were single occupant (Zhang & Zhang, 2018). To reduce negative externalities associated with car usage, public transport has been highlighted as environmentally sustainable and a cost-effective alternative. Accordingly, public transport and its improvement are the subjects of several studies, which included public transport and ridesharing (Bastien et al., 2020), natural gas fuel alternatives (Mena-Carrasco et al., 2012), an increase in public transport (Sun et al., 2019), bus rapid transit (BRT) (Alvanchi, Rahimi & Alikhani, 2019), and improvements to bus routes (McKinstry & Chowdhury, 2015).

McKinstry & Chowdhury (2015) argue that improvements to public transport can reduce transportation emissions. One highlighted approach is the addition of new bus routes and the improvement of any existing routes. Another is to increase the frequency of stops for buses and trolleys during peak traffic times. The study provided a comparison between National City and San Diego County and found that in the majority of places, trolleys and buses arrived every 15 minutes during weekdays and less frequently at weekends, resulting in long wait times at stops and acting as a key deterrent to public transportation use. The study suggests that bus frequency increases during peak times to every five minutes, resulting in a more rapid system and providing additional employment. Public transport could also be made more effective by the addition of bus lanes, within which buses could avoid traffic. These lanes are already utilised throughout the world and can provide buses with an electric power source and provide additional reductions to air pollution. Public transport emission reductions are dependent on the adopted strategies. National City has greater public transport participation than the rest of the United States, indicating residents are already open to its use. The study determines that a population already open to public transport use, coupled with a small land area (as is the case with National City), makes a five-year increase in public transit use from 6.9% to 10% realistic.

Studies assessing the effectiveness of public transport improvement policies have suffered common limitations, including residual confounding by temporal and spatial factors. Studies have exploited ‘natural experiments’ to counter this issue, which construe policies or interventions resulting in air pollution reductions. Rich (2017) compiled accountability studies of air pollution and health effects to address these limitations associated with observational epidemiology studies of air pollution. Natural experiments relating to initiatives resulting in increased use of public transport have demonstrated that improvements occur to both community health and air quality (Aldred et al., 2021; Mudway et al., 2019; Kelly et al., 2011a; Kelly et al., 2011b; Friedman et al., 2001). For example, during the 1996 Olympics in Atlanta, USA, childhood asthma instances were significantly reduced due to initiatives implemented during the games, which included increased telecommuting and public transport use (Friedman et al., 2001).

### 2.6.6 School Buses

Studies related to air pollution exposure on school buses have been conflicting in their conclusions, with some maintaining that child exposure on the school commute is reduced when taking the school bus compared to alternative methods of travel, such as private car use or walking (Ma et al., 2020). Other research highlights the high concentrations of air pollutants children are exposed to when on buses (Adar et al., 2015). Research conducted by Marshall & Behrentz (2005) in California, USA, identified that when aboard a school bus, the average per capita inhalation of emissions for a student was between $10^5$ and $10^6$ times greater than that of a typical resident in California's South Coast Air Basin (SoCAB). Much of the air pollution within school buses results from surrounding vehicles and the buses themselves. Up to 25% of the BC within school buses examined by Behrentz et al. (2004) was found to have been emitted by the exhaust of the bus itself. Sabin et al. (2005) asserted that when following a diesel school bus, particle-bound PAHs and BC were between 1.8 and 11 times higher than when following no target.

Fuel standards and protocols have been highlighted as an important area of exploration for the improvement of air quality around schools and for children riding school buses. Beatty & Shimshack (2011) assessed the effectiveness of retrofitting diesel school buses with pollution control technology. The effectiveness of legislation and taxation on air pollution reduction was also assessed. Based in Puget Sound, Washington, the accountability study evaluated a localised emission reduction program to retrofit diesel school buses with pollution control technology. The study was designed to evaluate if regulatory actions result in a beneficial health response. The key findings identified that school bus retrofits led to significant reductions in monthly counts of hospital admissions for respiratory illnesses for children and adults. The school districts that adopted the scheme experienced 23% and 37% fewer bronchitis/asthma and pleurisy/pneumonia hospital admissions, respectively (when compared to non-adopting school districts). The study included the use of a large hospital admission dataset that covered Washington state and captured nearly all health outcomes requiring hospitalisation. In addition, a control population was used to compare changes in respiratory outcomes before and after the intervention, for those school districts who adopted the bus retrofits and those that did not. In addition, several sensitivity analyses were conducted to assess the control population to determine if these non-adopter districts were similar to the adopter districts in terms of health outcomes and demography prior to the commencement of the retrofit program. A key limitation of the study was that no air pollution monitoring was conducted to assess changes in air pollutant concentrations after the school bus retrofitting program in adopter districts compared to non-adopter districts.

### 2.6.7 Rideshare

Ridesharing (or carpooling) is the organised sharing of a private vehicle for commuting purposes (Chaube, Kavanaugh & Perez-Quinones, 2010). Ridesharing arrangements may involve the payment of a nominal charge to the owner of the vehicle, but a more typical arrangement involves sharing different owner's vehicles on a rotational basis without charge (Lenhoff et al., 2022). For this reason, ridesharing is often considered in terms of public transport (Cui et al., 2021). Taking this a step further, Zhang & Zhang (2018) explored the lack of understanding regarding the relationship between ridesharing and public transport use. The study objective was to examine the associations between ridesharing and the frequency of public transport use. The study indicated that a general one-unit increase in the use of public transport is positively related to an increase of 1.2% in the monthly ridesharing frequency and an increase in ridesharing use probability of 5.7%. This positive relationship was more pronounced for households with fewer vehicles or those living in high-population-density areas. The findings support the potential integration of public transport and ridesharing for more accessible multimodal travel, promoting both modes, and enhancing sustainable transport mobility.

The benefits associated with a successful ridesharing scheme are substantial, including reducing emissions and fuel consumption, lowering congestion during peak traffic periods, and reducing parking costs for users (Cui et al., 2021). Those commuting by rideshare also save time and money in the form of fuel and parking costs (Lenhoff et al., 2022), and for employers, reductions of parking requirements and additional benefits associated with improved productivity among less stressed workers (Bastien et al., 2020). There are also broader benefits in the form of the reduction of congestion, improvements to energy security, and lower greenhouse gas emissions (Bertazzon & Shahid, 2017).

Greater transportation equity has also been argued to be a benefit of ridesharing schemes, which can help ensure greater mobility for travellers on lower incomes (Rodier, Alemi & Smith, 2016). However, despite the many argued stakeholder benefits associated with rideshare, schemes often lack popularity and commonly suffer from low participation rates. Chaube, Kavanaugh & Perez-Quinones (2010) argue that the low uptake of rideshare schemes can be attributed to several main reasons. Rideshare schemes suffer from system-level difficulties. The process of ride scheduling is often complex and requires substantial planning. Trust among co-passengers is critical, and the social discomfort accompanying rideshare is an important factor associated with an unwillingness to provide or share lifts with others. In addition, people prefer to choose their passengers, adding to the complexities of arranging rideshares. The research also identifies a general lack of motivation or perceived incentives to undertake ridesharing.

### 2.6.8 Active Travel

Examining the effects of active travel as a behavioural intervention for reducing air pollution is common in the literature. Studies utilised a range of methodological designs, including the assessment of cycling as an alternative to car travel (Buekers et al., 2015; Macmillan et al., 2014), the effectiveness of bike-sharing schemes (Li & Kamargianni, 2018; McKinstry & Chowdhury, 2015), and cycling and walking as active travel (Hankey, Lindsey & Marshall, 2017; Milner et al., 2012; De Nazelle et al., 2011; Giles et al., 2011; Woodcock et al., 2009).

Increased physical activity levels are associated with greater physical, psychological, and social health in children and young people. Active travel on the school commute is considered beneficial to children as a source of physical activity (Faulkner et al., 2009) and to lower traffic and pollution at peak times (Pang, Kubacki & Rundle-Thiele, 2017). There is an inverse relationship between physical activity and youth obesity (Moodie et al., 2011; Rosenberg et al., 2006; Tremblay & Willms, 2003; Mellin et al., 2002), and adult coronary heart disease has been associated with poor body composition in childhood (Baker, Olsen & Sørensen, 2007). For example, Buekers et al. (2015) modelled the health impacts of modal shifts from car use to active travel (walking and cycling) in Flanders, Belgium. Flanders experiences high levels of air pollution, and alternatives to car travel were implemented to increase the population's daily physical activity and reduce air pollution. The study aimed to evaluate the economic impact of an increase in cycling and walking. The robustness of the results was determined by using different sensitivity analyses with a variable number of cyclists and distances travelled, supporting the conclusion that increased physical activity outweighed the other impacts. A predominantly positive relationship was found between benefits and costs for health impacts and infrastructure construction.

Active travel has been demonstrated to help reduce body mass index (BMI) and consequently reduce long-term diseases such as those related to obesity (Faulkner et al., 2009; Dollman & Lewis, 2007; Janssen, 2007). The increased exercise associated with active travel uptake has also been shown to improve academic performance among pupils (Lee, Orenstein & Richardson, 2008; Dwyer et al., 2001) and also has the advantage over other physical activities of being low-cost and convenient (Moodie et al., 2011; Rosenberg et al., 2006). However, evidence suggests that active travel among schoolchildren has declined significantly since the 1980s (Mammen et al., 2014; Crawford & Garrard, 2013; Buliung, Mitra & Faulkner, 2009; Van Der Ploeg et al., 2008; McDonald, 2007), although a decline in overall physical activity levels among children within the same time period remains debated (Van Der Ploeg et al., 2008; Westerterp & Speakman, 2008). Reasons for the decline have been argued in studies that point to, among other factors, a shift in social norms (Mammen et al., 2014), concerns for child safety (Faulkner et al., 2009; McDonald, 2007), and increasing car use (Dollman & Lewis, 2007).

Arguments that physical activity undertaken by children and young people is lower than desirable for the improvement of health-related fitness (such as cardiorespiratory and muscular fitness, flexibility, and body composition) are pervasive (Faulkner et al., 2009; Davison, Werder & Lawson, 2008; Tudor-Locke et al., 2003). Whilst precision regarding the volume of fitness required for these health improvements is unclear (Janssen, 2007), it is commonly agreed that habitual exercise in the form of active travel is advantageous to child health (Mammen et al., 2014; Crawford & Garrard, 2013; Faulkner et al., 2009; Tremblay & Willms, 2003). Active travel provides the opportunity for children and young people to benefit from regular physical activity whilst reducing the traffic burden at peak travel times and lowering pollution around schools and on the school commute (Lee, Orenstein & Richardson, 2008). Furthermore, Milner, Davies & Wilkinson (2012) have asserted that according to WHO guidelines, switching to renewable fuel sources for motor vehicles and reducing the need for car journeys would be aided by the encouragement of active travel. The study also highlights the improvements in public health as a consequence of these strategies. Under reasonable assumptions, the substitution of regular walking or cycling in place of vehicular transport provides benefits in terms of increased physical activity that outweigh the adverse effects associated with the inhalation of air pollution during these physical activities (De Hartog et al., 2010).

### 2.6.9 Improved Cycle & Pedestrian Facilitation

The facilitation of active travel and encouraging the practice through additional support measures have been argued as critical to ensure maximum uptake (Larouche et al., 2014; Faulkner et al., 2009). Some evidence exists regarding the causal links between active travel among children and the built environment and associated infrastructure (Aldred et al., 2021; Witten & Field, 2020; Smith et al., 2015; Powell et al., 2010). Of the existing evidence, suggestions for improvements include installing pedestrian crossings, traffic calming measures, and additional cycle lanes and paths (Giles-Corti et al., 2016). Some have also argued that comprehensive and large-scale interventions to improve infrastructure to encourage active travel have been successful throughout the world (Aldred et al., 2021; Mackie et al., 2018; Goodman et al., 2014; McDonald et al., 2014). However, interventions on a smaller scale, or localised to a particular school, are far more common and are often supported by transport agencies or local urban planning (Witten & Field, 2020).

It has been argued that city planning, and the implementation of suitable and supportive infrastructure must be considered carefully for active travel uptake to be successful (Crawford & Garrard, 2013; Buliung, Mitra & Faulkner, 2009; Davison, Werder & Lawson, 2008). For example, Giles-Corti et al. (2016) considered the health impacts of city planning and the reduction of non-communicable diseases through transport mode choices. A series of integrated regional and local interventions were identified to be used in combination to encourage walking, cycling, and uptake of public transport whilst reducing the use of private motor vehicles. The interventions included destination accessibility, equitable employment distribution, reduced parking availability and increased costs, pedestrian and cycle-friendly movement network design, optimum residential density levels, reduced distance to public transport, and increased desirability of active travel mode. Combined, these interventions could create more sustainable, healthier compact cities that reduce the associated risk factors (environmental, social, and behavioural) that affect lifestyle decisions, traffic levels, and pollution. The study recommends that the health sector and ministers should advocate integrated multisector city planning, which prioritises health, sustainability, and liveability outcomes, which is particularly relevant in low- and middle-income countries. The importance of producing a set of indicators for benchmarking and monitoring progress towards these aims is also highlighted. These findings are supported in the literature with regards to the criticality of planning active travel infrastructure, which includes arguments for equity when implementing low-traffic neighbourhoods (LTNs) (Aldred et al., 2021), engaging children in the active travel infrastructure process (Witten & Field, 2020), and the socio-economic importance of active travel infrastructure improvements for citizen health (Mahajan et al., 2020; Powell et al., 2010).

Theories relating to behavioural change and mode shifts to active travel have postulated several routes between changes to infrastructure and shifts in behaviour, including a recognition of the role played by self-efficacy (Marcus et al., 1992), parent/child perceptions of social connectivity and safety in the neighbourhood (Ikeda et al., 2020), and planned behaviour theory (Murtagh et al., 2012). Additionally, a scenario of self-reinforcement may benefit uptake, whereby school programmes and infrastructural improvements to community active travel can provide increased visibility and cultural capital to support increases in uptake (Hawley et al., 2019).

Despite the perceived benefits, it is common for cities to face opposition when planning or proposing new or expanded pedestrian or cycle infrastructure and facilities (Hull & O’Holleran, 2014). The most vocal in opposition are commonly local business owners and drivers (Bubbers, 2019). Given that infrastructure to improve active travel often requires reducing or removing vehicle travel lanes or parking, concerns usually relate to increased parking or driving difficulties (Chapple, McCoy & Poirier, 2018). Concerns among business owners commonly include apprehension that patronage will be reduced by customers who shop using their cars and that these lost revenues will not be offset by the increase of those actively travelling to the shops (Liu & Shi, 2020; McCoy, Poirier, & Chapple, 2019; Bopp, Sims, & Piatkowski, 2018; Drennen, 2003). Such opposition can impede and even prevent the implementation of improved active travel infrastructure initiatives. There is a deficit of recent research on the economic impacts on local businesses of active travel infrastructure implementation, and existing research is conflicting (Volker & Handy, 2021; Hack, 2013; Rietveld & Bruinsma, 2012; Stantec, 2011). Accordingly, cost-benefit analyses are limited by this lack of quantitative evidence, although investments in pedestrian and cycle initiatives may, directly and indirectly, affect local economies (Flusche, 2012; Weigand, 2008; Krizec, 2007; Krizec et al., 2007). However, Volker & Handy (2021) argue that the installation or improvement of active travel infrastructure has non-significant or positive outcomes on the economies of food services and retail businesses within a short distance of the new facilities, although cycle infrastructure may negatively impact auto-centric businesses, such as petrol stations, garages, and large department stores. These results were similar irrespective of the removal of travel lanes or vehicular parking as part of the active travel implementation.

Relatively few countries have seen cycling as a method of contribution to green infrastructure or a way to make their cities more inclusive to their citizens (Hull & O'Holleran, 2014). The popularity of cycling is entrenched in a policy approach that promotes cycling accessibility for all ordinary purposes, including leisure, shopping, and commuting, and often using measures that restrict car use where possible or necessary (Hull, 2010). Germany, the Netherlands, and Denmark are European leaders in ensuring cycling is an attractive, convenient, and safe option of travel by prioritising cyclists and providing extensive supporting infrastructure, including promotion and education of cycling to its citizens, public transport integration, and widespread cycle parking (Volker & Handy, 2021). Car use has also become less convenient, more expensive, and increasingly unnecessary in modern cities (Liu & Shi, 2020). In these countries, the spatial policy has also developed a style of mixed-use compact building whereby travel distance is reduced and cycle accessibility is enhanced (Volker et al., 2019).

### 2.6.10 Urban Greening

It is acknowledged in the literature that ensuring cities are safe and inclusive spaces is of critical importance for sustainability, public well-being, and encouraging active travel, with a particular focus on green infrastructure and children (Amicone et al., 2018; Ling & Chiang, 2018; Chawla, 2015; Dadvand et al., 2015). The EU has maintained that nature-based solutions, such as urban greening, should be encouraged to mitigate urban air pollution effects (Lafortezza et al., 2018). Urban greening and green infrastructure provide a broad range of benefits beyond citizen well-being. For example, urban greening is effective for the improvement of air quality through the removal of different air pollutants (Duda et al., 2022; Baumgardner et al., 2012; Manes et al., 2008), although the degree of effectiveness is debated (Song et al., 2020; Roy, Byrne & Pickering, 2012). Increasing the level of urban greening in compact cities is highlighted as a challenge (Grêt-Regamey et al., 2020) due to the density of the urban environment, within which existing space to plant trees may be scarce (Hansen et al., 2019).

Urban greening and green infrastructure can be defined as the combination of urban planning and green spaces (Emilsson & Ode Sang, 2017). Green spaces include moss walls, green roofs, urban parks, peri-urban forests, and trees. As touched upon, the range of benefits associated with urban greening includes the improvement of psychological well-being (McCree, Cutting & Sherwin, 2018), the mitigation of climate change effects (Demuzere et al., 2014), and the improvement and preservation of biodiversity (Mayrand et al., 2018). However, a report by the Air Quality Expert Group (AQEG) found that overall, whilst vegetation and trees were beneficial to air quality, the impacts of green infrastructure on air quality were small (Air Quality Expert Group, 2018).

Urban environments are threatened by elevated air pollution concentrations (Grote et al., 2016). Urban greening introduces additional surface areas for the deposition of airborne particles to a far greater extent per unit area than car parks, buildings, or pavements (Manes et al., 2008). Trees, plants, and hedgerows can also act as a barrier to the dispersion of particulate matter and some gaseous pollutants (Abhijith et al., 2017). The barrier influences air flows, so it is vital to conduct positioning assessments before installing green barriers (Barwise & Kumar, 2020). Whilst deposition occurs with particulate matter onto leaf surfaces, the stomata can capture some gases, such as $NO_2$, and the cuticle can directly absorb some volatile organic compounds (VOCs) (Dover, 2018; Gunawardena, Wells & Kershaw, 2017; Calfapietra, Peñuelas & Niinemets, 2015). Conversely, the growth of plants can be negatively affected by air pollution, which can also limit the plant species that can survive within a specific area (Perini & Roccotiello, 2018). It is also the case that some trees can produce adverse impacts on air pollution. Some species of tree are to be avoided as they are sources of isoprene and other biogenic volatile organic compounds (BVOCs), that can enhance the formation of $O_3$ and PM (Monks et al., 2018).

The effects of urban greening on the uptake of airborne particles have been confirmed in the literature, citing climate and season (Ling & Chiang, 2018; Perini & Roccotiello, 2018; Sheweka & Mohamed, 2012), leaf area index (LAI) (Pérez et al., 2017), plant species (Dahanayake, Chow & Hou, 2017), shape and density of foliage (Weerakkody et al., 2018), and leaf morphology (Chávez-García & González-Méndez, 2021) as influencing parameters for effectiveness.

## 2.7 Conclusion

Children are considered a vulnerable population when setting air pollution exposure limits, and their greater metabolic and breathing rates lead to greater levels of exposure and more severe health impacts. The ways that children interact with their environment and their developing physiologies mean that they generally receive a higher level of exposure. Due to the sensitivity of children to harmful air pollution, the risk of exposure when travelling to school is of concern. Children are particularly vulnerable to the harmful effects of air pollution and other adverse environmental exposures because of their developing lungs. The consequences of exposure are profoundly affected by the developmental stage of childhood.

Whilst several UK studies and campaigns of note exist (Broekstra, Luck & Gordeljevic, 2019; Oxford City Council, 2019; Watts & Clark, 2019), there are currently no comprehensive academic studies that combine a systematic review of mitigation and reduction measures with stakeholder opinion on a large scale to inform intervention modelling for the assessment of effectiveness.

# 3.0 Systematic Review of Applicable Interventions for the Reduction of Potential Child Exposure to Traffic-Related Air Pollution at Schools

## 3.1 Introduction

A systematic review was conducted to identify studies supporting the effectiveness of traffic-related air pollution (TRAP) exposure reduction methods and strategies that apply to the school commute scenario. The methods or strategies were required to reduce TRAP concentrations or potential child exposure to TRAP when travelling to or from school or at the school gates during these congregative times.

A systematic review is a comprehensive literature survey using a focused question, with all included studies providing the highest evidence level. The studies are identified systematically prior to their appraisal. The results are then summarised according to a methodology that is both explicit and reproducible (Moher et al., 2010).

Systematic reviews differ from traditional commentaries and reviews in their adherence to a scientific methodology with the intention of error minimisation. Based on a set of explicit criteria, the systematic review aims to use a comprehensive strategy to identify all studies relevant to a particular topic, permitting the selection of appropriate studies. Furthermore, the study methodologies are assessed for quality under the specifications of these explicit criteria. Contrastingly to traditional literature reviews, the systematic review is verifiable, transparent, and reproducible, reducing the likelihood of bias (McKenzie et al., 2020).

Many applied disciplines utilise systematic reviews as an evidence-based framework to identify and disseminate intervention effectiveness for practice and policy (Higgins & Green, 2008). Systematic review frameworks are the most developed in the health service sector, within which reviews are firmly established and coordinated by networks such as the Cochrane Collaboration (Van Tulder et al., 2003). Networks such as this undertake systematic reviews according to a set of guidelines, including peer review, to ensure that standards are satisfied prior to dissemination.

### 3.1.1 Review Protocol

The review protocols were submitted to PROSPERO (International Prospective Register of Systematic Reviews) for validation prior to commencement. PROSPERO provides a comprehensive database of prospectively registered systematic reviews within the social sciences with a health outcome. Key review protocol features are registered at inception and maintained as permanent records. Using the PROSPERO system can increase the quality of a review, help avoid duplication of review topics, and reduce reporting bias by comparing the planned protocols and the completed review (Sideri, Papageorgiou & Eliades, 2018).

The review and its methodology were officially validated and registered on 10/03/2020 (ID: CRD42020167594).

### 3.1.2 Aims & Outcomes

The pre-specified primary aim of the review is to compile salient research pertaining to TRAP reduction, or the reduction of potential child exposure to TRAP, that can be applied to the UK school commute. This includes travelling to school, the school gates, and leaving school (hereafter referred to as the 'school commute'). The outcome will comprise a list of relevant interventions that will provide input to the stakeholder survey.

The outcome will be measured in terms of a reduction of TRAP against a study-dependent baseline level or the mitigation or reduction of potential exposure to TRAP against a study-dependent baseline at a specific location or building. However, the consequential summary interventions must be applicable to the school commute.

## 3.2 Preferred Reporting Items for Systematic Reviews & Meta-Analyses (PRISMA)

### 3.2.1 Background

Meta-analyses and systematic reviews have become important methodological tools in academia (Moher et al., 2009). They are perhaps more commonly associated with their use in clinical practice to maintain currency within the field (Higgins et al., 2019) and are often used as a point of conception for developing guidelines associated with clinical practice and other disciplines. Agencies may also require systematic reviews for grant applications to ensure that further research is justified (Moher et al., 2007), and many journals have also moved towards this position (Dixon et al., 2005). A systematic review's quality depends on its methodology, findings, and transparency of the reporting (Liberati et al., 2009). Reporting quality is varied, and this limits the ability of readers to assess these reviews in terms of their strengths and weaknesses.

Early studies have evaluated the quality of reporting associated with systematic reviews. Mulrow et al. (1988) examined articles detailing systematic reviews across four leading medical journals. The findings found none of the 50 articles examined met all eight explicit scientific criteria, including the quality of assessment of the studies included (Hemels et al., 2004). Sacks et al. (1987) evaluated reporting adequacy in 83 meta-analyses in six domains and 23 characteristics. The findings pointed towards a generally poor level of reporting, maintaining that between one and 14 of the outlined characteristics were reported adequately. The study was updated in 1996, finding little improvement (see Liberati et al., 2009).

To address the shortfall in meta-analysis reporting, guidance called the QUOROM Statement (Quality of Reporting of Meta-analyses) was developed in 1999. The Statement focused on meta-analysis reporting concerning randomised controlled trials (Moher et al., 2009). The guidance was updated in 2009 to address advances in the science of systematic reviews, both in conceptual and practical terms. The updated guidance was renamed PRISMA (Preferred Reporting Items for Systematic Reviews) (Higgins et al., 2019).

The systematic review process is rigorous, reducing bias in study selection by use of a systematic method of assessment. Both the search strategy and the methodology can enhance the review replicability. Drawbacks of the systematic review include the substantial time consumption of the review process and the remaining risk of bias in the selection process. Accordingly, the current research needed to ensure adequate time was available for undertaking the review, and an awareness of the risks of bias was maintained at each stage of the review process (Viswanathan et al., 2017). PRISMA was the preferable reporting method for the systematic review in the current research, given its prominence and wide acceptance in the social sciences (Chandra et al., 2022; Chaudhuri & Kumar, 2022; Diener & Mudu, 2021; Parasin, Amnuaylojaroen & Saokaew, 2021; Bekkar et al., 2020; Lu et al., 2020; Yang et al., 2020; Selçuk, 2019; Quarato et al., 2017).

### 3.2.2 Process

PRISMA facilitates the reporting of systematic reviews and meta-analyses and provides an evidence-based minimum set of items with which this can be achieved (Higgins et al., 2019). The PRISMA Statement comprises a four-phase flow diagram (Appendix B) and a 27-item checklist (see Appendix C), both evolving from the emergence of new evidence.

*Table 1 Nine steps of the PRISMA process (Moher et al., 2010).*

| **Step** | **Procedure** |
|---|---|
| Step 1: Preparation | A copy of the PRISMA diagram is used alongside each individual database search, with an additional copy for the totals. |
| Step 2: Database Search | Each key search term combination is individually entered into each database. All search terms, truncations and wildcards are logged. Where appropriate, Boolean operators are used with all search terms in different combinations and identified limits are applied. Once search terms have been combined and limits applied, a number of records are produced, which are entered into the PRISMA flow chart for each database. If databases are searched individually, the identified records are added, and the total number is entered into the final flow diagram. If databases are searched individually then the recording process is carried out for each individual database search. |
| Step 3: Additional Sources | Should articles have been identified through searches other than databases (such as manual reference list searches or search engine results), the total record number is entered separately into the flow diagram. |
| Step 4: Remove Duplicates | Any articles that appear more than once are manually removed to ensure against reviewing duplicates. The record number following duplicate removal is then recorded on the flow diagram. |
| Step 5: Screening Articles | The number of screened articles is recorded in the flow diagram and will be the same as entered for the previous step. |
| Step 6: Screening - Excluded Articles | Titles and abstracts are screened for relevance to the research question, and any articles that may appear suitable are included. The number of articles excluded in this step is then recorded on the flow diagram with a brief reason for the exclusion. |
| Step 7: Eligibility | The number of excluded articles is subtracted from the total number of records, and the result is entered under ‘Full-text articles assessed for eligibility’. The articles are then procured in full text for the eligibility review. |
| Step 8: Eligibility – Excluded Records | All full-text articles are reviewed for eligibility and inclusion in the final review. The number of articles excluded at this stage is recorded with a short reason for exclusion, which may be the same used in the screening phase. |
| Step 9: Included | The number of articles or records excluded during the full-text eligibility review is subtracted from the total number of articles reviewed for eligibility, thus completing the flow diagram. The entire process is repeated for multiple database searches, and a final flow chart is used to record the results. |

### 3.3 Objectives & Research Question

Systematic reviews begin with a clearly defined question that includes the subject, intervention, and research outcomes, all answerable in scientific terms. Critical to the process, the research question generates the search terms used to interrogate the literature and determines the criteria for the relevance of the returned studies. The development of an effective question involves a compromise between a holistic method of limiting the number of relevant studies across a larger number of variables and a reductionist method which can limit the review's relevance, utility, and value (Stewart et al., 2005).

To effectively discern between complex interventions, it is important to account for the contextual factors and sociocultural suitability that will affect the feasibility of the implementation of the interventions to be assessed (Booth et al., 2019). Using a framework provides the facility to structure the review research question by clarifying the critical focal topic concepts. The SPICE (Setting, Population, Intervention, Comparison, Evaluation) framework was used to provide structure for the research question (Booth, 2006) (Table 2).

*Table 2 SPICE framework criteria and application.*

| **Criteria** | **Application** |
|---|---|
| Setting | On the journey to or home from school, or applicable to this environment, and global or geographical location must apply to the UK environment. |
| Population | Schoolchildren or adolescents, under 18 years of age, at school or in further education, or applicable to this demographic. |
| Intervention | Air pollution reduction interventions. Air pollution exposure reduction interventions are defined as those applied to populations, groups, areas, jurisdictions, or institutions for the purpose of reducing potential child exposure to air pollution or are directly applicable or transferable to the school commute. Intervention examples in this respect include, but are not limited to, traffic-calming measures, schemes for alternative routes to school, building filtration systems, and urban greening. These approaches could be present in intervention strategies in other environments but should be included if they apply to the school commute (e.g., office commutes or traffic reduction interventions for a specific event). |
| Comparison | The comparison against a baseline or no intervention. Within this context, this refers to air pollution or traffic levels prior to the intervention. |
| Evaluation | The reduction of traffic, air pollution, or exposure when compared to the baseline or air pollution levels prior to the intervention. |

Using the specified criteria to structure and inform the research aims and objectives, the following research question has been constructed:

- What policies, interventions or strategies exist to reduce or mitigate potential air pollution exposure on the school commute?

## 3.4 Methods

### 3.4.1 Strategy for Synthesis

Methods and results were interpreted in terms of applicability to the school environment and their demonstrated reduction of TRAP or mitigation/reduction of TRAP exposure in a specific area/location. Interventions were required to be appropriate for application to the UK school commute (as defined in Section 1.1 Aims & Objectives). For example, studies that evidence mitigation of TRAP exposure by introducing different walking routes to work were considered acceptable. A study that corroborates improvements to air pollution exposure for shift workers undertaking different working hours would not be acceptable. The synthesis of results involved no minimum study number applied outside the identified criteria.

Mendeley Desktop (Version 1.19.4) was used for synthesis facilitation to compile and store articles from the first research phases (initial counts and abstract assessment). The subsequent full-text analysis phase was conducted using NVivo (Version 12.5.0.815).

Synthesised data included interventions and their effectiveness against baseline TRAP reduction or reduction/mitigation of exposure. Given the nature of the review, the level of reduction/mitigation was distinct to individual studies. Accordingly, results were combined where possible in terms of effectiveness regarding TRAP reduction or exposure reduction/mitigation. Given the nature of TRAP as a collection of many chemicals, direct comparisons were not possible between all synthesised studies. This was also the case for reduction methods through which human exposure was not quantifiable. Keeping these points under consideration, the synthesis only included those strategies, methods or interventions that showed demonstrable reductions of TRAP, traffic volume, or reduction/mitigation of exposure.

Additional analyses, such as sensitivity analyses or meta-analyses, were not conducted due to the relatively small number of studies procured and the practical problems associated with comparing the outcomes of different interventions. Instead, the existence of these processes within any included research was made explicit in the research summaries.

### 3.4.2 Search Criteria

Outcomes in terms of intervention effectiveness were synthesised. Interventions include those suitable for reducing traffic or TRAP exposure for children at the school gates or on the school commute compared to before the intervention. Only English language studies published between the years 2000 and 2020 were included to increase relevance to modern social, school, and traffic contexts. There were no restrictions to the types of study design eligible for inclusion. Studies based in the school building environment or context, or those applicable to reducing air pollution on the school commute, were considered valid for assessment.

### 3.4.3 Eligibility Criteria Summary

As outlined, the study characteristics were assessed using the SPICE framework and inclusion of studies in the English language, published in journals from the year 2000. English language studies were considered to be more (but not always) applicable to the UK school environment and studies from the current century provided a suitably recent approach to apply to the modern school context, and the status of journal publication ensured the peer-reviewed standing of the research.

### 3.4.4 Information Sources

Searches were performed on the following databases:

- Greenfile (EBSCO)

EBSCO's Greenfile is a free database that covers all aspects of human impact on the environment, providing articles on global warming, green building, pollution, sustainable agriculture, renewable energy, and recycling. The database draws connections between the environment and various ancillary disciplines, including agriculture, education, law, health, and technology.

- Google Scholar

Google Scholar facilitates broad searches for academic literature. Articles, books, thesis abstracts, online repositories, universities, and websites can all be searched by relevance.

Google Scholar ranks documents by weight, using the entire document text, where it was published, the author, and how often and recently it has been cited in academic literature. However, the full text’s availability depends on the access granted by the location at which the paper is held.

- ProQuest

ProQuest is a comprehensive and renowned database which comprises a searchable repository of dissertations and theses across a global network supported by contributing universities. ProQuest also comprises the official repository of the US Library of Congress.

- Sage Journals

SAGE is a publisher of academic books and journals. The database is searchable and consists of indexed summaries and abstracts as bibliographic records, in addition to complete texts of each journal article. Journal topics include humanities, health sciences, and social sciences.

- ScienceDirect

ScienceDirect is a database of full-text articles and chapters from over 11,000 books and 2,500 peer-reviewed journals. The intended audience of the database comprises researchers and librarians in life, health and physical sciences, and engineering. The database uses a federated search mechanism with a single search portal to search and retrieve results. ScienceDirect uses natural language searching and does not have a controlled vocabulary.

- Scopus

Scopus is Elsevier’s abstract and citation database of peer-reviewed literature, including scientific journals, conference proceedings and books.

- Taylor & Francis Online

Taylor & Francis Online is the content platform for the Taylor & Francis Group, providing online access to all published journals by the Taylor & Francis Group and by Routledge.

- Wiley

Wiley is a provider of content in scientific areas and scholarly research. The online repository provides a searchable database of content from over 1500 peer-reviewed multidisciplinary journals.

### 3.4.5 Data Extraction

Data extraction from study documents included the study design/methodology, the suitability of the mitigation or reduction measure to the school commute (if the study was not focussed on schools), and the outcome of measures against air pollution or traffic levels. The data was recorded in tabular form using Microsoft Excel (Version 1808). Studies with missing data were included based on the level of relevance, but the omitted data was noted.

Following deduplication, titles (+/- abstracts) retrieved from database searches were screened, and papers that clearly fell outside the pre-defined eligibility criteria were removed.

Shortlisted studies were subject to a full-text review to confirm that all match the full pre-documented review criteria. Mendeley Desktop (Version 1.19.8) was used for reference management throughout. Study flow and inclusion/exclusion at each stage were documented in PRISMA flow diagrams (Appendix B).

### 3.4.6 Risk of Bias

#### 3.4.6.1 Overview

Whilst PRISMA provides a standardised approach for conducting a systematic review, it was considered essential to apply additional strategies for risk of bias assessment, both in the selection process in the eligibility stage and within the methodologies of the selected primary studies. Given the solitary nature of the review process and its specificity to the current thesis, it was considered pertinent to employ these tools to ensure a standardised study selection and assessment process.

#### 3.4.6.2 Risk of Selection Bias

To ensure a systematised approach towards study selection in the eligibility stage, a range of checklists, such as the Newcastle-Ottawa Scale (NOS), were considered but were deemed unsuitable for use with the current review because of the rigidity of their application and their design focus on longitudinal studies (Luchini et al., 2017). The JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies was chosen as an appropriate approach to determine the suitability of each study for its inclusion or exclusion in the eligibility stage (JBI, 2022). Its ease of application and broad scope allowed it to be readily applied to a wide range of studies under review (Cuschieri, 2019).

#### 3.4.6.3 Risk of Bias in Primary Studies

Each study was judged for risk of bias in terms of its methods, ensuring that all entries relevant to the outcome were included in the outcome assessment and funding sources. Accordingly, these factors were assessed on the level of study methodology and outcome. Other considerations related to publication bias and the selectivity of reporting within studies. It was essential to take precautions against risks of bias in reporting these studies due to the risk of internal bias misleading the review.

Cochrane advises against using quality scales in Cochrane reviews but provides several tools to assess the existence of bias within selected studies for systematic reviews (Higgins, Altman & Sterne, 2022). Whilst several such tools exist, to provide this final check on the included primary studies, the ROBINS-I tool (Cochrane Methods, 2022) for non-randomised studies of interventions was used (Appendix D). This tool was considered the most applicable to the broad range of study types selected in the review as it assesses seven domains of bias: bias due to confounding, bias due to selection of participants, bias in classification of interventions, bias due to deviations from intended interventions, bias due to missing data, bias in the measurement of outcomes, and bias in the selection of the reported result. This assessment allows a structured judgement to be applied for each primary study and consideration when interpreting and reporting the outcomes in the synthesis (Higgins, Altman & Sterne, 2022).

### 3.4.7 Search Terms

The keywords within the research question were *Policies*, *Interventions*, *Mitigation*, *Reduction*, *Air Pollution*, and *Schools*. Corresponding synonyms for searching were identified as follows:

- Policies, strategies, policy, strategy, method.
- Interventions, mitigation measures.
- Reduction, decrease.
- Mitigation, prevention.
- Air pollution, traffic-related air pollution.
- Schools, educational establishments, school buildings.

### 3.4.8 Search Strategy Implementation

A primary Boolean string was constructed based on the keywords in the research question:

- (“air pollution” OR “air pollutant”) AND (“reduction” OR “mitigation”) AND (“intervention” OR “measure” OR “strategy”) AND (“school” OR “institution” OR “establishment”)

Whilst some databases permitted different search parameters, the search strategy and criteria remained the same for all databases for consistency. Superfluous words were removed to ensure operability within the 32-word limit imposed by Google and to maintain consistency. Plurals were also included where possible to encourage a greater return. Wildcards were added where appropriate to increase potential search results. The primary Boolean string was adjusted where necessary to make it suitable for searching within the specified parameters required by each database. Searching titles and abstracts was specified where this option was possible, and only peer-reviewed articles were included. In addition, only sources with the full text available online were included.

### 3.4.9 Screening, Eligibility & Inclusion

The screening process was the same for all journal searches. When searching within one journal, duplication should not occur unless articles report different aspects of the same studies. However, given the nature of the journal search platforms, some overlap exists whereby different journal database search engines may search the same journals. In some cases, the same studies were retrieved from two or more different databases. In these instances, duplicates were removed, and the most recent example of the study was retained. To identify duplicates for removal, all articles were compiled by reference alongside their relevant journal details in a spreadsheet and then alphabetised. Duplicates were removed using the duplicate removal function within Microsoft Excel. The list was then manually searched for duplicates that were subsequently removed.

Abstracts were then checked for relevance to the research question. If any implication of relevance to the research question existed, the study was retained, pending reading the entire study to determine relevance. The study was rejected if there was no relevance to the research question within the abstract.

The purpose of this process was to exclude non-relevant studies. Whilst some studies may have offered recommendations based on their findings, if these recommendations were not included in the abstract (i.e., deemed by the authors to be beyond the methodological scope of the research and untested directly), they were considered irrelevant to the research question.

## 3.5 Search Results

### 3.5.1 Study Selection

The study selection outcomes were recorded in individual flow diagrams for each database, and the details are summarised in Table 3.

*Table 3 Overview of the study selection process for all database searches.*

| **Phase** | **Greenfile** | **Google Scholar** | **ProQuest** | **Sage** | **Science Direct** | **Scopus** | **Taylor & Francis** | **Wiley** | **All Journals** |
|---|---|---|---|---|---|---|---|---|---|
| Identification | | | | | | | | | |
| Records Identified through database searching | 63 | 100 | 380 | 31 | 420 | 2000 | 1329 | 1211 | 5534 |
| Records after duplicates removed | 63 | 100 | 328 | 31 | 420 | 2000 | 1271 | 1097 | 5310 |
| Screening | | | | | | | | | |
| Records screened | 63 | 100 | 328 | 31 | 420 | 2000 | 1271 | 1097 | 5310 |
| Records excluded | 33 | 32 | 288 | 17 | 360 | 1962 | 1261 | 1089 | 5042 |
| Eligibility | | | | | | | | | |
| Full-text articles assessed for eligibility | 30 | 68 | 40 | 14 | 60 | 38 | 10 | 8 | 268 |
| Full-text articles excluded with reasons | 28 | 67 | 38 | 14 | 57 | 37 | 9 | 7 | 257 |
| Included | | | | | | | | | |
| Studies and articles included in the synthesis | 2 | 1 | 2 | 0 | 3 | 1 | 1 | 1 | 11 |

### 3.5.2 Summary

A standardised format was used for data extraction from the selected studies. Interventions were listed when they took prominence. However, many studies suggested or included additional interventions that were not part of the main study. These were disregarded unless they referenced another study, in which case that study was assessed for inclusion in the final synthesis by the same inclusion criteria. The data points extracted included, but were not necessarily limited to, those outlined in Table 4.

*Table 4 Data points for extraction.*

| Data Point | Summary |
|---|---|
| Citation | A simple citation referencing the study authors and year of publication. |
| Intervention | A brief description of the intervention. |
| Type | The type of intervention (active travel, campaigns & education, facemasks, fuel standards and protocols, legislation and taxation, anti-idling, car use disincentives, freight management, improved cycle & pedestrian facilitation, infrastructure, road greening, traffic flow improvement, traffic reduction, greening or rideshare). |
| Category | The broad category within which the intervention and type reside (behavioural, broad, road, and school interventions). |
| Aim | The key study aims and objectives. |
| Study Design. | A description of the methodological processes associated with the study. |
| Study Location. | If applicable, the location within which the study was conducted. |
| Sample Population/Data. | The nature of the sample population or data and where it was sourced. |
| Study Outcome. | The results of the study. |
| Recommendations. | Any recommendations made by the researchers based on the study results. |
| Study Strengths. | Positive aspects of the research or study design, such as easy replication of the methodology or precision of variable control. |
| Study Weaknesses. | Negative aspects of the research or study design, including study limitations that influenced or impacted the interpretation of application of the study results. |

The selected study interventions were categorised into the groups of behavioural interventions (mode shifts to cycling and walking, improved travel routes), broad interventions (public transport and vehicular improvements, low emission zones), road interventions (anti-idling, freight management, road greening), and school interventions (rideshare). The categories were determined by the nature of the intervention, although crossover existed between some interventions. The interventions were categorised by their best fit to similar interventions and the key societal or behavioural elements with which they could be most closely associated. The category within which a study was placed was selected based on the nature of the intervention, where it would occur, and the policy level at which its implementation would be delivered. The amounts within each category and subcategory, or type are summarised in Table 5.

*Table 5 Categorisation of synthesised interventions.*

| **Category** | **Sub-Category/Type** | **Number** |
|---|---|---|
| Behavioural Interventions | Active travel | 1 |
| | Improved travel routes | 1 |
| | Rideshare | 1 |
| | Anti-idling | 1 |
| Total | | 4 |
| Broad Interventions | Public transport | 1 |
| | Combination of vehicle improvements & LEZ | 1 |
| | Low emission zone | 1 |
| | Congestion charging zone | 1 |
| Total | | 4 |
| Road Interventions | Freight management | 1 |
| | Road greening | 2 |
| Total | | 3 |
| Overall Total | | 11 |

## 3.6 Discussion

### 3.6.1 Table of Interventions

The primary studies were tabulated and summarised to include the nature of the study, the intervention tested, and the resultant reduction of pollution or traffic associated with the intervention (Table 6).

*Table 6 Primary Studies & corresponding Interventions.*

| Citation | Category | Intervention | Measure | Traffic Reduction | Pollutant Reduction | Modelled/ Measured | Duration |
|---|---|---|---|---|---|---|---|
| Rojas-Rueda et al., 2012 | Behavioural Interventions | Active Travel | Mode shifts to active travel | 40% reduction in morning car trips | 0.14 μg/m$^3$ ($PM_{2.5}$) | Modelled (HIA) | Annual |
| Luo, Boriboonsomsin & Barth, 2018 | Behavioural Interventions | Active Travel | Improved travel routes | - | -44% inhaled $PM_{2.5}$ | Modelled (Combined) | Length of commute |
| Bistaffa et al., 2019 | Behavioural Interventions | Rideshare | Rideshare | -80.08% | -70.78% ($CO_2$) | Measured | - |
| Ryan et al., 2013 | Behavioural Interventions | Anti-idling | Anti-Idling | - | -3.12 ($PM_{2.5}$) | Measured | School day |
| Borrego et al., 2012 | Broad Interventions | Legislation | Public transport | - | -2.4% ($NO_x$) | Modelled (TAPM) | Annual |
| Duque et al., 2016 | Broad Interventions | Air Quality Action Plan | Combination of vehicle improvement and LEZ | - | -7.5% ($NO_2$) | Modelled (TAPM) | |
| Santos, Gómez-Losada & Pires, 2019 | Broad Interventions | Low Emission Zones | low emission zones (LEZ) | - | -29% ($PM_{10}$); 12% ($NO_2$) | Measured | 2009 to 2016 |
| Tonne et al., 2008 | Broad Interventions | Low Emission Zones | Congestion charging scheme (CCS) | - | -0.73 μg/m$^3$ ($NO_2$); -0.24 μg/m$^3$ ($PM_{10}$) | Modelled (ADMS Roads) | Annual |
| Pérez-Martínez, De Fátima Andrade & De Miranda, 2017 | Road Interventions | Freight Management | Freight management | 72% HV reduction | -43% ($NO_X$); -28% ($PM_{10}$) | Measured | 2008 to 2012 |
| Al-Dabbous & Kumar, 2014 | Road Interventions | Road Greening | Road greening | - | -37% PNC (5-560 nm particles) | Measured | Six days between 2012 and 2013 |
| Jeanjean et al., 2017 | Road Interventions | Green Infrastructure | Road greening | - | -9% ($PM_{2.5}$ dispersion) | Modelled (OpenFOAM) | - |

### 3.6.2 Behavioural Interventions

Active travel was the subject of two studies included in the current review. These studies assessed cycling and walking as alternatives to car travel (Rojas-Rueda et al., 2012) and the development of improved travel routes (Luo, Boriboonsomsin & Barth, 2018).

Rojas-Rueda et al. (2012) conducted a health impact assessment (HIA) and identified a 40% reduction in car trips, starting and ending in Barcelona, as their most impactful strategy for the improvement of health impacts in the city. The drivers who shifted modes to active travel would generate annual health benefits to the city's population (n=1,630,494) of 10.03 fewer deaths due to reduced exposure to $PM_{2.5}$. However, the study also recognised the increased inhalation of particulate as a confounding factor for potential exposure for those walking or cycling and increased breathing rates due to physical activity. A method for mitigating these risks was presented using a suburb of Riverside, California as a case study. It was found that if suitable low-inhalation routes were identified, they could reduce morning $PM_{2.5}$ inhalation among pedestrians by 48% and 44% in the afternoon. Such a strategy would be particularly suited to schoolchildren travelling to school, although it depends on the identification of suitable low-inhalation routes for each school location, and indeed for each school child and the circumstances of their individual travel. Combining a low-inhalation route with a walking buses scheme (see Smith et al., 2015; Collins & Kearns, 2010; Mackett et al., 2005; Mackett et al., 2003) may be a suitable method through which to safely optimise identified low-pollution routes for more significant numbers of children who may be travelling from different regions around their target school.

Ridesharing allows people to arrange shared rides with others using their own cars to take trips to common destinations. Benefits include traffic and noise reduction and reduced travel costs for the participants. Rideshare schemes have also been shown to be effective methods for reducing traffic during busy periods. Despite the positives of ridesharing, the study by Bistaffa et al. (2019) identified that uptake in such schemes is too low to achieve many of these benefits, stating that regulatory authorities lack effective incentive policies because of an inability to estimate the costs and benefits of the scheme, and this is a crucial reason for the lack of public engagement. The study developed an algorithm to assist authorities in decision-making by highlighting the associated benefits of $CO_2$ reduction, noise pollution and traffic congestion. When applied to a real-world dataset, the approach produced $CO_2$ reductions of 70.78% with a possible traffic congestion reduction of 80.08%. Ridesharing schemes have the potential to reduce traffic at busy times around schools and could be particularly effective given the common destination for all involved travellers. The ridesharing benefits would extend to most parents and children, who would save money and time whilst reducing air pollution on the school run. Schemes could also be extended to school trips, providing further economic savings for the schools.

Ryan et al. (2013) investigated an anti-idling campaign for school buses to determine the effect of idling traffic on particulate pollution at selected schools. At the school with the most buses, the study identified a $PM_{2.5}$ reduction of 3.12 $\mu g/m^3$ following the campaign. Misconceptions around idling have persisted for some time, such as the belief that it is more beneficial to idle a vehicle than turn it off (Carrico et al., 2009), but if these views and behaviours can be changed, decreasing the number of idling vehicles outside schools has the potential to reduce air pollution exposure for children in the locality (Burgess, 2019).

### 3.6.3 Broad Interventions

To determine the effectiveness of legislation on air pollution reduction, air pollution control policies were analysed by Borrego et al. (2012) whilst Duque et al. (2016) assessed a suite of simulated scenarios as part of an air quality plan. Borrego et al. (2012) modelled supra-municipal measures using The Air Pollution Model (TAPM), which included improvements to the public transport system, generating a 2% annual $NO_X$ emissions reduction. When combined with the introduction of low-emission vehicles for commercial passenger and freight transport, the reduction increased to 2.4%. Although not without challenges, improvements to public transport systems are commonly regarded as a positive approach towards a range of transport issues (Wang et al., 2018). School buses, in this respect, can be considered a valid option for alleviating peak morning traffic (Orejuela & Hernandez, 2019). Whilst factors such as exposure to self-pollution for children onboard school buses remain an issue (Austin, Heutel & Kreisman, 2019; Beatty & Shimshack, 2011; Marshall & Behrentz, 2005), improvements to school buses, including the adoption of clean fuels (Adar et al., 2015), cabin filtration systems (Lee, Fung & Zhu, 2015), and retrofit filtration systems (Zhang & Zhu, 2011) can all reduce the associated risks of pollutant exposure.

Several scenarios were modelled using TAPM by Duque et al. (2016). Scenario 1 reduced $NO_2$ levels by 4.5%, whilst Scenario 2 only showed an improvement of 3% specific to the local implementation area. However, the only combination which influenced $NO_2$ concentrations comprised the replacement of 10% of high-emission vehicles (those below the

EURO3 standard) with hybrid models (Scenario 1), and the introduction of a low-emission zone (LEZ) in a particularly polluted region of Porto City whilst restricting access to vehicles below EURO3 (Scenario 2). This strategy could show further improvements if implemented with the modern EURO6 standard[3], and a form of LEZ could be readily applied to the school environment to reduce traffic-related pollutants around school buildings, particularly during morning arrivals.

The mid-term effectiveness of LEZs was assessed by Santos, Gómez-Losada & Pires (2019), who identified air pollution reductions as a consequence of the Lisbon LEZ implementation between 2009 and 2016. Over the study period, both $PM_{10}$ and $NO_2$ were reduced by 29% and 12%, respectively. Tonne et al. (2008) used dispersion modelling to assess the impact of the 2003 London CCS. Modest reductions of annual average $PM_{10}$ (-0.24 $\mu g/m^3$) and $NO_2$ (-0.73 $\mu g/m^3$) were identified within the charging zone for the year following its implementation.

These findings support the introduction of traffic-free zones around schools during busy periods to reduce the area's traffic burden and associated pollution. The introduction of a fee-based system, or the restriction of only older, more polluting cars, may be problematic if imposed around schools by creating an area of exclusivity which would penalise poorer parents. In addition, such a zone should be of sufficient distance around the school to facilitate the installation of perimeter locations for parents who still drive to drop-off their children without creating new highly polluted congregative areas (the end of the school access road, for example).

### 3.6.4 Road Interventions

Traffic restrictions on polluting vehicles have been effective in the reduction of pollution. Pérez-Martínez, De Fátima Andrade & De Miranda (2017) examined the application of urban transport policies in São Paulo, Brazil. Following the introduction of traffic restrictions on diesel-fuelled heavy vehicles (HVs), reductions of $NO_X$ (43%) and $PM_{10}$ (28%) were measured after a 72% reduction in HV traffic in the study area. The study results indicate that such restrictions are effective measures to avoid increasing traffic and reduce pollution. Introducing similar measures around schools at busy times could also be effective,

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[3] The EURO3 (EC2000) standard limited diesel vehicle $NO_x$ emissions to 0.5 g/km, whilst the EURO6 standard limits $NO_x$ emissions to 0.08 g/km.

particularly as part of a broader low-emission zone strategy, for reducing potential child exposure to harmful pollutants from the most polluting vehicles (Holst et al., 2022; Patel et al., 2009).

Road greening for air pollution reduction presents a range of popular solutions that have received much attention in the literature. The introduction of vegetation barriers to urban areas has generally produced the most promising results for reducing pollution exposure (Jeanjean et al., 2017; Al-Dabbous & Kumar, 2014; Speak et al., 2012). The restriction of nanoparticles by roadside vegetation barriers was examined by Al-Dabbous & Kumar (2014), who found a particle number concentration (PNC) reduction of 37% (5-560 nm particles) during cross-road winds, demonstrating the potential for vegetation barriers to limit pedestrian exposure to near-road nanoparticles. The study by Jeanjean et al. (2016) used OpenFOAM (Open Source Field Operation and Manipulation) computational fluid dynamics (CFD) software to model the $PM_{2.5}$ reduction effectiveness of trees and grass using city-scale simulations. The study found that the aerodynamic effects of trees for winds at speeds greater than 2 m $s^{-1}$ produced a 9% reduction of $PM_{2.5}$. This effectiveness was far greater than their deposition abilities, which only produced a reduction of 2.8%. Green infrastructures are a desirable method for mitigating particle pollution exposure for pedestrians by providing a barrier between them and road traffic although they are not a solution for removing air pollution from a location. In addition, the vegetation species determine a broad range of $PM_{2.5}$ reduction potential (Al-Dabbous & Kumar, 2014). For deciduous varieties, the greatest reductions would not be possible during winter and much of spring, undermining their effectiveness in the school environment. Whilst the study results show that urban greening may have a potential role in citywide planning for air quality, this requires effective coordination with a consideration of traffic infrastructure and implementation contexts.

### 3.6.5 Synthesis of Selected Interventions

TRAP is an increasingly important environmental issue, and a range of interventions and measures have been investigated to determine their effectiveness in reducing human exposure to and the production of these harmful contaminants. Several of these interventions are suited to the school gates and school-run scenarios, both of which see children exposed to high levels of daily pollution due to rush hour traffic.

Research on reducing air pollution during school travel has highlighted active travel as an attractive method to reduce traffic and potential child exposure. Rojas-Rueda et al. (2012)

assessed the benefits of mode shifts from car travel to cycling and public transport, finding that a 40% reduction in car journeys could result in fewer deaths due to reduced exposure to $PM_{2.5}$. Nevertheless, there remains concern that the benefits of physical activity may be compromised by the greater potential for pollutant exposure due to proximity to emission sources (Rojas-Rueda et al., 2012) and an increased breathing rate due to physical exercise (Luo, Boriboonsomsin & Barth, 2018). To address the issue of increased pollutant inhalation during peak traffic, Luo, Boriboonsomsin & Barth (2018) assessed alternative walking routes as a means through which to reduce exposure, finding that suitable alternative routes could reduce $PM_{2.5}$ inhalation by 48% (morning) and 44% (afternoon). Contrastingly, anti-idling strategies for school buses were examined (Ryan et al., 2013) to reduce potential child exposure at the school gates, with comparatively smaller $PM_{2.5}$ reductions (3.12 $\mu g/m^3$).

However, active travel is not necessarily suitable or possible for everyone, and for those who are required to drive to school, ridesharing is proposed by Bistaffa et al. (2019) as a viable and attractive measure, albeit one that is lacking in potential due to low levels of public engagement. An algorithm applied to real-world data showed a reduction of traffic congestion of 80.08%, demonstrating the potential for rideshare to reduce school traffic at peak times.

Studies have also demonstrated the benefits of targeted legislation for reducing potential child exposure to air pollution and the effectiveness of LEZs for reducing traffic in specific areas. These efforts have taken several forms, including introducing legislation for public transport, freight management and a combination of measures, including LEZ. Highlighting the importance of legislation for reducing air pollution, public transport systems were assessed by Borrego et al. (2012), who identified an achievable reduction of 2.4% when combined with the introduction of low-emission vehicles, supporting the findings of Pérez-Martínez, De Fátima Andrade & De Miranda (2017).

Studies focused on the benefits of LEZ commonly assess the effectiveness of existing implementations of systems. Tonne et al. (2008) determined the effectiveness of the 2003 London Congestion Charging Scheme (CCS), using dispersion modelling to identify modest annual $PM_{10}$ (0.24 $\mu g/m^3$) and $NO_2$ (0.73 $\mu g/m^3$) reductions for the year after implementation. A later study by Santos, Gómez-Losada & Pires (2019) found more promising results in their assessment of the Lisbon LEZ between 2009 and 2016, with a reduction of both $PM_{10}$ (29%) and $NO_2$ (12%). A combined approach was used by Duque et al. (2016) in Porto City to assess the effectiveness of the replacement of 10% of vehicles below EURO3 standard with hybrids and the introduction of an LEZ with restricted access to vehicles below EURO3, producing $NO_2$ reductions of 4.5% and 3%, respectively.

Research has assessed road greening measures for reducing air pollution exposure, which are most effective when used as a barrier between the exposure source and the receptor. Al-Dabbous & Kumar (2014) examined the effectiveness of vegetation barriers in urban areas for the restriction of nanoparticles, finding a reduction of 37%. This outcome was supported by the study by Jeanjean et al. (2016), who modelled the $PM_{2.5}$ reduction capabilities of trees, finding that their aerodynamic effects were more effective (9%) than their capacity for deposition (2.8%).

### 3.7 Limitations

#### 3.7.1 Limitations of the Included Evidence

Research articles can vary in quality and accordingly, systematic reviews are significant undertakings. The current systematic review used a clearly stated objective, pre-defined criteria for study eligibility, and a reproducible and explicit methodology to minimise bias in the included evidence and to respond to a predefined research question. The search was systematised using the PRISMA framework and attempted to identify all relevant studies, and an assessment of the included studies was made to confirm the validity of the findings and identify any risk of bias. The included studies also systematically reported and synthesised their findings and characteristics. Given the nature of the current review, a meta-analysis was not possible. This was because the review intended to identify studies that had proven strategies and interventions for reducing pollution, or potential child exposure to pollution, associated with school and school travel. The broad range of methods through which this could be achieved means that they are not readily comparable in terms of effectiveness. Whilst the review was suitable for its specific purpose, future reviews intending to provide a meta-analysis of identified methods should adopt a narrower approach to compare findings in this fashion effectively. Through this more targeted approach, statistical methods could be applied to summarise the results of independent studies, providing a greater precision of estimates of the effects of the included strategies. This approach would also permit an analysis beyond integration and critique and facilitate a secondary analysis of studies. In this respect, the advantages of a meta-analysis are clear and would permit greater objectivity in the evaluation of the research findings. However, given that not all the retrieved studies had sufficient evidence to permit meta-analyses and the differences between the mitigation strategies, the integrative review was considered the more appropriate strategy.

### 3.7.2 Limitations of the Review Processes

To ensure the quality of the current systematic review, great care was taken to retrieve and critically assess each included study. The findings from the studies were synthesised in a structured manner to both minimise bias and to present a balanced summary of findings with explicit mention of any limitations in the evidence. The current review provided a method through which relevant research evidence could be summarised and positioned in terms of significance. Accordingly, the quality of the review is determined by the quality of the included studies, and should any fundamental flaws exist in the methodology of the included studies, and the pooled analyses will perpetuate these flaws (Egger, Davey-Smith & Altman, 2008). For example, whilst the excessive publication of multiple articles from a single dataset is commonly discouraged (Watson, et al., 2014), the practice still occurs (see Kelly et al., 2011a; Kelly et al., 2011b). Another pertinent issue is that positive and significant research is more likely to be published (Egger, Davey-Smith & Altman, 2008), and therefore insignificant or negative findings are less likely to be included in systematic reviews. The current review intended to find studies that identified effective methods to reduce potential child exposure to harmful pollutants. However, the included studies may have antitheses that were not made available for the aforementioned reason and due to the search methodology.

Research has also shown that English language journals are more likely to publish studies with positive than negative findings (Egger, Davey-Smith & Altman, 2008; Stern & Simes, 1997), and studies with positive results are more likely to be published in English language journals (Egger, Dickersin & Davey-Smith, 2001). Accordingly, the direction and magnitude of research results may determine the effect of results in the summary of a quantitative review. Positive and significant findings bias can also lead to publication delays for results. Median publication times for insignificant results have been estimated at eight years, compared to 4.8 years for positive findings (Egger, Davey-Smith & Altman, 2008). These delays could lead to a systematic review omitting studies if it is not updated periodically.

Concerted efforts were made in the current review to ensure that comprehensive literature searches were made to retrieve all relevant articles published within the search criteria and to minimise the possibility that any pertinent articles or studies were missed. Principle limitations, such as the availability of databases and their search protocols, exist in common with other review approaches (Hemmelmann & Ziegler, 2011), as does the bias towards study publication with positive results. Those only published in English can restrict the studies available to the review (Gopalakrishnan & Ganeshkumar, 2013) whilst other limitations can arise from the focus of the review process, which can potentially become so narrow that it holds little value.

The current review was perhaps most limited by being carried out by a sole researcher. Whilst measures were explicitly undertaken to minimise selection bias, this may be more effectively reduced by having two or more reviewers who can independently review all retrieved citations (Whiting et al., 2016). In addition, citation bias existed when searching the bibliographies of included articles to locate further studies that met the criteria for inclusion (Higgins et al., 2019). To mitigate citation bias, the only studies included in this fashion were explicitly stated in the retrieved research and fully met the research criteria for the current review. A systematised process of appraisal accompanied this process. Given that the study selection and data extraction were not performed in duplicate (by two reviewers), the study receives an overall AMSTAR (A MeaSurement Tool to Assess systematic Reviews) review quality rating of ‘moderate’ (AMSTAR, 2022).

### 3.8 Conclusion

A systematic review was conducted to source reduction methods and strategies that could be applied to the school environment to reduce potential child exposure to harmful TRAP on the school run and at associated congregative periods at the school gates.

The implications of the current review findings for practice, policy, and future research are primarily centred around reducing car use in the vicinity of schools and the school commute. This undertaking can be facilitated by anti-idling campaigns and strategies, the closure of roads around schools, and the limitation of vehicular travel around schools altogether (for example, clean air zones or low emission zones). Other areas of exploration for reducing TRAP exposure include greening strategies, which vary in effectiveness and implementation.

Given that several of the selected interventions are from studies in countries other than the UK, there are several notable challenges associated with their applicability to the UK context. Firstly, the UK has a unique climate and geography, with varying weather patterns, topography, and urbanisation levels, which could impact the effectiveness of the interventions within this environment. For example, wind patterns, which play a crucial role in air pollution dispersion, can vary greatly between the UK and other countries, making interventions that are effective in one location less so in another (Hoek et al., 2008). The UK also has a well-developed transport system, with a high level of car ownership and extensive road networks, which could make it challenging to implement the selected interventions, which are mostly aimed at reducing vehicle use (Grote, Waterson & Rudolph, 2021). It is also important to consider that public attitudes and behaviours towards air pollution can vary between countries and regions, which could further impact the success of the interventions in the UK context. For example, there is a strong cultural attachment to car ownership in the UK and a resistance to changes in travel behaviour, which could make it difficult to implement interventions aimed at reducing vehicle use (Mehdizadeh et al., 2017). Whilst it is important to consider these challenges, given the effectiveness of the interventions within their own contexts and their feasible applicability to the UK, they were considered suitable for exploration in the forthcoming modelling phase of the current research (Chapter 6: Intervention Modelling). In addition, the rigour of the systematic review process provides further justification for the use of these interventions, all of which have satisfied the required review criteria to demonstrate their potential to reduce TRAP concentrations or exposure to TRAP against a baseline.

The review findings have demonstrated that whilst strategies exist for reducing or mitigating exposure, such as improved travel routes, LEZ implementation, and urban greening, all studies have indicated that traffic volume presents the greatest challenge to overcome. These themes are consistent in the findings and provide a suitable platform for further research.

# 4.0 Stakeholder Survey

## 4.1 Chapter Overview

The findings of the systematic literature review were used to inform the development of a stakeholder survey. The survey comprised the dissemination of a questionnaire for key stakeholders at schools in England. The aim of the questionnaire was to gather primary data comprising the opinions and experiences of those involved in the school commute and for the ratification of the researched interventions and mitigation strategies. Responses from the questionnaire were used to determine key stakeholder attitudes to the interventions and strategies that would be most effective for the reduction of potential child exposure to TRAPs.

The strategy used the findings from the initial literature and systematic reviews to inform the construction of a questionnaire to co-design solutions and strategies with key stakeholders and experts. This approach provided the opportunity to determine the opinions of a large number of stakeholders in a broad set of contexts. The questionnaire was delivered to over 20 thousand schools in England (with an expected return of approximately 10%). The questionnaire responses helped ratify the design of strategies for reducing and mitigating potential child exposure to air pollution at schools.

## 4.2 Survey Design

### 4.2.1 Overview

The survey development began with sourcing all emails for schools in England, made available by a freedom of information request. The contact list was compiled and validated by removing duplicates and incomplete or defective entries. The questionnaire was constructed using Qualtrics software and included demographic and air pollution questions. The demographic questions related to the relevance of the respondents to the issues (for example, parent or teacher status, and the number of children) and broader demographic questions to assess whether the responses are representative of the population of interest (for example, ethnicity and level of education). Air pollution questions were compiled concerning interventions for the mitigation of exposure to air quality and were based on the findings of the literature and systematic reviews. The questionnaire gained ethical approval, and a pilot was distributed to the UWE Bristol Faculty of Environment and Technology. Once feedback was addressed, the questionnaire was distributed to the email list using the distribution function in Qualtrics.

### 4.2.2 Contact List Procurement

Email addresses for all schools in England were procured via an existing freedom of information request (WDTK, 2020). Whilst it would have been desirable to disseminate the questionnaire to all schools in the UK, the required contact email data were unavailable and could not be sourced in time for the survey timeline. The England school email addresses were to be used to invite people to participate in the survey. The procurement requested a list of schools in England with accompanying email addresses and was satisfied under the Freedom of Information Act 2000. All the procured information is also freely available at the Get Information About Schools Website (GOV.UK, 2020b) as of the 3rd of March 2020 and comprises a standard extraction of all educational establishments in England. The list contained no personal data, such as names and email addresses of head teachers, that includes third-party personal data, which is withheld information under Section 40(2) (personal data). Accordingly, personal data in this respect relates to any living individual identifiable from that data or from that data and any other information which can come into or is likely to be in possession of the requestor. Any disclosure of such information would be considered ‘unfair’, and a contravention of several data protection principles identified by the Data Protection Act 1998. In this respect, the likely expectations of the data subject are that their information is not and would not be disclosed to any others, in addition to the effect of such disclosure on the data subject. As such, Section 40(2) specifies an absolute exemption and is not subject to the criteria of the public interest test. The email list procured remains protected by copyright but is free for uses such as private study, non-commercial research, and any other purposes authorised by exceptions in current copyright law.

The Department for Education is responsible for education services in England and does not hold information for educational establishments in Wales, Scotland, and Northern Ireland. Whilst this information can be made available by request, it was not considered necessary for the scope of the current investigation.

### 4.2.3 Contact List Validation

It was important to mitigate against the possibility of duplicate or invalid emails to minimise the risk of spam filtering when sending emails in this volume. The contact list was opened in

Microsoft Excel (Microsoft Office Professional Plus 2019). Firstly, ‘Find and Select/Go to Special’ was selected, highlighting all blank rows, which were subsequently deleted. Email addresses are composed of the username, the ‘at’ symbol (@), and the domain. The Data Validation feature in Excel allows the validity of the emails to be determined based on this principle. Under the Settings tab, in the ‘Data Validation’ dialogue box, ‘Custom’ was selected from the ‘Allow’ drop-down menu. The formula ‘=ISNUMBER(MATCH("*@*.?*",A2,0))’ (where A2 is the first cell of the column containing the email list) was then used to validate the entries, and any invalid entries were deleted. The original list included 24,921 entries and, following validation, this was reduced to 24,009.

### 4.2.4 Questionnaire Construction

The questionnaire was constructed in Qualtrics and comprised a consent page, demographic questions, and questions about the respondent’s attitudes and experiences towards air pollution and associated mitigation interventions. Prior to the demographic question block was an introduction and consent page detailing the objectives of the survey, the anonymity of the collected data, and some brief guidance regarding generalised answering dependent on school contexts. This page also provided an opportunity for the respondent to confirm their consent to partake by clicking to proceed with the questionnaire. Display and response logic was also included to tailor the flow of the questionnaire, dependent on the responses provided (Appendix E).

### 4.2.5 Demographic Questions

Demographic data was considered imperative for the questionnaire, as any population’s requirements cannot be measured or met without sufficient knowledge of its characteristics (Table 7). Whilst the questionnaires were entirely anonymous, it is important to know some specifics about those responding, as this would allow the identification of a representative sample population. The procurement of relevant demographic information also enables the differentiation between sub-groups of responders. This segmentation holds the possibility of providing insights that may be missed when only assessing aggregate data.

*Table 7 Demographic survey questions.*

| Number | Question |
|---|---|
| Q1 | What is your age? |
| Q2 | What is the first part of your postcode? |
| Q3 | Please choose one option that best describes your ethnic group or background. |
| Q4 | What is the highest level of education you have completed? |
| Q5 | What best describes your school affiliation? |
| Q6 | How many children do you have? |

It is also important to procure a substantial sample to draw any statistically meaningful conclusions. Should the sample be of an insufficient size, the differentiation between any socio-demographic sub-categories or groups may reduce samples to less suitable sizes for drawing meaningful conclusions. In addition, socio-demographic questions will significantly lengthen the questionnaire. As demonstrated in previous research (Krosnick, 2018), a questionnaire’s dropout rate positively correlates with its length. It is also the case that participants may become concerned if they are required to answer several questions they consider to be identifying and could compromise the anonymity of the questionnaire or if they feel that the inclusion of specific questions may be an invasion of their privacy (Lietz, 2010).

In terms of positioning, the conventional thinking was to place demographic questions at the end of the questionnaire (Oppenheim, 1992; Converse & Presser, 1986). The reasoning behind this was that, if these questions were placed at the start the participants may hesitate, become irritated, or abandon the questionnaire. Additional arguments maintain that the answers of responders may be compromised if they know that their socio-demographic information, such as race or gender, is also under consideration. This situation is known as the ‘stereotype threat’, when the responder undergoes concerns or anxiety in situations which carry the potential to confirm negative stereotypes about a particular social group (Gilovich et al., 2006). Should a respondent belong to a social group that is negatively stereotyped, the knowledge that their social group is known to the researcher could compromise their responses. This supports the reasoning that socio-demographic questions should be placed at the end of the questionnaire to ensure that this phenomenon does not affect the results. However, more recent research indicates that positioning socio-demographic questions at the start of a questionnaire can increase the response rate to these questions (Teclaw, Price & Osatuke, 2012). The arguments posit that participants are more likely to lose interest in a questionnaire and drop out before the closing demographic questions, which go unanswered in these situations, regardless of whether responses are required before proceeding. Placing demographic questions at the start of the questionnaire ensures that they are more likely to be answered. Resultantly, given the importance of demographic information, it is now commonly considered appropriate for these questions should be placed at the start of the questionnaire.

Within this philosophy, there are also several socio-demographic questions that were desirable but unnecessary and would only serve to bloat the questionnaire and threaten response rates. Ensuring a suitable balance between useful socio-demographic questions with which a worthwhile responder profile can be constructed, and overall questionnaire length is important. For this reason, it was decided that it was unnecessary to ask about the sex of the participant. Whilst this information would have been desirable, it was unnecessary given the survey aims and may have risked stigmatising participants leading to their abandonment of the questionnaire (Gilovich et al., 2006). The inclusion of a question asking the number of children of the respondents was considered preferable to sex, as this would provide greater insight into the respondents' attitudes towards air pollution and child health from a parental and non-parental perspective. Given the importance of demographics in the current questionnaire, all socio-demographic questions were confined to the initial questionnaire phase and only included those necessary for the study's aims. The selection of relevant demographic questions could then ensure the procurement of meaningful and actionable insights.

A broad number of scientific disciplines have demonstrated that opinions differ between different age groups on many topics. Under ideal circumstances, the age could be expressed in numbers of years or by taking a birth date, each of which provides data as a continuous variable for analyses. This variable allows the expression of differences in magnitude and the recoding of ages into different age categories. However, each of these methods can be considered by the respondent as requesting the disclosure of personal or sensitive information, so non-overlapping, equal age categories are preferable. For this reason, the age categories used in the current questionnaire were 18-24, 25-34, 35-44, 45-54, 55-64, and 65 and over.

Apparent differences in opinion are also evident across many topics between participants of different levels of education. In addition, asked as 'what is the highest level of education you have completed?', the level of education can be used as a proxy for income (Brace, 2018). This is useful as asking about income can present problems when participants do not wish to disclose this information, even when the questionnaire is anonymous. Accordingly, questions about income can be excluded in favour of an education question to maximise respondent retention. The educational level can also provide an impression of socio-economic status. Whilst educational systems are rarely the same in practice across different countries, the current questionnaire includes only contacts in England, which is more conducive to a uniform context for participants. To answer this question, the questionnaire used the educational category responses of 'None', 'Secondary School', 'Bachelor', 'Master', 'PhD', and 'Trade/Apprenticeship'.

Whilst no personally identifiable information was collected, it was useful for the study to identify the region where the participants resided and commuted. This was determined by a request to enter the first part of their postcode, or the 'out-code', which is sufficiently broad in the catchment to ensure anonymity was maintained and the respondent was comfortable continuing the questionnaire honestly. The postcode map (including coordinates for GIS mapping purposes) was constructed from data sourced from Ordinance Survey data (OS, 2021). The UK postal system utilises postcodes to automate mail sorting and delivery. Each postcode is composed of two parts, the out-code (the first part before the space) and the in-code (the second part, following the space). There are approximately 2971 out-codes, of approximately 1.74 million full postcodes. As the most significant part of the postcode, the out-code can be used to determine the respondent's approximate area (ILR, 2012). Accordingly, the out-code still allows the data to be applied to the subdivisions of England commonly used for regional classification and the determination of deprivation.

The participants were also asked how many children they had. This valuable data can help determine parental and non-parental attitudes towards different transport modes, such as car sharing, public transport use, and walking to school.

### 4.2.6 Air Pollution Questions

The second block of the questionnaire addressed air pollution and mitigation interventions related to the respondent's experience (Table 8). The first question addressed the respondent's concerns regarding the effects of air pollution on the health of pupils at the school with which they were concerned or affiliated. Responses to this question were provided on a Likert scale. The benefit of a Likert scale in this context is that it permits a degree of opinion, allowing quantitative data to be obtained for an emotional question (Saris & Gallhofer, 2014). Should the concern be expressed in response to this question, display logic took the respondent to a follow-up question requesting specification of reasons for the concern, including the school being near or on a main road, many idling cars outside the school, air pollution monitors showing that air pollution levels at the school are constantly high, levels of respiratory illnesses (such as asthma) rising among school pupils or general concerns due to media coverage. The respondent could then specify that they did not know or could detail 'other', facilitating the addition of a reason not listed.

*Table 8 Air pollution survey questions.*

| Number | Question |
|---|---|
| Q7 | How concerned are you about the effects of air pollution on pupils' school health? |
| Q8 | Why are you concerned (select all that apply)? |
| Q8 | Why are you unconcerned (select all that apply)? |
| Q9 | What has your school/community/council/other done to improve school air quality? |
| Q10a | What measures do you think would be effective for improving air quality at school? |
| Q10b | What would be the most effective measure for improving air quality at school? |
| Q11a | What are the biggest obstacles to improving air quality and/or reducing car use at school? |
| Q11b | What is the biggest obstacle to improving air quality at school? |
| Q12 | Who do you consider to be the most important for supporting efforts to improve school air quality? |
| QZ | Thank you for completing this survey. Please feel free to add any additional comments below. |

Should the respondent have specified that they were not concerned about air pollution, a display logic took them to a follow-up question requesting specifications of the reasons why they were not concerned. The options provided a contrast to the options for the concerned parties, such as the school being in a rural area, little traffic near the school, and the majority of pupils using active travel modes (walking, scooting or cycling) to get to school, air pollution monitoring showing that air pollution levels at the school are consistently low, or that levels of respiratory illnesses (such as asthma) are low among pupils at the school. The respondent could again specify that they did not know or had the option to detail 'other', which permitted the addition of a reason not listed. An additional response logic was included so the options 'Don't know' and 'Not applicable' were selectable only as exclusive answers.

Responses to both follow-up questions returned the respondent to the main thread of the questionnaire, presenting a question asking what their school of concern has done to improve school air quality (see Appendix E). The respondent was prompted to select all applicable options. An additional response logic is imposed so that the options ‘Don’t know’ and ‘Not applicable’ are selectable only as exclusive answers. The next question requests details of interventions or strategies that the respondent feels would be most effective for the improvement of air quality at their school. The respondent was prompted to select as many options as they wished. The systematic literature review has determined all interventions from both questions to be suitable for potentially reducing child exposure to TRAP in the vicinity of schools.

The penultimate question requests opinions regarding the biggest obstacles the respondent considers to more children cycling, walking, or scooting to school. The final question requests information regarding which body the respondent considers to be most responsible for the provision of support for the initiation of changes to reduce air pollution outside schools. The question provides the option to select only one answer from local authorities, the local community, the national government, parents, school staff, campaign groups or none of the aforementioned. The respondent can also specify here that they do not know or have the option to detail ‘other’, which allows the addition of a reason not listed.

### 4.2.7 Ethics

An application for ethical approval was made to the Faculty Research Ethics Committee on the 15th of October 2019 and was approved on the 28th of November 2019. The ethical approval submission comprised the application, a data management plan, a consent form, a participant information sheet, a research participant privacy notice, and a sample questionnaire.

An amendment to the original application was approved on the 17th of December 2020 and detailed the shift from the Delphi approach to a single questionnaire to be disseminated to schools in England. The new application comprised a data management plan (Appendix F) and a participant information and privacy notice detailing the ethics approval from the university (Appendix G).

### 4.2.8 Pilot

An initial survey run was delivered to members of the Faculty of Environment and Technology (FET) at UWE Bristol to determine any design flaws and highlight any possible improvements, inconsistencies and errors in the questionnaire content and logic (Appendix H). The survey link was sent via the faculty email group and was posted to various faculty-related social media groups. A total of 67 responses were procured from the piloting, and minor issues were addressed (Appendix I).

### 4.2.9 Distribution

Once all issues were addressed and the content and logic of the questionnaire were sound, it was distributed using the Qualtrics survey distribution feature. Whilst other methods were considered, such as the use of a third-party email distribution system, the Qualtrics distribution was preferable given its functionality, the ability to log and track the distributions within the platform, and the fact that a trusted IP (Internet Protocol) address used by the distribution was more likely to be granted permission through spam filters (Sahu, 2021). At this point, a final survey link was produced, enabling the production of a generic invitation email message, an email invitation for schools, a follow-up email to schools, generic social media post templates, and an end-of-survey message with a shareable link (Appendices J-N).

The invitations and end-of-survey messages encouraged the participants to share the survey with any other relevant parties they deemed appropriate. This method of distribution uses snowball sampling and uses the initially established contacts to gain further participants, who can then go on to distribute the survey to additional participants (Etikan, Alkassim & Abubakar, 2016; Noy, 2008). Limitations of the snowball sampling method include stalling or failure to generate sufficient participation numbers (Handcock & Gile, 2011). However, given the large number of initial contacts for the survey distribution, this was not a concern. Rather, snowball sampling would encourage participation from stakeholders in addition to those reached via the initial distribution.

### 4.2.10 Delivery Timeline

Figure 2 depicts the delivery timeline established for the distribution of the questionnaire and the closure of data collection.

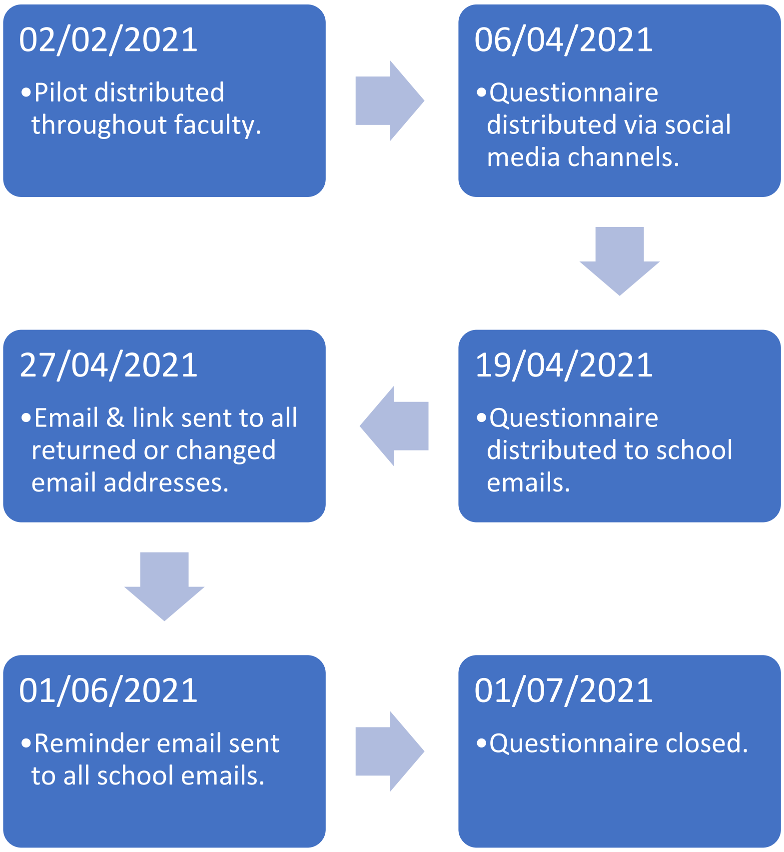

*Figure 2 Questionnaire delivery timeline.*

## 4.3 Response Rates

The survey acquired 1973 responses in its duration (Appendix O). Of these responses, 1665 completed all demographic questions, and 1644 progressed to the first air pollution question (Q7). 1470 participants completed the entire questionnaire, resulting in a completion rate of 88.29% (Figure 3).

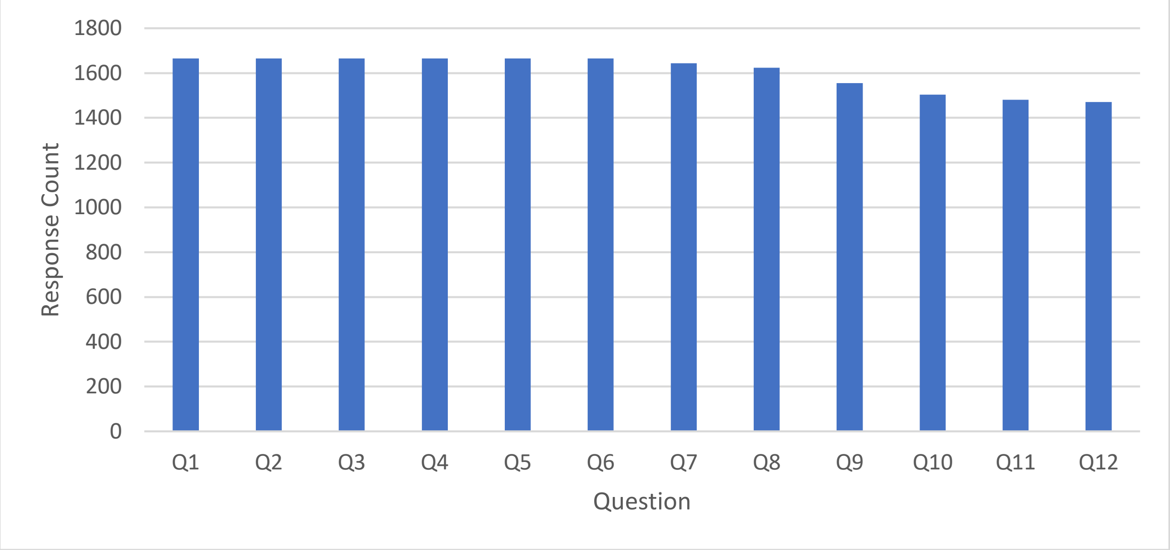

*Figure 3 Response counts by question.*

To manage and assess the volume of data more effectively, the responses were divided into categories comprising those who had specified they were answering as parents (including family members and carers) and teachers (including head teachers, school staff and support staff). This was considered suitable for the aims of the research given that these two groups were representative of the two realms of experience of the school commute, each with specific insights that were not necessarily apparent to the other.

The survey acquired 1441 responses from parents and teachers. 1441 completed all demographic questions, and 1424 progressed to the first air pollution question (Q7). 778 parents and 493 teachers, totalling 1271 participants, completed the entire questionnaire, resulting in a completion rate of 88.2% (Figure 4).

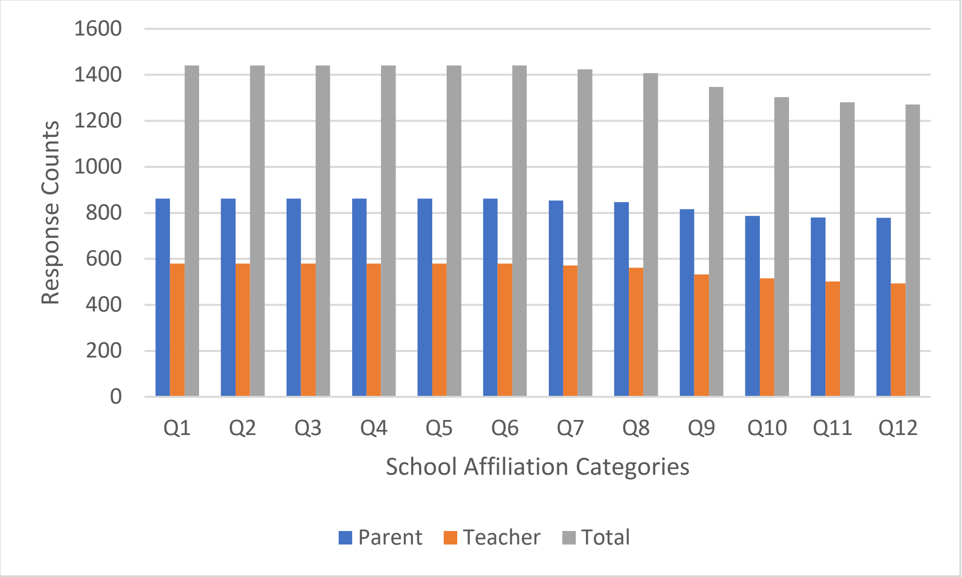

*Figure 4 Parent/teacher response counts by question.*

## 4.4 Results & Analysis

### 4.4.1 Demography

The survey results comprised 1441 responses, comprising 862 parents and 579 teachers and teaching staff. Figure 5 shows the composition of the respondents by percentage. The teacher response category is composed of 284 (49.05%) teachers, 85 (14.68%) teaching assistants and 210 (36.27%) who identified themselves as ‘other school staff’.

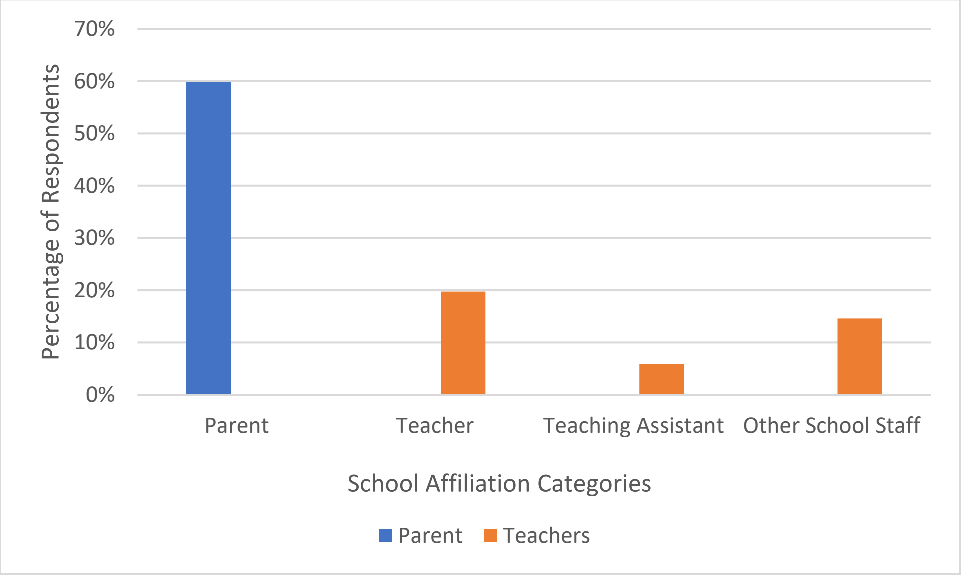

*Figure 5 Respondent percentages by stated affiliation.*

The survey received a greater number of parent respondents than teacher respondents (862:580, respectively). This is likely due to the distribution method, with schools as the survey gatekeepers.

A Jarque-Bera (JB) goodness-of-fit test was used to determine if skewness and kurtosis of the age data matched a normal distribution. The JB test has been used successfully in similar research to determine the distribution of a data population, so it was considered appropriate for the current purpose (Rahman & Alam, 2021; Soza et al., 2019; Senaviratna, 2017). The test uses the following hypotheses:

> $H_0$: The data are not normally distributed.
>
> $H_A$: The data are normally distributed.

The process outcomes of the JB test are shown in Table 9. The p-value for parents was greater than 0.05, so the null hypothesis was not rejected, indicating that there is insufficient evidence to state that the data are not normally distributed. The p-value for teachers was less than 0.05, so the data can be described as normally distributed.

*Table 9 Jarque-Bera goodness-of-fit test outcomes to determine the normality of distribution of data for respondent ages.*

| **Process** | **Parents** | **Teachers** |
|---|---:|---:|
| Observations | 862.00 | 580.00 |
| Sample Skewness | -0.02 | -0.53 |
| Sample Kurtosis | 0.36 | -0.66 |
| JB Test Statistics | 4.85 | 37.70 |
| p-value | 0.09 | 0.00 |

The respondents' ages are depicted in Figure 6. Most parents were aged 35-44 ($\bar{x}$ = 41.86), and most teachers were aged 45-54 ($\bar{x}$ = 45.71).

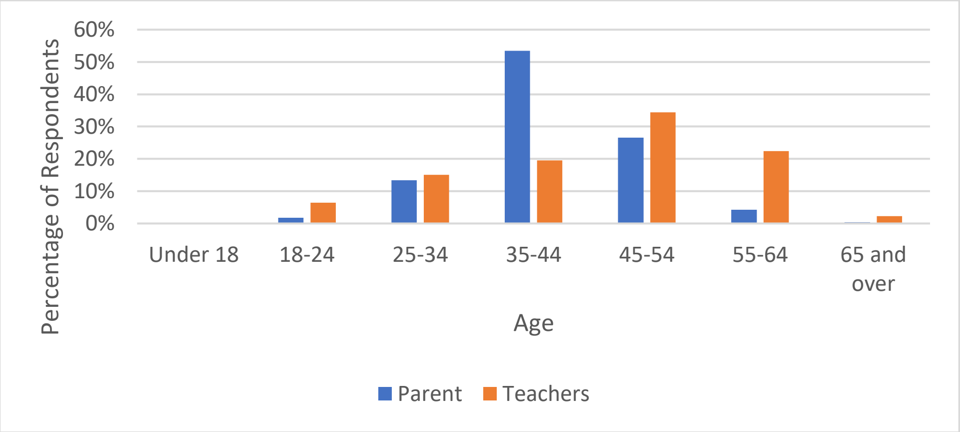

*Figure 6 Respondent percentages by age.*

Figure 7 depicts the regional distribution of the participants, with many of the greater concentrations of responses based in cities. However, a good level of general coverage exists across England and is evidenced by the distribution depicted in the map. Greater concentrations of parent respondents exist when compared to teacher response rates.

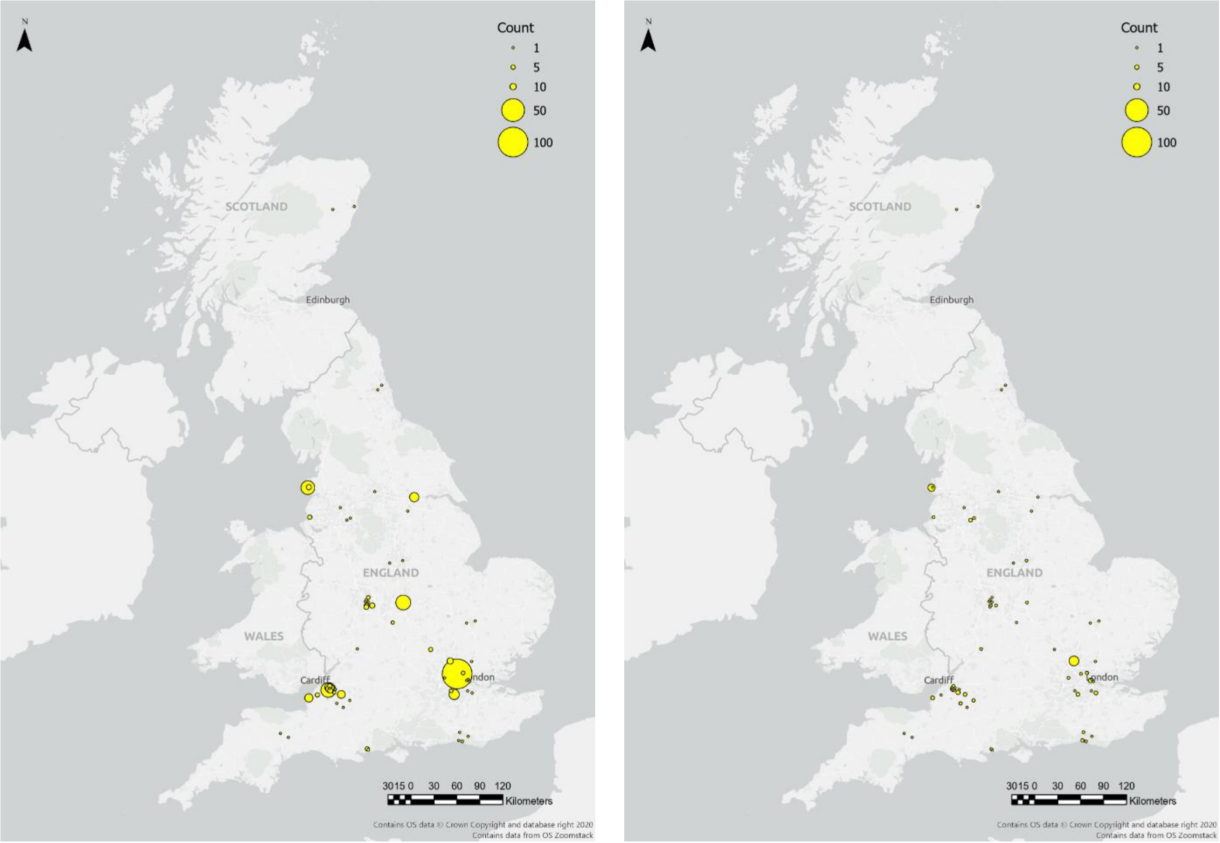

*Figure 7 Response counts by out-code postal districts: Parents (left); and Teachers (right).*

Whilst the respondent composition is skewed towards white ethnic groups, it is largely representative of the UK population. Of all the respondents, 756 (87.7%) parents and 528 (91.19%) teachers described themselves as White (compared to the population composition of 86%), 25 (2.9%) parents and 14 (2.42%) teachers listed themselves as mixed (compared to 2.2% of the population), 15 (1.74%) parents and 10 (1.73%) teachers as a Black ethnic group (compared to 3.3% of the population), 36 (4.18%) parents and 16 (2.76%) listed as Asian (compared to 10% of the population), 3 (0.35%) parents and 1 (0.17%) teachers were Arab, and 7 (0.81%) parents and 3 (0.52%) teachers stated their ethnicity as some other ethnic group (compared to 1% of the population ). 20 (2.32%) parents and 7 (1.21%) teachers preferred not to answer (Figure 8) (ONS, 2018)[4].

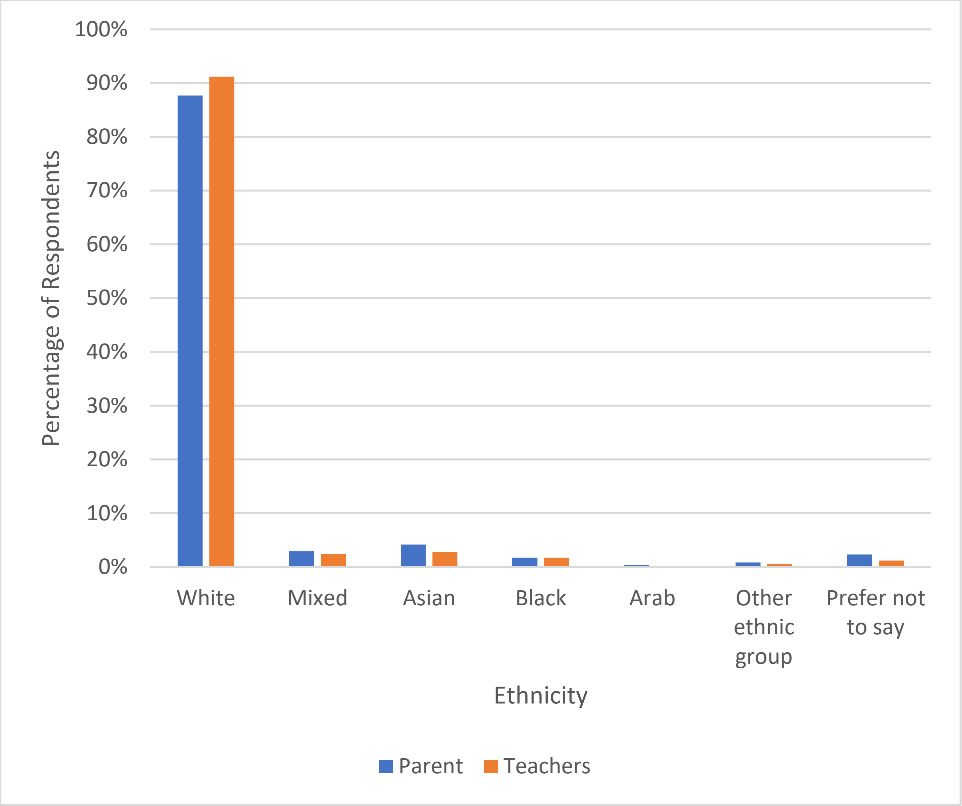

*Figure 8 Percentage of respondents by stated ethnic groups.*

The respondents were generally well-educated in comparison to the UK population. Of the respondents, 383 (44.43%) parents and 324 (55.96%) teachers held a degree, 194 (22.51%) parents and 101 (17.44%) teachers held a master's qualification and 47 (5.45%) parents, and 12 (2.07%) teachers held a PhD (Figure 9).

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[4] Comparisons are made according to Census 2011 data (ONS, 2018).

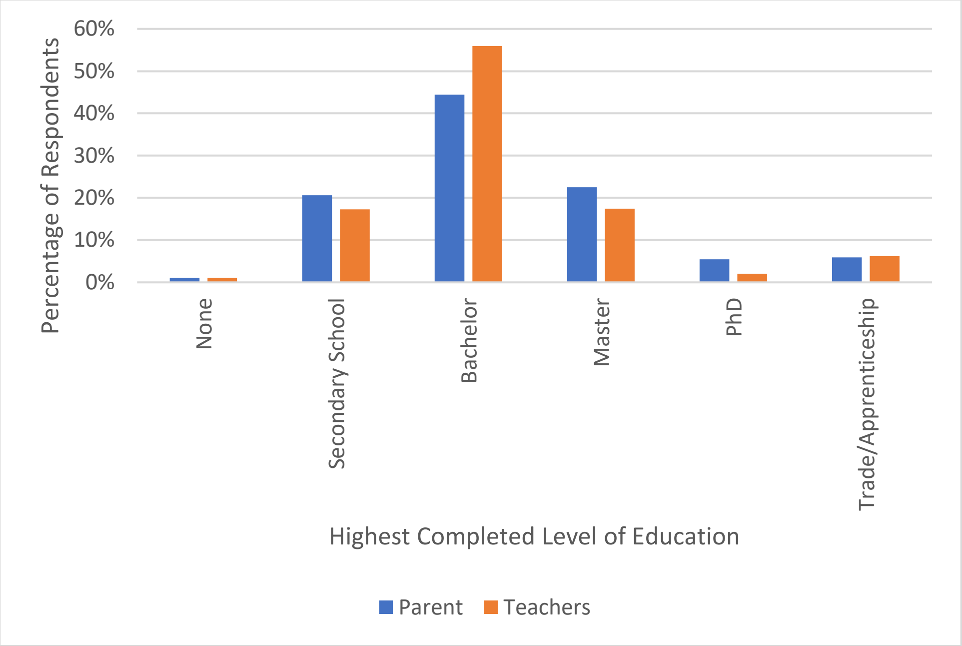

*Figure 9 Percentage of respondents by the highest completed level of education.*

A JB test was used to determine the normality of the number of children data. The process outcomes of the JB test are shown in Table 10. The p-value for parents and teachers was less than 0.05, so the data can be described as normally distributed for both groups.

*Table 10 Jarque-Bera goodness-of-fit test outcomes to determine the normality of distribution of data for the respondent's number of children.*

| **Process** | **Parents** | **Teachers** |
|---|---|---|
| Observations | 859.00 | 580.00 |
| Sample Skewness | 0.65 | 0.16 |
| Sample Kurtosis | 0.46 | -0.80 |
| JB Test Statistics | 67.57 | 18.06 |
| p-value | 0.00 | 0.00 |

Figure 10 shows the number of children of parents and teachers. Most parents (n = 481, 55.8%, $\bar{x}$ = 1.97) and teachers (n = 212, 36.61%, $\bar{x}$ = 1.54) specified 2 children.

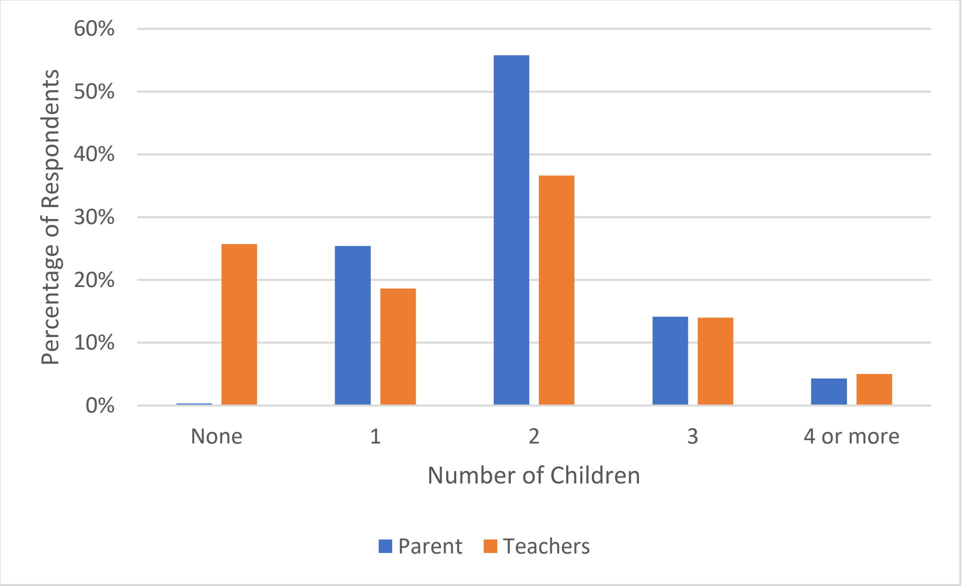

*Figure 10 Percentage of respondents by the number of stated children.*

### 4.4.2 Representativeness

For the sample to be representative of the population, it should provide an unbiased reflection of its composition (Ramsey & Hewitt, 2005). The current sample used several demographic factors to determine representativeness, including respondent parent status, age, ethnicity, and education. The parent/teacher data were normally distributed, with most parents aged between 35 and 44 and most teachers between 45 and 54. In addition, the teachers were generally older than the parents.

The number of participants was normally distributed, and most stated they had two children. The survey received a greater number of parent respondents than teacher respondents. This is likely due to the method of distribution, since schools were the gatekeepers prompted to send the survey on to parents via their distribution channels, including newsletters, emails and school bulletin boards. The concentrations of respondents at each geographical location also mirror the greater number of parents than teachers that would be associated with each school. It must also be considered that some teachers may have stated their affiliations as parents first, which as mentioned could be supported by the number of teachers who stated they have no children.

Given the composition of the demographic response data, the survey response sample is considered to be suitably representative of the population. Slightly more respondents describe their ethnicity as white than the UK population, according to census data (91.19% and 86%, respectively), although the ethnic composition was generally comparable. The education level of the respondents was generally high, with more than half of parents and teachers holding bachelor's degrees. This reflects expectations of the survey respondents in vocational terms, with many working in education. An accurate determination of the population in terms of educational standards is problematic, due largely to the broad range of definitions and datasets (GOV.UK, 2020c).

### 4.4.3 Air Pollution Questions

Figure 11 shows the percentage responses to the question, 'How concerned are you about the effects of air pollution on the health of pupils at school?'. The majority of parents (76.68% of parent responses to the question) and teachers (75.82% of teacher responses to the question) expressed some level of concern. 313 (36.31% of responses to the question) parents and 176 (30.4% of responses to the question) teachers indicated that they were very concerned about the effects of air pollution, 348 (40.37%) parents and 263 (45.42%) teachers stated they were fairly concerned, 160 (18.56%) parents and 111 (19.17%) teachers stated they were not very concerned, and 32 (3.71%) parents and 21 (3.63%) teachers stated they were not concerned at all.

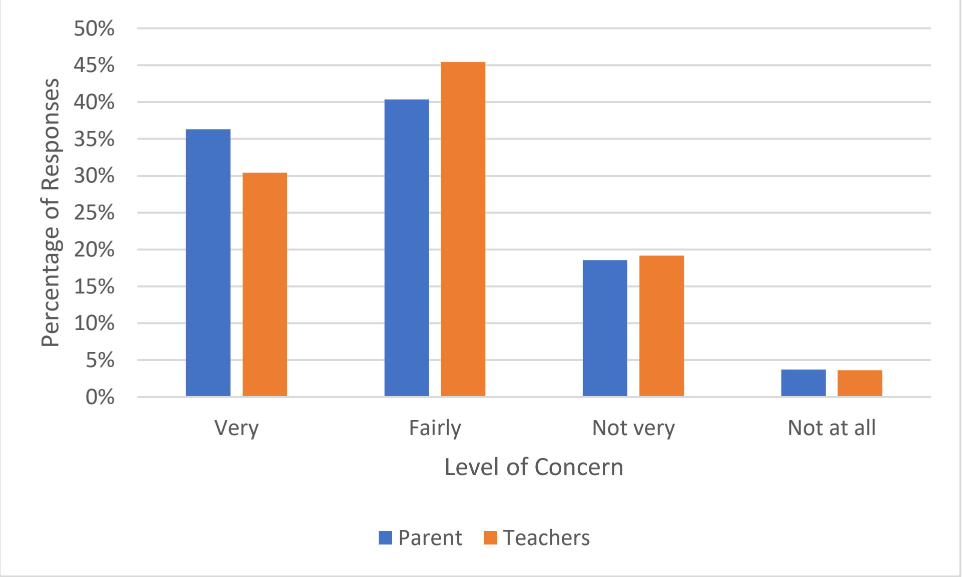

*Figure 11 Percentage responses for the level of concern for the effects of air pollution on the health of schoolchildren.*

More respondents were concerned than not, and there was little observable difference between parent and teacher responses. Most people stated they were fairly concerned. Whilst more teachers than parents expressed that they were fairly concerned, numbers were comparable between both groups. This is unsurprising, given that air pollution is a topical issue and children are an at-risk group.

The respondents who had expressed concerns were then prompted to clarify their reasons by selecting from a list of options (Figure 12). The greatest cause for concern was the school's proximity to a busy or main road, for both parents (44.20% of responses to the question) and teachers (42.49% of responses to the question). Other prominent causes for concern among parents and teachers were levels of idling outside the school (40.02% and 32.30% of responses to the question, respectively), general concerns due to media (33.06% and 32.30% of responses to the question, respectively) and congestion at the school location (30.74% and 25.73% of responses to the question, respectively).

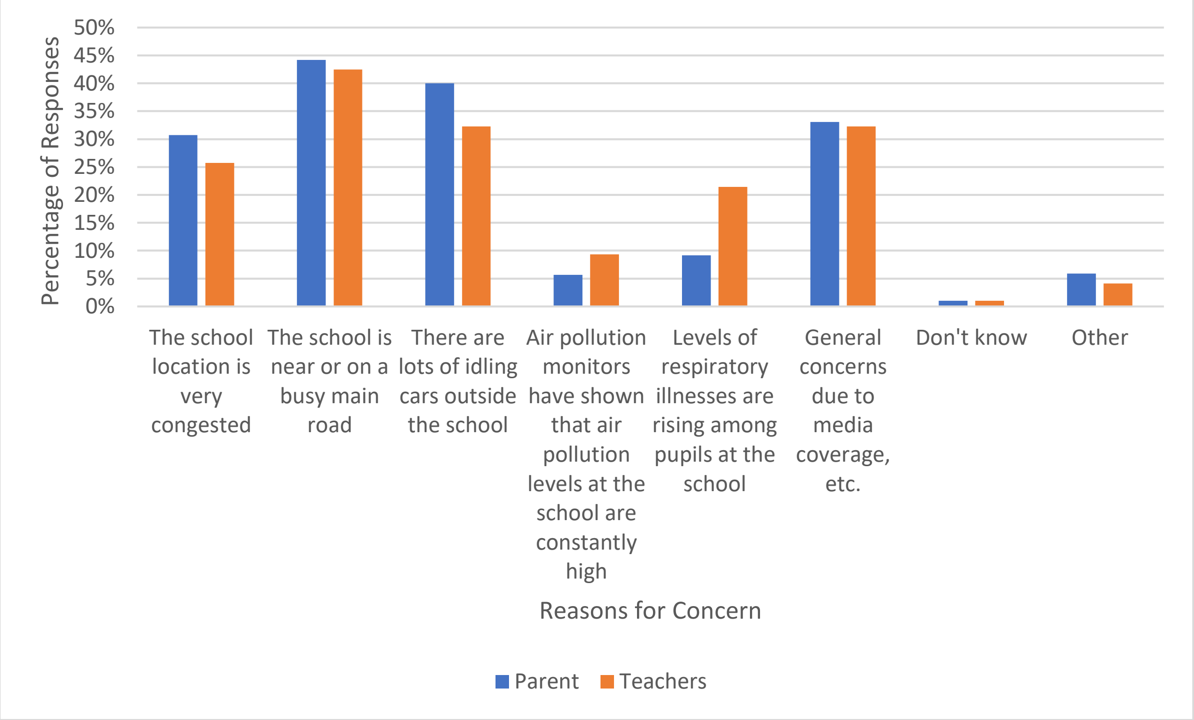

*Figure 12 Percentage responses for reasons for concern regarding air pollution's effects on schoolchildren's health.*

Consistently high concerns among parents and teachers were expressed for the school's proximity to traffic and roads. Both groups also expressed concern due to general media coverage. Teachers appeared to be more aware of increasing levels of respiratory illnesses among children at their school and monitored levels of air pollution. This may be because teachers are more able to observe trends, such as year-on-year increases in respiratory conditions in the classroom (see Hinton & Kirk, 2015). This also highlights an area in which parents could be better informed about poor air quality at their school, both in terms of concentration and health impact.

More parents cited school congestion and idling cars as an issue of concern, which is likely due to their own experiences of school drop-offs and pick-ups. Teachers will commonly begin their school days before pupils arrive and are less likely to experience this situation at their own school overall, aside from some individual teachers who may be required to oversee the morning and afternoon transitions.

For those responses under ‘other’, the provided statements were coded by theme (some statements included more than one topic) to show general sentiment (Figure 13). General concerns were high for both parents and teachers (35.29% and 30.43% of responses to the question, respectively). Concerns regarding morbidity, including child health, development, allergies, and asthma were also high among parents (33.33% of parent responses to the question), whilst school location was of greatest importance to teachers (39.13% of the teacher responses to the question).

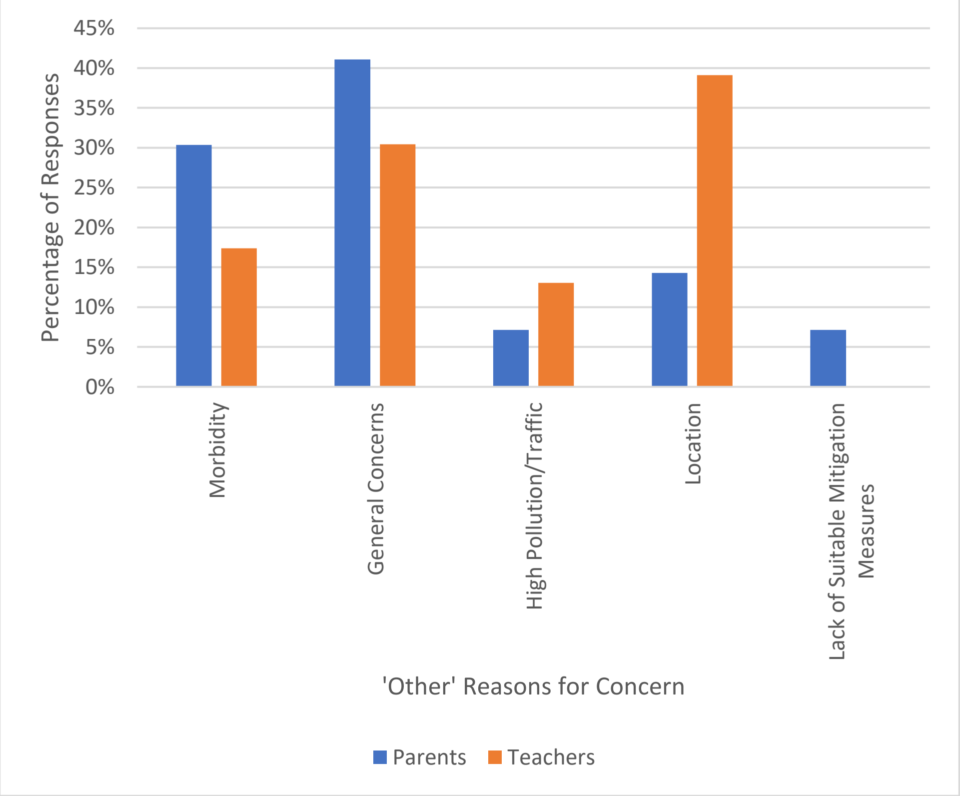

*Figure 13 Percentages of categorised coded responses for ‘other’ reasons for concern regarding air pollution’s effects on schoolchildren’s health.*

Broader concerns included general awareness, concerns due to media coverage, sustainability and idling at schools, and these were high for both parents and teachers, which is consistent with previous responses. General concerns also included those who expressed unease regarding the implementation of low-traffic neighbourhoods (LTNs). This was a recurrent cause for concern, which the respondents maintained has caused traffic to reroute past their children's schools. Whilst the list is not exhaustive, each of the following statements is from respondents in different postal out codes:

> "Clean air zone in centre of town has moved the traffic to the school recently."
>
> "The LTN has produced increased traffic around the school with idling vehicles all day on 2 roads surrounding the school."
>
> "A new LTN scheme has been introduced in Kings Heath, Birmingham. Oddly, it has closed off a lot of quiet suburban roads which always had low footfall and the consequence is significantly increased traffic on the roads with are more heavily populated. The local high street which is near my daughter's school now has constant idling traffic. Likewise, the only main park in our area has basically become a car park. There are constantly lines of traffic alongside it which means it is not a safe area for them to play. The local council has ignored the negative impact of this LTN and appear to plough on regardless. My 8-year-old daughter who has never had any health problems, has developed very worrying respiratory issues which I can only feasibly attribute to the impact the LTN has had."
>
> "A new LTN in Ealing is displacing the traffic towards our school."
>
> "An LTN has been placed meaning all traffic is now channelled past this school and two nearby primary schools. Their journey to school is also negatively impacted by LTN."

The concerns surrounding schemes such as Low-Traffic Neighbourhoods (LTNs) appear consistent regardless of their implementation region. Each maintains that the poor planning of LTNs has resulted in traffic becoming re-routed past their school, leading to greater congestion and air pollution in the area. It must also be considered that those who were satisfied with LTNs in their areas did not feel the need to express their approval although in any case, no positive comments about LTNs were provided.

Although teacher responses in the 'other' category are comparatively few, one teacher highlights LTNs as an issue, which is consistent with previous comments on the subject:

> "The imposition of LTNs by the council has increased both congestion and air pollution in our area. Traffic is slower and idling for longer periods. Absolute insanity!"

Among teachers, the most common concerns were associated with asthma and health (coded under 'morbidity'), which was also the second most popular reason for concern among parents. Some teachers expressed concern for their own health:

> “Have experience of asthma in my family.”
>
> “Concerned for my own respiratory health as I work there.”

Other teachers expressed concerns for child health:

> “The school is away from the main road but many of the children live directly off a main road and many travel to school by car despite living very nearby. Asthma in school in on the increase.”
>
> “Air pollution is an issue amongst both children and adults, I personally suffer from Asthma and notice it more in the workplace. This correlation must mean that there are high levels of pollution at/around school which will be affecting the children’s health.”

These comments each link morbidity to road and traffic proximity in their school areas. Concerns about school location in this regard (proximity to main roads, airports, or industry) were the most common response among teachers and were more than twice that of parents. However, more parents than teachers highlighted a lack of suitable interventions in place to mitigate against air pollution, including:

> “Poor quality active travel links to enable car free travel.”
>
> “The school cut down all of the established trees which makes the problem a lot worse.”

The disparity between parents and teachers regarding interventions may also be indicative of a lack of communication between the groups.

Respondents who did not express concern were presented with an alternative follow-up question and prompted to clarify their reasons (Figure 14). These responses largely contrasted those of the groups that expressed concern. The most popular reasoning among parents and teachers was that the school was in a rural location (9.05% and 9.50% of responses to the question, respectively), there was little nearby traffic (9.05% and 9.84% of responses to the question, respectively), or that many of the pupils used active travel to get to school (7.54% and 7.25% of responses to the question, respectively).

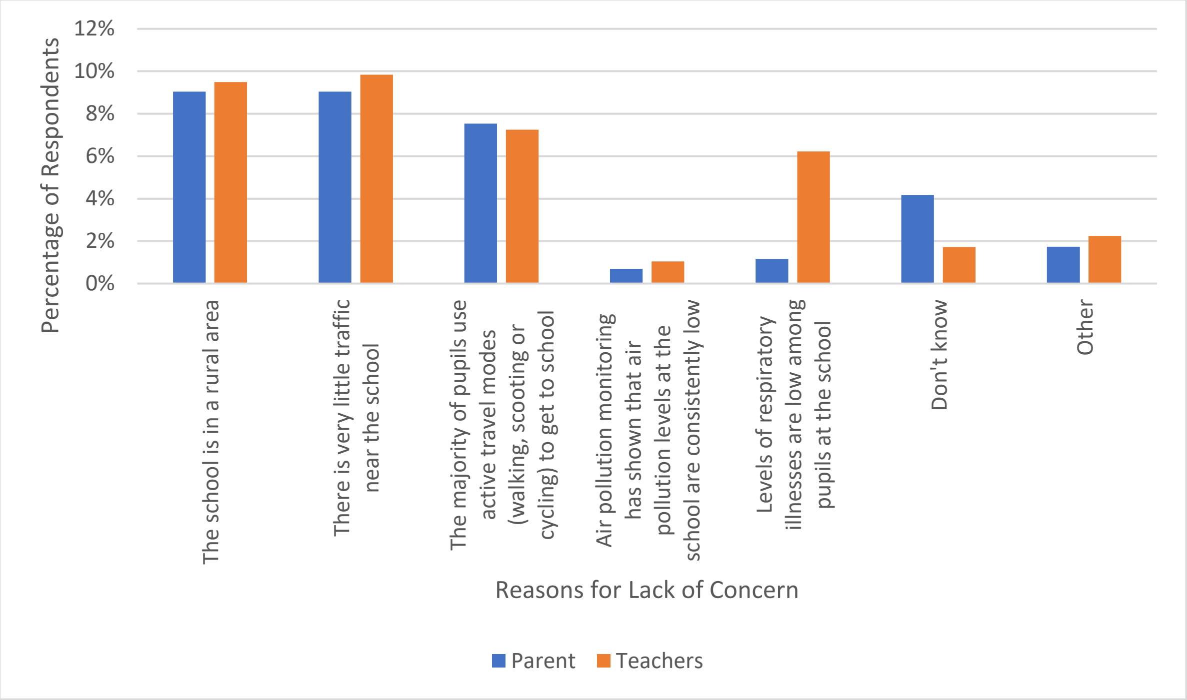

*Figure 14 Percentages of categorised coded responses for a lack of concern regarding air pollution's effects on schoolchildren's health.*

For those unconcerned, themes largely focused on the school location, including its rural area or lack of proximity to traffic. Strong uptake of active travel among pupils was also a popular reason for the lack of concern. More teachers than parents expressed that air pollution monitoring showed low levels, and many more teachers than parents indicated that levels of respiratory illness were low among their school pupils. Mirroring the previous responses, many more teachers than parents appear to have a grasp of respiratory illness numbers among pupils. More parents than teachers indicated that they did not know why they were not concerned.

School location presented the most popular reasoning for lack of concern. Schools in rural areas or away from busy roads appear to provide little concern to parents and teachers. This is supported by those who listed responses under ‘other’. The provided statements were coded by theme (some statements spanned more than one topic) to show general sentiment (Figure 15). The most popular reason for lack of concern for both parents and teachers was that they did not consider it an issue at their school (46.67% and 40% of responses to the question, respectively).

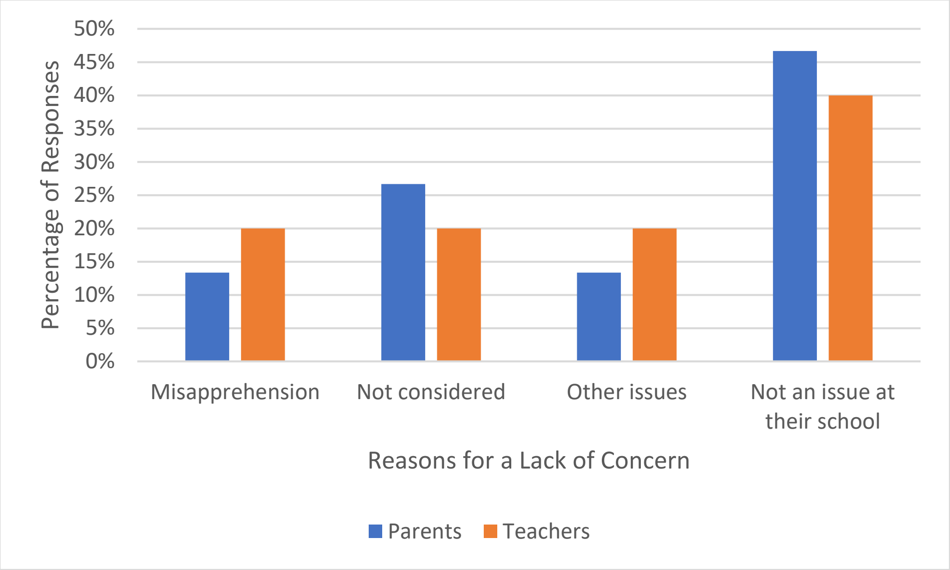

*Figure 15 Percentages of categorised coded responses under 'other' reasons for lack of concern regarding air pollution's effects on schoolchildren's health.*

The responses were broadly consistent with those of the main question. The misapprehension category comprised those who had stated in contradiction to the question that pollution is an issue at their school but did not explain why they were not concerned. Those whose responses were categorised as 'not considered/not noticed pollution' were apathetic to air pollution, stating:

> Parent: "Not really thought about it in detail."
>
> Parent: "I haven't really given it much thought before."
>
> Parent: "Not something I've considered."
>
> Teacher: "Never considered it."
>
> Teacher: "It's not something I think about."

Others maintained that there were more pressing issues to be concerned about ('other issues'), including:

> Teacher: "I can only worry about so many things at once."
>
> Parent: "I have other, more pressing, worries."

The most prominent reason for a lack of concern was that air pollution was not an issue at their school. This category included themes related to school location, such as low traffic, the school being sited away from main roads, and a rural location:

> Parent: "The school is semi-rural, and the children don't tend to walk near the main roads."

Respondents were then asked, ‘What has your school/community/council/other done to improve school air quality?’ and permitted to select multiple options (Figure 16). The promotion of active travel was the most popularly cited intervention for parents and teachers (21.57% and 17.77% of responses to the question, respectively).

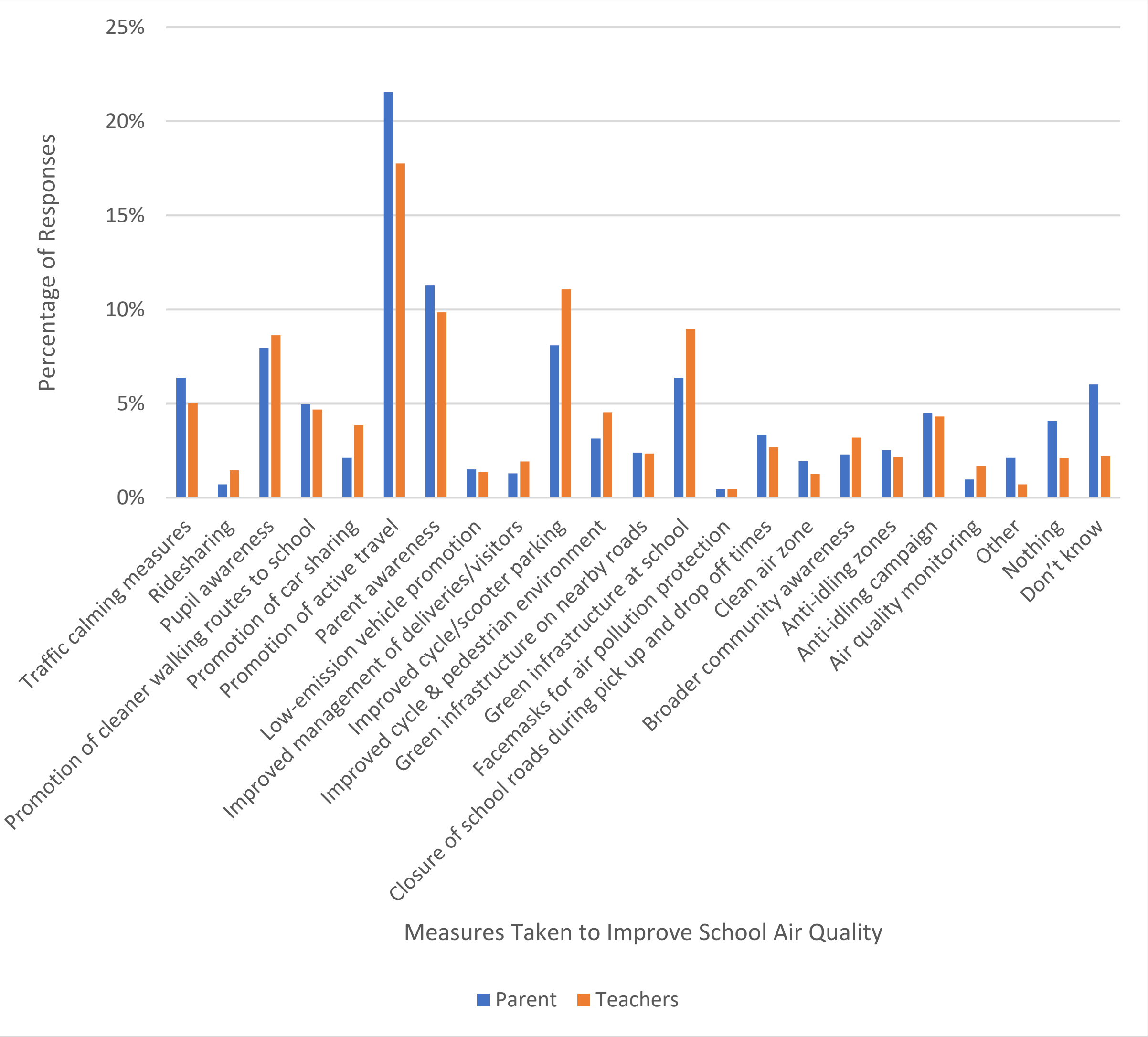

*Figure 16 Percentage of responses for interventions taken to improve school air quality.*

Understandably, active travel is a popular measure due to its ease of implementation and no associated costs. Parent awareness is also a popular measure stated by both parents and teachers. Whilst the groups are mainly in agreement in their responses, those that teachers have stated have relatively lower responses than those of parents and appear to be school-based interventions, such as improved cycle and scooter parking and green infrastructure at school. Teachers are more likely to be aware than parents of each of these due to their time spent at the school, but this may be indicative of an opportunity for better communication by facilities to parents to encourage greater uptake of active travel. The lack of communication is also supported by the greater number of parents than teachers who responded ‘nothing’ or ‘don’t know’, which could point to a lack of communication between schools and parents regarding measures they are taking.

For those responses under ‘other’, the provided statements were coded by theme (some statements included more than one topic) to show general sentiment (Figure 17). Teachers stated more school site interventions than parents (44.44% and 26.42% of responses to the question, respectively) whilst more parents than teachers maintained that either nothing had been done or what had been done was insufficient or ineffective (47.17% and 11.11% of responses to the question, respectively).

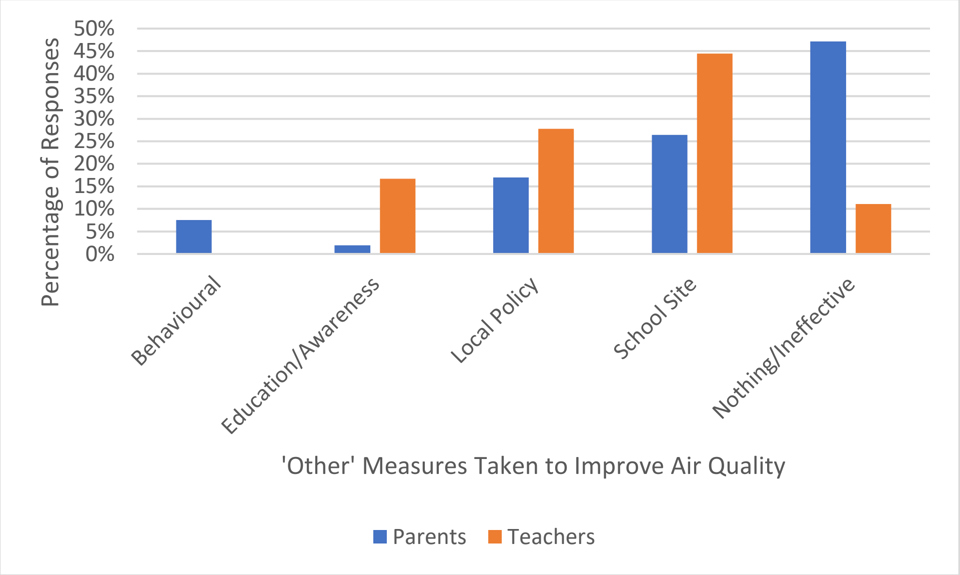

*Figure 17 Percentages of categorised coded responses for ‘other’ interventions to improve school air quality.*

These responses support the findings of the main question. Local policy interventions (including greening, parking zones, and road closures) and school site interventions (including parking restrictions, staggered collections, and School Streets) appear to be better known by teachers than by parents. The number of parents also supports this compared to teachers who stated ‘nothing’, although ~1/4 of responses (exclusively from parents) in this category also included statements maintaining that measures had been taken but were tokenistic or ineffective, including:

> “School has asked parents not to pull up and congest the small dead-end road at the school entrance during pick-up and drop of times. School has asked parents to park in proper parking spaces nearby and walk a short way to the school gates. Parents ignore requests.”

> "They try but many people don't really listen and can be out there for 20 mins or more 5 days a week twice a day."
>
> "The school is meant to be part of a local scheme to reduce cars around school. It doesn't work. On any given day there are loads of cars very close to school and on a wet day 10-30 cars can be idling very nearby."

Figure 18 shows the responses to the question, 'What measures do you think would be effective for improving air quality at school?'. The most popular measures among parents and teachers included the promotion of active travel (7.29% and 7.45% of responses to the question, respectively) and parent awareness (6.91% and 6.67% of responses to the question, respectively).

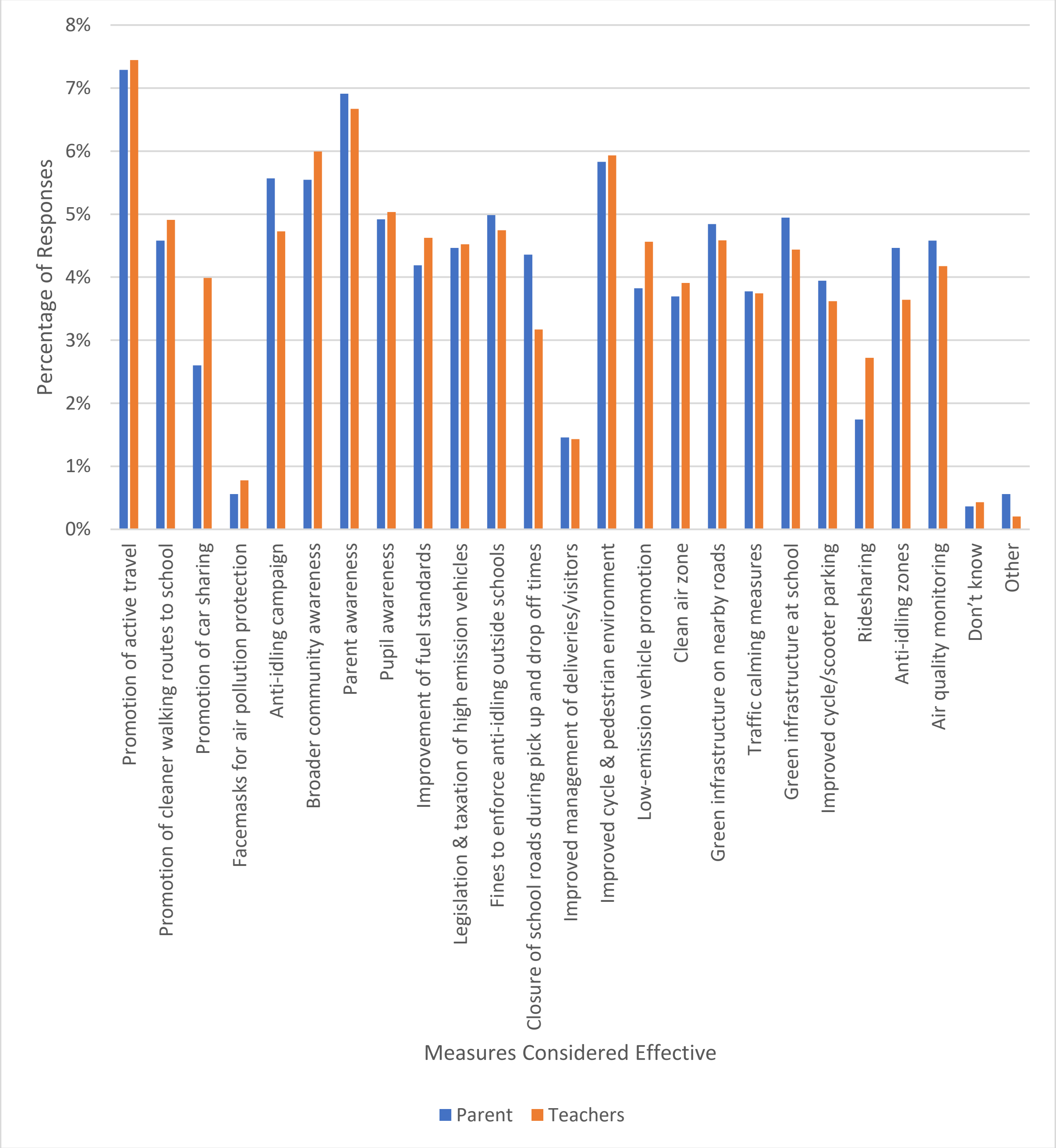

*Figure 18 Percentages of responses for measures considered to be effective for school air quality improvement.*

As already asserted, active travel is the most popular measure, likely due to ease of implementation. This position is also supported by a desire for improvements to the cycle and pedestrian environment. Parent awareness is also a popular measure among parents and teachers, which supports the position that better communication of measures undertaken and proposed would benefit both parties.

There appears to be greater disagreement for the promotion of car sharing, which more teachers than parents desire. This attitude may be apprehension due to the nature of the intervention in that parents rather than teachers would primarily undertake it. Conversely, a similar disparity exists with the closure of school roads during drop-off and pick-up times, which is favoured more by parents than teachers. Again, this may be due to the teacher's perception of an additional workload.

For those responses under 'other', the provided statements were coded by theme (some statements included more than one topic) to show general sentiment (Figure 19). Both parents and teachers had comparatively high expectations for active travel (30.77% and 22.22% of responses to the question, respectively).

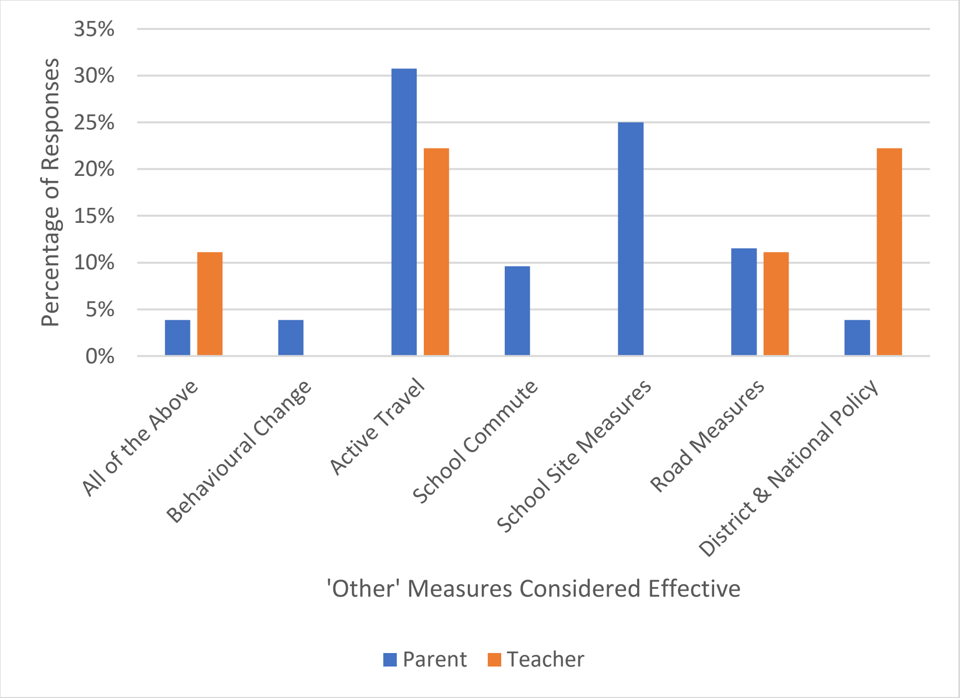

*Figure 19 Percentages of categorised coded responses under 'other' measures considered to be effective for school air quality improvement.*

The sentiments in the responses to the main question are broadly supported in the 'other' category (those coded 'unknown' were either unclear or the respondent stated they did not know). Active travel remains a popular measure for both groups. The school commute measures (including improved routes, better public transport, and school buses) were also popular among parents, which may be due to the parent experience of the school commute. School site measures (including staggered collections, greening, improved monitoring, closure of School Streets, and parking restrictions) were also only highlighted by parents, which may also be due to the perceived workload and cost of these measures among teachers. The following parent statements support this attitude:

> "Closure of through travel past the school site during pick-up and drop-off times to be enforced by number plate recognition camera evidence."
>
> "School Streets and encouraging teachers and school staff to walk & cycle to school."

Conversely, teachers were more in favour of district and national policy measures (including banning fossil fuel cars, government incentives and the location of schools away from sources of pollution) than parents.

The respondents were then prompted to select one measure they thought would be most effective from those they had already chosen (Figure 20). The promotion of active travel remained high for parents and teachers (47.29% and 39.92% of responses to the question, respectively). However, this was second to the most popular response from parents, who indicated that the closure of school roads during pick-up and drop-off times was the most preferable, and this measure was nearly twice as prevalent among parents than teachers (69.19% and 24.86% of responses to the question, respectively).

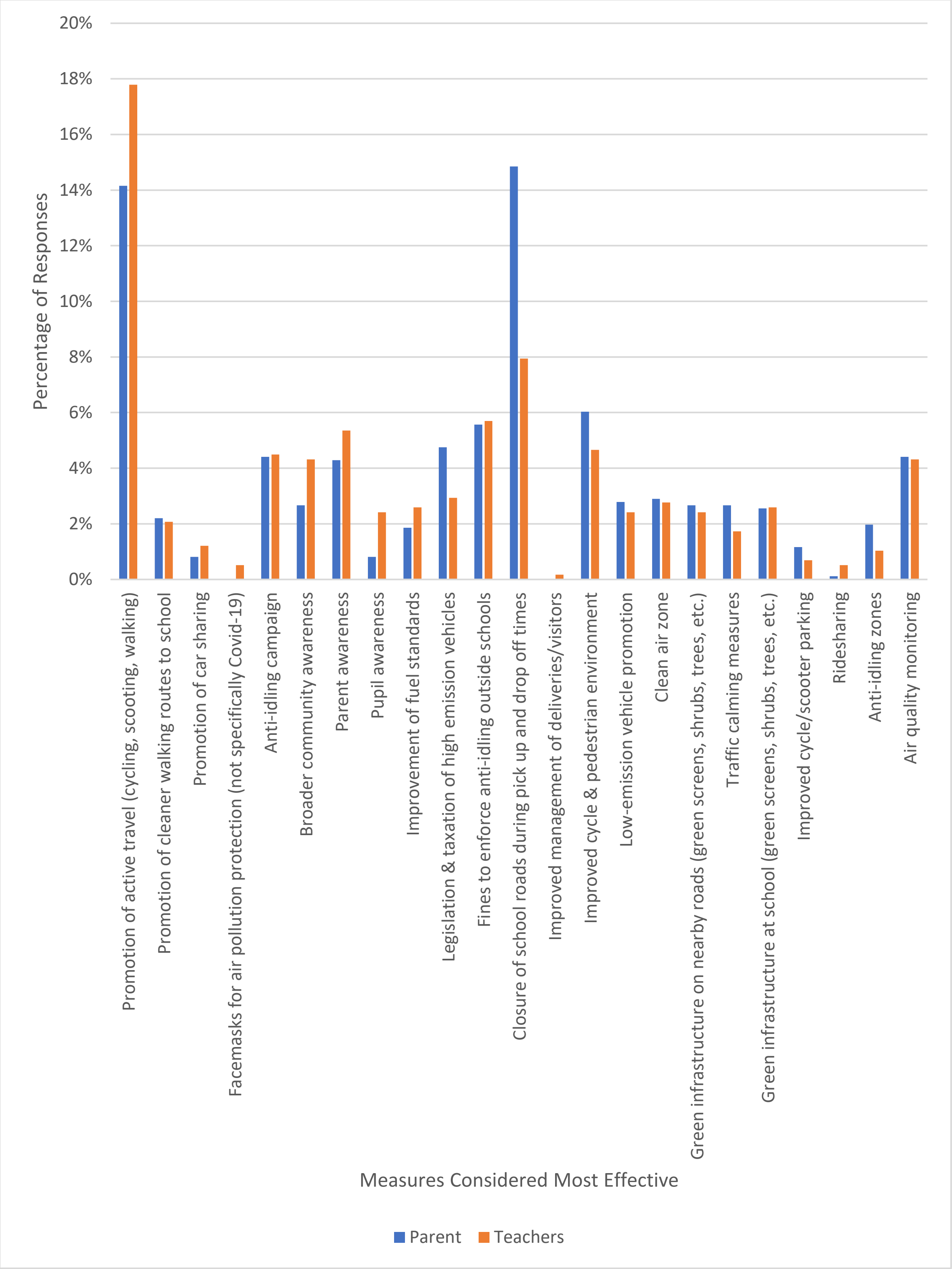

*Figure 20 Measures considered to be the most effective for the improvement of school air quality.*

These responses are consistent with the results from the previous question, placing a renewed emphasis on the promotion of active travel and the closure of school roads at pick-up and drop-off times; although the latter remains increasingly more popular among parents, but is the second most popular response for teachers after active travel.

The respondents were asked, ‘What are the biggest obstacles for improving air quality at school?’ and were permitted to select multiple options (Figure 21). There was a broad agreement among each group, with the most popular responses among parents and teachers being that driving is more convenient for many families (17.26% and 17.41% of responses to the question, respectively), school is close to busy or congested roads (12.76% and 12.18%, respectively) and there is a lack of parental support (11.46% and 11.11% of responses to the question, respectively). However, a more pronounced disagreement exists between parents and teachers regarding a lack of staff time to implement suitable initiatives (3.84% and 7.48% of responses to the question, respectively).

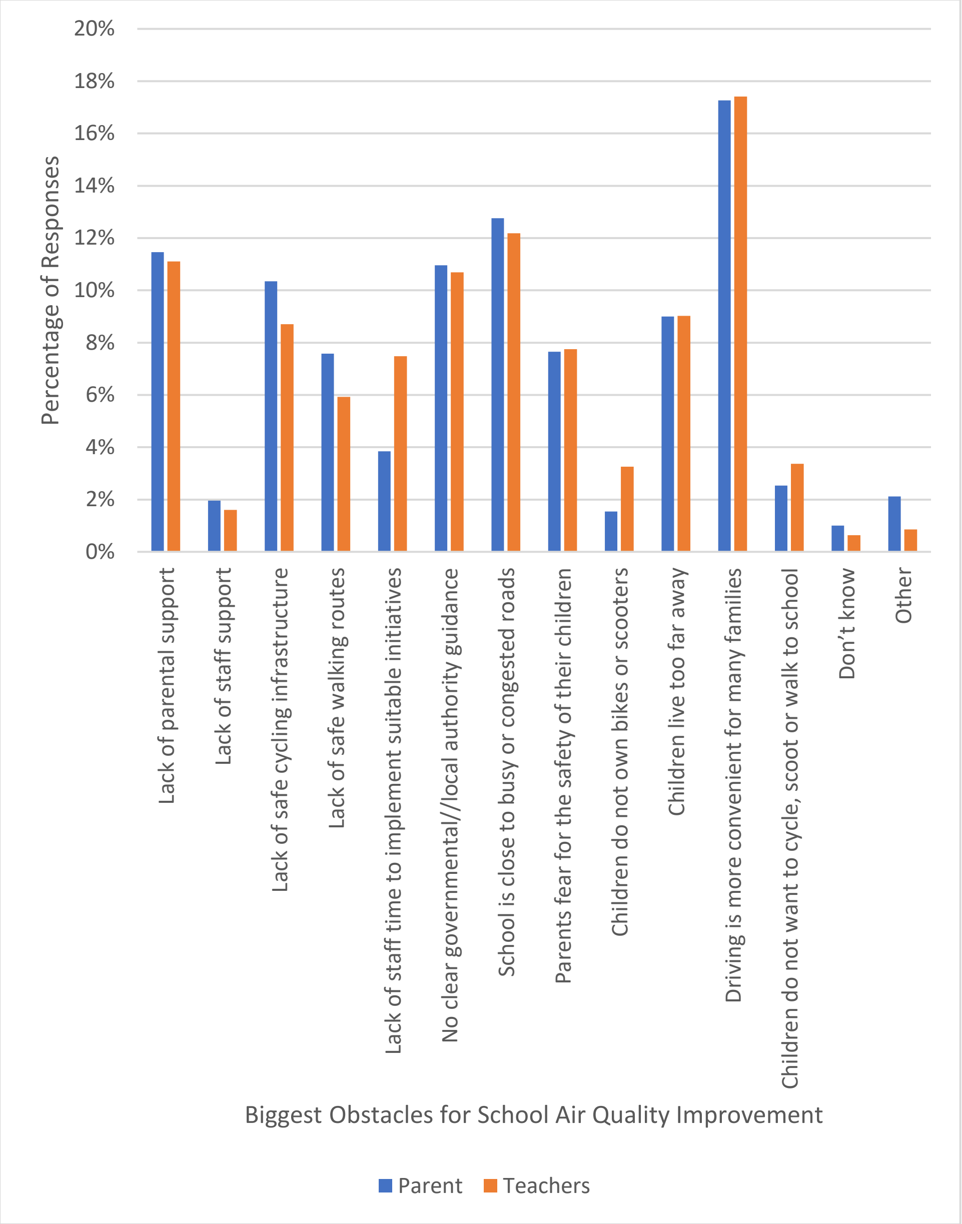

*Figure 21 The biggest obstacles for the improvement of school air quality and the reduction of car use.*

There is general agreement between parents and teachers regarding the biggest obstacles, although some responses depart from this trend. A lack of staff time to implement suitable interventions is agreed to more by teachers than parents, and teachers also show an awareness as to whether children own bikes or scooters.

There is an agreement between both groups that the convenience of driving is the biggest obstacle to overcome, followed by the school's proximity to a busy road. A lack of governmental/local authority support and a lack of parental support are also both popular, which may suggest that guidance is desirable. Concerns are also raised regarding a lack of safe pedestrian and cycling infrastructure, which is consistent with the sentiment of previous responses.

For those responses under ‘other’, the provided statements were coded by theme (some statements included more than one topic) to show general sentiment (Figure 22). Comparatively more accord existed between parents and teachers regarding the biggest obstacles to the improvement of air quality, with attitudes (26.09% and 29.17% of responses to the question, respectively), followed by school issues (18.84% and 20.83% of responses to the question, respectively) the most popular.

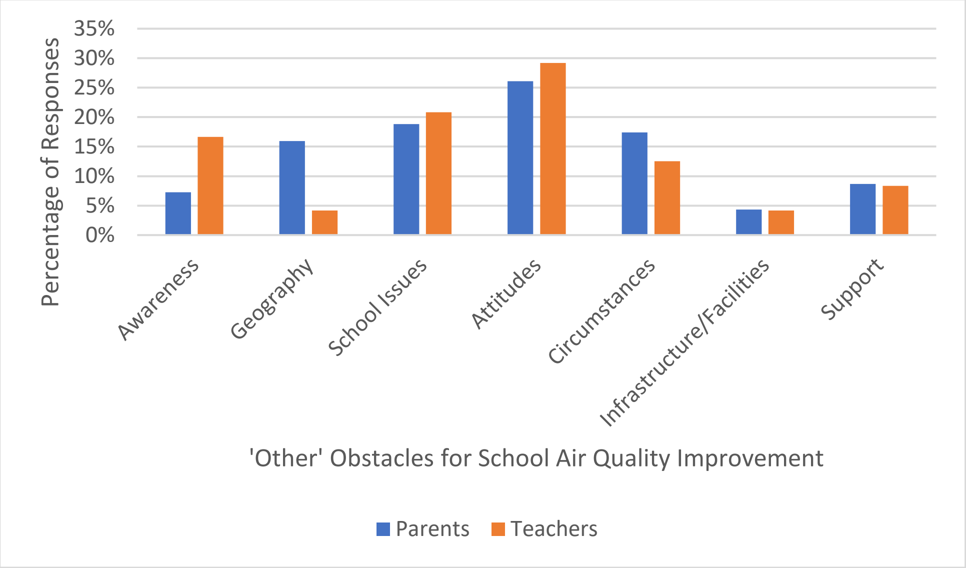

*Figure 22 Categories for coded responses under ‘other’ biggest obstacles for improving school air quality and reducing car use.*

Responses coded under ‘attitudes’ (including the necessity of driving, parents driving, the perception of driving, and priorities) were broadly consistent with the perception of the convenience of driving, coupled with having to work:

> Parent: “Parents often have to get straight to work after school run so there isn’t time to walk.”
>
> Parents: “Parents have to get to work after school drop-off. Time spent walking 15 mins back home on top of the commute, is more time out of the working day, or running further late to work, which just is not acceptable to businesses every day.”

Others maintained that parental attitudes were an issue:

> Parent: “Example: I arranged a playdate recently. I asked the mother if we should walk or cycle - she said they would take the car (said location is 10min walk away). This is what we are dealing with!!! (Exasperated tone)”

> Teacher: “As with anything, some parents are very onboard and travel actively as much as possible. Other parents need cars for onward journeys to work (although a little less so with working from home). And other parents appear to only consider their own convenience. Children are very supportive of active travel (as shown in recent hands up survey when they were asked how they did travel and how they would prefer to travel). Getting parents who are able to make changes on board is key to reducing car traffic around the school. Additionally active travel alternatives need to be improved to encourage them, e.g., safe cycling routes (there are no complete routes available), improved pedestrian crossings, improved railway bridge crossings etc.”

The desire for guidance was also apparent, with one parent stating:

> Parent: “So far it seems to be that is not a very high priority for our school, or it is not particularly on their radar. They are a great school - could be that they just don’t have the time/resources. A regional champion would be great - could visit each school with a pre prepared plan/pack.”

School issues were also a popular theme and included idling, a lack of active travel, and parent drop-offs, and are consistent with the previously stated needs of working parents:

> Parent: “Multiple children going to multiple schools mean that a car must be used for many parents. Another big one not represented here anywhere is Taxis. They do not shut off their engine when they are picking up and dropping off children at schools.”
>
> Parents: “Working parents often have to drop to school in order to get to work.”

An apparent disparity existed between the groups with awareness, with parents maintaining:

> “Parents seem unaware of the issues caused by pollution and idling.”
>
> “Parents aren’t aware of the detrimental effects of idling their cars.”
>
> “Lack of parents awareness of the risks of poor air quality.”

These positions are consistent with previous responses regarding a lack of awareness and the requirement for further information and communication between affected groups.

The respondents were then prompted to state the single biggest obstacle for the improvement of school air quality (Figure 23) based on the responses they provided in the previous question. Agreement persisted between parents and teachers, each stating that driving is more convenient for most families (27.75% and 28.22% of responses to the question, respectively) and the school is too close to busy or main roads (24.87% and 24.50% of responses to the question, respectively). For both parents and teachers, a lack of parental support (12.18% and 10.64% of responses to the question, respectively), no clear authority guidance (11.34% and 11.14% of responses to the question, respectively) and children living too far away (8.12% and 10.89% of responses to the question, respectively) were also popular responses.

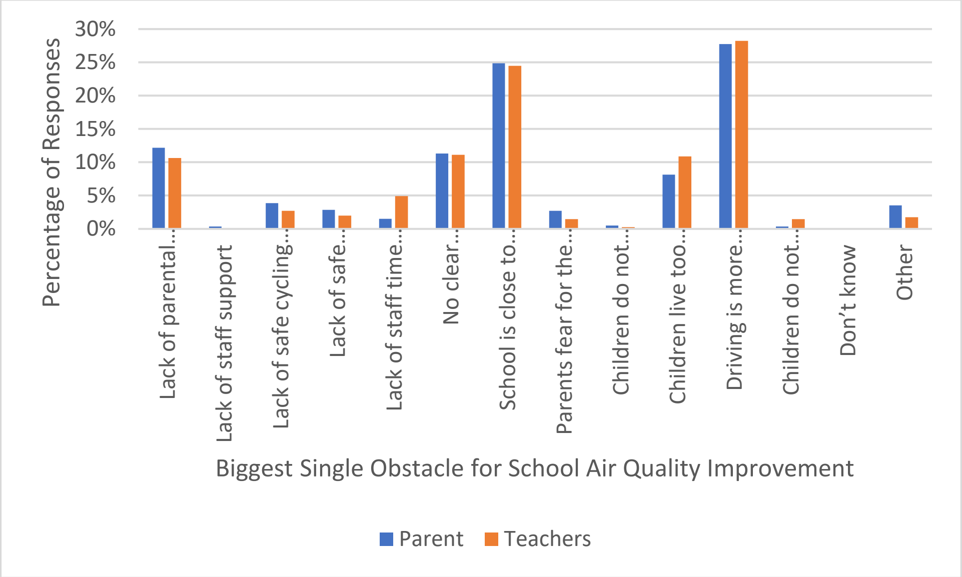

*Figure 23 The biggest stated obstacle to improving school air quality.*

The responses here support those of the previous question, emphasising the school's proximity to main roads and the convenience of driving as the biggest obstacles, with a lack of parental support, no clear authority guidance, and children living too far away from school as secondary issues.

The respondents were then asked, 'Who do you consider to be the most important for supporting efforts to improve air quality at schools?' (Figure 24). Agreement remained among parents and teachers that local authorities (43.13% and 38.48% of responses to the question, respectively), national government (23.32% and 27.45% of responses to the question, respectively), and parents (18.13% and 17.43% of responses to the question, respectively) were responsible.

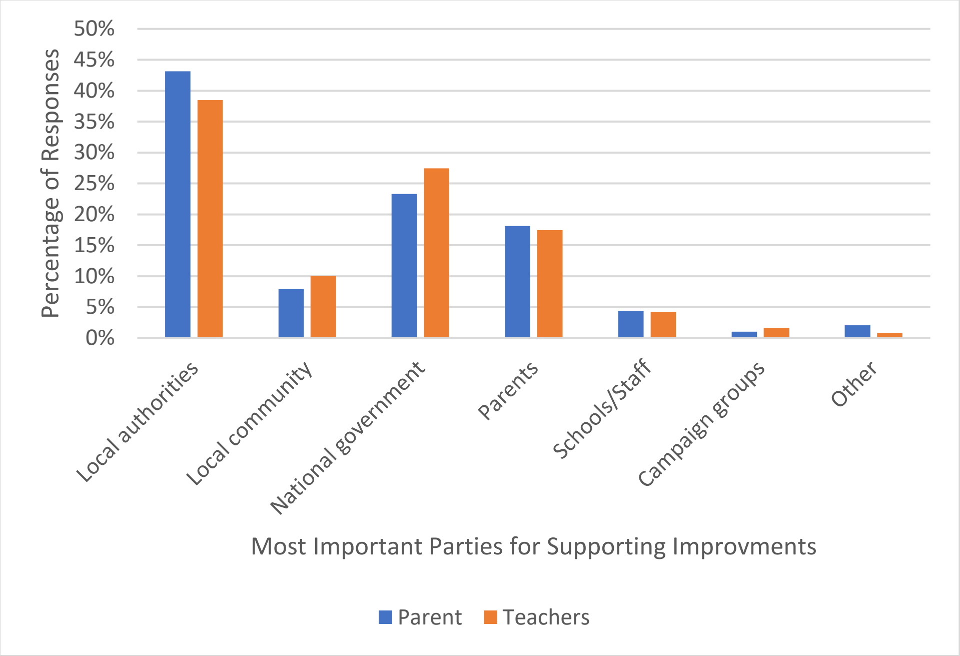

*Figure 24 Parties considered to be the most important for supporting air pollution improvement efforts.*

Conversely, neither parents nor teachers considered the local community (7.90% and 10.02% of responses to the question, respectively), schools and staff (4.40% and 4.21% of responses to the question, respectively) or campaign groups (1.04% and 1.60% of responses to the question, respectively) responsible.

There was general agreement between parents and teachers regarding the most important parties for supporting air pollution improvement, and both considered local authorities and the national government to be most important, followed by parents. This supports the position that guidance is desired and required by both parents and teachers to tackle air pollution at schools.

For those responses under ‘other’, the provided statements were coded by theme (some statements included more than one topic) to show general sentiment (Figure 25). Among parents and teachers, there was broad agreement that everyone (55.56% and 66.67% of responses to the question, respectively) and national authorities (16.67% and 33.33% of responses to the question, respectively) were most important.

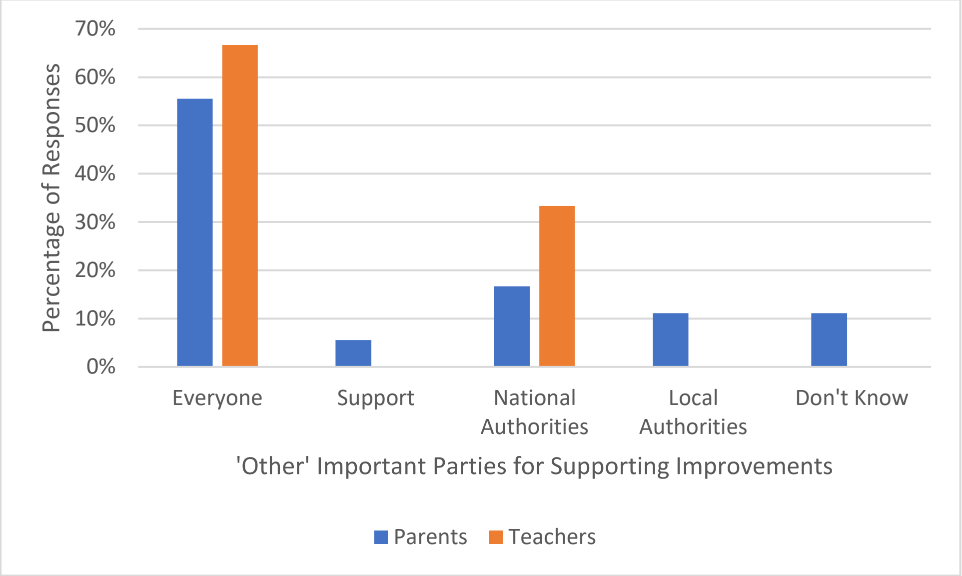

*Figure 25 Categories for coded responses under 'other' parties are considered the most important for supporting air pollution improvement efforts.*

The outcome of the responses listed under 'other' indicates that the majority of these respondents believe that everyone has a responsibility, although the provided statements may indicate that further guidance is still desired:

> Parents: "All of the above but it needs national leadership and funding."
>
> Parents "Both local authorities and the schools themselves would need to work together."

The final question allowed the respondents to give any further information or comments. These responses were coded by theme (some statements included more than one topic) to show general sentiment (Figure 26). The most recurrent themes among parents and teachers centred around the geography and environment of the respondent's school (22.36% and 31.58% of responses to the question, respectively) and included issues such as fossil fuels, urban greening, location, sustainability, and distance from schools. School measures and related issues were also common themes among parents and teachers (20.33% and 17.89% of responses to the question, respectively) and included themes such as catchments, school zones, School Streets, idling at schools and staggered collections.

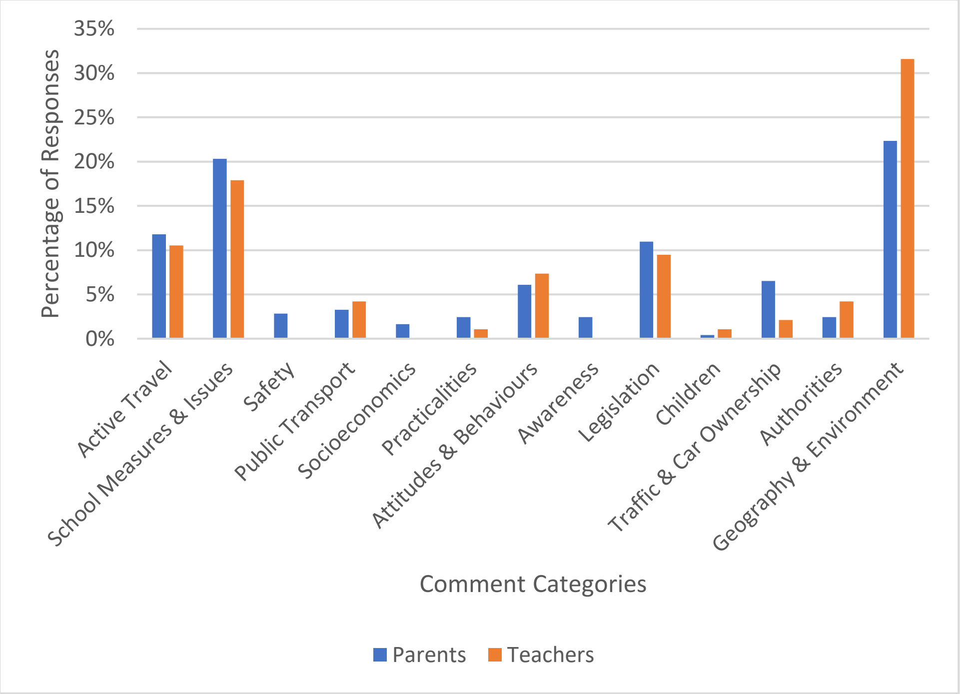

*Figure 26 Categories for coded responses when prompted for any further comments.*

Many comments centred on the school geography and environment and included concepts such as sustainability, proximity to roads, the environment, fossil fuel dependence, and greening:

> Parent: "Planting more trees seems crucial and working out better traffic plans for the south circular while building so much new housing along the route. Electric cars are only a temporary solution because the electricity is still being generated somewhere. We need to switch to entirely renewable energy as soon as possible. We have switched to Bulb at home and considered Octopus, I think a lot of parents have done this. We have also switched cars to have lower emissions but can't afford an electric car."

> Teacher: "The local school here serves a large rural sink. Council cuts eliminated additional bus transport and stops other than school buses a long time ago. Cycle routes are fragmented, token at best, and where they align with wider pathways are left unkempt, overgrown, with no long-term funding for bankside vegetation management. You could get pulled off your bike by bramble alone! Parents end up driving their kids to school as default, popping into the convenient, new, Costa drive-through by the roundabout afterwards for their latte enema. Endless congestion around key times. The local council and school are both under-funded, squander poorly what money they have, and are completely indifferent about supporting young local families sustainably. Epic housing inflation has pushed younger families far far away from the school to live on the fringes of town exacerbating the issue. [Sigh] What can someone expect from one of longest running Tory counties in the country?"

Many respondents indicated that they would like to do more to reduce air pollution and potential child exposure but felt unable to do enough, or what they felt was expected of them, due to financial concerns or a lack of purposeful guidance. These responses are typical of this category. A sentiment asserted by the following parent:

> “This is a pertinent issue for our community at school, but we feel powerless.”

Other common themes included school measures and issues, such as school Buses, School Streets, cars outside schools and catchment areas, and whilst some teachers expressed their concern, concerns about idling were prevalent among parents:

> Parent: “We live too far to walk, but not far enough for school bus eligibility. Also, there is no safe walking route - I really think if there were a suitable, nearby car park this would really help. Schools aren’t made with large car parks so everyone parks on the road right outside often idling. Which is a danger in itself re fumes and also accidents - there have been many pupil/driver collisions.”
>
> Parent: “We need less cars, people need to get in the habit of walking more and not leaving the cars running outside the school gates and on double yellow lines.”
>
> Parent: “I am so concerned about the levels of idling. We have a number of fantastic schools in our area which is great however people travel from all over to get here and the congestion is awful, I truly urgently think something needs to be done to address it.”
>
> Teacher: “Thank you for this survey. I am concerned about the number of people who sit in their cars with the engine idling. The default position seems to be, get in the car, switch on the engine and then sit scrolling through phone for as long as it takes. I have recently stopped asking people to switch off engines having had a couple of run-ins with car owners, and do not want to get involved in an altercation. Intelligent, thinking people are sitting in their cars with the engines on and windows open. Turning on the engine should be the last thing people do before starting their journey, not the first thing they do on getting in the car.”

These sentiments are consistent with the responses that idling outside schools is a prominent issue of concern, and one which appears to be affecting parents’ attitudes more than teachers, which is likely due to their participation at the school gates each morning.

Conversely, active travel was a recurrent issue for both parents and teachers:

> Parent: “If I lived closer to school I would absolutely walk or cycle with my child. To cycle would take 30 minutes, and this is not possible when I also then need to get to work straight after the school drop-off.”
>
> Parents: “Companies need to be more flexible on start and end times to allow parents to walk/cycle their kids to and from school. Too many parents use the excuse of having to go straight to/from work as a reason to drive the kids to and from school. Especially given the catchment is about half a mile.”
>
> Teacher: “So many of our children would like to cycle or scoot to school but do not own bikes or scooters. It would be great if there was a government led subsidy to ensure every child has the opportunity to own either a bike or scooter as so many of our children have shown they would prefer to come to school this way but cannot. As they grow bigger and need updated bikes there should be a trade-in scheme and the older bikes could be made available for younger/smaller children so there is a reduction in land waste and increase in recycling/sustainability.”

These comments are also consistent with the findings from previous questions, which maintained that active travel is desirable, but practicalities associated with morning drop-offs are prohibitive, particularly the time it takes to get children to school and then travel to work.

Legislation was also a common theme among parents and included aspects such as the banning of cars at schools and fining problem drivers:

> "I think showing people the impacts it has on their kids and emphasising that air quality in cars is bad too, that might help. But ultimately, we need fewer cars and bans on cars outside all schools. Make it as socially unacceptable as smoking inside!"
>
> "My daughter's school actively encourages pupils to travel to school by car and actively encourages cars onto the school site. Not only does this have an impact on air quality at the school, but it is dangerous for pupils. My daughter has nearly been run over several times whilst walking on the school site. As a parent, I would like to see parents banned from driving onto school sites during the school day and the creation of safe cycle routes so that pupils can cycle to school. My daughter walks to school (distance approx. 1 mile) but she does not have the option to cycle because the roads are far too congested and dangerous."
>
> "Due to the above this is a very difficult problem to address, but also one that could be made quite simple to address with strong national govt. action (i.e., ban cars on the school run for all except those that have an exempting need). But that is likely to be very unpopular, and difficult to enforce. But then, big problems sometimes need bold action! Many people manage to get their kids to school without using the car, and it is possible for many more people too!"

The comments mirror the sentiments of those who would like to see the closure of school roads, polluting vehicles, and increased safe active travel for children. These comments are also indicative of the further desire for authorities to provide guidance, perhaps in the form of legislation, to address issues surrounding air pollution at schools, as highlighted by the following parent:

> "I think in reality clean air measures will need to be enforced by the LA for everyone to adhere to them. Air pollution has been my biggest concern locally since my children were born."

Attitudes and behaviours were also popular topics in the responses and included themes such as complacency, driving convenience, behavioural change, and driving necessity:

> Parent: "Educating people is the most effective way to reduce air pollution. And getting people to realise that it is behaviour change that will reduce air pollution. Rather than just switching to another large vehicle that is electric. Less vehicles and smaller vehicles are the solution. Which requires behaviour change as well as finding jobs and schools that are closer to home. Another essential behaviour change!"
>
> Teacher: "We are fortunate enough to live in the 'greenest' borough however, with lack of parental support and their 'necessity/desire' to drive 'high output' cars will forever be a problem."
>
> Teacher: "Modern lifestyles mean we need our cars."

The need for effective communication is made apparent in these comments, as is the case for addressing driver behaviours. However, concerns implied in previous responses were confirmed in the following statement by a teacher:

> “We are a nursery school; most children walk to us as the live nearby. We do have some discussion with the children, but they are all under 5 which is why I said it needs to be with the parents. We are also already ‘greening’ our site. However, my staffing is cut it the minimum and I have no one who would be able to take the lead in this.”

This comment supports the position that whilst attitudinally people may be willing to do more to reduce air pollution exposure, concerns remain regarding staffing initiatives at schools, in addition to the provision of suitable funding.

### 4.5 Limitations

A key limitation of the current approach relates to the nature of the respondents. Those who are more likely to already find air pollution an issue may be more inclined to partake in a survey of this nature, whilst those who are either uninterested or generally unconcerned with air pollution at schools may be more likely to disregard this kind of survey. More critically, these people may be more likely to contribute negatively to the issue or less inclined to undertake measures for TRAP reduction due to their disinterest. Accordingly, the views of this group are essential for developing practical solutions for all involved but may be lacking in the data. Any solutions developed based on these findings should also consider the views of those stakeholders whose positions, circumstances or attitudes may have been absent from the survey results.

Another limitation is that the nature of the questioning may obfuscate the categorisation of the respondents as parents and teachers. The respondents were prompted to select their school affiliation and to respond to the questions based on this position. However, some of the parents may be teachers, and many of the teachers are parents. This duality of affiliation provides the potential for bias in the responses provided. Whilst this potential should be acknowledged, it should be considered that teachers will still be responding from a position of knowledge authority despite their position as parents, and parents are likely to be equally experienced in the pragmatics of child school travel.

## 4.6 Intervention Selection

### 4.6.1 Overview

The interventions selected for modelling were chosen based on a combination of those identified from the literature and systematic reviews and their popularity in the survey outcome. The most popular interventions among stakeholders that were identified in the literature and fit these criteria are mode shifts to active travel, anti-idling, rideshare, low emission zones (LEZs), and improved travel routes. The interventions were also required to be suited to the dispersion modelling process.

### 4.6.2 Selection Requirements Based on Survey Results

Based on the outcome of the stakeholder survey, the two largest areas for concern were:

- The school is near or on a busy main road (25.58%).
- There are lots of idling cars outside the school (21.88%).

Contrastingly, the two largest reasons for those unconcerned were:

- The school is in a rural area (25.5%).
- There is very little traffic near the school (25.99%).

The most desirable interventions for schools to implement were:

- The promotion of active travel (7.33%).
- Parent awareness (7.74%).
- Improved cycle and pedestrian environment (5.76%).

Of the interventions currently in place at schools, those considered to be the most effective were:

- The promotion of active travel (18.79%).
- The closure of school roads during pick-up and drop-off times (13.43%).

These attitudes are also supported in forthcoming regional analyses, which identify urban areas as more polluted than rural areas and more likely to have schools within AQMAs (see Chapter 5). Based on these key survey findings and regional analyses, schools in urban or semi-urban environments near main roads or heavy traffic would be suitable for modelling.

The school districts should also suit the application of active travel routes. With the consideration of further refining the number of schools to a more manageable selection, a series of filtering criteria were applied to the dataset that corresponded to the requirements of the model.

In addition, consideration had to be made regarding the nature of the current research as a traffic exposure reduction project, and the selected interventions must reflect this. For example, urban and road greening were popular measures in the literature and the outcome of the survey but are more suited to a computational fluid dynamics (CFD) modelling approach (see Guo et al., 2021; Buccolieri et al., 2020), so were omitted from the ADMS modelling.

Based on these criteria, the interventions selected for dispersion modelling (and their correspondence to the literature and survey results) are as follows:

- Mode shifts to active travel (promotion of active travel).
- Anti-Idling (parent awareness).
- Rideshare (parent awareness).
- Low Emission Zones (LEZ).[5]
- Improved travel routes (improved cycle and pedestrian environment).

A fundamental parameter of dispersion modelling permits the adjustment of traffic volumes within specific regions based on specified traffic volumes on mapped road links (Johnson, 2022). These traffic numbers can mimic or represent genuine or hypothetical traffic flows, and the associated air pollutants can then be determined and assessed. Each of these interventions is suitable for dispersion modelling in that they can be modelled by specifying a reduction of traffic or, in the case of improved travel routes, avoiding routes with heavy traffic by adjusting the placement of receptors representing points within travel routes to find the route with lowest potential air pollution exposure.

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[5] Implemented in the form of ‘School Streets’ for the forthcoming modelling phase (Chapter 6: Intervention Modelling), involving a school-specific context whereby road closures are modelled within a specified perimeter of the school building.

### 4.7 Summary & Conclusion

A survey was conducted among parents and teachers to determine their opinions on TRAP at schools and methods for mitigating potential child exposure to and the reduction of these harmful pollutants. It was hoped that by engaging with key stakeholders, insights could be gained to develop more effective strategies that could be implemented with greater harmony for these involved parties. The data was scrutinised using descriptive analysis to present the responses with clarity and conciseness. Whilst this level of sophistication was suitable for the current research, more advanced statistical analysis (for example, assessing spatial variability across the UK) could be applied in future research.

The respondent ethnicity was broadly representative of the population, and the parents were generally younger (mostly between 35 and 44 years old) than the teachers (mostly between 45 and 54 years old). The respondents were distributed throughout England, with more parents than teachers (862:579). The respondents were well-educated, with the majority holding at least a bachelor's degree, and with an average of two children. There were no notable regional variations.

The majority of parents' (76.68%) and teachers' (75.82%) responses to the question expressed that they were very or fairly concerned about air pollution at their school. School proximity to a busy road was the greatest cause for concern for parents (44.20%) and teachers (42.49%). Secondary concerns included idling outside the school (Parents, 40.02%; Teachers, 32.30%), general concerns due to media (Parents, 33.06%; Teachers, 32.30%) and congestion at the school (Parents, 30.74%; Teachers, 25.73%). These findings are supported in the literature, with the majority of parents exhibiting general concerns regarding child health as a consequence of air pollution exposure (Cobbold et al., 2022), particularly when in close proximity to busy roads (Liao et al., 2015; Stevens, Cullinan & Colvile, 2004).

For those parents and teachers who were not very or not at all concerned, the most common reasons were the rural location of the school (9.05% and 9.50% of each group's responses to the question, respectively), little nearby traffic (9.05% and 9.84% of each group's responses to the question, respectively), or that active travel was common among pupils (7.54% and 7.25% of each group's responses to the question, respectively). Reasons for the lack of concern among parents regarding air pollution are debated in the literature, although common reasons cited include a lack of awareness (Sunyer et al., 2017; Stafford & Brain, 2015) or a greater set of concerns taking priority, such as family or financial matters (Stafford & Brain, 2022; Rashid et al., 2021).

Active travel is a popular intervention in the literature, commonly due to its ease of implementation (Aldred et al., 2021; Pang, Kubacki & Rundle-Thiele, 2017) and its lack of requirement for financial investment (Witten & Field, 2020; Powell et al., 2010). The promotion of active travel was the most common measure already undertaken at schools for parents and teachers (21.57% and 17.77% of each group's responses to the question, respectively), which was considered one of the most effective measures (7.29% and 7.45%% of each group's responses to the question, respectively), followed by parent awareness (6.91% and 6.67% of each group's responses to the question, respectively). Prompted to choose the most effective measure from those selected, the highest response from parents was the closure of school roads during congregative times (69.19%), although the promotion of active travel remained high for parents and teachers (47.29% and 39.92% of each group's responses to the question, respectively).

The biggest obstacles chosen by parents and teachers for the improvement of air at school were the convenience of driving (17.26% and 17.41% of each group's responses to the question, respectively), the school's proximity to busy roads (12.76% and 12.18% of each group's responses to the question, respectively), and a lack of parental support (11.46% and 11.11% of each group's responses to the question, respectively). The single biggest obstacle based on these choices was the convenience of driving (27.75% and 28.22% of each group's responses to the question, respectively) and the school's proximity to busy roads (24.87% and 24.50% of each group's responses to the question, respectively). The convenience of driving is also highlighted in the literature as an issue that must be addressed, given its commonality as a reason for persistent car use among parents (Varaden et al., 2021; Nikitas, Wang & Knamiller, 2019; Ahern et al., 2017; Mehdizadeh et al., 2017) and commuters (Jayaraman et al., 2020; Kang et al., 2019; Buehler, Götschi & Winters, 2016).

Both parents and teachers stated that local authorities (43.13% and 38.48% of each group's responses to the question, respectively), national government (23.32% and 27.45%, respectively), and parents (18.13% and 17.43% of each group's responses to the question, respectively) were the most responsible parties for the improvement of school air quality. These views are also supported in the literature, with attitudes maintaining that national and local government failures are responsible for persistent air pollution (Dyer, 2020; Sofia et al., 2020).

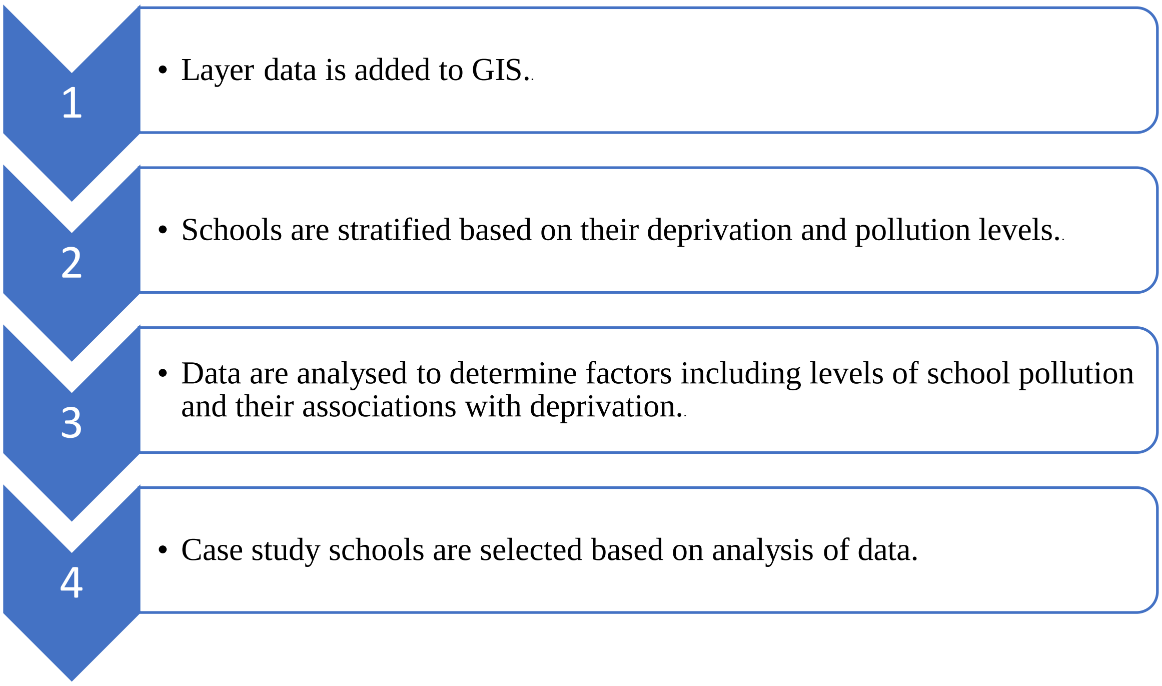
To summarise, the sample was broadly representative of the population. School proximity to main roads was of great concern, and conversely, those who were unconcerned about air pollution were predominantly from rural areas. The convenience of driving was viewed as a key obstacle to the improvement of school air quality, and both teachers and parents considered local authorities to be of key importance in actioning change. Active travel was a popular and desirable intervention for reducing potential child exposure to TRAP, and parental education on this and related topics were also desirable.

Based on the outcomes of the literature review (Chapter 2), the systematic review (Chapter 3) and the stakeholder survey described in the current chapter, and their suitability to the dispersion modelling process, mode shifts to active travel, anti-idling, rideshare, low emission zones (LEZs), and improved travel routes were the interventions selected for modelling (Chapter 6).

# 5.0 Case Study Selection

## 5.1 Introduction

The current chapter builds upon the stakeholder survey (Chapter 4) to identify sites that are suitable for dispersion modelling the interventions selected based on the survey findings (see section 4.6 Intervention Selection). To find suitable sites for modelling the TRAP exposure mitigation interventions, it was necessary to determine the levels of pollution currently experienced by UK schools to identify the most polluted. A GIS (Geographical Information System) was produced using ArcGIS ArcMap (Version 10.8.1) to facilitate the production of a baseline at schools in England, Northern Ireland, Scotland, and Wales, and to find which areas had the most polluted schools and how many schools were in AQMAs. $NO_2$ was mapped to the GIS as an indicator of TRAP (Janhäll, 2015; Tonne et al., 2008). $PM_{2.5}$ was also added due to its severe impacts on child health (Osborne et al., 2021b; Roberts et al., 2019; Zhang et al., 2018). This information helped to determine those areas in which children had the greatest potential for TRAP exposure and assist in selecting suitable locations for dispersion modelling. The chapter process is detailed in the process diagram depicted in Figure 27.



1. Layer data is added to GIS..
2. Schools are stratified based on their deprivation and pollution levels..
3. Data are analysed to determine factors including levels of school pollution and their associations with deprivation..
4. Case study schools are selected based on analysis of data.

*Figure 27 Process diagram for case study selection chapter.*

## 5.2 GIS Layer Data

### 5.2.1 Overview

A series of datasets were sourced for the GIS layers to facilitate the assessment of UK school pollution. The data included a UK basemap, which provided the foundation upon which to map the data, pollution climate mapping (PCM) data, which comprises modelled background pollution data for the UK and is provided by Defra, AQMA boundaries, the location of all schools in England, Northern Ireland, Scotland, and Wales, and deprivation data for each country.

### 5.2.2 Basemap

Initially, each pollutant was mapped onto a UK basemap, created in ArcMap using raw spatial data provided by the World Light Grey Base layer (Esri, 2021a). The map was updated in 2020 and provided an aesthetically superior base with an equally high level of positional accuracy and completeness for the purposes of the current analysis. Based on the basemap, all layers share a British National Grid projected coordinate system and a Transverse Mercator projection. The light grey, neutral tones draw attention to the thematic content added to the GIS with minimal use of labels, colours, and features.

The World Light Grey Base layer was combined with the World Light Grey Reference layer (Esri, 2021b). This combination provides labels for selected towns and cities and supports strong and diverse colour palates and allows a greater discernment of map graphics and contained patterns. The basemap combination depicts administrative boundaries, populated regions, roads, urban areas, building footprints, and parks. The basemap only depicts key information for the purposes of geographic contextualisation, allowing data prominence in the foreground.

### 5.2.3 Pollution Climate Mapping Data

Defra and the Devolved Administrations currently use a suite of models to assess a range of pollutants at differing spatial scales and to satisfy a range of requirements. One of the key models used by Defra and the Devolved Administrations is the Pollution Climate Mapping (PCM) model. The PCM model is designed for the fulfilment of the EU Directive (2008/50/EC) (Ricardo Energy & Environment, 2018). This component of the directive requires the UK to report atmospheric pollutant concentrations. Ricardo Energy &

Environment runs the models on behalf of Defra and provides one model per pollutant ($NO_X$, $NO_2$, $PM_{10}$, $PM_{2.5}$, $SO_2$, CO, benzene, ozone, As, Cd, Ni, Pb and B[a]p). Each model contains a base year model component and a projections model. The output of the PCM model is provided as a grid of annualised mean background values at 1x1 km resolution, with approximately 9000 values that are representative of roadsides. The PCM data was considered suitable for the construction of the background map due to its representation of atmospheric conditions and its resolution (Defra, 2021b). Whilst the PCM data are arguably only representative background concentrations and not population exposure, it was considered suitably representative of potential child exposure for the current project, given its coverage.

The most recent methodology report relevant to the PCM data used for the current study is available from Ricardo Energy & Environment (2018). The PCM model data are also freely available as national annualised mean background concentration maps by region (East of England, Greater London, Midlands, Northern England, Northern Ireland, Southern England, Scotland, and Wales). Each file provides summary dataset information, including pollutant, year, metric, and units. The data contains a unique UK grid code for each 1x1 km map cell, the x and y coordinates for each grid cell centroid, and the metric values. The map coordinate system is OSGB (Ordinance Survey of Great Britain), with each coordinate representing each cell centroid. It is also possible to join several maps into a single dataset using the UK grid code field. The model outputs are generally provided as annual mean concentrations ($\mu g/m^3$). The background maps' primary purpose is to provide background concentration estimates for the listed pollutants. These estimates can then be used to assess air quality to improve understanding of the local source contribution to total pollutant concentrations. The maps provide pollutant concentration information for time changes and across broad regions but also provide an estimated breakdown of relative pollution sources.

### 5.2.4 Air Quality Management Areas (AQMAs)

AQMA data was sourced from Defra (Defra, 2021a) as a shapefile (Figure 28). The 2020 AQMA dataset is based on information reported by local authorities for 2020 and was correct as of April 2021. The shapefile detailed all AQMAs. However, only traffic related AQMAs declared for exceedances of $NO_2$ were used for the analyses.

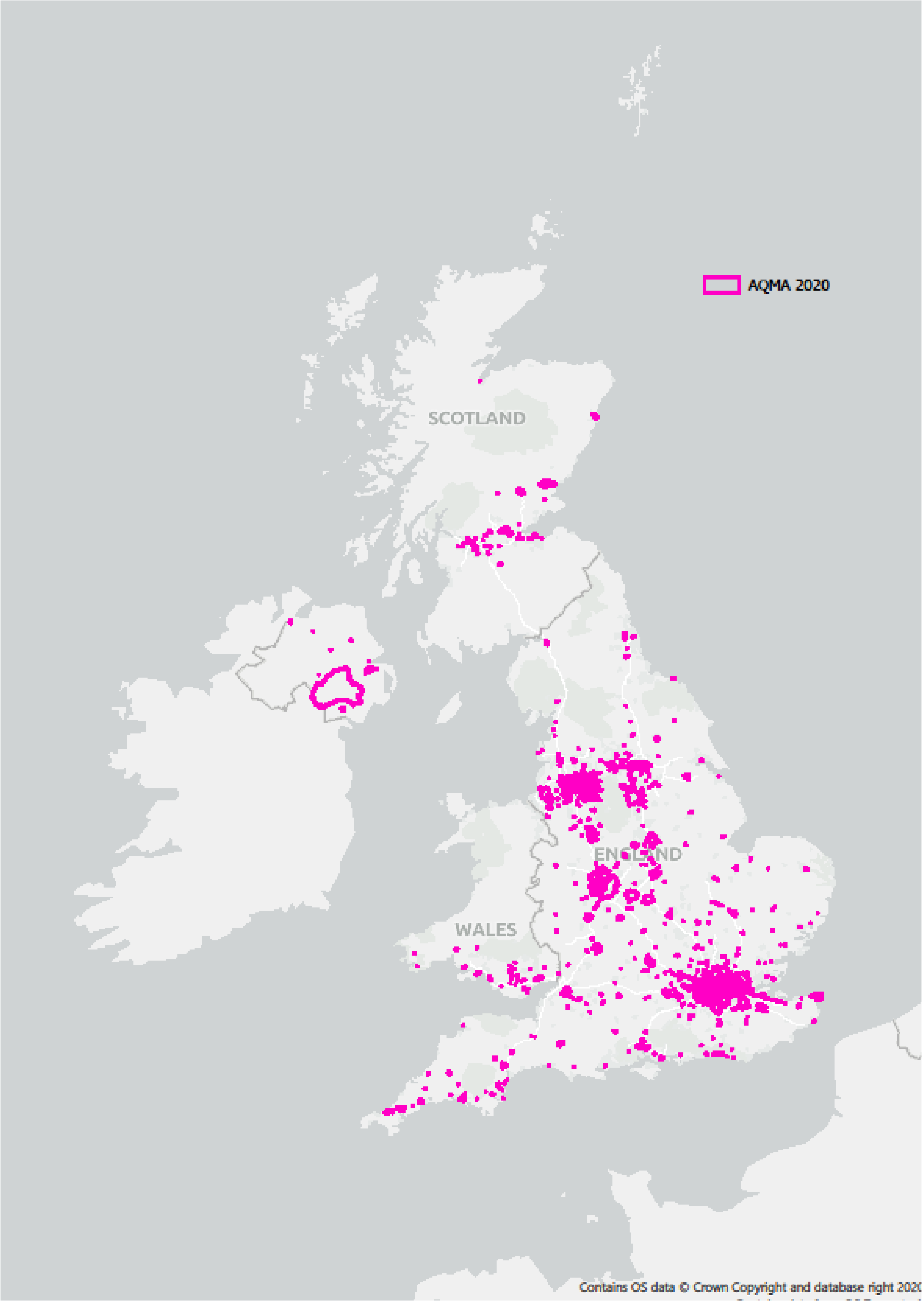


*Figure 28 2020 AQMA boundaries (Defra, 2021a).*

### 5.2.5 Schools

Locations for Schools in England and Wales were sourced from the UK government's online data repository (GOV.UK, 2020b). Establishment data are downloadable in spreadsheet format and comprise core data, including URN (Unique Reference Number), establishment name, address, type, and phase.

Scottish school locational data was sourced from the Scottish Government website (Scottish Government, 2019). Scottish school information is updated annually for the purposes of performance monitoring, equality, and policy. The provided dataset includes the geocoded location, address, roll numbers, number of teachers, denomination, and student composition (minority and ethnic groups), and data are provided for each special, primary, and secondary school in Scotland. The Scottish equivalent of the Department for Education number (associated with English and Welsh schools) is the SEED code, which is assigned to each school and comprises a 7-digit number with the addition of a suffix indicating primary ('P'), secondary ('S') or special school ('SP') denomination. This is provided as a school ID (SchUID), which is used as the unique field in the dataset due to the assignation of the same SEED code to primary and secondary schools that operate on the same campus. A point is created for each SchUID, and accordingly, a single SEED code may have multiple points. Each school is also assigned an urban or rural code based on the Scottish Government's Urban Rural Classification (GOV.SCOT, 2016). These assignments are provided both for the geocoded location of each establishment and its associated data zone. For approximately 2.5% of cases, assignments may differ for the address and data zone (ibid.). Accordingly, discretion is required when considering the assignments used. However, for the current project, the locational urban/rural classifications were considered appropriate as a more accurate representation of the area context of each establishment.

School locations for establishments in Northern Ireland were obtained from Open Data NI (2021). The datasets are comparatively sparse and comprise information including the establishment name, address, and coordinates.

### 5.2.6 Deprivation

Deprivation data was also added to the GIS in anticipation of the analyses and to provide a richer understanding of the nature of the air pollution issue at schools in the UK. The data are unique for each UK country and sourced from each relevant governmental body. Given the distinct deprivation scales which cover England, Wales, Northern Ireland, and Scotland, it is not meaningful to directly compare these indices, as the rankings are relative within each jurisdiction and are based on different indicators with distinct geographies. This was considered acceptable for the current research as the factors within levels of deprivation between countries were not being compared. Instead, the number of schools with high concentrations of air pollution also experiencing deprivation relative to their country was considered.

Initially, the Census-based Townsend index (Yousaf & Bonsall, 2017) was considered as it does allow a degree of comparison across the UK, although this was abandoned as comparisons between the area deprivations are not necessary for the study. Also, the data are decennial, with 2011 providing the most recent iteration, and the 2021 census data was not due to be released until after the analysis had taken place.

#### 5.2.6.1 England: Index of Multiple Deprivation

The official deprivation measure in England for Lower-layer Super Output Areas (LSOA) is the Index of Multiple Deprivation (IMD) (GOV.UK, 2020a). The LSOA is higher-level resolution geography than the Output Area (OA), which would commonly have grid references. The IMD ranks each LSOA in England from the most deprived (1) to the least deprived (32,844). The deprivation indices are produced by the Ministry of Housing, Communities and Local Government (MHCLG), with the most recent iteration at the time of writing published in 2015. The IMD is a combined overall measure of deprivation across seven domains. The domains and respective weights comprise: Income Deprivation (22.5%); Employment Deprivation (22.5%); Education, Skills, and Training Deprivation (13.5%); Health Deprivation and Disability (13.5%); Crime (9.3%); Barriers to Housing and Services (9.3%); and Living Environment Deprivation (9.3%). The weights have been derived from academic literature on poverty and deprivation alongside indicator robustness (GOV.UK, 2020a). The indices data are not supplied as a dataset ready for GIS, although the indices are published at the level of LSOA with unique identifiers for each region. LSOA geographical boundaries were obtained from the Office for National Statistics Open Geography Portal (ONS Geography, 2022). To visualise the indices on the GIS, the data was joined to the LSOA boundaries using the unique identifiers within ArcGIS (Figure 29).

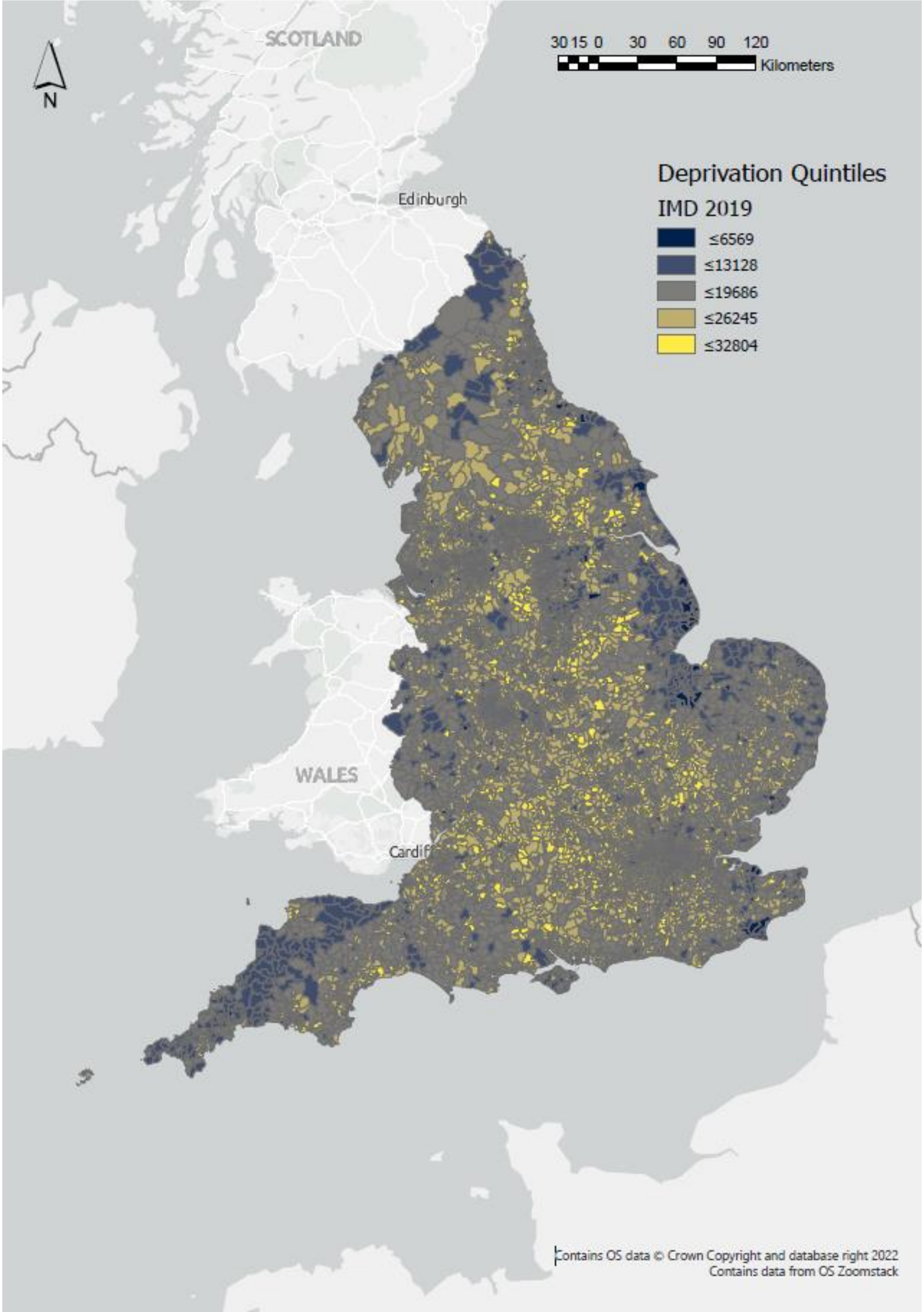


*Figure 29 2019 Index of Multiple Deprivation (IMD) quintiles for England (GOV.UK, 2020a).*

### 5.2.6.2 Northern Ireland: Northern Ireland Multiple Deprivation Measure

The Northern Ireland Multiple Deprivation Measure (NIMDM) is a small area-level measure of multiple deprivations (NISRA, 2019). The NIMDM was released in November 2017 and replaced the NIMDM 2010 as the new official deprivation measure in Northern Ireland. The measures provide a mechanism through which the Super Output Areas (SOAs) can be ranked from 1 (most deprived) to 890 (least deprived) and were informed by a Steering Group agreement and public consultation. The NIMDM model is based on seven distinct deprivation domains experienced by individuals within an area and is separately measured. The overall NIMDM is a weighted area-level aggregation of these domains: Income Deprivation; Employment Deprivation; Health Deprivation & Disability; Education, Skills & Training; Access to Services; Living Environment; and Crime & Disorder. The multiple deprivation measure ranks of the areas are combined from each of the seven deprivation domains. The MDM area ranks are intended to be considered in combination with each of the domains to determine a comprehensive understanding of the deprivation of an area. The data was combined with the SOA boundaries in GIS shapefile format, with both artefacts sourced from the NI (Northern Ireland) Statistics and Research Agency (NISRA, 2019) (Figure 30).

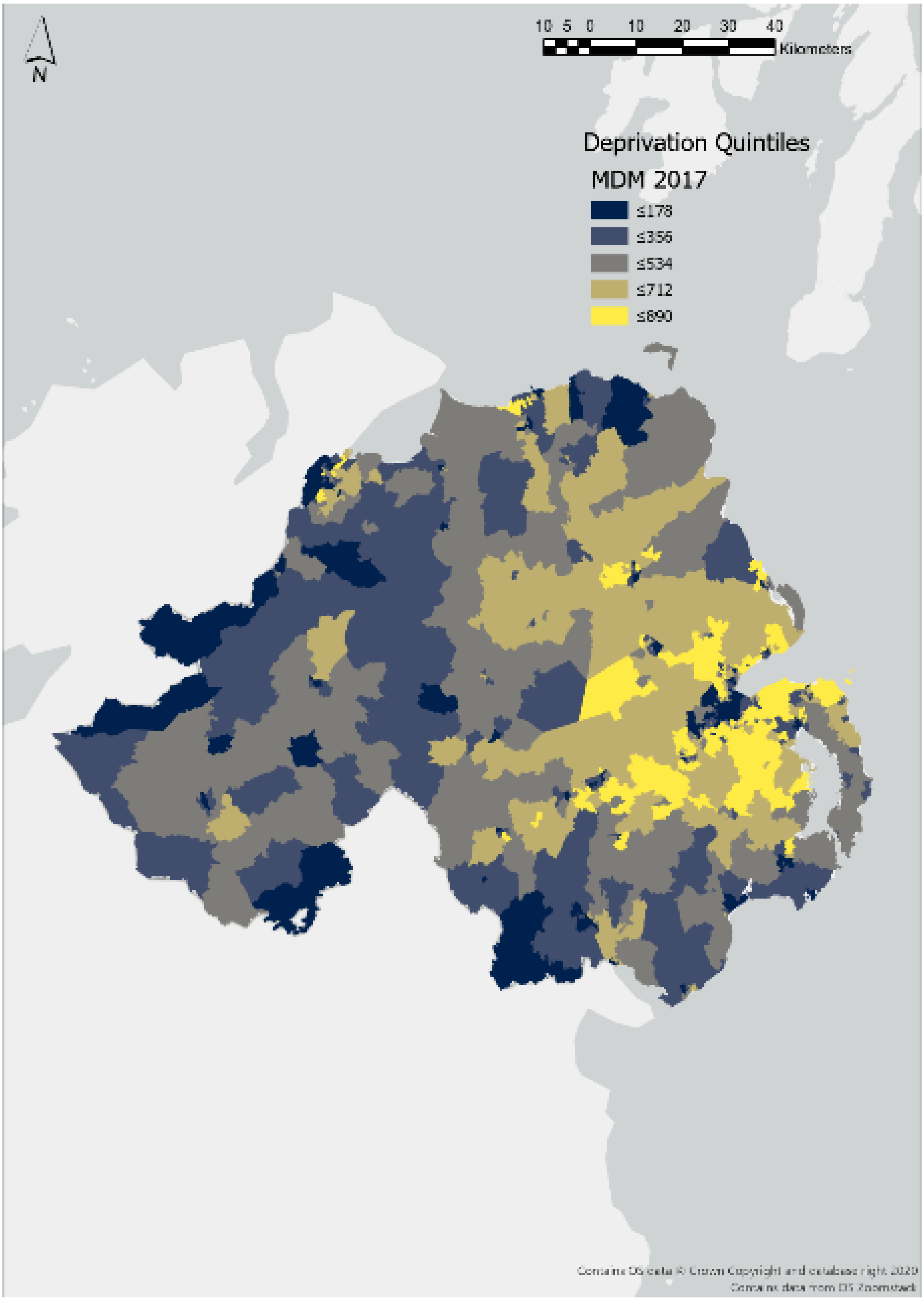


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*Figure 30 2017 Northern Ireland Multiple Deprivation Measure (MDM) quintiles (NISRA, 2019).*

### 5.2.6.3 Scotland: Scottish Index of Multiple Deprivation

The Scottish Index of Multiple Deprivation (SIMD) measures areas of poverty and inequality across Scotland. The SIMD is the standard approach for the Scottish Government for the identification of areas of multiple deprivations in the country. The SIMD can aid in understanding the circumstances of those living in deprived areas of Scotland and can assist in targeting funding and policies concerned with area deprivation. The SIMD measures relative deprivation across 6976 data zones. SIMD rankings and quantiles for 2020 within each data zone are available from the Scottish Government website (Scottish Government, 2020) in addition to a shapefile for GIS. Seven indicators are used for the SIMD: Income, Employment, Education, Health, Access to Services, and Crime and Housing. These indicators are represented in the SIMD ranks, ranging from the most deprived area (1) to the least deprived area (6,976). It is also common for the SIMD to be used in terms of percentile ranks. As with the other national deprivation indices, the SIMD is an area-based measure of relative deprivation. Accordingly, not all individuals in an area identified as highly deprived will necessarily experience high deprivation levels. Data zones that contain or cover rural areas also tend to reflect a broader mixture of people and their deprivation experiences. In this respect, the SIMD is less valuable when attempting to identify any smaller sectors of deprivation that may exist within rural areas than larger sectors found in urban regions. However, the domain indicators used are still useful when applied to rural areas when assessed separately from data zones in urban areas or in combination with additional data (ibid.) (Figure 31).

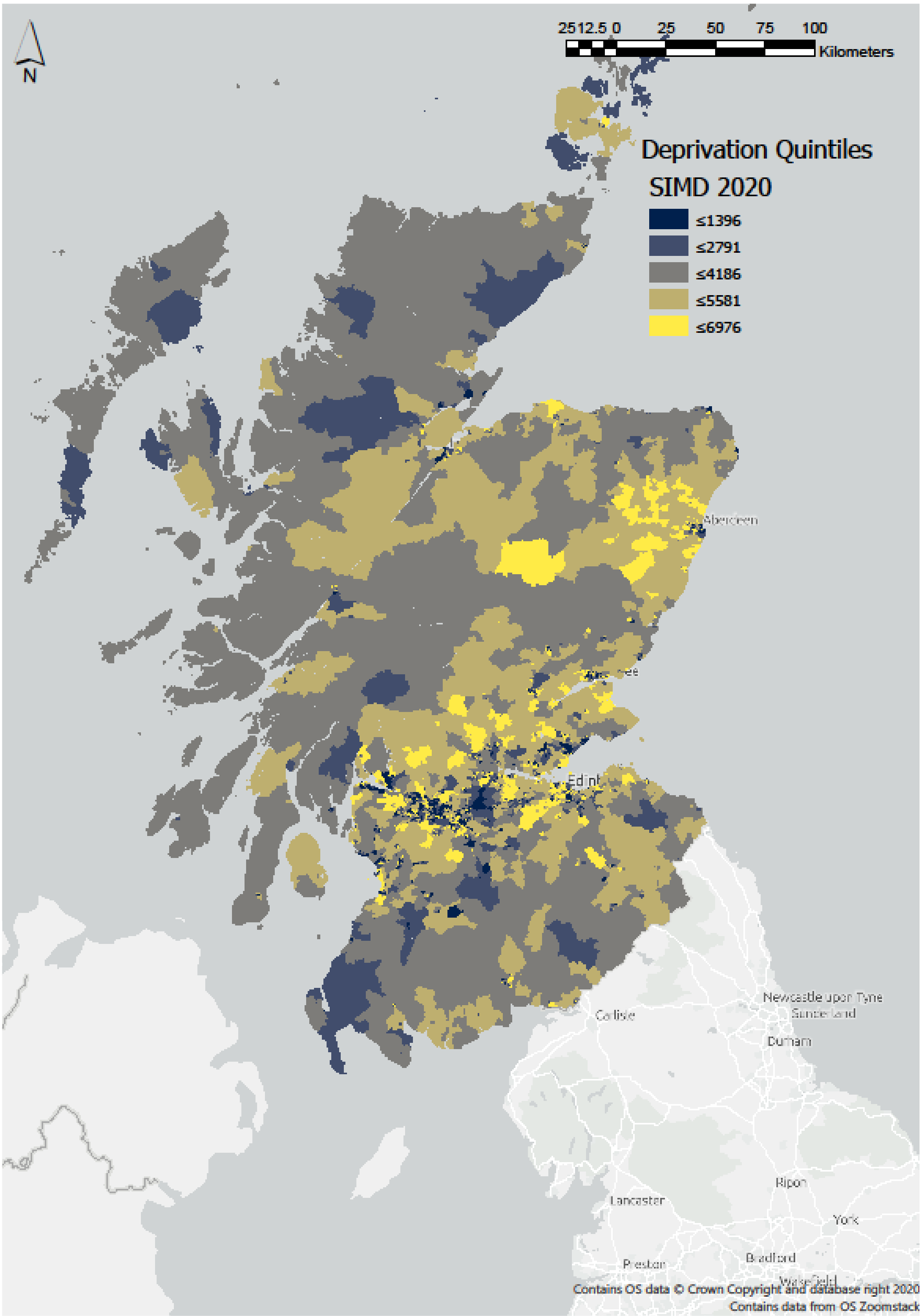

*Figure 31 2020 Scottish Index of Multiple Deprivation (SIMD) quintiles (Scottish Government, 2020).*

#### 5.2.6.4 Wales: Welsh Index of Multiple Deprivation

The Welsh Index of Multiple Deprivation (WIMD) identifies deprived areas of Wales and is the Welsh Government's official measure of relative deprivation for small areas in Wales. The LSOA is the lowest geographical level within which deprivation data for Wales is calculated. The index is designed for the identification of small areas where the highest concentrations of several types of deprivation exist. The WIMD ranks each LSOA in Wales from the most deprived (1) to the least deprived (1,909). The WIMD is composed of eight domains of deprivation, and each is compiled from a range of indicators. The domains are: Income, Employment, Health, Education, Access to Services, Community Safety, and Physical Environment and Housing. The indicators are measurable quantities that capture the deprivation concepts for each relevant domain. The most recent WIMD was published in 2014, although a selection of indicators within the WIMD was updated in 2017 and sourced through the Welsh Government (StatsWales, 2022) for use in the GIS. The LSOA map was also sourced from the same site and combined with the WIMD data to form the GIS shapefile layer (Figure 32).

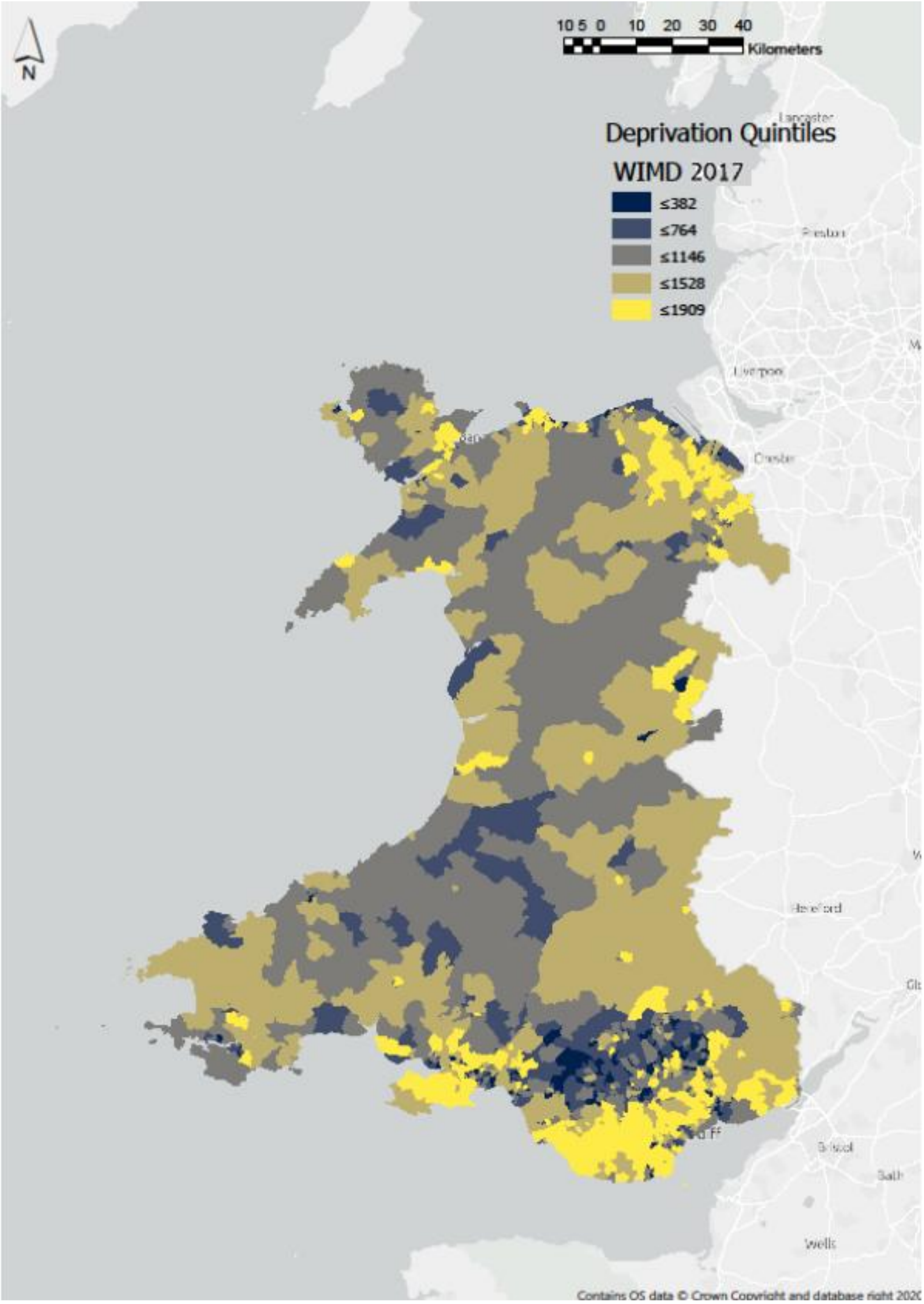

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*Figure 32 2017 Welsh Index of Multiple Deprivation (WIMD) quintiles (StatsWales, 2022).*

## 5.3 GIS Procedure

A baseline of TRAP around UK schools was constructed using GIS. $NO_2$ and $PM_{2.5}$ concentrations were sourced from the PCM model data (Defra, 2021c) and added to the GIS. $NO_2$ was used for the analyses because it is a key component of TRAP and a common indicator of traffic (Janhäll, 2015; Tonne et al., 2008), and $PM_{2.5}$ was added due to its severely detrimental health impacts for children (Osborne et al., 2021a; Roberts et al., 2019; Zhang et al., 2018).

Regional PCM model point data for 2019, AQMA boundaries, and school locations for England, Northern Ireland, Scotland, and Wales, were added to the GIS using the X/Y to point function within the ArcGIS software. The year 2019 was chosen as the last year representative of business-as-usual (BAU) prior to the onset of the Covid-19 international pandemic in late 2019, which disrupted usual traffic and behaviours, including school travel (Brown, Barnes & Hayes, 2021).

All schools in the UK are registered and identifiable by grid references or easting/northing, allowing this data to be input to the GIS (Open Data NI, 2021; GOV.UK, 2020b; Scottish Government, 2019; Welsh Government, 2019) (Figure 33). Schools in the Isle of Man were sourced as a shapefile by email contact with the MannGIS team and plotted to the GIS. However, the PCM data indicated trace levels for all pollutants in the region, so further investigation was unwarranted.

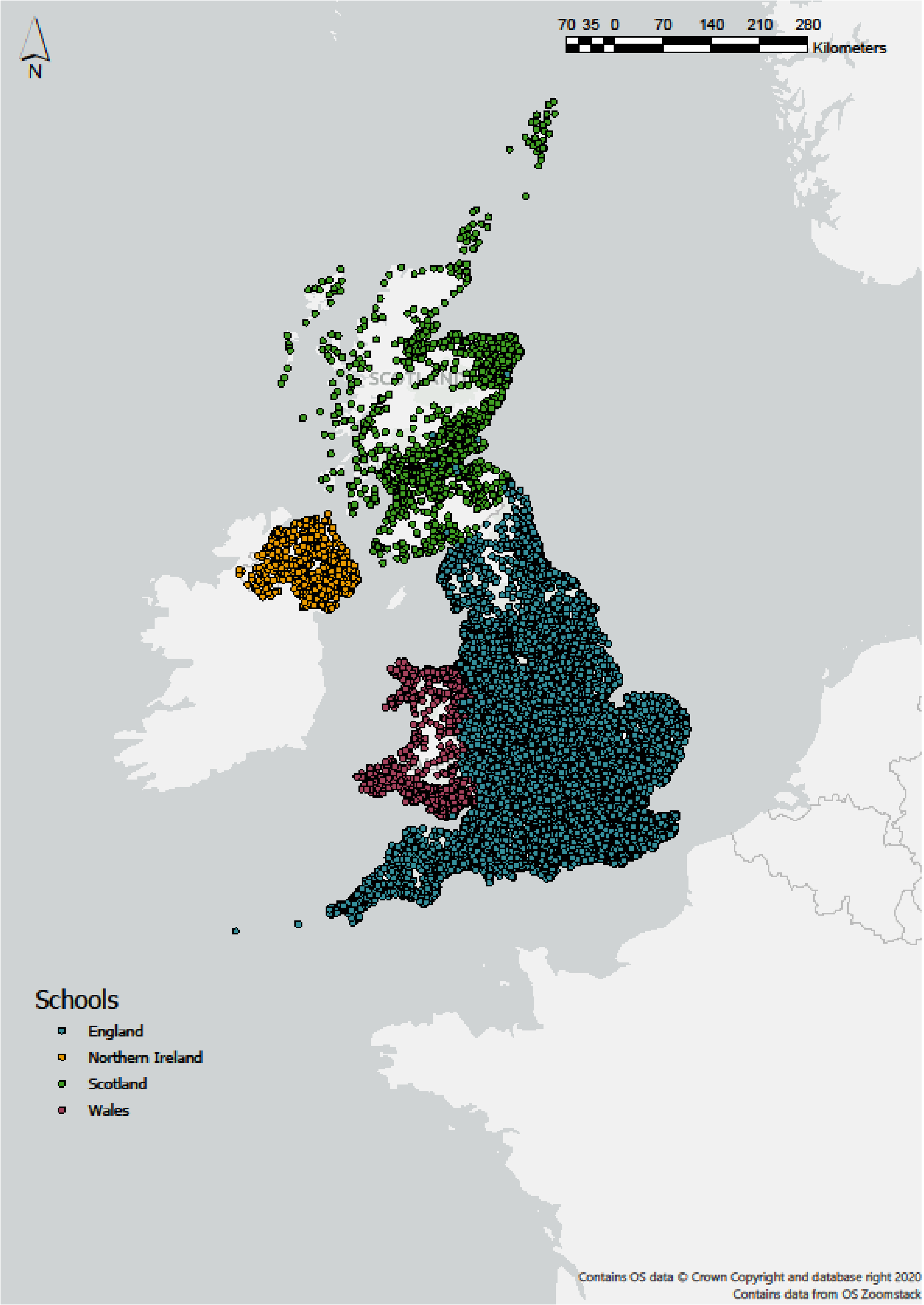


*Figure 33 UK school locations (Open Data NI, 2021; GOV.UK, 2020b; Scottish Government, 2019; Welsh Government, 2019).*

The PCM data was visualised in the GIS by quintiles, as any more categories would become difficult to interpret. A five-class quantile concentration banding was considered more suitable for a more accurate statistical representation of concentration differences and more effective subsequent data management. Whilst this resulted in unequal class widths, quantile banding distributes all observations equally across class intervals. A suitable colour banding was applied to the quantiles as best practice to ensure accessibility for people with colour-vision deficiency **(**Wadsworth & Treweek, 1999). This approach produced choropleth maps to determine TRAP severity around UK schools (Figure 34 and Figure 35).

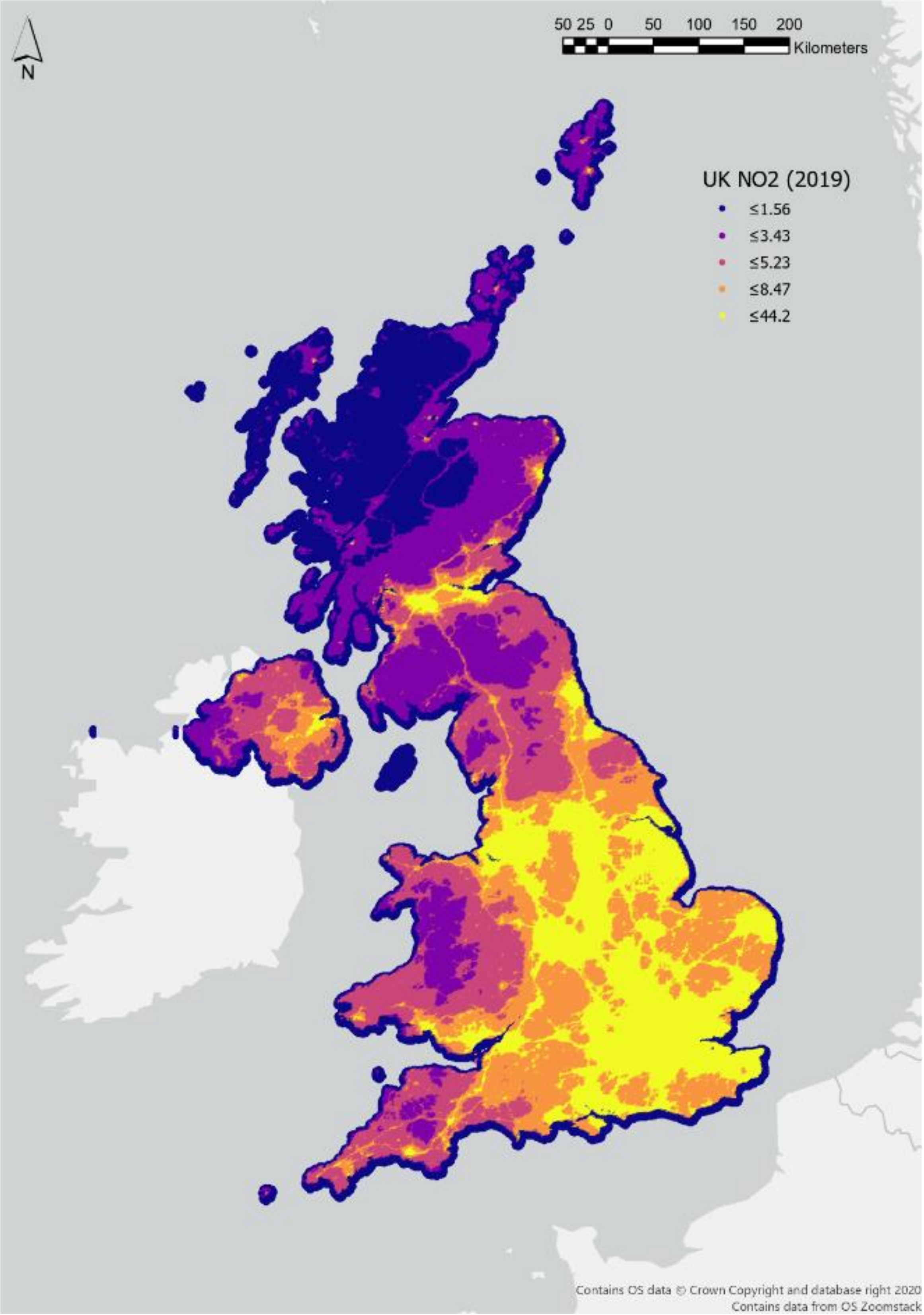


*Figure 34 Pollution Climate Mapping (PCM) quintiles for annualised mean UK 2019 $NO_2$ ($\mu g/m^3$) concentrations (Defra, 2021b).*

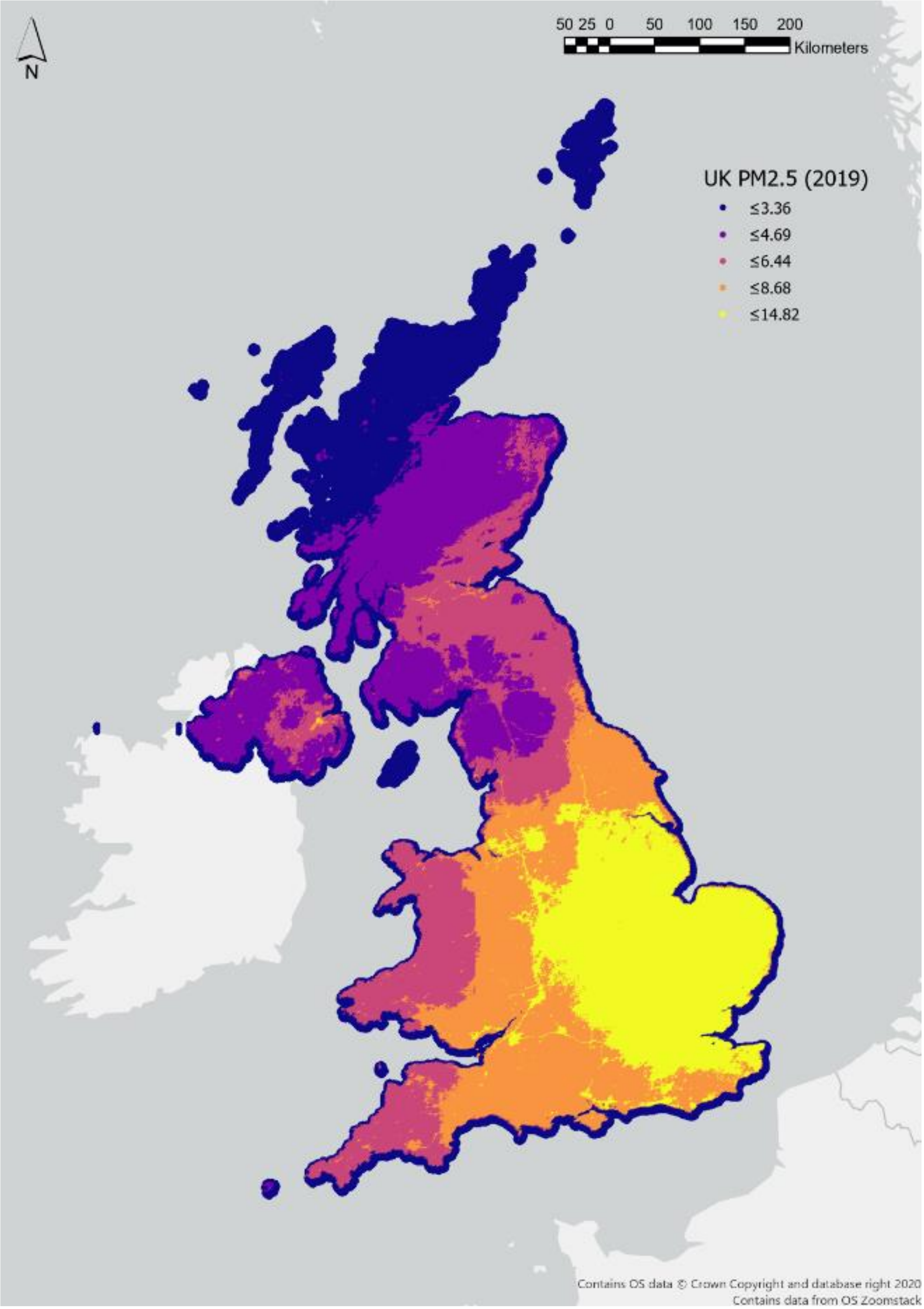


*Figure 35 Pollution Climate Mapping (PCM) quintiles for annualised mean UK 2019 $PM_{2.5}$ (µg/$m^3$) concentrations (Defra, 2021b).*

### 5.4 Determining School Pollution & Deprivation

The first analytical step determined which schools were exposed to the highest concentrations of pollutants. The 2005 World Health Organization (WHO) Air Quality Guidelines (Table 11) provide guidance on limits for $NO_2$ and $PM_{2.5}$, which were used as a threshold to determine the most exposed schools. 64 schools were found to be exposed to exceedances of all three pollutant limits, and all were in London.

*Table 11 2005 World Health Organization (WHO) Air quality guideline values (World Health Organization, 2018).*

| **Average** | **$NO_2$ (µg/m$^3$)** | **$PM_{2.5}$ (µg/m$^3$)** |
|---|---|---|
| Annual mean | 40 | 10 |
| 24-hour mean | N/A | 25 |
| 1-hour mean | 200 | N/A |

School exposure to background concentrations of $NO_2$ and $PM_{2.5}$ was assessed. Based on the produced GIS, search queries provided a method of filtration through which schools closest to the PCM grid centroids indicating high pollution concentrations were identified. To achieve this, a Euclidian ‘buffer’ with a 500-metre radius was applied to every school to create a zone of equidistance around the point location. A 500-metre buffer was created around each school to identify pollution concentrations associated with each location using the ‘summarise within’ tool within ArcMap. Studies have suggested that exposure to pollution within 500 metres of the source is potentially hazardous to human health (see Jerrett et al., 2007; Zhou & Levy, 2007; Reponen et al., 2003). For the considerations of pollution transportation and similar effects, and for comparative assessment, data was also produced for potential exposures 1 km of the school centroids. However, this generated anomalies when multiple centroids were equidistant from school sites so was abandoned in favour of the 500-metre diameter buffers.

To enable a complete analysis of the pollution coverage around the UK and its effect on schools, the PCM point data layers were rasterised using inverse distance weighting (IDW). IDW was chosen over kriging as the preferred method of interpolating the PCM data point centroids. Both IDW and kriging interpolation methods measure surrounding values and establish weights to determine predicted values for unmeasured locations. With both methods, the measured values in closest proximity to the unmeasured locations are assigned the greatest influence. Both forms of interpolation are reliant on Tobler’s first law of geography, which states that things that are closer are more related than those that are further apart (Tobler, 1970). However, IDW is a simpler technique than kriging: it involves the use of known z values (data points), and weights are determined as a function of the distance between known and unknown points. Accordingly, points in IDW that are farther away are of less influence than closer points (Miller, 2004).

IDW differs from kriging predominantly because no statistical models are used. The determination of spatial autocorrelation is not taken into consideration, as is the case with kriging. Accordingly, the degree of correlation of variables at different distances is undetermined. IDW determines unknown areas by only using known z values and distance weights. IDW also has the advantage of providing simplicity of definition and accordingly allows a more straightforward interpretation of the generated results. Kriging also presents problems when presented with outliers (Li & Heap, 2011).

The effect of the inverse distance weights is commonly determined by user input, which is achieved by changing the power to which the inverse distance is raised. Defining a higher power value places a greater emphasis on the nearest data points. Accordingly, data nearby will be of greatest influence, and the generated surface will be more detailed but less smooth. The interpolated values increase as they begin to approach the value of the closest data point. Specifying a lower power value will cause farther surrounding points to have more influence, resulting in a smoother surface. For the purposes of the current analysis, the power was kept at the default of 2, which was considered sufficient to provide a smooth output given the equally distanced 1 km gridded points of the PCM data. Cell size was reduced to 100 to provide a sufficient resolution and provided a compromise between computing power and a suitable resolution to provide data coverage for the majority of schools in the UK.

To explore the data further and to develop a more comprehensive understanding of potential school exposure in the UK for the modelling phase, layer selections were made by attributes to determine schools that were within traffic related $NO_2$ AQMA boundaries. AQMA boundaries for 2020 were sourced from Defra and plotted in anticipation of the forthcoming modelling. Schools within or intersecting the AQMA boundaries were identified, and the resulting data were tabulated. School location data was tabulated against the $NO_2$ PCM data and sorted in descending order of annual mean concentration levels. The tables were joined in ArcGIS, using unique identifiers to facilitate ranking schools within AQMAs according to their potential concentration exposure. The datasets were then explored, and outputs were produced for schools within AQMA boundaries and within each country's highest deprivation quantiles.

Zonal statistics produced mean $NO_2$ and $PM_{2.5}$ values around all schools. The mean values provided a basis with which to determine schools exposed to high levels of pollution and those which were affected by combined issues, such as those within AQMAs and severe deprivation. The results were then used to determine case study areas for the forthcoming modelling of interventions.

## 5.5 Analysis

### 5.5.1 Search Parameters

The number of schools within AQMA boundaries and low-deprivation quintiles was identified. Sensitivity analysis was undertaken using different distances to these areas, but due to geographical differences between countries, greater distances introduced differentials in the proportion of schools included.

Doubling the search radius from 500 m to 1 km disproportionately increased the number of schools included within the catchment area positively or negatively, depending on the country. In Northern Ireland and Wales, the number of included schools increased by 1536.36% and 1541.67%, respectively. The number of included schools in England and Scotland increased by 24.71% and 60.44%, respectively. This disparity in behaviours is likely due to each nation's differing land uses and continuous urban fabric (for example, greater expanses of rural areas outside of England). Sensitivity analysis of different proximities to the boundaries produced a similar pattern as before, with the doubling of the search distance. When compared to the number of schools within the highest deprivation quintiles, school numbers in England and Scotland within both AQMAs and highest deprivation quintiles showed comparatively modest increases of 16.02% and 62%, respectively. Northern Ireland and Wales produced rises of 254.55% and 1020%, respectively. It was therefore decided to only include schools within the AQMA boundaries for the analyses.

### 5.5.2 AQMAs & Deprivation

The number of schools located within AQMA boundaries was identified, in addition to the number of schools in each country within both AQMAs and the most deprived quintiles (Table 12). England shows the greatest proportion of schools within AQMAs (31.35%), as well as both AQMAs and highest deprivation quintiles (6.73%).

*Table 12 UK schools within AQMAs and highest deprivation quintiles.*

| Country | Total Schools | Schools within AQMAs | | Schools Within Highest deprivation Quintiles | | Schools within both AQMAs & Highest deprivation Quintiles | |
|---|---|---|---|---|---|---|---|
| | | **Count** | **% of Total** | **Count** | **% of Total** | **Count** | **% of Total** |
| England | 25771 | 8078 | 31.35 | 3661 | 14.21 | 1735 | 6.73 |
| Northern Ireland | 798 | 11 | 1.38 | 158 | 19.8 | 11 | 1.38 |
| Scotland | 2497 | 225 | 9.01 | 443 | 17.74 | 54 | 2.16 |
| Wales | 1381 | 12 | 0.87 | 233 | 16.87 | 5 | 0.36 |

### 5.5.3 Testing Difference

Differences in average pollutant concentrations are distinct between England and each other country in the UK. The IDW-derived annual mean concentrations of all pollutants were higher around the most deprived schools in England within AQMAs (Table 13).

*Table 13 Averages for IDW-derived mean $NO_2$ and $PM_{2.5}$ concentrations ($\mu g/m^3$) within 500 metres of schools within AQMAs and highest deprivation quintiles in the UK.*

| Country | IDW-derived average | $NO_2$ ($\mu g/m^3$) | $PM_{2.5}$ ($\mu g/m^3$) |
|---|---|---|---|
| England | Mean | 13.70 | 9.17 |
| | Median | 12.80 | 9.17 |
| Northern Ireland | Mean | 6.50 | 6.70 |
| | Median | 5.33 | 6.34 |
| Scotland | Mean | 7.62 | 5.45 |
| | Median | 6.81 | 5.63 |
| Wales | Mean | 7.74 | 7.37 |
| | Median | 7.11 | 7.31 |

Given this disparity, schools within both AQMAs and the most deprived quintiles in each country were tested for difference before proceeding. Given the non-normal distribution of the concentration data and the unequal group sizes, the Mann-Whitney U Test was considered appropriate for this purpose and has been used in similar studies (Ko et al., 2022; Araban et al., 2017; Langer et al., 2017; Vailshery, Jaganmohan & Nagendra, 2013; Koong et al., 2009; Nikolić, Nikić & Stanković, 2008; Mennis, 2005; Michalska et al., 1999). The following null hypothesis was used:

$H_0$ There is no difference in IDW-derived mean pollutant concentrations between schools in AQMAs and the highest deprivation quintiles in England and those in other UK nations.

Table 14 details the results of the Mann-Whitney U Test. It can be concluded that $NO_2$ and $PM_{2.5}$ concentrations for schools within AQMAs and the highest deprivation areas of England are statistically significantly higher than Northern Ireland, Scotland, and Wales.

*Table 14 Mann-Whitney U Test results for pollutant concentration comparisons between England and other UK nations.*

| **Country** | | **$NO_2$** | **$PM_{2.5}$** |
|---|---|---|---|
| Northern Ireland | U | 1362.00 | 2563 |
| | P | 0.00 | 0.00 |
| Scotland | U | 14792 | 266 |
| | P | 0.00 | 0.00 |
| Wales | U | 368 | 2086 |
| | P | 0.00 | 0.045 |

A p-value less than 0.05 is commonly considered an indicator of statistical significance (Liao, Delghust & Laverge, 2019). Given the statistically significant difference between $NO_2$ and $PM_{2.5}$ concentrations in England and the other UK nations, the null hypothesis was rejected. Given the far higher concentrations in England, coupled with the additional available data for the country when compared to the other nations, meant that further analysis of the other countries was considered unwarranted, and the research focus was directed towards England as the study area.

### 5.5.4 Exploration of England Concentrations

Having ensured a significant distinction between pollutant concentrations around schools in England and other UK nations, England schools were explored more closely to better understand the composition of the IDW-derived means. Table 15 details the numbers of schools in England regions and the distribution of schools within AQMAs and highest deprivation quintiles throughout each region.

*Table 15 Comparison of school numbers in England in government office regions at outset, within or intersecting AQMAs and within AQMAs & lowest deprivation quintiles.*

| **Regions** | **Total Schools** | **AQMAs** | **AQMAs as% of Total** | **AQMAs & Lowest Deprivation** | **AQMAs & Lowest Deprivation as% of Total** |
|---|---|---|---|---|---|
| East Midlands | 2406 | 350 | 14.55 | 107 | 4.45 |
| East of England | 2969 | 271 | 9.13 | 30 | 1.01 |
| London | 2944 | 2840 | 96.47 | 170 | 5.77 |
| North East | 1291 | 45 | 3.49 | 12 | 0.93 |
| North West | 3690 | 1328 | 35.99 | 565 | 15.31 |
| South East | 4201 | 794 | 18.9 | 49 | 1.17 |
| South West | 2831 | 437 | 15.44 | 107 | 3.78 |
| West Midlands | 2787 | 1511 | 54.22 | 586 | 21.03 |
| Yorkshire and the Humber | 2643 | 501 | 18.96 | 149 | 5.64 |

Figure 36 shows a comparison of school numbers in each region that are within AQMAs, and those within both AQMAs and highest deprivation quintiles. As a percentage of the total school numbers, 96.47% of schools in London are within AQMAs, although this number drops significantly for those schools within AQMAs and the highest deprivation quintiles, to 5.77%. As a proportion of total schools, the West Midlands and the North West both contain greater numbers of schools within AQMAs and the highest deprivation quintiles (21.03% and 15.31%, respectively). These numbers are consistently large as a percentage of total schools within each region. The West Midlands contained 54.22% of its schools within AQMAs and 21.03% of its schools in both AQMAs and the highest deprivation quintiles. The North West contained 35.99% of its schools within AQMAs and 15.31% of its schools within both AQMAs and the highest deprivation quintiles.

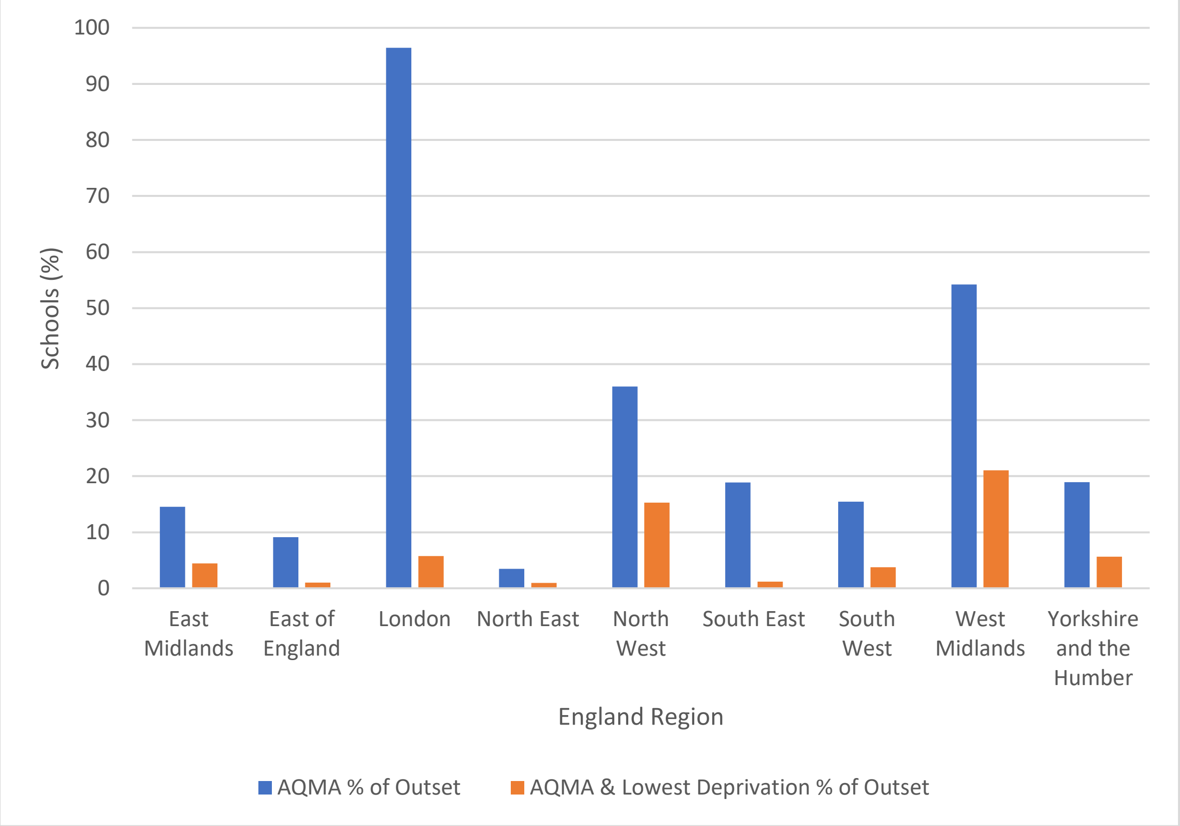


*Figure 36 Comparison of schools in England within AQMAs and both AQMAs and highest deprivation quintiles.*

The mean pollutant concentrations for schools within AQMAs and the highest deprivation quintiles were compared for each region. The regions with the greatest concentrations of $NO_2$ are London ($M$ = 26.77), West Midlands ($M$ = 20.11), and the East Midlands ($M$ = 18.64) (Figure 37).

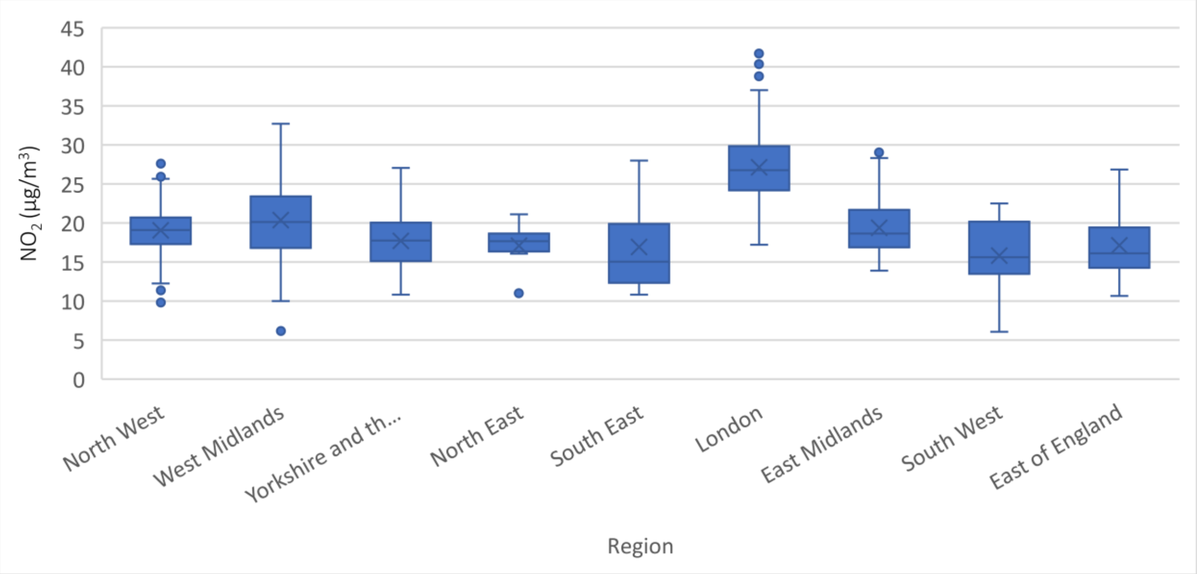


*Figure 37 $NO_2$ concentrations around schools in AQMAs & highest deprivation quintile by region.*

The regions with the greatest concentrations of $PM_{2.5}$ are London (*M* = 12.77), the South East (*M* = 11.26), and East of England (*M* = 10.85) (Figure 38).

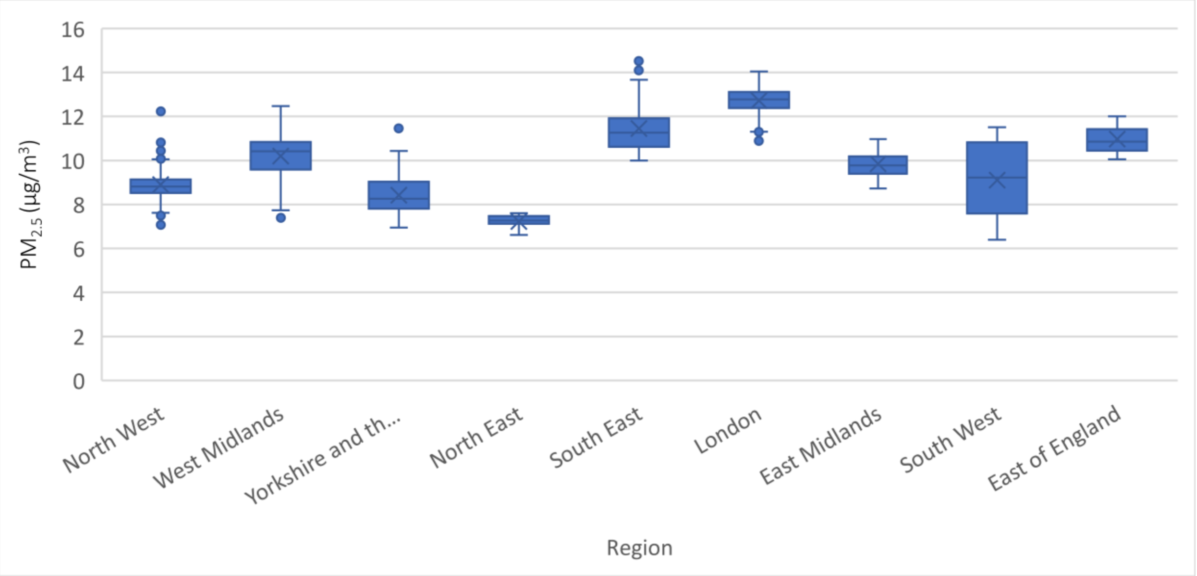


*Figure 38 $PM_{2.5}$ concentrations around schools in AQMAs & highest deprivation quintile by region.*

### 5.5.5 Urban/Rural Location

Table 16 details the number of schools by Urban/Rural location in England, the distribution of these schools within AQMAs and the highest deprivation quintiles in each area. Schools classified as within urban city and town and urban major conurbation areas show the greatest numbers of schools in AQMAs (2142 and 5357, respectively). However, the greatest proportion of schools in AQMAs when compared to the total schools can be found in urban major conurbation and urban minor conurbation areas (68.03% and 49.28%, respectively). The greatest proportion of schools within AQMAs and in the highest deprivation quintiles are also found in urban major conurbation and urban minor conurbation areas (15.52% and 18.38%, respectively).

*Table 16 Comparison of school numbers in England in urban and rural locations, within or intersecting AQMAs and within AQMAs & highest deprivation quintiles.*

| **Urban/Rural** | **Total Schools** | **AQMAs** | **AQMAs as% of Total Schools** | **AQMAs & Lowest Deprivation** | **AQMAs & Lowest Deprivation as % of Total Schools** |
|---|---|---|---|---|---|
| Rural hamlet and isolated dwellings | 1140 | 12 | 1.05 | 0 | 0.00 |
| Rural hamlet and isolated dwellings in a sparse setting | 103 | 0 | 0.00 | 0 | 0.00 |
| Rural town and fringe | 2517 | 123 | 4.89 | 1 | 0.04 |
| Rural town and fringe in a sparse setting | 140 | 8 | 5.71 | 0 | 0.00 |
| Rural village | 2386 | 21 | 0.88 | 0 | 0.00 |
| Rural village in a sparse setting | 166 | 1 | 0.60 | 0 | 0.00 |
| Urban city and town | 10552 | 2142 | 20.30 | 358 | 3.39 |
| Urban city and town in a sparse setting | 46 | 0 | 0.00 | 0 | 0.00 |
| Urban major conurbation | 7875 | 5357 | 68.03 | 1222 | 15.52 |
| Urban minor conurbation | 838 | 413 | 49.28 | 154 | 18.38 |

A comparison was made between the mean pollutant concentrations for schools within AQMAs and the highest deprivation quintiles by Urban/Rural location (Figure 39). Urban/Rural locations containing schools within AQMAs and the highest deprivation quintile with the highest concentrations of $NO_2$ (µg/m$^3$) are urban major conurbations (*M* = 20.40), urban minor conurbations (*M* = 17.45), and urban city and town locations (*M* = 16.00). Comparatively, the mean $NO_2$ concentrations at schools in rural towns and fringe locations is 10.80 (µg/m$^3$).

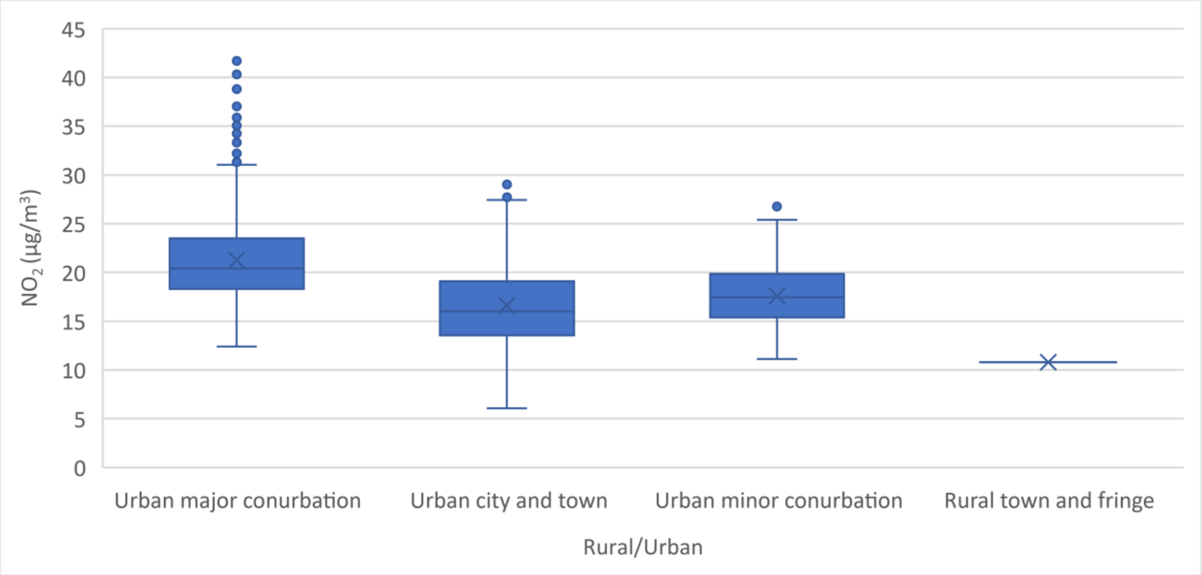


*Figure 39 $NO_2$ concentrations around schools in AQMAs & highest deprivation quintile by Urban/Rural location.*

The Urban/Rural locations containing schools within AQMAs and the highest deprivation quintile and the highest concentrations of $PM_{2.5}$ (µg/m$^3$) are urban city and town ($M$ = 9.97), urban major conurbations ($M$ = 9.93). The rural town and fringe concentration mean ($M$ = 8.79) is greater than that of the urban minor conurbation ($M$ = 8.41) (Figure 40).

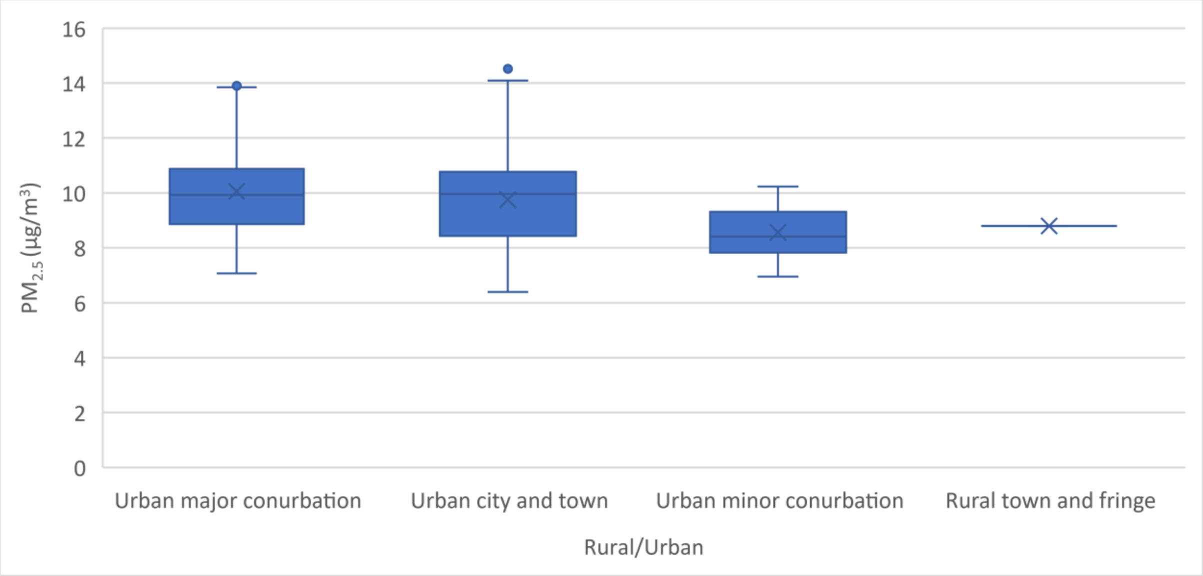


*Figure 40 $PM_{2.5}$ concentrations around schools in AQMAs & highest deprivation quintile by Urban/Rural location.*

### 5.6 Summary of Analyses

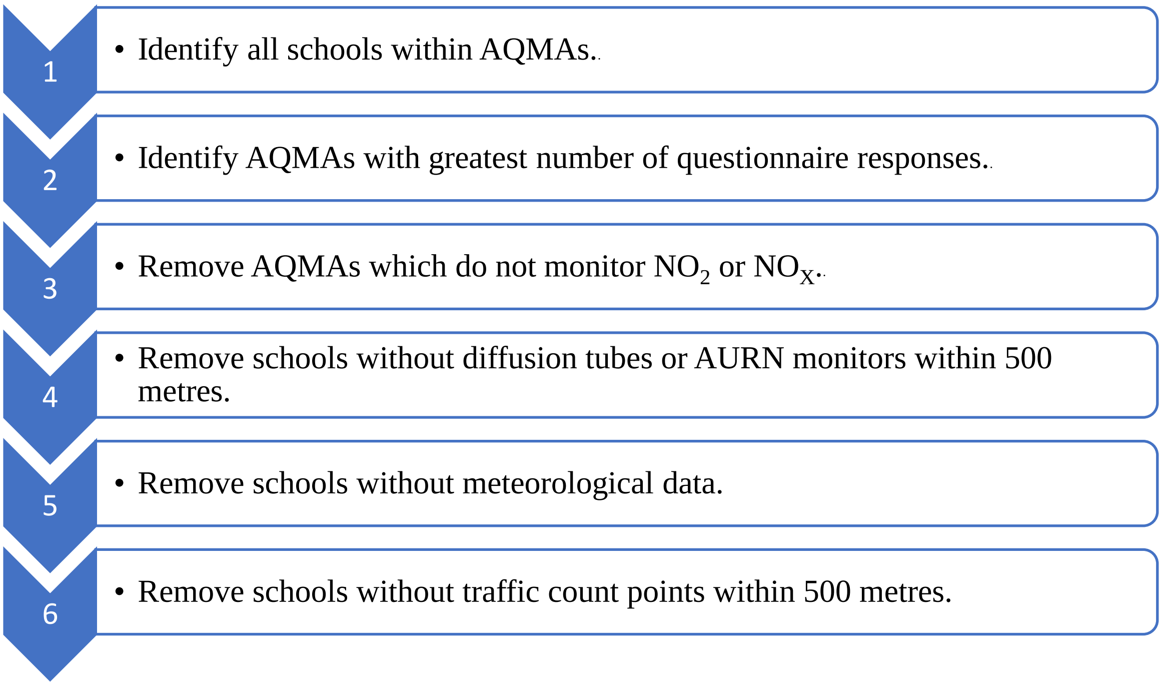
The data exploration used only schools within AQMA boundaries for analyses and IDW-derived annual mean $NO_2$ concentrations were used to determine the most polluted schools in the UK. WHO air quality guideline values were attempted as a marker for the most polluted schools, although this was abandoned as its application was not suited to the nature of the data in the current project. Whilst the guideline limits could provide a standard threshold with which to work, they have the potential to be misleading. Given that the greatest potential for child exposure to pollution occurs during the morning commute, the use of WHO guidelines that specify averages over longer-term time periods was not representative.

Compared to the other countries in the UK, England had the greatest proportion of schools within AQMAs, and within AQMAs and the highest deprivation quintiles. When investigated further, London had the greatest number of schools within AQMAs, although the West Midlands and the North West each had large proportions of schools within AQMAs and within the highest deprivation quintiles. When urban/rural location was considered, the highest proportions of schools within AQMAs were all in urban environments and showed comparatively high levels of deprivation.

## 5.7 Site Selection

### 5.7.1 Overview

Baseline concentrations of TRAP within 500 metres of all schools in the UK have been established, in addition to identifying those schools within AQMAs. This facilitates the selection of schools as case study areas for the purposes of pollutant modelling to establish the effectiveness of the interventions highlighted in the survey results. The selection process is visualised in Figure 41.



1
- Identify all schools within AQMAs.

2
- Identify AQMAs with greatest number of questionnaire responses.

3
- Remove AQMAs which do not monitor $NO_2$ or $NO_X$.

4
- Remove schools without diffusion tubes or AURN monitors within 500 metres.

5
- Remove schools without meteorological data.

6
- Remove schools without traffic count points within 500 metres.

*Figure 41 School selection filtering process.*

The structured refinement of school numbers was required for the selection of school locations for intervention modelling. The school modelling locations have been selected based on analyses relating to pollution levels in the local areas, availability of supporting data, and suitability to the modelling process. The location of the schools within the AQMAs implies access to publicly available air quality data, which can be used to model air pollution in the vicinity of schools using ADMS.

The initial analyses showed distinct differences in mean pollutant concentrations between England and other UK countries. English schools in AQMAs with low deprivation were found to be significantly more polluted than schools in other UK countries.

### 5.7.2 School Selection Criteria

Several criteria are desirable for the school selection based on the data input requirements of ADMS and the successful modelling of mitigation measures and interventions. These criteria include the following requirements:

- The school must be located within an AQMA.
- Suitable meteorological data must be available.
- Suitable traffic data must be available.

Any selectable schools should be within an AQMA, which would ensure that they were both polluted and had available monitored data for model verification. Ordering these schools into a hierarchy of severity was problematic. If the most polluted schools were modelled, all would be in London, which would be unrepresentative of the varying environments across the country. To assist the selection process and to increase the likelihood that the schools within the AQMAs would be suitably representative for the interventions to be modelled, school regions that received the most survey responses (471 responses were from within AQMAs) were selected. Whilst the number of survey results received is not necessarily indicative of location suitability, using the counts assists the selection of locations by providing an additional level of structure to the filtering process. The ten most polluted unique AQMAs, based on IDW-derived $NO_2$ ($\mu g/m^3$) concentrations at schools within their boundaries, were selected for further analysis (Table 17).

*Table 17 Ten most polluted unique AQMA regions selected for further analysis.*

| AQMA | AQMA ID | Survey Responses |
|---|---|---|
| Barnet AQMA | 14 | 78 |
| Birmingham AQMA | 17 | 53 |
| Bristol AQMA | 1118 | 36 |
| The City of Oxford | 249 | 12 |
| Sheffield Citywide AQMA | 284 | 8 |
| Walsall AQMA | 307 | 7 |
| AQMA 6 - Truro | 1081 | 7 |
| Worcester City (Political Boundary) | 1449 | 7 |
| Reading AQMA | 263 | 6 |
| Cheltenham Whole Borough AQMA | 794 | 5 |
| Liverpool City AQMA | 229 | 5 |
| Coventry City-Wide AQMA | 209 | 4 |

### 5.7.3.1 Monitored Pollution Data

As touched upon, a requirement for LAQM is the monitoring of pollutants within AQMAs. Local authority monitoring and AURN site data are accessible from Air Quality England (AQE, 2022). All AQMAs without $NO_2$ or $NO_X$ data for 2019 were removed, as data for these pollutants were required for the model and verification. The data were used with AQMA ID to identify the most polluted schools (using the maximum recorded hourly mean $NO_2$ values) to be selected for modelling. Peak morning $NO_2$ can be presumed to be peak traffic, when children are most likely to be exposed to pollution travelling to school (Boniardi et al., 2019; Spira-Cohen et al., 2010). A shortlist of the most polluted schools within the AQMAs was produced (Table 18).

*Table 18 Selected schools with corresponding AQMAs.*

| **Schools** | **AQMA Title** | **AQMA_ID** | **Survey Responses** |
|---|---|---|---|
| Chalgrove Primary School | Barnet AQMA | 14 | 78 |
| St Michael’s Catholic Grammar School | Barnet AQMA | 14 | 78 |
| Northside Primary School | Barnet AQMA | 14 | 78 |
| Sacks Morasha Jewish Primary School | Barnet AQMA | 14 | 78 |
| Ninestiles Academy Converter | Birmingham AQMA | 17 | 53 |
| Fox Hollies Children’s Centre | Birmingham AQMA | 17 | 53 |
| Nelson Junior and Infant School | Birmingham AQMA | 17 | 53 |
| Archway Academy | Birmingham AQMA | 17 | 53 |
| City United Academy | Birmingham AQMA | 17 | 53 |
| Rosemary Early Years Centre | Bristol AQMA | 1118 | 36 |
| Parson St School | Bristol AQMA | 1118 | 36 |
| Andalusia Academy | Bristol AQMA | 1118 | 36 |
| St Paul’s Nursery School & Children’s Centre | Bristol AQMA | 1118 | 36 |
| Catch22 Include Bristol | Bristol AQMA | 1118 | 36 |
| Cabot Primary School | Bristol AQMA | 1118 | 36 |
| St Ebbe’s Church of England Aided Primary School | The City of Oxford | 249 | 12 |
| Oxford Sixth Form College | The City of Oxford | 249 | 12 |
| Tinsley Green Children’s Centre | Sheffield Citywide AQMA | 284 | 8 |
| Tinsley Meadows Primary School | Sheffield Citywide AQMA | 284 | 8 |
| EP Collier Primary School | Reading AQMA | 263 | 6 |
| St John Vianney Catholic Primary School | Coventry City-Wide AQMA | 209 | 4 |
| Southfields Primary School | Coventry City-Wide AQMA | 209 | 4 |
| Gosford Park Children’s Centre | Coventry City-Wide AQMA | 209 | 4 |

Once the availability of meteorological data was determined (see section 5.7.3.2 Meteorological Data), the remaining schools from Table 18 were mapped to the GIS with a 500-metre buffer (the modelling radius) to determine which schools contained the most traffic count points and diffusion tubes (necessary for model verification).

#### 5.7.3.2 Meteorological Data

Site meteorological conditions are required for dispersion modelling and within the ADMS-Roads package, a minimum of wind speed, wind direction, and cloud cover are necessary alongside temporal data to run the model (ADMS-Roads, 2020).

Variations in meteorological conditions can have a profound effect on short-term air pollution changes resulting in the obfuscation of emission changes by weather (Baklanov et al., 2007). Policy intervention impacts on air quality can be difficult to discern from other air pollution causes, such as socio-economic factors, atmospheric chemistry, and natural emission changes (Elminir, 2005).

Meteorological data are available from the CEDA (Centre for Environmental Data Analysis) Archive (CEDA Archive, 2022), which was searched to find suitable data for each school region. Regions for which suitable meteorological data could not be sourced were removed.

#### 5.7.3.3 Traffic Count Data

As the key emission sources, traffic count data are required to be added to the dispersion model for each road link. The data were added as data collection points, providing traffic counts for all major roads, and providing a basis for estimation of traffic volume on adjacent minor roads (Department for Transport, 2022a).

### 5.7.3 Selected Sites

Five school sites were selected for modelling, each containing a suitable Primary school for use as a principal receptor. In those cases where other educational establishments existed within the boundary, these were added to the model as secondary receptors, although the interventions were only modelled on the Primary schools (principal receptors) in each site where possible (Table 19). Each site was demarcated by a 500-metre buffer surrounding each school to provide a boundary for the modelling area. In each site, Primary schools were preferred for use as principal receptors due to the vulnerability of their pupils. All selected schools adhered to the specified criteria (see section 5.6 Summary of Analysis) in that they were located within AQMA boundaries in England and were heavily polluted according to the IDW-derived annual mean $NO_2$ concentrations. Each of the selected schools also had all required input data available for dispersion modelling. Each region contained highly polluted schools and the surrounding sites contained air quality and traffic monitors, and access to the required meteorological data.

*Table 19 School sites and schools selected for modelling.*

| City | Locality | Establishment Name | Establishment Number | Receptor Type | Establishment Type[6] | Region |
|---|---|---|---|---|---|---|
| City of Bristol | St Paul's | Cabot Primary School | 2139 | Principal | Community school | South West |
| City of Bristol | St Paul's | St Paul's Nursery School & Children's School | 1010 | Secondary | Children's centre | South West |
| City of Bristol | Bedminster | Parson St Primary School | 2061 | Principal | Academy converter | South West |
| Coventry | Binley | Southfields Primary School | 2153 | Principal | Community school | West Midlands |
| Coventry | Binley | Gosford Park Children's Centre | N/A | Secondary | Children's centre | West Midlands |
| Oxford | St Ebbe's | St Ebbe's Primary School | 3833 | Principal | Voluntary aided school | South East |
| Sheffield | Tinsley | Tinsley Meadows Primary School | 2230 | Principal | Academy converter | South Yorkshire |
| Sheffield | Tinsley | Tinsley Green Children's Centre | N/A | Secondary | Children's centre linked site | South Yorkshire |

All schools were plotted to ADMS as receptors and the sites with schools were depicted using the ADMS Mapper function (Figure 42 to Figure 46).

---

[6] Establishment type group categorisations can be found in Appendix S.

**Legend**

Specified points (1)

🟩

*Figure 42 Bristol St Paul's site with Cabot Primary School (West) and St Paul's Nursery School and Children's School (East) (Specified points).*

**Legend**

Specified points (1)

🟩

*Figure 43 Bristol Bedminster site with Parson Street Primary School (Specified points).*

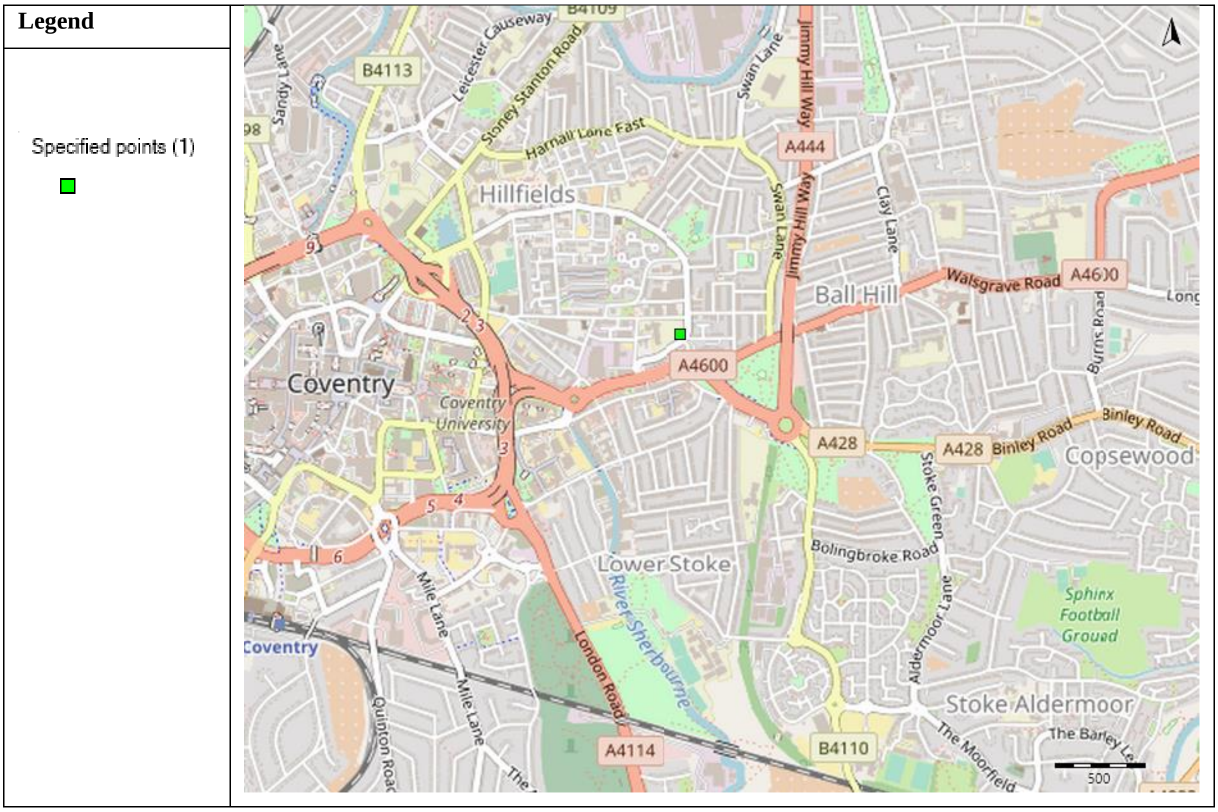


*Figure 44 Coventry Binley site with Southfields Primary School (Specified points).*

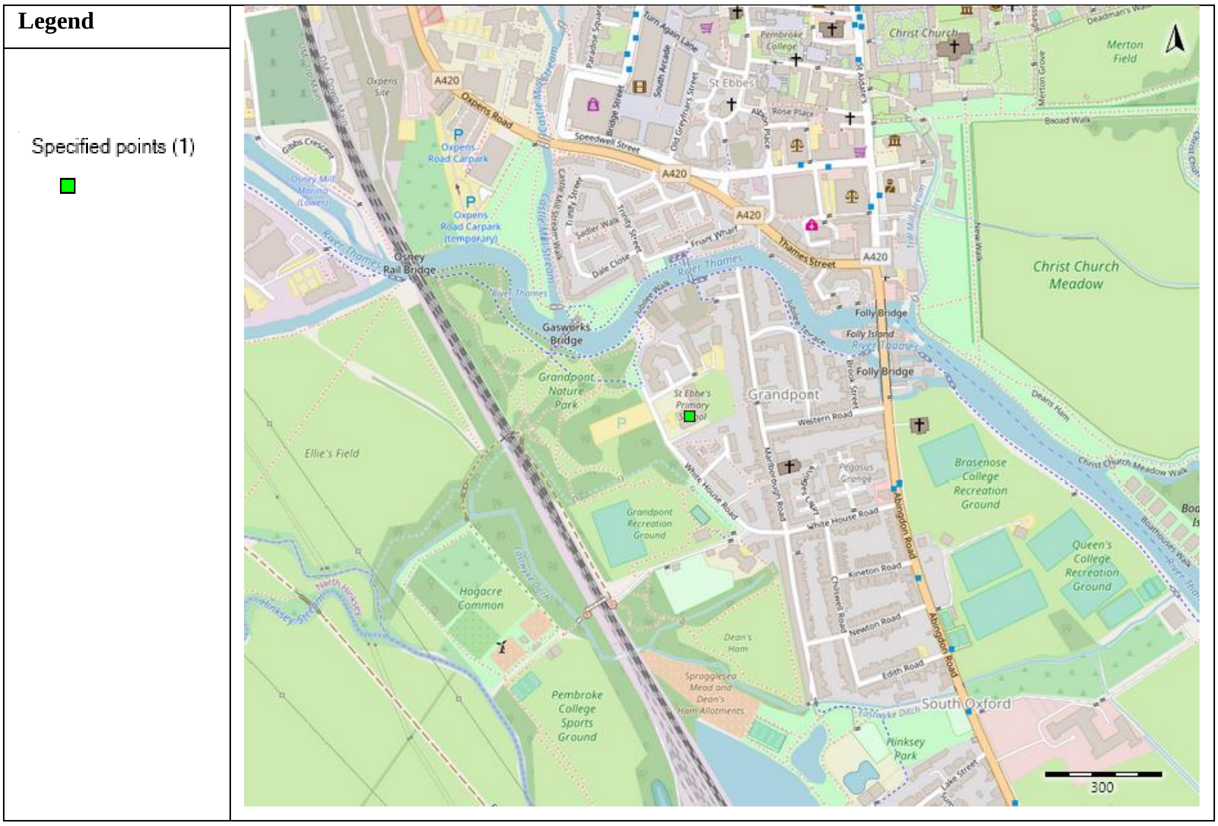


*Figure 45 Oxford St Ebbe's site with St Ebbe's Primary School (Specified points).*

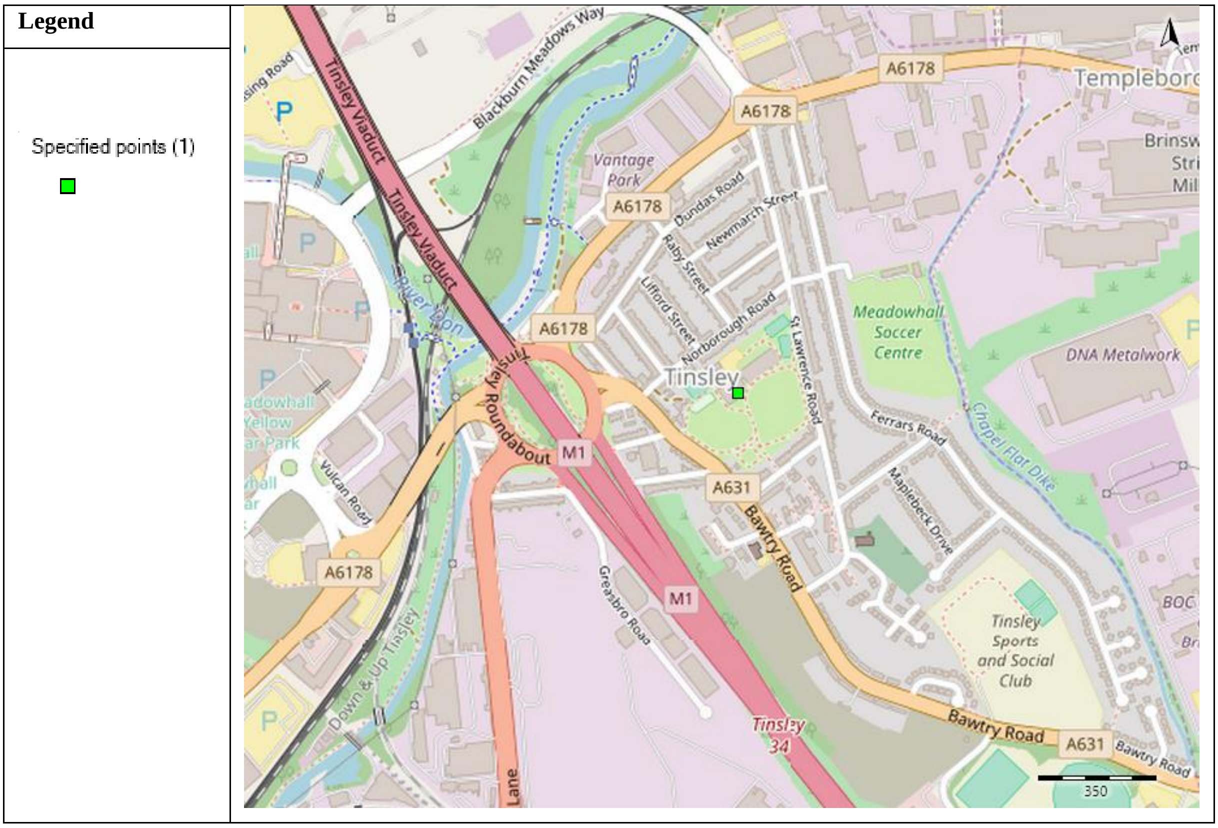


*Figure 46 Sheffield Tinsley site with Tinsley Meadows Primary School (Specified points).*

Diffusion tube and continuous monitoring data were available at all sites. AURN monitoring data were sourced from Air Quality England (AQE, 2022). Monitored data from local authorities were sourced from Bristol City Council (Open Data Bristol, 2022), Sheffield City Council (2022), Coventry City Council (2022), and Oxford City Council (Oxfordshire Air Quality, 2022). The continuous monitors report data as hourly means, and the diffusion tube data are reported as annual means.

All sites are roadside sites and provided data for 2019, so they were suitable for verification and adjustment. Predictions of pollutants closer to roadside sites are commonly used by local authorities because these are at greater risk of exceedances. Accordingly, the verification of models is generally based on these monitoring sites. Whilst continuous monitors are preferable, two AURN sites were not included: Oxford St Ebbe’s and Sheffield Tinsley. Both sites are AURN continuous monitoring urban background sites, and the nearest road to each is a minor road approximately five metres from the station. Both sites were considered unrepresentative of the nearby roads and were omitted from the models, as verification of modelled roadside concentrations should only take place against roadside sites. The rationale for discounting these sites from the verification process is justified in the Technical Guidance

(7.531) (Defra, 2021d), which maintains that dispersion models may perform differently at different site types.

Meteorological data for the year 2019 for all sites were sourced from the CEDA Archive (2022), and site data are detailed in Table 20. All observation stations are within 50 km of their respective school sites, and all had recorded suitable and sufficient data for 2019.

*Table 20 Meteorological observation station details for all sites.*

| Site | Observation Station | Station ID | County | Distance from Site (km) |
|---|---|---|---|---|
| Bristol St Paul's | Ammerdown House | 9529 | Somerset | 33.2 |
| Bristol Parson St | Ammerdown House | 9529 | Somerset | 29.3 |
| Coventry Binley | Little Risington | 692 | Gloucestershire | 38.5 |
| Oxford St Ebbe's | Radcliffe Observatory | 606 | Oxfordshire | 1.45 |
| Sheffield Tinsley | Nottingham Watnall | 556 | Nottinghamshire | 44.38 |

Based on observations of the sites as mapped in ArcMap, the site geographies were evaluated and simple visual descriptions of these assessments for each region are provided in Table 21.

*Table 21 Observations of modelling site geographies based on visual assessment of the sites using ArcMap.*

| City | Locality | Site Description |
|---|---|---|
| City of Bristol | St Paul's | A highly populated urban centre close to a motorway, several A-roads, and the city centre. Some urban green space. |
| City of Bristol | Bedminster | A mid-populated urban centre containing several A-roads. The school is located at a busy junction with traffic lights. |
| Coventry | Binley | A mid-populated urban centre containing two A-roads and some green space. |
| Oxford | St Ebbe's | A sparsely populated urban residential centre close to two A-roads, large green space, and a river. |
| Sheffield | Tinsley | A sparsely populated urban residential and industrial region, near a motorway and two A-roads. |

The St Paul's site in the City of Bristol is a highly populated urban centre that is close to the M32 motorway, which approaches the city centre. The site contains the A4032, A4044, and A38. Several small urban parks are sited throughout the densely packed housing area surrounding Cabot Primary School and St Paul's Nursery and Children's Schools.

The Bedminster site in the City of Bristol contains Parson St Primary School and is characterised by a busy road network comprising several A-roads. The school is located by traffic lights on a busy 3-way intersection joining the A38 and the A3029. There is limited green space within the site.

The Binley site in Coventry is comparatively less populated, containing many more commercial buildings and some larger areas of green space. The A4600 and A444 intersect by Gosford Green and run through the site.

The St Ebbe’s site in Oxford contains the most sparsely populated urban residential area, with large areas of green space and the River Thames crossing the region. The A420 and the A4144 intersect, and the latter crosses the length of the site.

The Sheffield Tinsley site is sparsely populated but is characterised by industrial buildings with some residential areas. The M1 runs through the site and intersects the A6178 and A631.

# 6.0 Intervention Modelling

## 6.1 Introduction

The initial literature review (Chapter 2), the systematic review (Chapter 3), the outcome of the stakeholder survey (Chapter 4), and the sites identified in the case study selection (Chapter 5) could now be utilised to inform the assessment of interventions desirable for key stakeholders and supported by the literature. Chapter 5 provided a dataset listing all UK schools and their corresponding pollution levels that could be used to identify school sites for modelling interventions determined in the stakeholder survey (Chapter 4). ADMS-Roads (Version 5.0) was used to model these interventions[7] to determine their effectiveness in a series of school commute locations.

## 6.2 Model Inputs

### 6.2.1 Receptors

Where the inlet height of diffusion tubes was not available from local authorities, the height was entered as 2 metres, which is typical for diffusion tube placement as it corresponds to approximate human height. Defra advice to local authorities on this issue maintains that, whilst samplers should ideally be placed at breathing height for local air quality management, it is recommended that they are placed between 2 and 4 metres to reduce tube theft if the risk is anticipated (Defra, 2022c). This advice is consistent with the Ambient Air Quality Directive (Annex III – C), which states that generally, sampling point inlets should be positioned between heights of 1.5 metres (the breathing zone) and 4 metres (Directive of the European Parliament & Council, 2008).

School receptor heights were set at the average height of the children attending. For primary Schools, this was 1.2 metres (the average height of a 7-year-old child[8]), and for children's Centres & infant schools, 1 metre (the average height of a 3-to-5-year-old child[9]) (RCPCH, 2022). All travel route receptors were allocated a height of 1.2 metres for consistency across all sites.

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[7] ADMS-Roads was used in conjunction with ArcGIS (ArcMap Version 10.8.1).

[8] A 7-year-old being the average age of a child attending primary school (RCPCH, 2022).

[9] 3 to 5 years being the average age of children in attendance of children's centres and infant schools (ibid.).

### 6.2.2 Background Pollution

Based on local authority mean concentrations, the background pollutant concentrations of $NO_X$ and $NO_2$ for all sites were determined using Defra’s background maps projected for 2019 (Defra, 2022e) and input to a GIS with mapped local authority boundaries (ONS Geography, 2022). Defra provides the background data for LAQM purposes, and the data are projected based on assumptions prior to the UK Covid-19 outbreak. The mean concentrations for each site area were calculated using the ‘summarize within’ function of ArcMap, specifying local authority boundaries as the boundary layer. The background values are displayed in Table 22.

*Table 22 PCM-derived mean background concentration input values of $NO_X$ and $NO_2$ (µg/m$^3$) for all modelling sites.*

| **Site** | **Background $NO_X$ (µg/m$^3$)** | **Background $NO_2$ (µg/m$^3$)** |
|---|---|---|
| Bristol St Paul’s | 20.25 | 14.81 |
| Bristol Bedminster | 20.25 | 14.81 |
| Coventry Binley | 21.35 | 15.38 |
| Oxford St Ebbe’s | 19.50 | 14.20 |
| Sheffield Tinsley | 13.17 | 9.82 |

### 6.2.3 Meteorology

The meteorological data were added to ADMS-Roads, having been compiled in .met file format containing a minimum set of data criteria (ADMS-Roads, 2020). The minimum criteria include wind speed (U), wind direction (PHI) and the Julian day number (DAY), time of day (HOUR), and cloud cover (CLOUD).[10] The data in the file is compiled in the format shown in Figure 47.

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[10] Sensible surface heat flux and reciprocal of Monin-Obukhov length can also be used (ADMS-Roads, 2020).

```
VARIABLES:
7
YEAR
DAY
HOUR
PHI
U
CLOUD
TEMPERATURE
DATA:
2005,1,0,190,4.115551949,7,6.6
2005,1,1,190,4.115551949,7,6.6
```

*Figure 47 Sample .met file format.*

The data are hourly and sequential, so each line of data represents one hour of meteorological measurements. Therefore, a data file for one year contains 8760 lines of data. Whilst the included data volume should be as high as possible, the model will stop if a period of 24 hours of required data are missing in any continuous block. The continued reduction of observational meteorological sites also means that it is often difficult to obtain data from locations near the modelled sites. In the current modelling process, it was particularly difficult sourcing suitable cloud cover data for each location, so a rule of thumb was applied to each region, permitting cloud cover data to be sourced from within 50 km of the modelling location.

Meteorological data for all sites are summarised in Table 23 and are stratified by the meteorological station from which the site data was sourced. Meteorological conditions in 2019 were broadly consistent across all sites. Dominant wind direction was south-south-westerly at all sites apart from Sheffield Tinsley, at which it was south-westerly. Mean wind speed across all sites ranged between 4.03 and 4.57 m s$^{-1}$, and mean cloud cover across all sites ranged between 4.87 and 5.39 oktas (or eighths of cloud cover). The mean temperature was also consistent across all sites, ranging between 8.94 and 9.23 °C. Surface roughness for the dispersion site was set to 1 for all sites, as is appropriate for cities (ADMS-Roads, 2020).

*Table 23 Summary data for 2019 from meteorological stations used for each modelling site.*

| **Meteorological Station** | **Site** | **Dominant wind direction (°)** | **Average wind speed (m s$^{-1}$)** | **Average cloud cover (oktas)** | **Average temperature (°C)** |
|---|---|---|---|---|---|
| Ammerdown House (mean) | Bristol St Paul's & Bristol Bedminster | 198.90 (SSW) | 4.57 (2.56) | 4.87 (2.50) | 9.20 (4.87) |
| Little Risington (mean (SD)) | Coventry Binley | 205.07 (SSW) | 4.48 (2.34) | 5.39 (3.27) | 8.94 (5.58) |
| Radcliffe Observatory (mean (SD)) | Oxford St Ebbe's | 204.24 (SSW) | 4.43 (2.45) | 5.39 (3.27) | 9.23 (5.63) |
| Nottingham Watnall (mean (SD)) | Sheffield Tinsley | 218.35 (SW) | 4.03 (1.97) | 5.06 (3.31) | 9.15 (5.61) |

### 6.2.4 Traffic Counts

Traffic data collection points were added to each site map to provide counts for major roads with which to base input data to the models (Department for Transport, 2022a). A limitation of the traffic data is that it is annualised and averaged. The Annual Average Daily Flow (AADF) measures one-way traffic flow. Annual Average Daily Traffic (AADT) is traffic measured in both directions. This value is determined by dividing the yearly traffic volume count by 365. The Average Daily Traffic (ADT) value is obtained by dividing a traffic count by the number of days within its collection period. When converted into AADF, AADT assumes an equal directional split unless additional data (studies or traffic counts) show a directional bias (ibid.). In this respect, school holiday times should be considered due to the reduction of traffic around schools during the summer holidays (Boniardi et al., 2019). However, this was not possible given the traffic count format and is identified as a limitation of the available data (see section 7.4.4 Dispersion Modelling).

### 6.2.5 Links

When mapping the school areas, there are limited links available in the model set up (150), so the road links surrounding the schools were selected based on their proximity to the school buildings (Table 24).

*Table 24 Number of road links to be modelled for selected school site areas.*

| **Site** | **Number of Modelled Road Links** |
|---|---|
| Bristol St Paul's | 149 |
| Bristol Bedminster | 139 |
| Coventry Binley | 150 |
| Oxford St Ebbe's | 52 |
| Sheffield Tinsley | 66 |

The number of road links modelled were ultimately determined by the geographies surrounding the schools. A 500-metre buffer was applied to each key school receptor in each site, as this distance has been identified as within which a source of pollution can be harmful to health (Jerrett et al., 2007; Zhou & Levy, 2007; Reponen et al., 2003). Input parameters for road links included the specification of road width, and canyon height (Appendix T). These parameters were calculated using measurements taken on Google Earth Pro (Version 7.3.4).

The 500-metre buffer surrounding St Paul’s Nursery and Children’s School in Bristol, St Pauls, included many road links due to the tightly knit network of residential streets contained within. A judgement was made to only model links north of the M32/A4044 East, as there would be too many links to suitably model the area. In addition, there is only one main road access point crossing the M32/A4044 (A4044 South), which was included. Small areas on the East and West sides of the site were extended slightly beyond the 500-metre boundary to suitably simulate those key access points as travel routes (Figure 48).

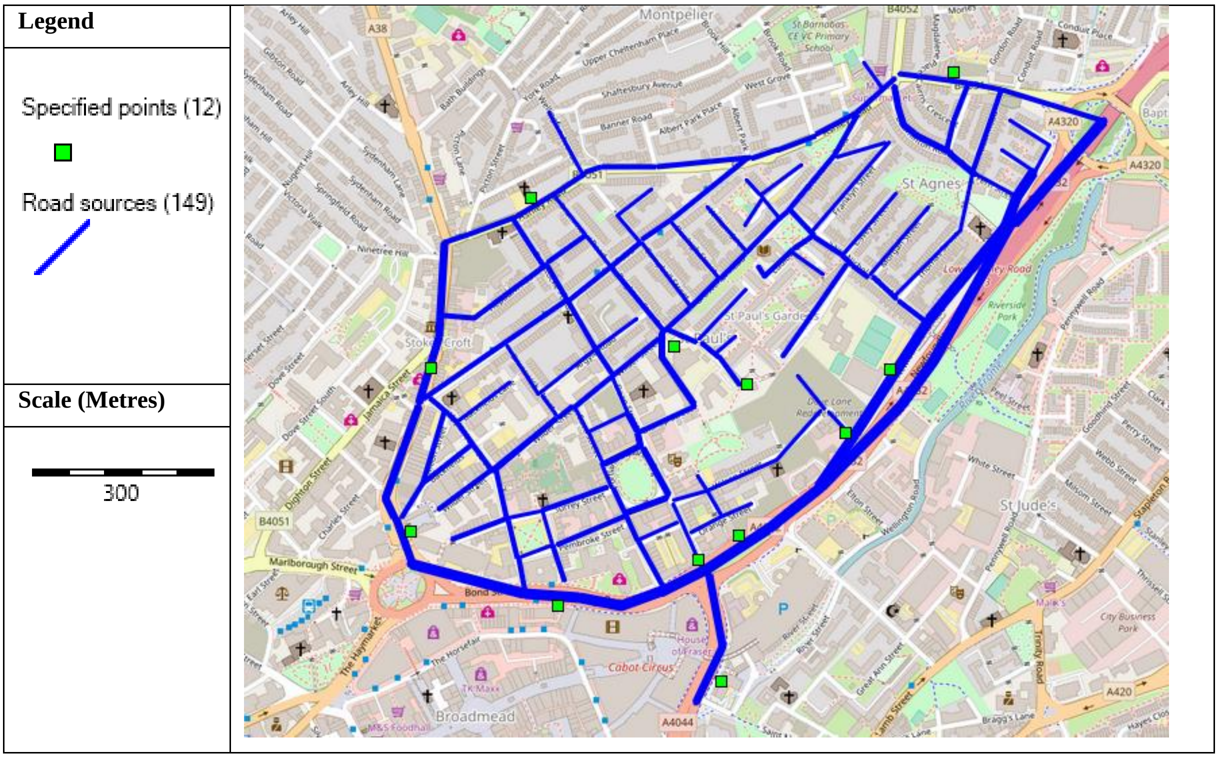

*Figure 48 Bristol St Paul’s modelling site with road links (Road sources) and receptors (Specified points).*

The 500-metre buffer surrounding Parson Street Primary School in Bristol, Bedminster, included a high number of road links due to the tightly knit network of streets and graduated junctions contained within (Figure 49). All key residential areas and main roads into the site were given priority when allocating links.

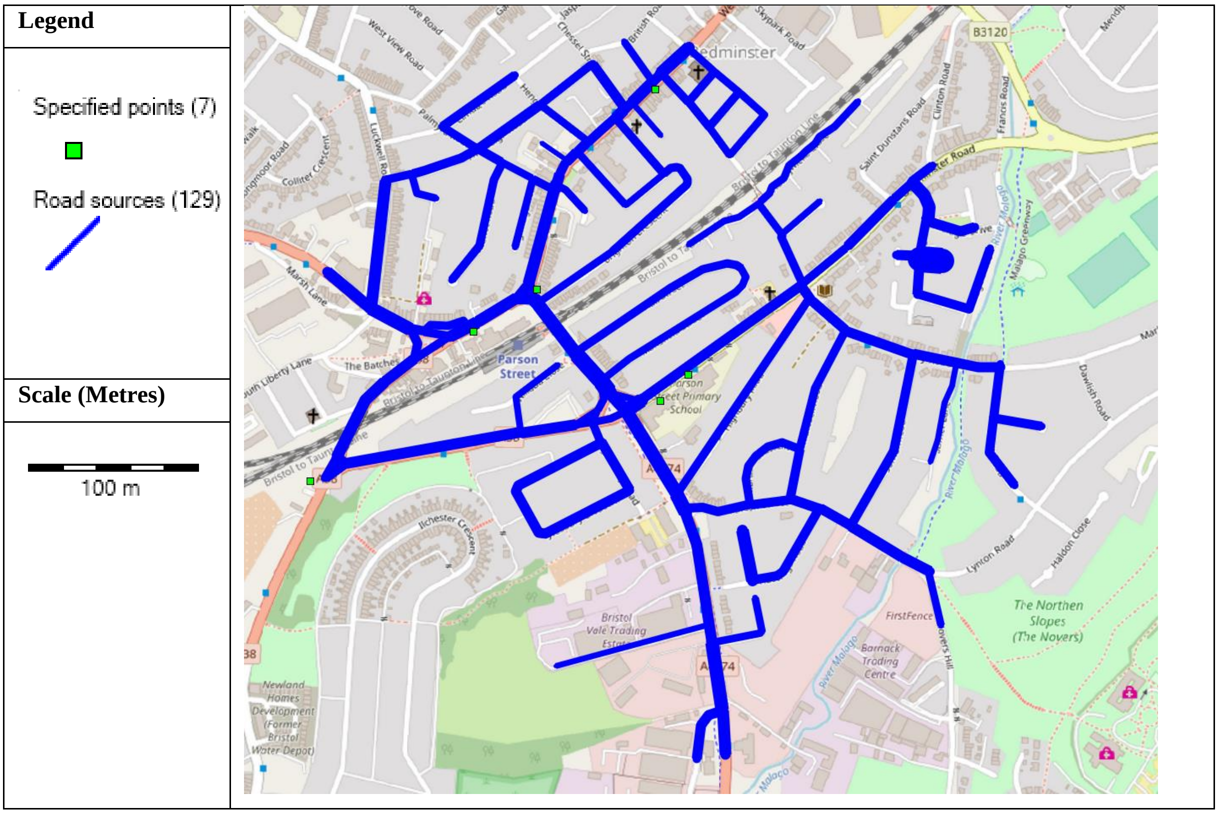

*Figure 49 Bristol Bedminster modelling site with road links (Road sources) and receptors (Specified points).*

The number of road links within 500 metres of Southfields Primary School in the Coventry Binley site was relatively few (totalling 118 road links). It was then possible to extend the modelling area south to add road links within 500 metres of Gosford Park Children’s Centre (Figure 50). The result provided a series of access points from large residential areas surrounding the site. The access points were used to simulate travel route entry points into the site to access Southfields Primary School.

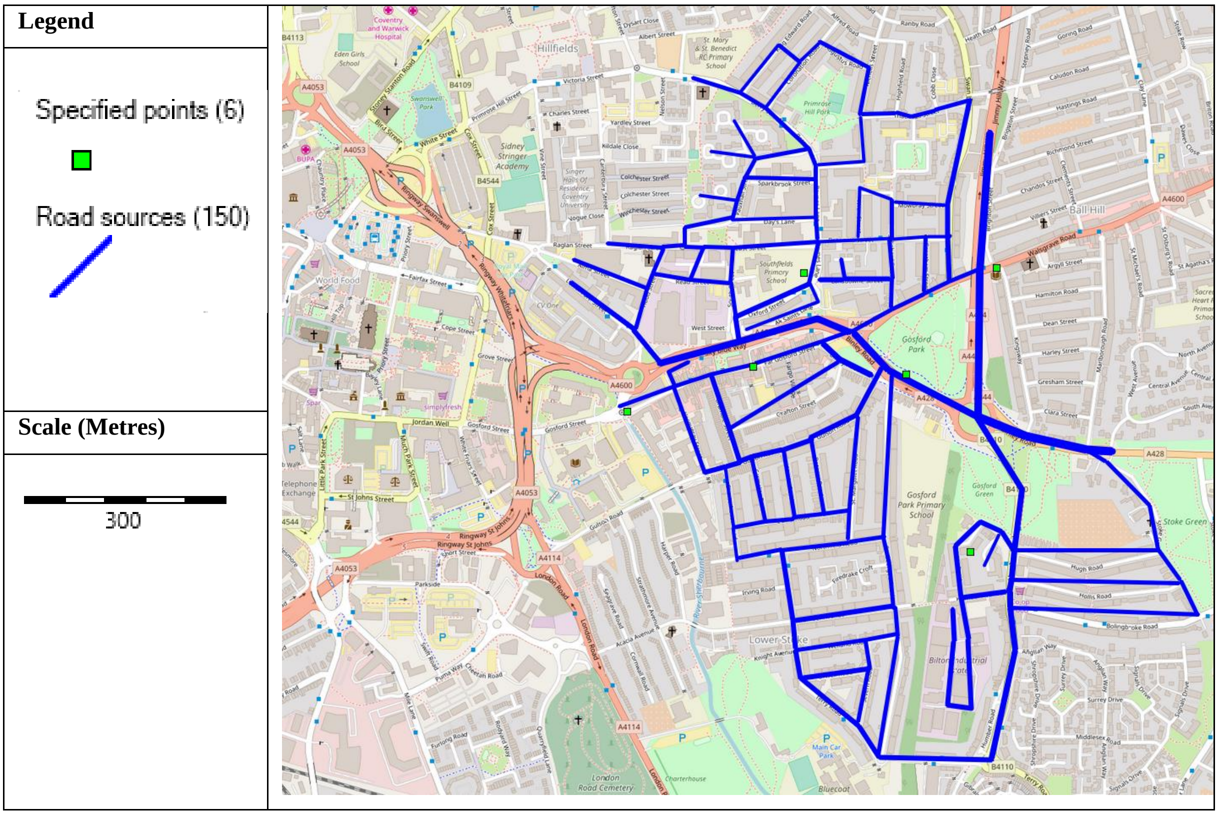

*Figure 50 Coventry Binley modelling site with road links (Road sources) and receptors (Specified points).*

The number of road links within the 500-metre buffer of St Ebbe’s Primary School in the Oxford St Ebbe’s site reflects the sparsely populated region containing large areas of green space (Figure 51). However, the site geography permitted multiple access points available to simulate travel routes from larger residential regions surrounding the site.

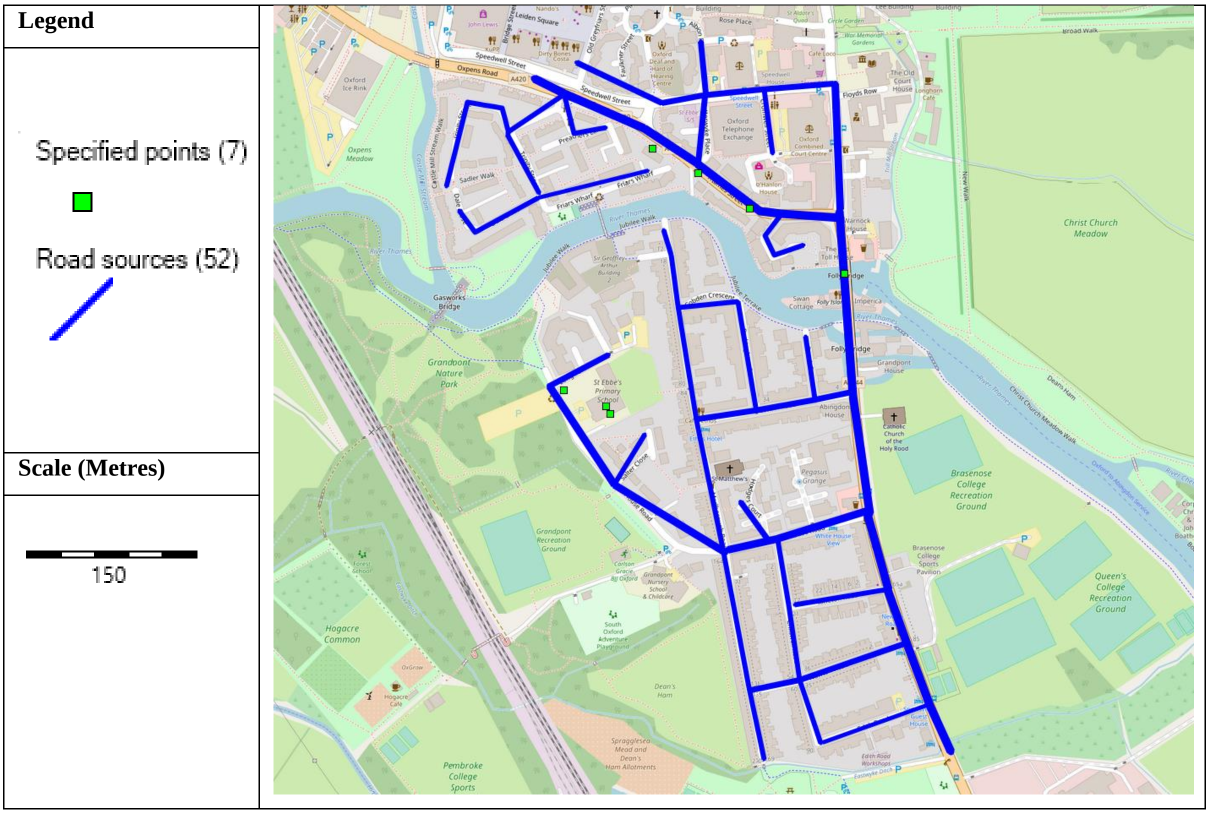

*Figure 51 Oxford St Ebbe’s modelling site with road links (Road sources) and receptors (Specified points).*

Sheffield was sparse and industrial and required comparatively fewer road links than the other sites (Figure 52). The surrounding area contained further industrial and commercial buildings, so additional road links to expand the site were considered unnecessary. Access points were designated to simulate key travel routes into the site and utilised the main roads surrounding Tinsley Meadows Primary School.

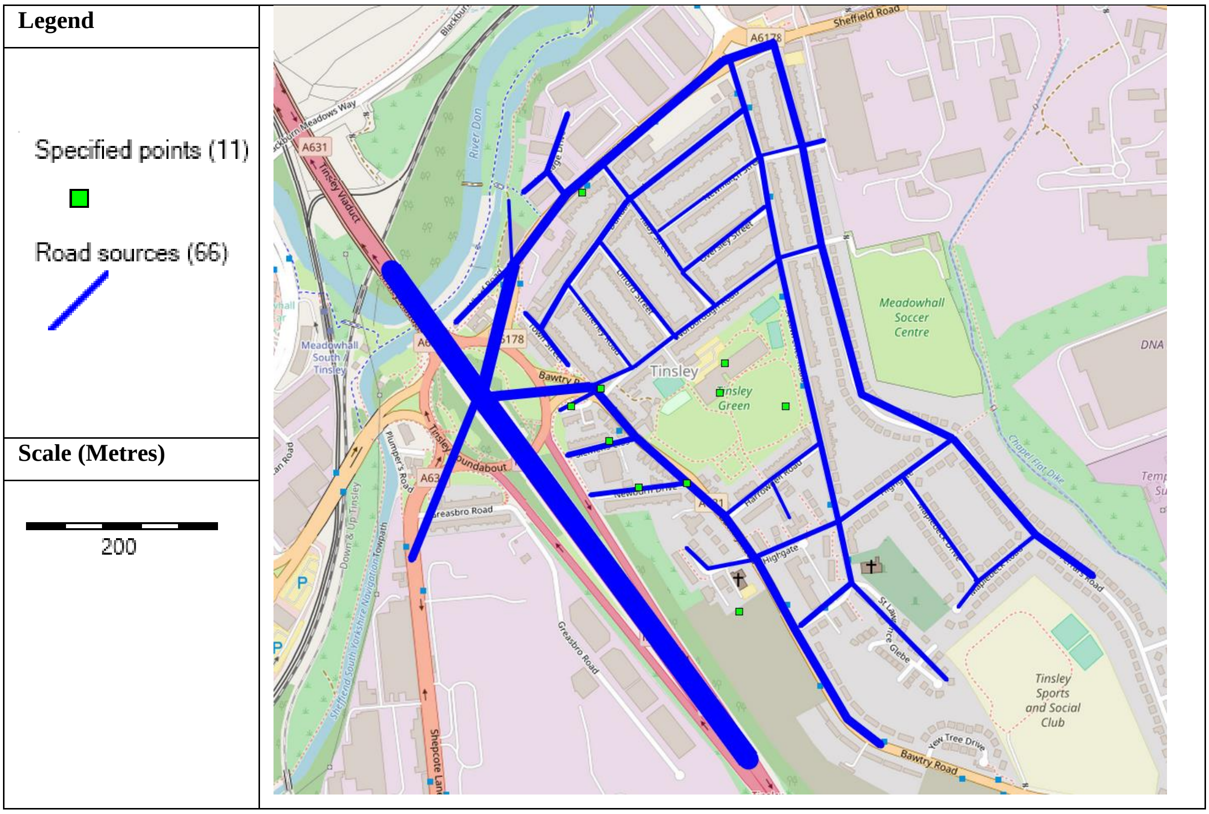

*Figure 52 Sheffield Tinsley modelling site with road links (Road sources) and receptors (Specified points).*

### 6.3 Modelling Interventions

Suitable case study schools and locations having been determined (and each with appropriate geographies and availability of all required data), preparations were made for modelling the interventions (see section 4.6 Intervention Selection) that were chosen based on the findings of the systematic review (Chapter 3) and stakeholder survey (Chapter 4).

#### 6.3.1 Assumptions

A set of assumptions was required for consistent modelling across all the sites. These were established prior to the modelling and acknowledged incomplete or unavailable data and limitations in the modelling software or process:

- In an ideal scenario, the interventions would be applied only to the morning rush hour for modelling. However, due to the composition of the available data (for example, traffic count data was averaged annually, and diffusion tube data was averaged over one month), the model averages the effects of the interventions over an entire day. This is accounted for in the application of the interventions to the models, in which any relevant traffic reductions were applied to all affected road links without temporal association.
- Due to the limited number of available road links in ADMS-Roads (150) and the content of the surrounding urban environment, the interventions were modelled across two schools at the Bristol St Paul's site (St Paul's children's centre and Cabot Primary school). St Paul's Children's centre was placed at the centre of the map. Because children would be too young to walk there alone, walking and driving routes were plotted to Cabot Primary school to enable comparison of effects of measures on the routes. Plotting active travel routes to the children's centre would have been unrepresentative of real-world conditions. However, the LEZ was modelled on the children's centre due to its central position allowing for a greater coverage and the facility to demarcate 100-metre radii up to 500 metres.
- Catchment data are unique to each school and problematic to identify, as many schools accept children from outside of the 500-metre boundary used for the models. To ensure a consistent application of interventions to all sites, travel routes were plotted for each site based on the assumption that most pupils will be travelling from the centre edge of each key residential area identified within the 500-metre vicinity of the schools. Receptors were placed at each road junction along the path of each of these routes to provide data

for the modelled interventions (Appendix P). When two road links were within 10 metres of each other, only one receptor was placed for consistency. Whilst there is no limit on the number of receptors that can be specified as points, a very large number can substantially increase the run time of the model and the required memory (ADMS-Roads, 2020).

- Data provided by the RAC (Royal Automobile Club) (2020) identified 55% of morning traffic as parents dropping children to school, so this figure was used across all sites as the assumed proportion of traffic associated with school travel.
- At Oxford St Ebbe's site the school centroid marks the position of the school according to local authority data. However, the main access point for children is approximately 217 metres East of this, which is represented in the plotted travel routes as the destination receptor.
- Converting the traffic data from AADT to AAHT has specific implications, such as the loss of morning and afternoon traffic peaks. Resultantly, the traffic volumes may be under-estimated in the models, although verification will ensure that appropriate volumes are specified for each model region for consistency with measured pollutants. However, within the models, the interventions will be assessed using traffic reductions that are proportional to their starting volumes. Accordingly, any greater degree of traffic volume accuracy is not necessary for the modelling but should be considered for future research that may require greater precision.

### 6.3.2 Application of Interventions to Sites

The following section describes key considerations and the practical points of application of the selected interventions to each site.

**Mode shifts to active travel:**

- School traffic was reduced by 40% on all school routes (Rojas-Rueda et al., 2012).
- School routes were plotted with receptors at each junction along the most direct driving routes. Driving routes for traffic reduction were plotted as the most direct road routes from the start points to the school.
- A reduction of 40% in 55% of assumed school travel (22% of overall traffic) was applied to each route.

**Improved travel routes:**

- The models assumed no change to traffic, instead assessing the effectiveness of the route changes under the same conditions.
- The direct travel routes plotted from the previous intervention were used to improve the walking routes using low-traffic and low-exposure routes (Luo, Boriboonsomsin & Barth, 2018).
- Receptors were placed at each road or path junction for each improved walking route. Placing the receptors at more central points in the road links may have risked underestimating exposure levels due to street canyons.
- To simulate walking routes via alleyways or green spaces, one receptor was placed at the entrance and exit points of the area considered.
- The total mean potential exposure to pollutants was determined for each route by averaging all receptors' $NO_2$ ($\mu g/m^3$) concentration values. This approach was necessary for comparative purposes because each route contained a different number of receptors.
- When assessing the effectiveness of the improved travel routes, the resultant concentration values for all external receptors (i.e., those that were not in travel routes, such as schools and air pollution monitors) did not change following the intervention, so they were omitted from the associated analyses.[11]

**Anti-Idling:**

- The anti-idling measure is time-dependent and, in real-world scenarios, would only be applied during morning drop-off and afternoon collection times (Ryan et al., 2013).
- A 55% traffic reduction in the street immediately adjacent to the school entrance was used to simulate the removal of idling traffic in the vicinity of the schools. It should be noted that this is likely an overestimate, as vehicles will still access the site. However, this simulates a best-case scenario as it effectively removes all school traffic from the associated street and is based on a School Streets initiative or a small-scale LEZ. For the purposes of the current research, this was considered acceptable as it provided an output that could be used for comparison with other measures that utilised broader zonal traffic reductions.

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[11] This was also the case with the combinations of improved travel routes and other interventions. The consequent analyses were accordingly conducted on the travel routes themselves.

- Some roads in the vicinity of school sites were not suitable for the application of this measure. At the Bristol Parson St site, the school road and surrounding roads are main roads and links, so it would be problematic to impose an anti-idling initiative on them. Given the high traffic volume, it can also be presumed that these roads are not used for child drop-offs or collections. Instead, anti-idling was modelled on the street immediately behind the school (Highbury Road) and the section of Parson St, which contains the entrance to the school car park, as these are areas that could readily facilitate child drop-offs and collections given their access to the school.

**Rideshare:**

- Existing travel routes were used to simulate the routes travelled by parents delivering their children to school.
- Under ideal circumstances, a rideshare scheme requires 25% uptake at any one time, assuming each car takes on an additional three people, holding four passengers in total (and one driver).
- School traffic (55% of the total) on each route was reduced by 80% to simulate the rideshare scenario (Bistaffa et al., 2019).

**Low Emission Zones (LEZ):**

- The simulation used a graded ‘School Streets’ approach and assumed all streets surrounding the school in 200, 300, 400, and 500-metre radii were closed to non-essential traffic (Santos, Gómez-Losada & Pires, 2019: Duque et al., 2016; Tonne et al., 2008). A traffic reduction of 55% was applied in each radius.
- Any road whose link was within the respective radial buffer had the applied reduction. This approach was sufficient to ensure the encapsulation of school grounds at each site and maintain consistency across each escalation of distance.

## 6.4 Model Verification

### 6.4.1 Overview

Whilst the ADMS modelling software has been validated (see Carruthers et al., 2000; Carruthers et al., 1999; McHugh et al., 1997), this only provides a generalised assurance that the model should perform well in a situation that is simple or idealised compared to reality. A process of verification was carried out to assess the performance of the models and ensure that they could perform well under different situations without tendency to over or under-predict concentrations. The process involved a comparison of predicted and measured concentrations. In the case of disparity, the model parameters and input data were re-evaluated to minimise the errors. Following verification, an appropriate adjustment factor could be applied.

### 6.4.2 Introduction

Within the LAQM (Local Air Quality Management) process, it is common for monitored concentrations to be over or under-predicted by models (Defra, 2021d). This could be due to reasons related to input data uncertainties or incorrect model parameterisation, or limitations of the model itself (ibid.).

When a significant error is detected, all model inputs and parameters must be checked to ensure they are as accurate as possible. There may still be a tendency for the model to over or under-predict, in which case it is pertinent to utilise the established LAQM method for model adjustment based on monitored data, which is commonly applied to modelled road sources due to uncertainties of emissions. Whilst adjustment is not ideal, it does allow models to be used more effectively for LAQM and the estimation of exceedances. In this respect, adjustment is not suitable for point sources due to the greater level of uncertainty regarding peak concentration relationships to monitored data (ibid.).

### 6.4.3 Uncertainties

The LAQM technical guidance determines the uncertainty of monitored data as approximately ±10% for continuous monitors and ±20% for diffusion tubes. Uncertainties are also acknowledged and estimated for traffic counts as model inputs, up to approximately ±28%, with fleet emissions up to approximately ±45%, and average speed data up to approximately ±26% (Defra, 2021d). In addition, street topography and urban area impacts can also add to data uncertainties. Accordingly, for model verification, an assumption must be made regarding the relative certainty of modelling data which can then be treated as correct.

### 6.4.4 Adjustment

The LAQM system prescribes a definitive process of verification and adjustment for dispersion models (Chapter 7 of LAQM.TG(16), Defra, 2021d). Whilst the process has received criticism (Shenton, 2018), it is considered necessary for the purposes of achieving usable model results (Righi, Lucialli & Pollini, 2009).

Model performance differs for kerbside, roadside, and background sites (Chapter 7 of LAQM.TG(16), Defra, 2021d). Accordingly, whilst verification should be conducted at all locations that possess monitoring data, for these purposes, only sites where there is a risk of exceedance and are representative of relevant exposure should be used. Whilst these sites can be commonly construed as roadside sites, they can also be verified and adjusted as appropriate should the modelling involve background concentration prediction from local emissions data (ibid.).

Initial verification can be carried out on total predicted concentrations, which includes both the explicitly modelled component and background, and any subsequent $NO_X/NO_2$ conversion. However, adjustment should be conducted on any explicitly modelled component, so in the case of modelling $NO_2$, the road $NO_X$ component should be assessed (ibid.).

### 6.4.5 $NO_X$ & $NO_2$

Reactions between NO and $O_3$ produce most $NO_2$, so $NO_X$ must be adjusted when necessary, as the primary pollutant. Technical guidance (Defra, 2021d) maintains that the determination of adjustment factors must be made by comparison of modelled road source $NO_X$ contributions to measured road source $NO_X$ contributions at each site.

It is important to verify $NO_X$ chemistry as the determinant of final $NO_2$ concentrations due to the generalised plateau at approximately 40 µg/m$^3$, which results in large $NO_X$ changes causing relatively small $NO_2$ changes (ibid.). When $NO_X$ concentration data cannot be provided by continuous monitoring, it must be calculated from $NO_2$ data commonly made available from diffusion tubes. The calculations were made using Defra’s $NO_X$ to $NO_2$ calculator (Defra, 2022d). LAQM technical guidance (LAQM.TG(16), Defra, 2021d) recommends that the verification of $NO_X$ must be conducted prior to conversion to $NO_2$, and this should be done using an empirical model or equation.

### 6.4.6 Verification Process

The modelled and monitored results were compared, and all were free of systematic errors. Adjustments were carried out on the input data of several sites in each model. For some main roads, but notably smaller street links such as those that represented side and back streets, traffic was required to be estimated due to a lack of suitable data. The TG16 (Defra (2021d) notes that it is important to ensure that traffic flow on modelled roads is representative of the actual traffic flow in the area. To achieve this, the guidance recommends that appropriate traffic data should be used to calibrate the model, and that sensitivity analyses should be carried out to ensure that the model is not overly sensitive to changes in traffic flow. Additionally, the TG16 recommends that the upscaling of traffic flow should be done in a manner that is consistent with the underlying principles of the model and that considers the spatial and temporal variability of traffic flow in the area. For the current research, it was only necessary to ensure that the estimated traffic flows were consistent with the monitored pollutant concentrations for the purposes of verification. Where appropriate, traffic estimations were evaluated, and they were adjusted in those cases where they may have been optimistic. In these cases, the models tended to under-predict pollutant concentrations, so the traffic volumes were increased until concentrations were within the acceptable tolerance amount of the monitored values. Traffic volume increases were based on road traffic estimates provided by the Department for Transport (2022b). $NO_2$ concentrations were determined by converting measured road $NO_X$ using Defra's LAQM calculator (Defra, 2022d) (see Appendix Q).

The model results were recorded before and after adjustments, and final differences were determined (see Appendix R). Monitored and adjusted modelled $NO_2$ for the Bristol St Paul's site is shown in Figure 53 and shows the reconciliation of all monitoring sites to within a suitable tolerance for the dispersion model (within 25%) and a goodness of fit ($R^2$) of 0.98.

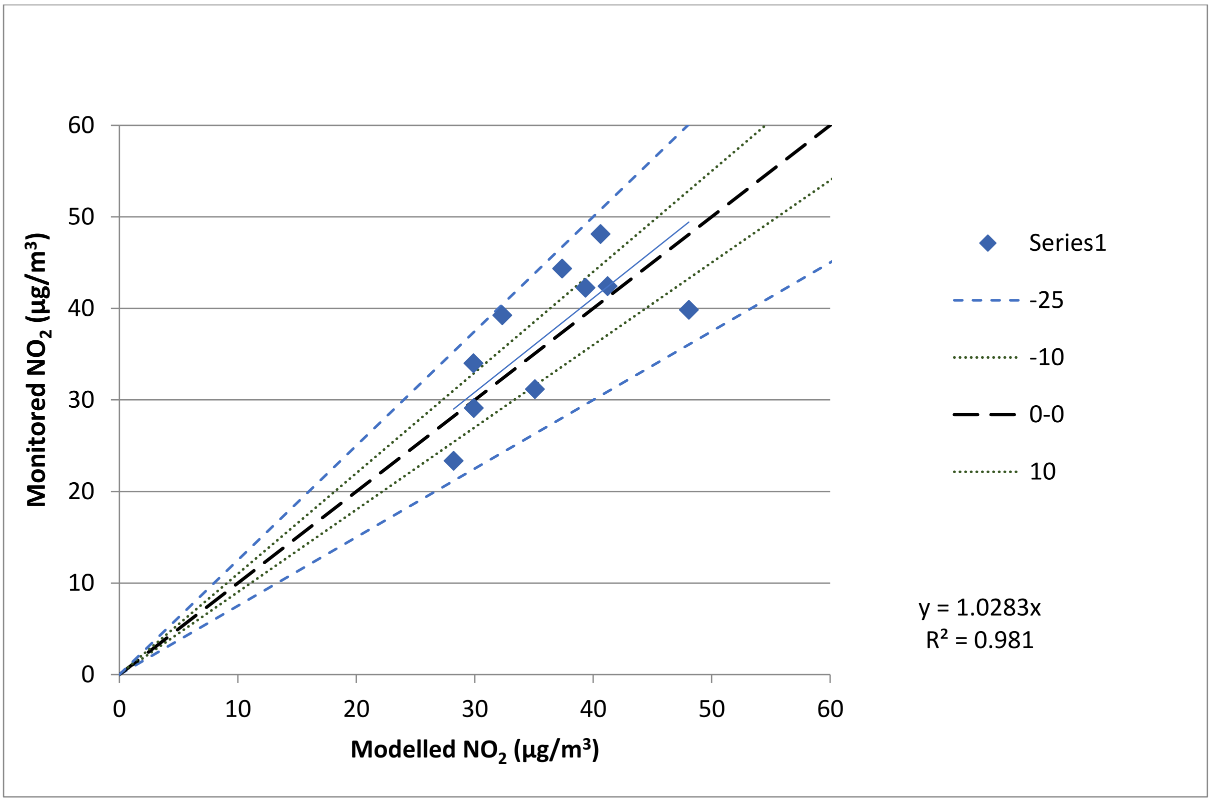


*Figure 53 Bristol St Paul's adjusted $NO_2$ ($\mu g/m^3$) with deviation interval classes at 10 and 25 per cent. Series 1 represents adjusted total $NO_2$ against total monitored $NO_2$.*

Monitored and adjusted modelled $NO_2$ for the Bristol Bedminster site is shown in Figure 54 and shows the reconciliation of all monitoring sites to within a suitable tolerance for the dispersion model (within 25%) and a goodness of fit ($R^2$) of 0.98.

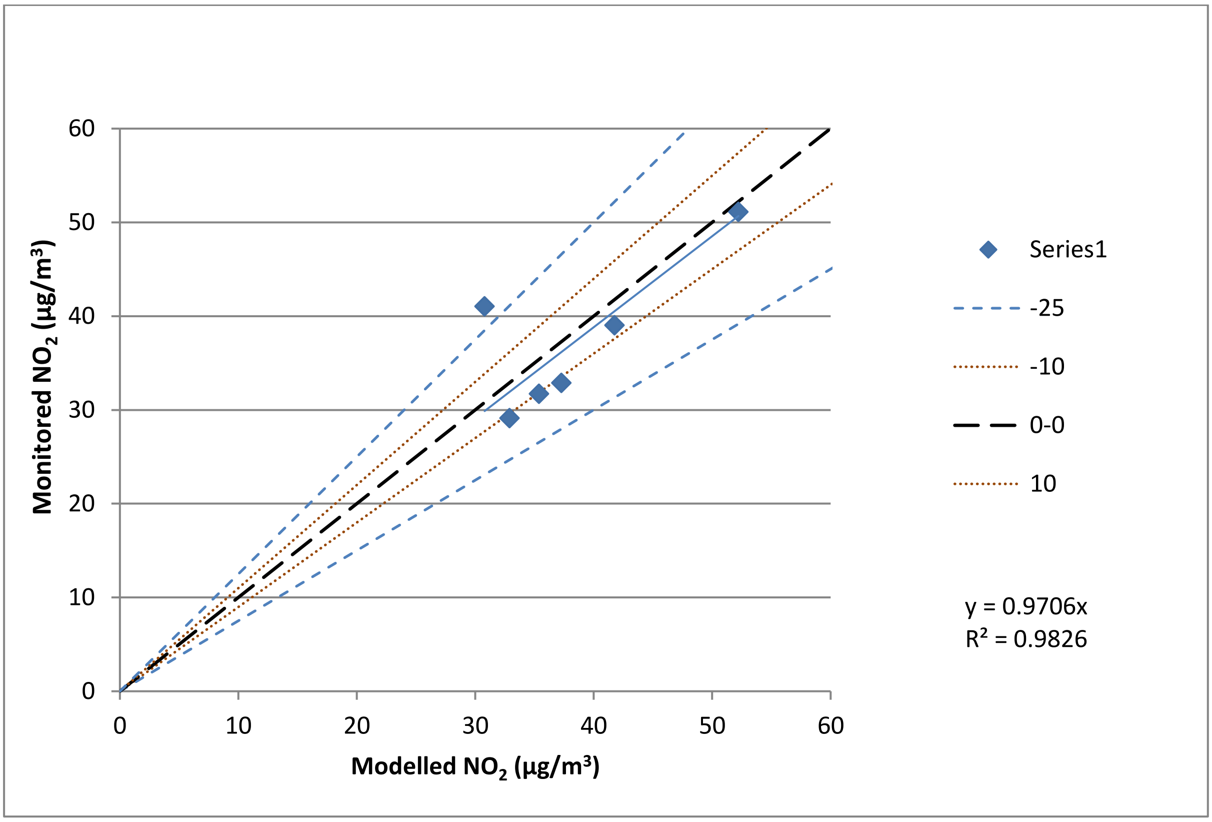


*Figure 54 Bristol Bedminster adjusted $NO_2$ (µg/$m^3$) with deviation interval classes at 10 and 25 per cent. Series 1 represents adjusted total $NO_2$ against total monitored $NO_2$.*

Monitored and adjusted modelled $NO_2$ for the Coventry Binley site is shown in Figure 55 and shows the reconciliation of all monitoring sites to within a suitable tolerance for the dispersion model (within 25%) and a goodness of fit ($R^2$) of 0.98.

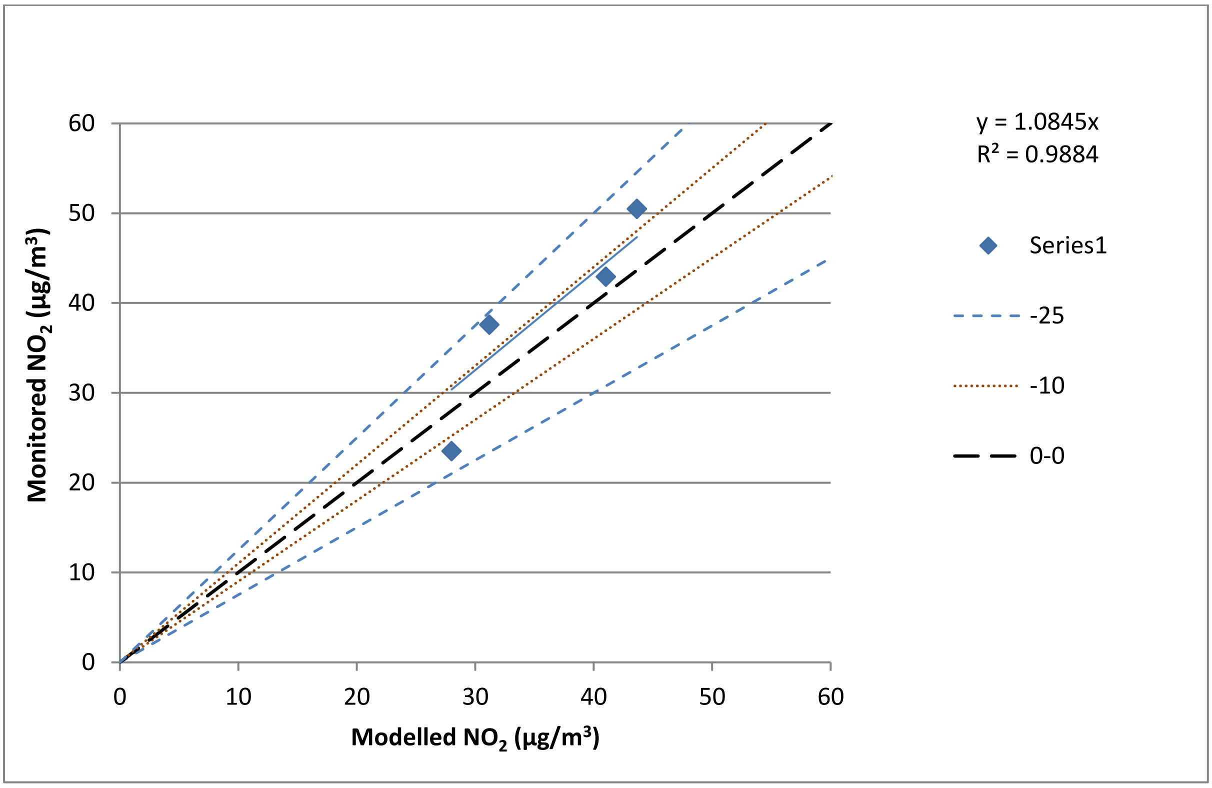


*Figure 55 Coventry Binley adjusted $NO_2$ (µg/m$^3$) with deviation interval classes at 10 and 25 per cent. Series 1 represents adjusted total $NO_2$ against total monitored $NO_2$.*

Monitored and adjusted modelled $NO_2$ for the Oxford St Ebbe’s site is shown in Figure 56 and shows the reconciliation of all monitoring sites to within a suitable tolerance for the dispersion model (within 25%) and a goodness of fit ($R^2$) of 0.93.

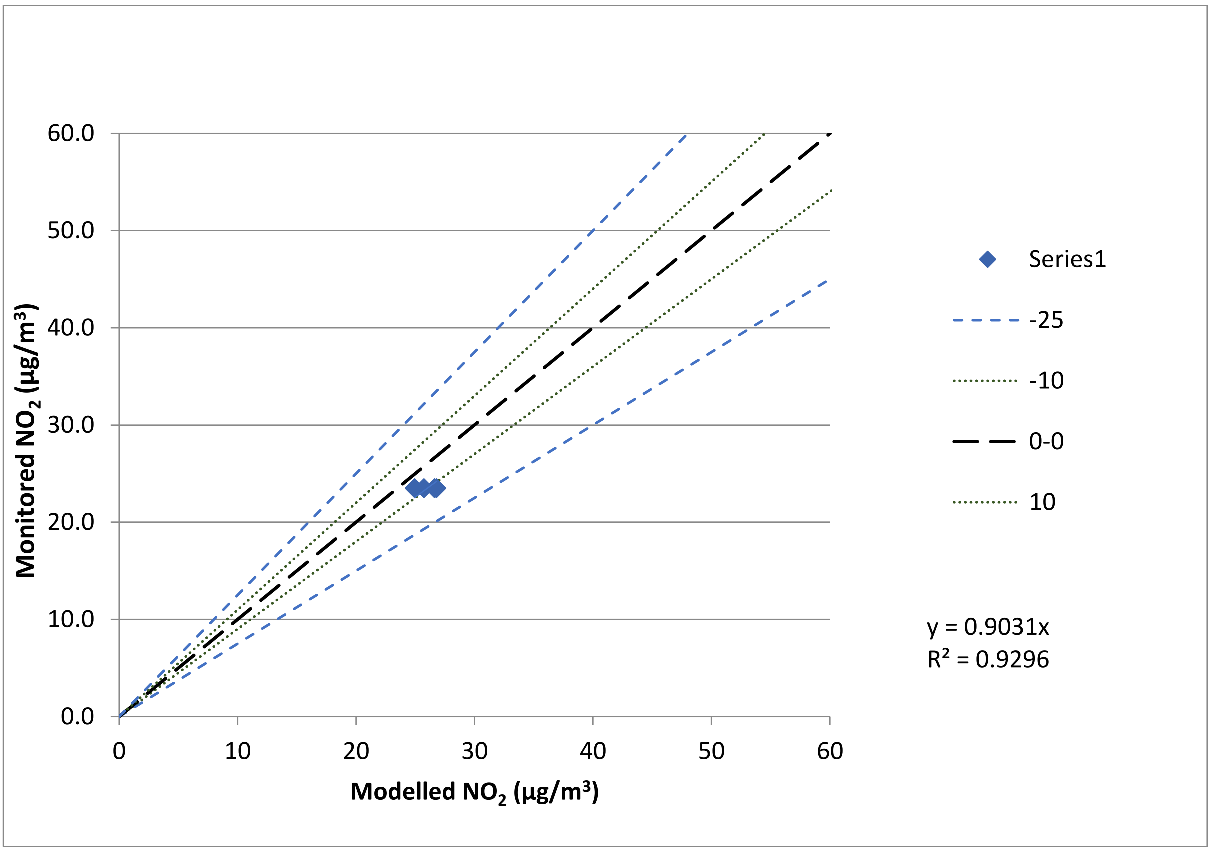


*Figure 56 Oxford St Ebbe’s adjusted $NO_2$ (µg/m$^3$) with deviation interval classes at 10 and 25 per cent. Series 1 represents adjusted total $NO_2$ against total monitored $NO_2$.*

Monitored and adjusted modelled $NO_2$ for the Sheffield Tinsley site is shown in Figure 57 and shows the reconciliation of all monitoring sites to within a suitable tolerance for the dispersion model (within 25%) and a goodness of fit ($R^2$) of 0.99.

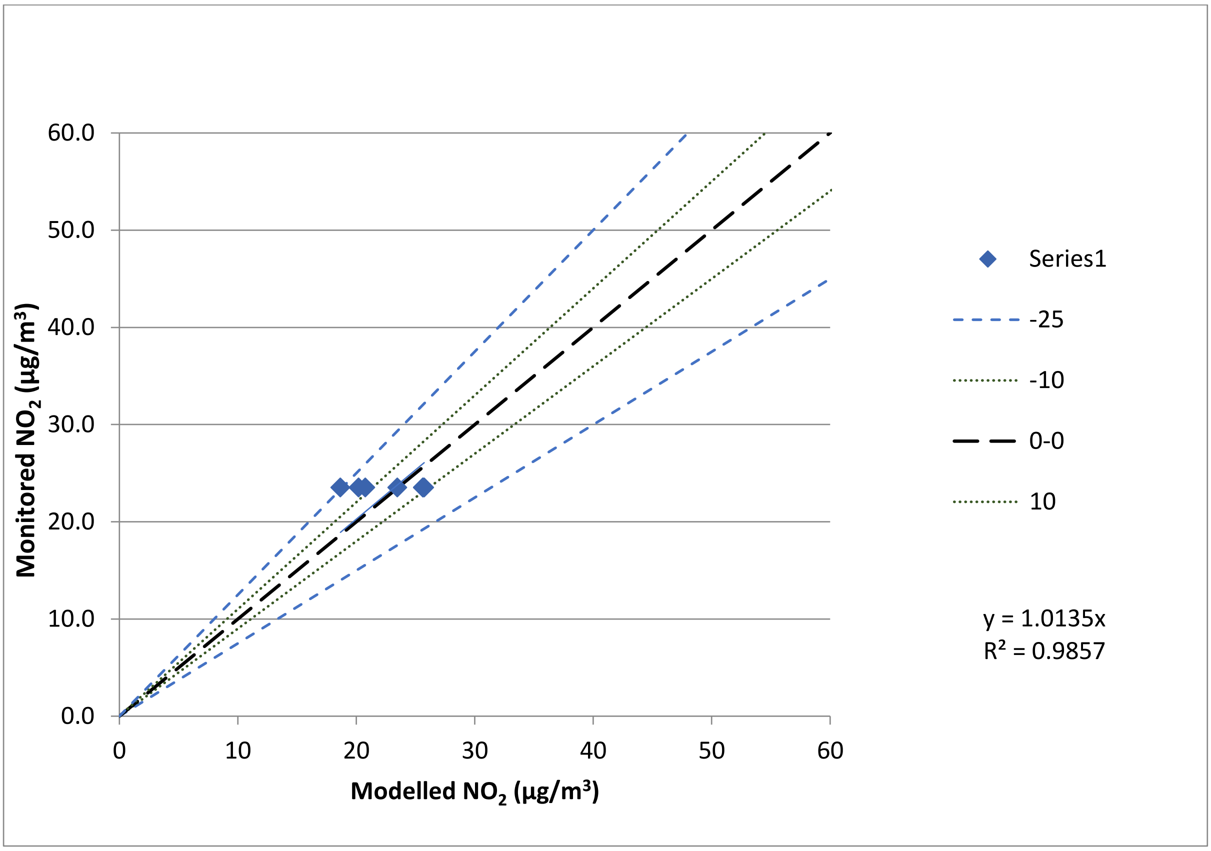


*Figure 57 Sheffield Tinsley adjusted $NO_2$ (μg/m$^3$) with deviation interval classes at 10 and 25 per cent. Series 1 represents adjusted total $NO_2$ against total monitored $NO_2$.*

### 6.4.7 Summary

The dispersion model was used to predict $NO_X$ concentrations to determine $NO_2$. A comparison of modelled and monitored data at all continuous monitoring sites and diffusion tubes in all locations suggests that all the models perform well. Differences between modelled and monitored data at all sites are within 25% (see Table 25).

*Table 25 Summary of site adjustment outcomes.*

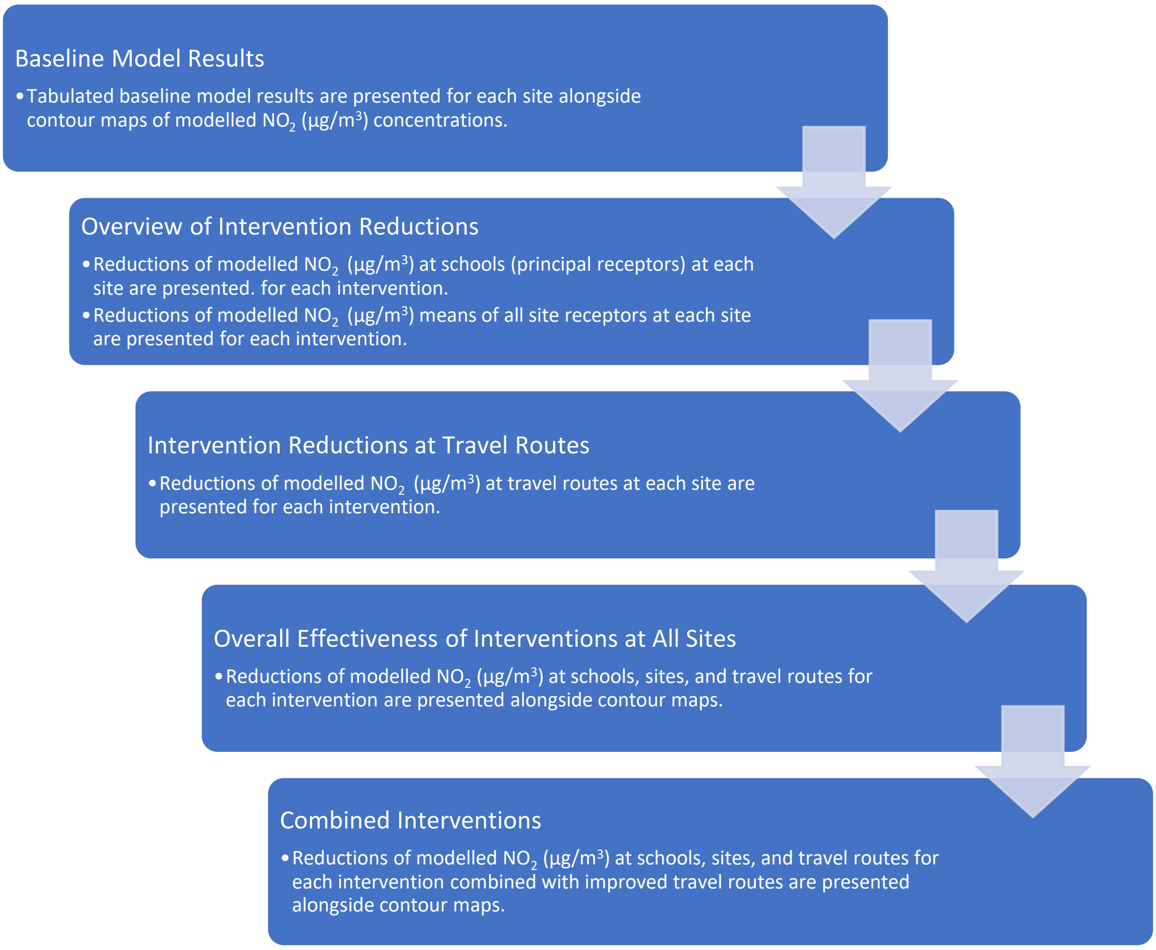
| Site | Number of Monitors | ±10% | ±25% | Adjustment Factor (Regression) |
|---|---|---|---|---|
| Bristol St Paul’s | 10 | 3 | 7 | 1.19 |
| Bristol Parson St | 6 | 2 | 4 | 0.99 |
| Coventry Binley Rd | 4 | 1 | 3 | 1.28 |
| Oxford St Ebbe’s | 5 | 3 | 2 | 0.93 |
| Sheffield Tinsley | 4 | 2 | 2 | 2.64 |

Following adjustment, none of the models showed any overall tendency to over or under-predict at sites close to the objective. Linear regression lines were derived for all locations, and further adjustment was not required (see Appendix R).

## 6.5 Model Results

### 6.5.1 Overview

The current section provides a summary of the dispersion modelling results in terms of the most effective interventions at each school site and associated travel routes. A flow diagram of the presented results is provided in Figure 58. The results are presented in terms of modelled reductions of $NO_2$ ($\mu g/m^3$) at schools (principal receptors), overall site means (using a combined mean of all site receptors[12], other than those that are part of plotted travel routes), and travel routes (using a combined mean of all receptors that make up the plotted travel routes[13]).



Baseline Model Results

- Tabulated baseline model results are presented for each site alongside contour maps of modelled $NO_2$ ($\mu g/m^3$) concentrations.

Overview of Intervention Reductions

- Reductions of modelled $NO_2$ ($\mu g/m^3$) at schools (principal receptors) at each site are presented. for each intervention.
- Reductions of modelled $NO_2$ ($\mu g/m^3$) means of all site receptors at each site are presented for each intervention.

Intervention Reductions at Travel Routes

- Reductions of modelled $NO_2$ ($\mu g/m^3$) at travel routes at each site are presented for each intervention.

Overall Effectiveness of Interventions at All Sites

- Reductions of modelled $NO_2$ ($\mu g/m^3$) at schools, sites, and travel routes for each intervention are presented alongside contour maps.

Combined Interventions

- Reductions of modelled $NO_2$ ($\mu g/m^3$) at schools, sites, and travel routes for each intervention combined with improved travel routes are presented alongside contour maps.

*Figure 58 Flow diagram overview of presented dispersion modelling results.*

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[12] All site receptors includes all schools (both principal and secondary receptors) and any continuous monitors or diffusion tubes that have been plotted to the site.

[13] Where a mean of travel routes for an entire site are presented, the mean has been constructed by taking the mean of all receptors on each travel route at a particular site, and then averaging these figures.

### 6.5.2 Baseline Model Results

Following verification and adjustment, the modelled $NO_2$ and $NO_X$ inputs for all receptors (including active travel routes) were established to identify the baseline $NO_X$ concentrations for 2019 at each site prior to modelling interventions.

Table 26 shows modelled $NO_X$ and $NO_2$ concentrations at each receptor in the Bristol St Paul's site prior to the application of any interventions. Baseline $NO_X$ (µg/m$^3$) at Cabot Primary School and St Paul's Children's Centre was 35.64 and 25.22, respectively. Baseline $NO_2$ (µg/m$^3$) at Cabot Primary School and St Paul's Children's Centre was 16.93 and 15.61, respectively. Because each travel route contains several receptors plotting the route itself, the means for travel routes at each site shown in Table 26 are means of all receptors within the route. The travel routes all contained areas of high $NO_X$ and $NO_2$ concentrations, with St Agnes showing the highest means (133.42 and 32.35 µg/m$^3$, respectively).

*Table 26 Bristol St Paul's modelled 2019 baseline concentrations of $NO_X$ and $NO_2$ (µg/m$^3$) at all receptors.*

| **Receptor Name** | **Type** | **Height (m)** | **$NO_X$ (µg/m$^3$)** | **$NO_2$ (µg/m$^3$)** |
|---|---|---|---|---|
| Cabot Primary School | School | 1.2 | 35.64 | 16.93 |
| St Paul's Children's Centre | School | 1.2 | 25.22 | 15.61 |
| Bristol St Paul's BRS8 AURN | Continuous Monitor | 4 | 25.92 | 15.88 |
| Bristol Temple Way BR11 AURN | Continuous Monitor | 1.5 | 34.51 | 16.94 |
| 15 Horsefair | Diffusion Tube | 2.2 | 49.93 | 18.72 |
| 363 5102 facade | Diffusion Tube | 2.7 | 29.39 | 16.64 |
| 22 Stokes Croft | Diffusion Tube | 2.5 | 45.52 | 21.08 |
| 497 20 Ashley Road | Diffusion Tube | 2.3 | 29.46 | 16.94 |
| 295 Lamppost 16 Ashley Rd St P | Diffusion Tube | 2.8 | 52.86 | 19.65 |
| 374 St Paul St | Diffusion Tube | 2.3 | 70.57 | 24.77 |
| 20 Newfoundland Way | Diffusion Tube | 2 | 54.23 | 19.40 |
| 373 123 Newfoundland St facade | Diffusion Tube | 2.1 | 40.44 | 17.65 |
| Ashley Road (mean of all receptors (SD)) | Travel Route | 1.2 | 60.11 (46.32) | 22.00 (7.40) |
| Stokes Croft (mean of all receptors (SD)) | Travel Route | 1.2 | 106.12 (59.37) | 27.27 (7.20) |
| St Agnes (mean of all receptors (SD)) | Travel Route | 1.2 | 133.42 (94.39) | 32.35 (14.07) |
| Bristol South (mean of all receptors (SD)) | Travel Route | 1.2 | 87.57 (54.86) | 24.01 (7.37) |
| Cheltenham Rd (mean of all receptors (SD)) | Travel Route | 1.2 | 68.17 (50.23) | 26.01 (12.30) |
| | | Site Mean (SD) | 73.45 (59.22) | 24.20 (10.08) |

Figure 59 depicts a contour map[14] showing baseline modelled $NO_2$ concentrations at the Bristol St Paul's site prior to the application of interventions. The highest concentrations are in the northeast, adjacent to the A4320/M32 roundabout, the centre of Wilder Street between the B4057 and A4032, the A38 south in Stokes Croft near the Jamaica Street and Cheltenham Road junction, and the south of the site on Bond Street where the M32 enters the city centre.

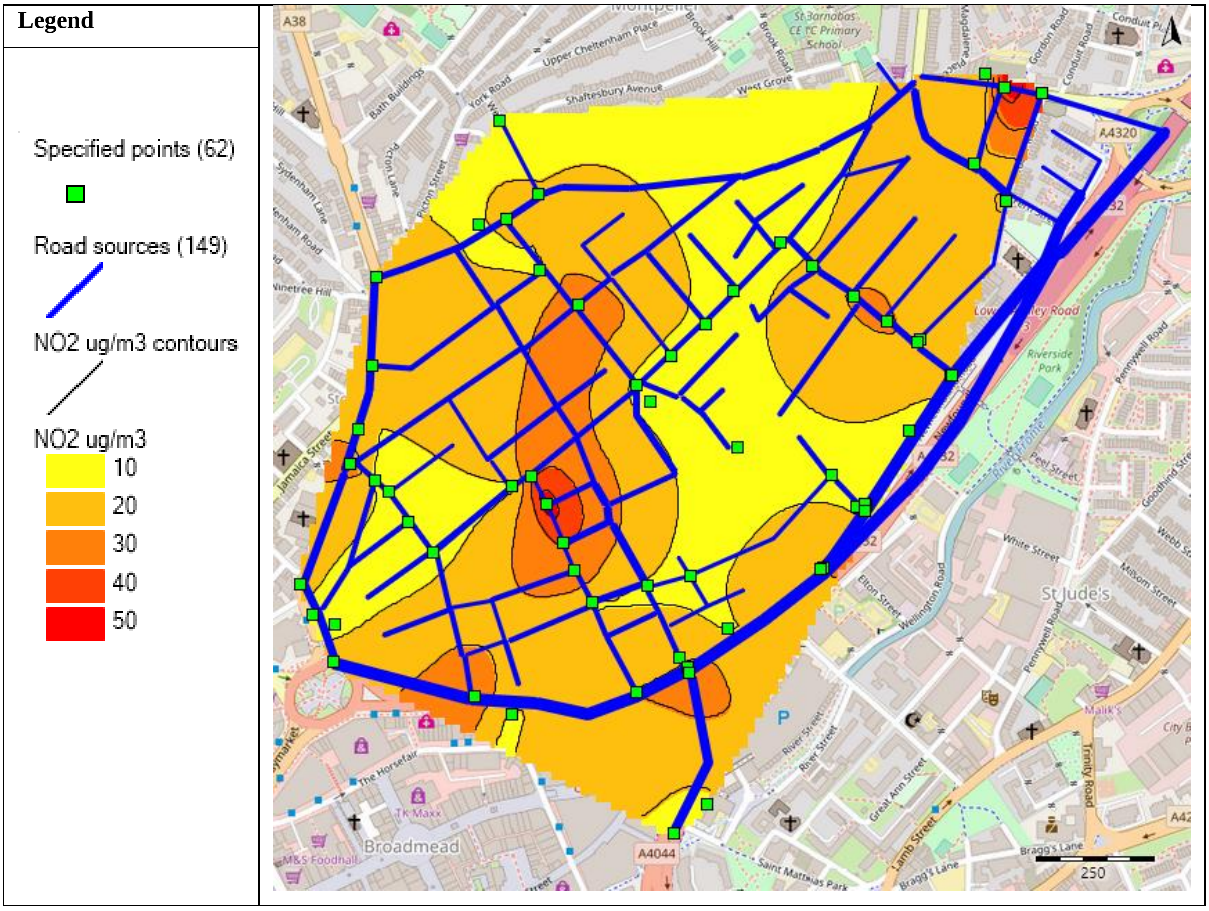

*Figure 59 Contour map showing Bristol St Paul's site modelled 2019 baseline $NO_2$ ($\mu g/m^3$) concentrations.*

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[14] Some link areas are not covered by the contour maps because ADMS-Roads provides the option of a 'gridded output' (which generates an output based on a specified grid) or 'specified' points (which generates an output based on the values of the site receptors). Whilst the gridded output option would permit a more complete contour map, the option is resource-heavy and was considered unnecessary for the current research. Rather, the specified points output was used because the initial and modelled values of the receptors were the elements desired for analysis.

Table 27 shows modelled $NO_X$ and $NO_2$ (µg/m$^3$) concentrations at each receptor in the Bristol Bedminster site prior to any interventions. Baseline $NO_X$ and $NO_2$ at Parson Street School were 45.59 and 19.77 µg/m$^3$, respectively. The travel routes all contained areas of high $NO_X$ and $NO_2$ concentrations, with the highest concentrations at Bedminster Down (115.46 and 29.55 µg/m$^3$, respectively) and Ashton Gate (109.91 and 30.52, respectively).

*Table 27 Bristol Bedminster modelled 2019 baseline concentrations of $NO_X$ and $NO_2$ (µg/m$^3$) at all receptors.*

| **Receptor Name** | **Type** | **Height (m)** | **$NO_X$ (µg/m$^3$)** | **$NO_2$ (µg/m$^3$)** |
|---|---|---|---|---|
| 215 Parson St School | Continous Monitor | 1.5 | 45.24 | 19.70 |
| 242 Parson St Bedminster Down Rd | Diffusion Tube | 3.2 | 31.28 | 16.23 |
| 418 Bedminster Down Rd lamppost | Diffusion Tube | 2.8 | 80.97 | 24.06 |
| 419 Parson St lamppost Scuba | Diffusion Tube | 2.8 | 55.49 | 21.23 |
| 439 Parson St School | Diffusion Tube | 1.5 | 41.09 | 19.03 |
| 474 Martial Arts West Street | Diffusion Tube | 2.4 | 35.72 | 17.71 |
| Parson St School | School | 1.2 | 45.59 | 19.77 |
| Ashton Gate (mean of all receptors (*SD*)) | Travel Route | 1.2 | 109.91 (46.82) | 30.52 (8.22) |
| Bedminster (mean of all receptors (*SD*)) | Travel Route | 1.2 | 69.73 (25.37) | 24.26 (5.04) |
| Victoria Park (mean of all receptors (*SD*)) | Travel Route | 1.2 | 59.52 (6.60) | 22.87 (1.48) |
| Knowle West (mean of all receptors (*SD*)) | Travel Route | 1.2 | 33.87 (8.81) | 17.52 (1.82) |
| Knowle West South (mean of all receptors (*SD*)) | Travel Route | 1.2 | 76.23 (43.05) | 26.69 (8.10) |
| Hartcliffe Way (mean of all receptors (*SD*)) | Travel Route | 1.2 | 74.75 (23.63) | 26.08 (4.63) |
| Bedminster Down (mean of all receptors (*SD*)) | Travel Route | 1.2 | 115.46 (73.38) | 29.55 (8.37) |
|  |  | Site Mean (*SD*) | 75.22 (45.76) | 25.00 (7.36) |

Figure 60 depicts a contour map showing baseline modelled $NO_2$ ($\mu g/m^3$) concentrations at the Bristol Bedminster site prior to the application of interventions. The highest concentrations are in the west of the site, emanating from the A38/A3029 intersection.

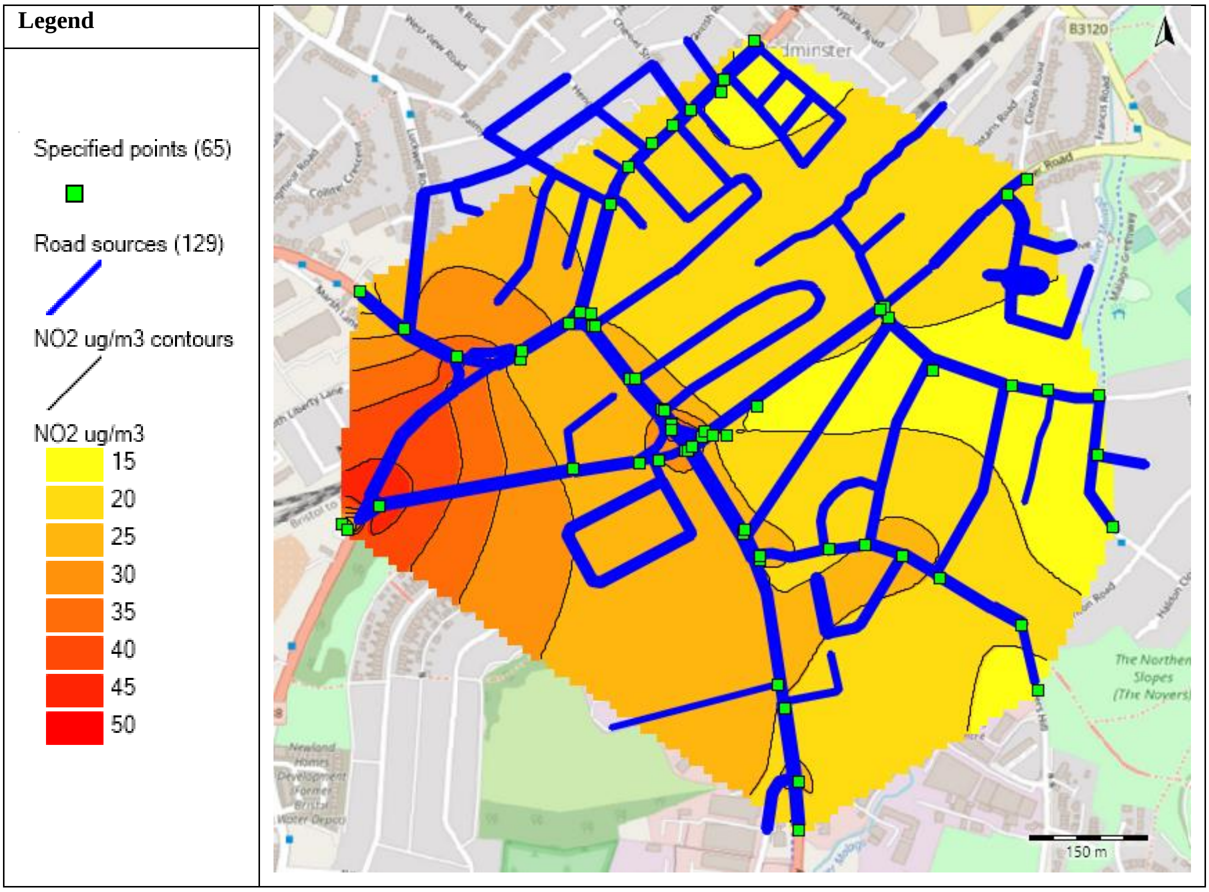

*Figure 60 Contour map showing Bristol Bedminster site modelled 2019 baseline $NO_2$ ($\mu g/m^3$) concentrations.*

Table 28 shows modelled $NO_X$ and $NO_2$ (µg/m$^3$) concentrations at each receptor in the Coventry Binley site prior to any interventions. Baseline $NO_X$ (µg/m$^3$) at Southfields Primary School and Gosford Park Children's Centre was 26.10 and 25.58, respectively. Baseline $NO_2$ (µg/m$^3$) at Southfields Primary School and Gosford Park Children's Centre was 16.44 at both sites, respectively. The travel routes all contained areas of high pollution, with Barras Heath, Charterhouse Park, and Callice Court showing the highest $NO_X$ (µg/m$^3$) means (63.26, 63.91, and 64.14, respectively), and Barras Heath and Charterhouse Park showing the highest $NO_2$ (µg/m$^3$) means (24.31 and 24.82, respectively).

*Table 28 Coventry Binley modelled 2019 baseline concentrations of $NO_X$ and $NO_2$ (µg/m$^3$) at all receptors.*

| **Receptor Name** | **Type** | **Height (m)** | **$NO_X$ (µg/m$^3$)** | **$NO_2$ (µg/m$^3$)** |
|---|---|---|---|---|
| Southfields Primary School | School | 1.2 | 26.10 | 16.44 |
| Gosford Park Children's Centre | School | 1 | 25.58 | 16.44 |
| Coventry Binley Road COBR AURN | Continuous Monitor | 1.5 | 59.02 | 23.54 |
| FGS4 Callice Court | Diffusion Tube | 2.8 | 31.09 | 17.27 |
| FGS2 Select and Save FrGosfrd | Diffusion Tube | 2.7 | 52.86 | 21.47 |
| BH1a Walsgrave Rd Library | Diffusion Tube | 2.67 | 24.48 | 16.09 |
| Bishopsgate Green (mean of all receptors (*SD*)) | Travel Route | 1.2 | 27.00 (2.49) | 16.82 (0.66) |
| Barras Heath (mean of all receptors (*SD*)) | Travel Route | 1.2 | 63.26 (55.30) | 24.31 (11.00) |
| Gosford Park (mean of all receptors (*SD*)) | Travel Route | 1.2 | 59.44 (36.67) | 23.97 (7.92) |
| Stoke Aldermoor (mean of all receptors (*SD*)) | Travel Route | 1.2 | 53.42 (33.08) | 22.35 (6.96) |
| Charterhouse Park (mean of all receptors (*SD*)) | Travel Route | 1.2 | 63.91 (34.06) | 24.82 (7.32) |
| Callice Court (mean of all receptors (SD)) | Travel Route | 1.2 | 64.14 (28.52) | 23.97 (5.86) |
| Coventry Centre (mean of all receptors (SD)) | Travel Route | 1.2 | 44.44 (29.38) | 20.67 (6.32) |
|  |  | Site Mean (*SD*) | 52.49 (35.50) | 22.16 (7.42) |

Figure 61 depicts a contour map showing baseline modelled $NO_2$ ($\mu g/m^3$) concentrations at the Coventry Binley site prior to the application of interventions. The highest concentrations are located centrally, emanating from the A4053 from the west to the junction on the A4600, where Sky Blue Way joins the A428 at Gosford Park.

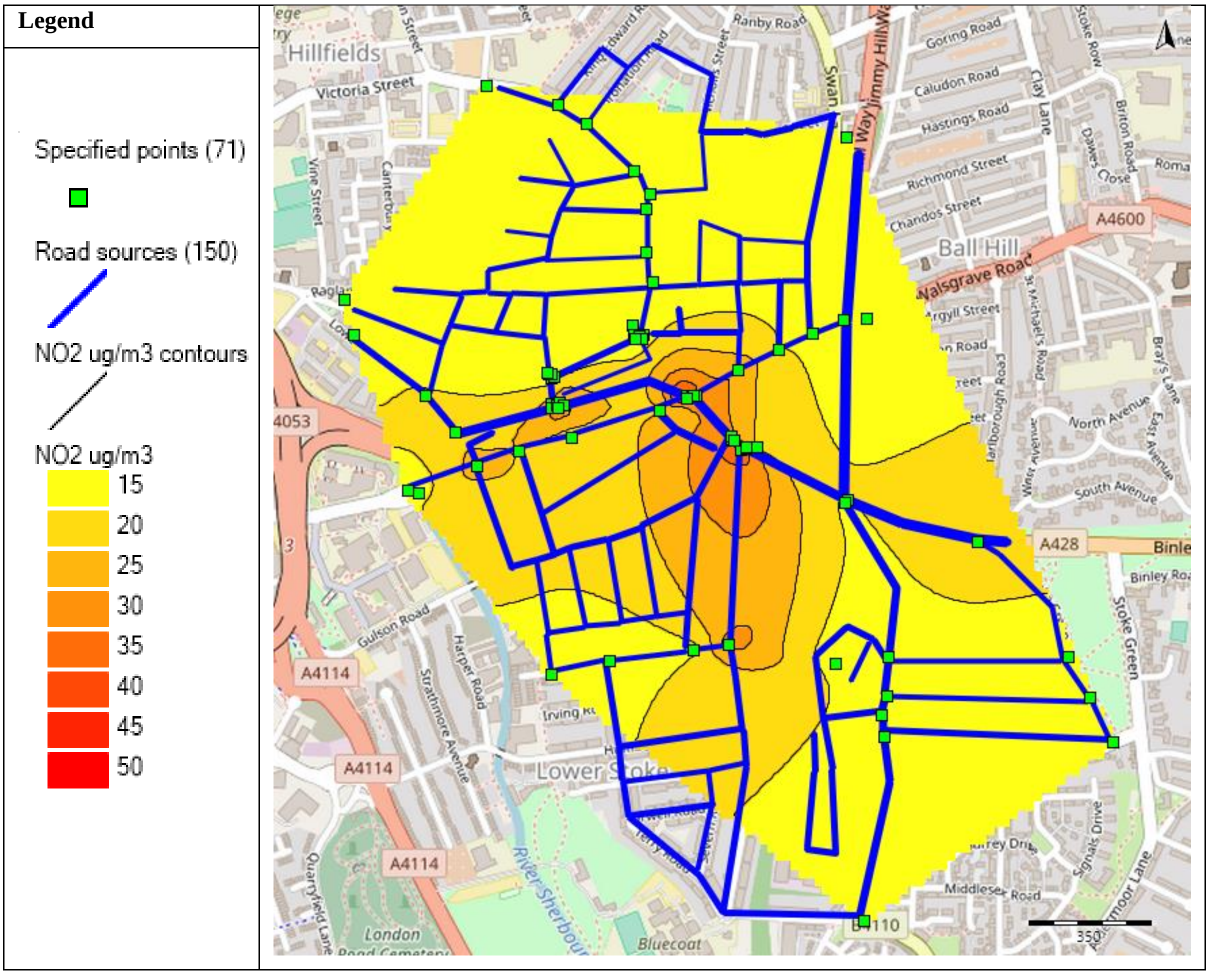

*Figure 61 Contour map showing Coventry Binley site modelled 2019 baseline $NO_2$ ($\mu g/m^3$) concentrations.*

Table 29 shows modelled $NO_X$ and $NO_2$ concentrations at each receptor in the Oxford St Ebbe's site prior to any interventions. Baseline $NO_X$ and $NO_2$ (µg/m$^3$) at St Ebbe's Primary School were 22.01 and 14.75 µg/m$^3$. The Westgate travel route had the highest mean $NO_X$ and $NO_2$ concentrations (37.63 and 18.53 µg/m$^3$, respectively).

*Table 29 Oxford St Ebbe's modelled 2019 baseline concentrations of $NO_X$ and $NO_2$ (µg/m$^3$) at all receptors.*

| **Receptor Name** | **Type** | **Height (m)** | **$NO_X$ (µg/m$^3$)** | **$NO_2$ (µg/m$^3$)** |
|---|---|---|---|---|
| St Ebbe's Primary School | School | 1.2 | 22.01 | 14.75 |
| Oxford St Ebbe's OX8 AURN | Continuous Monitor | 3.5 | 21.96 | 14.74 |
| DT61 Friars Wharf | Diffusion Tube | 3 | 21.62 | 14.70 |
| DT60 N Butterwyke Place Thames | Diffusion Tube | 3 | 22.67 | 15.02 |
| DT59 Thames St | Diffusion Tube | 3 | 24.32 | 15.49 |
| DT58 Folly Bridge | Diffusion Tube | 3 | 24.52 | 15.57 |
| DT1 St Ebbe's First School | Diffusion Tube | 2.5 | 26.08 | 15.61 |
| Westgate (mean of all receptors (*SD*)) | Travel Route | 1.2 | 37.63 (12.88) | 18.53 (2.72) |
| Gloucester Green (mean of all receptors (*SD*)) | Travel Route | 1.2 | 31.42 (7.36) | 17.16 (1.57) |
| Christ Church (mean of all receptors (*SD*)) | Travel Route | 1.2 | 35.49 (14.33) | 17.85 (2.93) |
| Hinksey (mean of all receptors (*SD*)) | Travel Route | 1.2 | 27.97 (4.32) | 16.26 (0.90) |
| | | Site Mean (*SD*) | 31.70 (10.81) | 17.12 (2.32) |

Figure 62 depicts a contour map showing baseline modelled $NO_2$ ($\mu g/m^3$) concentrations at the Oxford St Ebbe's site prior to the application of interventions. The highest concentrations follow the A420 in the northwest of the site, near the northeast where the A420 joins the A4144 south, and the roads adjacent to St Ebbe's Primary School in the southwest of the site.

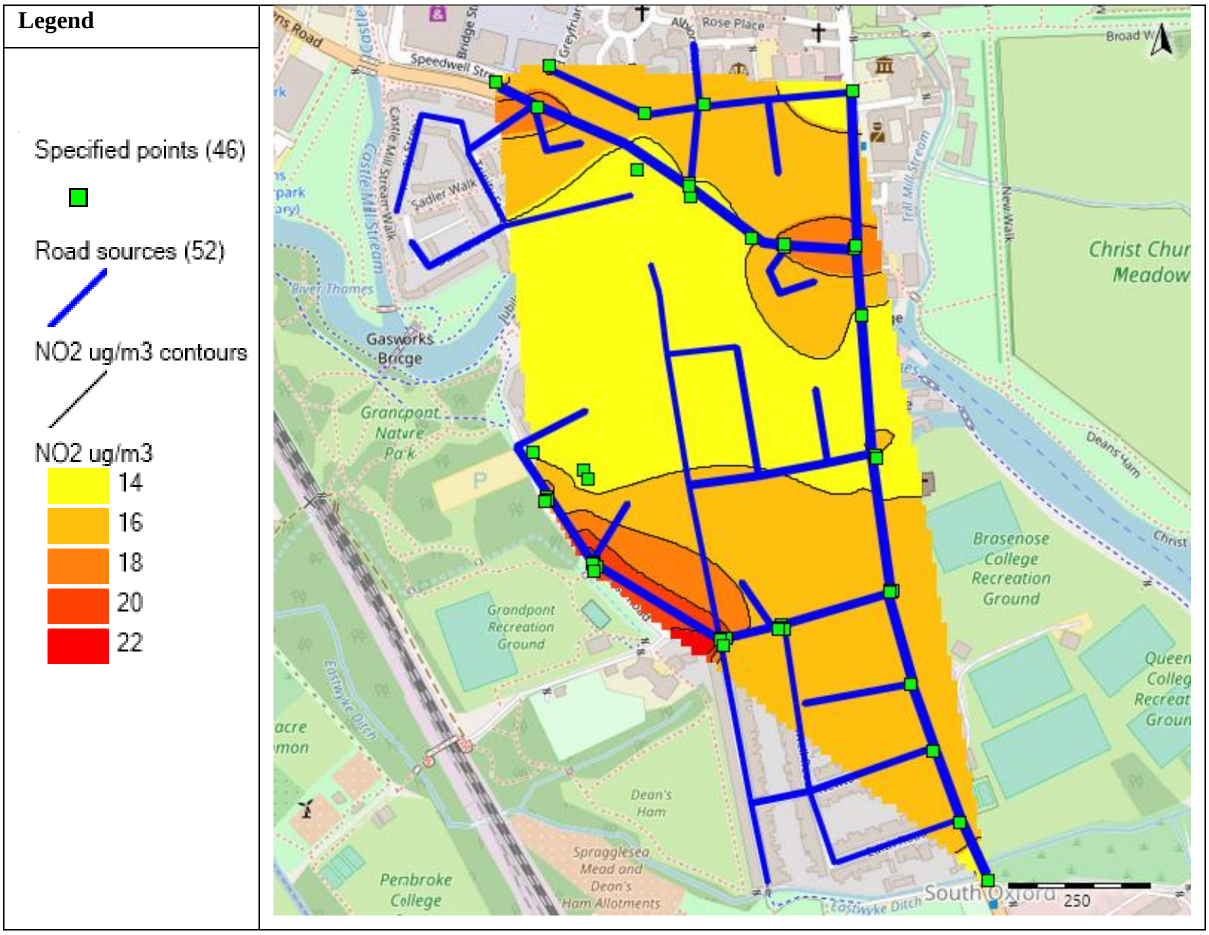

*Figure 62 Contour map showing Oxford St Ebbe's site modelled 2019 baseline $NO_2$ ($\mu g/m^3$) concentrations.*

Table 30 shows modelled $NO_X$ and $NO_2$ (µg/m$^3$) concentrations at each receptor in the Sheffield Tinsley site prior to any interventions. Baseline $NO_X$ (µg/m$^3$) at Tinsley Meadows Primary School and Tinsley Green Children's Centre was 16.49 and 15.94, respectively. Baseline $NO_2$ (µg/m$^3$) at Tinsley Meadows Primary School and Tinsley Green Children's Centre was 10.61 and 10.50, respectively. The travel routes all contained areas of high pollution, with Greenland and Sheffield Road showing the highest $NO_X$ means (42.05 and 39.42 µg/m$^3$, respectively) and $NO_2$ means (16.84 and 15.70, respectively).

*Table 30 Sheffield Tinsley modelled 2019 baseline concentrations of $NO_X$ and $NO_2$ (µg/m$^3$) at all receptors.*

| **Receptor Name** | **Type** | **Height (m)** | **$NO_X$ (µg/m$^3$)** | **$NO_2$ (µg/m$^3$)** |
|---|---|---|---|---|
| Tinsley Meadows Primary School | School | 1.2 | 16.49 | 10.61 |
| Tinsley Green Children's Centre | School | 1.2 | 15.94 | 10.50 |
| Sheffield Tinsley SHE AURN | Continuous Monitor | 1.5 | 16.91 | 10.75 |
| Site 7 Bawtry Gate | Diffusion Tube | 2.5 | 26.43 | 12.95 |
| Site 47 Bawtry Rd | Diffusion Tube | 2.5 | 31.25 | 14.21 |
| Site 30 Siemens Close | Diffusion Tube | 2.5 | 19.6 | 11.40 |
| Site Tinsley Meadows Primary A | Diffusion Tube | 2.5 | 16.56 | 10.61 |
| Site Ferrars Road | Diffusion Tube | 2.5 | 20.62 | 11.61 |
| Site 109 Bawtry Rd | Diffusion Tube | 2.5 | 30.39 | 14.38 |
| Site Tinsley Infant School | Diffusion Tube | 2.5 | 19.71 | 11.48 |
| Blackburn Meadows (mean of all receptors (*SD*)) | Travel Route | 1.2 | 27.10 (9.34) | 12.97 (2.00) |
| Brinsworth (mean of all receptors (*SD*)) | Travel Route | 1.2 | 27.86 (11.71) | 13.44 (3.16) |
| Catcliffe (mean of all receptors (*SD*)) | Travel Route | 1.2 | 34.00 (8.71) | 15.02 (1.97) |
| Greenland (mean of all receptors (*SD*)) | Travel Route | 1.2 | 42.05 (24.19) | 16.84 (5.95) |
| Sheffield Rd (mean of all receptors (*SD*)) | Travel Route | 1.2 | 39.42 (15.85) | 15.70 (3.50) |
|  |  | Site Mean (*SD*) | 30.73 (14.48) | 14.01 (3.45) |

Figure 63 depicts a contour map showing baseline $NO_2$ concentrations at the Sheffield Tinsley site prior to the application of interventions. The highest concentrations are located in the west of the site, at the M1 Tinsley Roundabout, the north of the site at the A6178 junction, and towards the south central commercial/industrial region of the site.

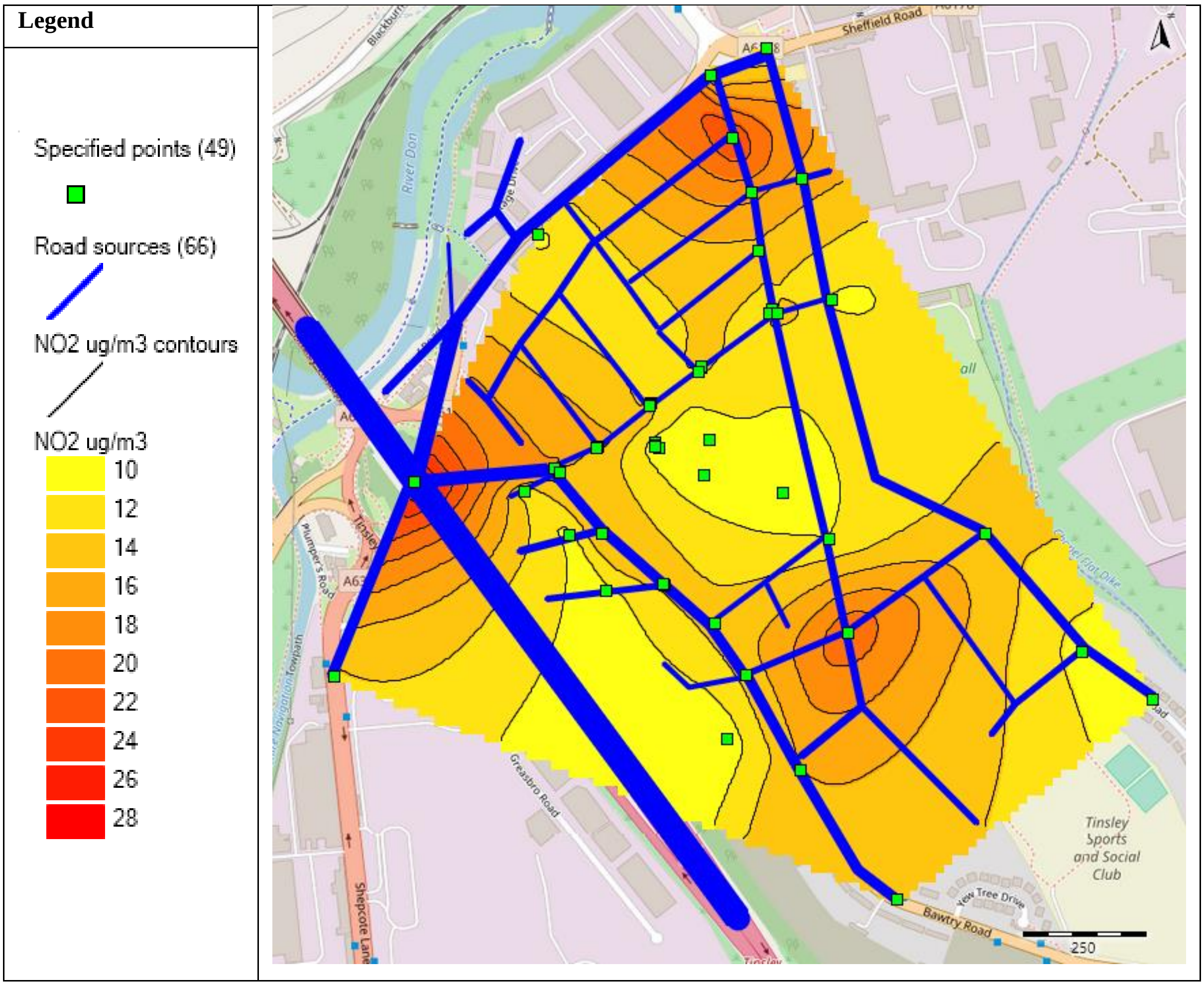

*Figure 63 Contour map showing Sheffield Tinsley site modelled 2019 baseline $NO_2$ ($\mu g/m^3$) concentrations.*

### 6.5.3 Overview of Intervention Reductions

A percentage reduction was calculated based on the baseline school receptor value and its new value following the intervention model run. Table 31 shows modelled $NO_2$ percentage reductions at each selected school due to the active travel, anti-idling, and rideshare interventions. The active travel intervention was most successful at Cabot Primary School, Southfields Primary School, and Parson St School. All three sites are characterised by heavy traffic and congestion, with tightly knit roadways and nearby major road networks.

*Table 31 Modelled percentage reductions of $NO_2$ at selected schools due to active travel, anti-idling, & rideshare interventions.*

| **School Sites** | **Active Travel (% reduction $NO_2$)** | **Anti-Idling (% reduction $NO_2$)** | **Rideshare (% reduction $NO_2$)** |
|---|---|---|---|
| Cabot Primary School, Bristol St Paul’s | 4.16 | 3.14 | 3.27 |
| Parson St School, Bristol Bedminster | 12.41 | 5.51 | 11.16 |
| Southfields Primary School, Coventry Binley | 3.15 | 1.74 | 2.91 |
| St Ebbe’s Primary School, Oxford St Ebbe’s | 1.31 | 1.87 | 1.77 |
| Tinsley Meadows Primary School, Sheffield Tinsley | 2.34 | 2.40 | 2.47 |

All interventions had a similar effect at St Ebbe’s Primary School, Oxford St Ebbe’s and Tinsley Meadows Primary School, Sheffield Tinsley. Both sites have a similarly sparse urban population and limited roads surrounding the schools. Contrastingly, far greater reductions were found at the heavy-traffic site of Parson St School, Bristol Bedminster, although anti-idling had a comparatively lower effect (5.51% reduction) when compared to active travel promotion (12.41%) and rideshare (11.16%).

A similar but less pronounced pattern was observable at Southfields Primary School, Coventry Binley, which also showed that active travel promotion (3.15%) and rideshare (2.91%) were comparatively more effective than anti-idling (1.74%) (Figure 64).

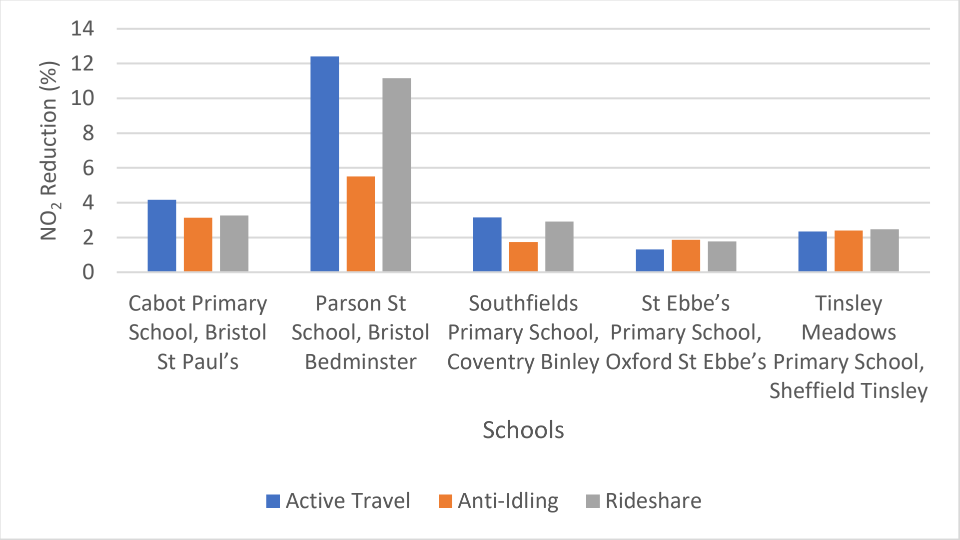

*Figure 64 Modelled percentage reductions of $NO_2$ at selected schools due to active travel, anti-idling, & rideshare interventions.*

Table 32 shows modelled $NO_2$ percentage reductions at schools following the introduction of LEZs at several distances. The introduction of LEZs was more effective with greater applied distance, although this was less pronounced at St Ebbe's Primary School, Oxford.

*Table 32 Modelled percentage reductions of $NO_2$ at schools due to Low Emission Zone implementation at 200m, 300m, 400m, & 500m.*

| **School Sites** | **200m** | **300m** | **400m** | **500m** |
|---|---|---|---|---|
| Cabot Primary School, Bristol St Paul's | 3.81 | 4.04 | 4.18 | 4.27 |
| Parson St School, Bristol Parson St | 11.09 | 11.54 | 12.06 | 12.16 |
| Southfields Primary School, Coventry | 1.91 | 2.22 | 2.48 | 2.56 |
| St Ebbe's Primary School, Oxford | 2.49 | 2.78 | 2.82 | 2.85 |
| Tinsley Meadows Primary School, Sheffield | 2.58 | 3.18 | 3.44 | 3.55 |

At all sites, whilst $NO_2$ levels continued to reduce, the relative degree of change in terms of $NO_2$ percentage reduction tended to decline as the LEZ distance increased, although the percentage reduction itself continued to increase (Figure 65).

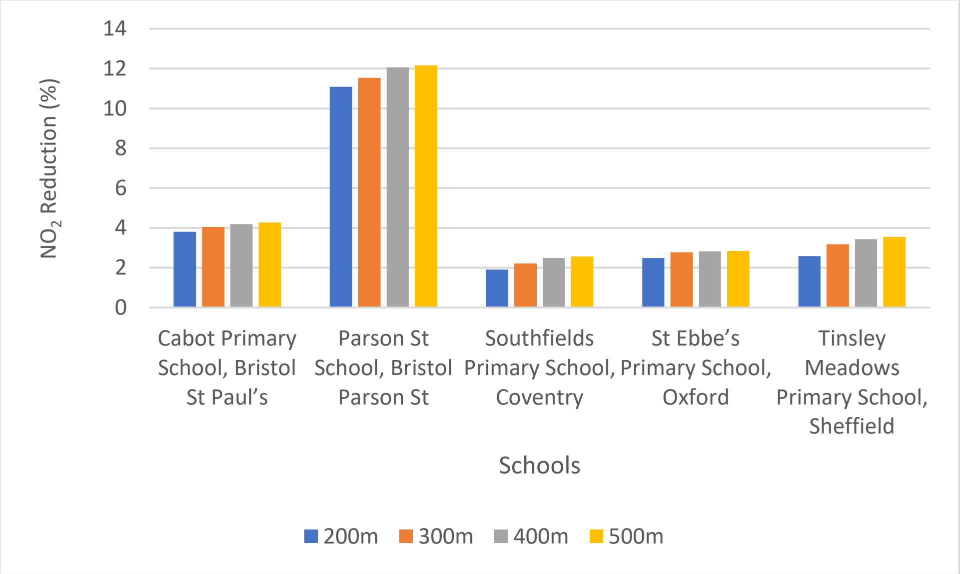

*Figure 65 Modelled percentage reductions of $NO_2$ at schools due to Low Emission Zone implementation at 200m, 300m, 400m & 500m.*

The mean $NO_2$ ($\mu g/m^3$) values of all receptors (including schools) combined at each site were produced to discern the overall percentage reductions for the interventions (Table 33).

*Table 33 Modelled percentage reduction of $NO_2$ ($\mu g/m^3$) at each site (based on mean of all site receptors) due to active travel, anti-idling & rideshare interventions.*

| Site | Active Travel | Anti-Idling | Rideshare |
|---|---|---|---|
| Bristol St Paul's | 4.81 | 3.25 | 4.90 |
| Bristol Bedminster | 9.57 | 3.73 | 7.65 |
| Coventry Binley | 8.17 | 3.04 | 7.10 |
| Oxford St Ebbe's | 1.70 | 1.46 | 2.42 |
| Sheffield Tinsley | 5.35 | 6.03 | 5.71 |

Sheffield Tinsley was the only site in which anti-idling was more effective than rideshare and active travel (Figure 66). At Bristol St Paul’s, Bristol Bedminster, and Coventry Binley, active travel was the most effective intervention, followed by rideshare. At the Oxford St Ebbe’s site, rideshare was more effective than active travel and anti-idling.

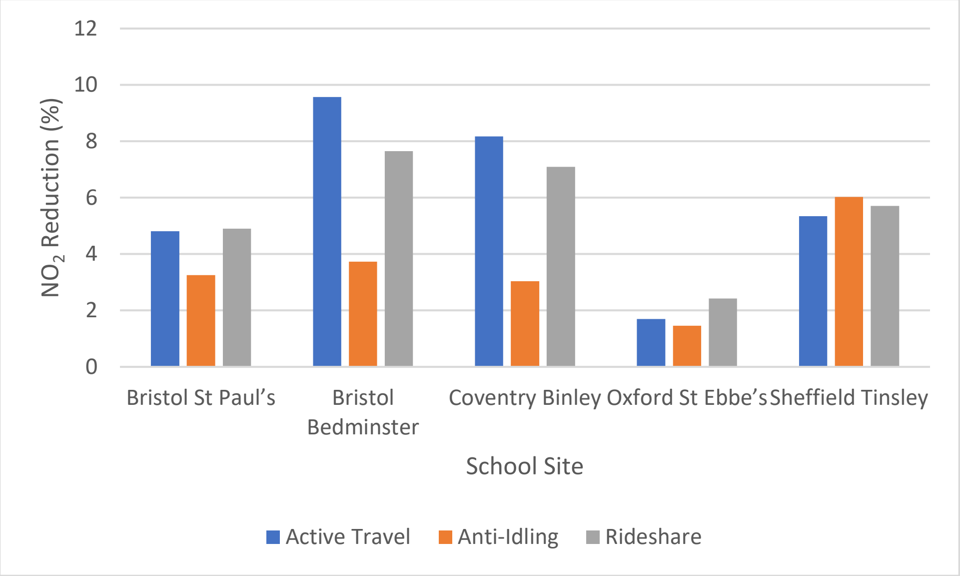

*Figure 66 Modelled percentage reduction of $NO_2$ ($\mu g/m^3$) at each site (based on mean of all site receptors) due to active travel, anti-idling, & rideshare interventions.*

Table 34 shows the percentage reductions of the means of receptors at each site due to the implementation of the LEZ.

*Table 34 Modelled percentage reduction of $NO_2$ ($\mu g/m^3$) at each site (based on mean of all site receptors) due to Low Emission Zone implementation at 200m, 300m, 400m & 500m.*

| **Site** | **200m** | **300m** | **400m** | **500m** |
|---|---|---|---|---|
| Bristol St Paul’s | 3.35 | 4.46 | 4.82 | 6.12 |
| Bristol Bedminster | 6.50 | 7.96 | 9.89 | 10.83 |
| Coventry Binley | 3.45 | 5.32 | 8.23 | 8.86 |
| Oxford St Ebbe’s | 1.76 | 2.70 | 3.63 | 3.78 |
| Sheffield Tinsley | 6.30 | 6.98 | 7.33 | 7.60 |

For all sites, increasing the distance of the LEZ produced a greater percentage reduction of concentrations (Figure 67). However, the degree of reduction with increased distance is inconsistent across sites.

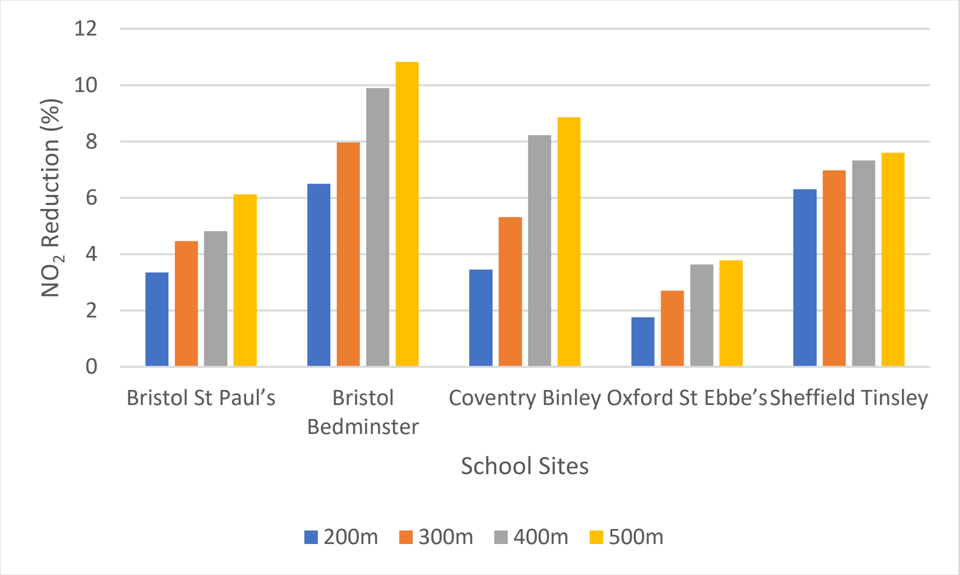

*Figure 67 Modelled percentage reduction of NO₂ (µg/m³) at each site (based on mean of all site receptors) due to Low Emission Zone implementation at 200m, 300m, 400m & 500m.*

### 6.5.4 Intervention Reductions at Travel Routes

Means of the concentrations of all travel routes within each site were produced and the percentage reductions against the baseline mean were calculated. Table 35 shows the modelled total mean percentage $NO_2$ reductions of all modelled travel routes to each of the schools. The shift to improved travel routes was the most effective intervention for mean concentration reduction on travel routes at Bristol St Paul's (21.90%), Bristol Bedminster (18.67%), and Oxford St Ebbe's 10.36%). At Sheffield Tinsley rideshare was also the most effective (12.02%) and was marginally more effective than improved travel routes at Coventry Binley (19.35 and 18.96%, respectively.

*Table 35 Modelled mean percentage reductions of $NO_2$ ($\mu g/m^3$) at travel routes due to active travel, anti-idling, rideshare measures & improved travel routes.*

| **Travel Routes** | **Active Travel** | **Anti-Idling** | **Rideshare** | **Improved Travel Routes** |
|---|---|---|---|---|
| Bristol St Paul's | 16.26 | 11.59 | 16.82 | 21.90 |
| Bristol Bedminster | 16.90 | 7.46 | 15.15 | 18.67 |
| Coventry Binley | 15.33 | 5.97 | 19.35 | 18.96 |
| Oxford St Ebbe's | 5.62 | 6.06 | 8.18 | 10.36 |
| Sheffield Tinsley | 10.73 | 10.26 | 12.02 | 10.21 |

Observable reduction patterns largely mirrored the interventions' effectiveness at schools (Figure 68), with anti-idling performing poorly compared to other interventions at Bristol St Paul's, Bristol Bedminster, and Coventry Binley. Greater reduction proportions were achieved at these sites with heavier traffic.

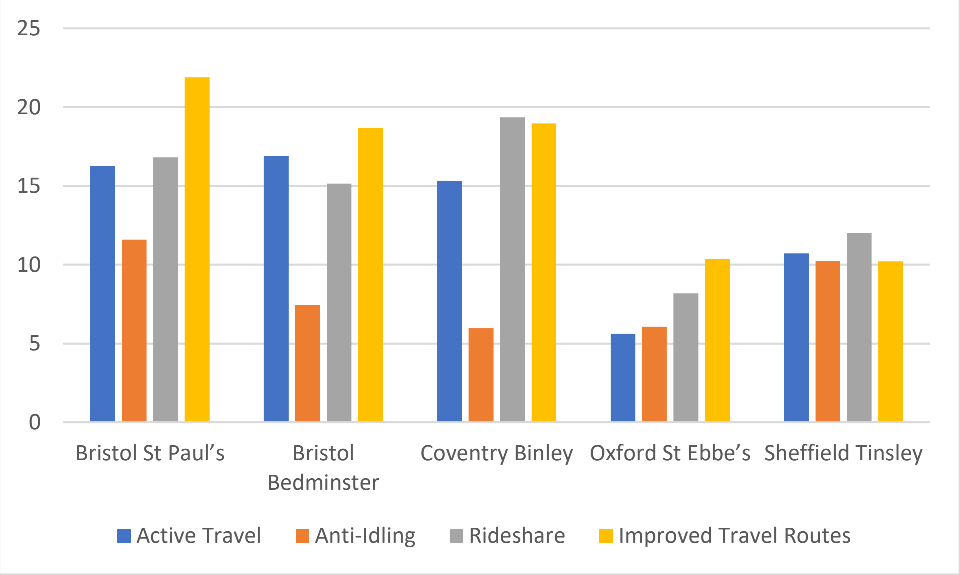

*Figure 68 Modelled mean percentage reductions of $NO_2$ at travel routes due to active travel, anti-idling, rideshare measures, & improved travel routes.*

The introduction of a 500m LEZ was the most effective distance for concentration reduction at all sites (Table 36). The degree of effectiveness of increasing the LEZ radius declined at Coventry Binley and Oxford St Ebbe’s.

*Table 36 Modelled mean percentage reductions of $NO_2$ (µg/m$^3$) at travel routes due to Low Emission Zone implementation at 200m, 300m, 400m, & 500m.*

| **Travel Routes** | **LEZ (200m)** | **LEZ (300m)** | **LEZ (400m)** | **LEZ (500m)** |
|---|---|---|---|---|
| Bristol St Paul’s | 14.84 | 17.44 | 17.63 | 18.91 |
| Bristol Bedminster | 12.65 | 14.96 | 17.38 | 20.25 |
| Coventry Binley | 7.14 | 8.97 | 11.52 | 11.85 |
| Oxford St Ebbe’s | 7.05 | 10.07 | 11.33 | 12.05 |
| Sheffield Tinsley | 11.28 | 13.61 | 14.75 | 16.17 |

Compared to active travel, anti-idling, rideshare and improved travel routes, the comparative effectiveness of LEZ differs among sites (Figure 69). Improved travel routes were more effective than all other interventions at Bristol St Paul’s and second to LEZ (500 m) at Bristol Bedminster and rideshare at Coventry Binley. Active travel was also more effective than all LEZ radii at Coventry Binley.

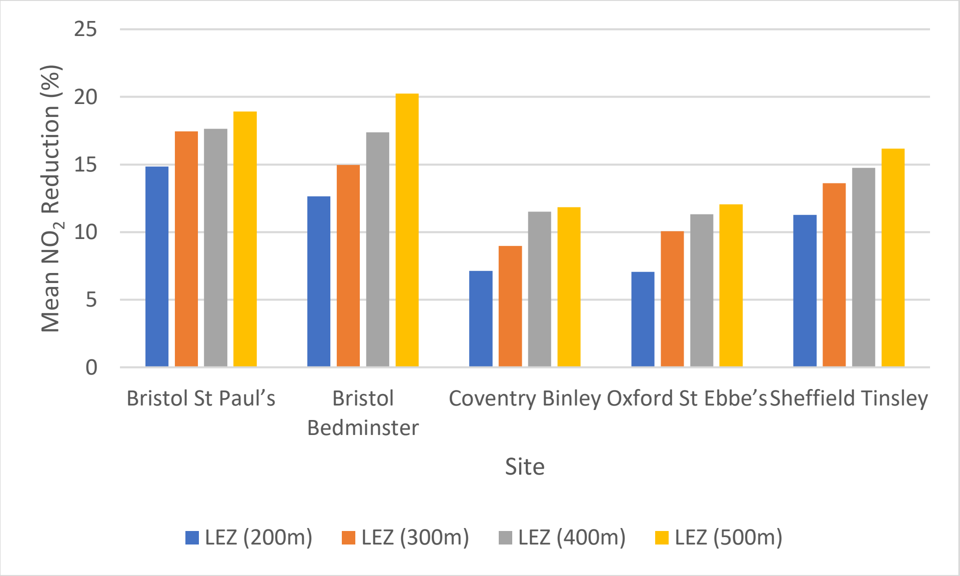

*Figure 69 Modelled mean percentage reductions of $NO_2$ at travel routes due to active travel, anti-idling, rideshare, improved travel routes, and Low Emission Zone implementation at 200m, 300m, 400m, & 500m.*

### 6.5.5 Overall Effectiveness of Interventions at All Sites

#### 6.5.5.1 Overview

To consider the overall performance of interventions, mean reductions were produced by combining modelled $NO_2$ reductions for schools, all site receptors, and combined travel routes at all sites as a consequence of the interventions. Percentage reductions compared to the baseline were then calculated for each intervention (Table 37).

*Table 37 Comparison of modelled $NO_2$ ($\mu g/m^3$) concentration reductions (%) for all interventions.*

| | **Active Travel** | **Anti-Idling** | **Rideshare** | **Improved Routes** | **LEZ (Low Emission Zones)** | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | **200m** | **300m** | **400m** | **500m** |
| Schools | 4.11 | 2.57 | 4.36 | - | 3.46 | 4.04 | 4.56 | 5.12 |
| All Receptors | 8.15 | 4.54 | 5.56 | - | 6.44 | 7.61 | 9.67 | 7.44 |
| Travel Routes | 12.97 | 8.27 | 13.16 | 16.02 | 10.59 | 13.01 | 14.52 | 15.85 |

For all travel routes, improved travel routes produced the greatest percentage of $NO_2$ reduction, followed by LEZ (500 m) (16.02% and 15.85%, respectively) (Figure 70). When considering all site receptors, the LEZ (400 m) produced the greatest percentage reduction (9.67%), followed by active travel (8.15%). Whilst the LEZ was more effective at 500 metres at all sites (see Table 34), the degree of effectiveness differed from site to site, making the 400-metre iteration the most effective overall when considering all sites. When considering all schools, the proportions of reduction were closer, although LEZ (500 m) was the most effective.

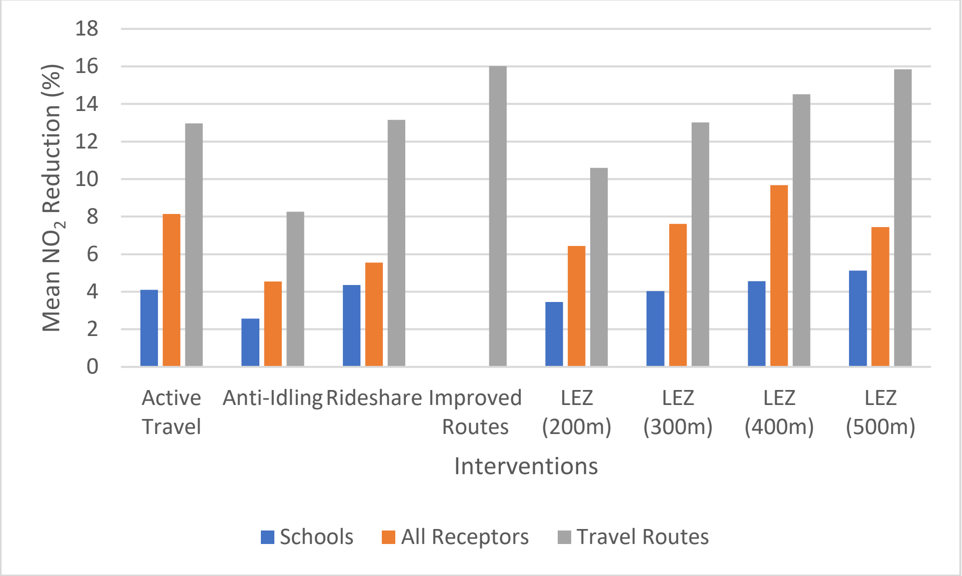

*Figure 70 Comparison of modelled $NO_2$ concentration reductions (%) for all interventions.*

### 6.5.6 Effectiveness of Individual Interventions

The current section describes the effectiveness of each intervention at all sites, considering reductions at schools, all site receptors, and travel routes.

#### 6.5.6.1 Active Travel

The effectiveness of the active travel intervention was assessed against the baseline at each site to determine the difference and percentage reduction achieved for site schools, all site receptors, and the combined mean of each site's travel routes (Table 38).

*Table 38 Effects of active travel measures on modelled $NO_2$ (µg/m$^3$) concentrations at schools, receptors, and travel routes.*

| Site | Receptors | Baseline | Post Intervention | Difference | % Reduction |
|---|---|---|---|---|---|
| Bristol St Paul's | Cabot Primary School | 16.93 | 16.23 | 0.70 | 4.16 |
| | Receptors | 18.35 | 17.43 | 0.93 | 4.81 |
| | All Routes | 26.33 | 22.05 | 4.28 | 16.26 |
| Bristol Bedminster | Parson St School | 19.77 | 17.28 | 2.50 | 12.63 |
| | Receptors | 19.68 | 17.79 | 1.88 | 9.57 |
| | All Routes | 25.35 | 21.07 | 4.29 | 16.90 |
| Coventry Binley | Southfields Primary School | 16.44 | 15.92 | 0.52 | 3.15 |
| | Receptors | 18.54 | 17.03 | 1.51 | 8.17 |
| | All Routes | 22.41 | 18.98 | 3.44 | 15.33 |
| Oxford St Ebbe's | St Ebbe's Primary School | 14.75 | 14.56 | 0.19 | 1.31 |
| | Receptors | 15.13 | 14.87 | 0.26 | 1.70 |
| | All Routes | 17.45 | 16.47 | 0.98 | 5.62 |
| Sheffield Tinsley | Tinsley Meadows Primary School | 10.61 | 10.36 | 0.25 | 2.34 |
| | Receptors | 11.82 | 11.19 | 0.63 | 5.35 |
| | All Routes | 14.79 | 13.21 | 1.59 | 10.73 |

Figure 71 shows that the active travel intervention was most effective at reducing $NO_2$ concentrations on travel routes at all sites. The intervention was least effective at school receptors at all sites apart from Parson Street School, Bristol Bedminster, which is the site with the heaviest traffic.

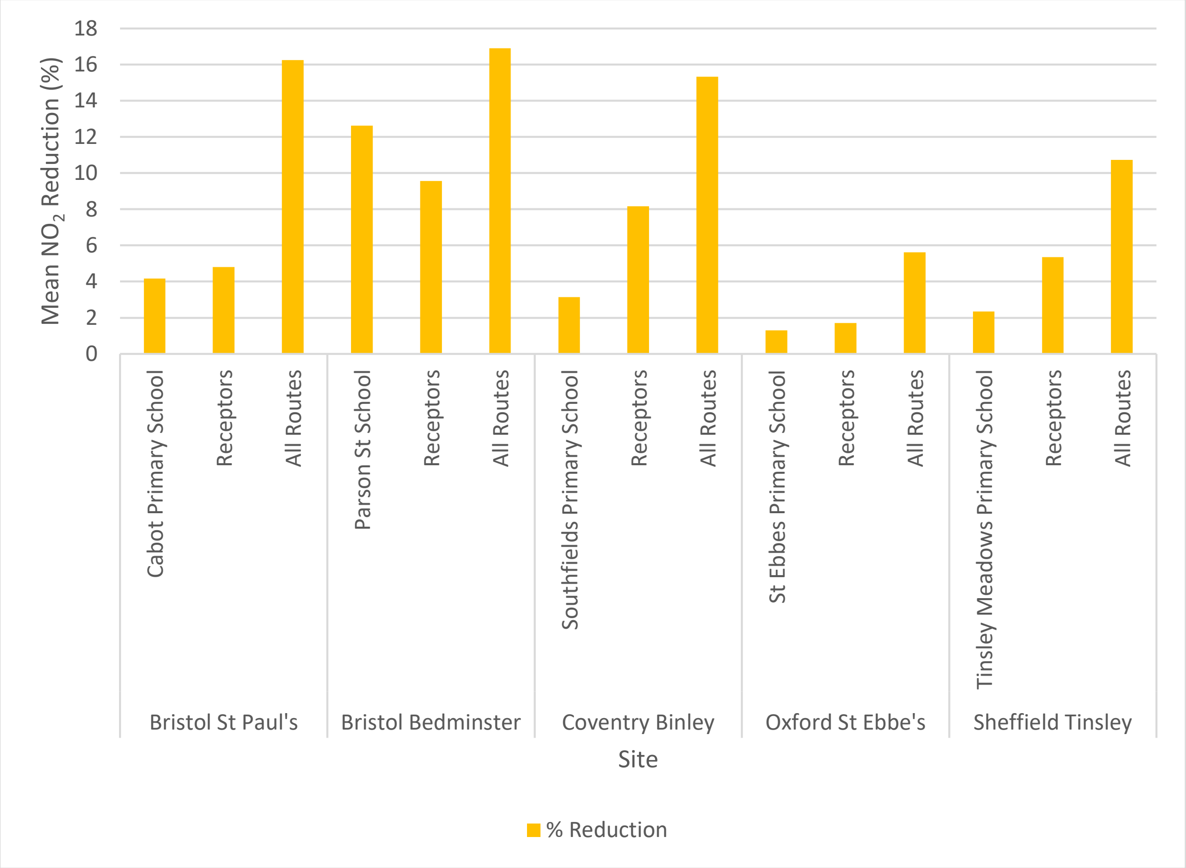

*Figure 71 Effects of active travel measures on mean modelled $NO_2$ (µg/$m^3$) concentrations as a percentage reduction at schools, receptors, and mean travel routes.*

### 6.5.6.2 Contour Maps for Active Travel

Figure 72 depicts a contour map of the Bristol St Paul’s site $NO_2$ concentrations (µg/m$^3$) following the active travel intervention. Compared to the baseline, the highest concentrations are still found in the northeast, adjacent to the A4320/M32 roundabout, the centre of Wilder Street between the B4057 and A4032, the A38 south in Stokes Croft, and the south of the site where the M32 enters the city centre, although all are reduced, particularly in the south of the site, Stokes Croft, and Wilder Street.

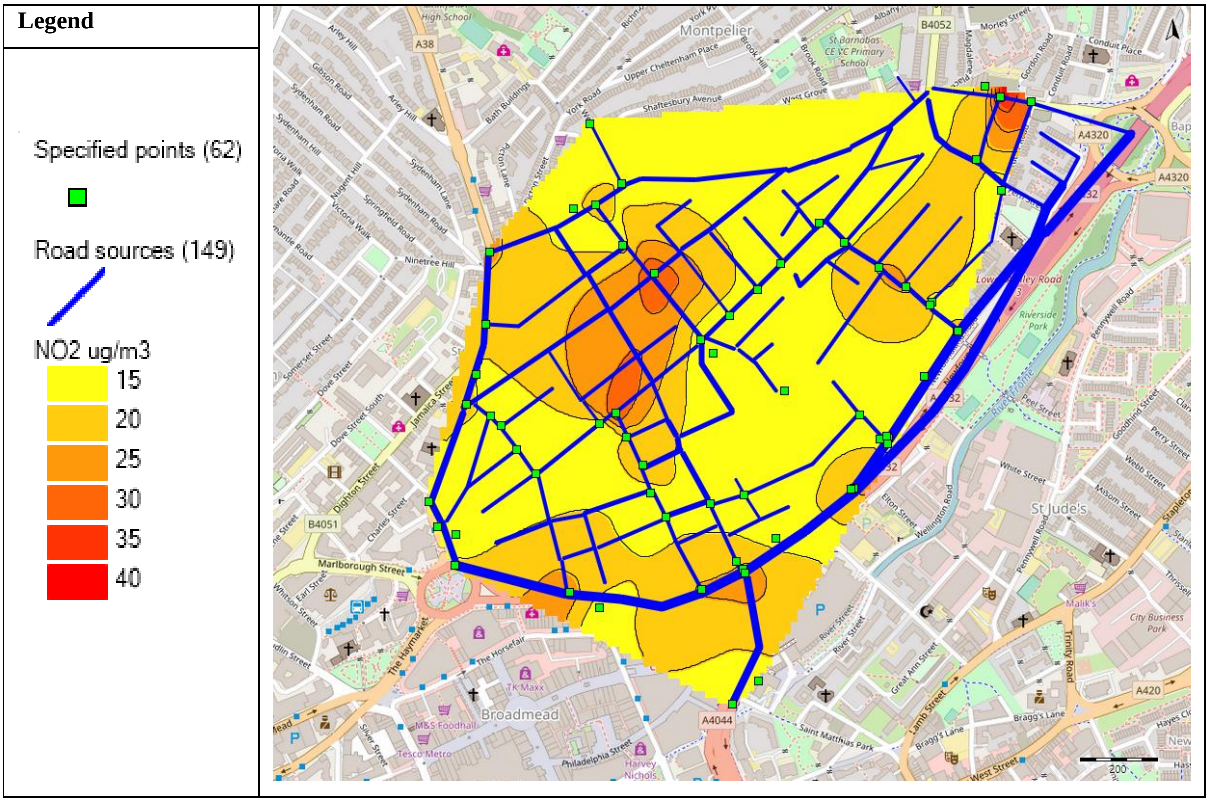

*Figure 72 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following active travel intervention at Bristol St Paul’s site.*

Figure 73 depicts a contour map of Bristol Bedminster site $NO_2$ concentrations (µg/m$^3$) following the active travel intervention. Compared to the baseline, high concentrations to the west of the site persist, although the easterly majority of the site shows reduced concentrations.

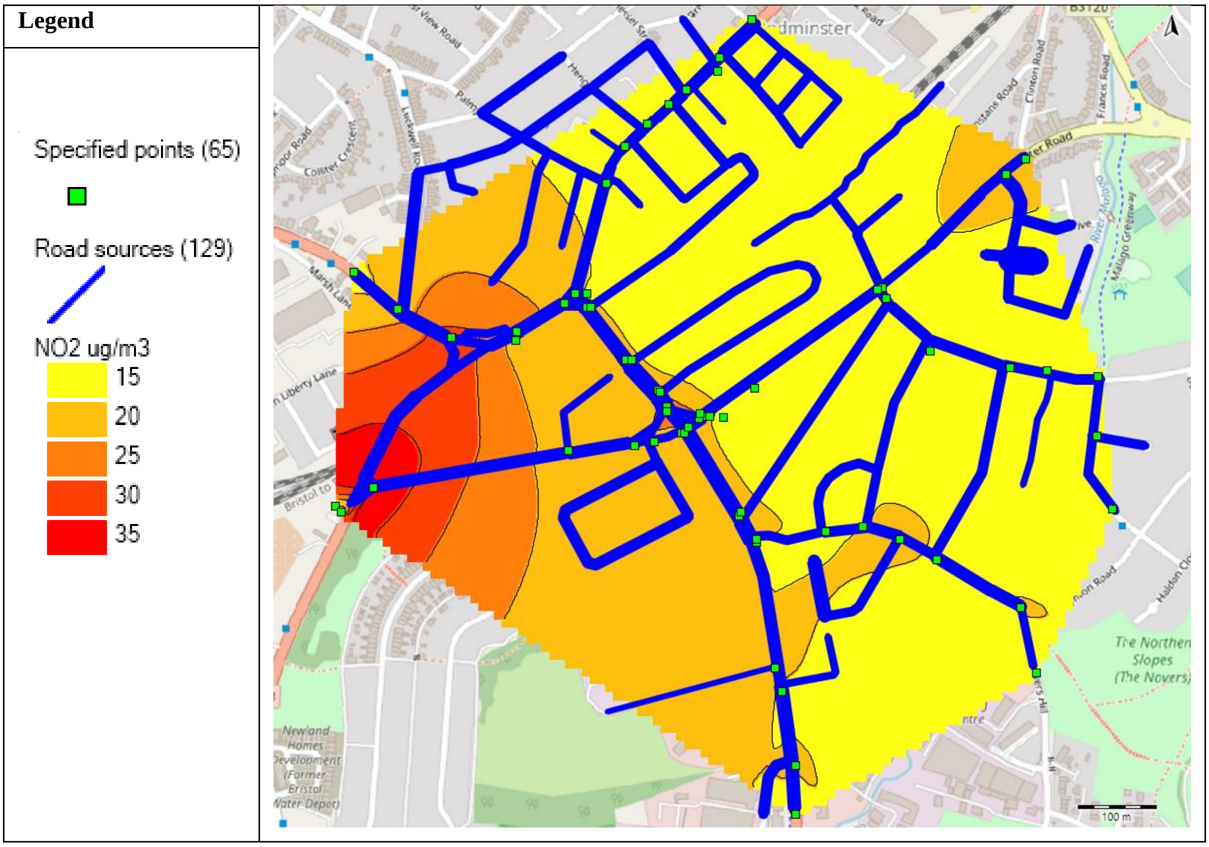

*Figure 73 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following active travel intervention at Bristol Bedminster site.*

Figure 74 depicts a contour map of Coventry Binley $NO_2$ concentrations ($\mu g/m^3$) following the active travel intervention. Compared to the baseline, concentrations are generally lower in the north and south of the site, and higher concentrations remain condensed around the centre of the site between the A4053 and A4600 junction.

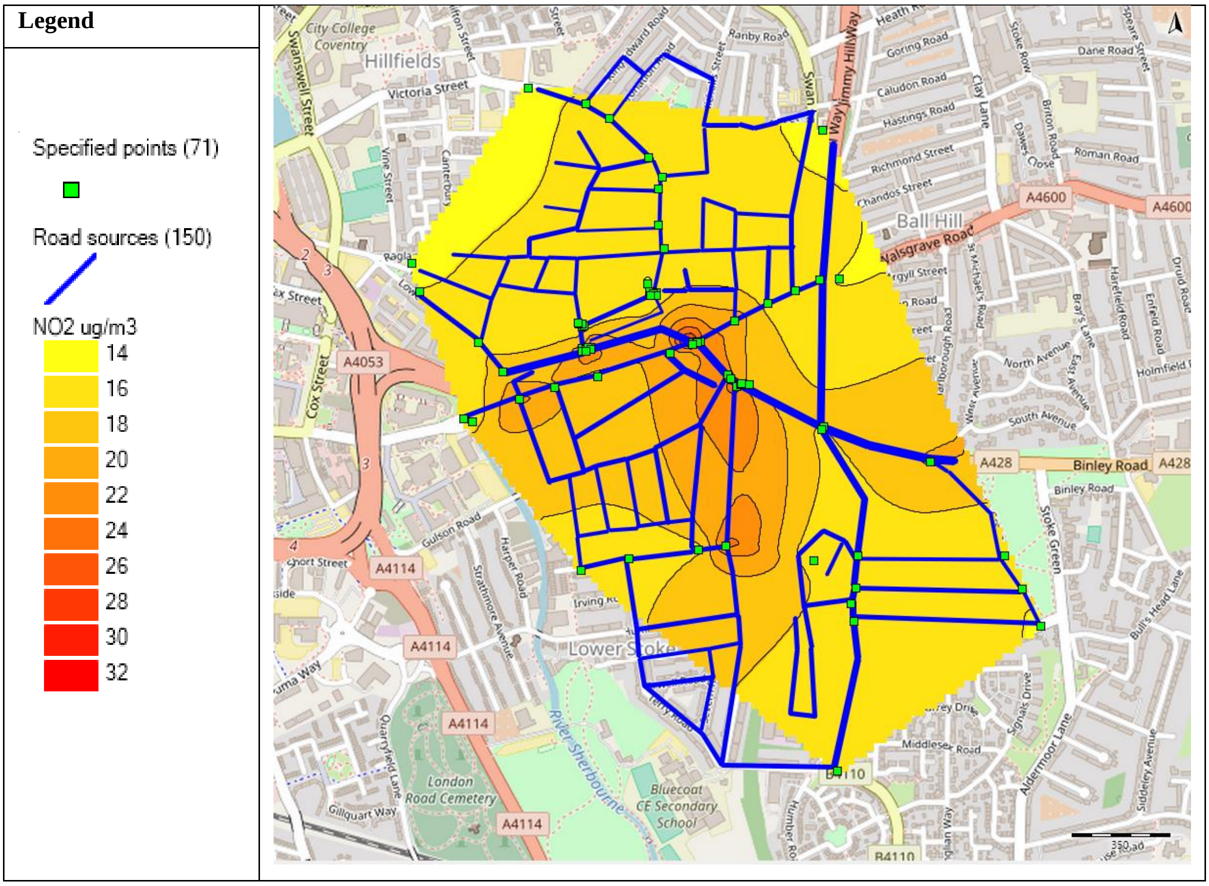

*Figure 74 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following active travel intervention at Coventry Binley site.*

Figure 75 depicts a contour map of Oxford St Ebbe’s $NO_2$ concentrations (µg/m$^3$) following the active travel intervention. Compared to the baseline, concentrations are generally lower across the site, and the roads adjacent to St Ebbe’s Primary School show the greatest reductions.

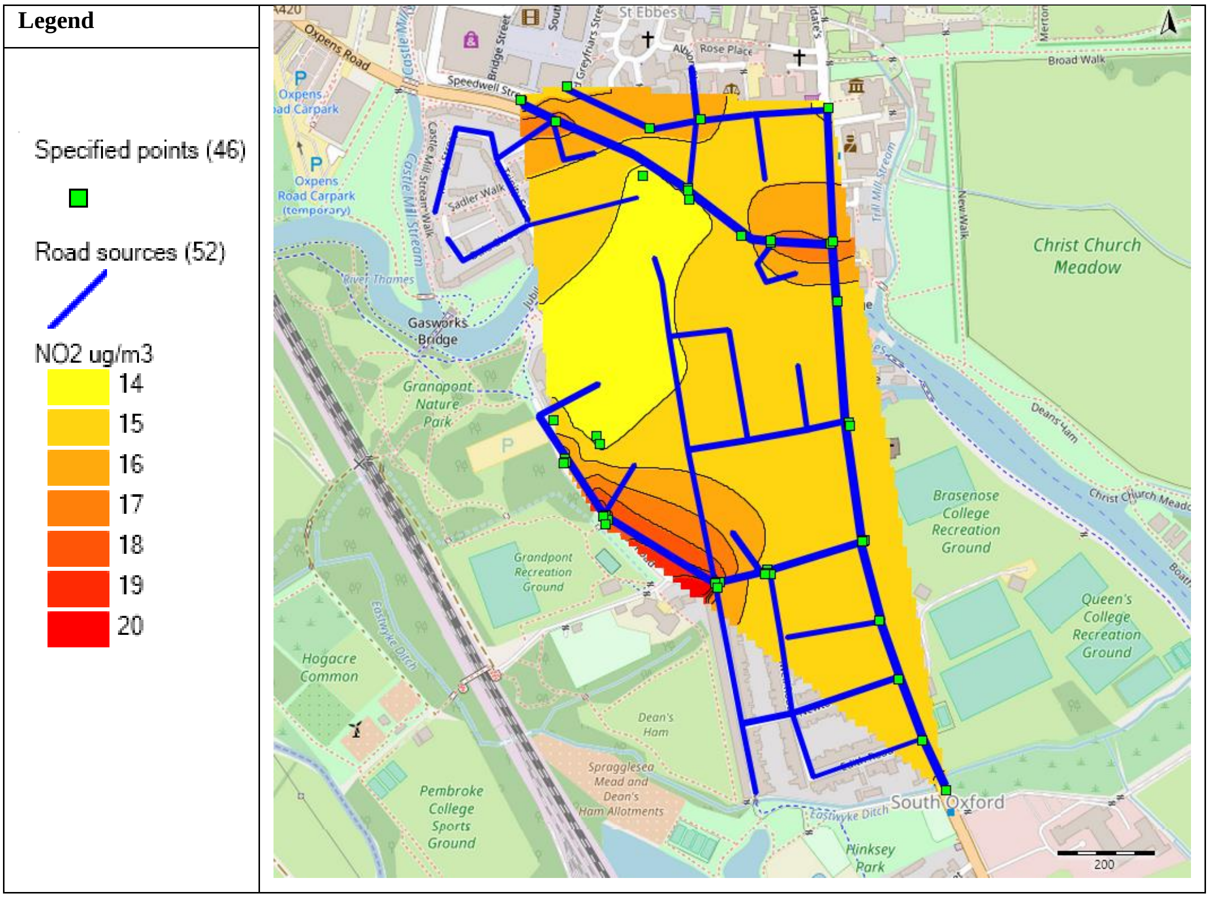

*Figure 75 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following active travel intervention at Oxford St Ebbe’s site.*

Figure 76 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the active travel intervention. Compared to the baseline, high concentrations are reduced but persist in the west of the site, the A6178 junction, and towards the south central commercial/industrial region.

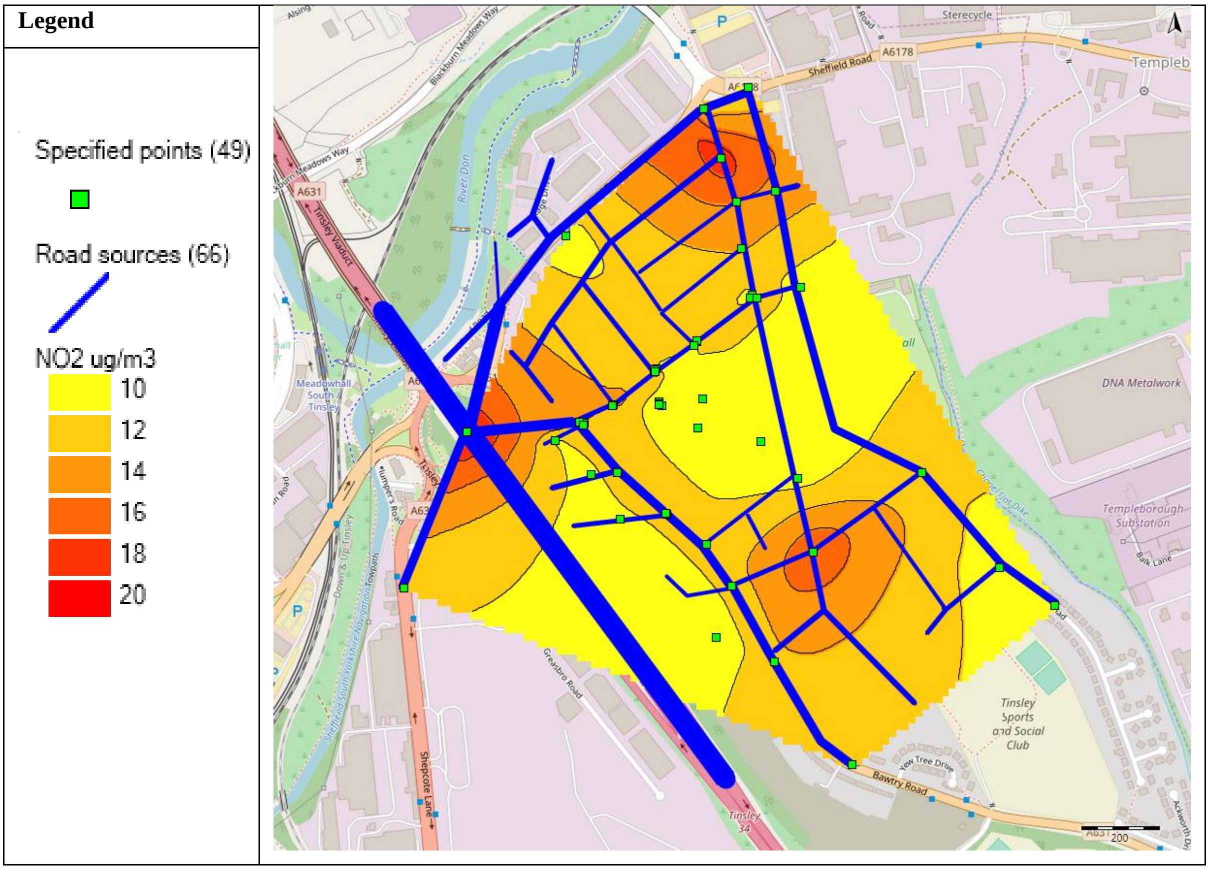

*Figure 76 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following active travel intervention at Sheffield Tinsley site.*

### 6.5.6.3 Anti-Idling

Table 39 details the effects of anti-idling on $NO_2$ ($\mu g/m^3$) concentrations at site schools, all site receptors, and travel route means. Reductions are observable at all sites, although the smallest reductions are found at Oxford St Ebbe's.

*Table 39 Effects of anti-idling measures on modelled $NO_2$ ($\mu g/m^3$) concentrations at schools, receptors, and means of travel routes.*

| Site | Receptors | Baseline | Post Intervention | Difference | % Reduction |
|---|---|---|---|---|---|
| Bristol St Paul's | Cabot Primary School | 16.93 | 16.40 | 0.53 | 3.14 |
| | Site Mean | 18.35 | 17.72 | 0.63 | 3.25 |
| | All Routes | 26.33 | 23.28 | 3.05 | 11.59 |
| Bristol Bedminster | Parson St School | 19.77 | 18.65 | 1.12 | 5.66 |
| | Receptors | 19.68 | 18.94 | 0.73 | 3.73 |
| | All Routes | 25.35 | 23.46 | 1.89 | 7.46 |
| Coventry Binley | Southfields Primary School | 16.44 | 16.15 | 0.29 | 1.74 |
| | Receptors | 18.54 | 17.98 | 0.56 | 3.04 |
| | All Routes | 22.41 | 21.08 | 1.34 | 5.97 |
| Oxford St Ebbe's | St Ebbe's Primary School | 14.75 | 14.47 | 0.28 | 1.87 |
| | Receptors | 15.13 | 14.91 | 0.22 | 1.46 |
| | All Routes | 17.45 | 16.39 | 1.06 | 6.06 |
| Sheffield Tinsley | Tinsley Meadows Primary School | 10.61 | 10.36 | 0.25 | 2.40 |
| | Receptors | 11.82 | 11.11 | 0.71 | 6.03 |
| | All Routes | 14.79 | 13.28 | 1.52 | 10.26 |

Figure 77 depicts the effects of the anti-idling intervention and shows the most effective concentration reductions for the travel routes of each site. Parson Street School, Bristol Bedminster, shows the greatest reduction among schools (5.66%). The Sheffield Tinsley site shows the greatest overall reduction (mean reduction of all receptors, 6.03%).

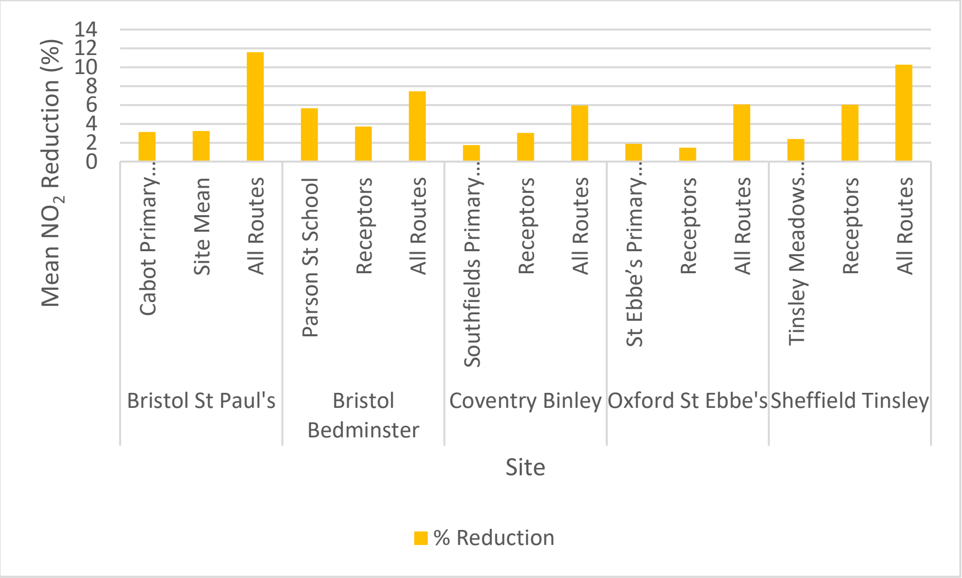

*Figure 77 Effects of anti-idling measures on modelled $NO_2$ (µg/m$^3$) concentrations as percentage reduction at principal schools.*

### 6.5.6.4 Contour Maps for Anti-Idling

Figure 78 depicts a contour map of Bristol St Paul’s $NO_2$ concentrations (µg/m$^3$) following the anti-idling intervention. Overall concentrations are reduced throughout the site compared to the baseline, and the originally heavily polluted regions are lessened. Higher concentrations persist in the northwest by the A4320/M32 roundabout and the west of the site at Stokes Croft near the Jamaica Street and Cheltenham Road junction.

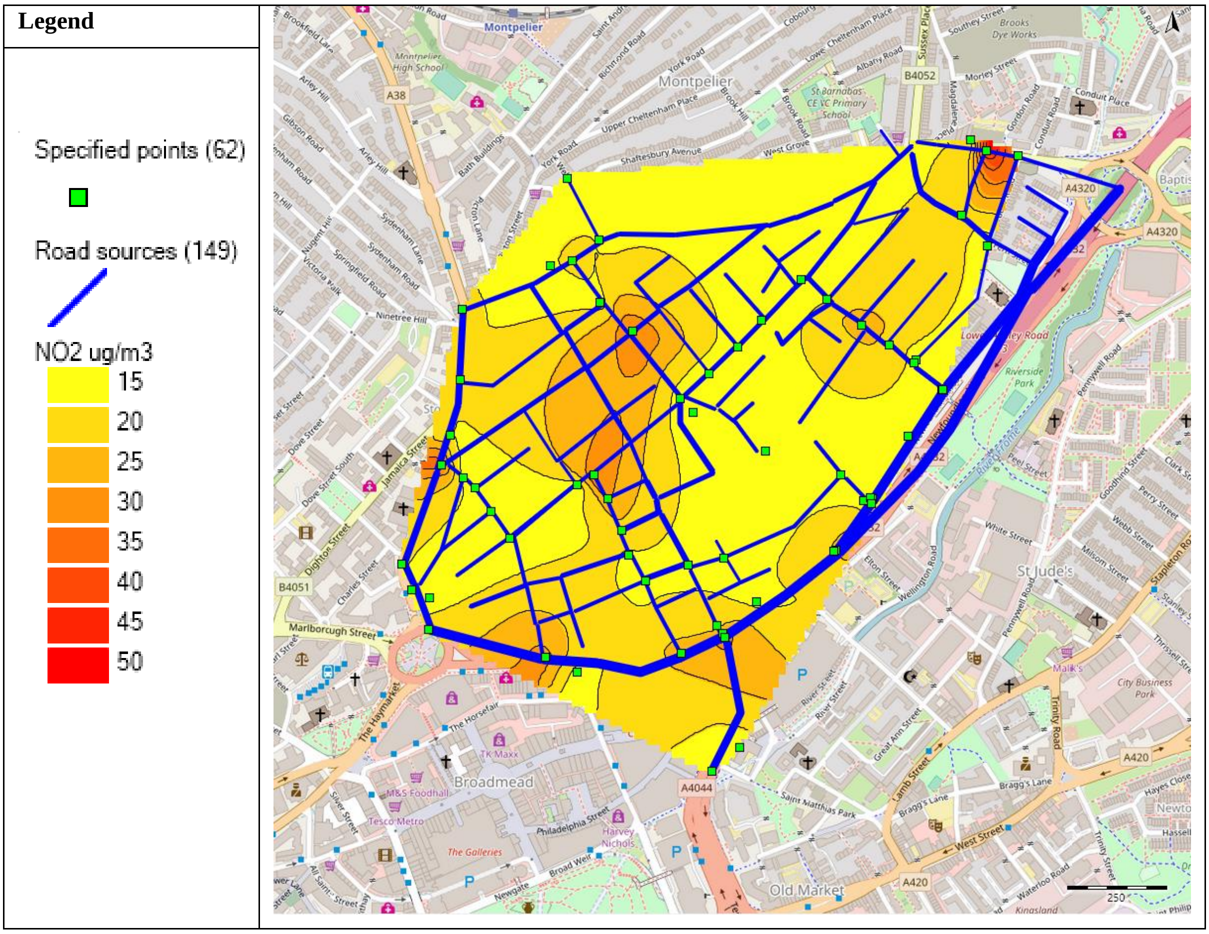

*Figure 78 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following anti-idling intervention at Bristol St Paul’s site.*

Figure 79 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/$m^3$) following the anti-idling intervention. Compared to the baseline, site concentrations emanating from the north through the centre of the site to the west are reduced. Higher concentrations persist in the west at the A38/A3029 intersection.

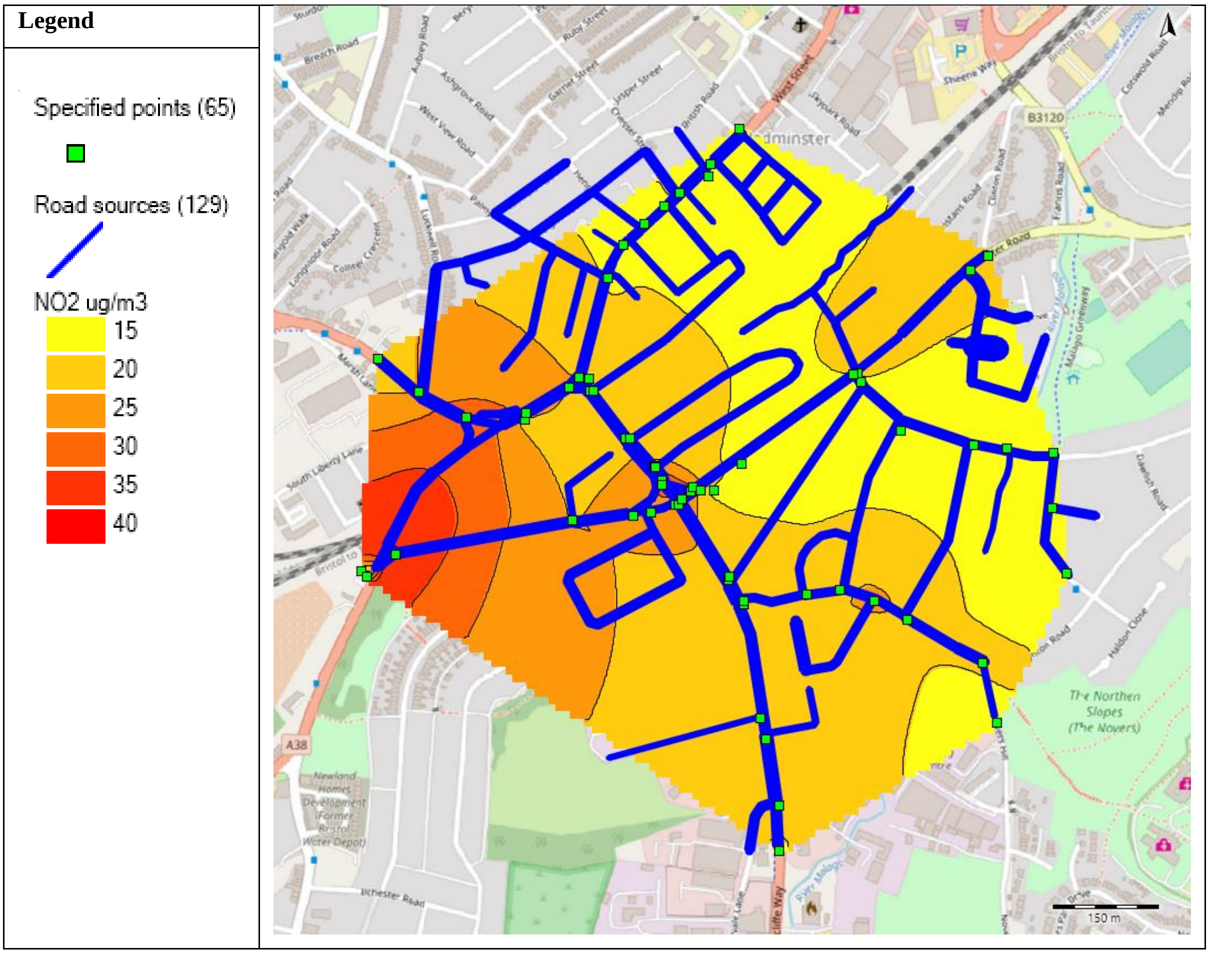

*Figure 79 Contour map showing modelled $NO_2$ (µg/$m^3$) concentrations following anti-idling intervention at Bristol Bedminster site.*

Figure 80 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/m$^3$) following the anti-idling intervention. Compared to the baseline, marginal reductions are visible from the East to the centre of the site at the A4600/A428 junction.

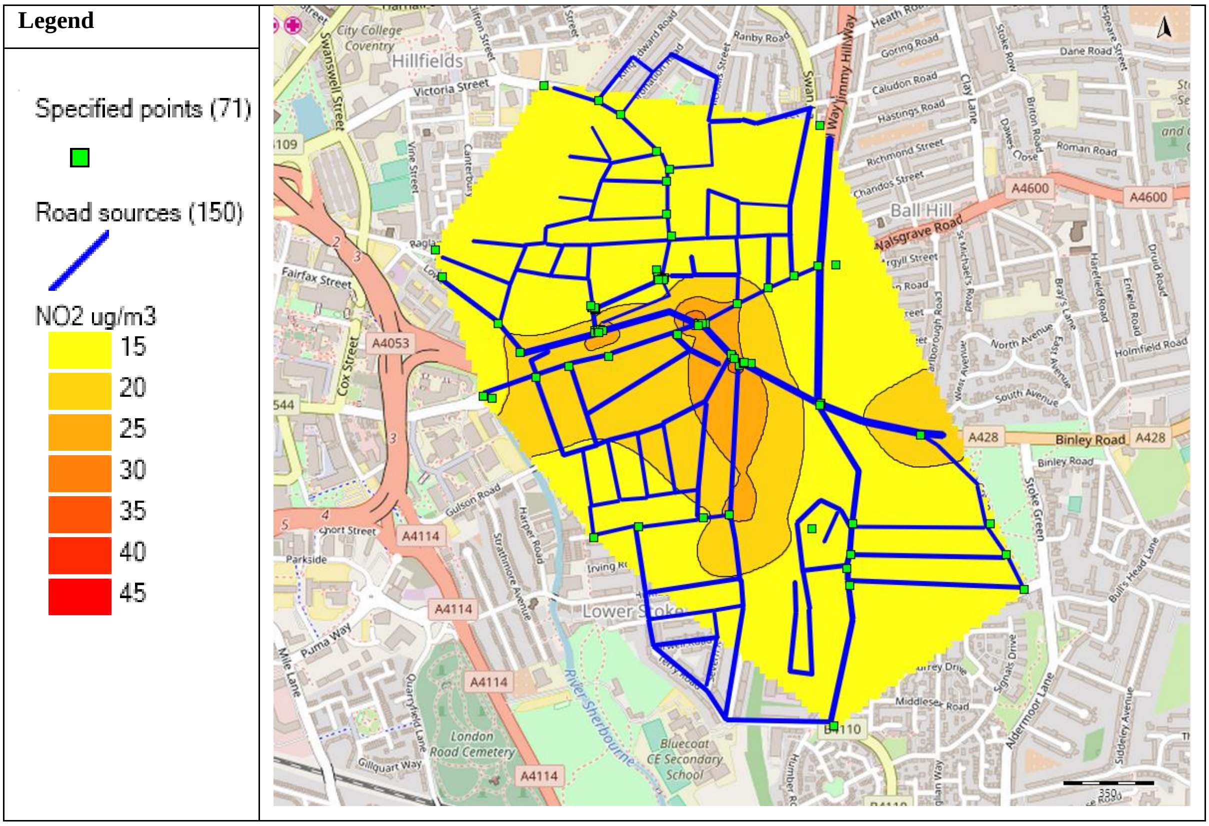

*Figure 80 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following anti-idling intervention at Coventry Binley site.*

Figure 81 depicts a contour map of Oxford St Ebbe’s $NO_2$ concentrations (µg/$m^3$) following the anti-idling intervention. Compared to the baseline, graduated concentration levels are visible across the centre of the site, emphasising peak concentrations to the northwest and northeast of the site following the A420 south, and surrounding St Ebbe’s Primary School in the southwest.

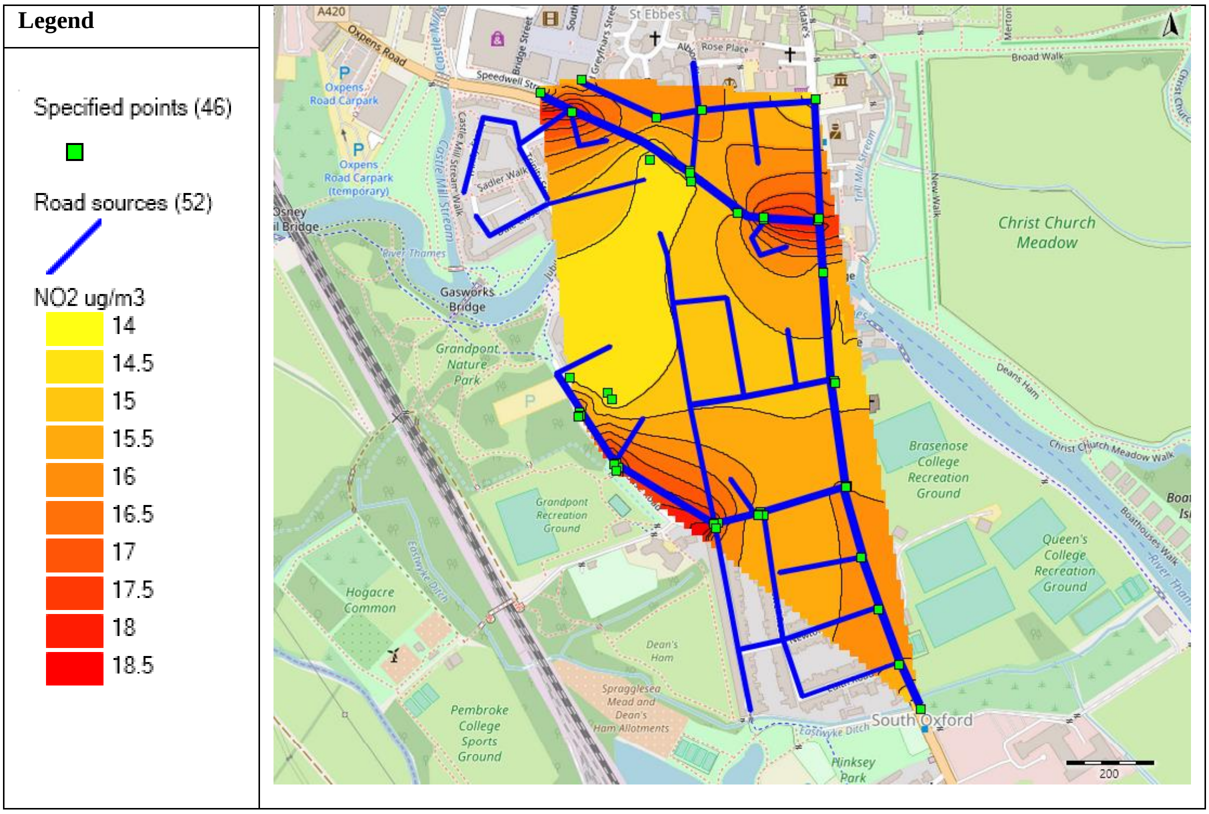

*Figure 81 Contour map showing modelled $NO_2$ (µg/$m^3$) concentrations following anti-idling intervention at Oxford St Ebbe’s site.*

Figure 82 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the anti-idling intervention. Compared to the baseline, concentrations in the centre of the site have reduced to low levels, emphasising the remaining peaks at the north A6178 junction, the M1 roundabout, and the south central commercial/industrial area.

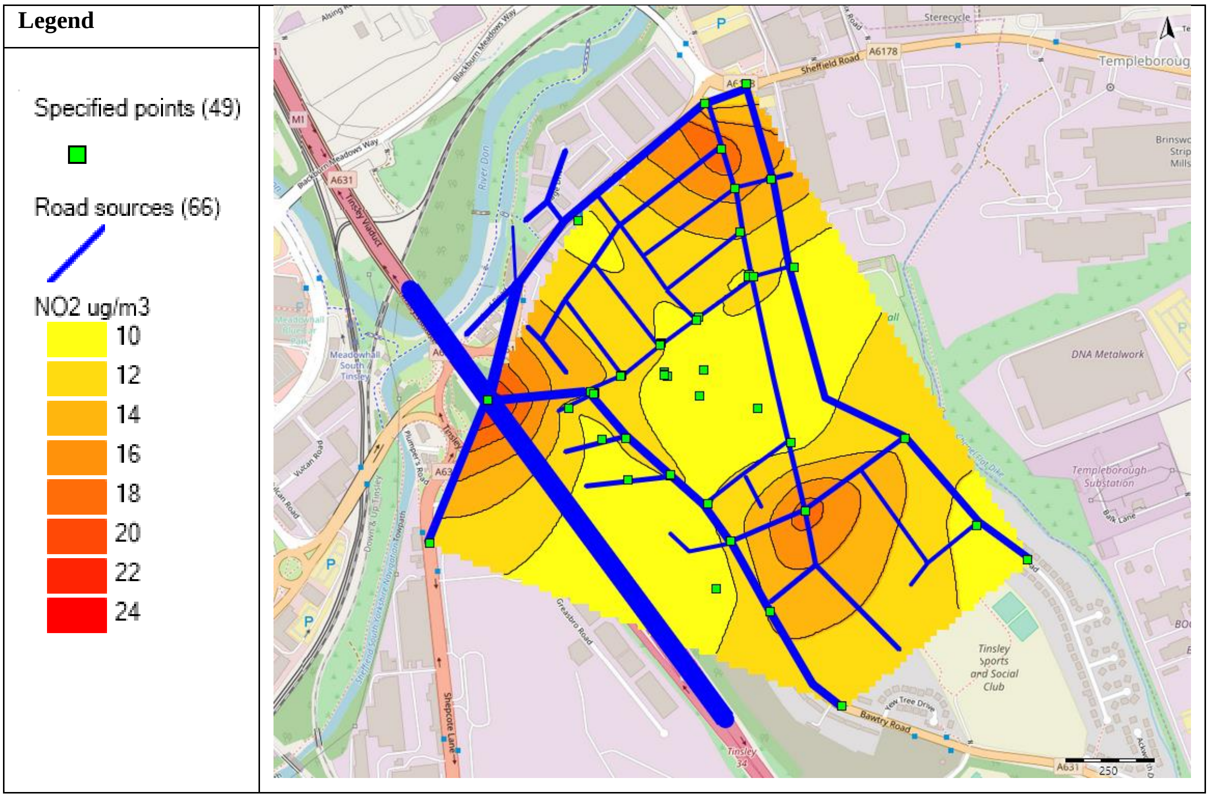

*Figure 82 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following anti-idling intervention at Sheffield Tinsley site.*

### 6.5.6.5 Rideshare

Table 40 shows the effects of the rideshare intervention across all sites. The greatest proportional reductions are on travel routes at all sites, with the greatest reductions at the sites with heavier traffic, Bristol St Paul's and Bristol Bedminster (16.82 and 15.15%, respectively), and comparatively smaller reductions at the more sparsely populated Oxford St Ebbe's site (8.18%).

*Table 40 Effects of rideshare intervention on modelled $NO_2$ ($\mu g/m^3$) concentrations at selected schools, sites, and means of site travel routes.*

| Sites | Receptors | Baseline | Post Intervention | Difference | % Reduction |
|---|---|---|---|---|---|
| Bristol St Paul's | Cabot Primary School | 16.93 | 16.38 | 0.55 | 3.27 |
| | Site Mean | 18.35 | 17.41 | 0.94 | 4.90 |
| | All Routes | 26.33 | 21.90 | 4.43 | 16.82 |
| Bristol Bedminster | Parson St School | 19.77 | 17.53 | 2.25 | 11.36 |
| | Receptors | 19.68 | 18.17 | 1.51 | 7.65 |
| | All Routes | 25.35 | 21.51 | 3.84 | 15.15 |
| Coventry Binley | Southfields Primary School | 16.44 | 15.96 | 0.48 | 2.91 |
| | Receptors | 18.54 | 17.23 | 1.32 | 7.10 |
| | All Routes | 22.41 | 19.35 | 3.06 | 13.65 |
| Oxford St Ebbe's | St Ebbe's Primary School | 14.75 | 14.49 | 0.26 | 1.77 |
| | Receptors | 15.13 | 14.76 | 0.37 | 2.42 |
| | All Routes | 17.45 | 16.02 | 1.43 | 8.18 |
| Sheffield Tinsley | Tinsley Meadows Primary School | 10.61 | 10.35 | 0.26 | 2.47 |
| | Receptors | 11.82 | 11.14 | 0.67 | 5.71 |
| | All Routes | 14.79 | 13.02 | 1.78 | 12.02 |

Figure 83 depicts the resultant reductions, showing a trend of increasing reductions, starting with the lowest at schools, and followed by all site receptor means, and then mean travel routes at all sites apart from Bristol Bedminster. Parson St School reductions at the Bedminster site are greater than the site receptors mean (11.36 and 7.65%, respectively).

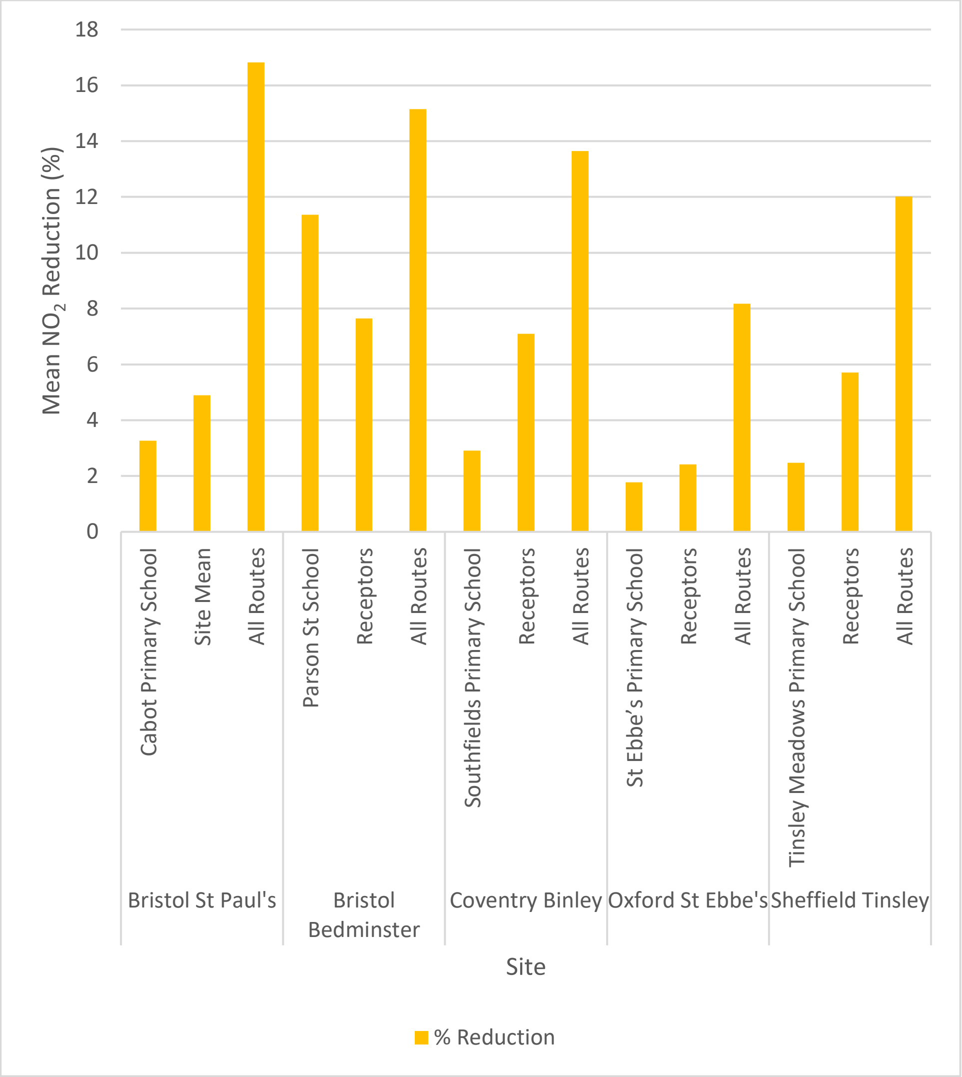

*Figure 83 Effects of rideshare measures on modelled $NO_2$ (µg/m$^3$) concentrations as percentage reductions at principal schools.*

### 6.5.6.6 Contour Maps for Rideshare

Figure 84 depicts a contour map of Bristol St Paul's $NO_2$ concentrations ($\mu g/m^3$) following the rideshare intervention. Compared to the baseline, concentrations are reduced across the site, particularly along the A38 to the west of the site through Stokes Croft. High concentrations persist at Wilder Street between the B4057 and A4032, and the south of the site on Bond Street where the M32 enters the city centre, although these are substantially reduced.

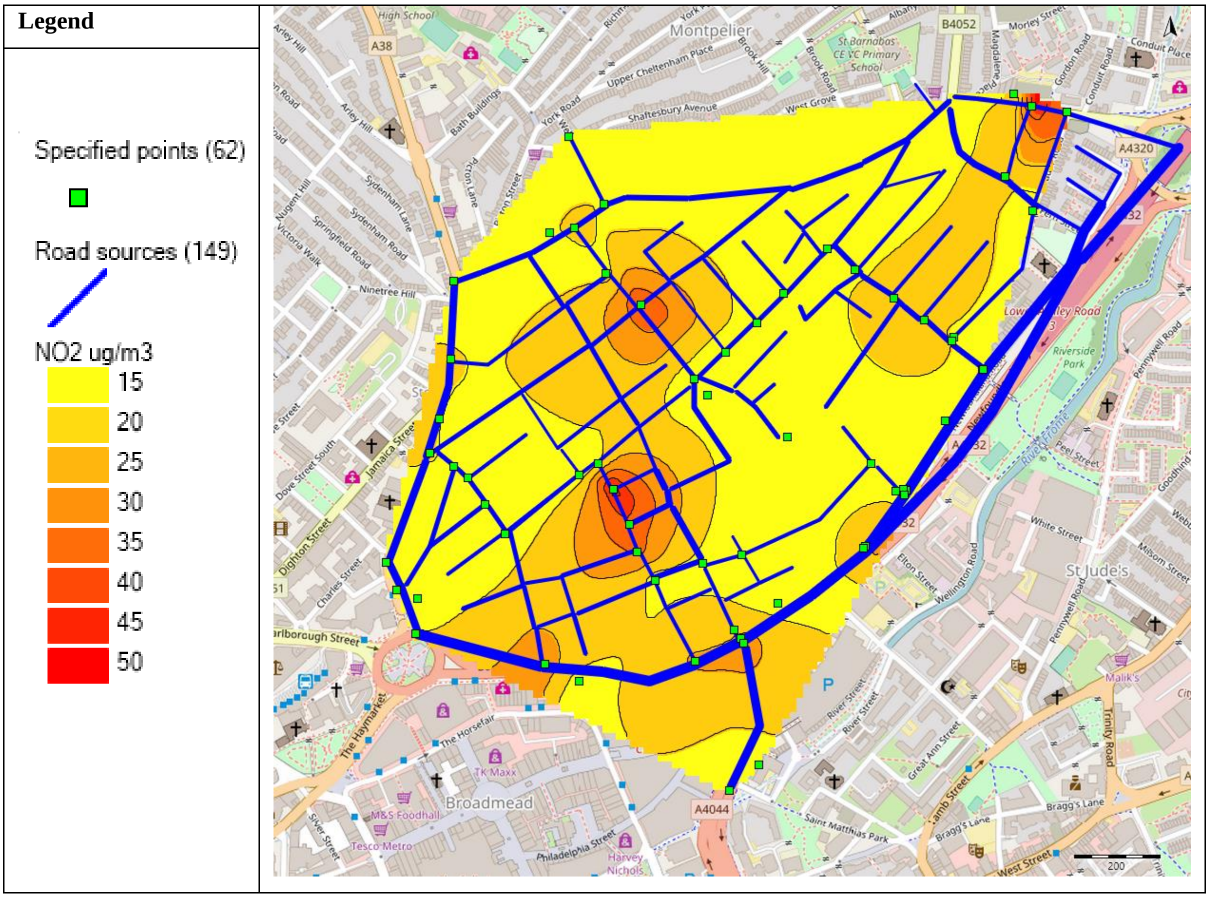

*Figure 84 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following rideshare intervention at Bristol St Paul's site.*

Figure 85 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/$m^3$) following the rideshare intervention. Compared to the baseline, site concentrations are substantially reduced, and the reductions are particularly noticeable south along West Street. The highest concentrations persist in the west of the site, at the A38/A3029 intersection.

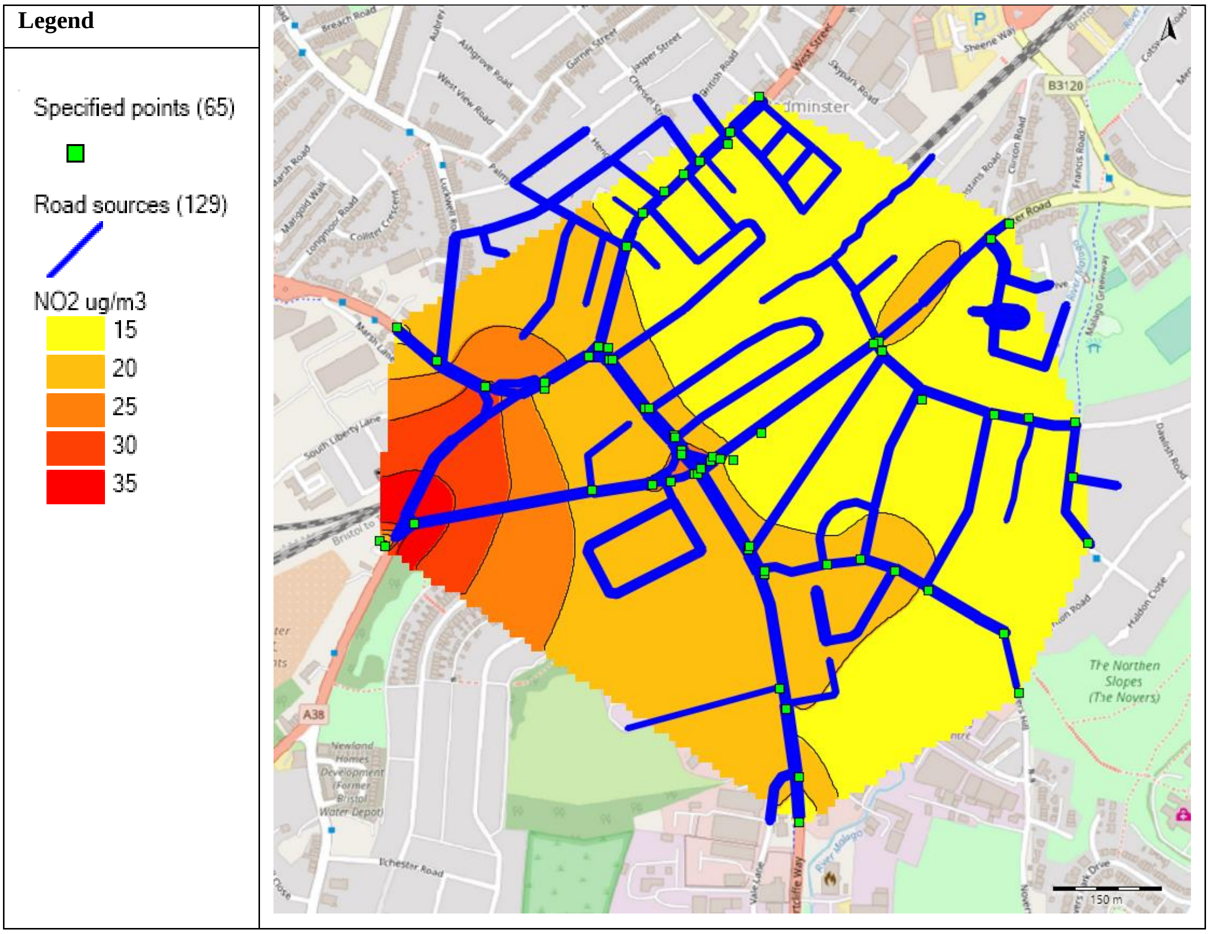

*Figure 85 Contour map showing modelled $NO_2$ (µg/$m^3$) concentrations following rideshare intervention at Bristol Bedminster site.*

Figure 86 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/m$^3$) following the rideshare intervention. Compared to the baseline, concentrations are substantially reduced across the site, with peaks remaining near the A4600/A428 junction.

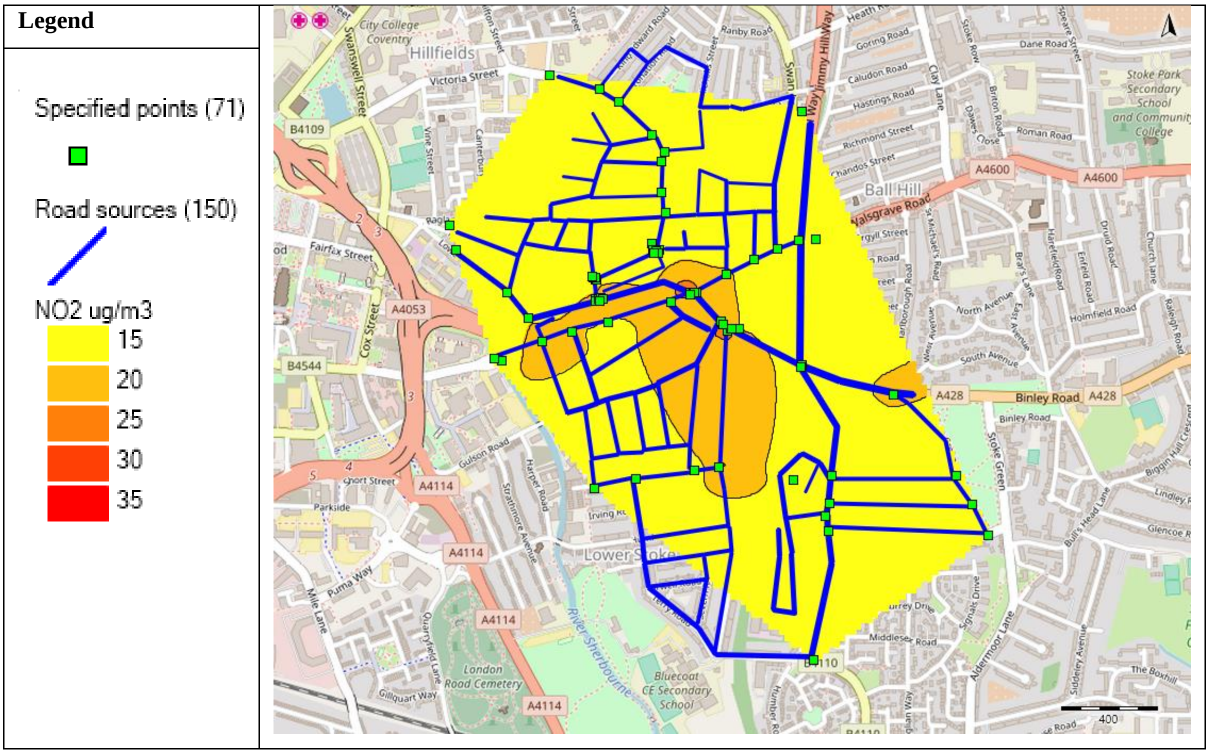

*Figure 86 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following rideshare intervention at Coventry Binley site.*

Figure 87 depicts a contour map of Oxford St Ebbe's $NO_2$ concentrations (µg/$m^3$) following the rideshare intervention. Compared to the baseline, concentrations are reduced throughout the centre of the site with relatively high concentrations persisting across the A420 site entrance/exit points and around St Ebbe's Primary School.

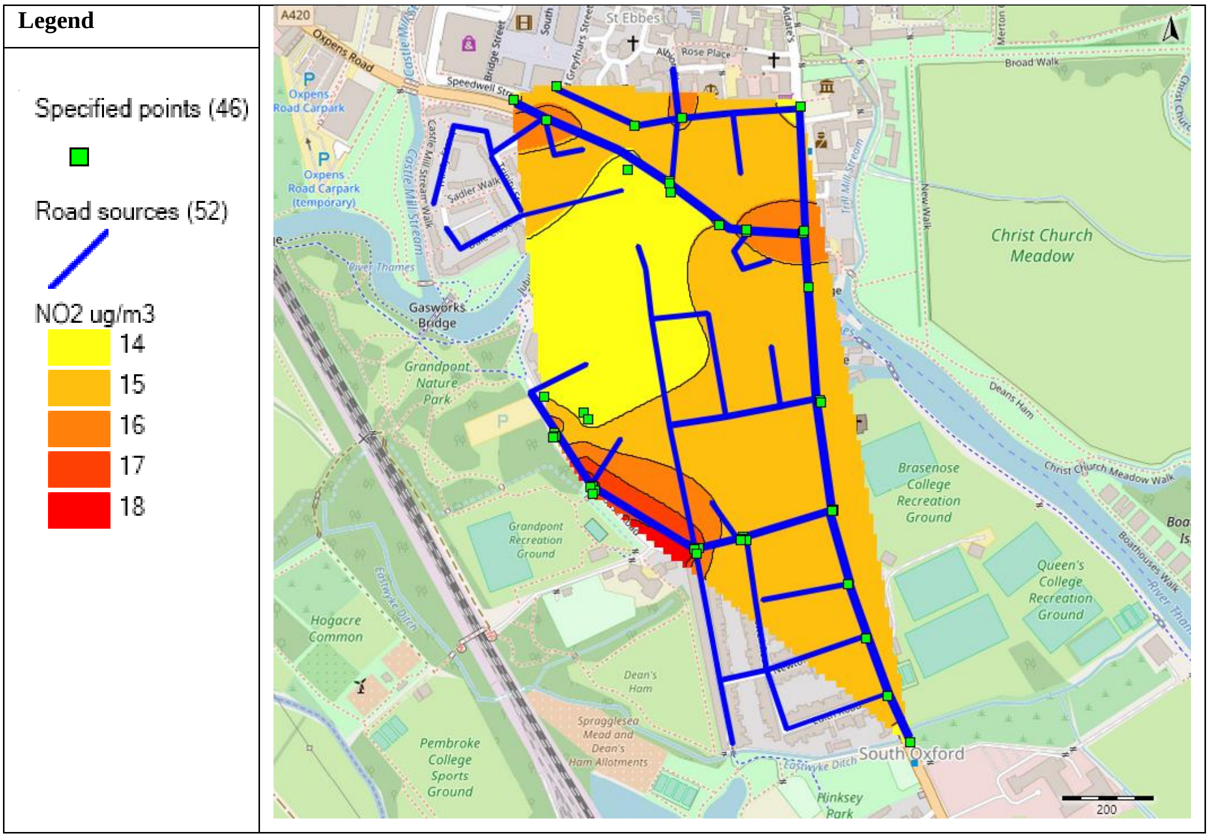

*Figure 87 Contour map showing modelled $NO_2$ (µg/$m^3$) concentrations following rideshare intervention at Oxford St Ebbe's site.*

Figure 88 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the rideshare intervention. Compared to the baseline, reductions are visible throughout the site, with peaks persisting at the M1 Roundabout, the A6178 junction, and the south central commercial/industrial region.

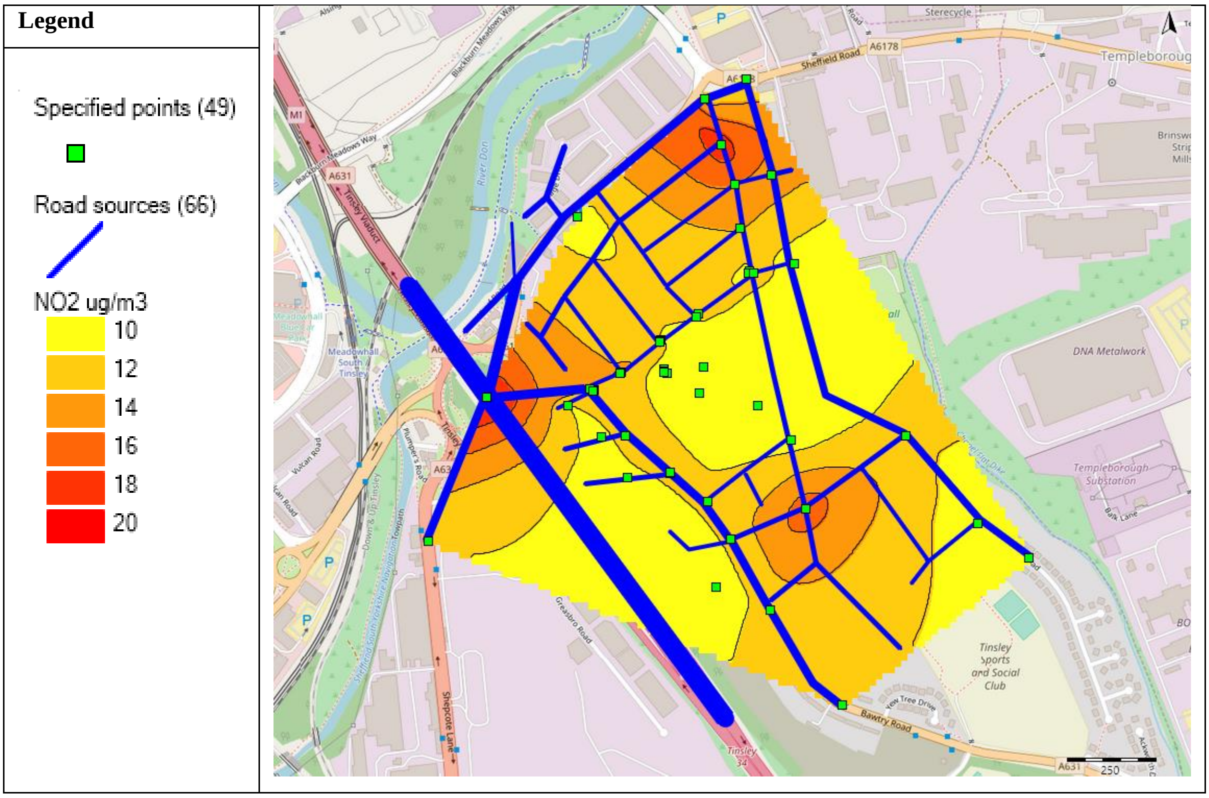

*Figure 88 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following rideshare intervention at Sheffield Tinsley site.*

### 6.5.6.7 Improved Travel Routes

A sensitivity analysis was conducted to determine the most effective improved travel routes for each site. Several alternative travel routes were plotted for each site, and their mean concentration values were calculated. The values were compared, and the most effective were considered those with the greatest percentage reduction $NO_2$ (µg/m$^3$) against the baseline. These were then compiled for each site to form a group of improved travel routes used for further analysis (Appendix P).

Mean concentrations were found for all travel routes within each site to provide a baseline value, and means were found for all improved travel routes within each site. The differences and percentage differences were calculated. Table 41 shows mean $NO_2$ (µg/m$^3$) concentrations at all sites following improved travel route intervention.

*Table 41 Modelled mean $NO_2$ (µg/m$^3$) concentrations at all sites following improved travel route intervention.*

| **Site** | **Mean Baseline $NO_2$ (µg/m$^3$)** | **Post Intervention $NO_2$ (µg/m$^3$)** | **Difference $NO_2$ (µg/m$^3$)** | **Reduction (%)** |
|---|---|---|---|---|
| Bristol St Paul’s | 26.33 | 20.56 | 5.77 | 21.90 |
| Bristol Bedminster | 25.35 | 20.62 | 4.73 | 18.67 |
| Coventry Binley | 22.81 | 18.49 | 4.32 | 18.96 |
| Oxford St Ebbe’s | 17.45 | 15.64 | 1.81 | 10.36 |
| Sheffield Tinsley | 14.79 | 13.28 | 1.51 | 10.21 |

Figure 89 shows mean $NO_2$ ($\mu g/m^3$) concentrations at all sites following the improved travel route intervention. The greatest proportional reductions are found in the travel routes at Bristol St Paul's (21.90%), Bristol Bedminster (18.67%), and Coventry Binley (18.96). Comparatively lower proportional reductions are found in the travel routes at Oxford St Ebbe's and Sheffield Tinsley (10.36 and 10.21%).

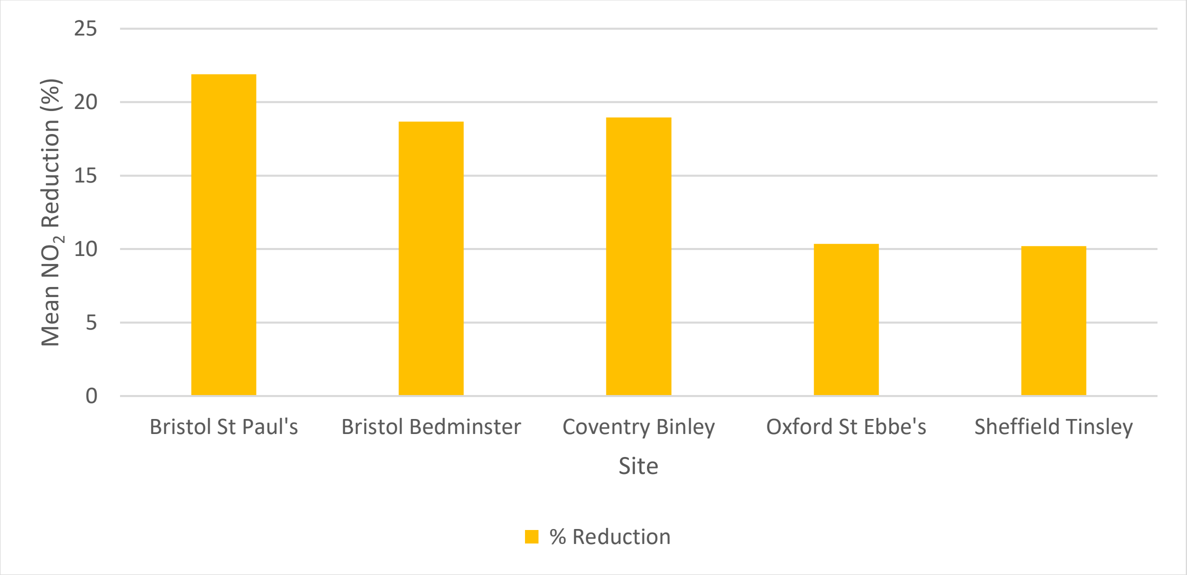

*Figure 89 Modelled mean $NO_2$ ($\mu g/m^3$) concentrations at all sites as percentage reductions following improved travel route intervention.*

### 6.5.6.8 Contour Maps for Improved Travel Routes

Figure 90 depicts a contour map of Bristol St Paul's $NO_2$ concentrations (µg/m$^3$) following the improved travel routes intervention. Compared to the baseline, concentration patterns have shifted slightly due to the change in travel route receptor number and location, more noticeably in the south of the site on Bond Street. Higher concentrations persist in the northwest of the site at the A4320/M32 roundabout, and in Stokes Croft on the A38 south of the Jamaica Street and Cheltenham Road junction.

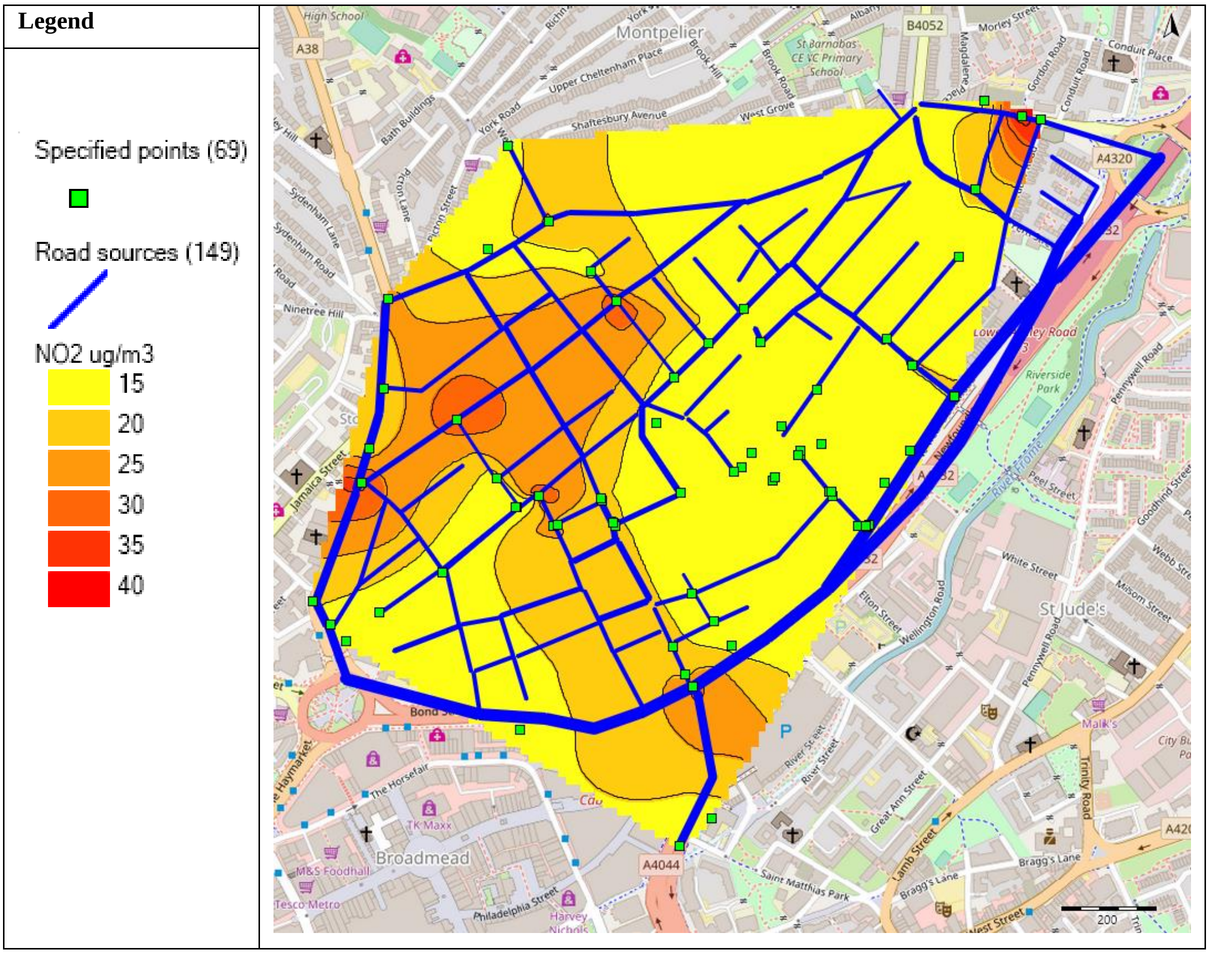

*Figure 90 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following Improved travel routes on Bristol St Paul's site.*

Figure 91 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/m$^3$) following the improved travel routes intervention. Compared to the baseline, reductions are visible throughout the site. The most noticeable reductions are visible at the Wilder Street junction, and reduced concentrations across the south of the site.

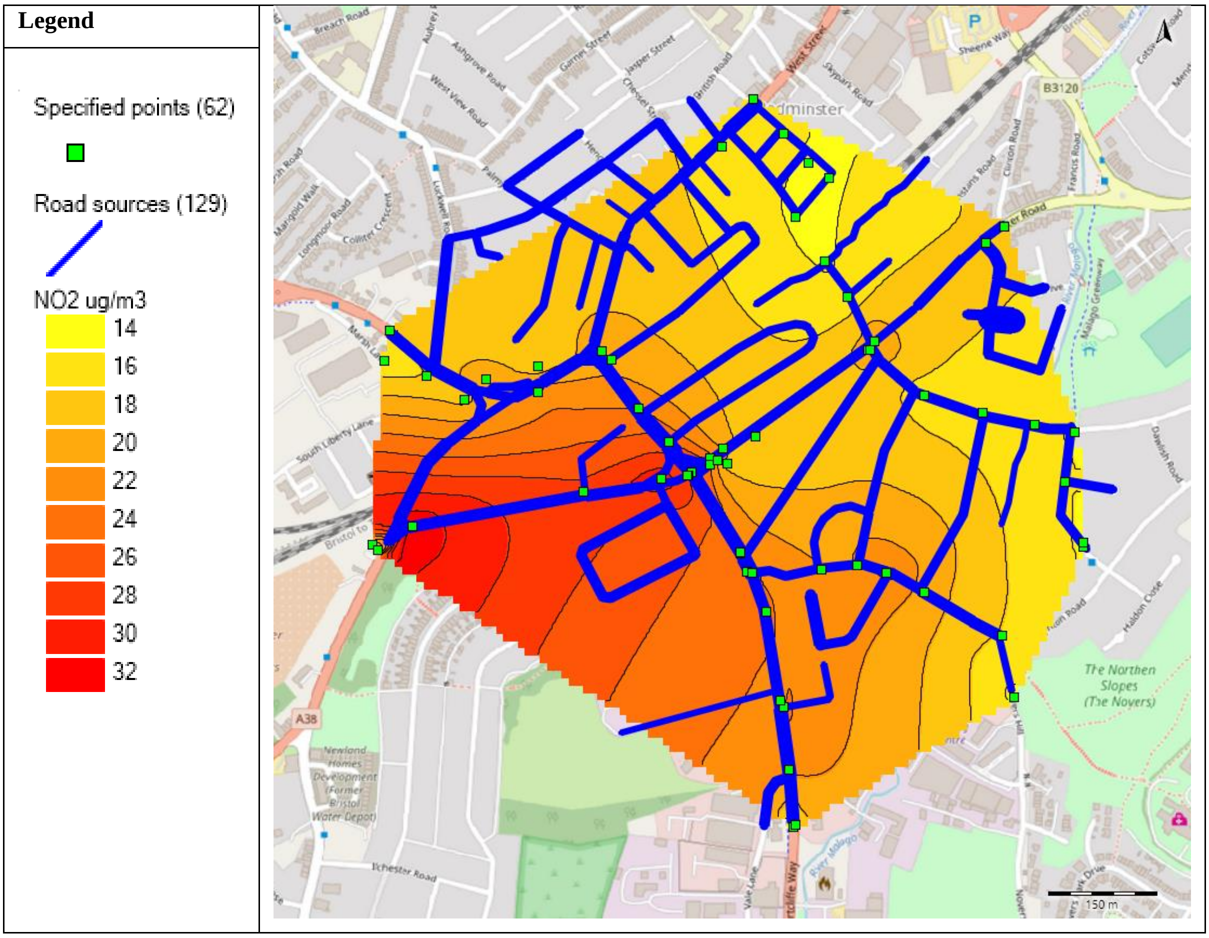

*Figure 91 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following improved travel routes on Bristol Bedminster site.*

Figure 92 depicts a contour map of Coventry Binley $NO_2$ concentrations (μg/m$^3$) following the improved travel routes intervention. Compared to the baseline, reductions are clear throughout the site, with more heavily graduated concentrations at the previously high concentration areas in the site centre along the A4600.

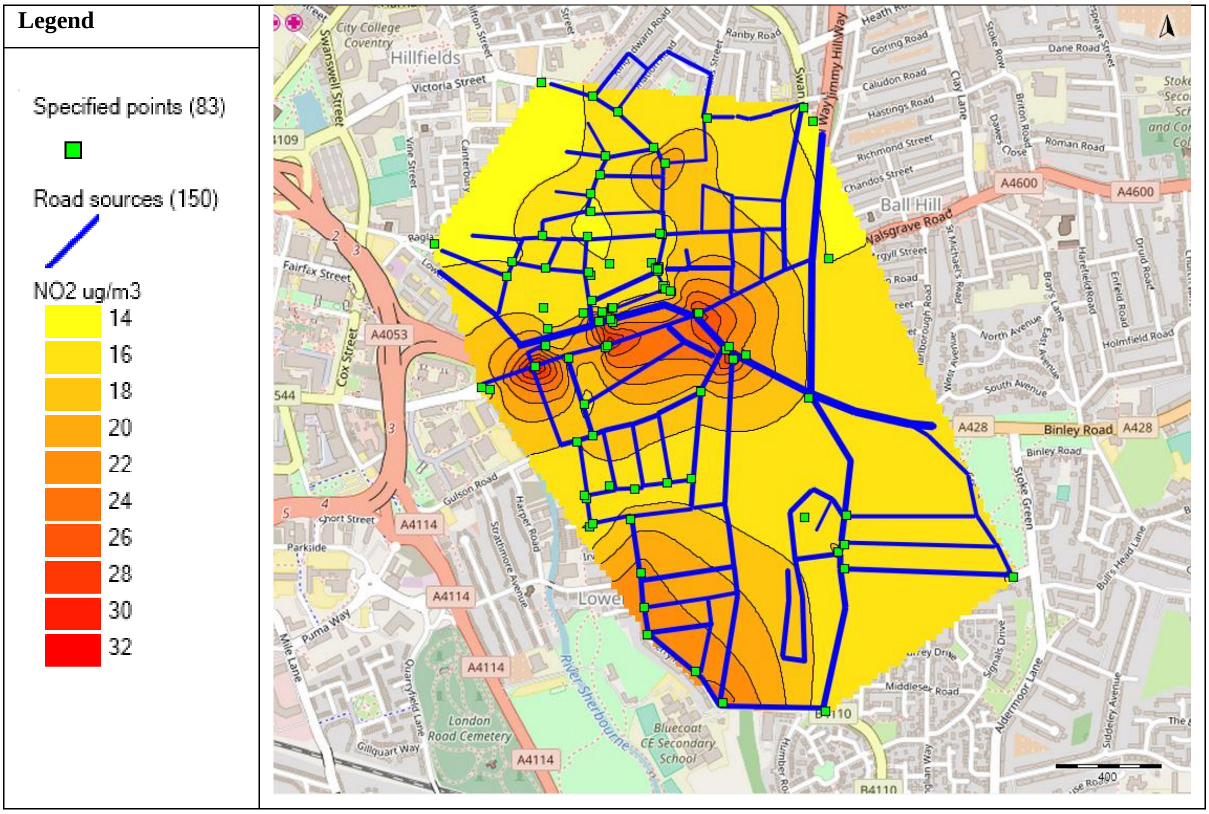

*Figure 92 Contour map showing modelled $NO_2$ (μg/m$^3$) concentrations following improved travel routes on Coventry Binley site.*

Figure 93 depicts a contour map of Oxford St Ebbe’s NO$_2$ concentrations (µg/m$^3$) following the improved travel routes intervention. Compared to the baseline, marginal reductions are visible across the site, with the clearest differences visible at St Ebbe’s Primary School and the A420.

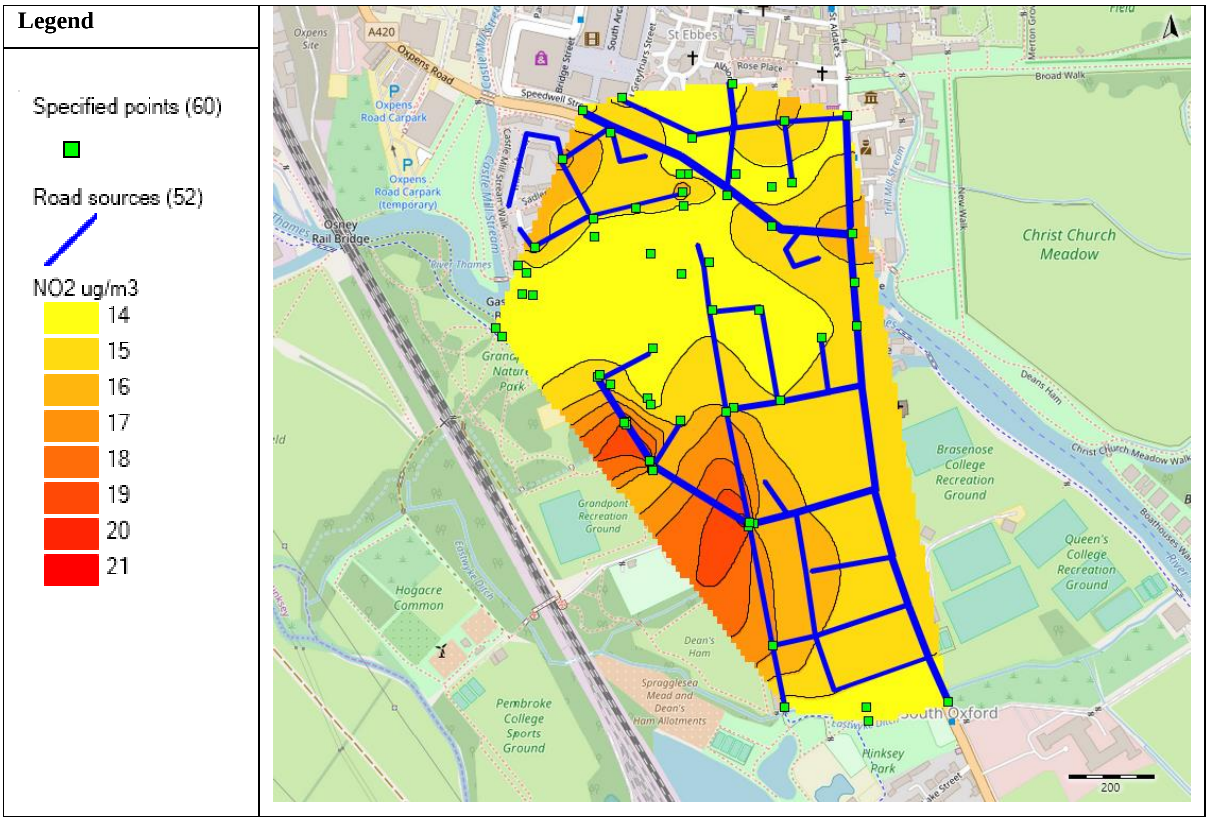

*Figure 93 Contour map showing modelled NO$_2$ (µg/m$^3$) concentrations following improved travel routes on Oxford St Ebbe’s site.*

Figure 94 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations ($\mu g/m^3$) following the improved travel routes intervention. Compared to the baseline, marginal reductions are visible throughout the site, with the clearest visible at the M1 junction and to the north of the site at the A6178 junction.

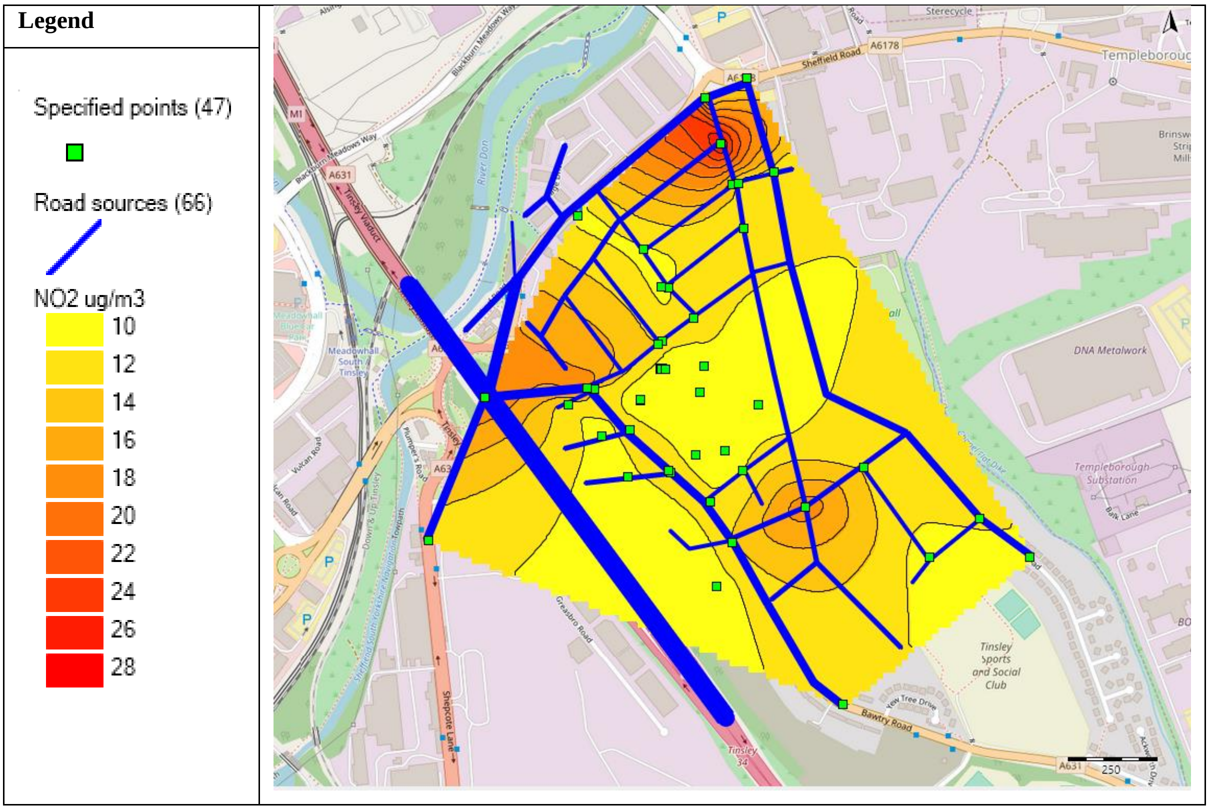

*Figure 94 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following improved travel routes on Sheffield Tinsley site.*

### 6.5.6.9 Low Emission Zones

Concentration values were taken from schools at each site and means of all receptors were produced for each site. Mean values of all combined travel routes at each site were also generated. Resultant $NO_2$ ($\mu g/m^3$) reductions were calculated (Table 42). Concentration reductions from baseline were found at all sites and increased with increasing LEZ radii. The greatest reductions between baseline and LEZ of 200 m were found on travel routes at Bristol St Paul's and Bristol Bedminster (-3.91 and -3.2 $\mu g/m^3$, respectively).

*Table 42 Modelled $NO_2$ ($\mu g/m^3$) means at schools due to Low Emission Zone implementation at 200m, 300m, 400m & 500m.*

| Site | Receptors | Baseline | 200 m | 300 m | 400 m | 500 m |
|---|---|---|---|---|---|---|
| Bristol St Paul's | Cabot Primary School | 16.93 | 16.29 | 16.25 | 16.22 | 16.21 |
| | Site Mean | 18.35 | 17.70 | 17.45 | 17.38 | 17.12 |
| | Travel Routes | 26.33 | 22.42 | 21.74 | 21.69 | 21.35 |
| Bristol Bedminster | Parson St School | 19.77 | 17.54 | 17.45 | 17.35 | 17.33 |
| | Travel Routes | 19.68 | 18.40 | 18.11 | 17.73 | 17.54 |
| | Mean | 25.35 | 22.15 | 21.56 | 20.95 | 20.22 |
| Coventry Binley | Southfields Primary School | 16.44 | 16.12 | 16.07 | 16.03 | 16.01 |
| | Site Means | 18.54 | 17.90 | 17.56 | 17.01 | 16.90 |
| | Travel Routes | 22.41 | 20.81 | 20.40 | 19.83 | 19.76 |
| Oxford St Ebbe's | St Ebbe's Primary School | 14.75 | 14.38 | 14.34 | 14.33 | 14.33 |
| | Site Means | 15.13 | 14.86 | 14.72 | 14.58 | 14.55 |
| | Travel Routes | 17.45 | 16.22 | 15.69 | 15.47 | 15.35 |
| Sheffield Tinsley | Tinsley Meadows Primary School | 10.61 | 10.34 | 10.27 | 10.25 | 10.24 |
| | Site Means | 11.82 | 11.07 | 10.99 | 10.95 | 10.92 |
| | Travel Routes | 14.79 | 13.12 | 12.78 | 12.61 | 12.40 |

Figure 95 shows the patterns of reduction for each site as a consequence of the LEZ intervention. Patterns are largely consistent at each site, with the most prominent reductions with each LEZ radii found at travel routes at all sites. Far lower iterative reductions were found at the schools, and slightly more graduated reductions were found with means of all site receptors.

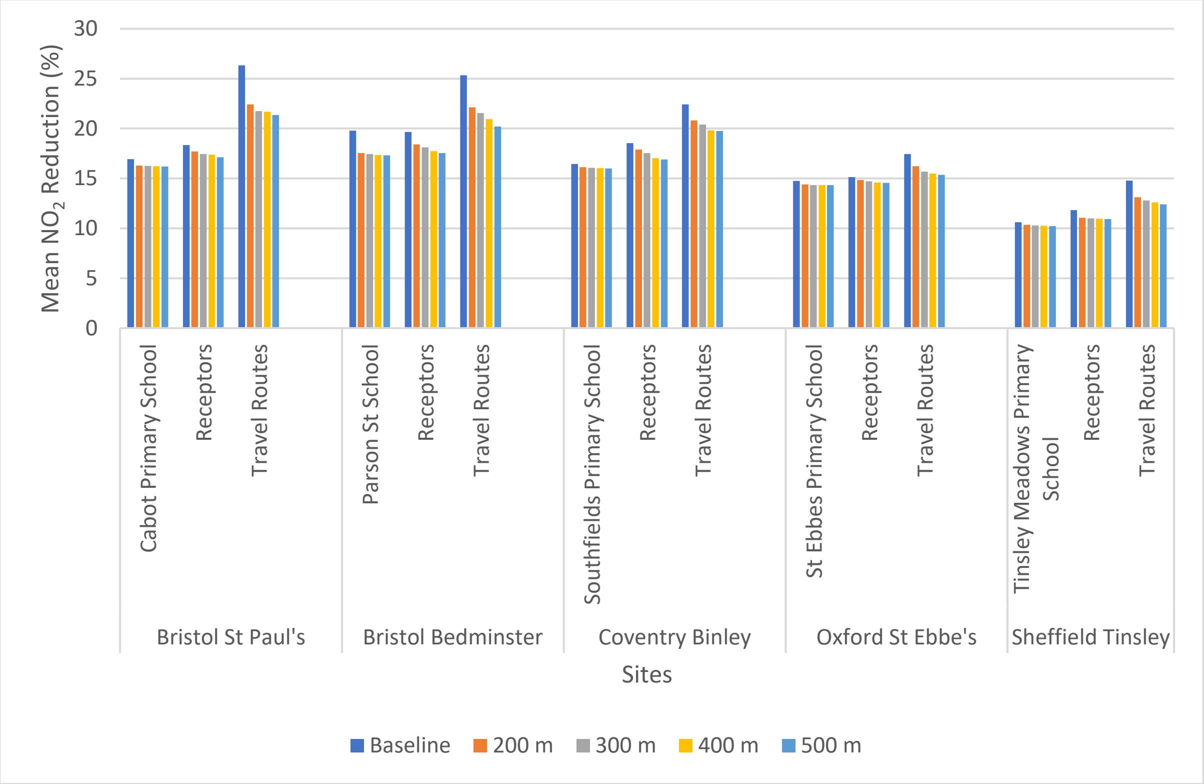

*Figure 95 Modelled $NO_2$ (µg/$m_3$) means at principal schools, all site receptors and travel routes due to Low Emission Zone implementation at 200m, 300m, 400m & 500m.*

Table 43 shows the percentage reductions of $NO_2$ at schools due to the implementation of each iteration of LEZ (200m, 300m, 400m, and 500m). Greater reductions are found at all travel routes on all sites. Of all schools, Parson Street School shows the greatest reduction at the 500 m iteration (12.36%).

*Table 43 Percentage reductions of $NO_2$ at schools due to Low Emission Zone implementation at 200m, 300m, 400m & 500m.*

| **Site** | **Receptors** | **Baseline** | **200 m** | **300 m** | **400 m** | **500 m** |
|---|---|---|---|---|---|---|
| Bristol St Paul’s | Cabot Primary School | 16.93 | 3.81 | 4.04 | 4.18 | 4.27 |
| | Receptors | 18.35 | 3.35 | 4.46 | 4.82 | 6.12 |
| | Travel Routes | 26.33 | 14.84 | 17.44 | 17.63 | 18.91 |
| Bristol Bedminster | Parson St School | 19.77 | 11.30 | 11.74 | 12.27 | 12.36 |
| | Receptors | 19.68 | 6.50 | 7.96 | 9.89 | 10.83 |
| | Travel Routes | 25.35 | 12.65 | 14.96 | 17.38 | 20.25 |
| Coventry Binley | Southfields Primary School | 16.44 | 1.91 | 2.22 | 2.48 | 2.56 |
| | Receptors | 18.54 | 3.45 | 5.32 | 8.23 | 8.86 |
| | Travel Routes | 22.41 | 7.14 | 8.97 | 11.52 | 11.85 |
| Oxford St Ebbe’s | St Ebbe’s Primary School | 14.75 | 2.49 | 2.78 | 2.82 | 2.85 |
| | Receptors | 15.13 | 1.76 | 2.70 | 3.63 | 3.78 |
| | Travel Routes | 17.45 | 7.05 | 10.07 | 11.33 | 12.05 |
| Sheffield Tinsley | Tinsley Meadows Primary School | 10.61 | 2.58 | 3.18 | 3.44 | 3.55 |
| | Receptors | 11.82 | 6.30 | 6.98 | 7.33 | 7.60 |
| | Travel Routes | 14.79 | 11.28 | 13.61 | 14.75 | 16.17 |

Figure 96 shows the percentage reductions at each site following the implementation of the LEZ intervention. Patterns largely follow the $NO_2$ concentration reductions, with smaller increments of improvement at schools than at travel routes. However, increments of reduction improvement at site means become more pronounced at Bristol Bedminster, Coventry Binley, and Oxford St Ebbe’s.

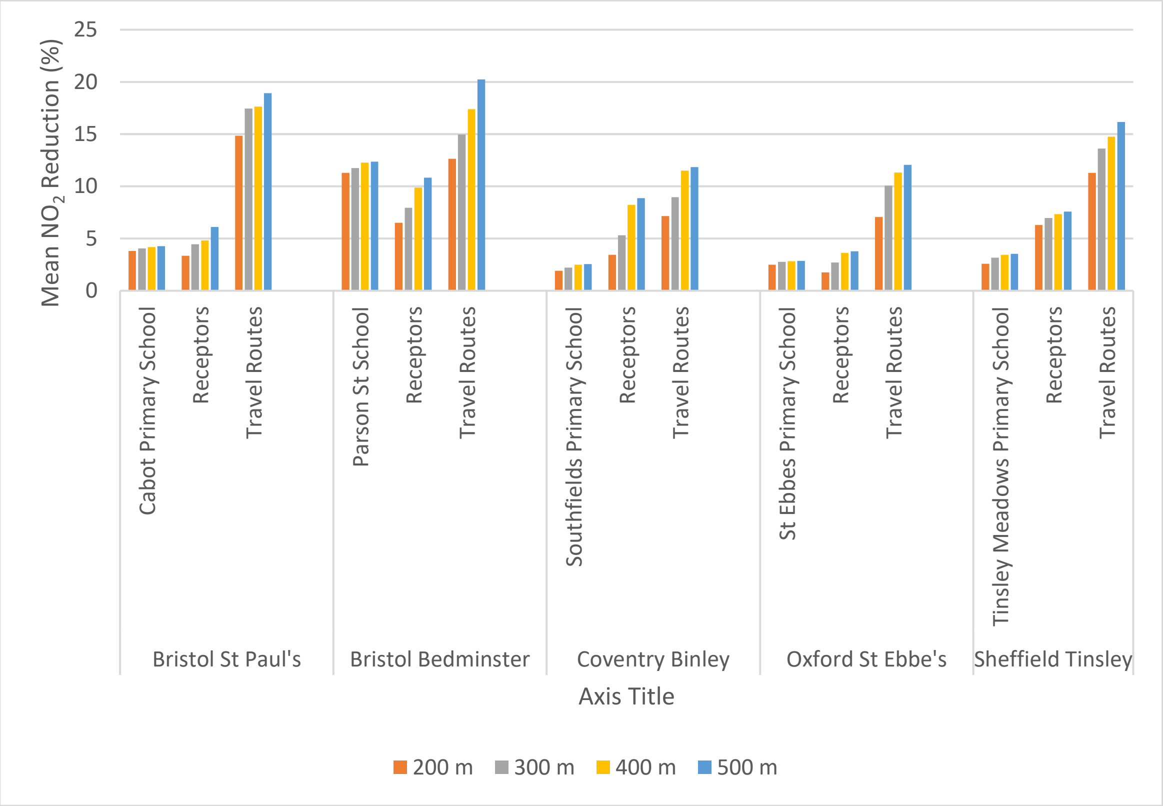

*Figure 96 Percentage reductions of modelled $NO_2$ at schools due to Low Emission Zone implementation at 200m, 300m, 400m & 500m.*

### 6.5.6.10 Contour Maps for Low Emission Zones (200 Metres)

Figure 97 depicts a contour map of Bristol St Paul's $NO_2$ concentrations (µg/m$^3$) following the LEZ (200 m) intervention. Compared to the baseline, substantial reductions are visible at the A38 south to Stokes Croft, and at Wilder Street between the B4057 and A4032. High concentrations persist at the A4320/M32 roundabout.

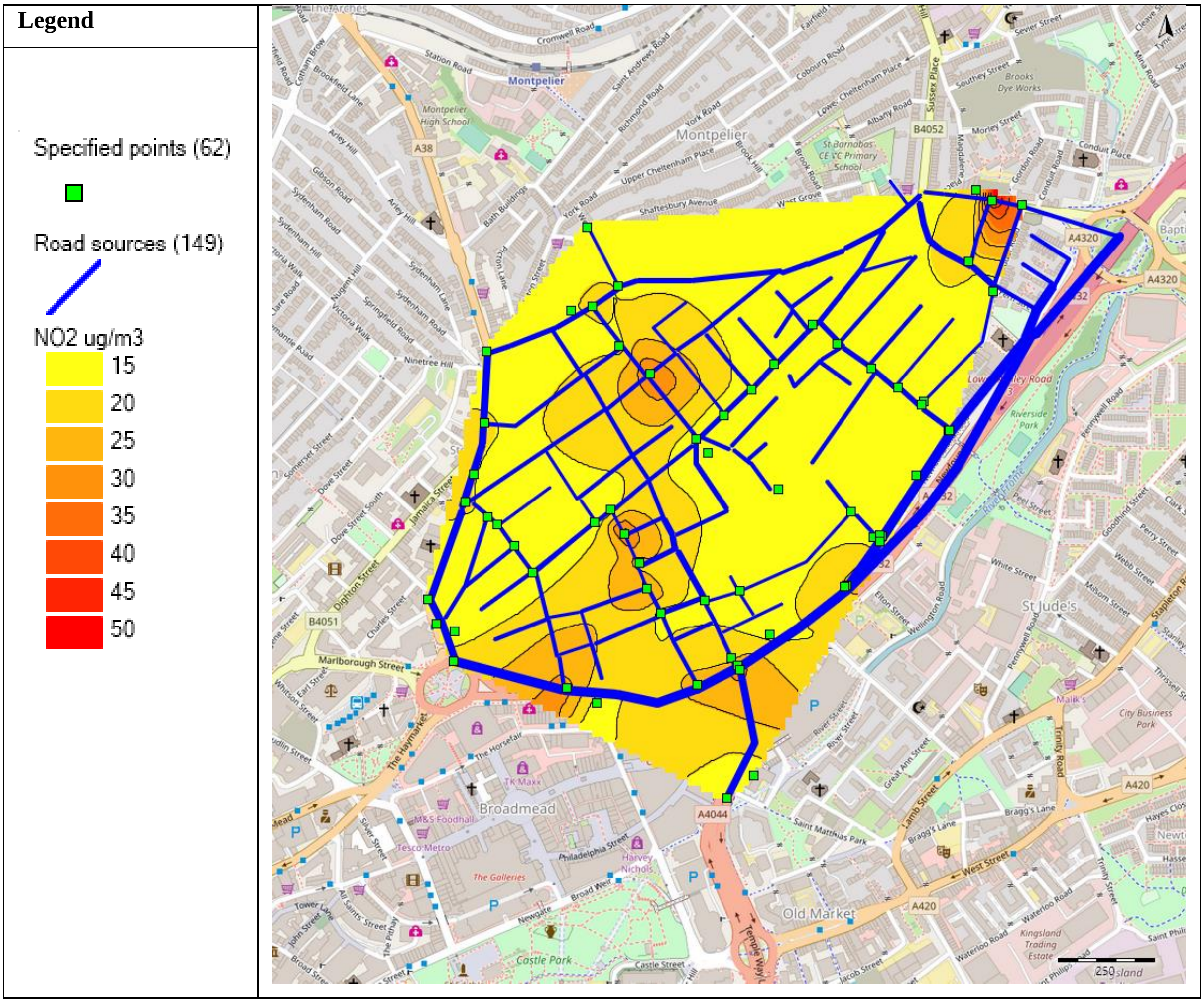

*Figure 97 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (200 m) on Bristol St Paul's site.*

Figure 98 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/m$^3$) following the LEZ (200 m) intervention. Compared to the baseline, concentration reductions are visible across the site, although high concentrations persist at the west of the site at the A38/A3029 intersection.

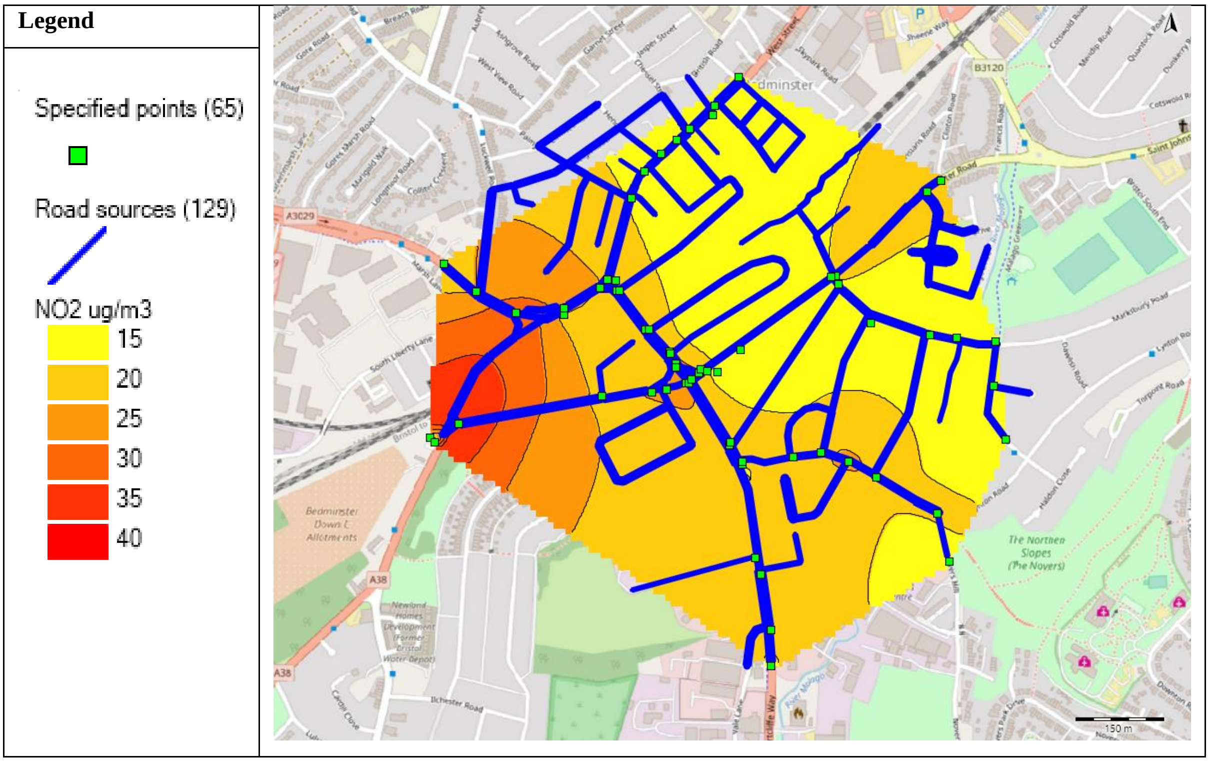

*Figure 98 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (200 m) on Bristol Bedminster site.*

Figure 99 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/m$^3$) following the LEZ (200 m) intervention. Compared to the baseline, concentrations are generally reduced, although central concentrations remain comparatively high around the A4053 and towards the A429.

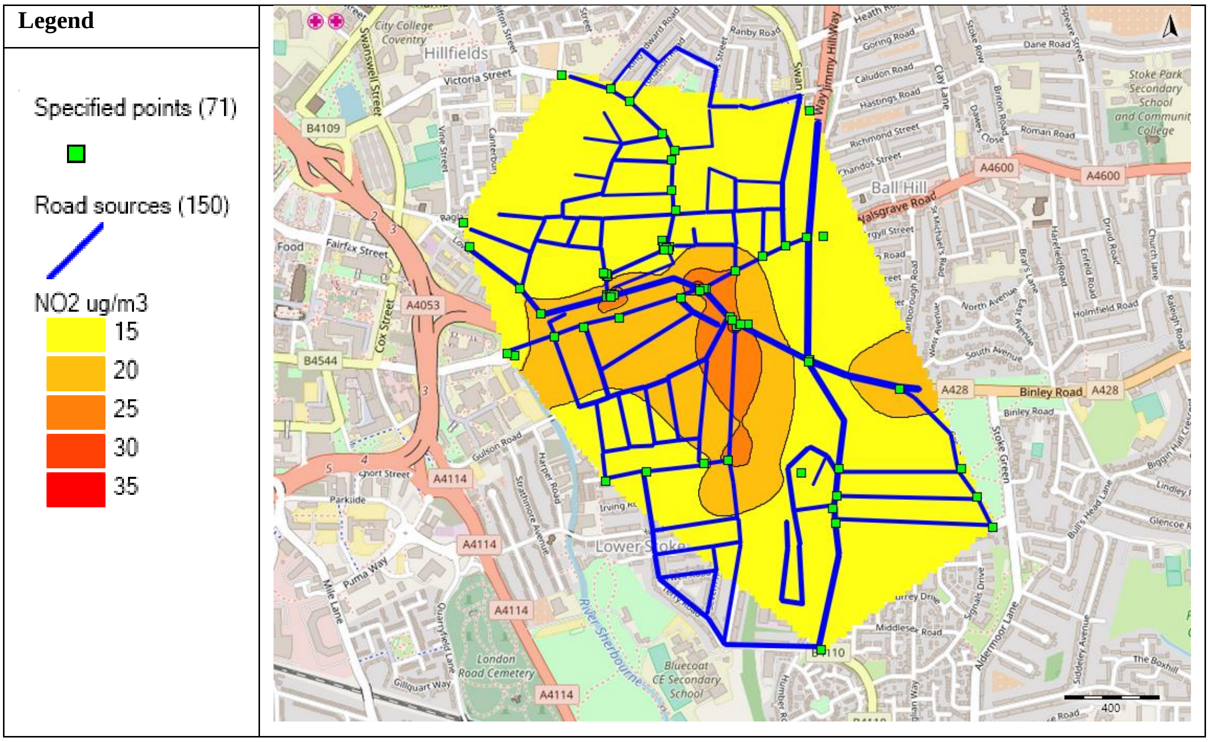

*Figure 99 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (200 m) on Coventry Binley site.*

Figure 100 depicts a contour map of Oxford St Ebbe's $NO_2$ concentrations (μg/$m^3$) following the LEZ (200 m) intervention. Compared to the baseline, marginal reductions are visible throughout the site, with peaks persisting on the A420.

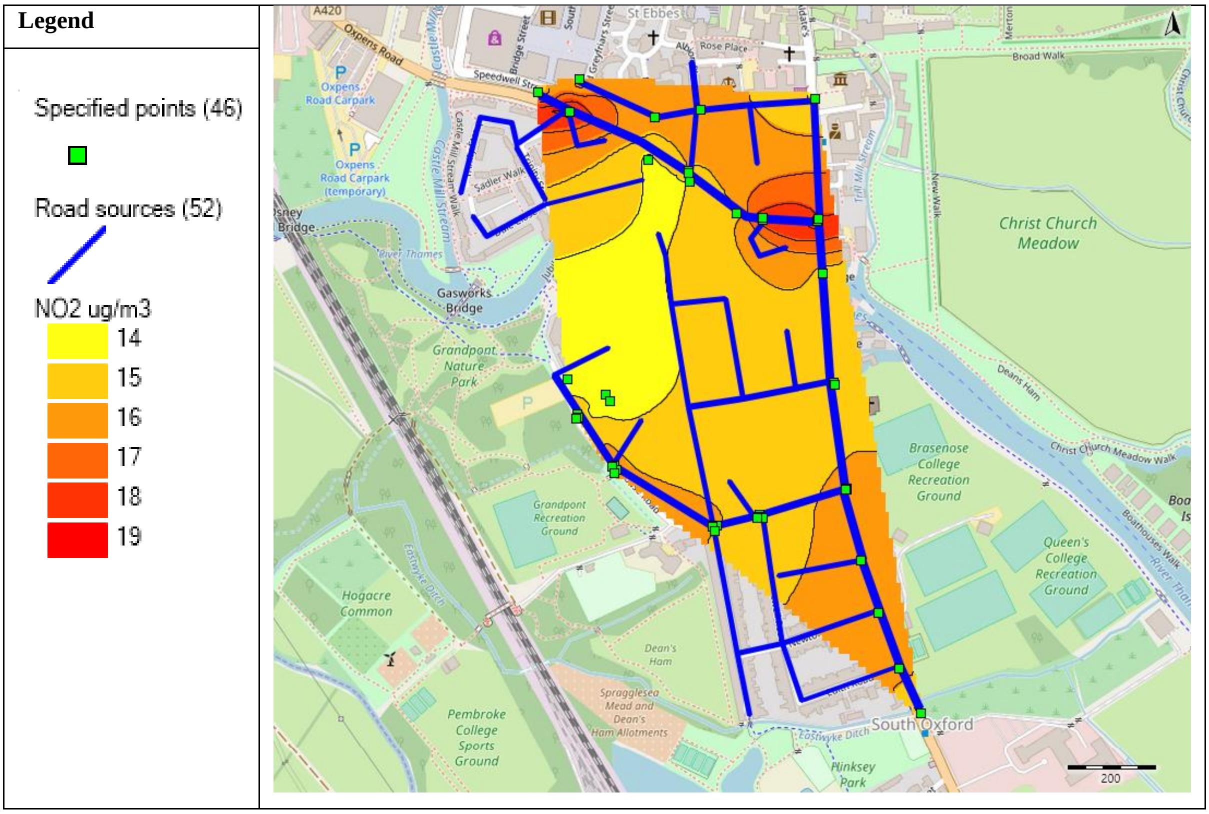

*Figure 100 Contour map showing modelled $NO_2$ (μg/$m^3$) concentrations following LEZ (200 m) on Oxford St Ebbe's site.*

Figure 101 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the LEZ (200 m) intervention. Compared to the baseline, some reductions exist throughout the site with peaks persisting at the M1 roundabout, the A6178 junction, and the south central region.

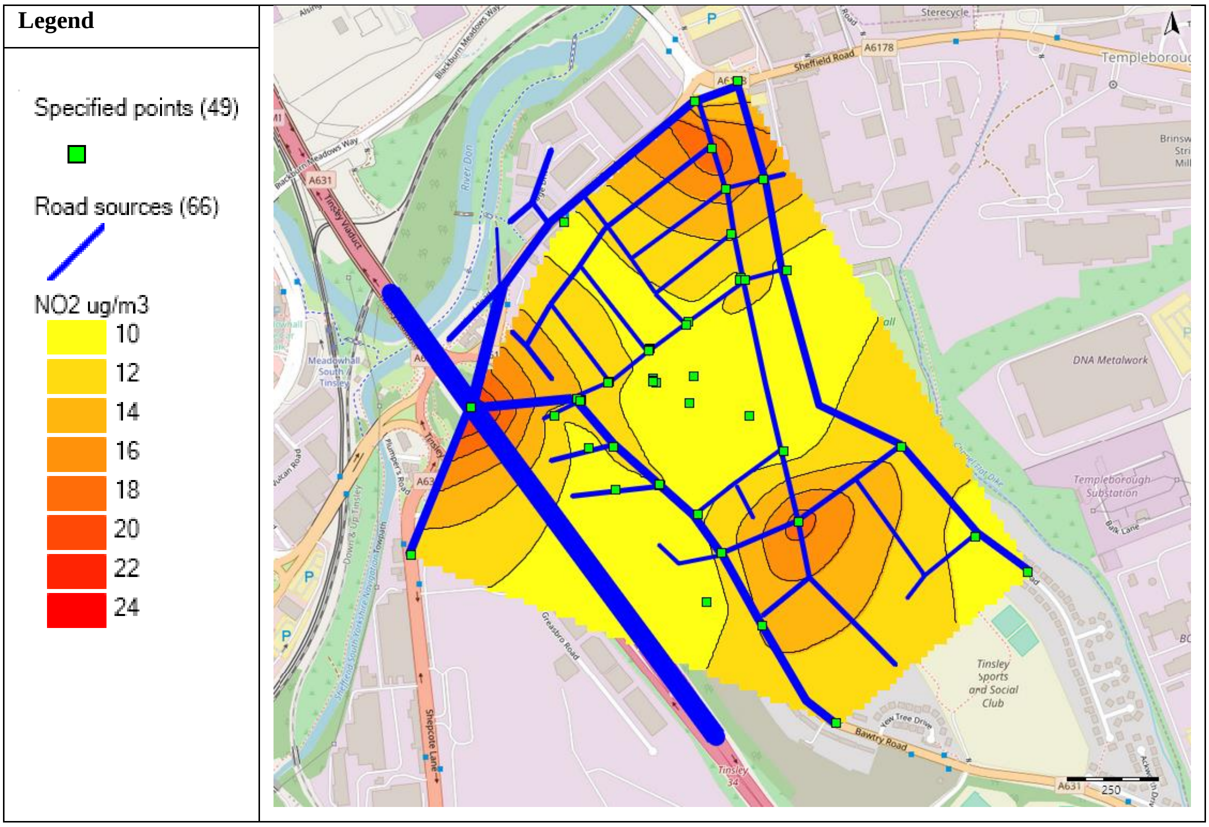

*Figure 101 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (200 m) on Sheffield Tinsley site.*

### 6.5.6.11 Contour Maps for Low Emission Zones (300 Metres)

Figure 102 depicts a contour map of Bristol St Paul's $NO_2$ concentrations ($\mu g/m^3$) following the LEZ (300 m) intervention. Compared to the baseline, substantial reductions are visible across the site, particularly at the A38 south to Stokes Croft, and at Wilder Street between the B4057 and A4032, although comparatively high concentrations are visible at the south of the site on Bond Street. High concentrations persist at the A4320/M32 roundabout.

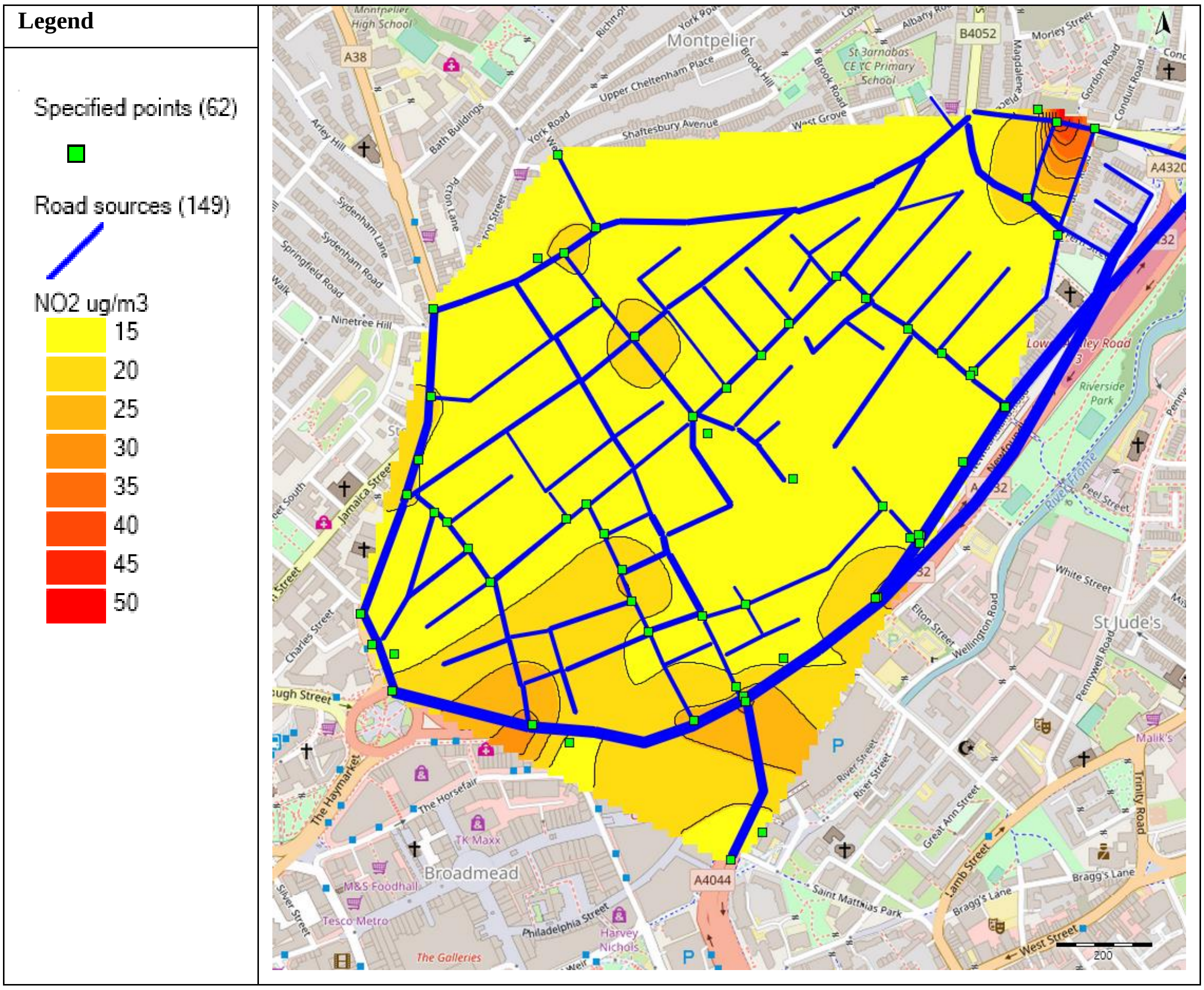

*Figure 102 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following LEZ (300 m) on Bristol St Paul's site.*

Figure 103 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/$m^3$) following the LEZ (300 m) intervention. Compared to the baseline, concentrations are reduced throughout the site, with peaks remaining in the west at the A38/A3029 intersection.

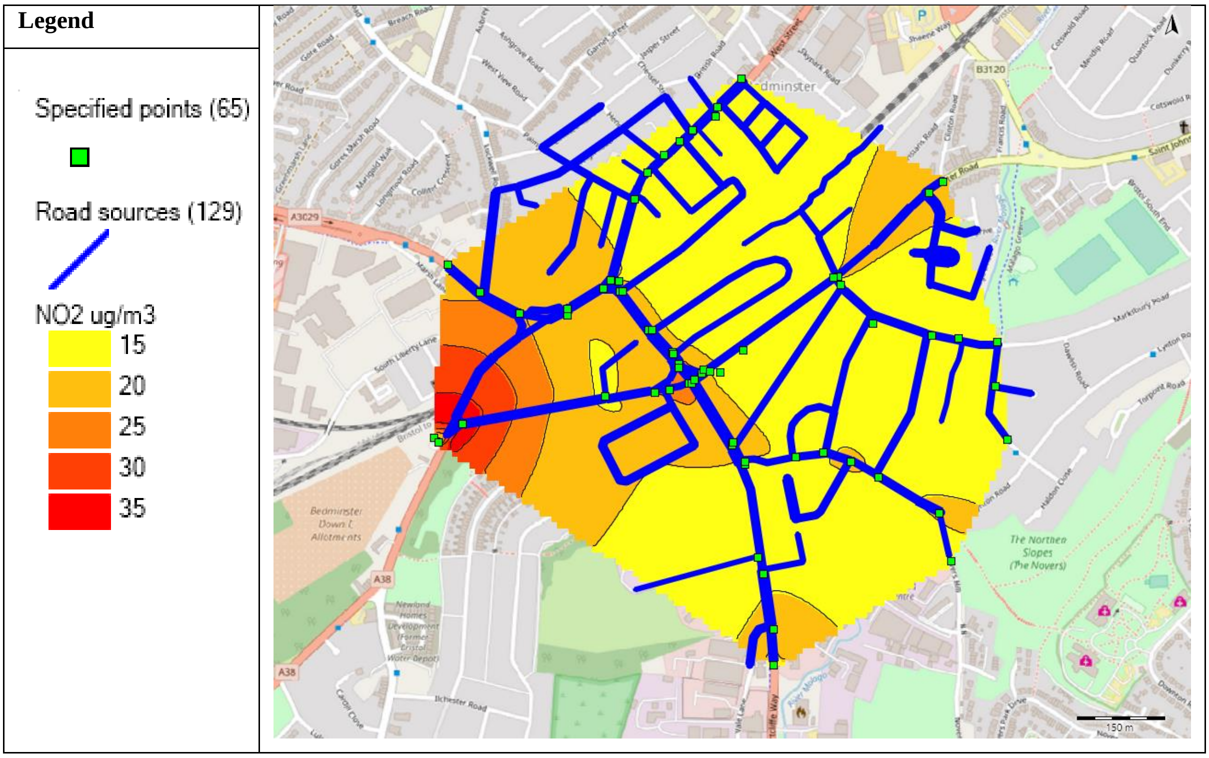

*Figure 103 Contour map showing modelled $NO_2$ (µg/$m^3$) concentrations following LEZ (300 m) on Bristol Bedminster site.*

Figure 104 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/m$^3$) following the LEZ (300 m) intervention. Compared to the baseline, prominent reductions are visible across the centre of the site, with peaks persisting at the A4600/A428 junction.

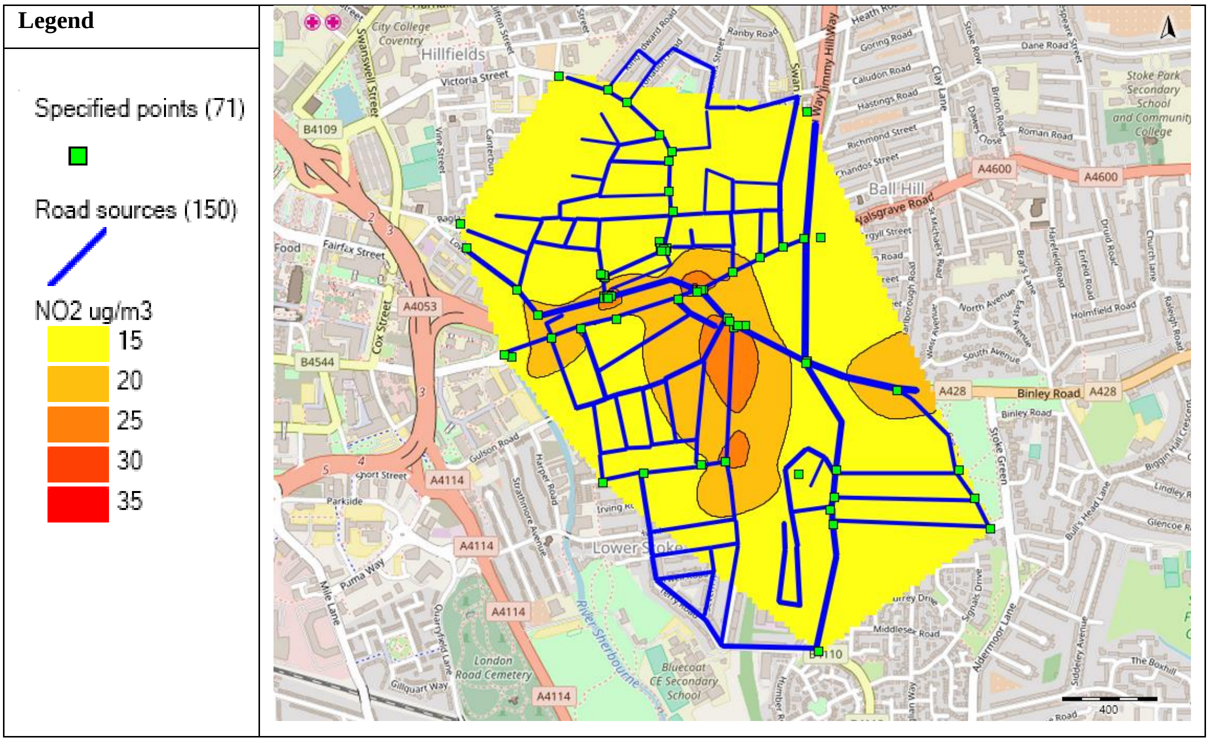

*Figure 104 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (300 m) on Coventry Binley site.*

Figure 105 depicts a contour map of Oxford St Ebbe’s $NO_2$ concentrations (µg/m$^3$) following the LEZ (300 m) intervention. Compared to the baseline, reductions are visible throughout the site, with peaks persisting on the A420 and at St Ebbe’s Primary School.

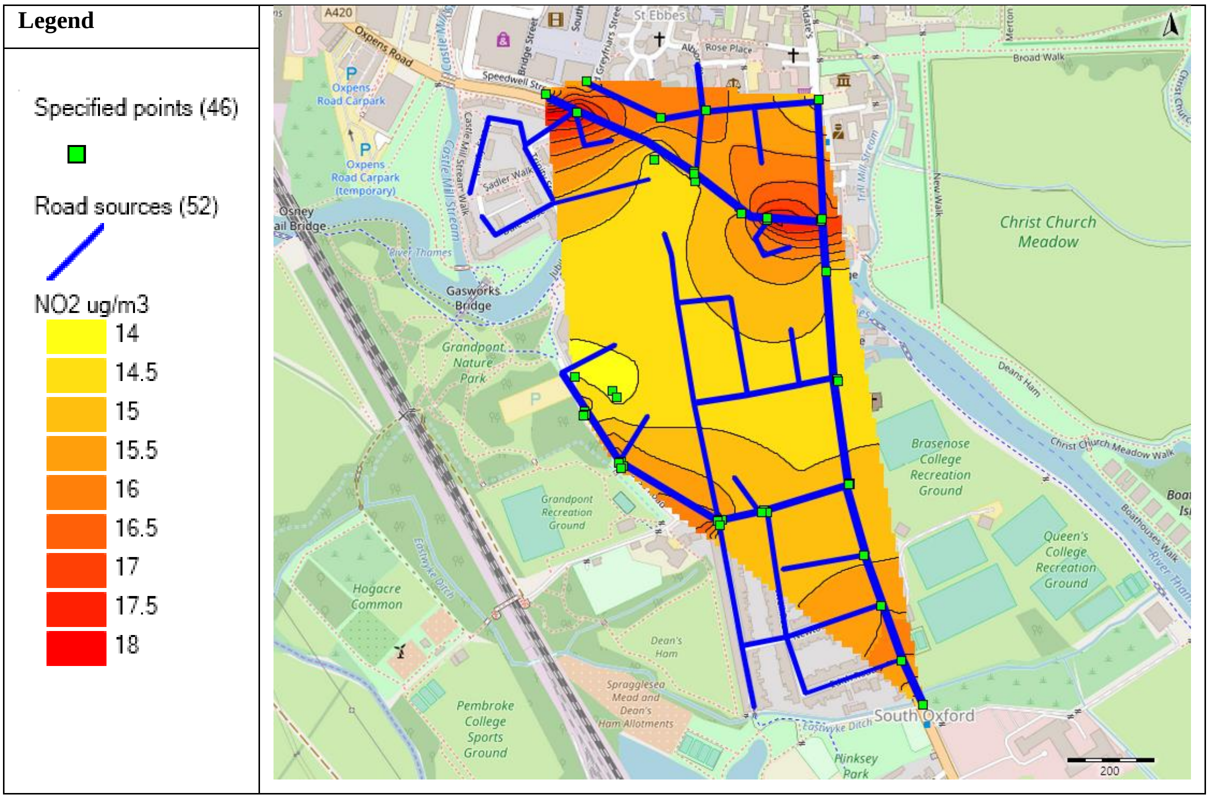

*Figure 105 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (300 m) on Oxford St Ebbe’s site.*

Figure 106 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations ($\mu g/m^3$) following the LEZ (300 m) intervention. Compared to the baseline, reductions are visible throughout the site, with flattened graduations of concentrations surrounding peaks at the M1 roundabout and the A6178 junction.

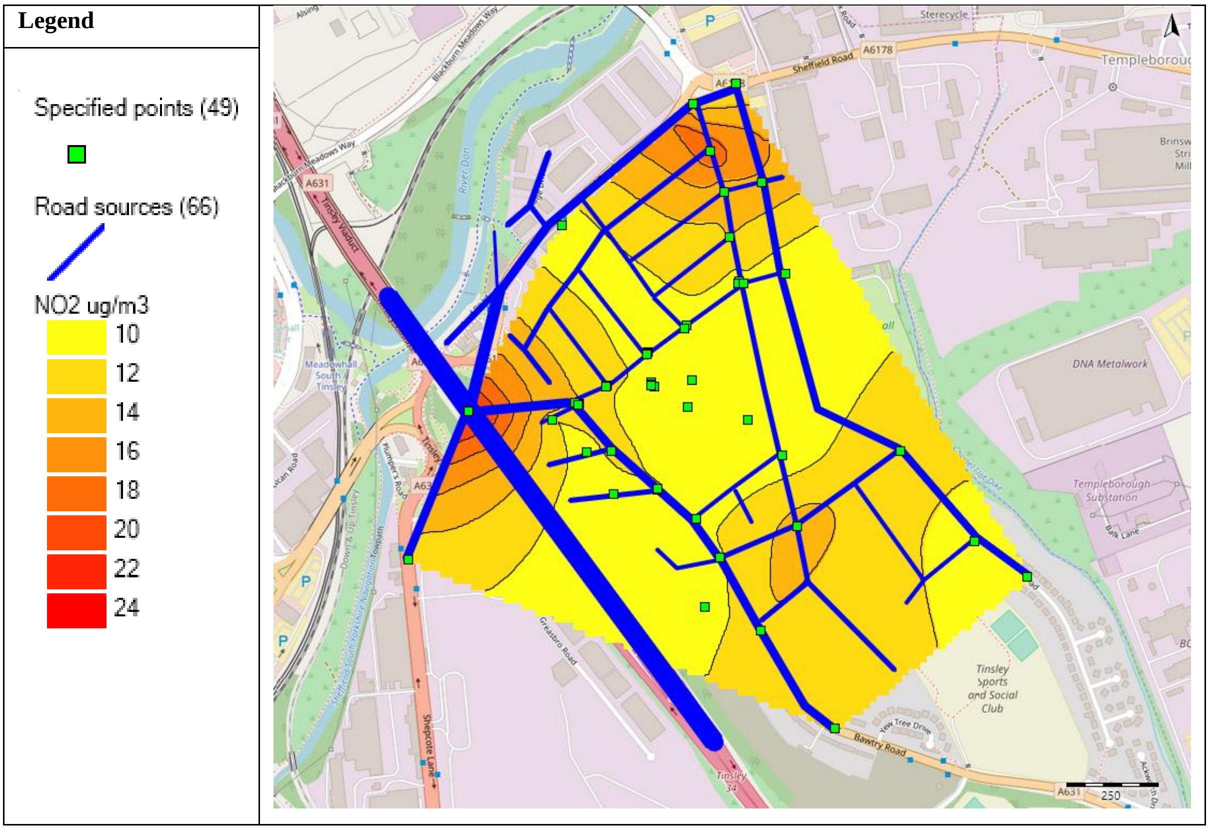

*Figure 106 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following LEZ (300 m) on Sheffield Tinsley site.*

### 6.5.6.12 Contour Maps for Low Emission Zones (400 Metres)

Figure 107 depicts a contour map of Bristol St Paul's $NO_2$ concentrations (µg/m$^3$) following the LEZ (400 m) intervention. Compared to the baseline, concentration reductions are visible across the site, with A38 and Wilder Street concentrations substantially reduced. High concentrations persist at the A4320/M32 roundabout.

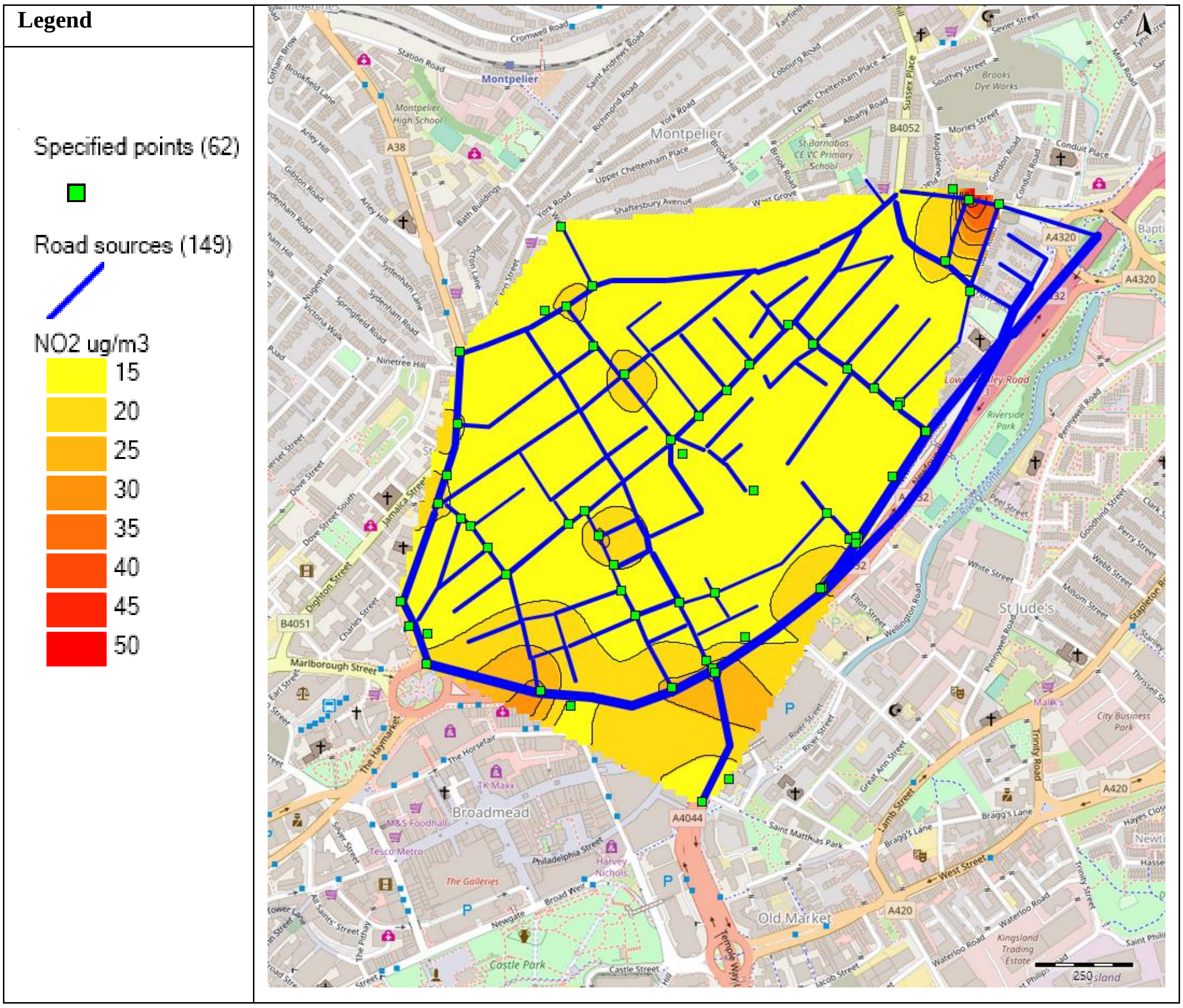

*Figure 107 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (400 m) on Bristol St Paul's site.*

Figure 108 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/m$^3$) following the LEZ (400 m) intervention. Compared to the baseline, reductions are visible throughout the site although are marginal by comparison to LEZ (300 m). Higher concentrations persist at the A38/A3029 intersection.

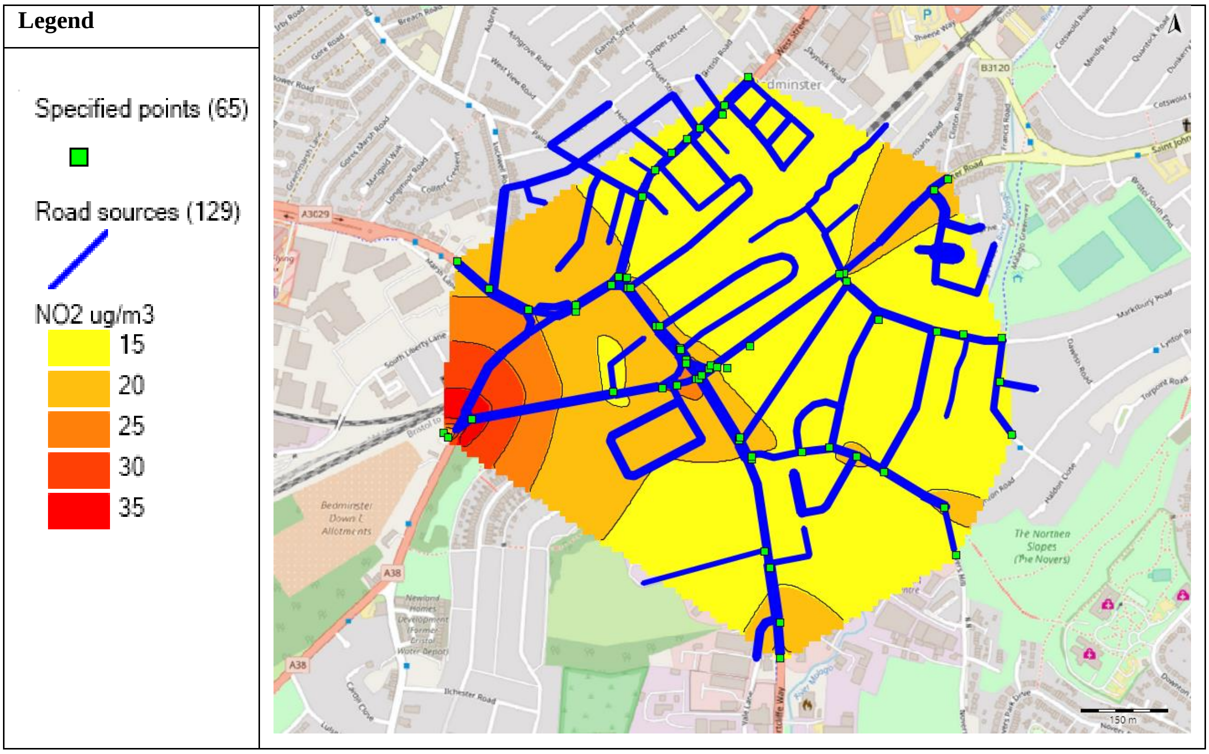

*Figure 108 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (400 m) on Bristol Bedminster site.*

Figure 109 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/$m^3$) following the LEZ (400 m) intervention. Compared to the baseline, prominent reductions are visible throughout the site and the central peaks are now largely localised at two points on the A4600.

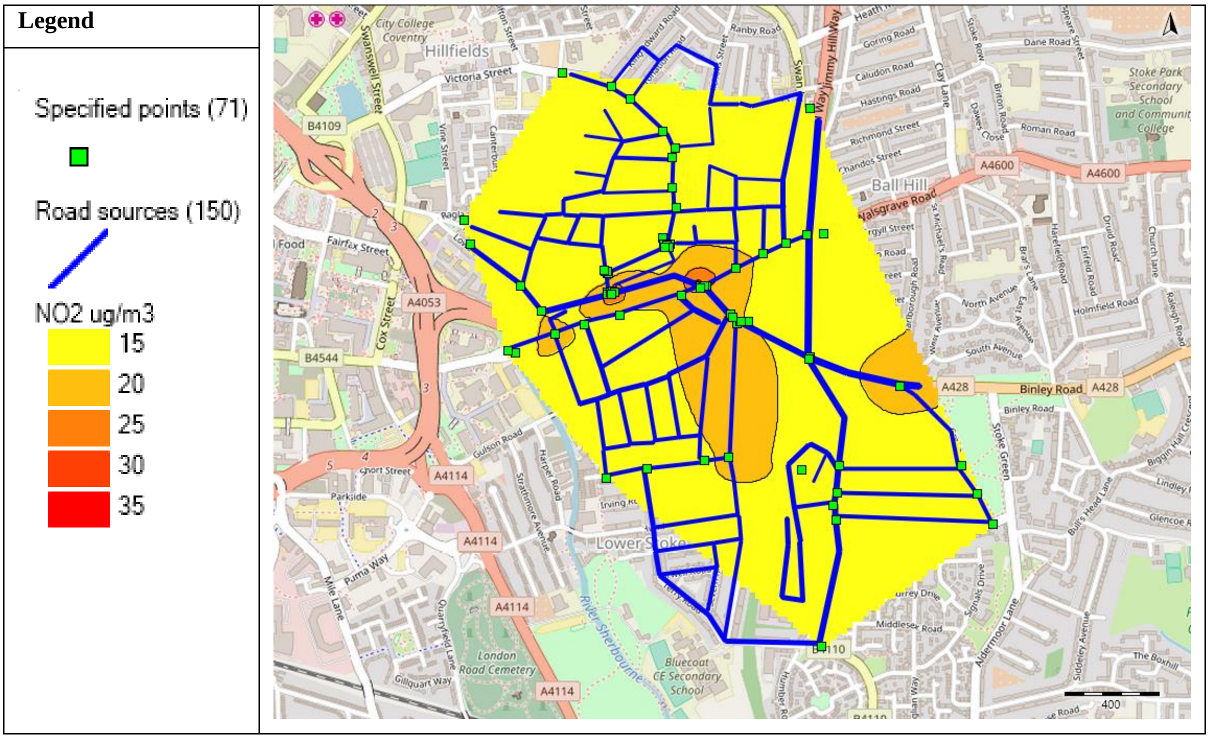

*Figure 109 Contour map showing modelled $NO_2$ (µg/$m^3$) concentrations following LEZ (400 m) on Coventry Binley site.*

Figure 110 depicts a contour map of Oxford St Ebbe's $NO_2$ concentrations (µg/m$^3$) following the LEZ (400 m) intervention. Compared to the baseline, concentrations throughout the site are reduced, with peaks persisting at the A420 and St Ebbe's Primary School.

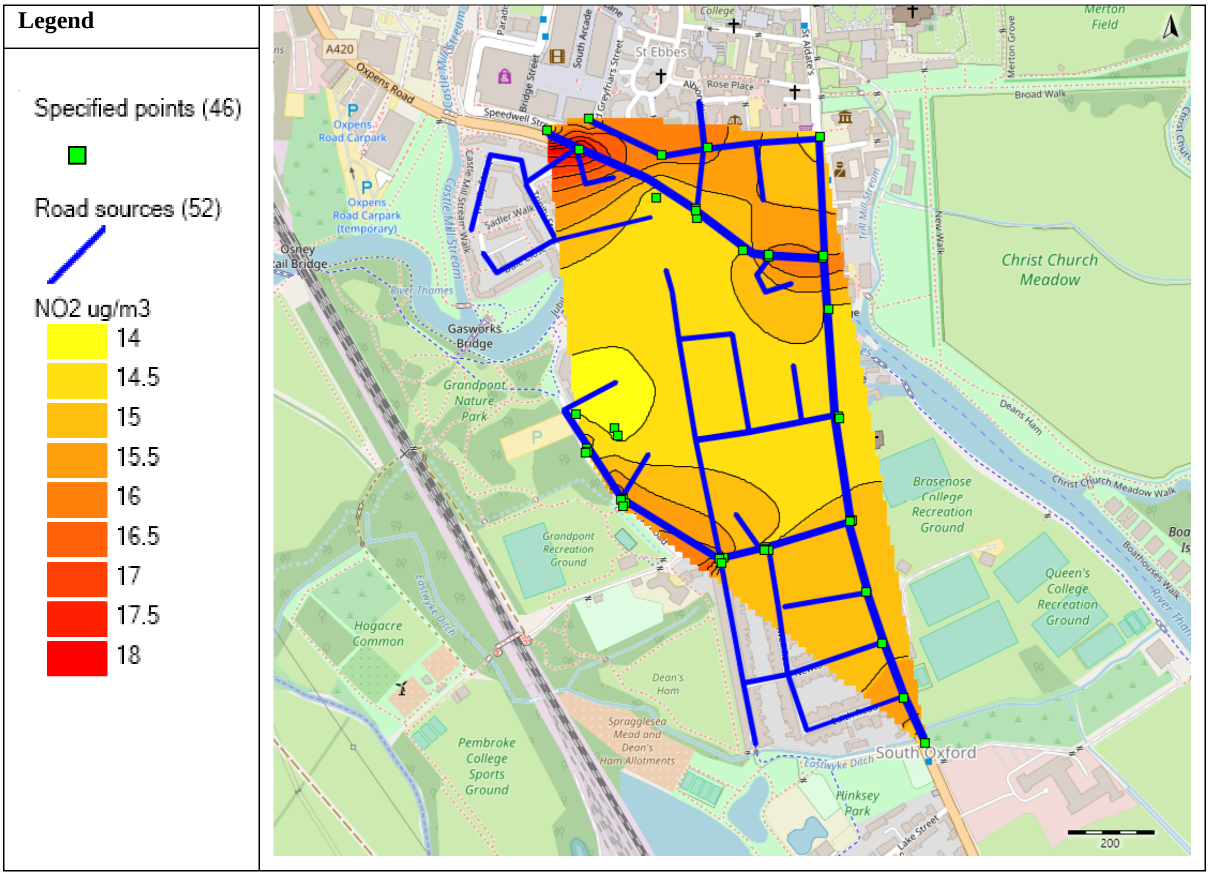

*Figure 110 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (400 m) on Oxford St Ebbe's site.*

Figure 111 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the LEZ (400 m) intervention. Compared to the baseline, concentrations throughout the centre of the site are largely reduced and peaks remain at the M1 roundabout at the A6178 junction.

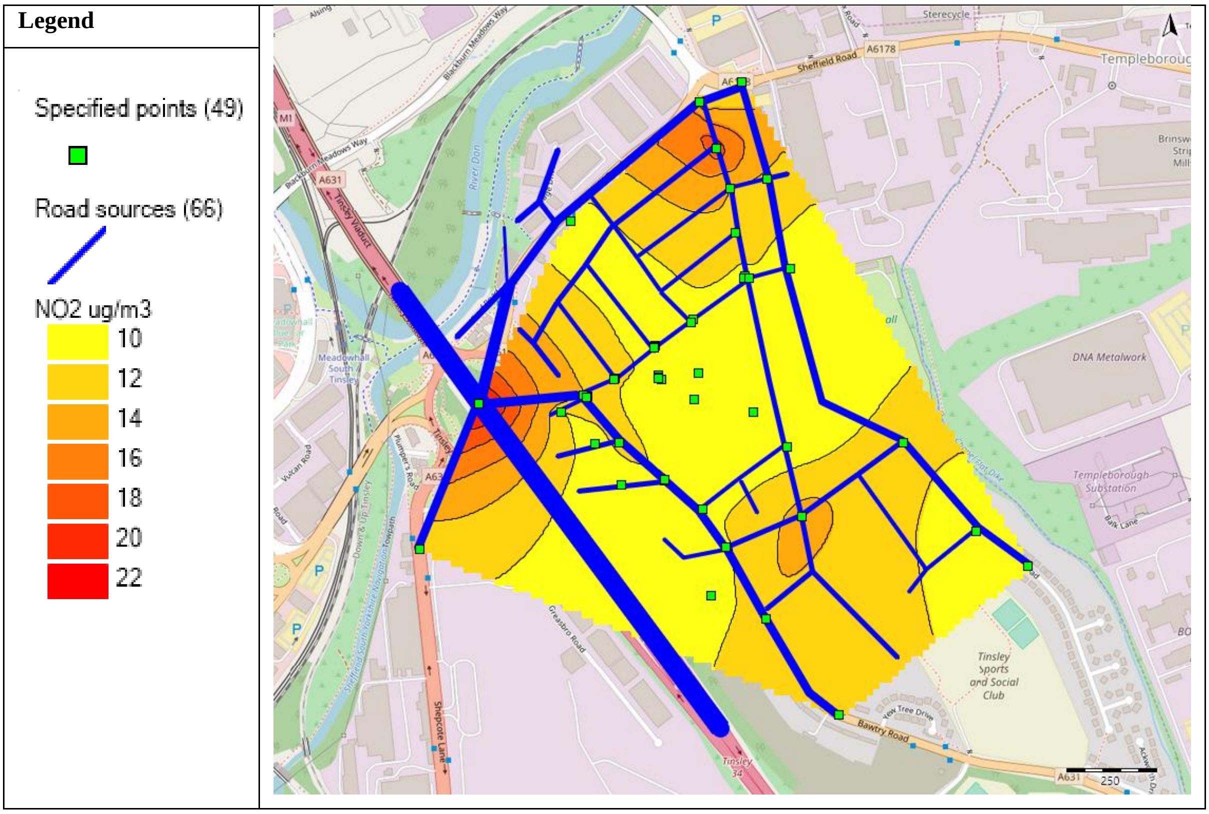

*Figure 111 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (400 m) on Sheffield Tinsley site.*

### 6.5.6.13 Contour Maps for Low Emission Zones (500 Metres)

Figure 112 depicts a contour map of Bristol St Paul's $NO_2$ concentrations (µg/m$^3$) following the LEZ (500 m) intervention. Compared to the baseline, substantial reductions are visible at the A38 south to Stokes Croft, at Wilder Street, and Bond Street. High concentrations persist at the A4320/M32 roundabout.

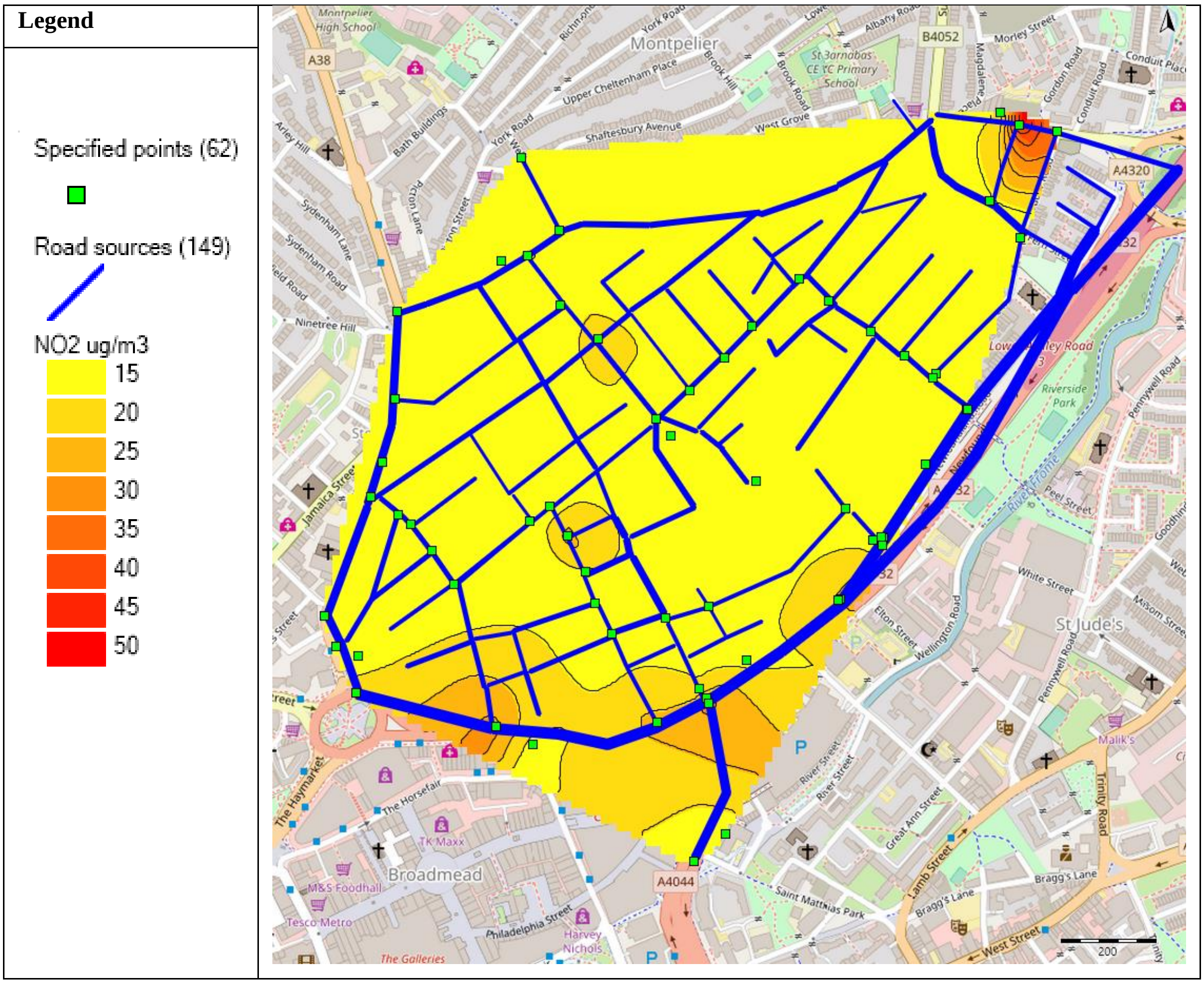

*Figure 112 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (500 m) on Bristol St Paul's site.*

Figure 113 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/m$^3$) following the LEZ (500 m) intervention. Compared to the baseline, reductions exist throughout the site, although highest concentrations persist in the west of the site at the A38/A3029 intersection, with graduated reductions emanating from this point.

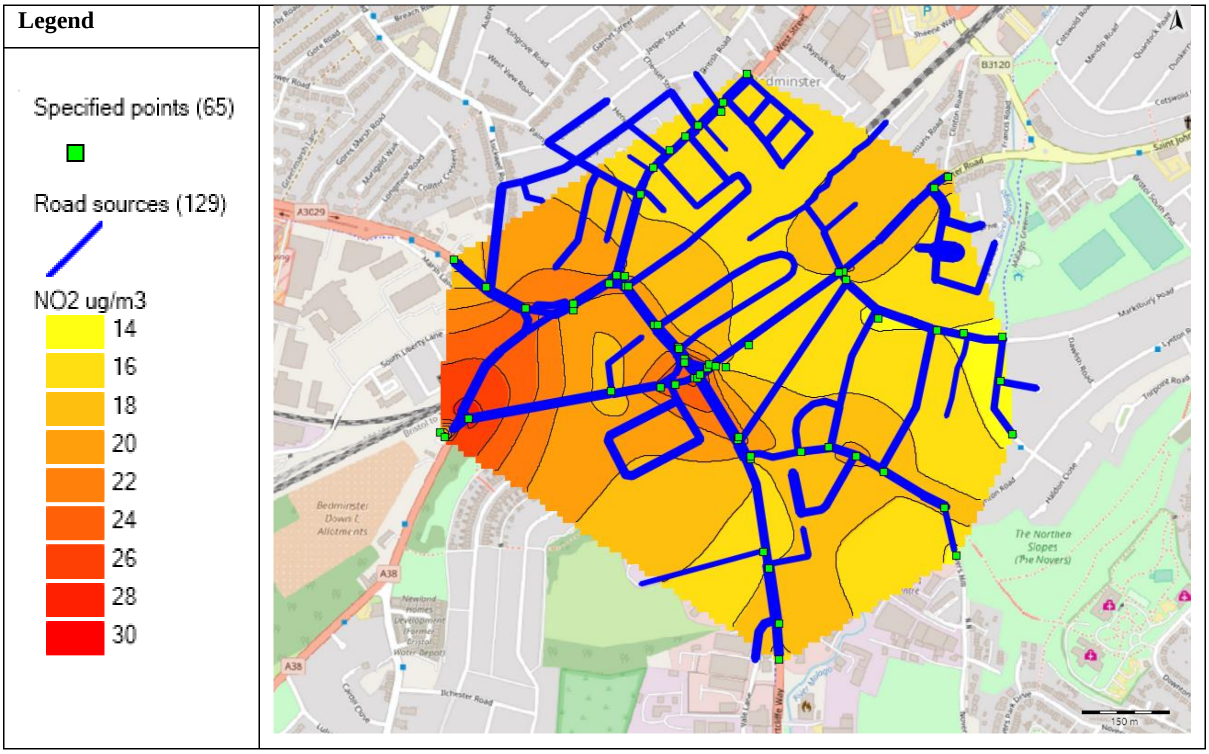

*Figure 113 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (500 m) on Bristol Bedminster site.*

Figure 114 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/m$^3$) following the LEZ (500 m) intervention. Compared to the baseline, prominent reductions are visible throughout the site, although peaks remain at the A4600.

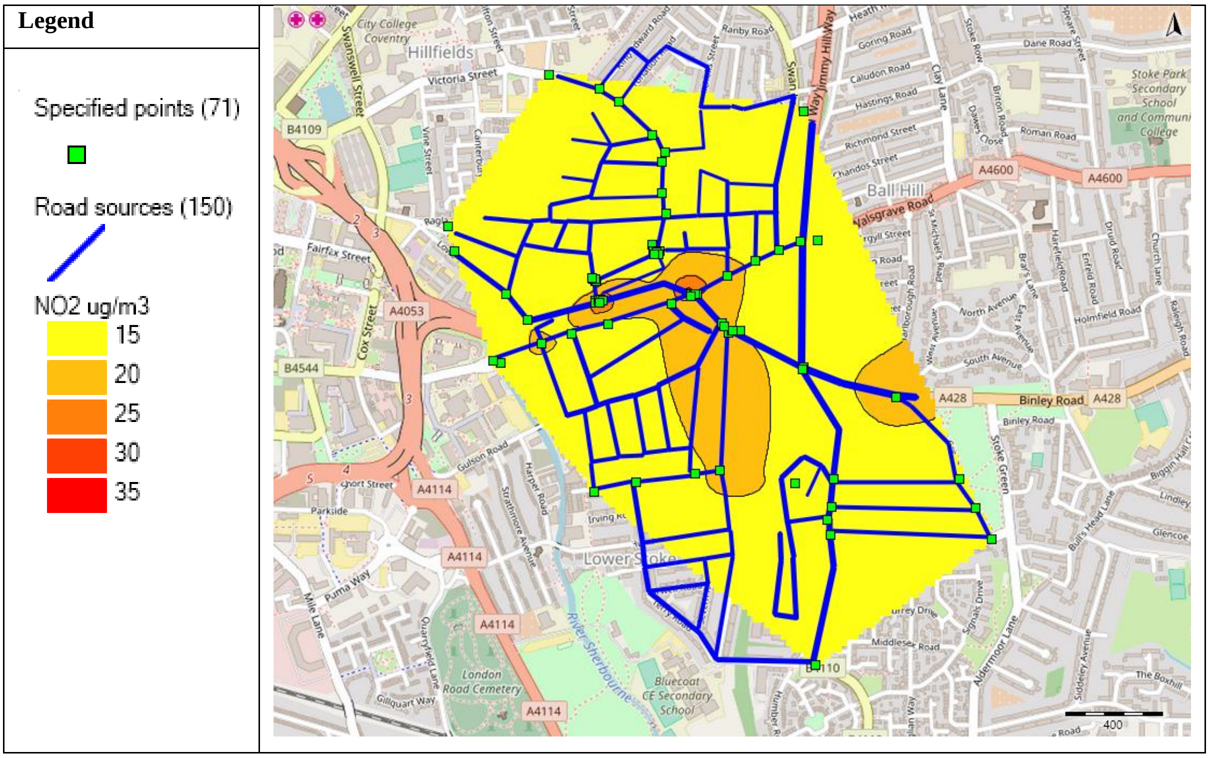

*Figure 114 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (500 m) on Coventry Binley site.*

Figure 115 depicts a contour map of Oxford St Ebbe's $NO_2$ concentrations (µg/m$^3$) following the LEZ (500 m) intervention. Compared to the baseline, substantial reductions are visible across the site. Peak concentrations remain at the A420 and St Ebbe's Primary School, although these are now substantially reduced.

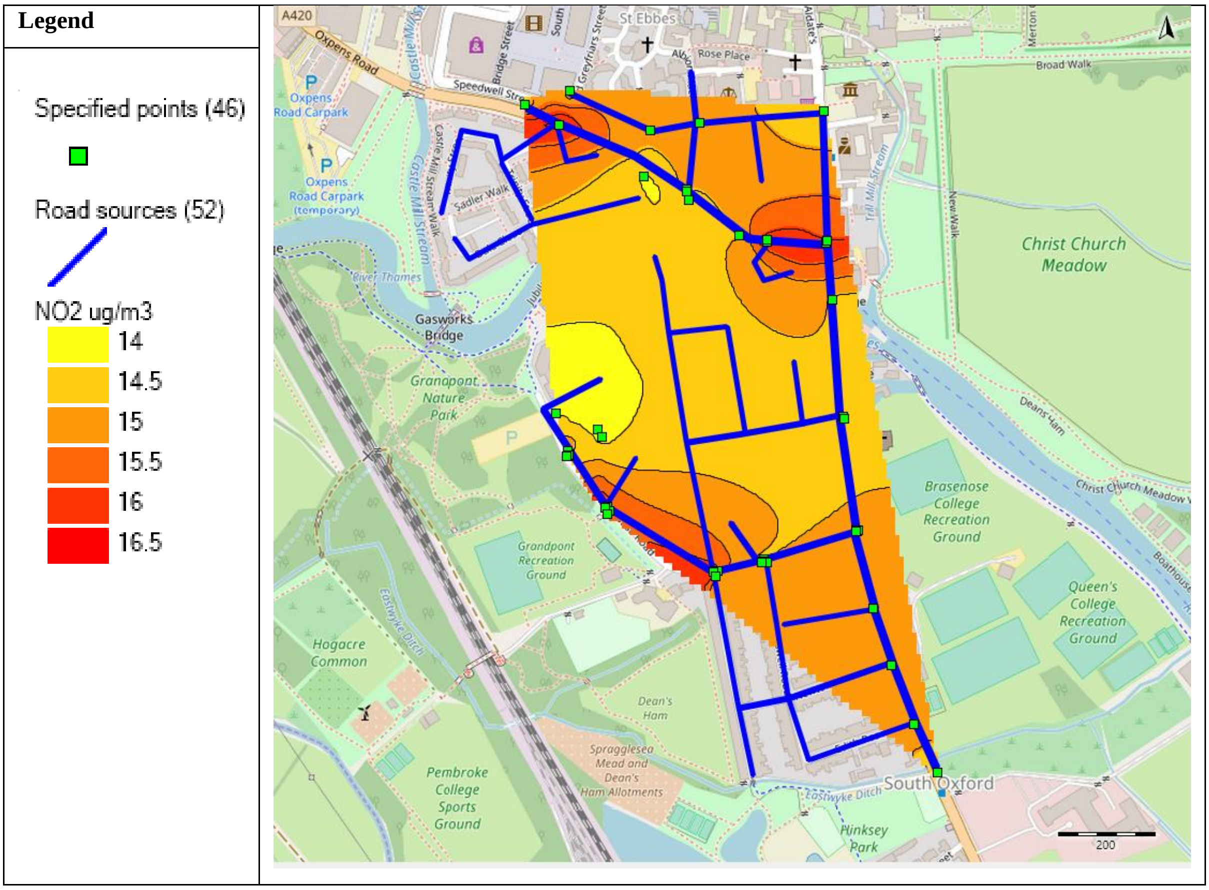

*Figure 115 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (500 m) on Oxford St Ebbe's site.*

Figure 116 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the LEZ (500 m) intervention. Compared to the baseline, concentrations are substantially reduced across the site. Peaks remain at the M1 and A6178, although graduations surrounding both peak points are increased.

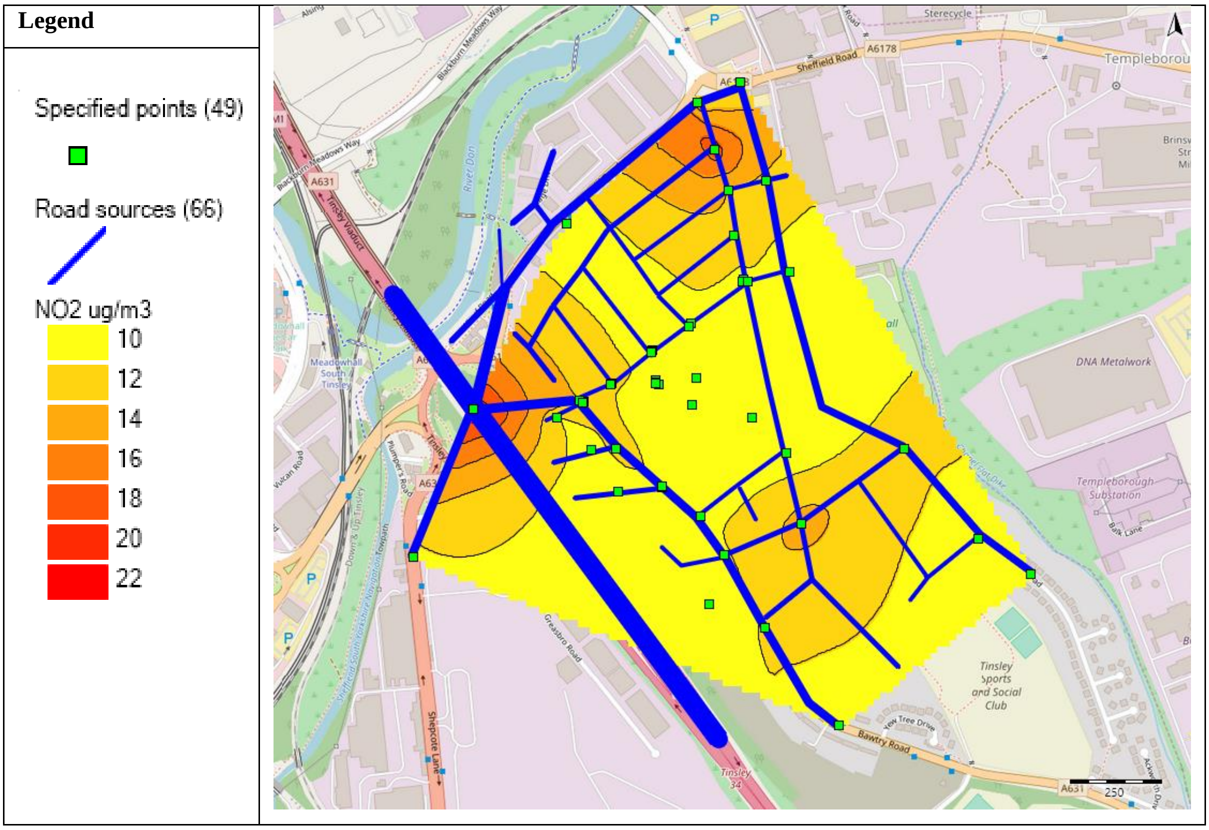

*Figure 116 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following LEZ (500 m) on Sheffield Tinsley site.*

### 6.5.7 Combined Interventions

#### 6.5.7.1 Overview

Combinations were modelled to determine any increased effectiveness of interventions. It was considered that any combination of intervention that used traffic reduction metrics in its modelling would be unreliable, as any further reductions would not be based on any known or verifiable value, such as the RAC statistic of 55% parent travel (RAC, 2020). To combine these interventions would require arbitrary calculations based on estimations of traffic reduction from different spheres of activity, so were dismissed. However, the improved travel routes could be combined effectively with the other interventions to assess their aggregate effectiveness. All original parameters remained the same, but the improved travel routes were combined with each other intervention to determine their combined effectiveness. The improved travel routes were additionally desirable because they demonstrated comparatively positive potential exposure reductions. The combination of improved travel routes with additional interventions had the effect of further reducing concentrations on each route and the overall mean concentrations of each site's combine travel routes. Given that no parameters were changed from the additional interventions, no difference was found for schools or other receptors external from the improved travel route receptors.

### 6.5.7.2 Improved Travel Routes & Active Travel

The active travel intervention was combined with improved travel routes to determine its effectiveness on the routes. Mean $NO_2$ (µg/m$^3$) values were calculated for all travel routes on all sites, and the differences against the site baselines were determined (Table 44).

*Table 44 Modelled mean $NO_2$ (µg/m$^3$) reductions of all improved travel routes when combined with active travel intervention.*

| | **Baseline** | **Post Intervention** | **Difference** | **% Reduction** |
|---|---|---|---|---|
| Travel Route Mean | 21.35 | 16.87 | 4.48 | 19.86 |

Figure 117 shows the overall differences on improved travel routes when combined with the active travel intervention, demonstrating a mean difference of 4.48 µg/m$^3$ and a reduction of 19.86% against the baseline.

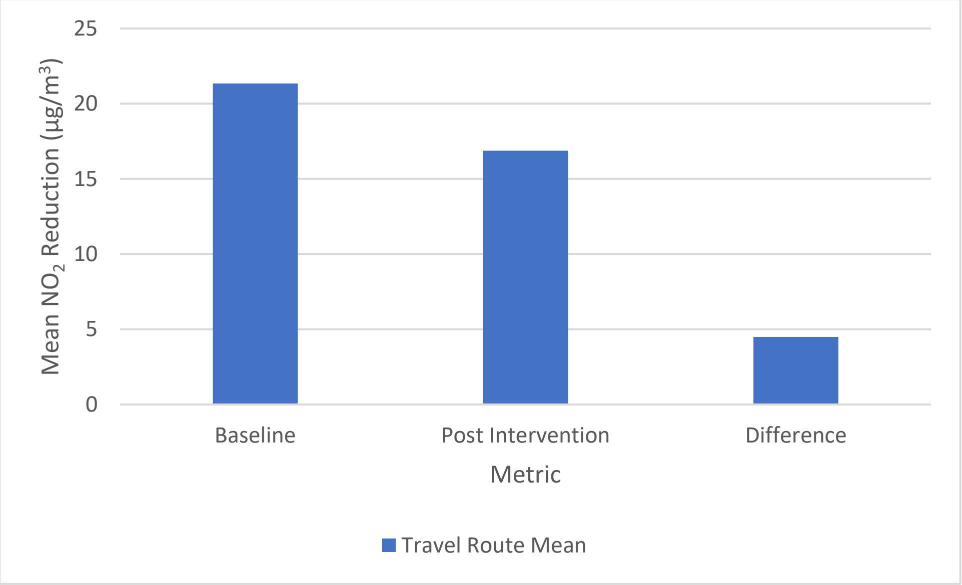

*Figure 117 Modelled mean $NO_2$ (µg/m$^3$) reductions of all improved travel routes when combined with active travel intervention.*

Table 45 shows the mean values of all improved travel routes at each site. The greatest reductions were found at Bristol St Paul’s, Bristol Bedminster, and Coventry Binley (24.58, 25.62, and 22.65%, respectively).

*Table 45 Modelled mean $NO_2$ (µg/m$^3$) reductions at all improved travel routes when combined with active travel intervention.*

| **Site** | **Mean Baseline $NO_2$ (µg/m$^3$)** | **Post Intervention $NO_2$ (µg/m$^3$)** | **Difference $NO_2$ (µg/m$^3$)** | **Reduction (%)** |
|---|---|---|---|---|
| Bristol St Paul’s | 26.33 | 19.86 | 6.47 | 24.58 |
| Bristol Bedminster | 25.35 | 18.86 | 6.50 | 25.62 |
| Coventry Binley | 22.81 | 17.65 | 5.17 | 22.65 |
| Oxford St Ebbe’s | 17.45 | 15.12 | 2.33 | 13.34 |
| Sheffield Tinsley | 14.79 | 12.85 | 1.94 | 13.13 |

Figure 118 shows the mean concentration reductions on the improved travel routes of each site. Bristol St Paul’s, Bristol Bedminster, and Coventry Binley are largely consistent in their reductions, and Oxford St Ebbe’s and Sheffield Tinsley show comparatively smaller reductions (13.34 and 13.13%, respectively).

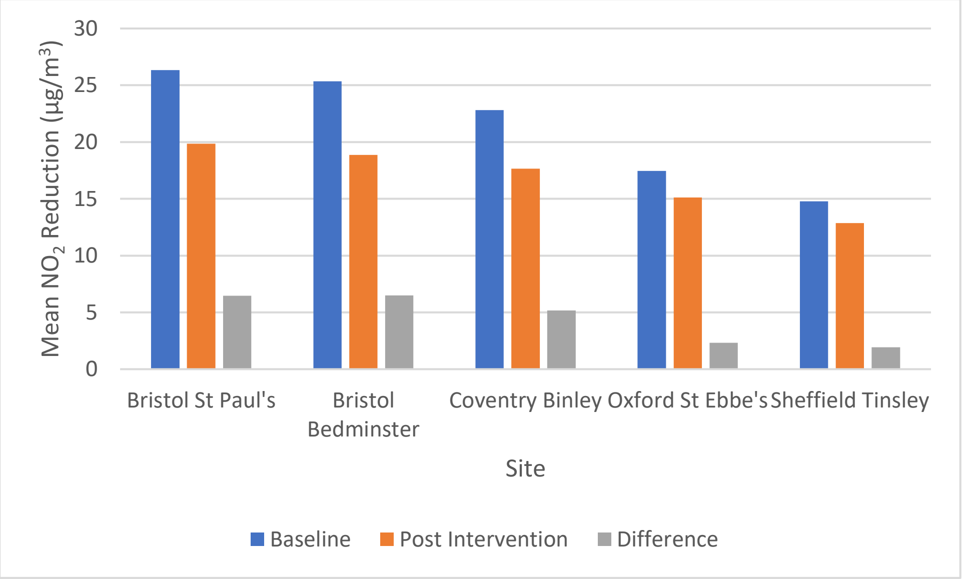

*Figure 118 Modelled mean $NO_2$ (µg/m$^3$) reductions at all improved travel routes when combined with active travel intervention.*

### 6.5.7.3 Contour Maps for Improved Travel Routes & Active Travel

Figure 119 depicts a contour map of Bristol St Paul's $NO_2$ concentrations (μg/m$^3$) following the combined improved travel routes and active travel intervention. Compared to the baseline, reductions are visible throughout the site, with the Wilder Street peak shifting towards the A38, and far lower concentrations at the south of the site near Bond Street and the M32.

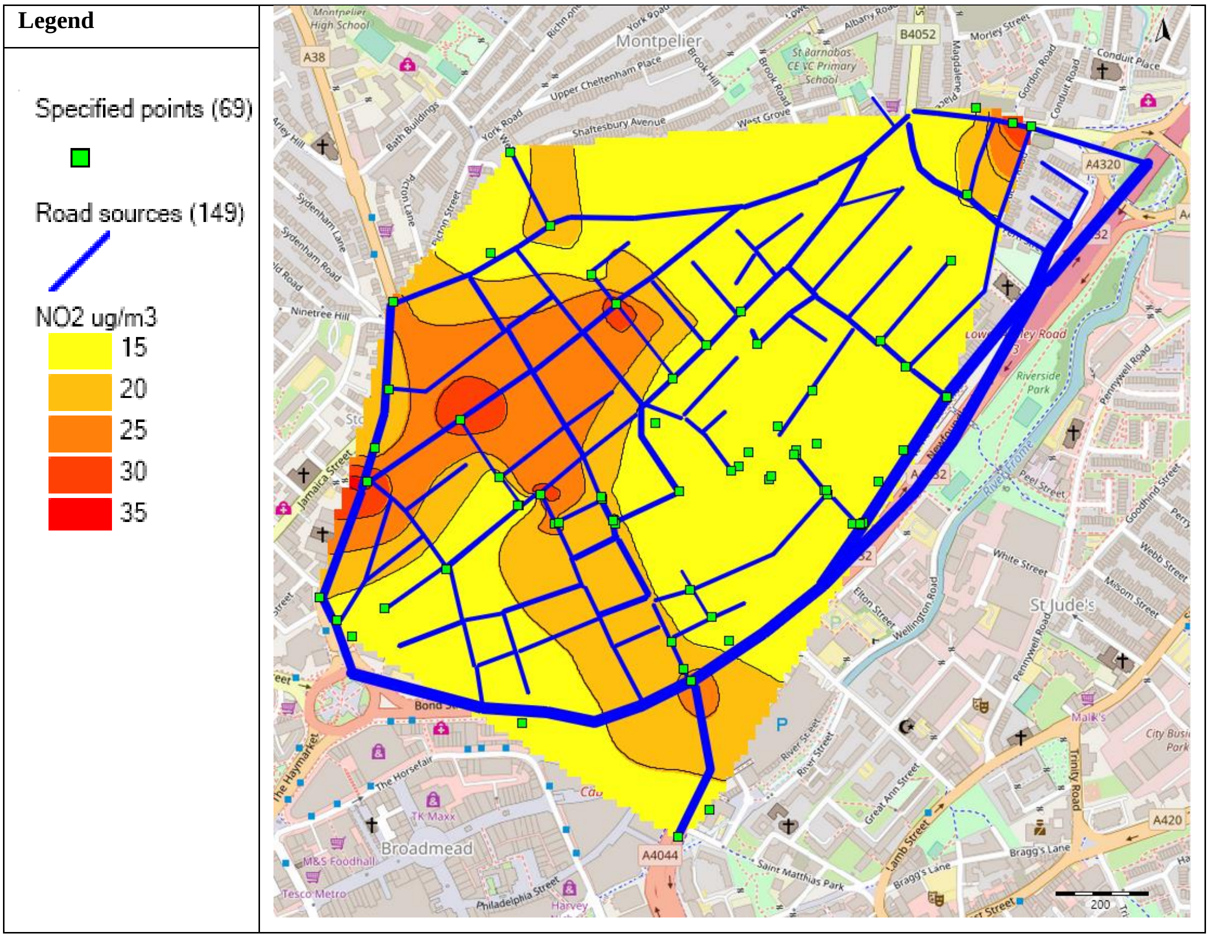

*Figure 119 Contour map showing modelled $NO_2$ (μg/m$^3$) concentrations following combined improved travel routes and active travel intervention at Bristol St Paul's site.*

Figure 120 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and active travel intervention. Compared to the baseline, far lower concentrations are visible throughout the site, with peak concentrations persisting to the west at the A38/A3029 intersection.

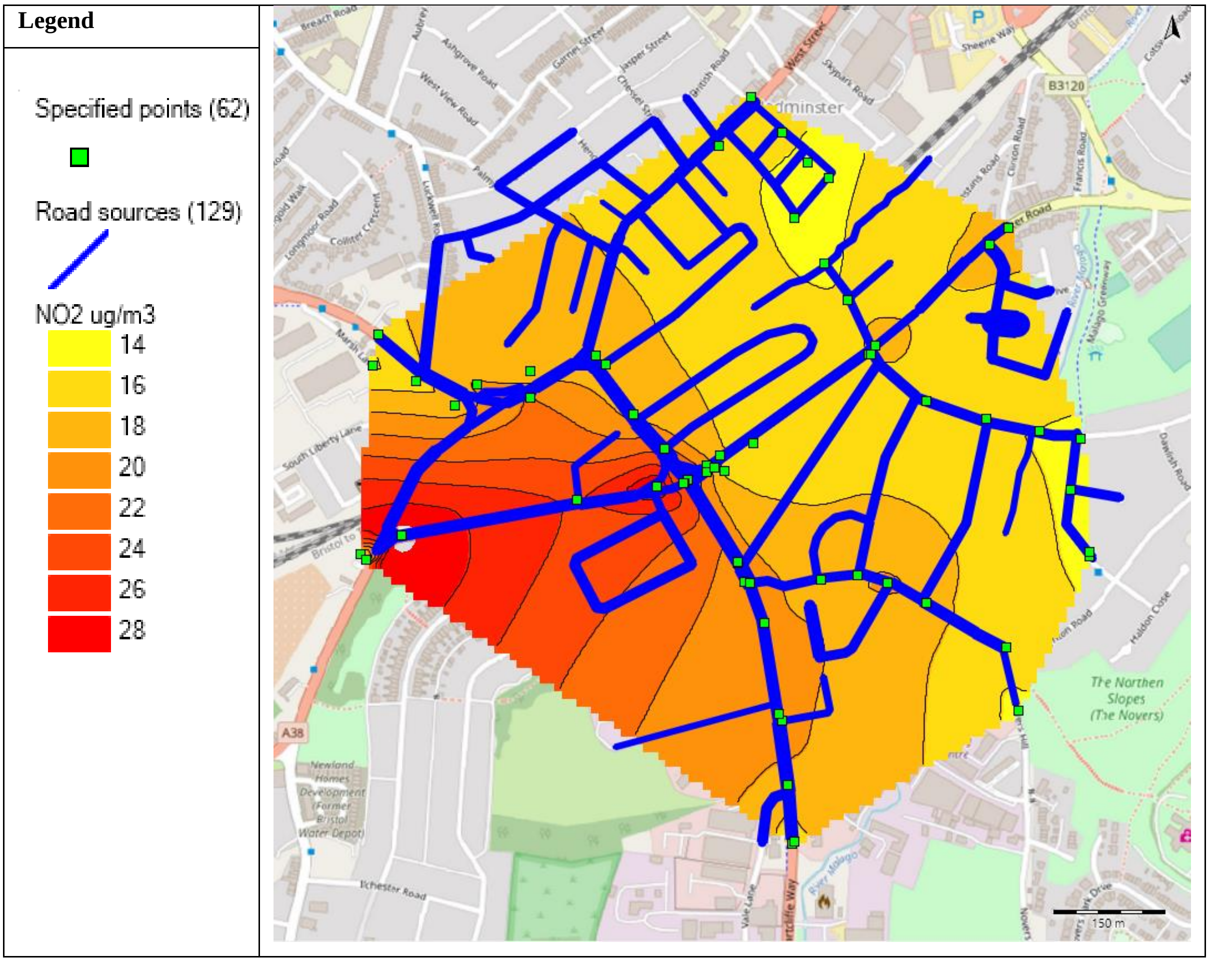

*Figure 120 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and active travel intervention at Bristol Bedminster site.*

Figure 121 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and active travel intervention. Compared to the baseline, concentrations throughout the site are substantially reduced, with peaks persisting along the A4600.

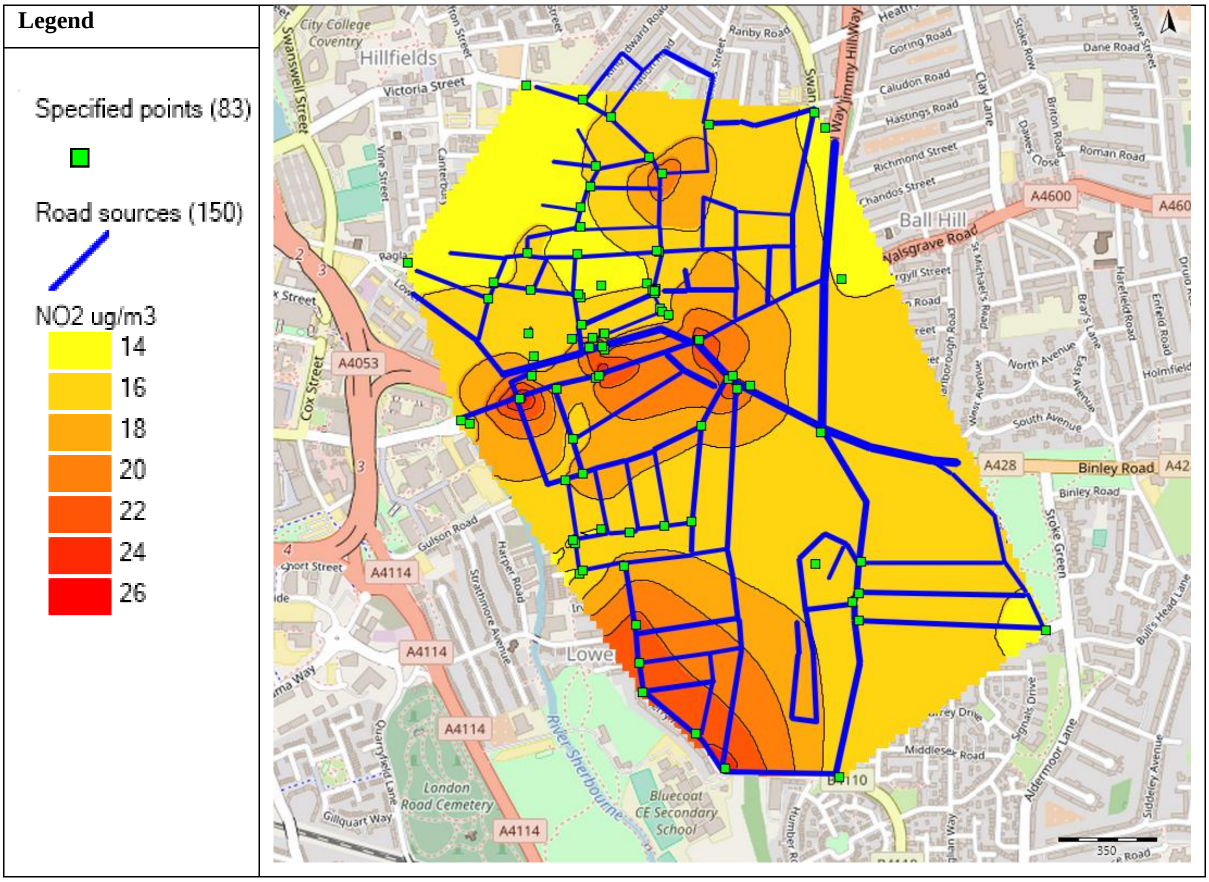

*Figure 121 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and active travel intervention at Coventry Binley site.*

Figure 122 depicts a contour map of Oxford St Ebbe’s $NO_2$ concentrations (µg/$m^3$) following the combined improved travel routes and active travel intervention. Compared to the baseline, concentrations are marginally reduced, with comparative peaks persisting at St Ebbe’s Primary School.

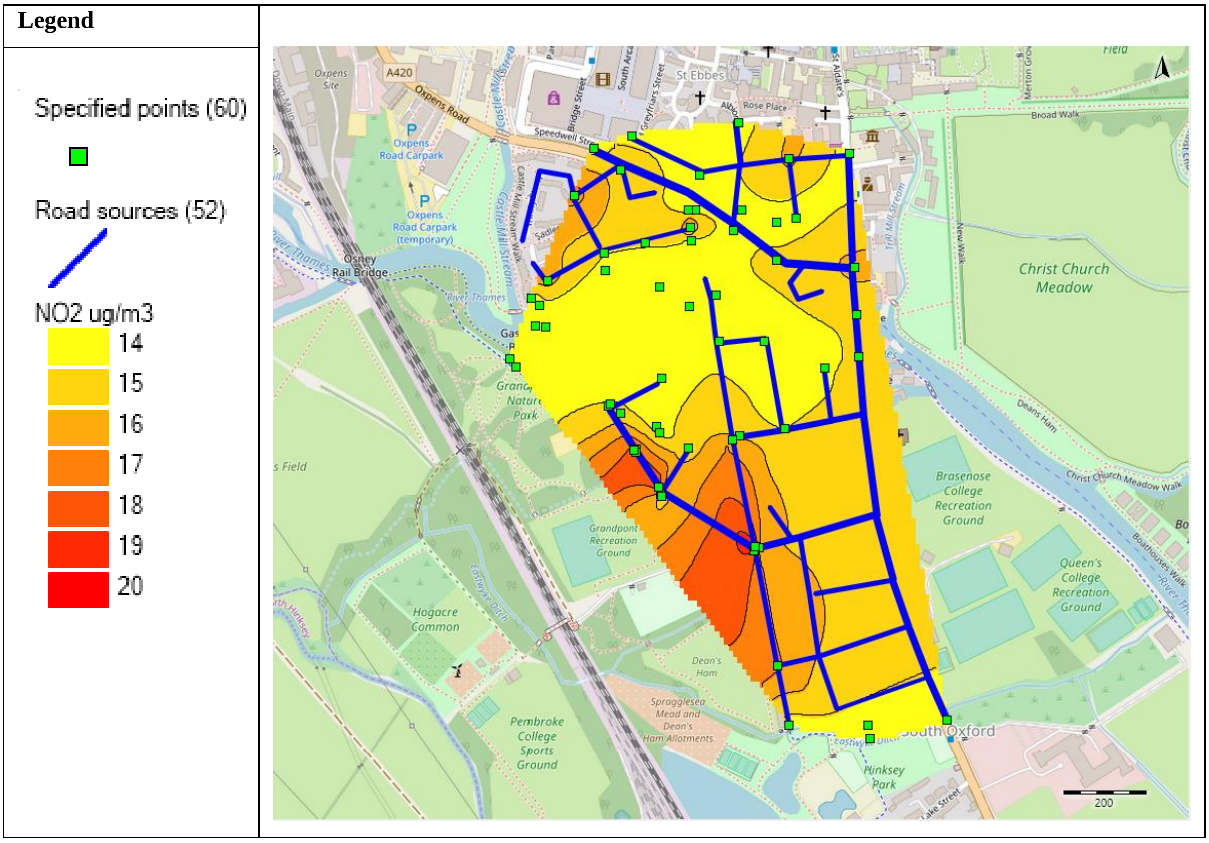

*Figure 122 Contour map showing modelled $NO_2$ (µg/$m^3$) concentrations following combined improved travel routes and active travel intervention at Oxford St Ebbe’s site.*

Figure 123 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and active travel intervention. Compared to the baseline, site concentrations are somewhat reduced, although the M1 roundabout peak has been flattened.

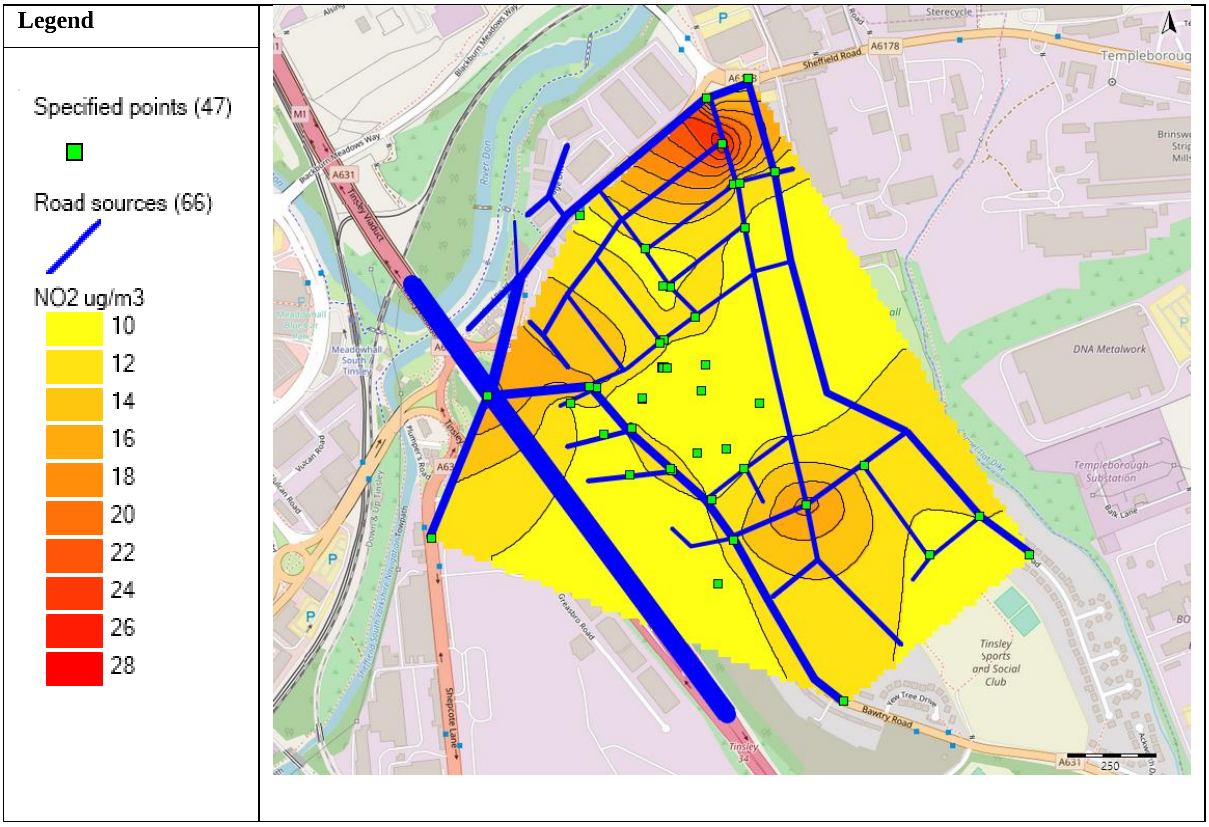

*Figure 123 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and active travel intervention at Sheffield Tinsley site.*

#### 6.5.7.4 Improved Travel Routes & Anti-Idling

The anti-idling intervention was combined with improved travel routes to determine its effectiveness on the routes. Mean $NO_2$ (µg/m$^3$) values were calculated for all travel routes on all sites, and the differences against the site baselines were determined (Table 46).

*Table 46 Modelled mean $NO_2$ (µg/m$^3$) reductions of all improved travel routes when combined with anti-idling intervention.*

| | Baseline | Post Intervention | Difference | % Reduction |
|---|---|---|---|---|
| Travel Route Mean | 21.35 | 17.46 | 3.89 | 17.47 |

Figure 124 shows the overall differences on improved travel routes when combined with the anti-idling intervention, demonstrating a mean difference of 3.89 µg/m$^3$ and a reduction of 17.47% against the baseline.

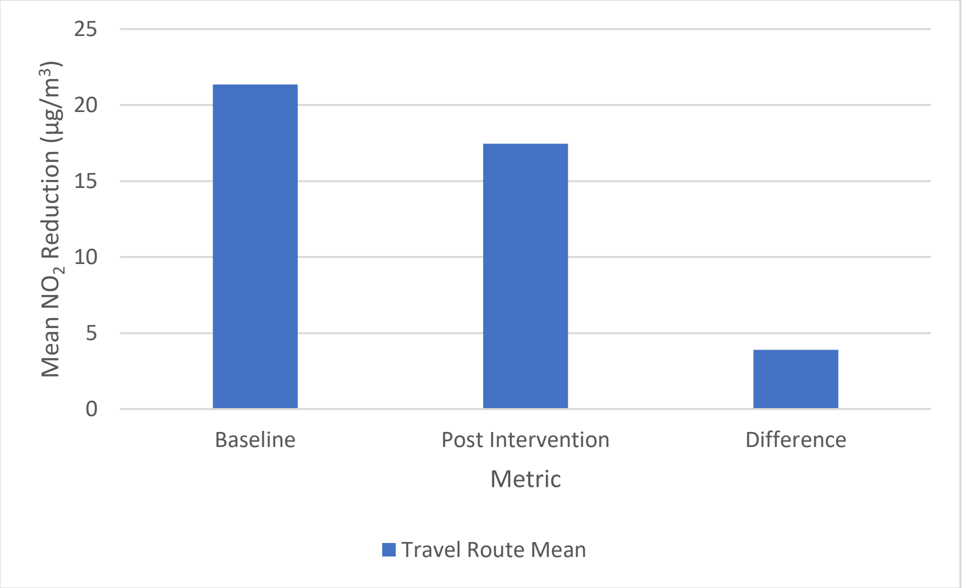

*Figure 124 Modelled mean $NO_2$ (µg/m$^3$) reductions of all improved travel routes when combined with anti-idling intervention.*

Table 47 shows the mean values of all improved travel routes at each site. The greatest proportional reductions were found at Bristol St Paul’s, Coventry Binley, and Bristol Bedminster (22.64%, 19.15%, and 19.05%, respectively).

*Table 47 Modelled mean $NO_2$ ($\mu g/m^3$) reductions at all improved travel routes when combined with anti-idling intervention.*

| Site | Baseline | Post Intervention | Difference | % Reduction |
|---|---|---|---|---|
| Bristol St Paul’s | 26.33 | 20.37 | 5.96 | 22.64 |
| Bristol Bedminster | 25.35 | 20.52 | 4.83 | 19.05 |
| Coventry Binley | 22.81 | 18.44 | 4.37 | 19.15 |
| Oxford St Ebbe’s | 17.45 | 15.06 | 2.39 | 13.70 |
| Sheffield Tinsley | 14.79 | 12.90 | 1.89 | 12.79 |

Figure 125 shows the mean concentration reductions on the improved travel routes of each site. Bristol St Paul’s, Bristol Bedminster, and Coventry Binley are largely consistent in their reductions, and Oxford St Ebbe’s and Sheffield Tinsley show comparatively smaller reductions (13.70% and 12.79%, respectively).

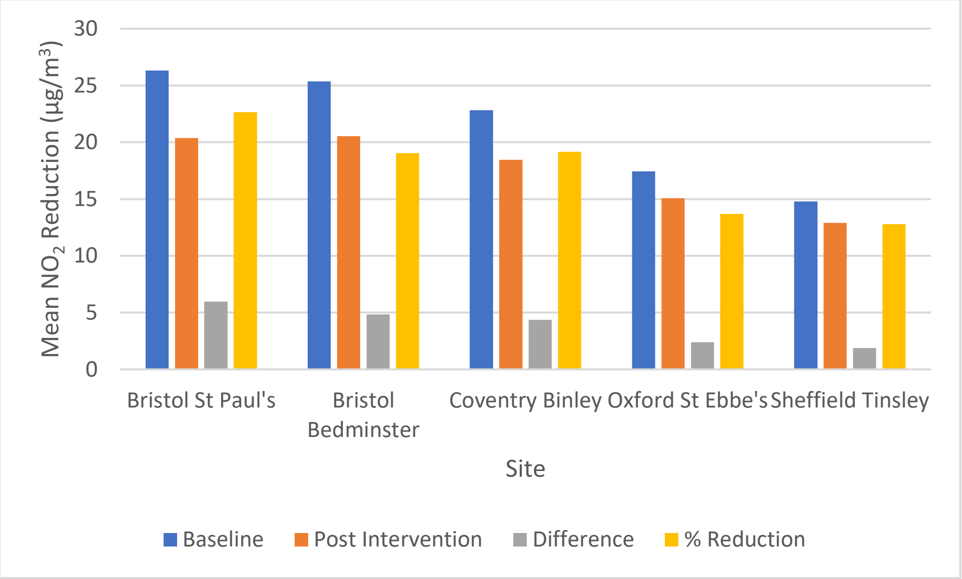

*Figure 125 Modelled mean $NO_2$ ($\mu g/m^3$) reductions at all improved travel routes when combined with anti-idling intervention.*

### 6.5.7.5 Contour Maps for Improved Travel Routes & Anti-Idling

Figure 126 depicts a contour map of Bristol St Paul’s $NO_2$ concentrations ($\mu g/m^3$) following the combined improved travel routes and anti-idling intervention. Compared to the baseline, concentrations are largely reduced throughout the site, although peaks persist towards the northeast of the site at the A4320/M32 roundabout.

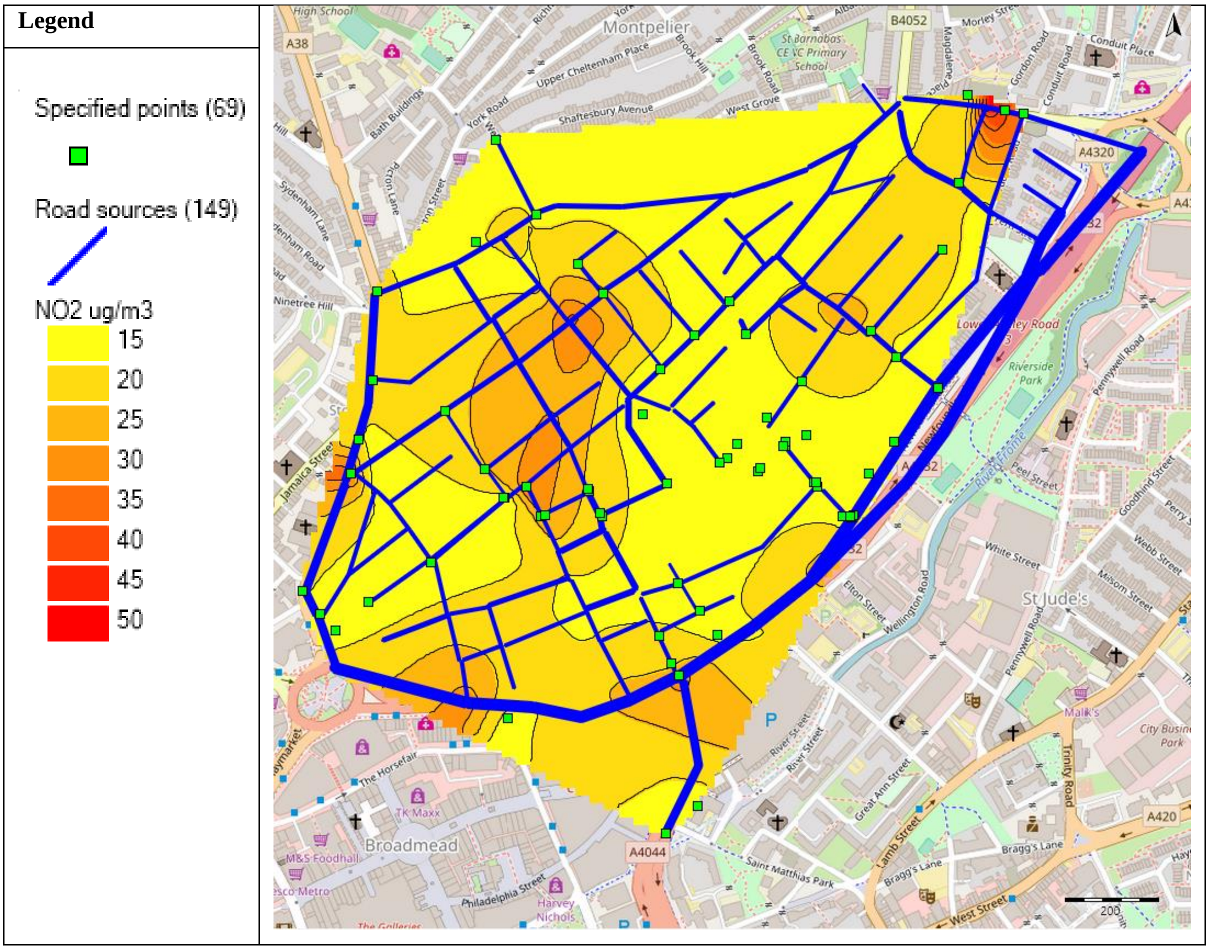

*Figure 126 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following combined improved travel routes and anti-idling intervention at Bristol St Paul’s site.*

Figure 127 depicts a contour map of Bristol Bedminster $NO_2$ concentrations ($\mu g/m^3$) following the combined improved travel routes and anti-idling intervention. Compared to the baseline, concentrations are reduced throughout the site, with peaks persisting at the A38/A3029 intersection, although these are both reduced and graduated towards the centre of the site.

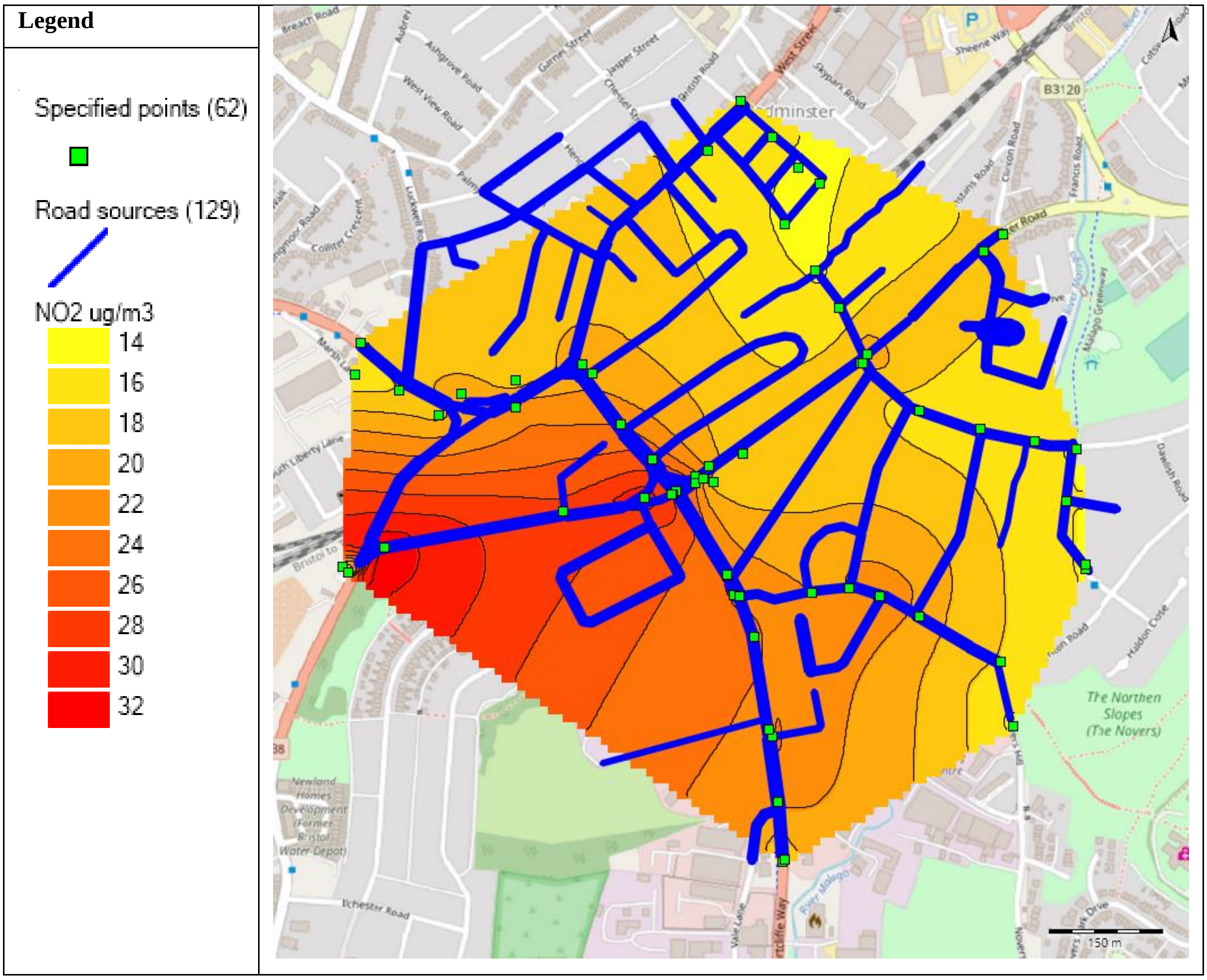

*Figure 127 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following combined improved travel routes and anti-idling intervention at Bristol Bedminster site.*

Figure 128 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and anti-idling intervention. Compared to the baseline, concentrations are reduced throughout the site, although a peak is now visible towards the south of the site where previously there were no receptors.

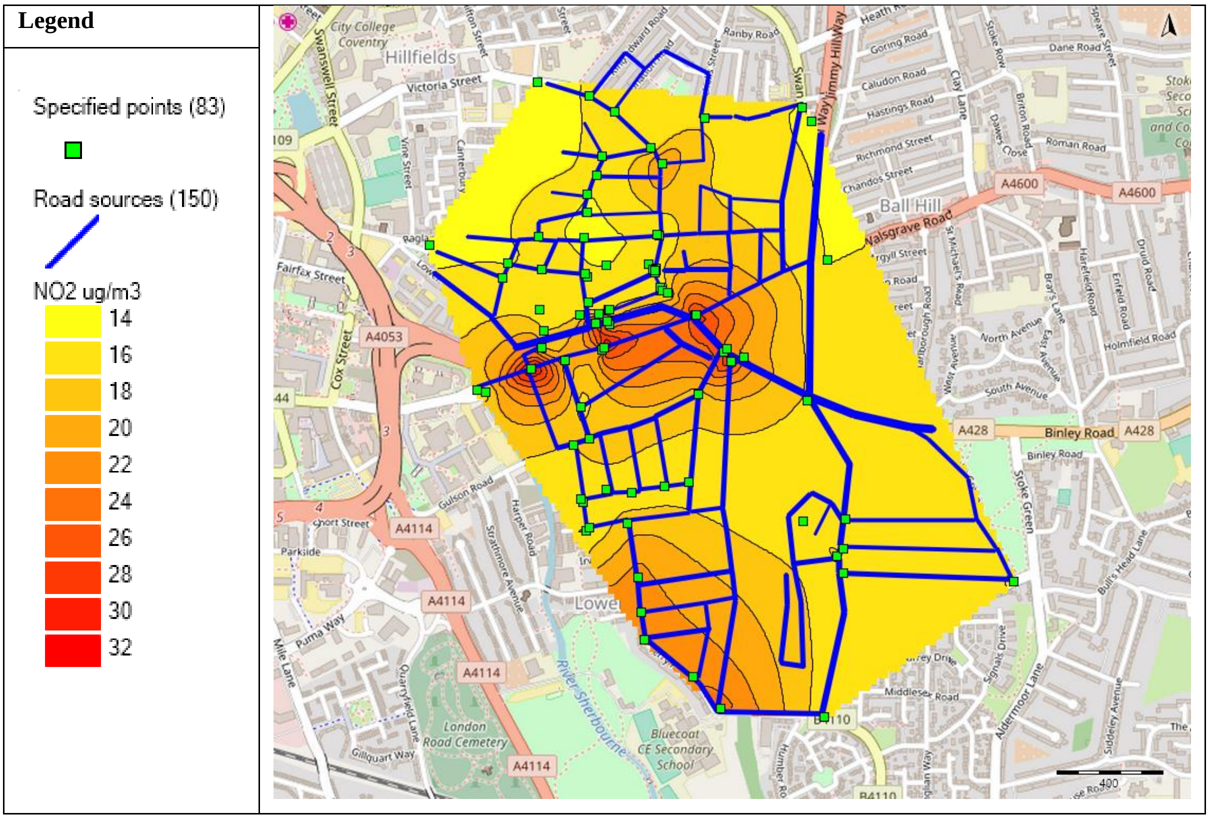

*Figure 128 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and anti-idling intervention at Coventry Binley site.*

Figure 129 depicts a contour map of Oxford St Ebbe's $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and anti-idling intervention. Compared to the baseline, concentrations are lower across the site, although a peak now exists at the south of the site where previously there were no receptors.

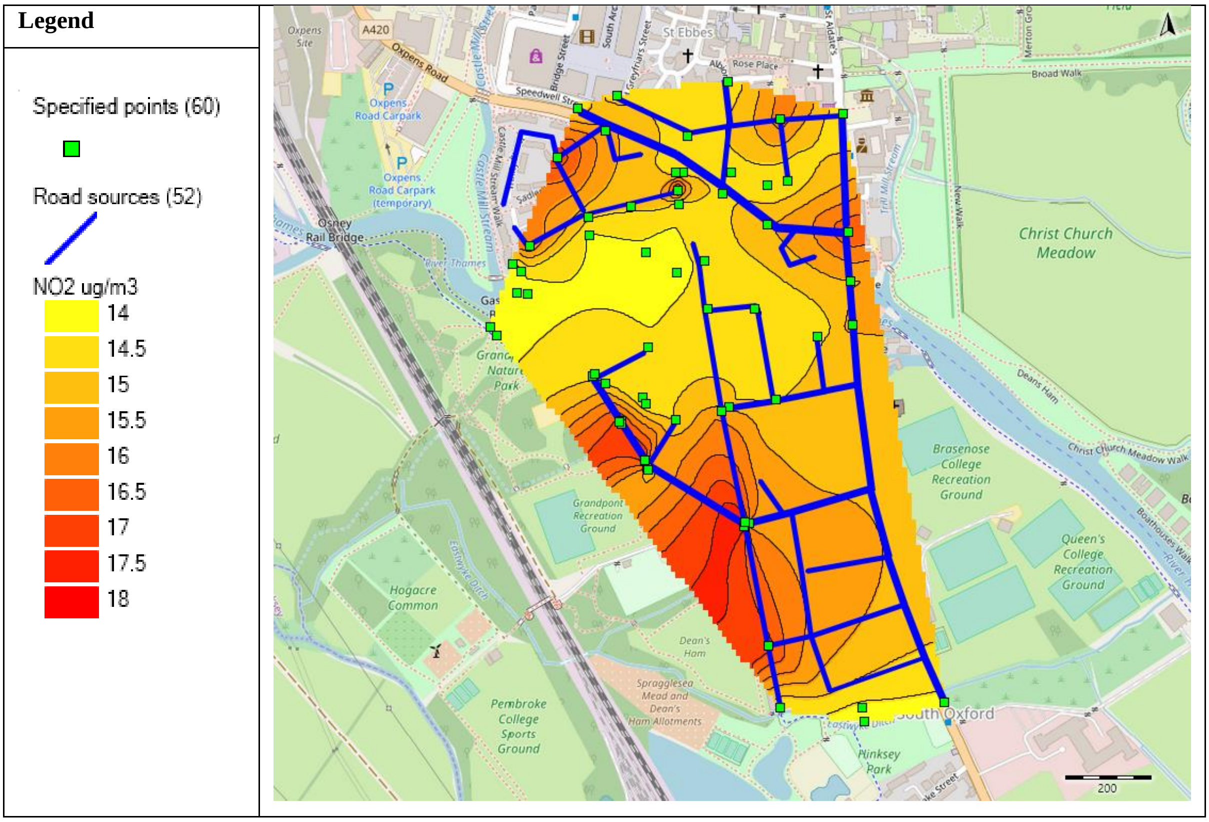

*Figure 129 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and anti-idling intervention at Oxford St Ebbe's site.*

Figure 130 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and anti-idling intervention. Compared to the baseline, concentrations are generally lower throughout the site, and the M1 roundabout peak is flattened.

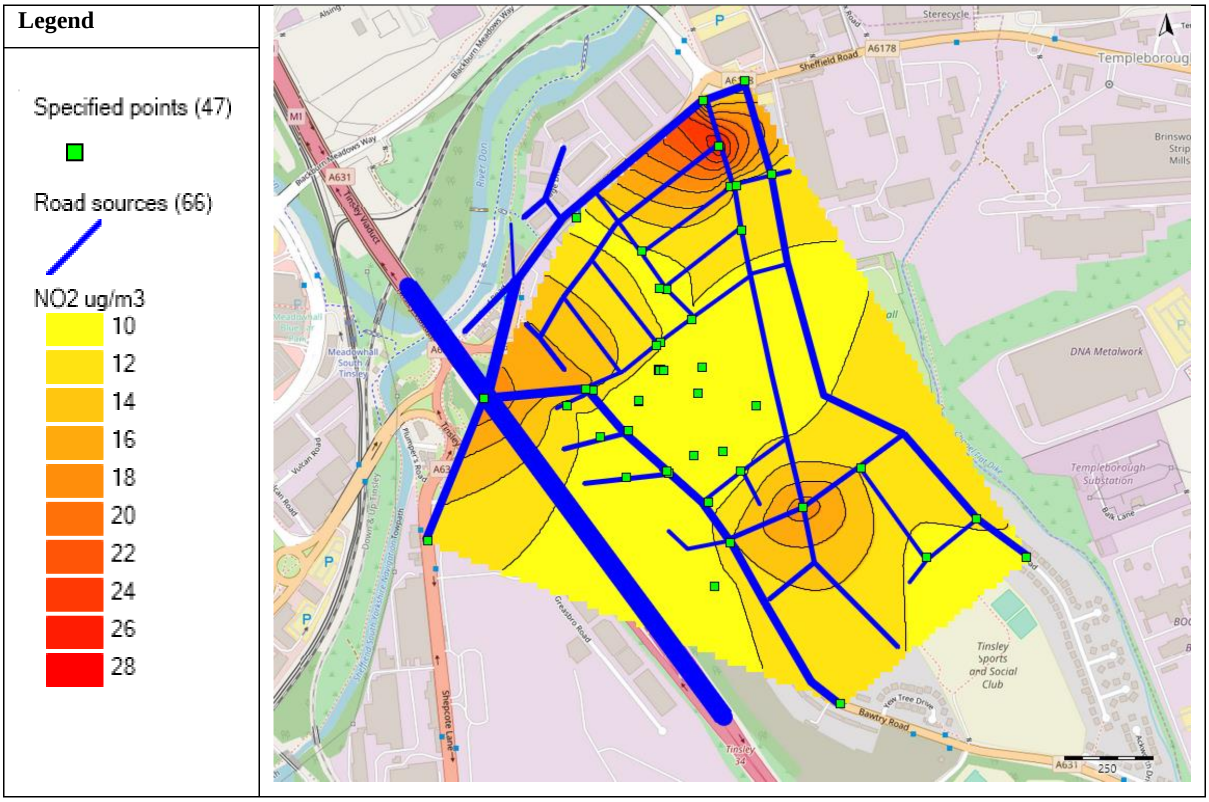

*Figure 130 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and anti-idling intervention at Sheffield Tinsley site.*

### 6.5.7.6 Improved Travel Routes & Rideshare

The rideshare intervention was combined with improved travel routes to determine its effectiveness on the routes. Mean $NO_2$ (µg/m$^3$) values were calculated for all travel routes on all sites and the differences against the site baselines were determined (Table 48).

*Table 48 Modelled mean $NO_2$ (µg/m$^3$) reductions of all improved travel routes when combined with rideshare intervention.*

| | **Baseline** | **Post Intervention** | **Difference** | **% Reduction** |
|---|---|---|---|---|
| Travel Route Mean | 21.35 | 16.89 | 4.46 | 19.86 |

Figure 131 shows the overall differences on improved travel routes when combined with the rideshare intervention, demonstrating a mean difference of 4.46 µg/m$^3$ and a reduction of 19.86% against the baseline.

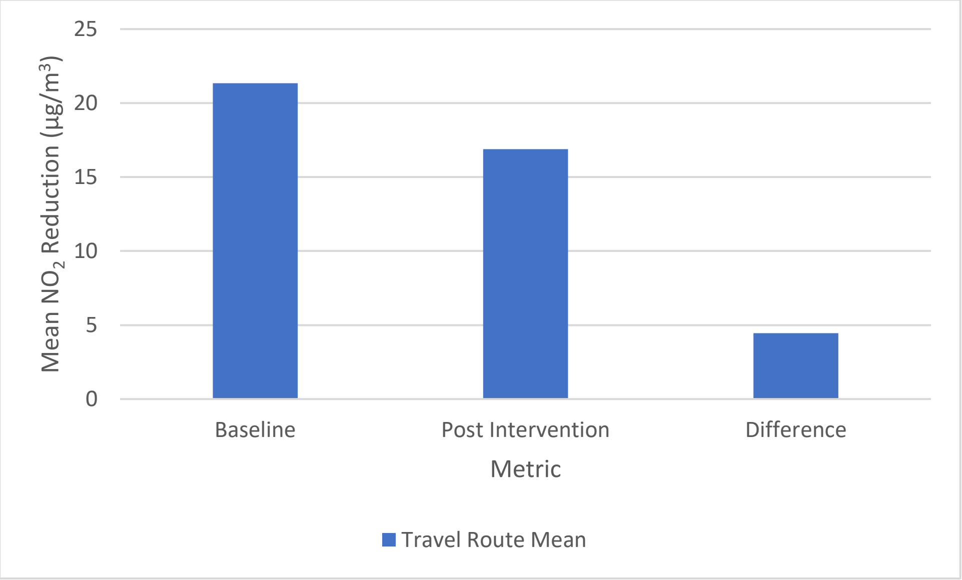

*Figure 131 Modelled mean $NO_2$ (µg/m$^3$) reductions of all improved travel routes when combined with rideshare intervention.*

Table 49 shows the mean values of all improved travel routes at each site. The greatest reductions were found at Bristol St Paul’s, Bristol Bedminster, and Coventry Binley (25.15, 24.21, and 22.00%, respectively).

*Table 49 Modelled mean $NO_2$ (µg/m$^3$) reductions at all improved travel routes when combined with rideshare intervention.*

| **Site** | **Mean Baseline $NO_2$ (µg/m$^3$)** | **Post Intervention $NO_2$ (µg/m$^3$)** | **Difference $NO_2$ (µg/m$^3$)** | **Reduction (%)** |
|---|---|---|---|---|
| Bristol St Paul’s | 26.33 | 19.71 | 6.62 | 25.15 |
| Bristol Bedminster | 25.35 | 19.22 | 6.14 | 24.21 |
| Coventry Binley | 22.81 | 17.79 | 5.02 | 22.00 |
| Oxford St Ebbe’s | 17.45 | 15.03 | 2.42 | 13.85 |
| Sheffield Tinsley | 14.79 | 12.71 | 2.08 | 14.08 |

Figure 132 shows the mean concentration reductions on the improved travel routes of each site. Bristol St Paul’s, Bristol Bedminster, and Coventry Binley are largely consistent in their reductions, and Oxford St Ebbe’s and Sheffield Tinsley show comparatively small reductions (13.85 and 14.08%, respectively).

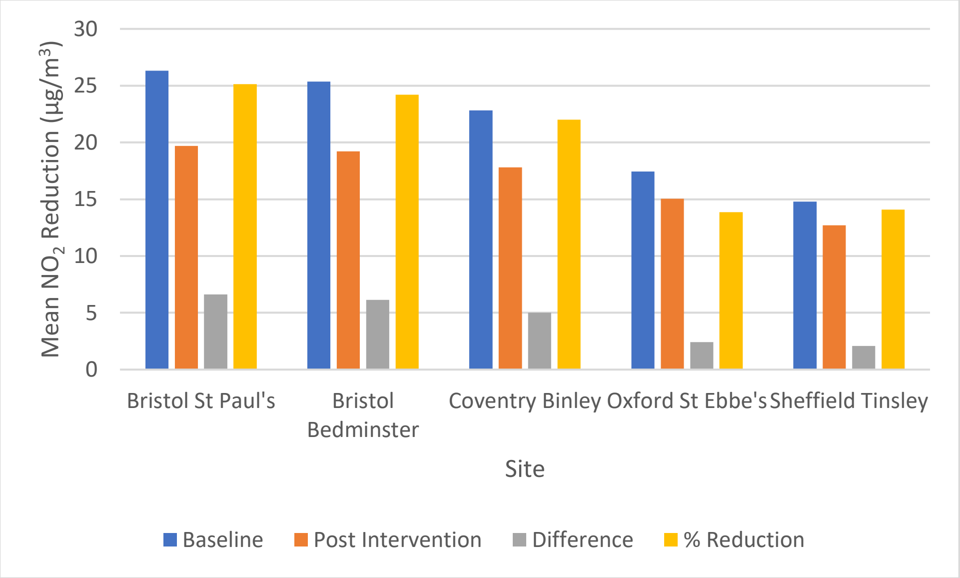

*Figure 132 Modelled mean $NO_2$ (µg/m$^3$) reductions at all improved travel routes when combined with rideshare intervention.*

### 6.5.7.7 Contour Maps for Improved Travel Routes & Rideshare

Figure 133 depicts a contour map of Bristol St Paul’s $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and rideshare intervention. Compared to the baseline, reductions are visible throughout the site, although peaks persist in the northeast at the A4320/M32 roundabout.

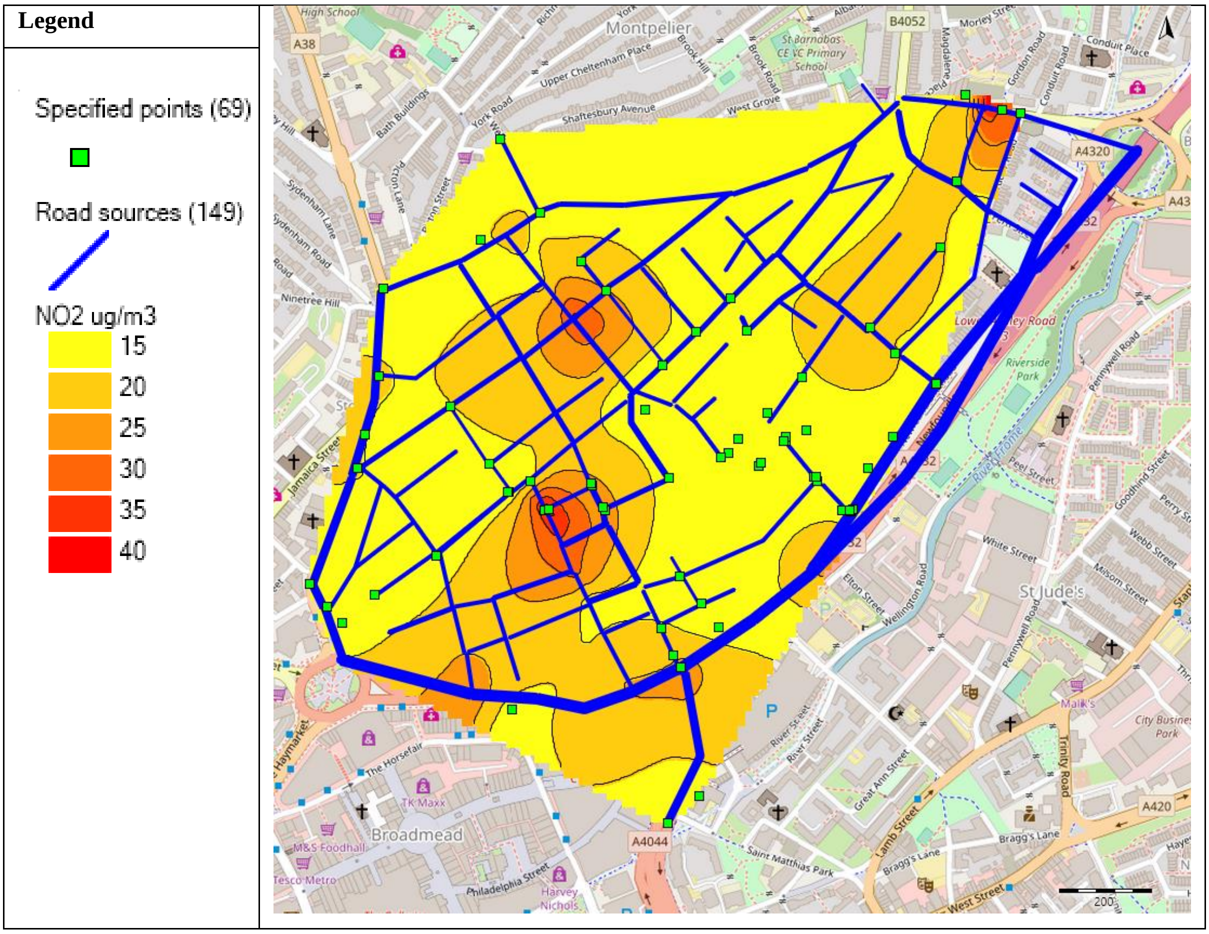

*Figure 133 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and rideshare intervention at Bristol St Paul’s site.*

Figure 134 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and rideshare intervention. Compared to the baseline, substantial concentration reductions are visible throughout the site, with a peak persisting at the A38/A3029 intersection.

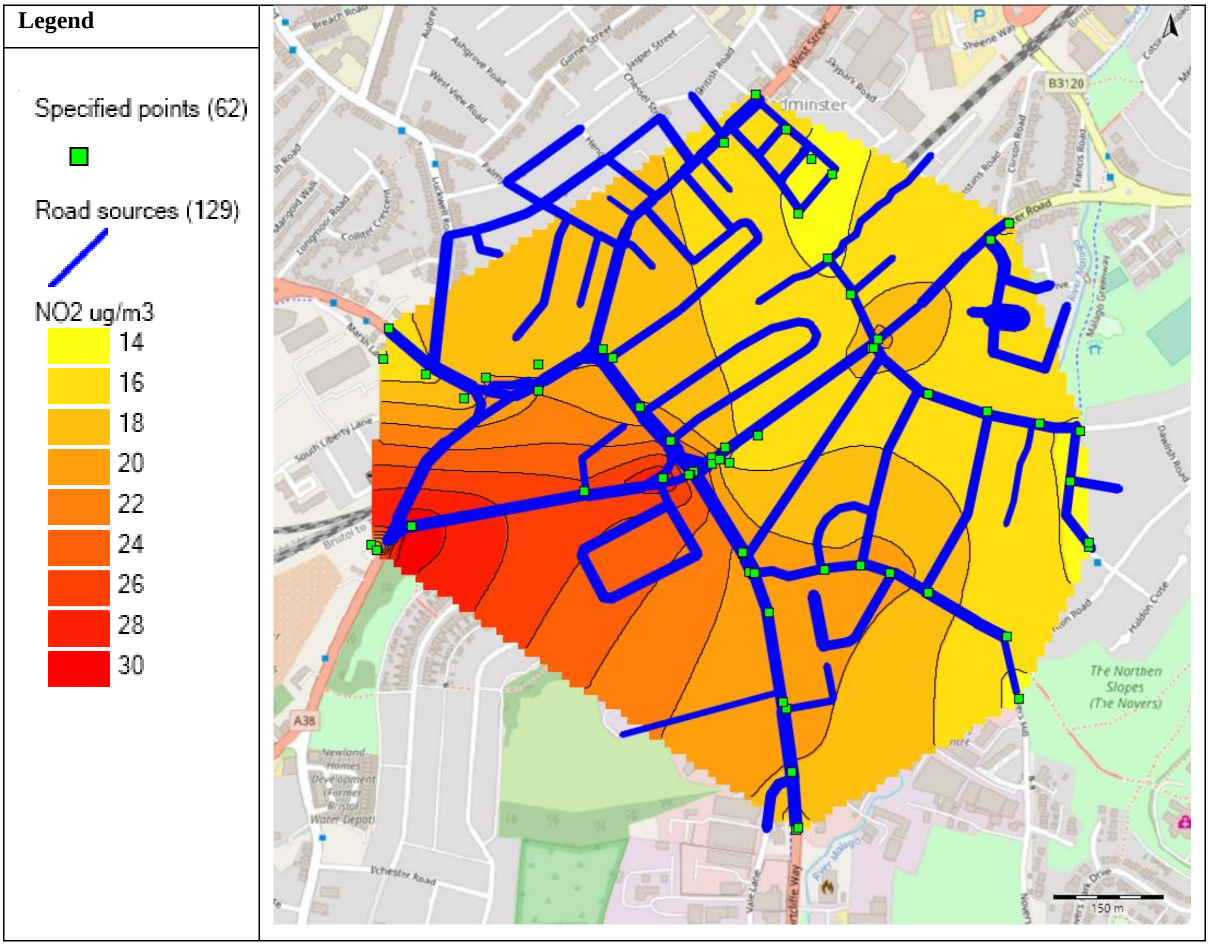

*Figure 134 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and rideshare intervention at Bristol Bedminster site.*

Figure 135 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and rideshare intervention. Compared to the baseline, substantial reductions are visible across the site, with peaks persisting in the centre on the A4053 from the west to the junction on the A4600.

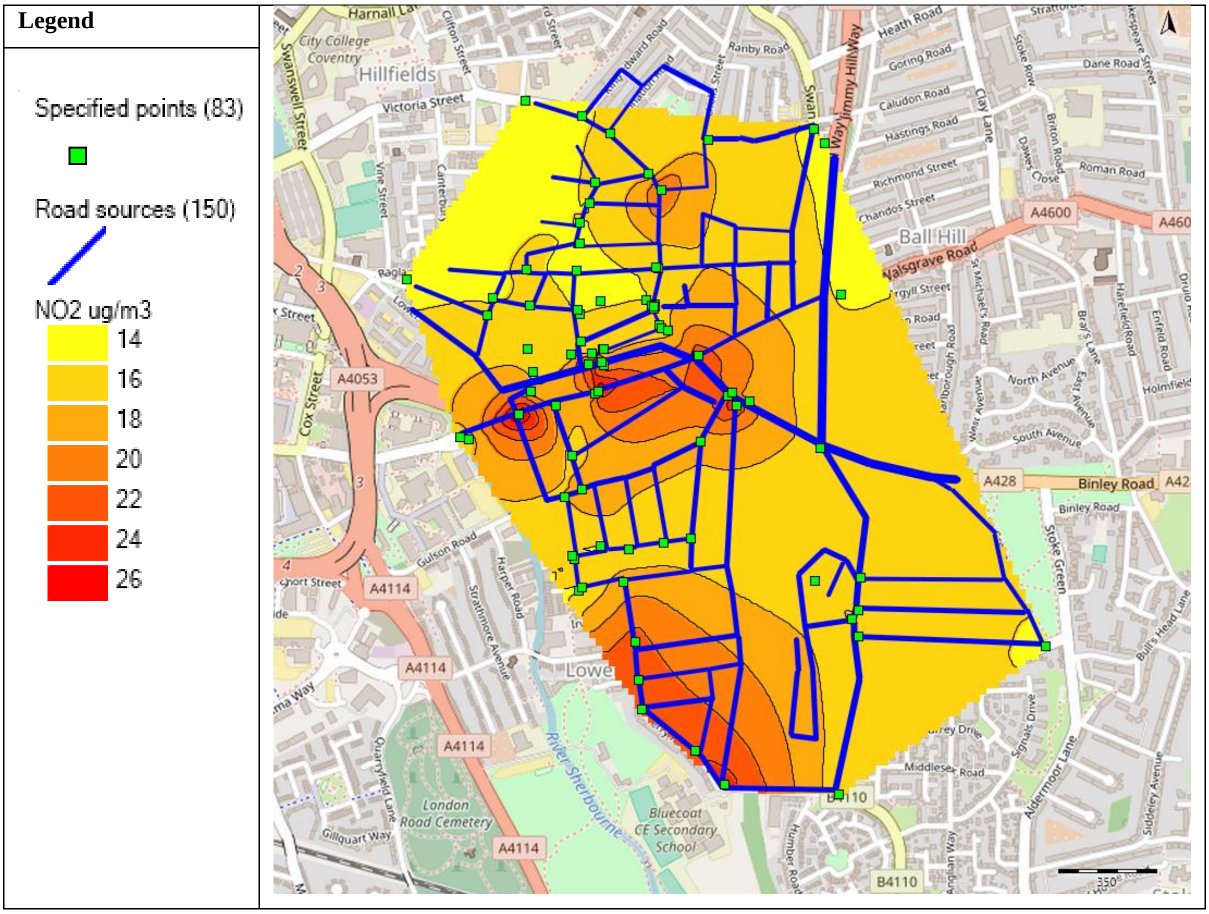

*Figure 135 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and rideshare intervention at Coventry Binley site.*

Figure 136 depicts a contour map of Oxford St Ebbe’s $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and rideshare intervention. Compared to the baseline, marginal concentration reductions are visible throughout the site, with peaks persisting in the south west.

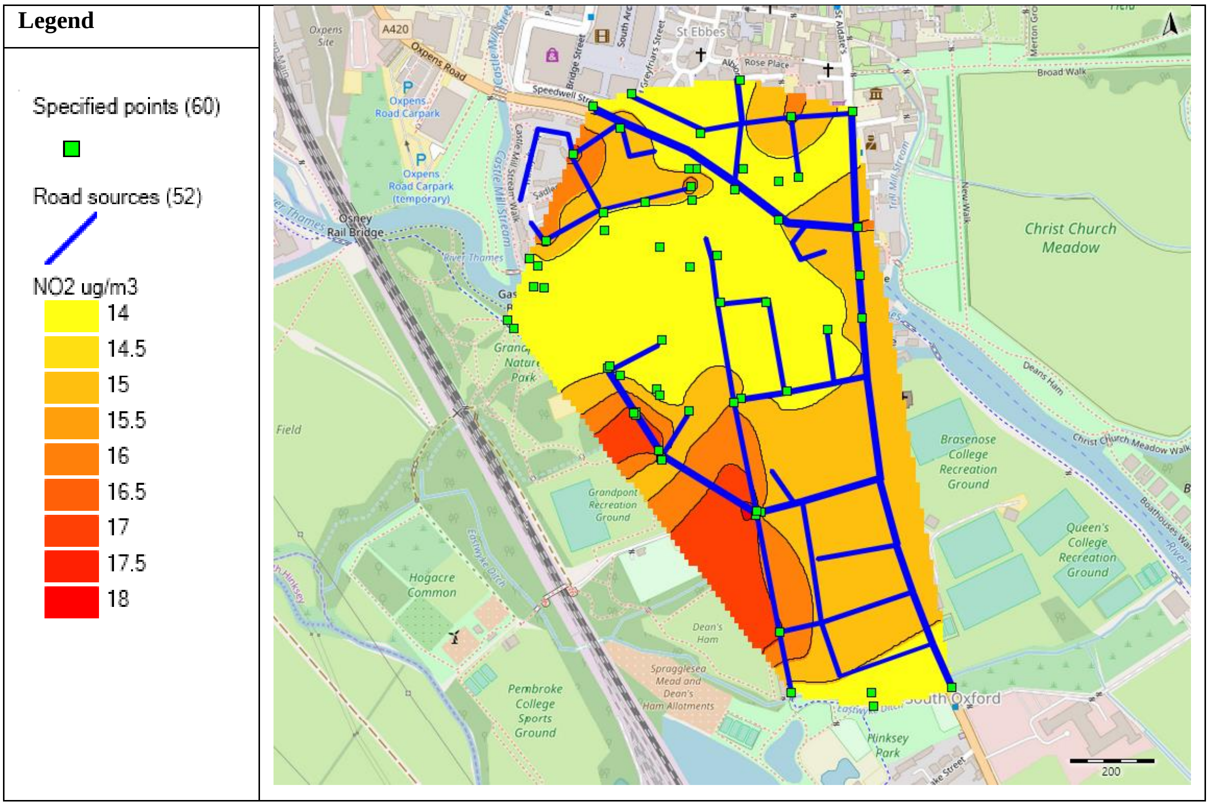

*Figure 136 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and rideshare intervention at Oxford St Ebbe’s site.*

Figure 137 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations ($\mu g/m^3$) following the combined improved travel routes and rideshare intervention. Compared to the baseline, site concentrations appear somewhat reduced, although peaks persist at the M1 Roundabout, the A6178 junction, and towards the south central commercial/industrial region.

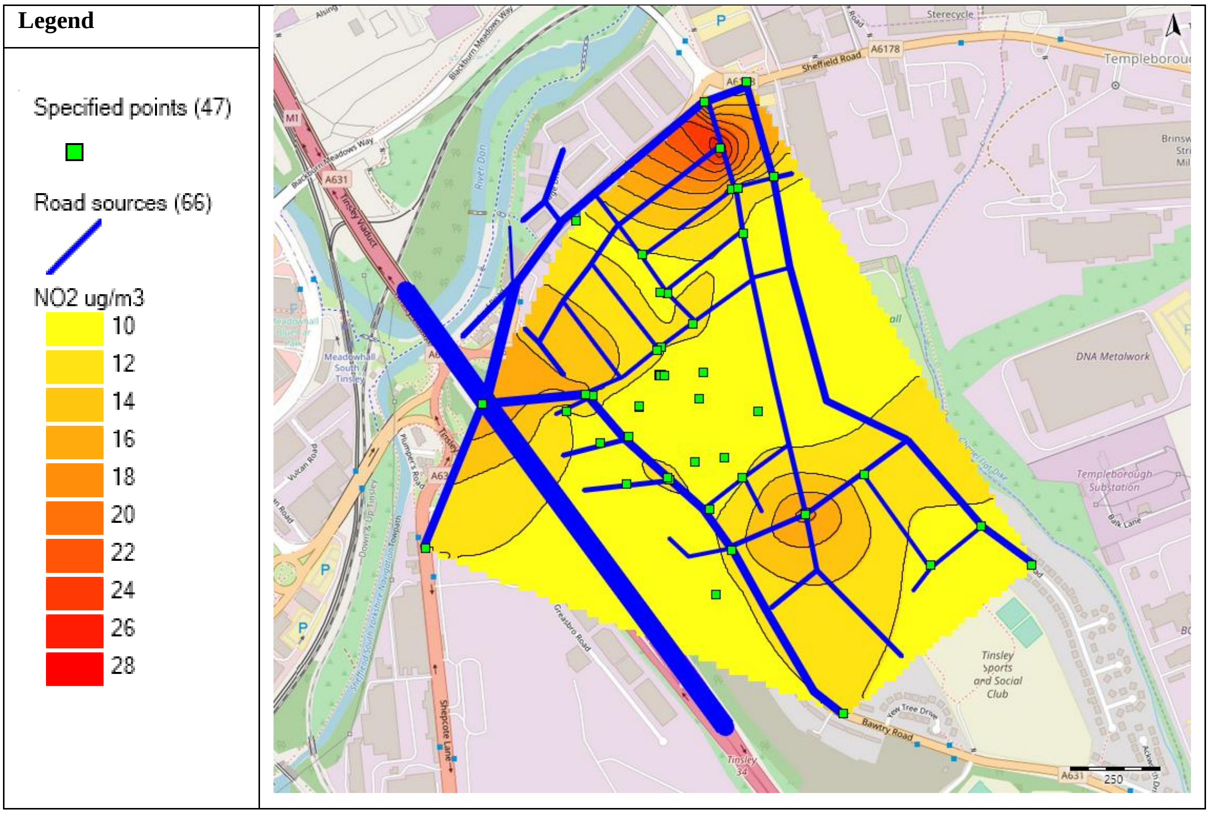

*Figure 137 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following combined improved travel routes and rideshare intervention at Sheffield Tinsley site.*

### 6.5.7.8 Improved Travel Routes & Low Emission Zones

The Low Emission Zone (LEZ) intervention was combined with improved travel routes to determine its effectiveness on the routes. Mean $NO_2$ (µg/m$^3$) values were calculated for all travel routes on all sites and the differences against the site baselines were determined (Table 50**).**

*Table 50 Modelled $NO_2$ (µg/m$^3$) means at schools due to Low Emission Zone implementation at 200m, 300m, 400m, & 500m.*

| **Site** | **Baseline** | **200 m** | **300 m** | **400 m** | **500 m** |
|---|---|---|---|---|---|
| Bristol St Paul’s | 26.33 | 20.17 | 19.56 | 19.21 | 18.89 |
| Bristol Bedminster | 25.35 | 19.71 | 19.11 | 18.59 | 18.3 |
| Coventry Binley | 22.81 | 18.36 | 17.94 | 17.73 | 17.68 |
| Oxford St Ebbe’s | 17.45 | 15.1 | 14.93 | 14.79 | 14.67 |
| Sheffield Tinsley | 14.79 | 12.8 | 12.45 | 12.33 | 12.15 |

Figure 138 shows the overall $NO_2$ reductions on improved travel routes when combined with the LEZ intervention, demonstrating the largest mean difference for LEZ 500 m at the Bristol St Paul’s and Bristol Bedminster site improved travel routes (-7.44 and -7.05 µg/m$^3$, respectively).

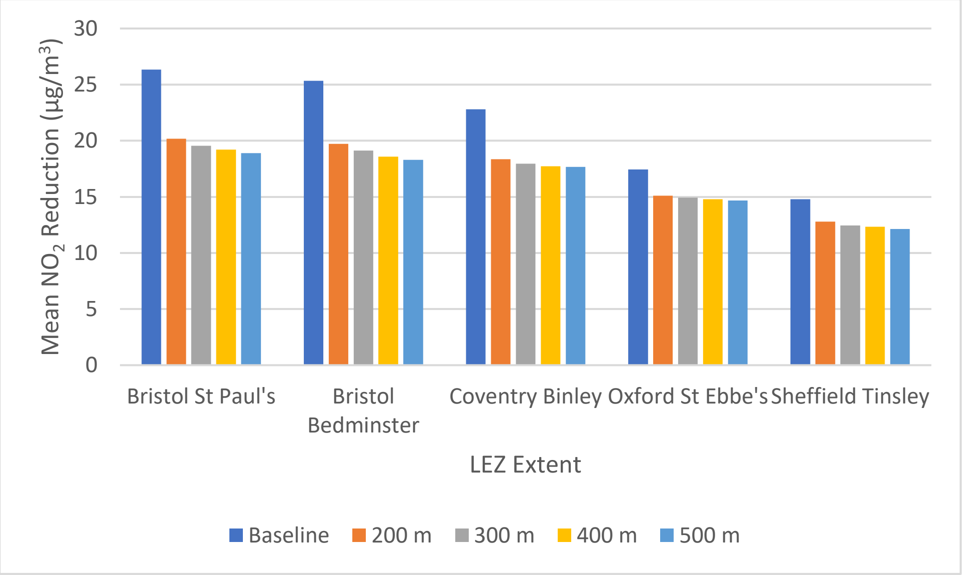

*Figure 138 Modelled $NO_2$ (µg/m$^3$) means at schools due to Low Emission Zone implementation at 200m, 300m, 400m, & 500m.*

Table 51 shows the percentage reduction of $NO_2$ at all mean site travel routes following the implementation of the LEZ intervention. The greatest proportionate reductions were found at Bristol St Paul’s and Bristol Bedminster (18.89% and 18.30%, respectively).

*Table 51 Modelled percentage reductions of $NO_2$ (µg/$m^3$) at all mean site travel routes due to Low Emission Zone implementation at 200m, 300m, 400m, & 500m.*

| **Site** | **Baseline** | **200 m** | **300 m** | **400 m** | **500 m** |
|---|---|---|---|---|---|
| Bristol St Paul’s | 26.33 | 20.17 | 19.56 | 19.21 | 18.89 |
| Bristol Bedminster | 25.35 | 19.71 | 19.11 | 18.59 | 18.30 |
| Coventry Binley | 22.81 | 18.36 | 17.94 | 17.73 | 17.68 |
| Oxford St Ebbe’s | 17.45 | 15.1 | 14.93 | 14.79 | 14.67 |
| Sheffield Tinsley | 14.79 | 12.8 | 12.45 | 12.33 | 12.15 |

Figure 139 shows the patterns of reduction with increasing LEZ radius distance at each site. The percentage of reduction follows a similar pattern at all sites, with the effectiveness of the LEZ increasing with a greater distance, although the magnitude of effectiveness declines with increasing distance at the Coventry Binley and Oxford St Ebbe’s sites.

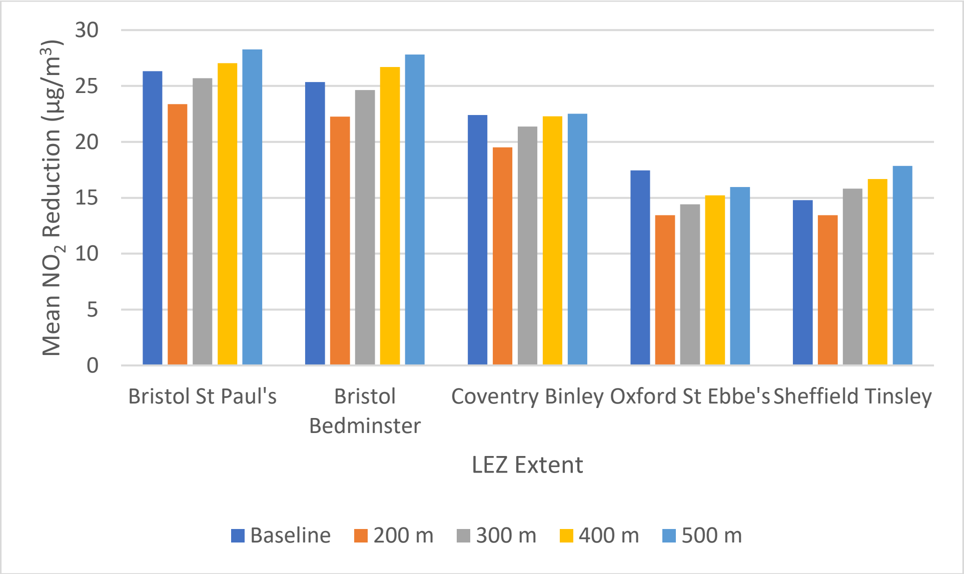

*Figure 139 Modelled percentage reductions of $NO_2$ (µg/$m^3$) at schools due to Low Emission Zone implementation at 200m, 300m, 400m, & 500m.*

### 6.5.7.9 Contour Maps for Improved Travel Routes & Low Emission Zones (200 Metres)

Figure 140 depicts a contour map of Bristol St Paul’s $NO_2$ concentrations ($\mu g/m^3$) following the combined improved travel routes and LEZ (200 m) intervention. Compared to the baseline, substantial reductions are visible throughout the site, with peaks persisting at the A38 and the A4320/M32 roundabout.

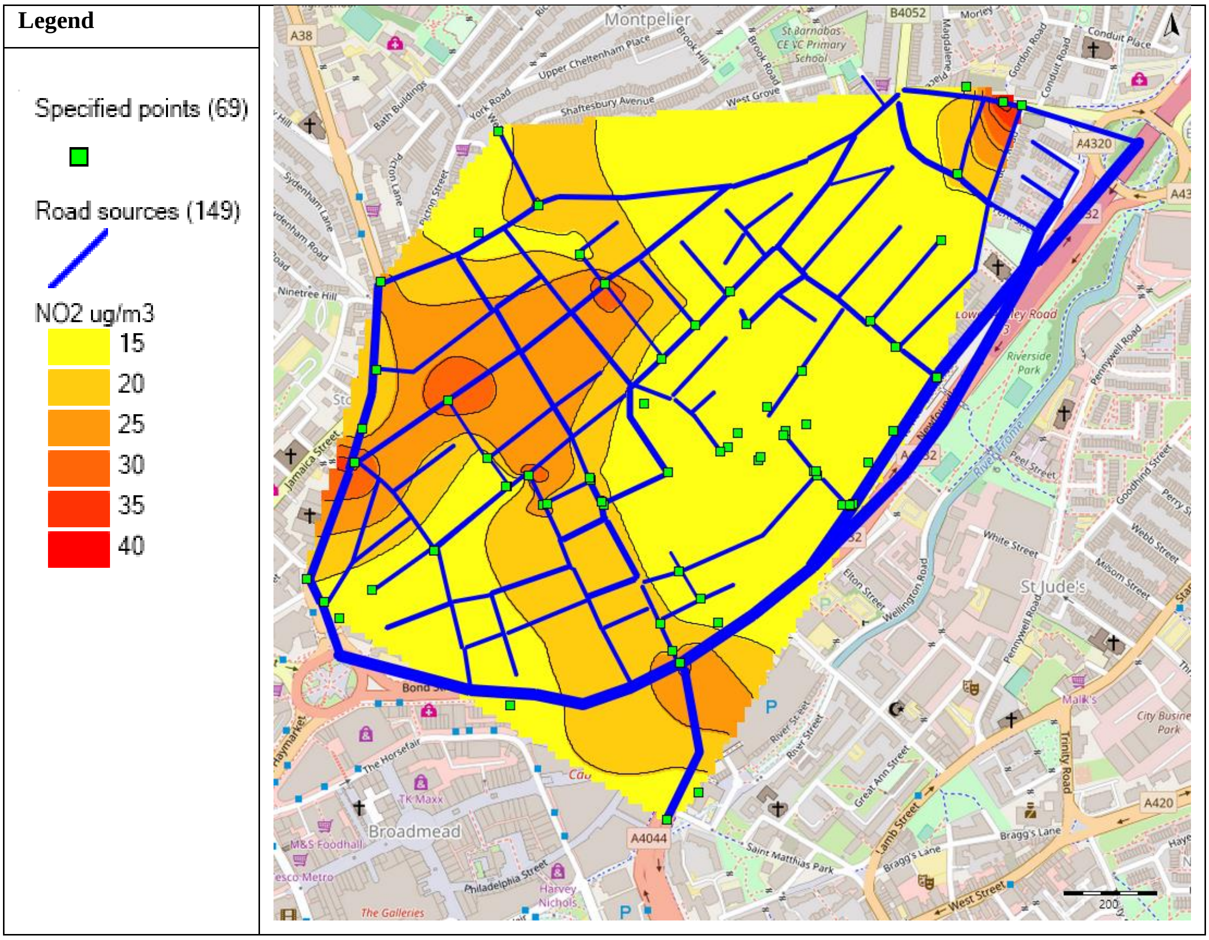

*Figure 140 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following combined improved travel routes and LEZ (200 m) on Bristol St Paul’s site.*

Figure 141 depicts a contour map of Bristol Bedminster NO2 concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (200 m) intervention. Compared to the baseline, substantial reductions are visible throughout the site, with a peak persisting at the A38/A3029 intersection.

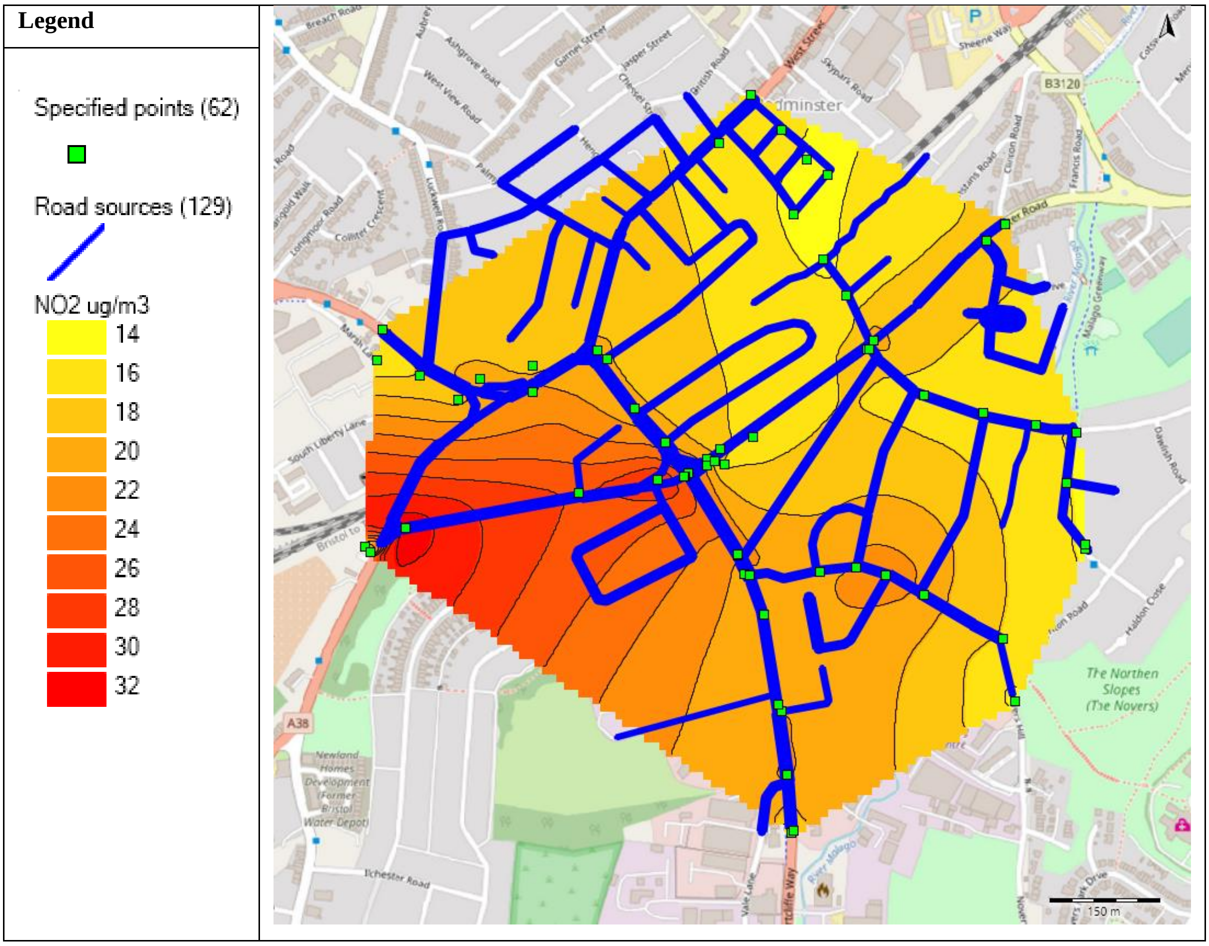

*Figure 141 Contour map showing modelled NO2 (µg/m$^3$) concentrations following combined improved travel routes and LEZ (200 m) on Bristol Bedminster site.*

Figure 142 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/$m^3$) following the combined improved travel routes and LEZ (200 m) intervention. Compared to the baseline, substantial reductions are visible across the site, with comparatively high peaks on the A4053 from the west to the A4600/A428 junction.

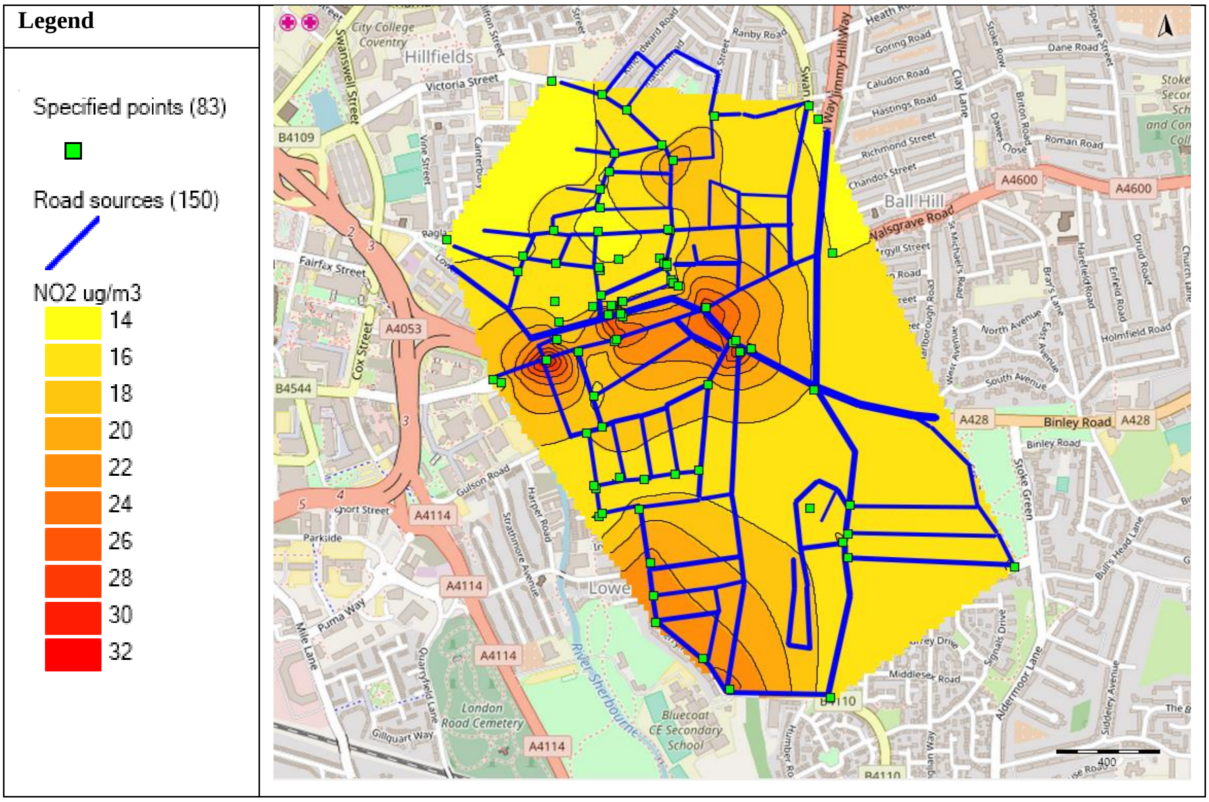

*Figure 142 Contour map showing modelled $NO_2$ (µg/$m^3$) concentrations following combined improved travel routes and LEZ (200 m) on Coventry Binley site.*

Figure 143 depicts a contour map of Oxford St Ebbe’s $NO_2$ concentrations (µg/$m^3$) following the combined improved travel routes and LEZ (200 m) intervention. Compared to the baseline, marginal reductions are visible across the site, although peaks persist at the south and the north of the site, along the A420.

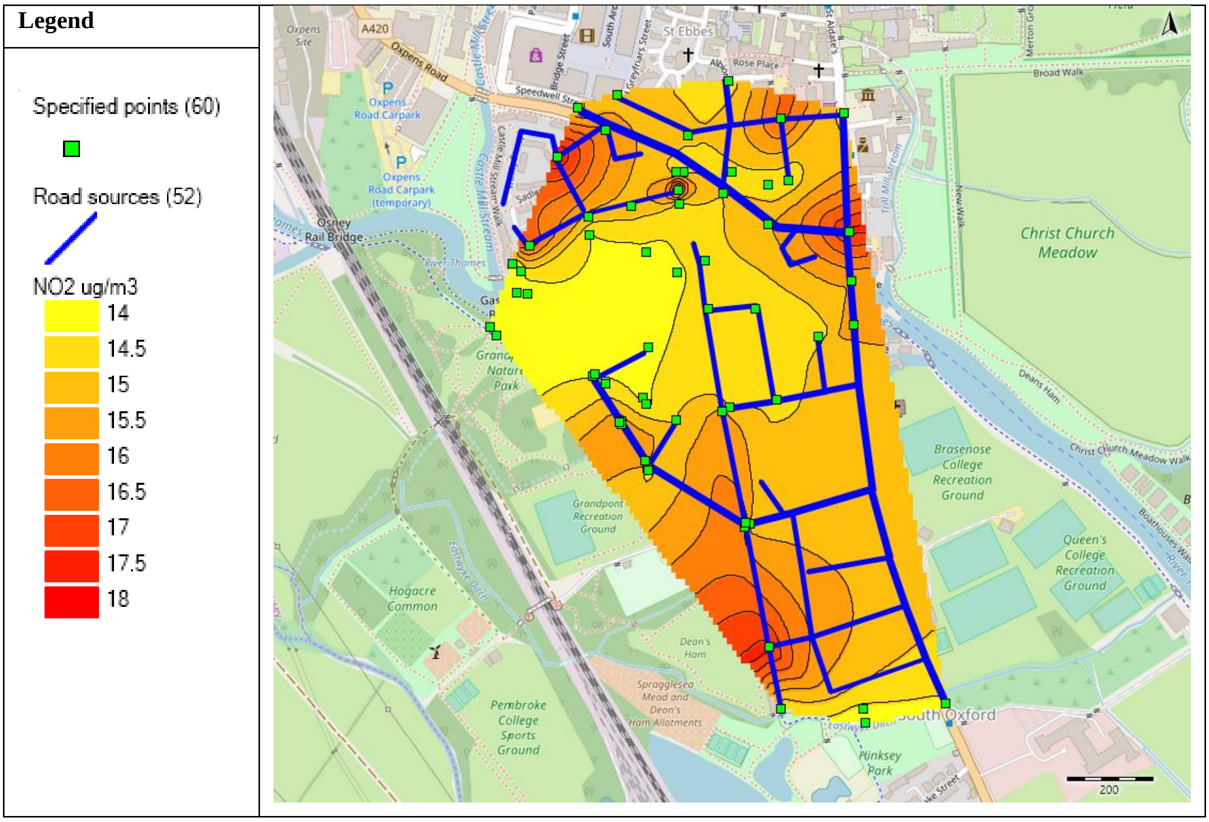

*Figure 143 Contour map showing modelled $NO_2$ (µg/$m^3$) concentrations following combined improved travel routes and LEZ (200 m) on Oxford St Ebbe’s site.*

Figure 144 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (200 m) intervention. Compared to the baseline, marginal reductions are found throughout the centre of the site. Concentrations at the M1 roundabout are reduced and persistent peaks remain towards the north at the A6178 junction.

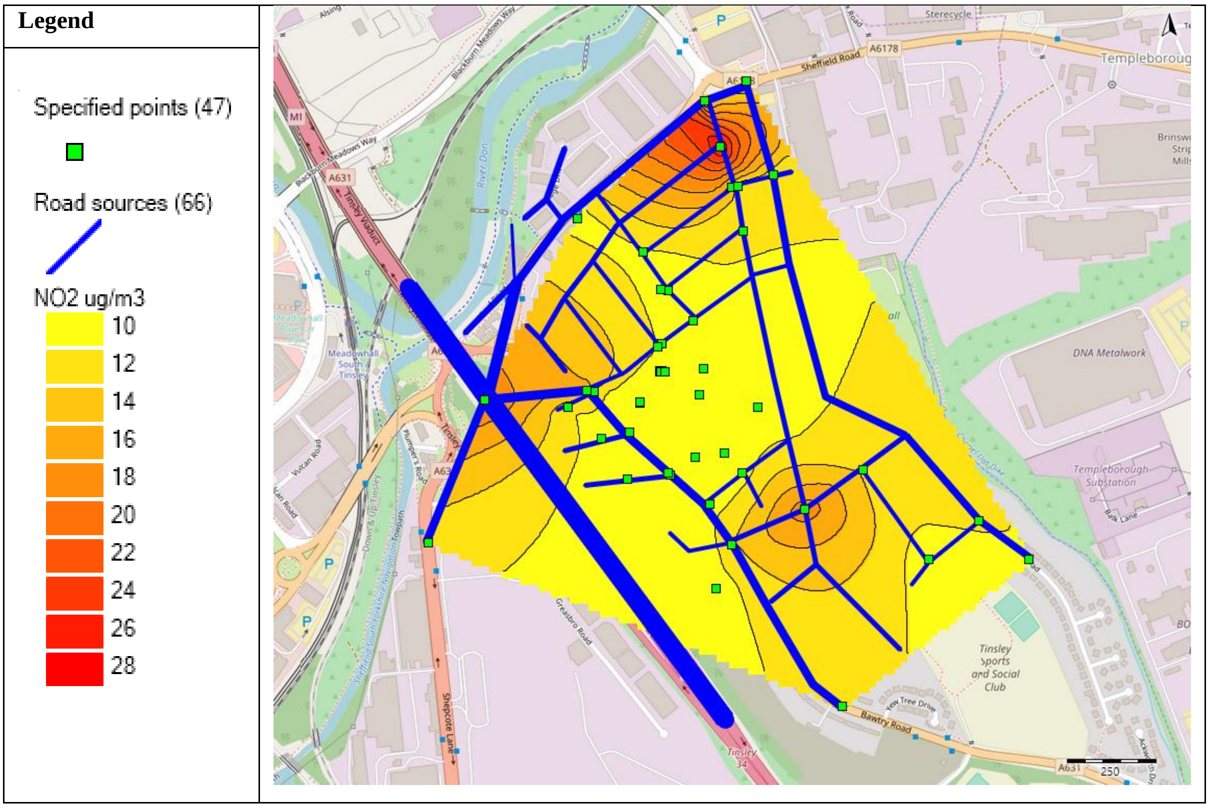

*Figure 144 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (200 m) on Sheffield Tinsley site.*

### 6.5.7.10 Contour Maps for Improved Travel Routes & Low Emission Zones (300 Metres)

Figure 145 depicts a contour map of Bristol St Paul's $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (300 m) intervention. Compared to the baseline, substantial reductions are visible, although peaks persist at the A38 and the A4320/M32 roundabout.

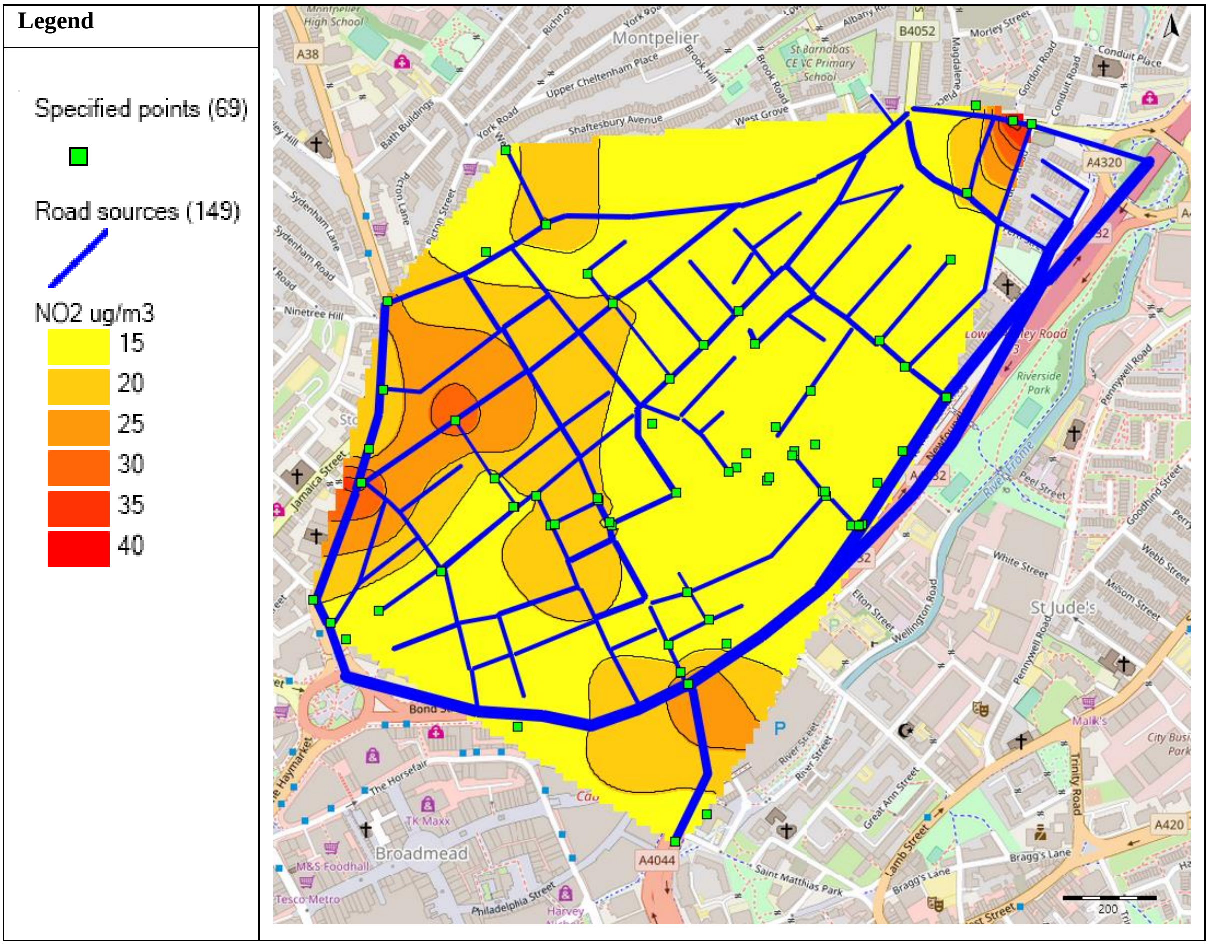

*Figure 145 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (300 m) on Bristol St Paul's site.*

Figure 146 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (300 m) intervention. Compared to the baseline, substantial reductions are visible, although peaks persist at the east of the site, at the A38/A3029 intersection.

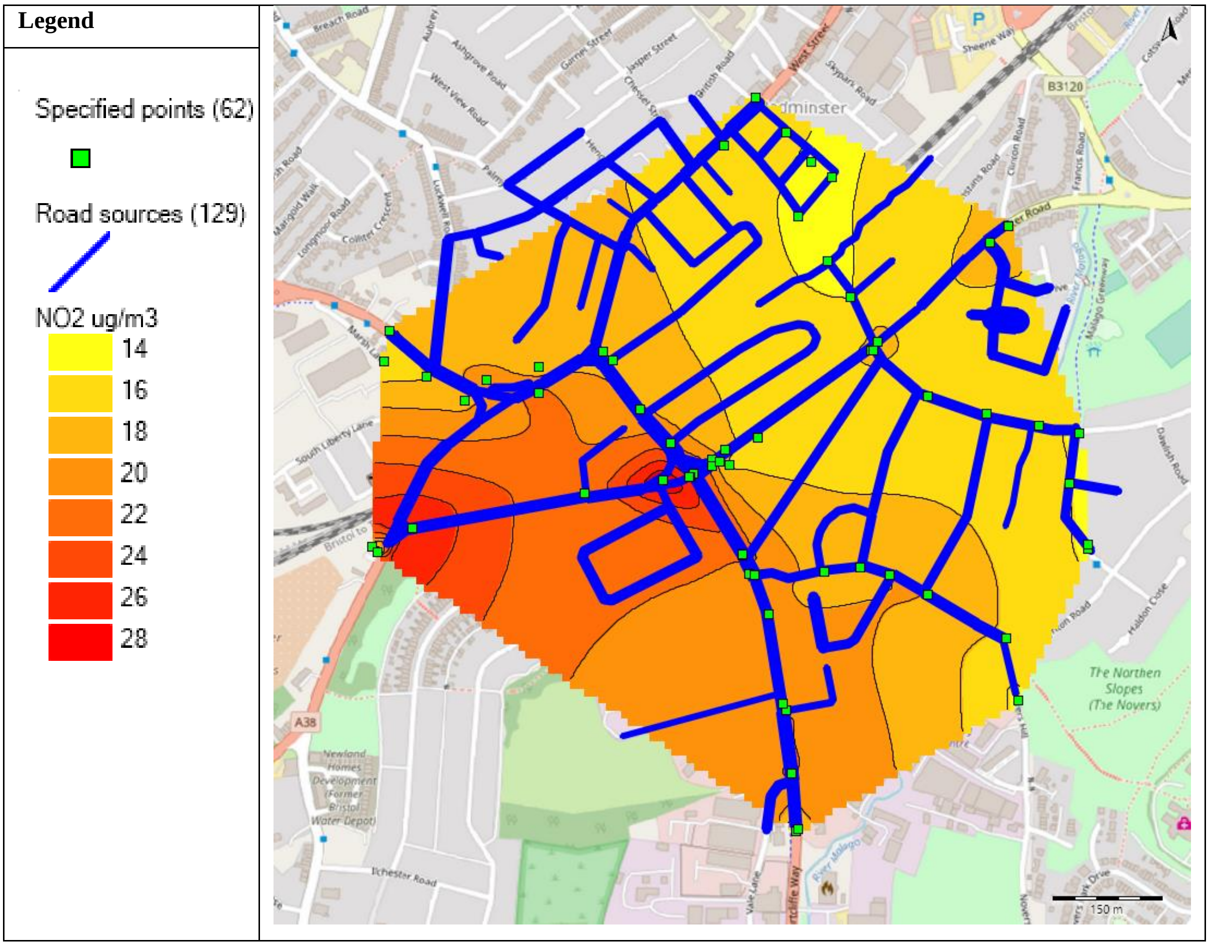

*Figure 146 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (300 m) on Bristol Bedminster site.*

Figure 147 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (300 m) intervention. Compared to the baseline, substantial reductions are visible across the site, with comparatively high peaks on the A4053 and along the A4600.

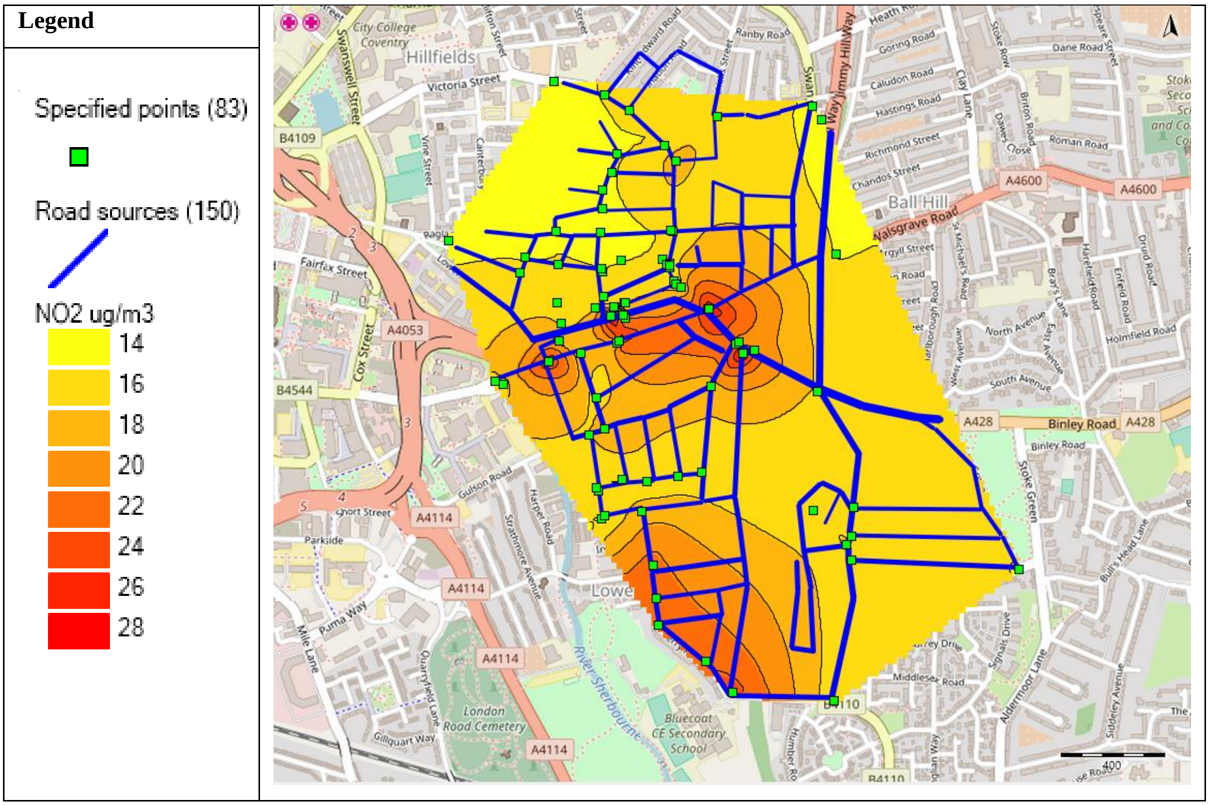

*Figure 147 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (300 m) on Coventry Binley site.*

Figure 148 depicts a contour map of Oxford St Ebbe’s NO₂ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (300 m) intervention. Compared to the baseline, substantial reductions are visible across the site, although peaks persist at the south and the north of the site, particularly along the A420.

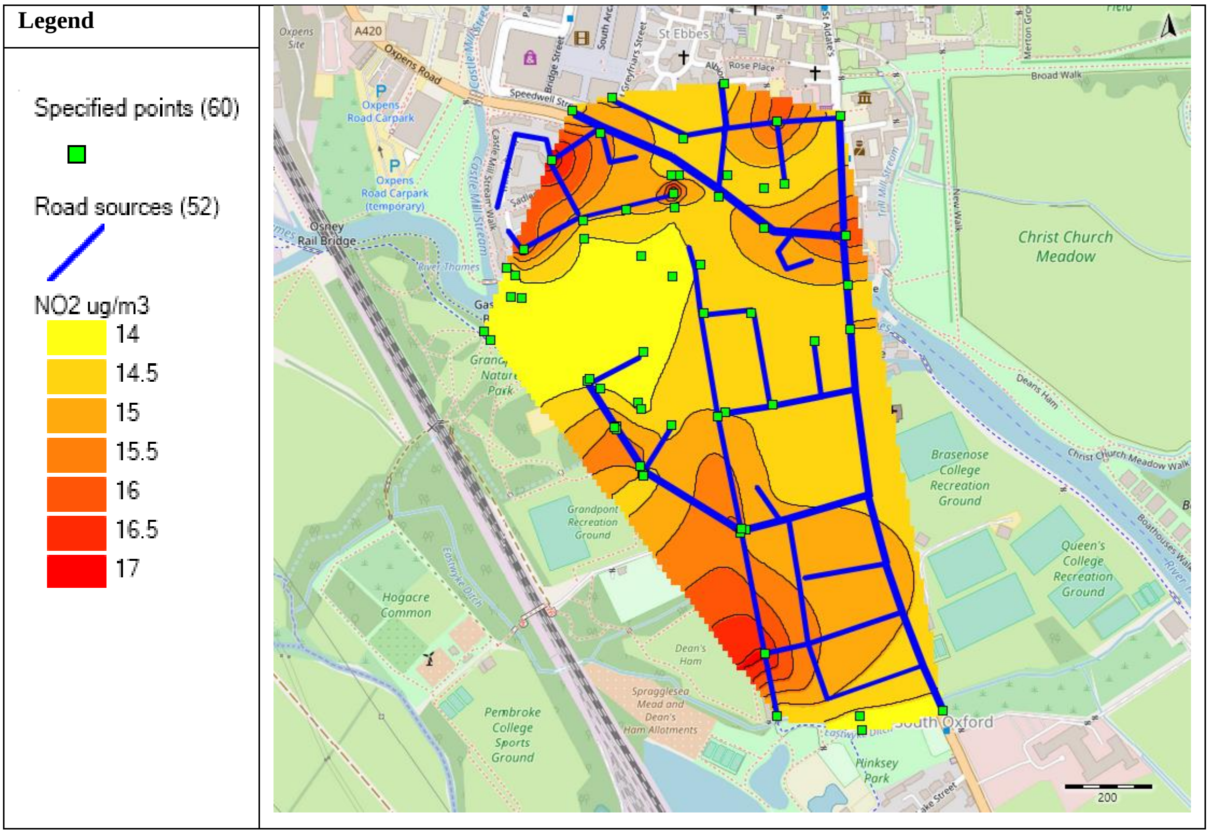

*Figure 148 Contour map showing modelled NO₂ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (300 m) on Oxford St Ebbe’s site.*

Figure 149 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (300 m) intervention. Compared to the baseline, marginal reductions are found throughout the centre of the site. Concentrations at the M1 roundabout are largely reduced, and a persistent peak remains towards the north at the A6178 junction.

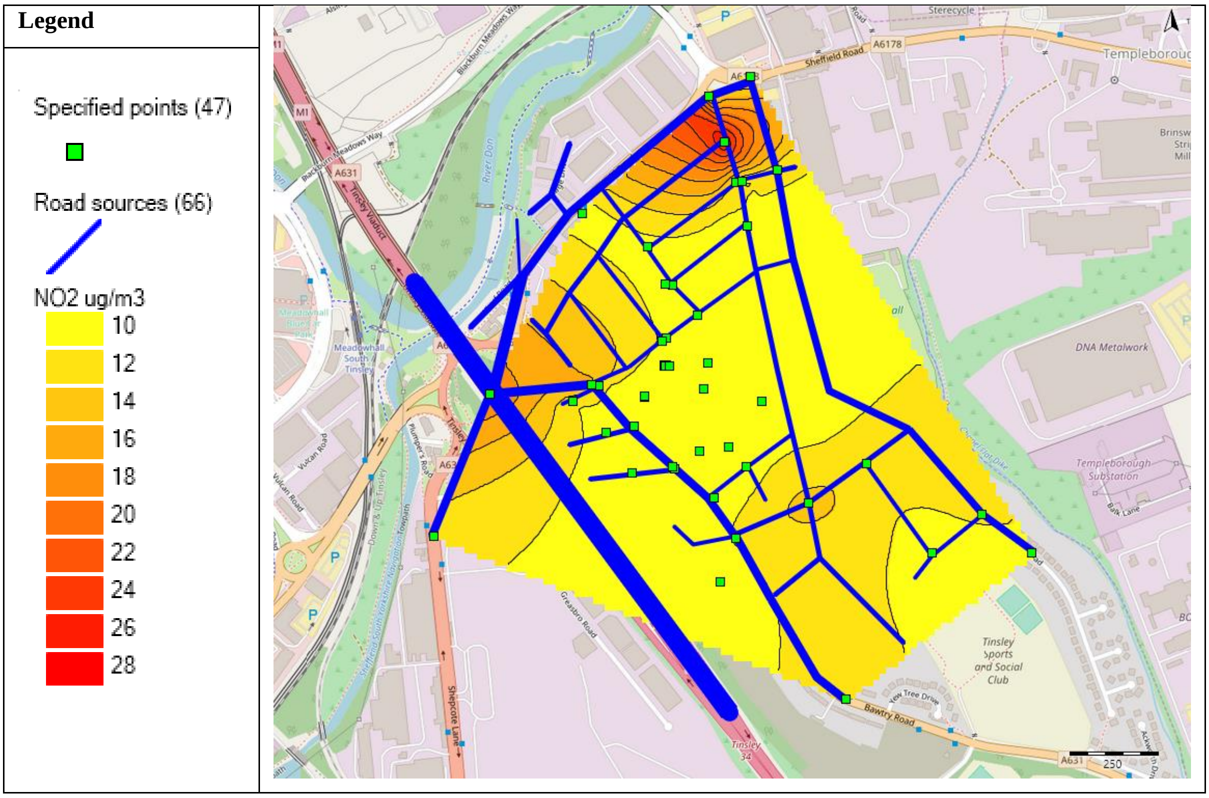

*Figure 149 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (300 m) on Sheffield Tinsley site.*

### 6.5.7.11 Contour Maps for Improved Travel Routes & Low Emission Zones (400 Metres)

Figure 150 depicts a contour map of Bristol St Paul’s $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (400 m) intervention. Compared to the baseline, substantial reductions are visible throughout the site, with previous peaks largely flattened and a peak persisting at the A38 and the A4320/M32 roundabout.

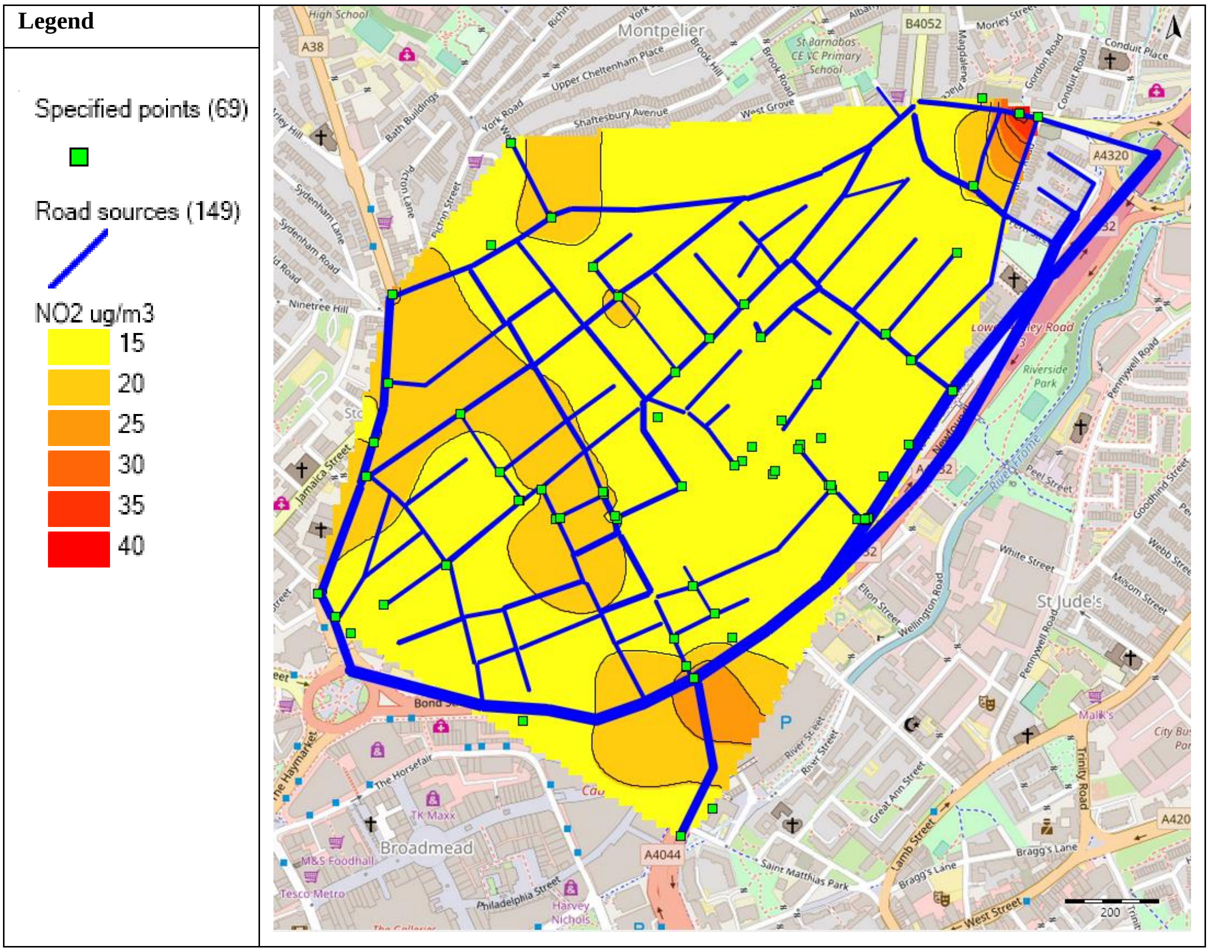

*Figure 150 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (400 m) on Bristol St Paul’s site.*

Figure 151 depicts a contour map of Bristol Bedminster $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (400 m) intervention. Compared to the baseline, substantial reductions are visible throughout the site, with a peak persisting at the A38/A3029 intersection and the centre of the site near Wilder Street.

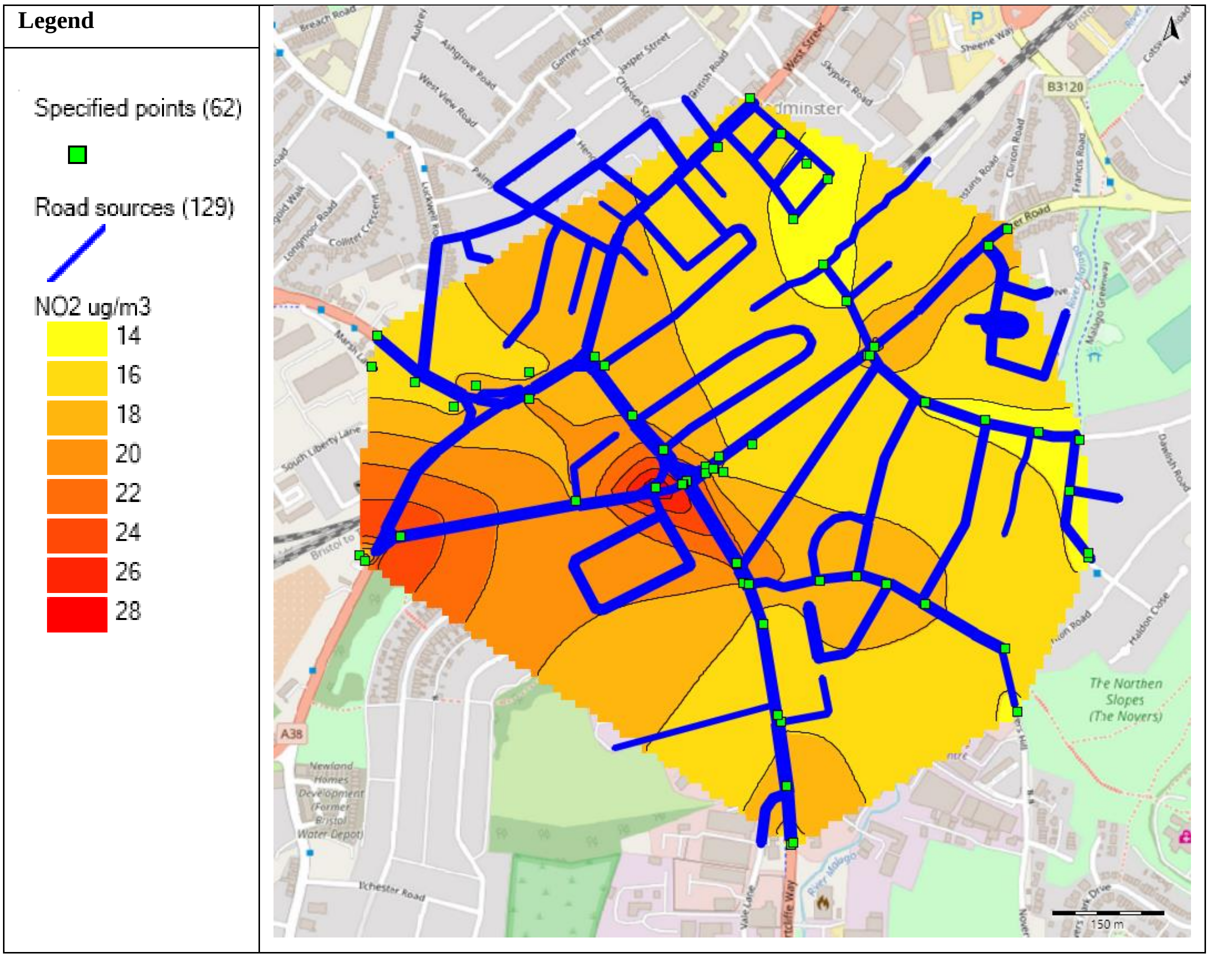

*Figure 151 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (400 m) on Bristol Bedminster site.*

Figure 152 depicts a contour map of Coventry Binley $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (400 m) intervention. Compared to the baseline, substantial reductions are visible across the site, with comparatively high peaks on the A4053 from the west to the A4600/A428 junction.

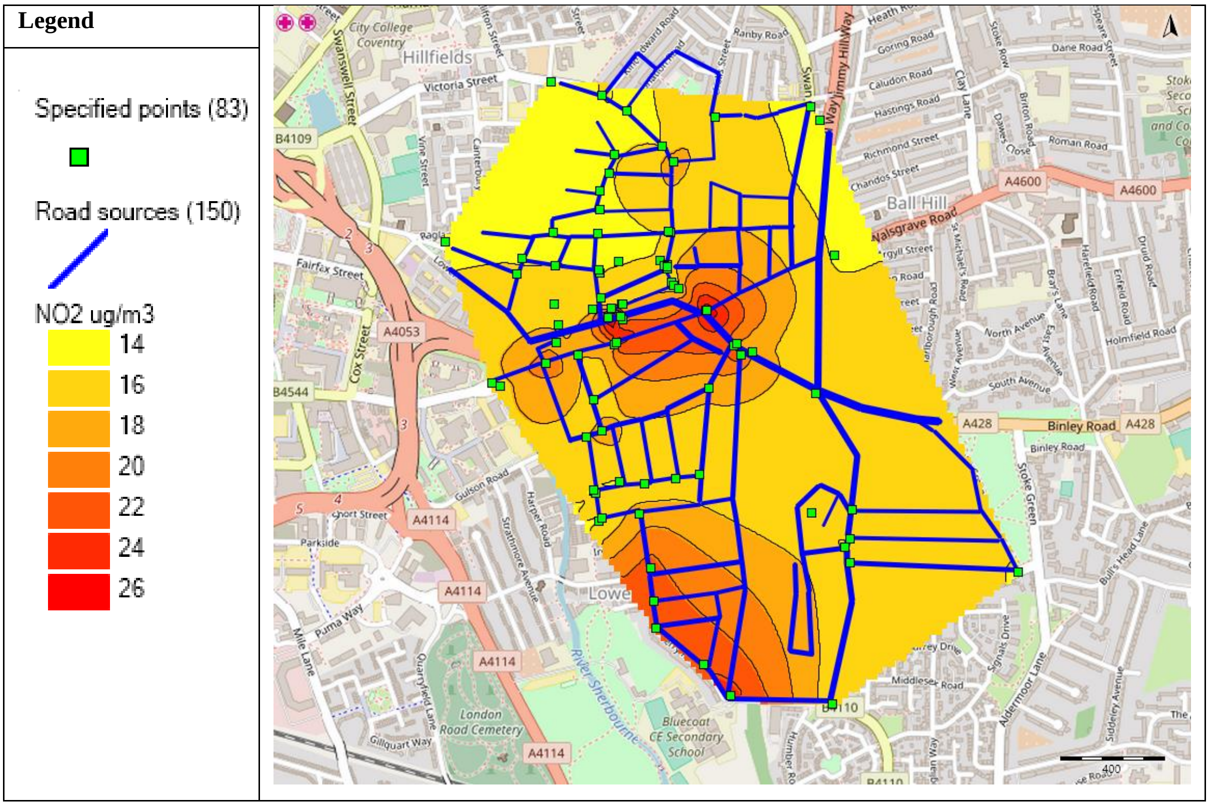

*Figure 152 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (400 m) on Coventry Binley site.*

Figure 153 depicts a contour map of Oxford St Ebbe's $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (400 m) intervention. Compared to the baseline, reductions are visible across the site, although peaks persist at the south and the north of the site, along the A420.

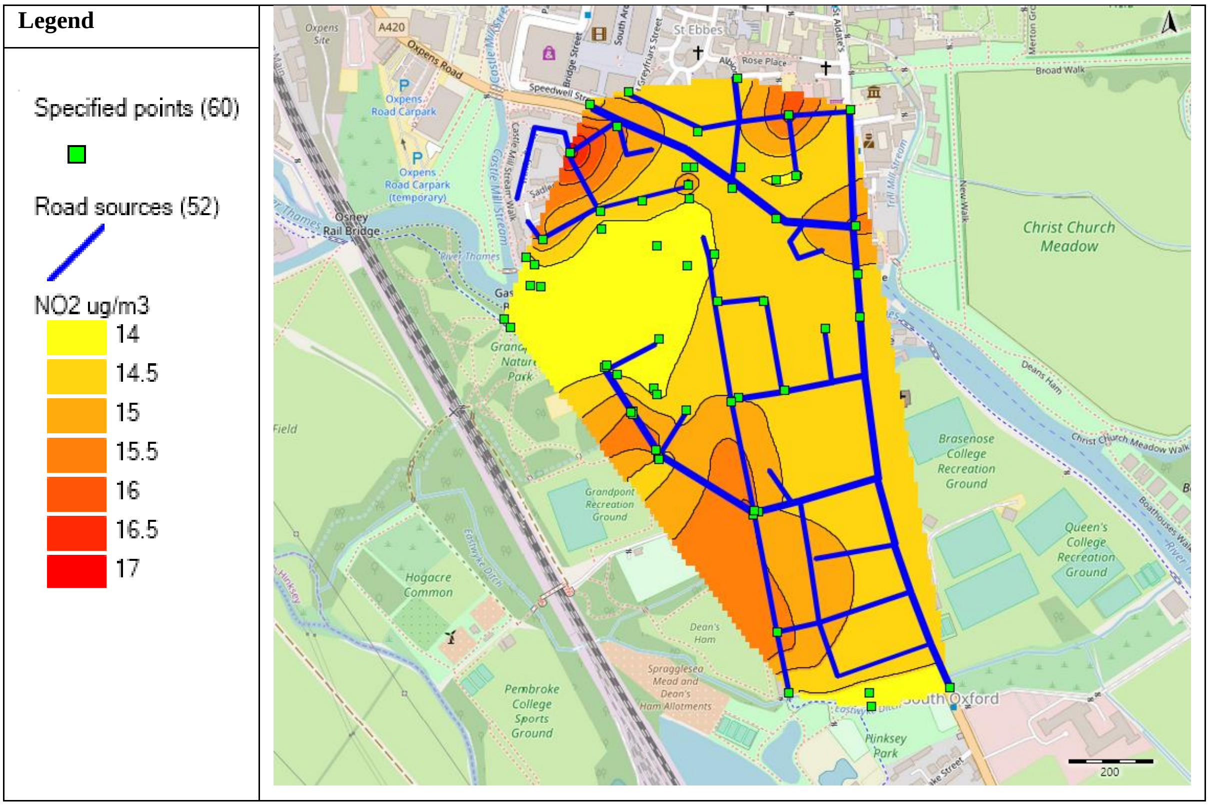

*Figure 153 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (400 m) on Oxford St Ebbe's site.*

Figure 154 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations ($\mu g/m^3$) following the combined improved travel routes and LEZ (400 m) intervention. Compared to the baseline, marginal reductions are found throughout the centre of the site. Concentrations at the M1 roundabout are largely reduced although a persistent peak remains to the north, at the A6178 junction.

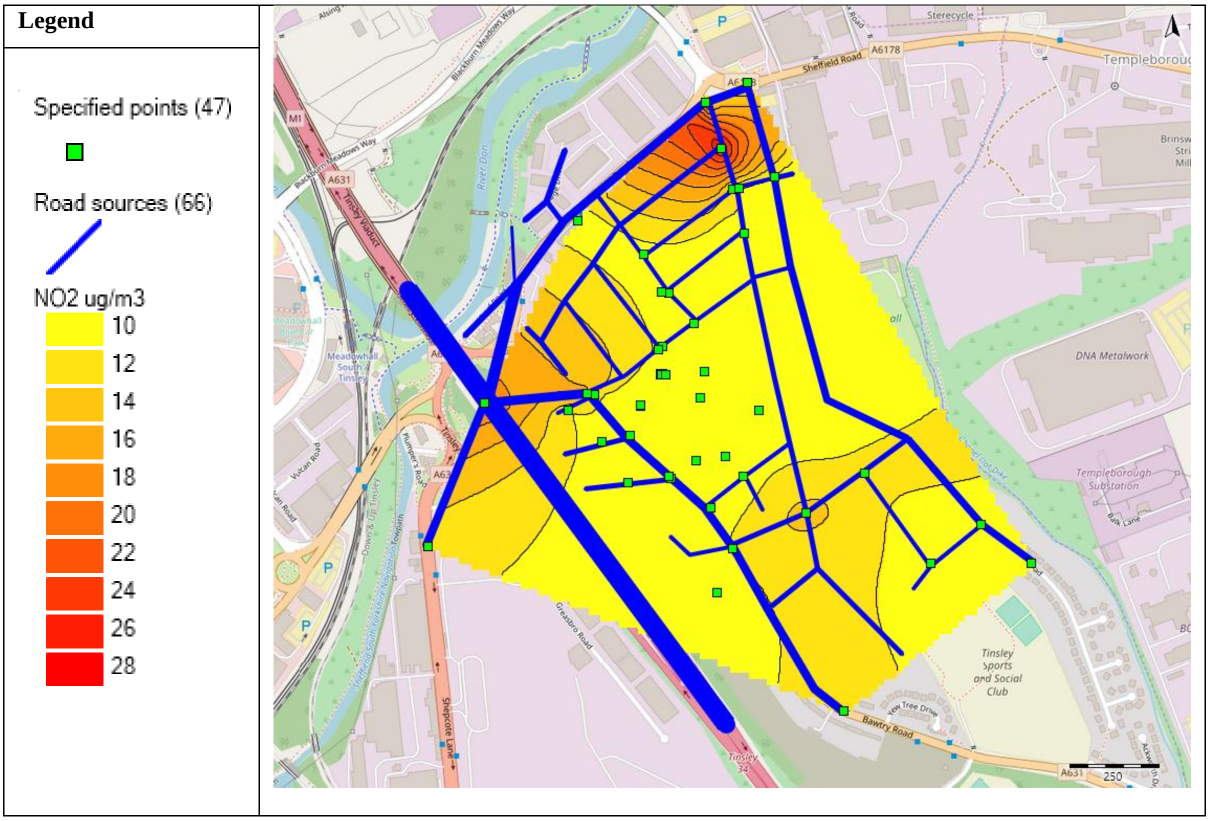

*Figure 154 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following combined improved travel routes and LEZ (400 m) on Sheffield Tinsley site.*

### 6.5.7.12 Contour Maps for Improved Travel Routes & Low Emission Zones (500 Metres)

Figure 155 depicts a contour map of Bristol St Paul’s $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (500 m) intervention. Compared to the baseline, substantial reductions are visible throughout the site, with a peak persisting at the A38 and the A4320/M32 roundabout. Previous peaks are largely flattened.

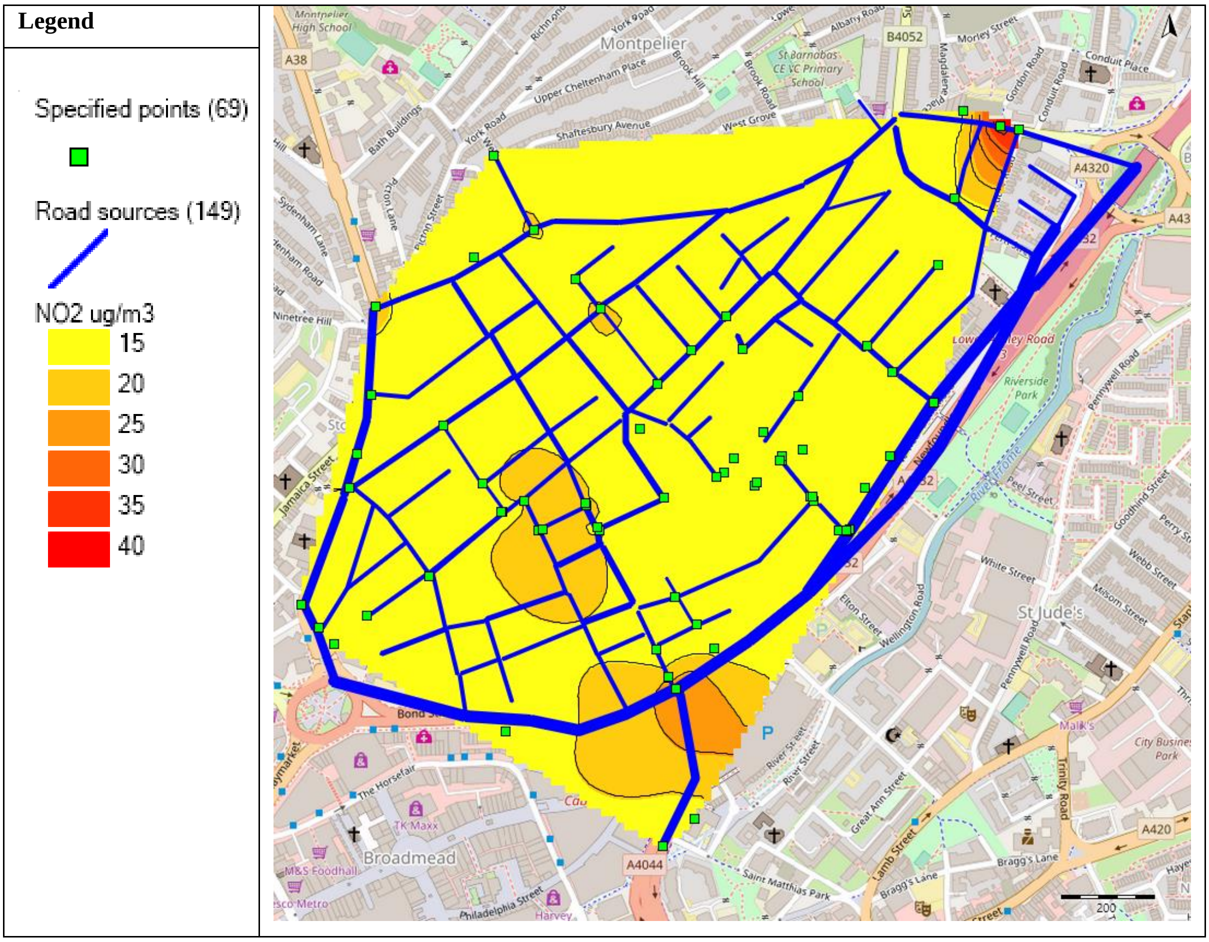

*Figure 155 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (500 m) on Bristol St Paul’s site.*

Figure 156 depicts a contour map of Bristol Bedminster $NO_2$ concentrations ($\mu g/m^3$) following the combined improved travel routes and LEZ (500 m) intervention. Compared to the baseline, substantial reductions are visible throughout the site, with the peak at the A38/A3029 intersection largely flattened, although a peak remains to the centre of the site at the Parson Street junction.

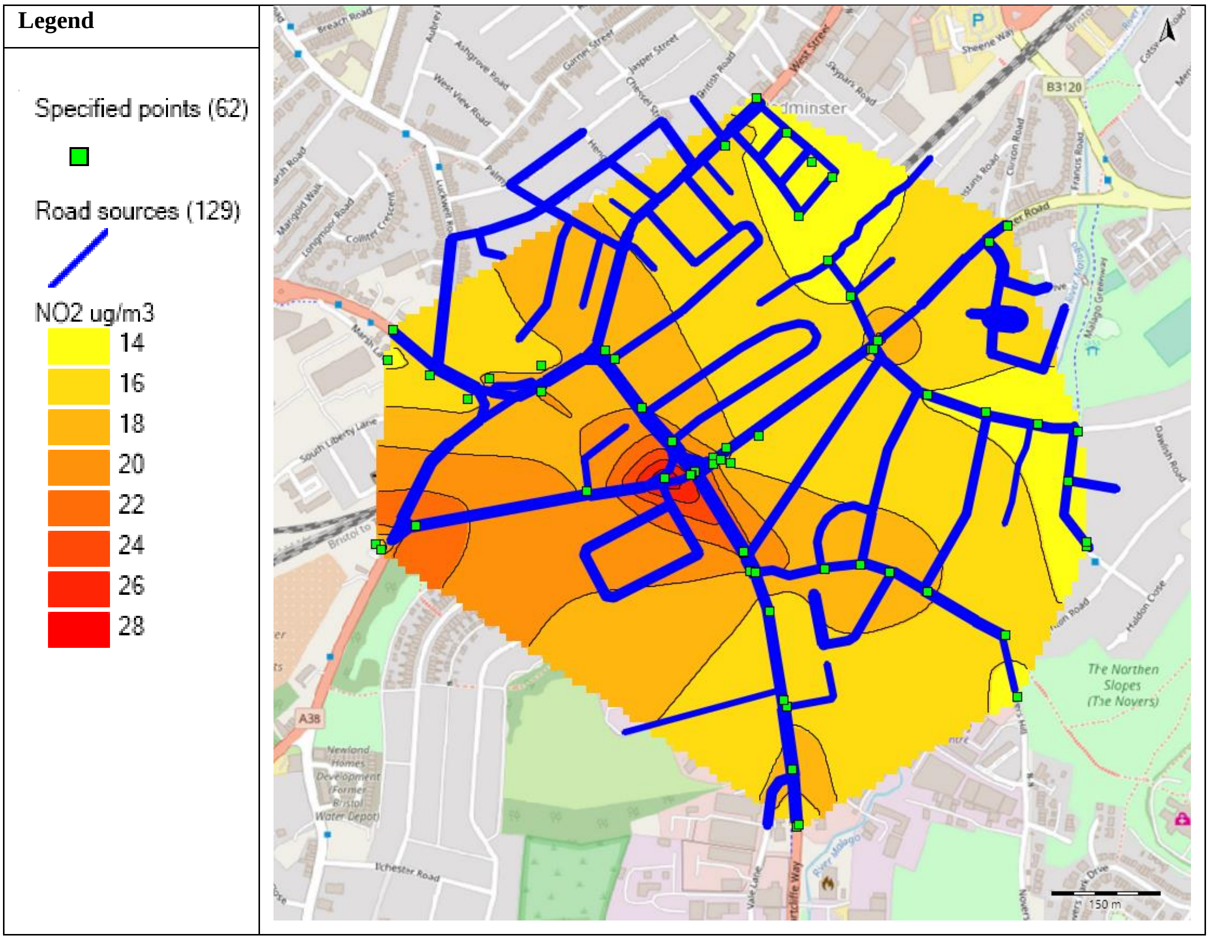

*Figure 156 Contour map showing modelled $NO_2$ ($\mu g/m^3$) concentrations following combined improved travel routes and LEZ (500 m) on Bristol Bedminster site.*

Figure 157 depicts a contour map of Coventry Binley NO$_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (500 m) intervention. Compared to the baseline, substantial reductions are visible across the site, with comparatively high peaks on the A4053 from the west to the A4600/A428 junction.

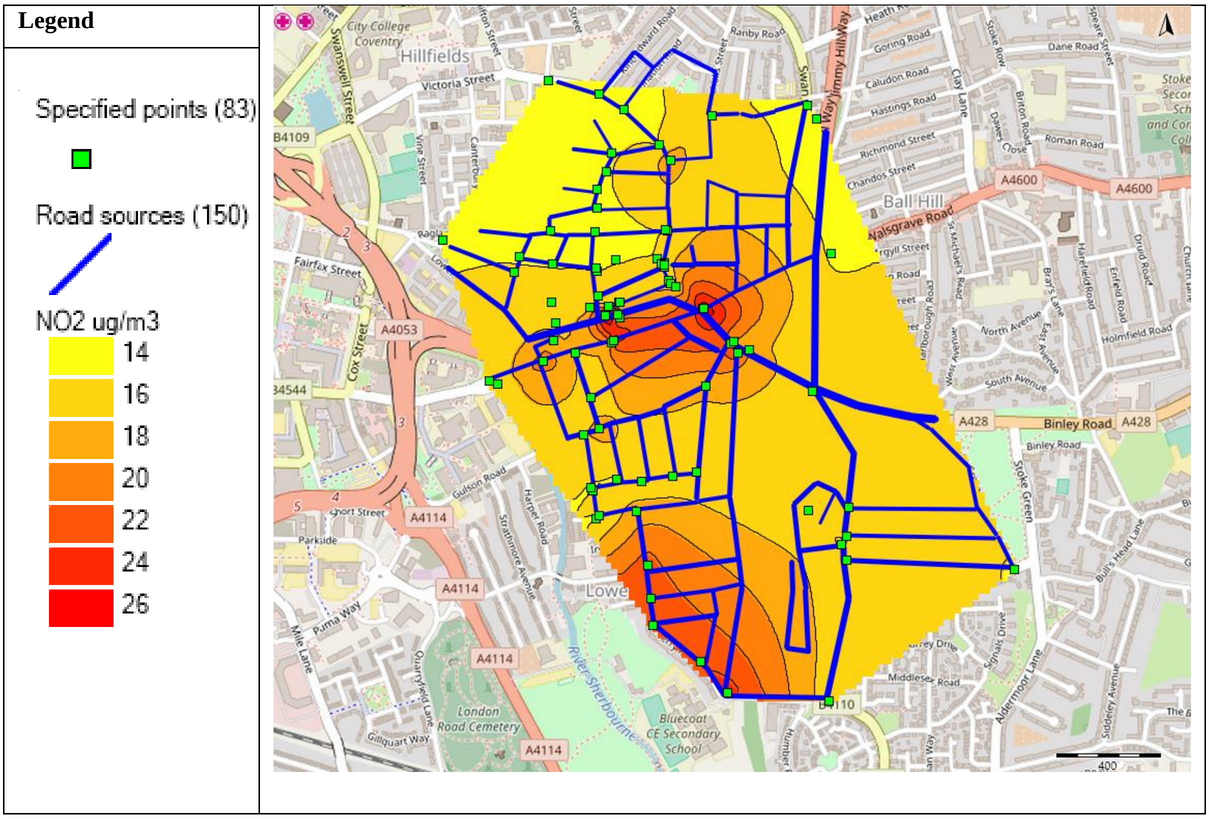

*Figure 157 Contour map showing modelled NO$_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (500 m) on Coventry Binley site.*

Figure 158 depicts a contour map of Oxford St Ebbe's $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (500 m) intervention. Compared to the baseline, reductions are visible across the site, although peaks persist at the south and the north of the site, along the A420.

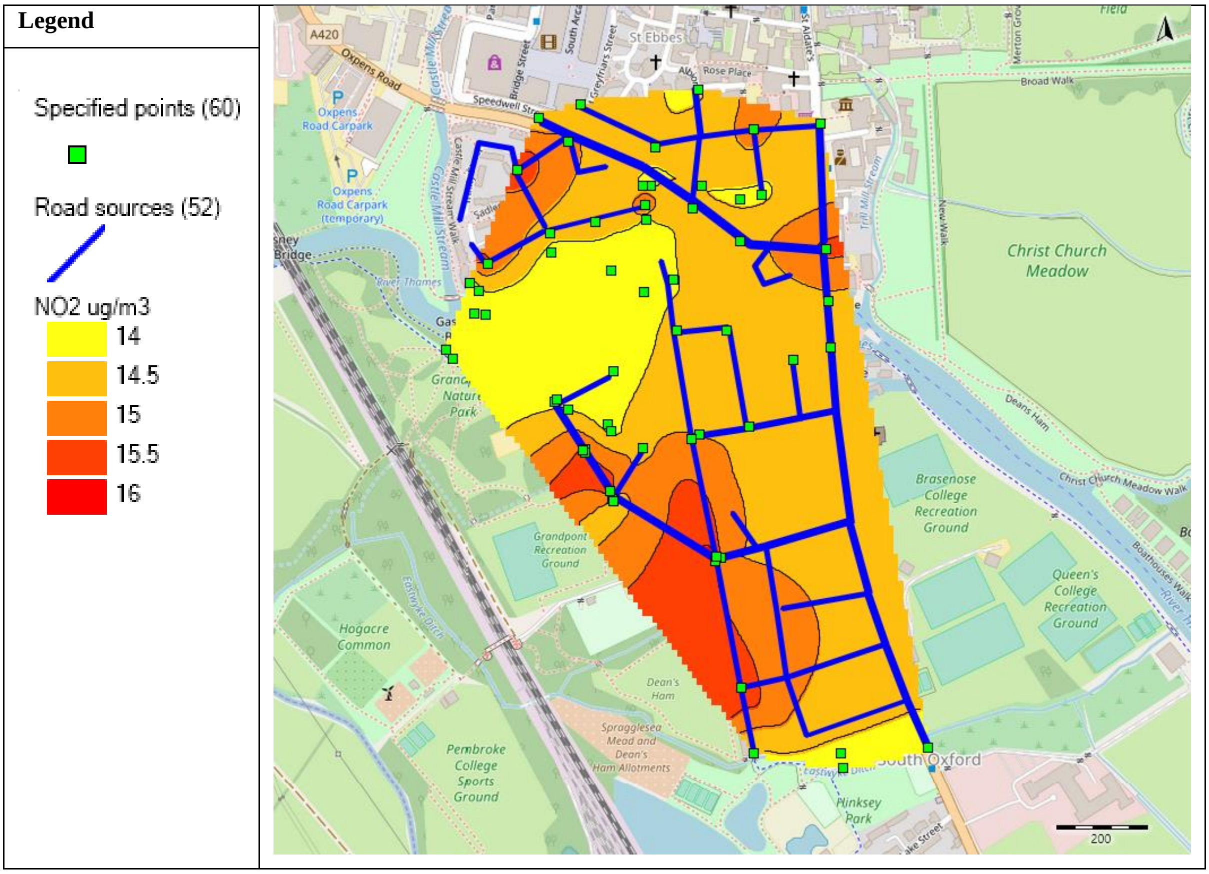

*Figure 158 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (500 m) on Oxford St Ebbe's site.*

Figure 159 depicts a contour map of Sheffield Tinsley $NO_2$ concentrations (µg/m$^3$) following the combined improved travel routes and LEZ (500 m) intervention. Compared to the baseline, reductions are found throughout the site. Concentrations at the M1 roundabout are largely reduced, and a persistent peak remains at the A6178 junction.

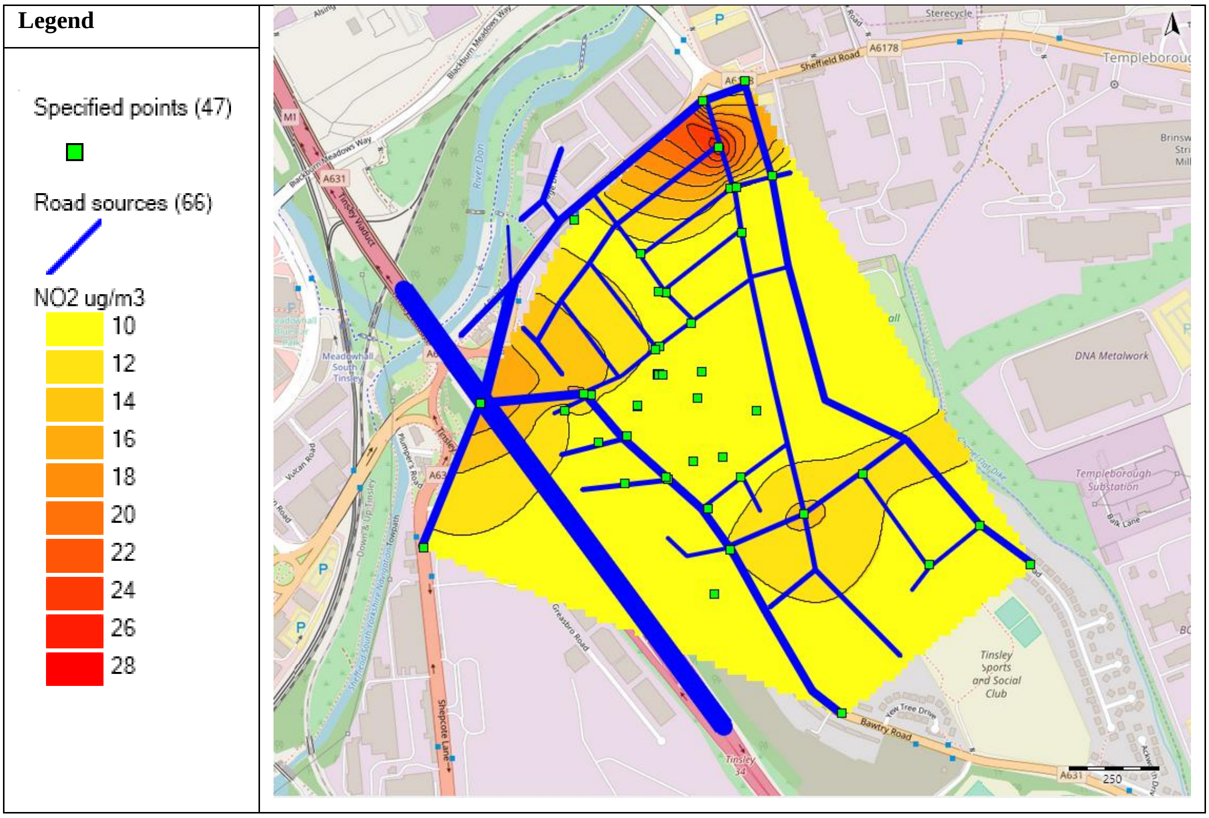

*Figure 159 Contour map showing modelled $NO_2$ (µg/m$^3$) concentrations following combined improved travel routes and LEZ (500 m) on Sheffield Tinsley site.*

### 6.5.8 Comparison of Combined Interventions with Single Interventions

#### 6.5.8.1 Summary

Mean concentrations of each site's improved travel routes and mean concentrations of all site's improved travel routes combined with each intervention were produced. These were combined to determine the percentage of reduction achieved for comparison (Table 52). The most effective interventions combined with improved travel routes were active travel and rideshare (each 19.86%) and anti-idling (17.47%).

*Table 52 Modelled percentage reduction of $NO_2$ (µg/$m^3$) due to interventions and improved travel routes combined with interventions.*

| **Site** | **$NO_2$ reduction (%) of Intervention on travel routes** | **$NO_2$ reduction (%) of Intervention combined with improved travel routes** |
|---|---|---|
| Active Travel | 12.97 | 19.86 |
| Anti-Idling | 8.27 | 17.47 |
| Rideshare | 13.16 | 19.86 |
| LEZ (200 m) | 10.59 | 17.23 |
| LEZ (300 m) | 13.01 | 16.80 |
| LEZ (400 m) | 14.52 | 16.53 |
| LEZ (500 m) | 15.85 | 16.34 |

Figure 160 shows the overall reductions associated with improved travel routes when combined with each intervention. Implementation of LEZ produced a generally consistent percentage reduction, with increasing distance when compared to the original reductions achieved without the addition of improved travel routes.

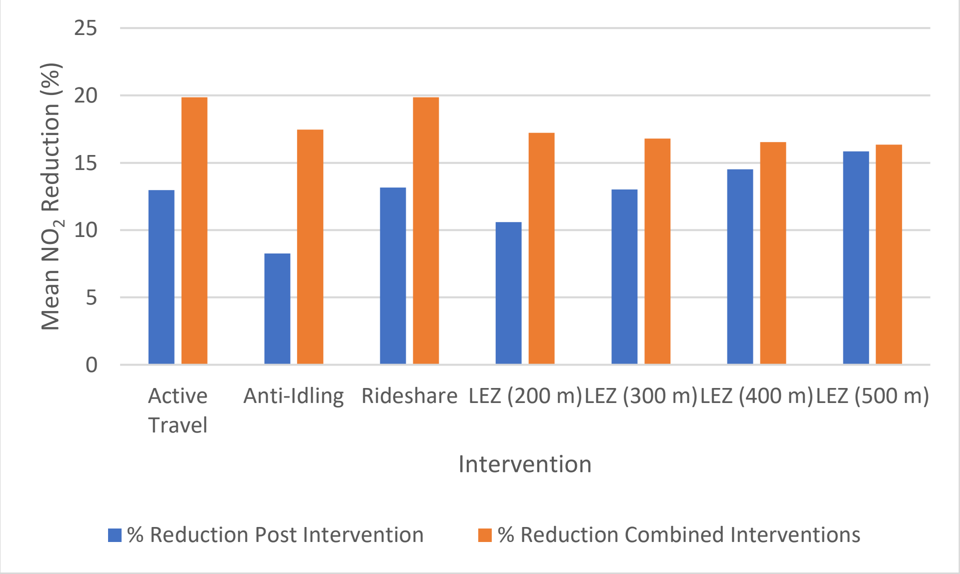

*Figure 160 Modelled percentage reduction of $NO_2$ (µg/$m^3$) due to interventions and improved travel routes combined with interventions.*

### 6.5.8.2 Active Travel

Table 53 shows a comparison of the outcome of the active travel intervention, with the improved travel routes combined with active travel intervention. Coventry Binley showed the greatest difference in $NO_2$ between the combined intervention and the single intervention (3.59 µg/m$^3$). Sheffield Tinsley showed the smallest difference (0.36 µg/m$^3$).

*Table 53 Comparison of modelled $NO_2$ (µg/m$^3$) concentration reductions following active travel intervention and combined improved travel routes and active travel intervention.*

| **Site** | **Baseline** | **Post Intervention** | **Difference to Baseline** | **Combined Intervention** | **Difference to Single Intervention** |
|---|---|---|---|---|---|
| Bristol St Paul’s | 26.33 | 22.05 | 4.28 | 19.86 | 2.19 |
| Bristol Bedminster | 25.35 | 21.07 | 4.29 | 18.86 | 2.21 |
| Coventry Binley | 22.41 | 17.65 | 4.76 | 21.24 | 3.59 |
| Oxford St Ebbe’s | 17.45 | 16.47 | 0.98 | 15.12 | 1.35 |
| Sheffield Tinsley | 14.79 | 13.21 | 1.59 | 12.85 | 0.36 |

Figure 161 shows the effectiveness of the combined interventions when compared to the single intervention. The more heavily congested sites of Bristol St Paul’s, Bristol Bedminster, and Coventry Binley all show high comparative differences (2.19, 2.21, and 3.59 µg/m$^3$, respectively).

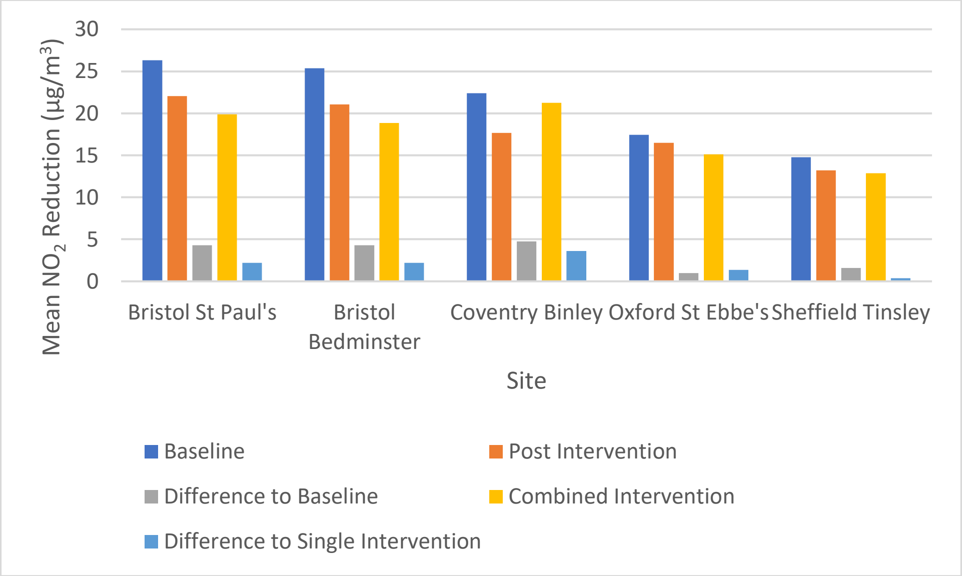

*Figure 161 Comparison of modelled $NO_2$ (µg/m$^3$) concentration reductions following active travel intervention and combined improved travel routes and active travel intervention.*

Table 54 shows the percentage of $NO_2$ (µg/m$^3$) reduction following the single active travel intervention and combined improved travel routes and active travel intervention. The greatest differences between the combined intervention and single intervention are at the Bristol St Paul's and Bristol Bedminster sites (8.32 and 8.72, respectively).

*Table 54 Modelled percentage $NO_2$ (µg/m$^3$) reduction following single active travel intervention and combined improved travel routes and active travel intervention.*

| Site | % Reduction Post Intervention | % Reduction Combined Intervention | % Difference |
|---|---|---|---|
| Bristol St Paul's | 16.26 | 24.58 | 8.32 |
| Bristol Bedminster | 16.9 | 25.62 | 8.72 |
| Coventry Binley | 15.33 | 21.24 | 5.91 |
| Oxford St Ebbe's | 5.62 | 13.34 | 7.72 |
| Sheffield Tinsley | 10.73 | 13.13 | 2.4 |

Figure 162 shows the effectiveness of the combined interventions when compared to the single intervention in terms of percentage reduction. The more heavily congested sites of Bristol St Paul's, Bristol Bedminster, and Oxford St Ebbe's all show high percentage differences (8.32, 8.72, and 7.72%, respectively).

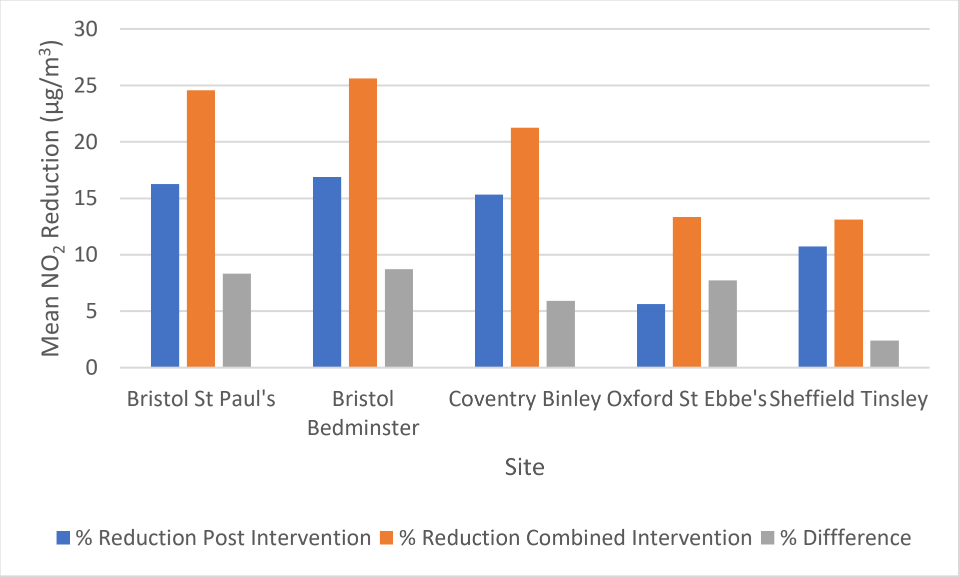

*Figure 162 Modelled percentage $NO_2$ (µg/m$^3$) reduction following single active travel intervention and combined improved travel routes and active travel intervention.*

### 6.5.8.3 Anti-Idling

Table 55 shows a comparison of the outcome of the anti-idling intervention with the improved travel routes combined with anti-idling intervention. Coventry Binley showed the greatest difference in $NO_2$ between the combined intervention and the single intervention (17.1 µg/$m^3$). Sheffield Tinsley showed the smallest difference (1.89 µg/$m^3$).

*Table 55 Comparison of modelled $NO_2$ (µg/$m^3$) concentration reductions following anti-idling intervention and combined improved travel routes and active travel intervention.*

| Site | Baseline | Post Intervention | Difference | Combined Intervention | Difference |
|---|---|---|---|---|---|
| Bristol St Paul's | 26.33 | 23.28 | 3.05 | 20.37 | 2.91 |
| Bristol Bedminster | 25.35 | 23.46 | 1.89 | 20.52 | 2.94 |
| Coventry Binley | 22.41 | 21.08 | 1.34 | 18.44 | 2.64 |
| Oxford St Ebbe's | 17.45 | 16.39 | 1.06 | 15.06 | 1.33 |
| Sheffield Tinsley | 14.79 | 13.28 | 1.52 | 12.90 | 0.38 |

Figure 163 shows the effectiveness of the combined interventions when compared to the single intervention. The more heavily congested sites of Bristol St Paul's, Bristol Bedminster, and Coventry Binley all show higher comparative differences (2.91, 2.94, and 2.64 µg/$m^3$, respectively).

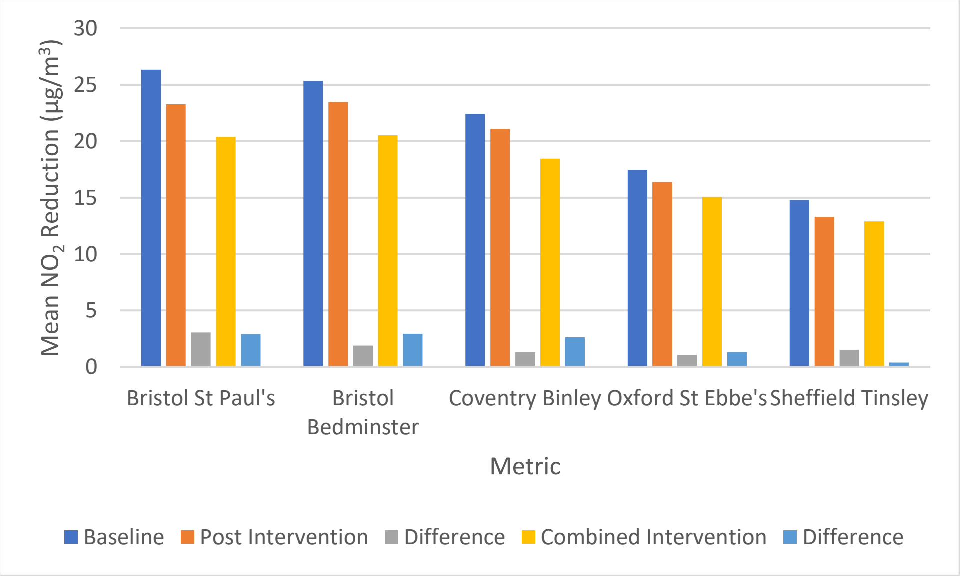

*Figure 163 Comparison of modelled $NO_2$ (µg/$m^3$) concentration reductions following anti-idling intervention and combined improved travel routes and active travel intervention.*

Table 56 shows the percentage of $NO_2$ (µg/m$^3$) reduction following the single active travel intervention and combined improved travel routes and active travel intervention.

*Table 56 Modelled percentage $NO_2$ (µg/m$^3$) reduction following single anti-idling intervention and combined improved travel routes and active travel intervention.*

| Site | % Reduction Post Intervention | % Reduction Combined Intervention | % Difference |
|---|---|---|---|
| Bristol St Paul’s | 11.59 | 22.64 | 11.05 |
| Bristol Bedminster | 7.46 | 19.05 | 11.59 |
| Coventry Binley | 5.97 | 17.72 | 11.75 |
| Oxford St Ebbe’s | 6.06 | 13.7 | 7.64 |
| Sheffield Tinsley | 10.26 | 12.79 | 2.53 |

Figure 164 shows the effectiveness of the combined interventions when compared to the single intervention in terms of percentage reduction. The greatest differences between the combined intervention and single intervention are at the Bristol St Paul’s, Bristol Bedminster, and Coventry Binley sites (11.05, 11.59, and 11.75%, respectively).

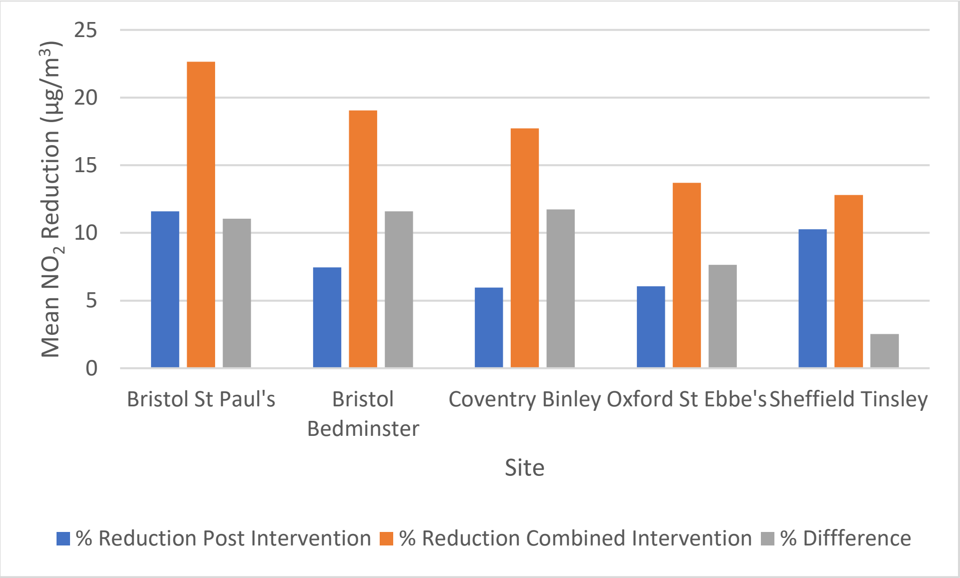

*Figure 164 Modelled percentage $NO_2$ (µg/m$^3$) reduction following single anti-idling intervention and combined improved travel routes and active travel intervention.*

### 6.5.8.4 Rideshare

Table 57 shows a comparison of the outcome of the rideshare intervention with the improved travel routes combined with rideshare intervention. Bristol St Paul's and Bristol Bedminster showed the greatest difference in $NO_2$ between the combined intervention and the single intervention (6.62 and 6.14 µg/$m^3$).

*Table 57 Comparison of modelled $NO_2$ (µg/$m^3$) concentration reductions following rideshare intervention and combined improved travel routes and active travel intervention.*

| Site | Mean Baseline $NO_2$ (µg/$m^3$) | Post Intervention $NO_2$ (µg/$m^3$) | Difference $NO_2$ (µg/$m^3$) | Combined Intervention $NO_2$ (µg/$m^3$) | Difference (µg/$m^3$) |
|---|---|---|---|---|---|
| Bristol St Paul's | 26.33 | 21.90 | 4.43 | 19.71 | 6.62 |
| Bristol Bedminster | 25.35 | 21.51 | 3.84 | 19.22 | 6.14 |
| Coventry Binley | 22.41 | 19.35 | 3.06 | 17.79 | 4.62 |
| Oxford St Ebbe's | 17.45 | 16.02 | 1.43 | 15.03 | 2.42 |
| Sheffield Tinsley | 14.79 | 13.02 | 1.78 | 12.71 | 2.08 |

Figure 165 shows the effectiveness of the combined interventions when compared to the single intervention. Oxford St Ebbe's and Sheffield Tinsley show comparatively lower differences (2.42 and 2.08 µg/$m^3$).

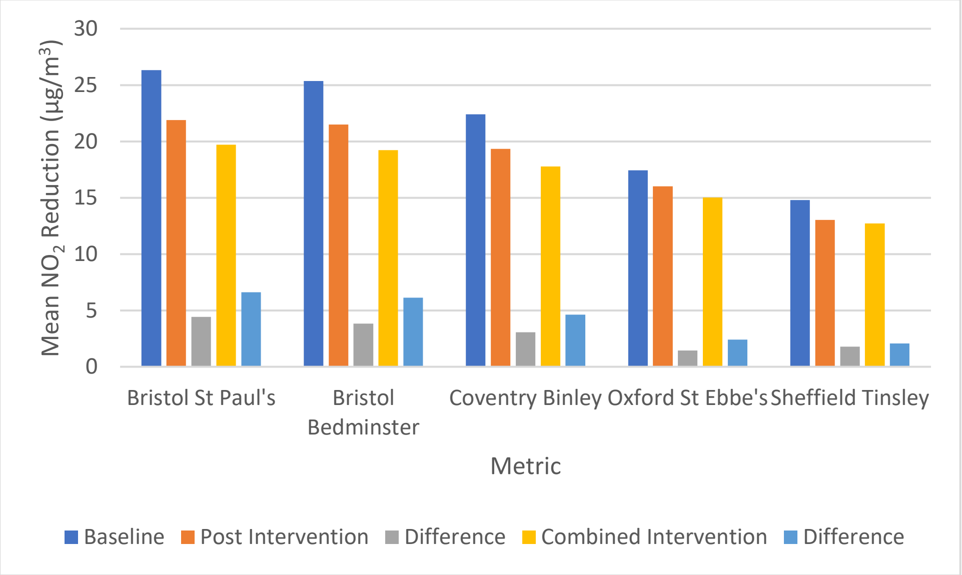

*Figure 165 Comparison of modelled $NO_2$ (µg/$m^3$) concentration reductions following rideshare intervention and combined improved travel routes and active travel intervention.*

Table 58 shows the percentage of $NO_2$ (µg/m$^3$) reduction following the single rideshare intervention and combined improved travel routes and active travel intervention. The greatest differences between the combined intervention and single intervention are at the Bristol St Paul’s and Bristol Bedminster sites (8.33 and 9.06%, respectively).

*Table 58 Modelled percentage $NO_2$ (µg/m$^3$) reduction following single rideshare intervention and combined improved travel routes and active travel intervention.*

| Site | % Reduction Post Intervention | % Reduction Combined Intervention | % Difference |
|---|---|---|---|
| Bristol St Paul’s | 16.82 | 25.15 | 8.33 |
| Bristol Bedminster | 15.15 | 24.21 | 9.06 |
| Coventry Binley | 13.65 | 20.62 | 6.97 |
| Oxford St Ebbe’s | 8.18 | 13.85 | 5.67 |
| Sheffield Tinsley | 12.02 | 14.08 | 2.06 |

Figure 166 shows the effectiveness of the combined interventions when compared to the single intervention in terms of percentage reduction. The sites with heavier traffic of Bristol St Paul’s, Bristol Bedminster, and Oxford St Ebbe’s all show high percentage differences when compared to the comparatively sparsely populated sites, Oxford St Ebbe’s and Sheffield Tinsley (5.67% and 2.06%, respectively).

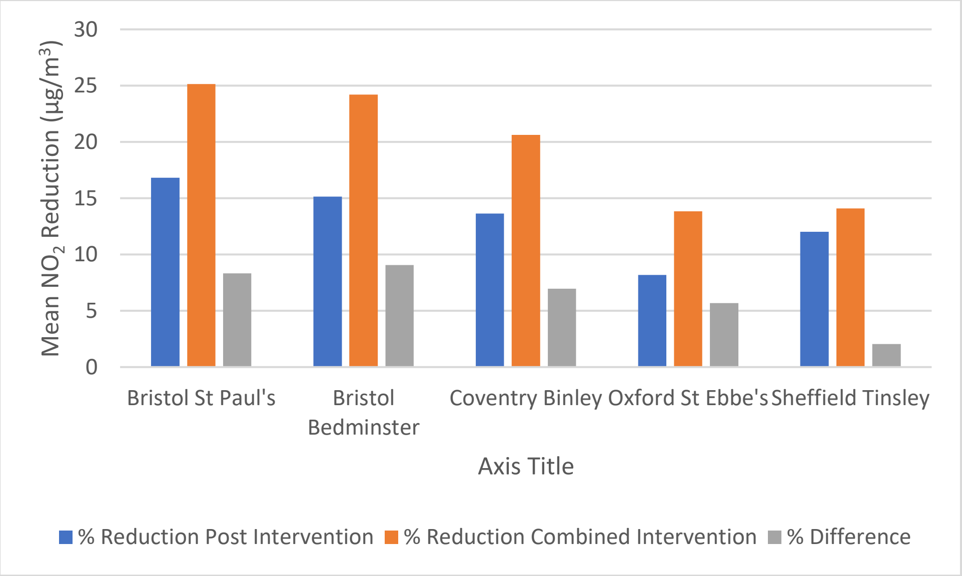

*Figure 166 Modelled percentage $NO_2$ (µg/m$^3$) reduction following single rideshare intervention and combined improved travel routes and active travel intervention.*

### 6.5.8.5 Low Emission Zones

Table 59 compares the outcome of the LEZ intervention with the improved travel routes combined with the LEZ intervention. The greatest percentage of $NO_2$ (µg/m$^3$) differences were found at the Bristol Bedminster site between the LEZ (200 m), iterations (20.17%) and LEZ (500 m) iterations (20.25%).

*Table 59 Percentage comparison of modelled $NO_2$ (µg/m$^3$) concentration reductions following low emission zone intervention and combined improved travel routes and active travel intervention.*

| **Site** | **LEZ (200 m)** | **Combined (200 m)** | **LEZ (300 m)** | **Combined (300 m)** | **LEZ (400 m)** | **Combined (400 m)** | **LEZ (500 m)** | **Combined (500 m)** |
|---|---|---|---|---|---|---|---|---|
| Bristol St Paul’s | 14.84 | 20.17 | 17.44 | 19.56 | 17.63 | 19.21 | 18.91 | 18.89 |
| Bristol Bedminster | 12.65 | 19.71 | 14.96 | 19.11 | 17.38 | 18.59 | 20.25 | 18.3 |
| Coventry Binley | 7.14 | 18.36 | 8.97 | 17.94 | 11.52 | 17.73 | 11.85 | 17.68 |
| Oxford St Ebbe’s | 7.05 | 15.10 | 10.07 | 14.93 | 11.33 | 14.79 | 12.05 | 14.67 |
| Sheffield Tinsley | 11.28 | 12.80 | 13.61 | 12.45 | 14.75 | 12.33 | 16.17 | 12.15 |

## 6.6 Limitations

Limitations associated with the dispersion modelling process principally include the temporal specificity of the interventions and the application of travel routes and, by extension, the improved travel routes.

The available data was limited, particularly in terms of timely traffic data. This resulted in an inability to model the interventions for the morning traffic peaks (i.e., ‘rush hour’) within which the majority of children are likely to undertake school travel. Rather, the models assess the reductions associated with the application of interventions as an overall mean, which is still useful for a comparative assessment (against a baseline and other interventions) to determine intervention effectiveness.

ADMS-Roads is a complex and sophisticated model, but like all models, it has certain limitations. Specifically, the model is limited to 150 plotted road links for each run. This was sufficient for the scope of the current research which assessed TRAP concentrations within a

500-metre radius of the selected school buildings, and the road links modelled were determined by the school's surrounding geographies (see section 6.2.5 Links). Whilst this did not present an issue for the current modelling phase, this should be a consideration for future research that may require modelling over a larger region.

The original travel routes were plotted according to the most direct road routes from external urban/residential centres and access points (e.g., nearby large residential estates or main road junctions) surrounding the modelling sites. This does not necessarily represent all points of access for children but is intended to simulate prevalent driving and travel routes, using main roads to provide the most likely direct route to the school. All routes were plotted based on a visual assessment of the mapped terrain. The improved travel routes were intended to be representative of the best routes in terms of potential $NO_2$ exposure, but they were not necessarily the shortest, nor most effective. A physical exploration of each site was not possible in the current research but may yield more effective or more practical improved travel routes. In addition, plotting the entry and exit points to green space on travel routes and improved travel routes did not account for the size of the green space nor the proportion of time spent in the green space by the child on their school journey. This is beyond the scope of the current thesis but should be explored further in future research to assess the potential pollutant exposure reduction and the proportion of time spent in green spaces.

Whilst traffic volume did not change in the improved travel routes, the contour maps show how ADMS interprets the pollution concentrations based on the introduction of new receptors. This demonstrates the importance of the availability of reliable and comprehensive monitored data for accurate modelling and to determine pollutant concentrations beyond the mapped area or site of interest.

## 6.7 Summary & Conclusion

All interventions showed positive improvements in $NO_2$ ($\mu g/m^3$) concentrations. Overall, improved travel routes were comparatively the single most effective intervention for the improvement of travel route concentrations (with no effect on school concentrations). The introduction of LEZs was most effective for reducing $NO_2$ concentrations at schools, with greater effect at a greater distance. However, LEZ implementation showed a decline of effectiveness with greater distance. The effectiveness of greater distance was more pronounced for travel routes. Active travel was also effective at the schools in sites with heavier traffic (within Bristol St Paul’s and Bristol Bedminster, and to a lesser extent, Coventry Binley).

When considering all receptors (overall site means) LEZ implementation was also effective, with a greater distance providing the greatest reductions. Active travel and rideshare were also effective at the sites with heavier traffic (Bristol St Paul’s, Bristol Bedminster, and Coventry Binley), with anti-idling showing greater comparative effectiveness at the more sparsely populated sites (Oxford St Ebbe’s and Sheffield Tinsley). Behind the improvement of travel routes, the travel routes benefitted most from active travel and rideshare interventions, although LEZ implementation was also effective on all sites. Anti-idling was the least effective measure overall on travel routes.

Overall, when combined with improved travel routes, anti-idling showed the greatest percentage difference for concentrations on improved travel routes when compared to the original implementation without improved travel routes (9.2%). Active travel and rideshare were also effective in this respect (6.89% and 6.70%, respectively). LEZ implementations of 300, 400, and 500 metres combined with improved travel routes were not so effective (3.79%, 2.01%, and 0.49%), although the 200-metre iteration showed a greater comparative improvement (6.64%). Bristol St Paul’s, Bristol Bedminster, and Coventry Binley had generally greater reductions with the combined measures. Oxford St Ebbe’s and Sheffield Tinsley showed far smaller reductions by comparison.

# 7.0 Discussion & Conclusion

## 7.1 Chapter Overview

This thesis intends to answer three questions: (1) What are effective TRAP and exposure reduction interventions supported by evidence suitable for the school commute?, (2) What are the current levels of TRAP in the vicinity of UK schools?, and (3) What is the effectiveness of the interventions on air quality and potential child exposure on school commutes?

Correspondingly, the study has several research objectives. Firstly, (Objective 1) to research suitable interventions from academic and grey literature has been met with the findings presented in the literature review (Chapter 2) and the systematic review (Chapter 3). Several interventions were identified from the review that informed the construction of a survey, disseminated to key stakeholders, and described in Chapter 4. The survey's outcome satisfies the second objective (Objective 2), to identify solutions and strategies for mitigating TRAP or reducing potential child exposure on the school commute, based on the systematic literature review and ratification from key stakeholders. The third objective (Objective 3), to identify TRAP concentrations in the vicinity of UK schools, is detailed in Chapter 5, which describes the method and attainment of TRAP concentrations within 500 metres of UK schools and explores this data in terms of the most polluted schools, their locations and their types. Chapter 6 details the modelling of the interventions in five school locations to determine their effectiveness in the school commute environment. The process and results detailed here respond to Objective 4, to model the interventions on school case study locations.

To address the research questions and objectives, the current chapter considers the findings identified in Chapters 2 to 6 in section 7.2. Drawing from this, the thesis contributions are presented in section 7.3. Section 7.3.2 details a series of policy recommendations in satisfaction of Objective 5 to produce a series of recommendations based on the study findings. This chapter concludes with an assessment of the limitations of the current study, its implications and recommendations for future research and some concluding thoughts (sections 7.4 to 7.6).

## 7.2 Discussion of Findings

### 7.2.1 (Q1) What are effective TRAP and exposure reduction interventions supported by evidence suitable for the school commute?

Traffic pollution around schools has gained increasing attention over recent years, and a growing body of research is focused on mitigating the adverse effects of TRAP on children's health. Whilst its effects are not limited to the following consequences, many studies demonstrated the detrimental outcomes of TRAP concentrations in the school vicinity. These studies have highlighted the adverse effects of air pollution exposure on the internal organs of children (Hamra et al., 2015; Ebi & McGregor, 2008; Kampa & Castanas, 2008; Kulkarni & Grigg, 2008), their cardiovascular, nervous, and respiratory systems (Diener & Mudu, 2021; Boningari & Smirniotis, 2016; Adar et al., 2015; Kim, Kabir & Kabir, 2015; Beatty & Shimshack, 2011; Mejía et al., 2011; Salvi, 2007; Kulkarni et al., 2006; Bruce et al., 2000), and indeed their levels of concentration and academic ability (Chandra et al., 2022; Fyhri et al., 2022; Requia et al., 2022; Grineski, Collins & Adkins, 2020; Webber, 2019; Chen, Guo & Huang, 2018; Zhang, Chen & Zhang, 2018). It has been demonstrated that existing conditions, such as asthma, can worsen, and allergic symptoms can be affected (Beemer et al., 2022). However, other negative impacts, such as the effects of TRAP on children's mental health and well-being, are yet to be as thoroughly investigated.

Comparatively, respiratory disease gained considerable attention in the literature, primarily due to the ease and efficiency of detecting related symptoms and its high prominence (see Goldizen, Sly & Knibbs, 2016; Grigg, 2007; Pierse et al., 2006; Fusco et al., 2001). However, other aspects of child health are not affected to any lesser extent. It is also the case that epidemiological research focused on the relationship between TRAP and child health tends to address the consequential effects on the health of the entire exposure timeframe, which can include the influence of diffused TRAP on children who are located away from roads (Ma et al., 2020). Indeed, quantifying TRAP exposure and its impacts on human health is problematic. A prominent commonality in the studies is related to difficulties associated with determining the extent of child exposure to TRAP during the school commute (Bistaffa et al., 2019; Dalene et al., 2018; Whitehouse & Edwards, 2018; Stewart et al., 2017). Children are at the greatest risk of direct and repeated exposure to TRAP during the school commute, and there is a deficit of research that explores the consequences of this exposure on child health in terms of its severity. Accordingly, the development of new and improved techniques for detecting and analysing exposure to TRAP during specific time periods and quantifying its effects on health is urgently required.

Many studies were assessed to find effective TRAP and exposure reduction interventions for application to the school commute. The interventions assessed could be approximately grouped into five categories: behavioural measures (including adopting cleaner walking routes, uptake of active travel, or car sharing); educational or awareness measures (including anti-idling campaigns, community education, or parent and pupil awareness); national policy measures (including the improvement of fuel standards, legislation and taxation of high-emission vehicles, and fines to enforce anti-idling outside schools); local policy measures (including the closure of school roads during school commute times, improvements to the management of deliveries and visitors, improvement to the cyclist and pedestrian environments, low-emission vehicle promotion, clean air zones, green infrastructure, and traffic calming); and school site measures (including the introduction of green infrastructure, improvements to cycle or scooter parking, rideshare initiatives, anti-idling zones, or air quality monitoring). The survey was developed from the findings of the literature and systematic reviews and disseminated to key stakeholders via schools in England. The questionnaire responses were used to determine what parents and teachers considered the most effective or appropriate mitigation strategies and interventions to reduce potential child exposure to TRAP. However, the strict inclusion criteria meant that far fewer studies met the selection criteria to be accepted for the final synthesis.

The shift from Delphi to questionnaire (see section 1.5 Covid-19 Impact Statement) provided benefits and drawbacks. Delphi is particularly useful in situations with no empirically true answers, as is the case with policy development (Linstone, Turoff & Helmer, 2002). Additionally, a broad range of opinions can be included, reducing the bias associated with a single expert (Keeney, Hasson & McKenna, 2001). However, the questionnaire provided a suitable volume of data with which to work and was sourced from a broad range of respondents. The survey participants included members of school governor boards, parents, teachers, local council representatives and parent/teacher associations. However, they were encouraged to participate based on their proximity to the issues at hand, enabling their categorisation of parents and teachers (including teaching staff). Schoolchildren were not included in the survey as the study considered the parental viewpoint suitably representative of the children and their involvement with associated issues, such as the selection of transport modes to school. Expertise was considered as the experiential opinions of those who were close to the issue in practical terms, and the use of schools for the dissemination of the survey was considered appropriate for this purpose. It was important to conceptualise and define ‘Expertise’ for the study as the survey could have been undermined were respondents who lacked specialist knowledge or an interest in the topic recruited (Keeney, Hasson & McKenna, 2001). A varied selection of respondents was desired for the survey to be suitably representative of the stakeholders, and snowball sampling was undertaken, whereby participants were encouraged to forward the questionnaire to anyone they considered to have a relevant perspective on these issues covered via their available channels, which had the dual intention of encouraging a more diverse response group, but more importantly in practical terms enabled efficient sharing of the survey through many different channels (Linstone & Turoff, 2002).

Beyond the screening phase of the review, the studies which included interventions could be considered in terms of those which intended to mitigate potential child exposure to TRAP and those whose intention was to reduce TRAP, either by reducing traffic or reducing active engine time (anti-idling, for example). Interventions included for synthesis were unsurprisingly primarily focused on peak traffic volume at schools and on the school commute as the issue. Many of these interventions were suited to reducing TRAP on the school commute and at school buildings during peak traffic times. In 2021, 66% of new car registrations in the UK were petrol or diesel, totalling 1.107 million cars (of 1.677 million). This represents a reduction of 46% compared to the previous year, whilst battery electric vehicle registrations increased by 76% (GOV.UK, 2021). Indeed, whilst the number of electric vehicle purchases is increasing, the fossil-fuelled vehicles in use at peak traffic times contribute significantly to air pollution. Supplementing more of these vehicles with electric vehicles could reduce $NO_2$ and exhaust-related particulate pollution significantly (although particulate pollution in the form of tyre and brake wear and resuspended road dust will persist), reducing potential child exposure on the school commute. However, access to these newer vehicles is prohibitively expensive, and current incentives are arguably inadequate for the required uptake. Whilst long-term TRAP will be alleviated by an increase in electric vehicles, sufficient uptake and the implementation of the required infrastructure must be achieved in the short and mid-term to ensure a smooth transition to the new technology when UK restrictions are imposed. Accordingly, more thorough strategies for funding and incentives are required for the widespread adoption among the majority who are currently priced out of the purchase of electric vehicles.

In addition, a more comprehensive approach toward the categorisation of vehicle emissions is arguably required. For example, standards that account for particulate from tyre and brake wear associated with different vehicle classes and an assessment of emissions under real-world driving conditions to generate real driving emissions (RDE) would benefit interventions such as clean air, low emission, or congestion charging zones. Whilst tests now include a RDE component, rather than the previous system of ensuring compliance under laboratory conditions, the EURO6 standard now includes earlier EURO6-compliant vehicles that were tested under flawed type approval tests (Söderena et al., 2020).

Measuring the health effects of vehicular emissions could also potentially provide a more detailed and useful method through which to formulate targeted policies. This could be preferable to the use of specific categories that define acceptable exhaust emission limits, which have been notably compromised (Eger & Schäfer, 2018) and insufficient for the implementation of more sophisticated policy strategies.

Many of the issues regarding the proximity of schools to traffic were supported in the survey results. Recurrent themes throughout from both parents and teachers included the proximity of the travelling children and the school buildings to busy roads, and this was mirrored in the responses of those who were unconcerned about air pollution because their school was in a rural area. The historical approach towards siting schools near main roads for ease of access for parents and comparatively cheaper land is consequently flawed (Webber, 2019). This presents fundamental challenges when attempting to address the issue of potential child exposure to TRAP, particularly in those cases where such locations make it more difficult for parents and children to travel to school without driving. There was also palpable disdain for inadequately planned initiatives which were felt ultimately to cause greater harm than good. For example, several respondents from a number of different regions highlighted concerns over Low-Traffic Neighbourhood (LTN) schemes which they maintained had resulted in traffic becoming rerouted past their schools and creating greater levels of pollution than before. In this respect, there is a case to be made for these initiatives in the planning phase to identify children as the most vulnerable to TRAP and ensure their safety with effective implementation. In addition, without viable alternatives, these initiatives are destined to move the problem of TRAP to surrounding areas rather than provide any traffic reduction other than in the neighbourhoods they immediately serve.

Significant consistencies were found in the literature regarding the complexity of the issue of TRAP at schools and on the school commute. A commonality in the research regarding many interventions, but particularly those that focus on the selection of driving routes and strategies (such as ridesharing) or traffic control measures (such as exclusion zones), require the combined efforts of parents, teachers, schools, communities, and regional and national authorities, and in some cases additional social sectors. There is also a multitude of factors to be considered with the implementation of any policy. For example, the implementation of a low-emission zone requires consideration of the entire traffic system, as well as the effects on the immediate and broader environment. In this respect, parents should adhere to any arrangements in place at their school to reduce idling, driving, and parking in inappropriate areas during the school commute or generally reduce traffic at peak times. However, these strategies are difficult to enforce. Other strategies, such as the selection of low-exposure active travel routes, are popular and effective but may require additional support from schools and local authorities to maximise their benefit. This would come in the form of additional monitoring and publication of low-exposure areas, coupled with suitable and safe route suggestions. In general terms, a comprehensive and sustained effort is required, with continued optimisation, to reduce potential child exposure to TRAP on the school commute. For example, active travel was a consistently popular measure for both parents and teachers in the survey data, and its ease of implementation and lack of cost makes it a suitable strategy for the reduction of car use. In addition, it promotes physical activity, and all these benefits are supported in the literature. However, for all its benefits, collaborative efforts are required to ensure its maximum uptake. Several parents cited the convenience of car travel or the perceived requirement to use the car to ensure they get their child to school and then get to work on time or deliver multiple children to different schools. To counter this, an approach from schools and policymakers alike when promoting active travel could reframe its uptake as liberation from car use rather than an additional chore. The rebranding of active travel as a way to remove the stress of the morning commute whilst also reducing morning traffic, saving money on fuel, and saving time, is a simple step toward changing attitudes on car use.

Parental concerns regarding mode shifts were also presented in the survey data. Such fears are genuine and should be treated with appropriate respect. For example, concerns surrounding child safety and travel distance on the school commute were highlighted. The latter, in this case, presents additional issues regarding school catchment areas and pupil selection. Should catchments be determined via a structured and consistent methodology that requires residency within a particular area, for example, then active travel distances would present as less of an issue, although for this to be justified, then a far narrower inequality between the performance of schools would also be highly desirable. Concerns for child safety as a barrier to active travel can also be addressed with effective information sharing and targeted initiatives. For example, walking buses or active travel partners and groups. Whilst concerns for safety and distance could also be addressed with initiatives such as ridesharing, for these to be effective, awareness and collaboration are still necessary.

A deficit of effective information sharing and communication was also made apparent in the survey results. For example, an awareness of respiratory illness among teachers, but not parents, is indicative of this disparity of knowledge. Conversely, parents appeared more aware of congestion and idling outside schools. These collective experiences are worthy of cross-sharing, particularly as they can provide the foundation to build effective traffic reduction strategies and TRAP exposure mitigation. Other aspects of the findings support this, such as measures including improved cycle and scooter parking and green infrastructure at school. In both instances, teachers were aware that these measures were in place at their schools, but parents were not, indicating that more communication is required. In addition, there was a persisting sentiment, more so among parents but also among teachers, that parents both require and desire further education on these topics.

As touched upon, determining exposure is fundamentally reliant on improved monitoring systems and strategies. The infrequency of monitoring data is mirrored in the research, in which secondary analyses of data are commonplace. In addition, child pedestrian exposure data remains limited and current methods require updating. For example, diffusion tubes generate monthly-averaged data and are also located high above the ground, meaning that data on the actual exposure experienced by children on the school commute is not commonly collected. For example, at 1.5 m, roadside $PM_{10}$ concentrations are 10% lower than at 0.3 m (Mitchell & Maher, 2009). This lack of suitable data is problematic when developing strategies that are targeted, effective, and accurate for the reduction of potential child exposure to TRAP.

Efforts by local and national authorities should focus on urgent improvements to TRAP monitoring, particularly around schools and their districts. This level of comprehensive data, published in real-time, could support the implementation of effective strategies and technologies with which to reduce potential child exposure to TRAP on the school commute and would also benefit broader society. Monitoring comparisons could be used for the optimisation of school commute drop-offs and collections, and the selection of low-exposure active travel routes would be uncomplicated and sufficiently informed. Monitoring on this scale could also address concerns regarding the implementation of community-wide interventions, such as LTNs or exclusion zones. Measuring air pollutant concentrations comprehensively prior to and following the introduction of such measures could allow their effectiveness to be determined with active data at the local level. Access to comprehensive data on the behaviour of traffic and commuters, the meteorological environment, and the consequential TRAP would be greatly beneficial to society as a whole and could further assist in informing targeted policy interventions.

The findings of the literature review and the survey data are important when considering effective strategies for the reduction of traffic and child TRAP exposure, both in terms of their demonstrable effectiveness and in highlighting the key areas where parents and teachers agree and differ. There was broad agreement among parents and teachers regarding potential suitable solutions and the obstacles to achieving reductions. A need for the education of parents on the consequence of air pollution on child health, and methods to mitigate potential child exposure, are required. Rather, such measures should be co-constructed and reframed in terms of empowerment through emancipation from car use, a greater amount of free time, stress reduction for parents and teachers at school gates, improved child health, and in the case of increased active travel, improved concentration and better-behaved children in classrooms, improvements to child learning, wellbeing, and overall fitness. In addition, teachers should be encouraged to work with parents to understand their experiences and to help them work together more cohesively and effectively, particularly regarding measures that they may feel would create more work for them.

### 7.2.2 (Q2) What are the current levels of TRAP in the vicinity of UK schools?

The analysis reported in Chapter 4 follows from the systematic review (Chapter 2) and survey results (Chapter 3) and aimed to identify TRAP concentrations within the vicinity of UK schools. For the purposes of the analyses, $NO_2$ was used as a proxy for traffic pollution (Kendrick, Koonce, & George, 2015), and 500 metres was considered a suitably representative distance around schools for the intended purposes (Tonne et al., 2008). In addition, the analysis intended to address specific gaps in the literature review that would support the current investigation. Specifically, to produce a country-wide evaluation of $NO_2$

within 500 metres of schools, to determine schools with the greatest pollutant exposures, and to determine the types of schools suffering from the greatest pollutant exposures. The chapter analysis also followed from a study that was conducted to assess the reductions achievable if public behaviours shifted towards a greater reduction of non-essential travel (Brown, Barnes & Hayes, 2021). The study identified the reduction of TRAP around schools in England as a consequence of the national stay-at-home order of 2020 in response to the Covid-19 pandemic, finding that $NO_2$ was significantly reduced at schools within 500 metres of background (−35.13%) and traffic (−40.82%) AURN sites in England. To achieve these aims, a GIS (Geographical Information System) was generated to identify $NO_2$ concentrations at all UK schools.

The GIS map used pollution climate mapping (PCM) data provided by Defra. The PCM is based on dispersion modelling techniques, meteorological data, national atmospheric emission inventory data and terrain characteristics (Brookes et al., 2021). The mapped PCM data in the GIS provided a searchable system through which schools with the highest TRAP in the UK are identifiable along with their locational and deprivation contexts. This approach has been justified in similar studies which have assessed pollutant exposure (Forbes et al., 2009) and modelled air quality limit values (Oxley et al., 2009). $NO_2$ concentrations are commonly used as an indicator of traffic emissions (Janhäll, 2015; Tonne et al., 2008), and these were used for the identification of affected schools. Schools that are located within areas with the highest background concentrations of traffic-related pollution were identified, with areas containing the largest number of affected schools forming the basis of a deeper analysis. A series of conditional criteria were applied to the areas with the greatest numbers of affected schools to filter the results, producing several schools that were suitable for modelling the measures identified by the survey.

The analysis found that schools in England were significantly more polluted than those of the UK nations. This is understandable, considering the greater population densities and the larger number of cities and other urban areas. The results also showed that England had far greater proportions of schools within AQMAs and the highest deprivation quintiles. The nature of the deprivation indices is such that further investigation is required to determine to what extent the different environmental domains correlate to higher levels of air pollution. However, nearly half of the IMD is composed of domains relating to financial wellbeing (income deprivation, 22.5%, and employment deprivation, 22.5%), and the literature confirms that generally, poorer households are subject to greater levels of air pollution

(Ferguson et al., 2021; Aerts et al., 2020; Fairburn et al., 2019; Bailey et al., 2018; Li et al., 2018). It should also be considered that whilst England has a greater proportion of polluted and deprived schools, this is not to say that the problem is any less severe for those schools and schoolchildren in other countries. It is also important to reiterate that the deprivation indices for each country are not directly comparable. However, they can be considered in parallel as deprived schools according to the standards imposed by each country.

Whilst the analysis stands alone as a searchable record of school proximity to key air pollutants, the aim of the analysis within the current study was to assess the severity of school pollution but also to assist the process of selection of case study locations for modelling. This was achieved by reducing the schools to a manageable number from which to select suitable candidates for intervention modelling. The case study regions were required to be polluted to assess the effectiveness of interventions but were not necessarily required to be in deprived areas. Rather, this provided a useful metric to assist in refining the many thousands of schools that were potential modelling sites. However, the presented data also serves to compound concerns regarding pollution exposure and divides in academic achievement between deprived and non-deprived areas. Whilst the links between academic performance and air pollution exposure continue to be explored throughout the world (see Grineski, Collins & Adkins, 2020; Chen, Guo & Huang, 2018; Zhang, Chen & Zhang, 2018; Grineski, Clark-Reyna & Collins, 2016), students in deprived areas are more likely to perform comparatively poorer academically than those in less deprived areas (Miller, Votruba-Drzal & Coley, 2019; Banerjee, 2016; Ndaji, Little & Coe, 2016), whilst also suffering with a greater likelihood of poor health. It is also worth noting that many other measures of deprivation possess their own advantages and disadvantages, and these are worthy of further research to assess how these different metrics compare in terms of school air pollution exposure and inequality. The data also raises questions regarding other negative health impactors, such as noise pollution and its association with schools and deprivation.

The results indicate that the potential for air pollution exposure varies greatly depending on the circumstances and geographical context of the population. Location is a significant factor to consider in this respect, and schools present a locational classification of where children spend substantial periods of their time. For example, using AQMAs as an indicator of pollution exceedances, 2840 schools were located within the 38 London AQMAs in 2019. The region of London not only had the greatest numbers of polluted schools but the largest proportion in areas of high deprivation. However, London is unique by comparison to other areas of the UK, mainly due to its size as a city. In this respect, it may not provide the best sense of the impact cities, and other urban centres have on school pollution. For example, second to London in terms of polluted schools was the North West region. Of the 3690 schools in the region, the two largest cities (each with city-wide AQMAs) are Manchester and Liverpool. In 2019, the Greater Manchester AQMA was declared, comprising a single AQMA covering all ten Greater Manchester local authorities: Manchester, Salford, Stockport, Tameside, Oldham, Bury, Bolton, Wigan, Rochdale, and Trafford. All areas had exceeded the annual $NO_2$ mean limit of 40 $\mu g/m^3$ and contained 1053 of the 1328 schools within AQMAs in the North West of England. The Liverpool City AQMA encompasses the entire City of Liverpool and, whilst significantly smaller in area than Manchester, contains 239 schools. The combined total of these two AQMAs accounts for 35.01% of schools in the entire region or 97% of all the region’s schools within AQMAs. Accordingly, cities are characteristically urban sites that present areas that are of particular concern when assessing potential air pollution exposure.

Of course, city-wide AQMAs are themselves particular areas of concern. However, the theme of location as a determinant of pollution exposure was persistent throughout the analysis, with urban environments containing the majority of polluted schools and all highly polluted schools. Whilst this is unsurprising, it does confirm a stark contrast between the experiences of schoolchildren in urban and rural environments. For example, school types did not show any significant differences in pollution concentrations. This supports the findings that location is a key factor in determining air pollution concentrations, above all other considered factors.

Whilst $NO_2$ was used as an indicator of traffic in the modelling phase, PM was also assessed in the analysis and the outcomes largely mirrored those of the oxides of nitrogen. The severity of particulate presence around schools should not be discounted, and should form the basis of further investigations, although efforts towards this are being made (see Osborne et al., 2021b).

As touched upon, the analysis informed the development of case study locations for the modelling phase of the current research but also provided a record of school pollution and potential child exposure in 2019. The data provided can serve many purposes in future research. In its current form, it provides a searchable archive with which to query UK schools in terms of their pollution levels and deprivation. Whilst outside the scope of the current thesis, the database could be readily developed into an online entity which could allow access to the data for parents to make informed decisions about their children’s schools, to provide teaching staff with information to implement mitigation strategies or interventions, to inform local authorities regarding policy decisions, and to serve as a repository for academics to gather data efficiently and effectively. However, this database would need to be maintained by updating the data annually to ensure that current information was made available to users when it was released.

The data and analysis presented in Chapter 4 highlight the significant number of children in England who are exposed to poor air quality daily as a consequence of their school attendance.

### 7.2.3 (Q3) What is the effectiveness of the interventions on air quality and risk of exposure?

The determined measures and strategies were modelled on the case study schools and vicinities selected in the previous phase. A 500-metre buffer surrounding each school was initially modelled and verified using the dispersion model ADMS-Roads. Upon satisfactory verification of each model, TRAP reduction and mitigation interventions, whose selection was based on data sourced from the systematic review and survey results, were modelled in each region based upon data sourced from the systematic review to determine their effects on potential child exposure. The interventions were assessed based on changes in concentrations on travel routes to the school and the school itself. Overall, LEZs were most effective for reducing concentrations on active travel routes and at the school buildings, and increasing distance consistently improved concentration reductions at schools, although the rate of effectiveness declined with each level of increased distance. Improved travel routes to avoid the most polluted roads were the most effective for reducing pollution exposure on the routes, although they did not affect school building concentrations in any scenario. All interventions led to pollution reductions, and all were more effective at reducing pollution on travel routes than at school buildings.

Vehicle exclusion zones, such as low emission zones, clean air zones, and congestion charging zones, are an increasingly popular measure for many cities to address the interrelated issues of greenhouse gas emissions and air pollution, both of which are associated with traffic. The zones restrict vehicle entry based on a set of criteria, usually emission standards, to reduce congestion and emissions (Holman, Harrison & Querol, 2015). To model

LEZs in the case study areas, all roads within a series of radii (200, 300, 400, and 500 metres) were assumed to be closed to non-essential traffic and traffic in each boundary was reduced by 55%. The modelling criteria were averaged over a day, but in reality, an LEZ around schools may only practically be in operation during peak traffic times or just in the morning.

Whilst LEZs are typically placed in city centres and other congested areas and carry their own set of criteria and practical considerations (Tarrino-Ortiz et al., 2022), implementing this form of intervention around schools holds a set of additional and unique challenges. This was also mirrored in the modelling process. For example, whilst contradictory, it is impractical and unrealistic to limit particularly busy roads, such as the M1 in Sheffield, or the A4600 in Coventry, within the school boundaries at peak traffic times. This obstacle was perhaps most extreme in the Bristol Parson St model. Parson St Primary School is situated at the busy intersection of the B3122, A38, and A3029. However, should parents be excluded or limited from driving their children to the school gate, then the traffic reduction of 55% on the B-road (the street physically containing the school gates) is justifiable as a best-case scenario. To address the issue of main roads (A-roads and motorways) in the models, all streets that were closable within the marked LEZ boundaries had traffic reduced. In a real-world situation, minor roads within the boundaries may have little to no impact on concentrations. However, for consistency, they were adjusted for the models. In addition, should these small roads and closes be left open, then they could quickly become access routes for rat-running or used for child drop-offs, creating new pollution hotspots.

The success of the LEZs in the modelling results supports their rising popularity as an effective method for traffic reduction. The modelling results have demonstrated the potential for pollution reduction when traffic is restricted from an area, although the practical limitations of LEZ implementation at schools should not be discounted. As touched upon, many schools, by their nature, are located near main roads, and the closure of these roads is problematic in practical terms. The typical model for LEZs, in which drivers are charged to enter, could penalise poorer parents, and the scheme could lose support. Of course, the purpose of exclusion zones is to exclude traffic, but given the nature of schools as socio-economically divisive entities, this is best avoided where possible. As is the case with all LEZs, to be effective, the implementation should be accompanied by effective and attractive alternatives (Zhai & Wolff, 2021). Within the school context, this could take the form of active travel schemes or zone access for rideshare initiatives. However, all should be collaborative and informed by communication between parents and teachers.

Overall, rideshare was comparable to the reductions achieved by active travel. The existing travel routes were used for the model, simulating the most direct routes travelled by parents to deliver their children to school. This also allowed a greater capacity for comparison with other measures at each site. As detailed in Chapter 5, a rideshare scheme only requires around a quarter of all driving parents to use their cars daily. However, participation from other children to take up the spaces and parents to return the service on other days are both still required for any scheme to be successful and sustainable. As shown in the model results, this can dramatically reduce air pollution on the school commute.

Rideshare showed generally consistent pollutant reduction effects with slight fluctuation at all sites and on all travel routes. This is particularly positive as rideshare, or carpool, schemes provide a method through which to support parents who are required to drive their children to school, for example, parents with disabled children, or those who live too far away for their children to walk, cycle, or use public transport to get to school. Whilst these parents should be encouraged to partake, rideshare schemes should not be limited to these groups. Rather, all parents should be urged to take part in ridesharing to reduce the traffic burden on the school commute. The immediate benefits of ridesharing for both parents and teachers are compelling. Sharing the school run not only reduces traffic on the school commute for all road users and active travellers but also reduces the travel burden for parents, saving them time and, perhaps more importantly, money on fuel. Schools have an important role to play here by facilitating ridesharing cooperation among participating parents from the same areas or taking similar routes. Compiling and sharing this information, with permission and relevant safeguarding protocols in place, is highly desirable. For example, a database of this type can also be used to share travel routes among children to find active travel partners to travel to school together. Rideshare participation can lengthen the working days of parents previously cut short by the requirements of the school run. Whilst freeing up time, parents can also save money whilst reducing their environmental impact and improving the health of their children. Other initiatives can also be used in combination with ridesharing, such as park and stride or walking buses. The rideshare can culminate at one of any number of locations away from the school, where the children’s journey is continued by active travel modes.

Mode shifts to active travel provided positive results at all sites and overall was comparable to ridesharing and the 200-metre LEZ on travel routes. After LEZs, active travel was also overall the most effective intervention at schools. Active travel was also more effective at the more congested school sites with dense residential populations, such as Bristol Parson St

Primary School. Mode shifts to active travel were more effective than all LEZs at Bristol St Paul’s Cabot Primary School and at Coventry Southfields Primary School, Coventry. Each of these sites is characterised by a dense residential population.

Given the greater effectiveness of mode shifts to active travel at more congested sites, encouraging active travel at schools could present an extremely effective method for TRAP and exposure reduction. Of course, active travel is already promoted in many schools as a desirable method of travel to school, and the results of the models support its efficacy as a valuable form of behavioural change in terms of child health. Active travel in this context can refer to any physical travel form, including walking, cycling, scooting, or skating. As is the case with the other interventions, mode shifting to active travel can be framed in terms of its benefits. Parents can be unburdened of the stress and costs associated with driving their children to school and back each day and, under ideal circumstances, could actively travel with their children. In terms of macro effects, there is a range of benefits to the community relating to its broad adoption, including TRAP reduction but also a reduction of noise pollution (Khan et al., 2018). The results indicate that the school commute is heavily affected by traffic volume, and the reductions associated with mode shifts to active travel can not only improve air and noise pollution on a broader scale but can also contribute to improvements in road safety at and near the school gates.

Active travel promotes regular physical activity, which is important for all but particularly children, for whom active travel is also beneficial in terms of other areas of development. Active travel to school can provide children with an increased ability to evaluate and manage risk, improve navigational skills, and enhance a sense of inclusion through community interaction and presence in their surroundings (Hillman, Logan & Shigeta, 2019). Active travel schemes also present a method through which local authorities, parents, and schools can form functional partnerships to improve physical activity levels among children. Incentive programs for children who shift modes to active travel could include discounts for sports club memberships, swimming pools, ice rinks, or other physical leisure activities. Direct benefits for children undertaking active travel have been explored thoroughly in the literature and include improvements to physical and mental well-being. For example, walking and cycling have been linked to improvements in concentration and mood (Fyhri et al., 2022), in addition to contributing significantly to levels of physical activity. Active travel also presents a simple way to promote socialisation with peers and increase independence and self-reliance. The benefits of active travel for schools also relate to the child’s well-being.

Many schools must bear the responsibility of providing what may be the majority of physical activity undertaken by children. This burden is accordingly reduced when children are undertaking daily active travel to school. Research also maintains that when it is part of their daily routine, children are more readily encouraged into other forms of physical activity (Dalene et al., 2018). For schools, the formal provision of physical education and sports can be tempered by a culture of physical activity involving daily active travel, with benefits for staff and children. The greater concentration levels and improved behaviour of the children can benefit school staff, and the traffic reduction can alleviate the stress of the school gates during peak traffic times.

Overall, improved travel routes were the most effective intervention on all travel routes, although pollution at the school sites remained unaffected. This is unsurprising given the nature of the intervention modelling, which essentially changed the location of receptors to mark out less polluted routes. Whilst the change to travel routes had no effect on school concentrations, in an ideal scenario, more parents would be encouraged to take these demonstrably improved routes as active travel routes, reducing traffic at schools and accordingly reducing pollution at the school gates.

The shift to improved travel routes builds upon mode shifts to active travel and was demonstrably more effective than all other interventions at all sites. This was less pronounced at Sheffield Tinsley, which was the only site where improved travel routes were not more effective than any LEZ boundary. This is likely due to the sparse geography of the site and the limited number of substantial changes that could be made to improve travel routes. There were comparatively more options for improved travel routes at the Bristol Parson St site, and this area produced a comparatively far better reduction outcome. This may be due to the contrasting geography of the region, which has a far denser population distribution, providing more streets and a greater number of potential routes. In addition, the limited areas being modelled should not be discounted. Should people be travelling from farther afield (which many will) there may be more options for improved travel routes. A greater number of adjoining paths and non-urban routes were available in Coventry Binley and Bristol St Paul’s. In each of these sites, in many cases, improved routes permitted cuts through green spaces, which also allowed more direct routes to the school without having to use main roads.

Improved travel routes provided consistently strong pollutant exposure reductions in the model results for all sites. This is understandable, given that the initial travel routes were all direct routes, often using main roads. As was shown in the reduction results of active travel, removing traffic from these roads will accordingly reduce the potential for pollutant exposure for those still walking and driving on these routes. Shifting these routes away from the road pollution sources will undoubtedly reduce exposure, and given the sheer volumes of traffic on congested roads, may be more immediately effective than efforts to convince people out of their cars.

Considerations should be taken regarding route length, which could change the time taken to get to school, although small increases will be undoubtedly outweighed by the benefits of physical activity. By their design, the existing travel routes were the most direct road routes, and pollutant exposure for many travel routes in the models was improved by taking more indirect routes away from main roads. Exceptions to this were in situations where adjoining paths between backstreets were available or green space could be crossed. Some of the improved routes crossed grass or other terrains inappropriate for scooting or skating, but all were deemed to be generally suited to walking or cycling. Low-pollution routes that only used alternative roads could be used to reduce in-car exposure, but active travel remains the preferable option. Once too many cars take low-traffic routes, these routes become more polluted, and the additional fuel used would increase overall emissions per vehicle journey, compromising any benefits for active travellers.

In practice, identifying improved travel routes is not without obstacles, but parents could be encouraged to find new safe travel routes with their children, combining their efforts to enable the child to meet with local friends or other children en route should that be desirable or possible, and to ensure the child feels safe and confident. Collaboration with the school in this process is also important, and schools have a significant role to play in ensuring the delivery of these measures is effective. At the very least, schools should be in communication with parents regarding the implementation of these initiatives. With very little additional workload, schools can assist in the allocation of active travel partners and meeting points for walking buses, for example. Each of these endeavours also helps to alleviate the prominent concern highlighted in the survey results detailed in Chapter 3 regarding child safety as a barrier to active travel and also encourages children to take part with their peers.

Different approaches for low-exposure route planning have been detailed in the literature, including GPS (Duncan & Mummery, 2007), GIS (Dalton et al., 2015), and online mapping (Stewart et al., 2017). However, for wide adoption throughout schools, practicality is an important issue. It would be unreasonable to expect teaching staff to work out alternative, safe active travel routes for all their pupils. Any data-driven solution should be presented as an automated system that is made freely available to parents and teaching staff. Improved and accurate monitoring of air pollution throughout communities would greatly benefit these efforts and allow decisions to be made in real time. In any case, solutions should be co-developed with those who must travel the routes to ensure they are effective, practical, and desirable for the people who have to use them.

The model results demonstrate that anti-idling was more effective for the reduction of pollution in sparser geographies. Despite being the least effective measure overall at school sites and travel routes, anti-idling was the most effective behind LEZs at St Ebbe's Primary School, Oxford and Tinsley Meadows Primary School, Sheffield. A comparatively sparse urban residential population characterises both sites and both had comparatively fewer roads surrounding the schools. The effectiveness of anti-idling was comparatively lower for Oxford St Ebbe's travel routes but became very effective for Bristol St Paul's and remained similarly effective at Sheffield Tinsley. This is likely due to the increased access to school via green space at the Bristol St Paul's site.

The traffic reduction used to simulate the anti-idling intervention in the model represented a best-case scenario, within which all motorised school travel was removed from the school building. As highlighted, this is optimistic and arguably unrealistic but provided the best available method to simulate the intervention. In real-world scenarios, traffic would not be banned from the school vicinity but would not idle outside the school when dropping off or picking up children. The time dependence of the intervention also remains untested, given the intervention simulation averaged over the space of a day in the model.

Reducing idling can reduce wear, maintenance, and vehicle operating costs whilst also reducing air pollution. In addition to producing air pollution (Mendoza et al., 2022), idling vehicles waste fuel and reduce engine life (Daniels, 2006). When idling, an engine cannot achieve proper combustion due to insufficient heat production, leading to black carbon (BC) deposits that can contaminate the oil and attach to cylinders and pistons, leading to engine component wear due to increased friction. The incomplete combustion associated with idling engines has been shown to increase exhaust pollutants, including CO (Storey et al., 2003), hydrocarbon (HC) (Brodrick et al., 2002), and $NO_X$ (Khan et al., 2018). All of these reasons can be used to encourage behavioural change among parents and the wider public to reduce idling around schools. Behavioural change and increased awareness are low-cost solutions to the problems presented by idling and could help reduce idling where enforcement is not possible (Popoola et al., 2018). For example, enforcing idling around schools is particularly problematic, but measures can be taken to target difficult parents by their frequency of attendance. However, in some cases, the wider public can present the greatest polluting entity. As shown in the Bristol Parson St model, the school building is flanked by a busy junction and traffic lights. The queues of idling vehicles at peak traffic times have gained media attention, and posters have been installed requesting that motorists turn off their engines whilst waiting for the lights (Jackson, 2022). The model results mirrored the issue, and anti-idling was the least effective measure at the site and travel routes due largely to the large traffic volumes in such close proximity to the school and surrounding areas. A similar pattern was visible in the results of the Coventry Binley site and travel routes, which has a similar, albeit slightly less congested, geography.

Leaving a stationary vehicle engine running unnecessarily is an offence under Regulation 98 of The Road Vehicles (Construction and Use) Regulations (1986). Since 2002, local authorities have been granted powers of enforcement for switching off engines when vehicles are stationary on the roadside. Fixed Penalty Notices (FPNs) of £40 can be issued to drivers contravening the regulation, and councils can also create a Traffic Management Order (Road Traffic Regulation Act, 1984) allowing traffic enforcement officers to issue Penalty Charge Notices (PCNs) of £80. Should these methods be introduced around schools, they may prove to be effective in reducing idling and accompanying air pollution. Sheffield has introduced anti-idling zones around schools with accompanying fines of £20 for offenders, although few fines have been issued, and the scheme has been criticised for lack of enforcement, which critics argue has been left to teachers and parents (BBC, 2019).

When considering the exclusion of vehicles on roads around schools, as is the case with the LEZ, the anti-idling intervention appears relatively ineffective at sites with nearby heavy traffic. However, the intervention led to effective reductions at the sites with more sparse geographies, and the implementation of anti-idling campaigns can still form an important part of broader pollution reduction and awareness campaigns on the presumption that their effectiveness will increase as nearby traffic volumes are reduced.

### 7.2.4 Summary

A systematic literature review was conducted, and the findings identified a series of interventions that were demonstrably effective for the reduction of air pollution around schools. The effective interventions included methods for the reduction, mitigation, and obstruction of TRAP. The systematic review also informed a survey distributed to UK schools to gather information from parents, teachers, and other key stakeholders to determine attitudes and experiences regarding TRAP on the school commute. The results were assessed under the categories of parents and teachers and indicated that whilst experiences were distinct, there was broad agreement between the two groups regarding possible solutions for the reduction of potential child exposure to TRAP. A need for communication was also apparent, and it is expected that an increased level of collaboration between the groups would help to alleviate several issues surrounding differing attitudes towards responsibility and future directions, in addition to providing a more robust basis upon which to develop and implement TRAP mitigation and reduction strategies. Simple and cost-effective reduction strategies, including active travel, ridesharing, and anti-idling, should be reframed and explained to both groups, not only in terms of child health and additional positive consequences but also the many additional benefits for parents and teachers.

A GIS analysis of the UK informed the identification of a series of case study locations for modelling reduction and mitigation interventions. A database of school pollution exposure was produced, and the results highlighted the significant number of schools in England that experienced dangerous levels of air pollution and poor air quality. Interventions were modelled based on their popularity among teachers and parents, and their applicability to the school environment. Regions around schools were selected, and models were produced and verified to assess the effectiveness of Low Emission Zones (LEZs), anti-idling, mode shifts to active travel, ridesharing, and improved travel routes. All interventions were effective at reducing pollution around schools and travel routes, with LEZs and improved active travel routes showing the greatest pollutant reductions. The school site geography was a factor in the effectiveness of the interventions, with sparse residential areas benefitting more from anti-idling than those with greater population densities.

## 7.3 Contributions of the Thesis

### 7.3.1 Implications for Policy & Recommendations for Implementation

Based on the dispersion modelling findings and contextualised by the literature, a series of policy recommendations were produced for authorities and key stakeholders for the reduction of TRAP and potential child exposure on the school commute. The policy recommendations are presented for national, local authority, and teacher/parent levels.

### 7.3.2 National Level

#### 7.3.2.1 Overview

The UK government has already acknowledged that air pollution is the ‘largest environmental risk to public health in the UK’ (Public Health England, 2022). Beyond the immediate concerns for human health, the implications of poor air quality also include economic considerations and the natural environment (Rao et al., 2017). The effects of air pollution require a united and cohesive strategy to mitigate the health consequences and protect children and other at-risk groups from poor air quality.

$PM_{2.5}$ is regarded as the air pollutant most harmful to human health, disproportionately affecting vulnerable groups such as children and people with pre-existing respiratory conditions (Xing et al., 2016). Over 31% of schools in England are located within AQMAs and are subject to levels of air pollution that are dangerously high and current legislation does not go far enough. Whilst it is acknowledged that there are no safe levels of air pollution (Al-Kindi et al., 2020), the World Health Organization has set guidance that $PM_{2.5}$ concentrations should not annually exceed 5 $\mu g/m^3$ (World Health Organization, 2021), whilst current UK targets are to reduce concentrations to 10 $\mu g/m^3$ by 2040 (Defra, 2022f). During this time, several generations of schoolchildren will be exposed to harmful levels of pollution.

Areas including London, the North West, and the West Midlands are regions containing the greatest numbers of polluted schools, and of these, the most polluted can be found in London, Liverpool, Manchester, Sheffield, and Birmingham, each containing schools subject to illegal levels of $NO_2$ and $PM_{2.5}$ concentrations. However, all regions contain highly polluted schools which children attend every day.

The economic cost of this pollution is severe. As a consequence of air pollution exposure, the expense to the NHS will exceed £5 billion between 2017 and 2025, given current levels of

$NO_2$ and $PM_{2.5}$ (Dunning, 2021). Reducing these harmful pollutants will not only provide immediate improvements to the quality of life and health of all children but will also dramatically reduce the medical expenses associated with these exposures, resulting in significant economic savings.

The negative health effects of child exposure to air pollution are unequivocal. Bold political action is required to enable an effective shift from reliance on car use to clean up the school commute and immediately protect child health and wellbeing. The following are a series of recommendations to the government based on the current thesis findings.

#### 7.3.2.2 Legislation

Legislation has many benefits, including creating a set of clearly defined and workable goals rather than relying on other inducements, such as market-based incentives, that may be slow to become effective or to work at all (De Vries & Hanley, 2016). In addition, meaningful legislation can set a standard for public expectation (Héroux et al., 2015). A key drawback of regulation relates to enforcement. For example, air pollution limits set standards but do little to address how they will be achieved. The following legislative considerations relate to practicable standards that will help to ensure against unnecessary child exposure to harmful pollutants.

Potential school site selection should require a thorough analysis of air pollutant exposure. All potential sources of air pollution, including major roadways, airports, and industry, should be identified and inventoried. This should be coupled with an assessment of the local climate characteristics and topography of the site and surrounding area to determine potential exposure for children travelling to the school. A minimum distance should be ensured between the school and major polluting roads, and existing school locations should be considered when siting new roadways. Whilst no research states a safe distance for pollution, levels decrease with a greater distance from pollution sources (Tong et al., 2016).

Environmental mitigation policies should be enacted to reduce potential child exposure to TRAP. Of particular importance is the implementation of mitigation methods in urban areas where potential sites for schools that are a suitable distance from polluting roads may be more difficult to find. However, site use should not be permanently restricted from school building use if pollution is abated in the future. In order to enact effective policies, their development should be made by collaboration between all relevant national and local stakeholders, including health professionals, education policymakers, headteachers, teachers, parents, school administrators, and environmental scientists. Collaboration between these groups can help to develop policies that can create schools that are safe for children to travel to and learn within.

#### 7.3.2.3 Behavioural Change

Legislation that encourages people to change their behaviours is an important part of any strategy to reduce child exposure to pollution on the school commute. Current voluntary policies such as anti-idling should be enforced around schools, and additional powers granted to teachers to impose punitive measures on repeat offenders. Anti-idling laws already exist, but stricter enforcement could promote behavioural change. ‘Nudge’ behaviours, such as signs at schools encouraging parents to turn their engines off when waiting to collect children, may be effective (Capraro et al., 2019) but can be further supported by legislation and penalties for non-compliance. Such efforts can improve current school air pollution conditions and change behaviours by settings strict standards for conduct at schools and providing recognition of their status as a congregative location for a vulnerable group.

Any legislation should be accompanied by a thorough marketing campaign to raise awareness of the economic costs associated with driving and the health costs to children associated with the resultant pollution. Public health campaigns have used these strategies before to great effect, for example, with anti-smoking or campaigns against drunk driving (Cismaru, Lavack & Markewich, 2009). A hard-hitting public health campaign extolling the virtues of active travel and explaining the negative health consequences for children associated with traffic pollutants may have some real effect on changing attitudes. There are currently many comparatively small-scale campaigns, but they are disjointed, and a government-led strategy could provide greater cohesion in its approach leading to greater benefits. In this regard, air quality and strategies for exposure mitigation could also be taught to children through incorporation into the national curriculum.

#### 7.3.2.4 Subsidies

Legislation and campaigns for behavioural change may be ineffective if people are not provided with desirable practical alternatives. Should the government provide subsidies for alternatives, such as electric cars and bicycles for children, the public may be more willing to make the changes. These subsidies are justifiable by the money they will save through the mitigation of environmental damage and negative health impacts, each of which will be abated by the reduction of polluting vehicle use.

Some subsidies for cycle purchase exist, but they tend to be focused on employer-based incentives, such as the UK Cycle to Work scheme. A national cycle subsidy or grant scheme that facilitates children purchasing a road-worthy bike would allow many disadvantaged children, particularly those that live in deprived areas with high levels of pollution, to make a shift to active travel for school journeys. This would reduce air pollution at peak traffic times and promote physical activity whilst improving child health and lowering health service costs.

#### 7.3.2.5 Improved Data & Monitoring Network

Air pollution data should be made more readily accessible and searchable for parents, teachers, and local authorities to make informed and timely decisions. The existing monitoring network should be expanded to include all schools and educational buildings. Diffusion tubes are not sufficient as they only provide averaged information. Real-time air quality monitoring should be in place so that peak pollution times can be readily identified. The creation of a searchable national air quality database that details air pollution at schools in real time would be of great benefit to all stakeholders, allowing them to develop targeted strategies for the reduction of pollution and the mitigation of child exposure.

### 7.3.3 Local Authority level

#### 7.3.3.1 Overview

It is recommended that local authorities work together closely with schools to mitigate the potential exposure of children to harmful TRAP on school commutes. Strategies and interventions to limit child exposure to air pollution include both mitigation and reduction strategies. In the former, the children avoid the existing pollution, and in the latter, the pollution sources are reduced. The following are some recommendations for this aim that are supported by the findings of the current thesis.

#### 7.3.3.2 Traffic Management & LEZs

The creation of a LEZ around schools at peak traffic times is an extremely effective way of reducing potential child exposure to harmful pollutants on the school commute. Drop-off and collection points can be moved away from the school gates outside of the zonal boundary to minimise potential child exposure to pollutants at the school gates. In addition, the introduction of LEZs around schools at congregative times may also discourage the use of cars when combined with active travel campaigns. Local authorities must support schools in the implementation of LEZs at peak traffic times where possible. In circumstances where LEZs are not possible, traffic-management measures, such as access restrictions, or anti-idling enforcement, could help to restrict vehicular emissions around schools or in specific zones where children can be safe from exposure on their school commute and encourage behavioural changes among parents to mode shift their children to active travel.

Traffic reduction methods have strong potential effectiveness at the local level. Restrictions placed around driving have produced consistent air pollution reductions and should be considered for all schools where possible. It should also be considered that whilst LEZs can produce rapid reductions in traffic in a specific area, if no suitable alternatives are offered, then the traffic is simply relocated, and the problem may persist elsewhere. An argument towards LEZ implementation can be made based on the vulnerability of children, and given this status, the reduction of TRAP at schools is of more immediate concern. However, encouraging traffic to pollute elsewhere is not an effective solution, and incentives must be provided to ensure that as much as possible, traffic is kept away from schools whilst also reducing traffic volume overall.

#### 7.3.3.3 Behavioural Interventions

Behavioural interventions include raising awareness and the provision of educational campaigns towards reducing car use at peak traffic times and explaining the health impacts of TRAP on children. To maximise effectiveness, these should be combined with other behaviour-modifying interventions, for example, the development of cycling infrastructure to encourage safe active travel or the improvement of public transport for schoolchildren. When used in combination, the effectiveness of these measures can be maximised. Indeed, raising awareness alone may be insufficient to create a change. These measures must be undertaken in conjunction with other interventions to ensure their success. Programmes for exposure reduction are effective at providing advice on how to reduce personal air pollution exposure. These should be targeted at schoolchildren as a vulnerable group and can include educational and information programmes that can encourage them to make improved and informed choices using national advice tailored to the local environment.

### 7.3.4 Teacher/Parent Level

#### 7.3.4.1 Overview

Schools are required to protect pupils against health risks, and the threat of air pollution is real and immediate. Due to child vulnerability, schools and associated travel present important areas for the reduction of TRAP and the mitigation of child exposure. To achieve the pollution reductions known to be possible, it is essential to develop and implement effective strategies for the reduction of traffic on the school commute. This is achievable by a combined approach involving the reduction of school-related traffic and the development of broader strategies to reduce overall levels of traffic to end daily child exposure to air pollution. The current section details the implementation of effective interventions, supported by the current thesis findings, for reducing and mitigating child exposure to harmful TRAP on the school commute.

#### 7.3.4.2 Awareness & Communication

A holistic approach towards generating awareness should be encouraged, with participation and communication between local authorities, government actors, communities, parents, and schools all working together towards solutions. Communication between schools and parents at every stage of strategy development is encouraged. As evidenced in the current thesis, many parents have the desire to help and engage with air pollution strategies, but they feel unable or suitably uninformed to do so. For those who are unengaged, then motivating them by explaining the impacts on their children’s health may help, particularly when combined with education on alternatives to car use and the associated benefits of interventions such as mode shifts to active travel. For teachers who may be reluctant to undertake new and integrated strategies due to the possibility of increased workloads, the benefits of increased levels of active travel should be fully explained in the context of the literature, including healthier, happier, more relaxed children with improved concentration and better behaviour in class (Fyhri et al., 2022).

#### 7.3.4.3 Active Travel

Beyond ensuring effective communication and awareness among parents, teachers, and children, many practical strategies can be undertaken to reduce potential child exposure to TRAP on the school commute. Mode shifting to active travel is an effective measure due to its minimal cost and ease of implementation. Whilst active travel is generally cheap (e.g., walking is free) and requires very little action from the school, there are several ways that it can be encouraged to ensure maximum uptake among parents and children. Carrying out a survey of the attitudes of children and parents towards active travel, specifically walking and cycling to school, may be beneficial. This can identify the proportion of children who currently engage in active travelling on the school commute, in addition to any concerns that may be preventing children or parents from participating. The information can also help to determine what the school can do to address these apprehensions. Once complete, the findings should be shared among children and their parents, in addition to materials that outline the benefits associated with active travel, safe practices for commuting to and from school, the best active travel routes for the area, and any additional information that could help or encourage participation with the scheme.

It is also pertinent to consider if there are any changes to current school facilities or routines that could help to enable active travel among children. This could include the installation of bicycle racks, providing access to changing rooms and drying areas, increasing staff supervision, or any available training courses that the school could easily facilitate. Beyond these measures, schools and parents should also engage with local government to help find ways to make active travel routes to school safer or potentially create broader exclusion zones for drop-offs to minimise local traffic volume. Child exposure to harmful air pollutants is an issue of current concern for governments and local authorities, and this provides the opportunity for schools to lead the way towards informing long-term changes to local infrastructure that can then lead to the positive uptake of active travel in the future.

For those parents who are concerned about child safety on the school commute, walking buses can be effective for encouraging active travel among children (Smith et al., 2015). As with any strategy, some initiative from the schools may be required to implement an effective system that can overcome obstacles preventing people from participating. The common issue of safety is one that cannot be ignored, and the introduction of walking buses for children can help to mitigate safety fears to enable and encourage participation. Walking bus measures commonly operate in one of two ways. Adult volunteers or teachers begin the walking bus at a predesignated starting point. They follow a predetermined route, stopping at pre-arranged points at specific times to collect pupils en route to school. The return journey sees the bus follow the same route in reverse, dropping off children at their relevant stops. The other method is the park and stride, which differs slightly. A walking bus is conducted from a designated car parking area. In the morning, pupils gather at the designated area, and adult volunteers then escort them for the remaining walking journey into school. At the end of the day, the adult volunteers escort the pupils back to the car park. This type of walking bus can also contain designated stops on its walking routes where pupils can be collected and dropped off at specific times.

In all active travel scenarios, it is essential to identify routes that have low exposure to TRAP. This can be achieved using existing data, or by producing new monitored data, or by simply avoiding main roads wherever possible.

#### 7.3.4.4 Rideshare

Ridesharing is an effective method for the reduction of traffic on the school commute and can be promoted to the parents of children who are unable to mode shift to active travel. The school must be more involved in the construction of a rideshare scheme for it to be effective. Parents can also initiate the undertaking by asking around other known parents in the neighbourhood if they want to share the school run. Should this not be possible or is ineffective, then parents should approach the school directly and request the implementation of a more formal scheme or pass details on to other families who live nearby, who can then make contact should they wish to partake. For rideshare schemes to be successful and have longevity, it is important that the child is introduced to the other family prior to the lift sharing and that all parties, parents, and children are happy with the arrangement (Jain, Johnson & Rose, 2020). Children must also be clear on what is expected of them during the trip in terms of their behaviour. For example, some drivers will not allow eating in their car, and the children must understand not to distract the driver and wear a seatbelt (Zhang et al., 2015). Whilst these are basic principles, they are important to clarify prior to any undertaking. It is also important to ensure that all parties have the contact details of the other party and are clear about the collection and drop-off locations and times.

#### 7.3.4.5 Anti-Idling

Whilst not as effective as other measures for the reduction of TRAP on the school commute, anti-idling zones around schools can send an important message to parents and the public regarding expected behaviour and safeguarding child health. Until current anti-idling laws are properly enforced, the responsibility of enforcing anti-idling zones must be placed with the school. Letters to parents who are repeat offenders explaining the harm they are doing to their own and other children could form part of this strategy. Volunteering parents should not be left to police any anti-idling zones as this could lead to conflict and division.

The effectiveness of self-interest cues has been highlighted as effective for encouraging positive environmental behaviour and can be beneficial for promoting anti-idling compliance. Messages to promote the anti-idling campaign should accordingly be centred on cues for financial loss and child health interests (Van De Vyver et al., 2018).

## 7.4 Limitations

To answer the research questions and aims, the project undertook four methodological stages comprising a systematic review (Chapter 2), a survey (Chapter 3), a GIS database (Chapter 4), and dispersion modelling (Chapter 5). Each of these processes had its drawbacks, and these limitations are explored in the current section, with suggestions for improvements in future research.

### 7.4.1 Systematic Review

The review only assessed positive studies confirming the effectiveness of interventions suitable for implementation around UK schools. Whilst the inclusion criteria were intentionally narrow to ensure specificity for the current project, the review may be subject to positive publication bias in that only research papers with a positive outcome were included. Other studies that contradict these results may exist in the literature and negate the findings of the included studies. Given the nature of academic journal publication, combatting this issue presents a challenge. Several journals were used to source studies from as broad a range as feasibly possible, but positive publication bias inevitably narrowed the available results. Research with null or negative results is now rarely published, and this publication bias permeates all academic disciplines (see Sharma & Verma, 2019). A systematic review devoted to comparing positive and negative results would be beneficial to establish the effectiveness of interventions for the mitigation of child exposure to air pollution. For this to happen, journal editors, academics, and other stakeholders should work towards shifting the publication culture towards recognising and accepting the importance of publishing negative results. Currently, the non-reporting of negative results not only introduces bias into systematic reviews and meta-analyses, distorting the decisions made by policymakers, doctors, and researchers but also wastes thousands of hours of time and money, which may be better spent were it based on complete information.

The review only included studies published in English, which may have discounted relevant studies that were published in other languages. The reasoning for this was twofold and based on practicality. Firstly, it was considered a convenient method through which to filter out studies that may not have been relevant to the UK environment. For example, air pollution around Spanish schools may comprise compositions and meteorological conditions distinct from those in the UK and therefore require different interventions for its effective removal or mitigation. Secondly, language barriers would prohibit the adequate assessment of texts in foreign languages. Were the time and resources available, fluent researchers could be employed to undertake this task of classifying and verifying non-English studies for inclusion in the review to ensure that any useful studies were not omitted based on their publication language.

The greatest limitation of the review was that it was conducted by a sole researcher. A systematic review is a substantial undertaking, and the workload is compounded by time limitations. Additional researchers not only alleviate the burden of the review in practical terms but can also provide supplementary judgements on article inclusion to mitigate selection bias. Given that the review forms part of an individual thesis, the assistance of additional researchers was not appropriate. However, efforts were made to assure against inclusion bias to the greatest possible extent by using structured selection criteria and tools (PRISMA, SPICE, and ROBINS-I), achieving an AMSTAR rating of ‘moderate’. If a future review is conducted outside of an individual thesis, then an additional researcher would be beneficial to better mitigate against bias in study selection and data extraction.

### 7.4.2 Survey

All surveys are subject to possible bias, including non-response bias and response bias (Sedgwick, 2013). Whilst selection bias could be discounted on the basis of the participants being largely representative of the population, the response rate to the survey could imply that non-response bias may exist in the results. The quantification of those who responded and those who did not is difficult due to the nature of dissemination (i.e., through schools as gatekeepers). Only four schools declined outright, but this does not account for the several thousand more whose responses were absent. Any further contact made to these schools regarding their non-participation would have been ethically inappropriate, so determining reasons for non-respondence is also problematic.

It is also the case that the survey may be susceptible to response bias, whereby participants answered in a way that they felt was appropriate given the subject matter. This is a particular issue in questionnaires that deal with social issues such as child health. To mitigate against these forms of bias, efforts were made to ensure participants knew their data would be confidential and completely anonymous, providing the participants with the assurance that they could reveal their opinions without personal judgement. However, there remains the possibility that people who were already interested or familiar with the topic would have been more likely to respond to a survey of this nature.

The categorisation of respondents into parents and teachers also presents an issue regarding the nature of responses, in that participants may not have been answering solely from their initially stated position. For example, some teachers may respond based on their experiences as teachers and parents. However, a judgement was made in that the experiences of teachers, irrespective of their parental status, would provide unique insights into their roles and duties that were valuable for the current project.

### 7.4.3 GIS Database

Compromises in the construction of the GIS database were necessary for practical purposes. The pollution maps did not account for industrial pollution and other sources. The PCM data used for the GIS is modelled and provides no information on pollution sources but rather serves as a baseline of pollution around UK schools and fits the requirements of the current project. However, a more detailed assessment of the current state of pollution at UK schools would identify the source apportionment of pollutants to better determine targeted solutions for the reduction and mitigation of child exposure. This would require detailed information on traffic and land use across the UK, in addition to improvements to the current platform (see AQE, 2022) to provide a unified, national data repository for AURN and local authority monitoring data that could be queried and interrogated effectively to gather multiple datasets by a range of search queries.

The use of a 500-metre buffer around schools is supported in the literature as suitably representative of air pollution conditions of a research project of this scale (Tonne et al., 2008), but even at this distance, background effects beyond this perimeter can affect the local environment to a great extent. Geographical features, including woodland, high buildings, canyons, and urban infrastructure, could all deliver additional impacts on the pollutant levels in any region, none of which was accounted for in the GIS. Given the scope of the current project, the inclusion of this level of detail was not only unnecessary but would present a practical impossibility to factor in all this additional information. Should more detailed analyses be required in similar studies, some of these elements could be included using lidar and similar data to establish the effects of terrain on potential exposure, although this remains limited by practical considerations.

Whilst the GIS provides a lookup of pollution concentrations at UK schools, the database does not take into account potential child exposure at peak times for the school commute. The commute is time-specific and predominantly occurs coincidentally with peak daily traffic. The GIS data are averaged and does not account for the times children are travelling to and from school and will be most exposed. To address this issue, daily peak concentration data were used for each day on the presumption that this represents peak traffic and the point that children will be most exposed on the school commute. In addition, school holidays and weekends are not accounted for because the PCM data are annually averaged. PCM data was preferable for the current study over AURN data because of its nationwide coverage. AURN monitors provide a greater degree of accuracy but omit many schools that are not within 500 metres of a monitoring station. To explore potential exposures further, better data availability and increased monitoring are required. For more limited studies, AURN data could be used, and a greater level of temporal detail could be achieved.

### 7.4.4 Dispersion Modelling

Models are reliant on the quality of their data, and any conciliation in this regard can compromise the integrity of the output. The traffic data used for the dispersion models were provided by the UK Department for Transport (2022a; 2022b) and only provided detailed data for all major roads and streets, so traffic volumes had to be estimated for minor roads. The estimations were made using the existing traffic data, flow rates, speed limits and street types (i.e., residential, industrial, or commercial). Whilst beyond the scope of the current project, a traffic modelling system such as Paramics (see Bartin et al., 2018; Al-amedy & Al-Obaedi, 2021; Al-Kareawi & Al-Obaedi, 2021) or SUMO (see Liao et al., 2021; Olaverri-Monreal et al., 2018) could be used in conjunction with the dispersion model to determine if more accurate traffic volumes can be achieved that may generate finer detailed results.

Given the nature of the input data, the interventions were modelled in terms of their daily effects rather than hourly. Hourly modelling would be preferable to determine potential child exposure at peak traffic times and the school commute, but this was not possible with the available data. For example, the traffic data was annualised, and the diffusion tube data (used for verification) was averaged over approximately one month. Because the input data was of different temporal classifications, concessions were made regarding their inclusion to ensure consistency. With more accurate data, a more detailed assessment of the effectiveness of interventions in terms of their effects on air pollution at specific times of day, particularly during peak traffic and the school commute, could be achieved. In addition, the availability of suitably comprehensive meteorological data limited the selection of school sites. Meteorological data are sparse, and for many otherwise desirable sites, there was no available data, prohibiting those sites from inclusion in the models. More adequate meteorological data in conjunction with a greater number of monitoring stations would be beneficial for air pollution research.

School catchment area data are problematic to determine and are unique and changeable for each school in the UK. Many schools accept pupils from outside of the 500-metre boundary used in the model, and as such much of those journeys would be unassessed in the output. Whilst the routes used in the models were constructed and suitable for the purposes of the current project, determining catchments and researching genuine travel routes would provide interesting insights into child and parent travel patterns. This would support the development of more detailed and effective improvements to travel routes based on terrain and behaviours.

### 7.5 Recommendations for Future Research

In addition to the aforementioned avenues for more detailed analyses and improved methodologies, a series of further recommendations can be made for future research based on the findings described in the current thesis. For example, the co-design of interventions with a survey produced a sizable amount of data and generated some important findings. However, the originally planned Delphi approach towards the co-design of interventions could also generate additional insights into the suitability of interventions from key stakeholders. The findings from a Delphi approach could provide co-designed and desirable solutions for implementation around schools to mitigate or reduce potential child exposure to TRAP.

Given the level of consternation in the survey results regarding the implementation of LTNs, a study should determine the effectiveness of LTNs in terms of their reduction of traffic volume and air pollution. Any study should also consider the broader area and assess the effectiveness of the LTN in these reductions outside of its immediate vicinity to identify the consequences of the implementation on the wider neighbourhood. A regional assessment of deprivation and of public opinion within and beyond the LTN boundaries regarding the effectiveness of any intervention would also provide important insights into the development of future research on the efficacy of these measures.

It is also worthy of note that there are many other measures of deprivation that possess their own advantages and disadvantages, and these are worthy of further research to assess how these different metrics compare in terms of relative school air pollution exposure and inequality. The data also raises questions regarding other negative health impactors, such as noise pollution and its association with schools and deprivation. Potential developmental avenues include determining any association between $NO_2$ concentrations around schools and deprivation and assessing the interactions of air pollution health impacts and other child inequalities to affect academic attainment.

The findings provide the basis for several future dispersion modelling studies, including a time-specific assessment of intervention effectiveness. Such a study would be bound by data availability, and site selection may be restricted by that factor. The results could help to inform parents and teachers regarding the immediacy of benefits associated with interventions and assess the longevity of the air pollution reduction beyond the school commute and peak traffic times.

Further to the modelling outcomes presented here, the categorisation of school environments based on intervention effectiveness presents a range of challenges but would be of great benefit for parents and teachers alike. The development of a set of categories to make interventions generalisable across different types of institutions could permit the application of a combination of measures based on factors such as local geography and terrain, green space, and local mass transit systems.

The current study focused on the effect of traffic on potential child exposure to air pollution on the school commute. Future research should assess additional factors associated with child exposure following the commute. Determining diurnal variation throughout the school day, patterns of exposure during playtimes and breaks, and additional forms of ambient exposure in the classroom all present avenues of exploration to assess total exposure during the school day. Other considerations include the post-Covid classroom, in which windows are kept open. However, as with all exposure studies, this research will ultimately be determined by the availability of reliable data.

The current research considered short-term pollution variation as a consequence of interventions to mitigate exposure on the school commute. Building upon this, future research could assess the effectiveness of these interventions under different seasonal conditions. Given the significant changes in seasonal climate throughout the school year, changes in TRAP concentrations on the school commute and the impacts on child health should not be ignored. Future research addressing these issues could inform the application of traffic planning and management strategies to different seasons and climatic conditions.

$NO_2$ was used in the current research as a proxy for traffic. Whilst $NO_2$ and particulate are likely to decline with the introduction of electric vehicle legislation, particulate, in the form of resuspended road dust and tyre and brake wear, will persist. Future research should identify the PM reductions achievable with the currently assessed and additional interventions in anticipation of these events.

Whilst the current research compared different residential and industrial densities in modelling sites, rural regions were not included due to the selection criteria (i.e., highly polluted schools). Research generally neglects rural locations in favour of more polluted areas. Whilst there is less TRAP in rural locations due to the lower traffic volumes, pollution concentrations at school gates still present an important area of investigation due to the high potential exposures associated with congregative periods when large groups of children are being dropped off and collected. In larger rural schools, it may be the case that more parents drive out of necessity, for example. This deficit of research should be addressed to determine the levels of TRAP experienced by children who attend these schools so that measures can be taken to reduce their exposure.

## 7.6 Conclusion

The school commute is an undertaking that the majority of children in the UK experience on a daily basis, and that also coincides with peak traffic. The worst consequence of these events is that the most vulnerable members of society are placed in the highest concentrations of pollution every morning when they go to school.

The current study investigated interventions for reducing and mitigating exposure to TRAP on the school commute. The outcome of the investigation has provided the basis of recommendations for policymakers, teachers, and parents. The implications of these recommendations focus on reducing car use and traffic on the school commute as the most effective method of mitigating child exposure to harmful pollutants on their daily journeys. Whilst many more measures and approaches than described here exist to help to achieve this goal, the analyses conducted in the current thesis have identified that low emission zones, mode shifts to active travel, improved travel routes, ridesharing, and anti-idling, are all demonstrably effective methods for the reduction of child exposure to TRAP when they travel to and from school. The efficacy of these measures is also supported in the literature and by stakeholder support in the results of a survey delivered to UK schools. In addition, the level of pollution currently experienced by schools in the UK was also determined to inform the modelling of the aforementioned interventions. Unsurprisingly, the most polluted schools are found in urban environments. By comparison to other UK countries, schools in England are significantly more polluted, and London has a significantly greater number of polluted schools than any other region in England.

The current research findings are transferable beyond the case study schools presented here and could be applied to schools in other regions of the UK and the EU, although this depends on several factors. Firstly, it is important to ensure that the interventions used are relevant and applicable to the region in question. For example, the specific road network and traffic conditions in other regions may differ, making it necessary to use different interventions to achieve similar results. Contextual distinctions must also be considered, and other regions may have different conditions, such as land use patterns, population densities, and climate, all of which could impact the effectiveness of the interventions. It is also important to determine local air pollution sources and their relative contributions, which differ between regions, and the most appropriate interventions for these contexts. However, the results of the study still provide valuable information and insights into the effectiveness of the assessed interventions for reducing TRAP and potential child exposure. The research may be used as a starting point for similar studies in other regions, taking into account the specific contextual differences and stakeholder involvement. It may also inform policy decisions and raise awareness about the importance of reducing TRAP and potential child exposure to these harmful pollutants.

The project limitations were constraints of resources and the solitary nature of the research. Steps were taken at every point to ensure consistency and accuracy throughout all analyses and to mitigate any negative consequences of these limitations. For example, the systematic review was conducted by a sole researcher, so the records could not be verified to ensure against inclusion bias. To abate this issue, rigid verification structures were adhered to that ensured all studies included had to fit the inclusion criteria without ambiguity.

Whilst efforts persist towards identifying solutions, the problem remains centred on the volume of traffic currently on the roads. Many local authorities and interest groups continue to produce toolkits for cleaning the air and reducing child exposure to pollution. It is noted that the trajectory of air pollution over recent years has improved, and the current research joins a growing base of evidence that targeted interventions can be effective in the mitigation of child exposure to these harmful pollutants.

Reductions continue, and whilst future legislation will help, the issue remains immediate and further action must be taken. The forthcoming banning of fossil-fuel car purchases will reduce the problem in the future, although some forms of particulate will persist from tyre and brake wear, and resuspended road dust. Accordingly, action must be taken immediately to ensure that the current and future generations no longer must suffer the ill effects of pollution exposure. The findings also highlight the importance of effective communication between stakeholder groups, particularly between parents and teachers. There is ample evidence that significant proportions of both parties are concerned and willing to act, but it appears there is insufficient cohesion between strategies and information sharing. In addition, meaningful legislation should underpin continuing efforts towards traffic-related pollution reduction, in addition to widespread information campaigns. Both measures have been historically effective in changing public behaviours and are essential for the rapid cessation of polluting behaviours to minimise the negative health impacts for children and the broader public. Waiting for future legislation and policymakers to solve the issue will continue to harm children and other vulnerable groups.

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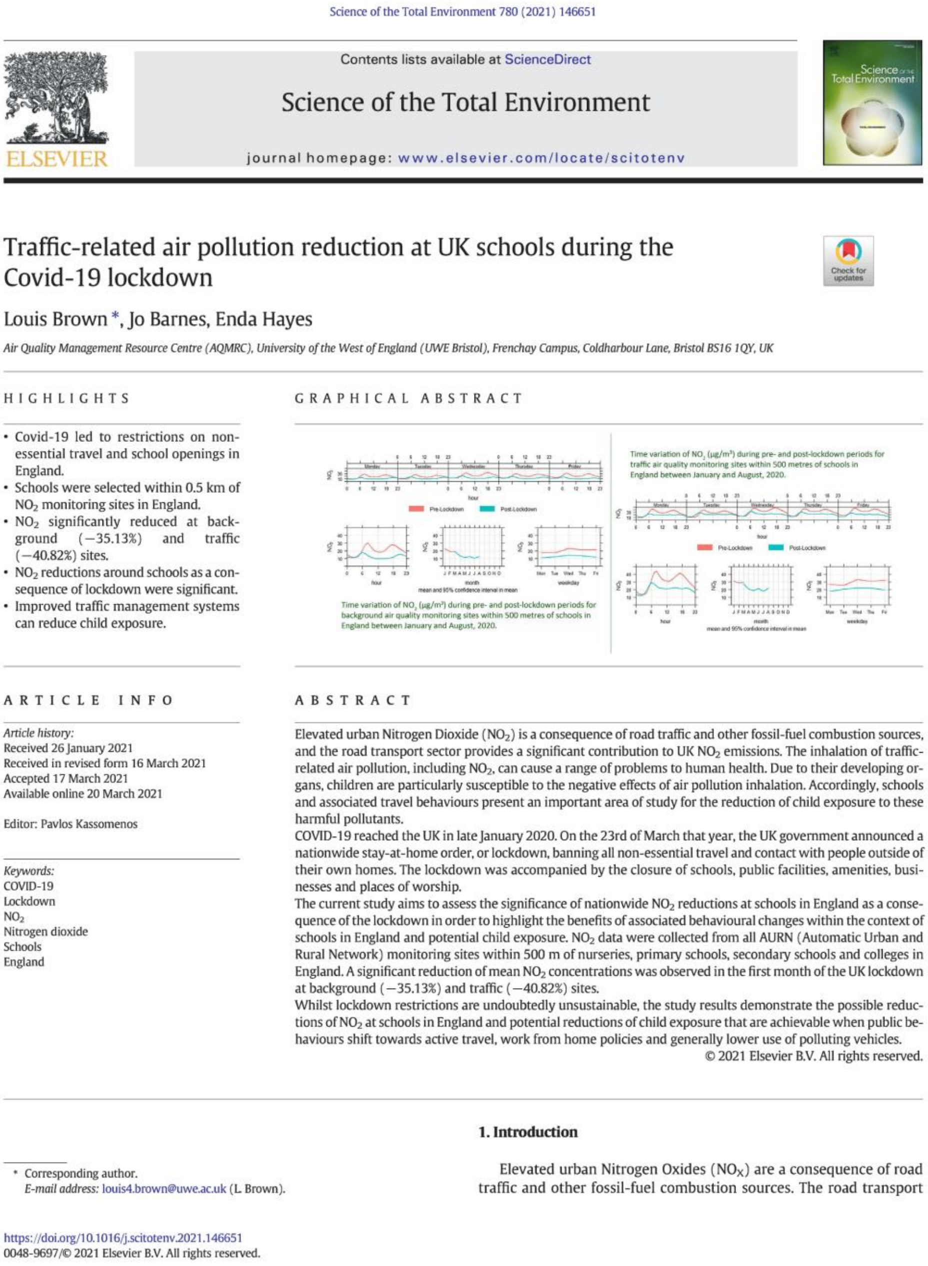
# 9.0 Appendix

## Appendix A: Traffic-Related Air Pollution Reduction at UK Schools During the Covid-19 Lockdown (Brown, Barnes & Hayes, 2021).



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### Traffic-related air pollution reduction at UK schools during the Covid-19 lockdown

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H I G H L I G H T S

- Covid-19 led to restrictions on non-essential travel and school openings in England.
- Schools were selected within 0.5 km of $NO_2$ monitoring sites in England.
- $NO_2$ significantly reduced at background (−35.13%) and traffic (−40.82%) sites.
- $NO_2$ reductions around schools as a consequence of lockdown were significant.
- Improved traffic management systems can reduce child exposure.

G R A P H I C A L A B S T R A C T

Time variation of $NO_2$ (μg/m³) during pre- and post-lockdown periods for background air quality monitoring sites within 500 metres of schools in England between January and August, 2020.

Time variation of $NO_2$ (μg/m³) during pre- and post-lockdown periods for traffic air quality monitoring sites within 500 metres of schools in England between January and August, 2020.

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A B S T R A C T

Elevated urban Nitrogen Dioxide ($NO_2$) is a consequence of road traffic and other fossil-fuel combustion sources, and the road transport sector provides a significant contribution to UK $NO_2$ emissions. The inhalation of traffic-related air pollution, including $NO_2$, can cause a range of problems to human health. Due to their developing organs, children are particularly susceptible to the negative effects of air pollution inhalation. Accordingly, schools and associated travel behaviours present an important area of study for the reduction of child exposure to these harmful pollutants.

COVID-19 reached the UK in late January 2020. On the 23rd of March that year, the UK government announced a nationwide stay-at-home order, or lockdown, banning all non-essential travel and contact with people outside of their own homes. The lockdown was accompanied by the closure of schools, public facilities, amenities, businesses and places of worship.

The current study aims to assess the significance of nationwide $NO_2$ reductions at schools in England as a consequence of the lockdown in order to highlight the benefits of associated behavioural changes within the context of schools in England and potential child exposure. $NO_2$ data were collected from all AURN (Automatic Urban and Rural Network) monitoring sites within 500 m of nurseries, primary schools, secondary schools and colleges in England. A significant reduction of mean $NO_2$ concentrations was observed in the first month of the UK lockdown at background (−35.13%) and traffic (−40.82%) sites.

Whilst lockdown restrictions are undoubtedly unsustainable, the study results demonstrate the possible reductions of $NO_2$ at schools in England and potential reductions of child exposure that are achievable when public behaviours shift towards active travel, work from home policies and generally lower use of polluting vehicles.

#### 1. Introduction

Elevated urban Nitrogen Oxides ($NO_X$) are a consequence of road traffic and other fossil-fuel combustion sources. The road transport

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sector accounts for a significant proportion of UK $NO_X$ emissions, contributing 31% (NAEI, 2020). The inhalation of traffic-related air pollution, including Nitrogen Dioxide ($NO_2$), a component of $NO_X$, can cause a range of problems to human health. Short-term exposure to these concentrations can lead to the aggravation of existing respiratory problems (Esposito et al., 2014; Goldizen et al., 2016; Searing and Rabinovitch, 2011), and increased cases of hospitalisation (Kampa and Castanas, 2008). Long-term exposure has been linked to further issues, including greater susceptibility to infections of the respiratory system (Ryan et al., 2013). Children have been identified as a vulnerable group due to their developing organs, making them particularly susceptible to the negative effects of $NO_2$ (Guarnieri and Balmes, 2014; WHO, 2018). Accordingly, schools and associated travel present an important area of study for the reduction of child exposure to harmful traffic-related pollutants.

COVID-19 reached the UK in late January 2020. On the 23rd of March the same year, the UK government announced a nationwide stay-at-home order, or lockdown, which banned all non-essential travel and contact with people outside of their own homes (Iacobucci, 2020). This was accompanied by the closure of schools, public facilities, amenities, businesses and places of worship. Whilst forecasts predicted the negative financial consequences of a prolonged lockdown, the considerable effects of population confinement and travel restrictions on air pollution reduction were promptly highlighted (Berman and Ebisu, 2020; Dutheil et al., 2020).

The current study aims to assess and highlight the benefits of these behavioural changes within the context of schools in England, to demonstrate the child exposure reductions that are possible when public behaviours shift towards active travel, work from home policies and generally lower use of polluting vehicles. The study does not seek to estimate actual reductions in child exposure for the study periods, due to children's absence from schools during the lockdown period.

It is not the intention of the current research to attribute pollutant reductions to specific behavioural changes as a consequence of lockdown measures, nor does it seek to quantify the influence of other factors, such as pollutant transportation. This study acknowledges that a deeper analysis is required to accurately ascertain this information. However, the effects of the lockdown measures on air pollution provide a unique opportunity to assess the reductions that are possible due to the associated behavioural changes, and to determine further policies for the reduction of child exposure to these harmful pollutants.

### *1.1. Research question*

The study aim can be summarised in the following statement:

- To assess the significance of nationwide $NO_2$ reductions at schools in England as a consequence of the lockdown in order to highlight the benefits of associated behavioural changes within the context of schools in England and potential child exposure.

Accordingly, the aforementioned study approach can be summarised in the following research question:

- To what extent did traffic-related air pollution reduce around schools in England during the first month of the UK lockdown in 2020?

## 2. Methods

Air quality data were collected from background and traffic monitoring sites within 500 m of schools in England. The data was analysed using R (Version 3.6.3) in R Studio (Version 1.3.1093) to determine the significance of difference between the lockdown period and the same time period for the five previous years, and to adjust the data for meteorological influence.

### *2.1. Site selection*

Using ArcGIS Pro (Ver 2.4.0, Esri Inc.), school locations in England were plotted with Automatic Urban and Rural Network (AURN) air quality monitoring sites. AURN monitors are sited according to specific requirements (Directive 2008/50/EC) and are defined in terms of background sites that are representative of general urban population exposure, and traffic sites located within 10 m from the kerbside and at least 25 m from major junctions. Background sites are located so that recorded pollution levels are not significantly influenced by any single source and are representative of several square kilometres. Traffic sites are located so that recorded pollution levels are predominantly determined by nearby traffic emissions, and are representative of air quality for a street segment greater than 100 m (Defra, 2020a). All AURN site information, including historical data, is made freely available by Defra (Defra, 2020b).

A Geographical Information System (GIS) was used to identify all AURN sites in England within 500 m of an educational establishment for use as representative of pollution levels and exposure. The locations of all AURN sites are made available by Defra and are searchable by location (Defra, 2020c). The 500-m distance is supported by studies that have suggested exposure to $NO_2$ within 500 m of the source is potentially hazardous to human health (Zhou and Levy, 2007). Educational establishments included nurseries, primary schools, secondary schools and colleges. The list was classified by AURN site type and all valid urban background and traffic sites were selected for further analysis and comparison. Using the Openair package in R Studio, data for all selected AURN sites were collected for the years 2015 to 2020. The data included the site names, $NO_2$ concentration readings for the 5-year period, and modelled temperature, wind speed and wind direction (Defra, 2020d).

### *2.2. Data preparation*

The first month of the lockdown period was considered appropriate for the scope of the investigation. This time period is representative of the time that lockdown measures were more closely followed by the general public (Sibley et al., 2020). Longer time periods would incur the effects of too many variables, including 'crisis fatigue' (Aras and Yorulmazlar, 2020), and a general easing of attitudes and compliance with the measures (Jackson et al., 2020), due to the public becoming accustomed to the impositions and more willing to contravene the restrictions. To prepare the datasets for analysis the sites were categorised into background and traffic groups, and time periods were selected within each category. Time periods were specified as 'Historical' (23rd of March to 23rd of April, each year from 2015 to 2019, as a combined average) and 'Lockdown' (23rd of March to 23rd of April 2020). Weekend data were removed and weekday data retained to better represent the days children attend school. Datasets were also created for each site category for weekdays between January and August 2020, for time series analysis.

### *2.3. Analysis*

Descriptive statistics were calculated for the data and the normality of the data was checked by visual inspection. To confirm the data distribution, the Anderson Darling test was conducted. The data did not follow a normal distribution so a Mann-Whitney *U* test was used to determine the significance of difference in background and traffic $NO_2$ concentrations between the Lockdown and Historical periods. Time variation data was plotted for pollutant concentrations at background and traffic sites before and after the lockdown measures (from January to August 2020) to assess the pollutant reduction as a consequence of the restrictions.

### *2.4. Adjustment for meteorological influence*

A persistent issue when analysing air pollution levels is the role of the weather, which can affect changes in concentrations. The general

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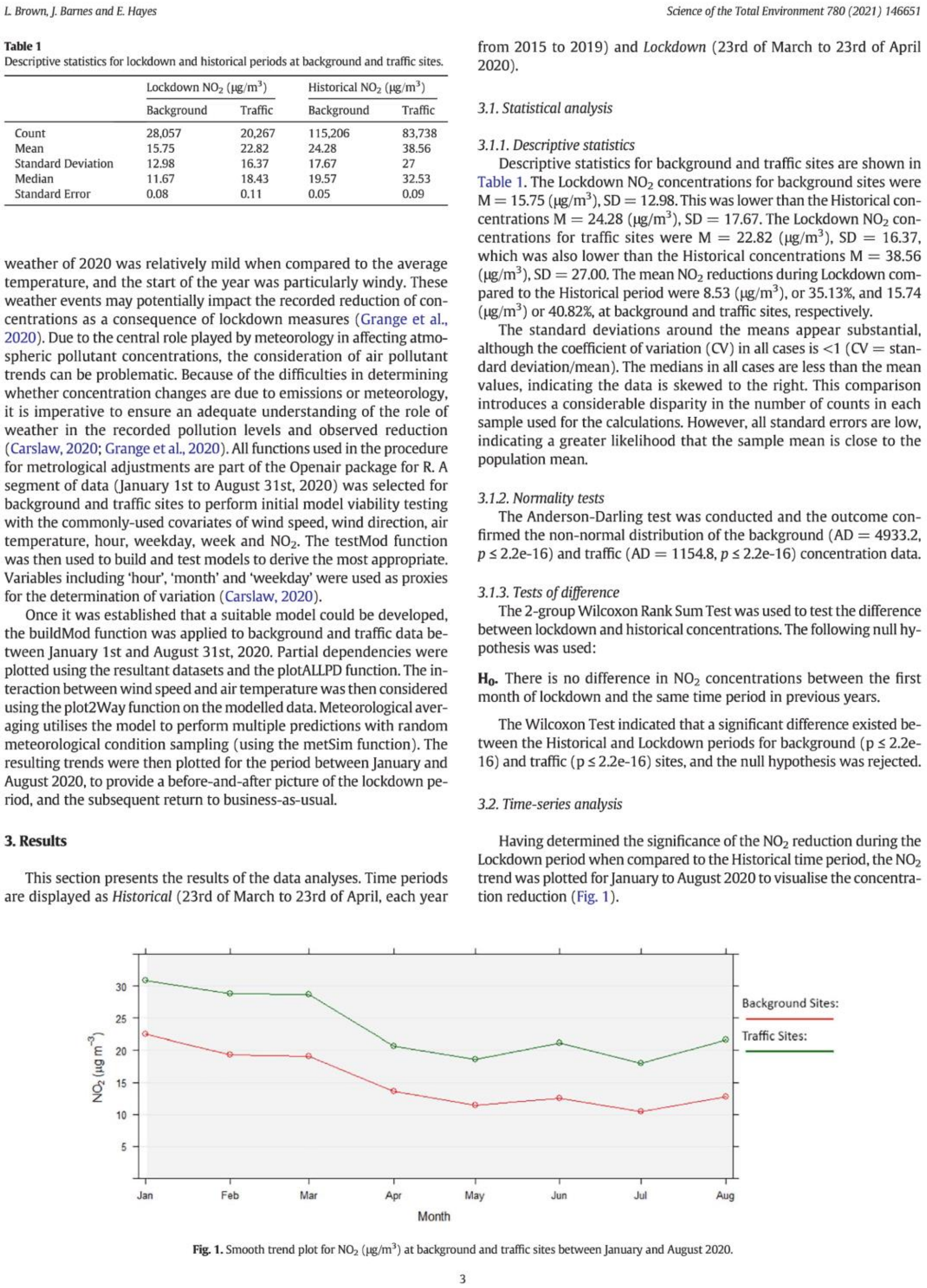

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**Table 1**
Descriptive statistics for lockdown and historical periods at background and traffic sites.

| | Lockdown $NO_2$ (μg/m$^3$) | | Historical $NO_2$ (μg/m$^3$) | |
|---|---|---|---|---|
| | Background | Traffic | Background | Traffic |
| Count | 28,057 | 20,267 | 115,206 | 83,738 |
| Mean | 15.75 | 22.82 | 24.28 | 38.56 |
| Standard Deviation | 12.98 | 16.37 | 17.67 | 27 |
| Median | 11.67 | 18.43 | 19.57 | 32.53 |
| Standard Error | 0.08 | 0.11 | 0.05 | 0.09 |

weather of 2020 was relatively mild when compared to the average temperature, and the start of the year was particularly windy. These weather events may potentially impact the recorded reduction of concentrations as a consequence of lockdown measures (Grange et al., 2020). Due to the central role played by meteorology in affecting atmospheric pollutant concentrations, the consideration of air pollutant trends can be problematic. Because of the difficulties in determining whether concentration changes are due to emissions or meteorology, it is imperative to ensure an adequate understanding of the role of weather in the recorded pollution levels and observed reduction (Carslaw, 2020; Grange et al., 2020). All functions used in the procedure for metrological adjustments are part of the Openair package for R. A segment of data (January 1st to August 31st, 2020) was selected for background and traffic sites to perform initial model viability testing with the commonly-used covariates of wind speed, wind direction, air temperature, hour, weekday, week and $NO_2$. The testMod function was then used to build and test models to derive the most appropriate. Variables including 'hour', 'month' and 'weekday' were used as proxies for the determination of variation (Carslaw, 2020).

Once it was established that a suitable model could be developed, the buildMod function was applied to background and traffic data between January 1st and August 31st, 2020. Partial dependencies were plotted using the resultant datasets and the plotALLPD function. The interaction between wind speed and air temperature was then considered using the plot2Way function on the modelled data. Meteorological averaging utilises the model to perform multiple predictions with random meteorological condition sampling (using the metSim function). The resulting trends were then plotted for the period between January and August 2020, to provide a before-and-after picture of the lockdown period, and the subsequent return to business-as-usual.

## 3. Results

This section presents the results of the data analyses. Time periods are displayed as *Historical* (23rd of March to 23rd of April, each year from 2015 to 2019) and *Lockdown* (23rd of March to 23rd of April 2020).

### 3.1. Statistical analysis

#### 3.1.1. Descriptive statistics

Descriptive statistics for background and traffic sites are shown in Table 1. The Lockdown $NO_2$ concentrations for background sites were M = 15.75 (μg/m$^3$), SD = 12.98. This was lower than the Historical concentrations M = 24.28 (μg/m$^3$), SD = 17.67. The Lockdown $NO_2$ concentrations for traffic sites were M = 22.82 (μg/m$^3$), SD = 16.37, which was also lower than the Historical concentrations M = 38.56 (μg/m$^3$), SD = 27.00. The mean $NO_2$ reductions during Lockdown compared to the Historical period were 8.53 (μg/m$^3$), or 35.13%, and 15.74 (μg/m$^3$) or 40.82%, at background and traffic sites, respectively.

The standard deviations around the means appear substantial, although the coefficient of variation (CV) in all cases is <1 (CV = standard deviation/mean). The medians in all cases are less than the mean values, indicating the data is skewed to the right. This comparison introduces a considerable disparity in the number of counts in each sample used for the calculations. However, all standard errors are low, indicating a greater likelihood that the sample mean is close to the population mean.

#### 3.1.2. Normality tests

The Anderson-Darling test was conducted and the outcome confirmed the non-normal distribution of the background (AD = 4933.2, $p \le$ 2.2e-16) and traffic (AD = 1154.8, $p \le$ 2.2e-16) concentration data.

#### 3.1.3. Tests of difference

The 2-group Wilcoxon Rank Sum Test was used to test the difference between lockdown and historical concentrations. The following null hypothesis was used:

**$H_0$.** There is no difference in $NO_2$ concentrations between the first month of lockdown and the same time period in previous years.

The Wilcoxon Test indicated that a significant difference existed between the Historical and Lockdown periods for background ($p \le$ 2.2e-16) and traffic ($p \le$ 2.2e-16) sites, and the null hypothesis was rejected.

### 3.2. Time-series analysis

Having determined the significance of the $NO_2$ reduction during the Lockdown period when compared to the Historical time period, the $NO_2$ trend was plotted for January to August 2020 to visualise the concentration reduction (Fig. 1).

**Fig. 1.** Smooth trend plot for $NO_2$ (μg/m$^3$) at background and traffic sites between January and August 2020.

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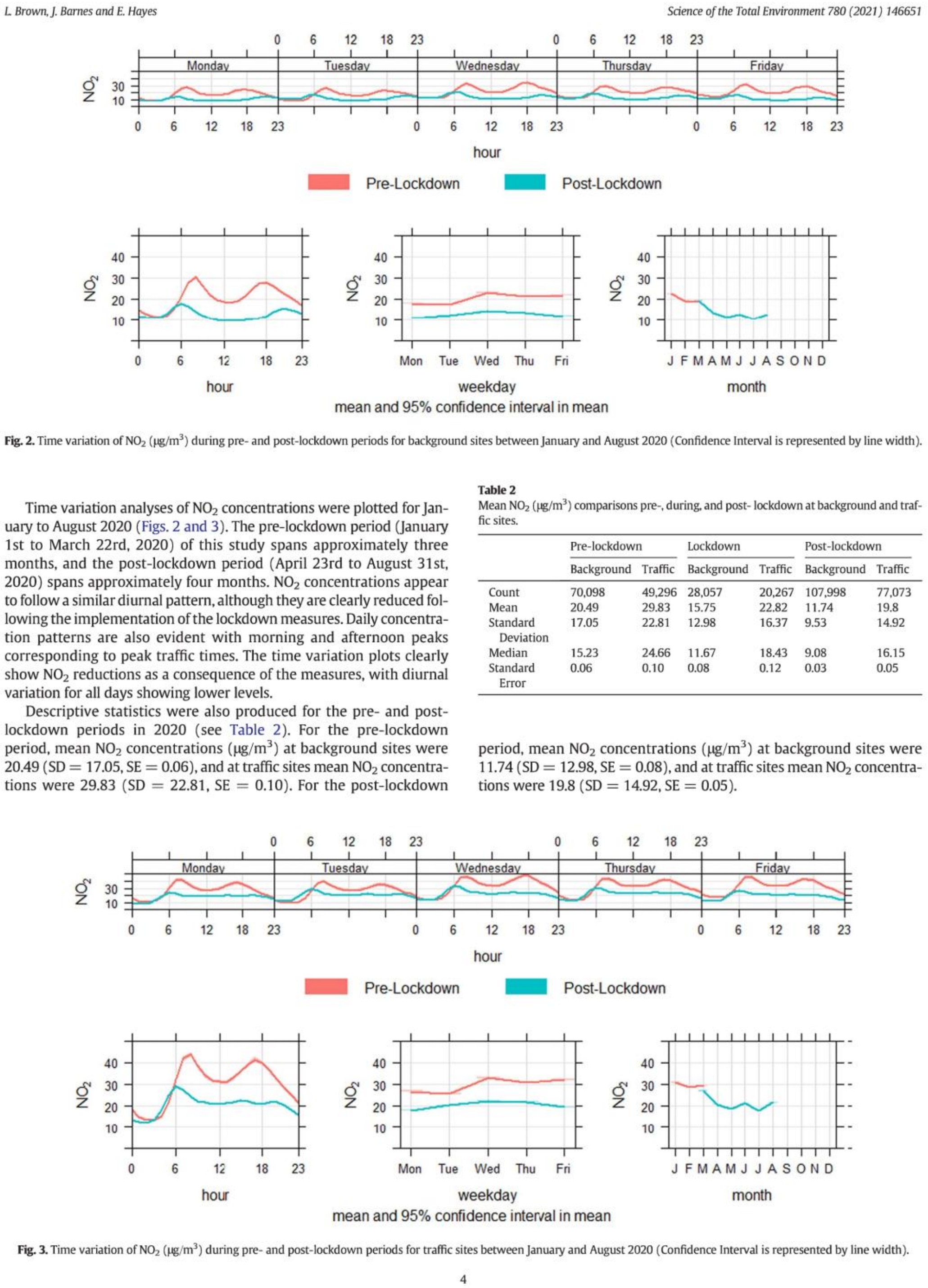

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**Fig. 2.** Time variation of $NO_2$ (μg/m$^3$) during pre- and post-lockdown periods for background sites between January and August 2020 (Confidence Interval is represented by line width).

Time variation analyses of $NO_2$ concentrations were plotted for January to August 2020 (Figs. 2 and 3). The pre-lockdown period (January 1st to March 22rd, 2020) of this study spans approximately three months, and the post-lockdown period (April 23rd to August 31st, 2020) spans approximately four months. $NO_2$ concentrations appear to follow a similar diurnal pattern, although they are clearly reduced following the implementation of the lockdown measures. Daily concentration patterns are also evident with morning and afternoon peaks corresponding to peak traffic times. The time variation plots clearly show $NO_2$ reductions as a consequence of the measures, with diurnal variation for all days showing lower levels.

Descriptive statistics were also produced for the pre- and post-lockdown periods in 2020 (see Table 2). For the pre-lockdown period, mean $NO_2$ concentrations (μg/m$^3$) at background sites were 20.49 (SD = 17.05, SE = 0.06), and at traffic sites mean $NO_2$ concentrations were 29.83 (SD = 22.81, SE = 0.10). For the post-lockdown period, mean $NO_2$ concentrations (μg/m$^3$) at background sites were 11.74 (SD = 12.98, SE = 0.08), and at traffic sites mean $NO_2$ concentrations were 19.8 (SD = 14.92, SE = 0.05).

**Table 2**
Mean $NO_2$ (μg/m$^3$) comparisons pre-, during, and post- lockdown at background and traffic sites.

| | Pre-lockdown | | Lockdown | | Post-lockdown | |
|---|---|---|---|---|---|---|
| | Background | Traffic | Background | Traffic | Background | Traffic |
| Count | 70,098 | 49,296 | 28,057 | 20,267 | 107,998 | 77,073 |
| Mean | 20.49 | 29.83 | 15.75 | 22.82 | 11.74 | 19.8 |
| Standard Deviation | 17.05 | 22.81 | 12.98 | 16.37 | 9.53 | 14.92 |
| Median | 15.23 | 24.66 | 11.67 | 18.43 | 9.08 | 16.15 |
| Standard Error | 0.06 | 0.10 | 0.08 | 0.12 | 0.03 | 0.05 |

**Fig. 3.** Time variation of $NO_2$ (μg/m$^3$) during pre- and post-lockdown periods for traffic sites between January and August 2020 (Confidence Interval is represented by line width).

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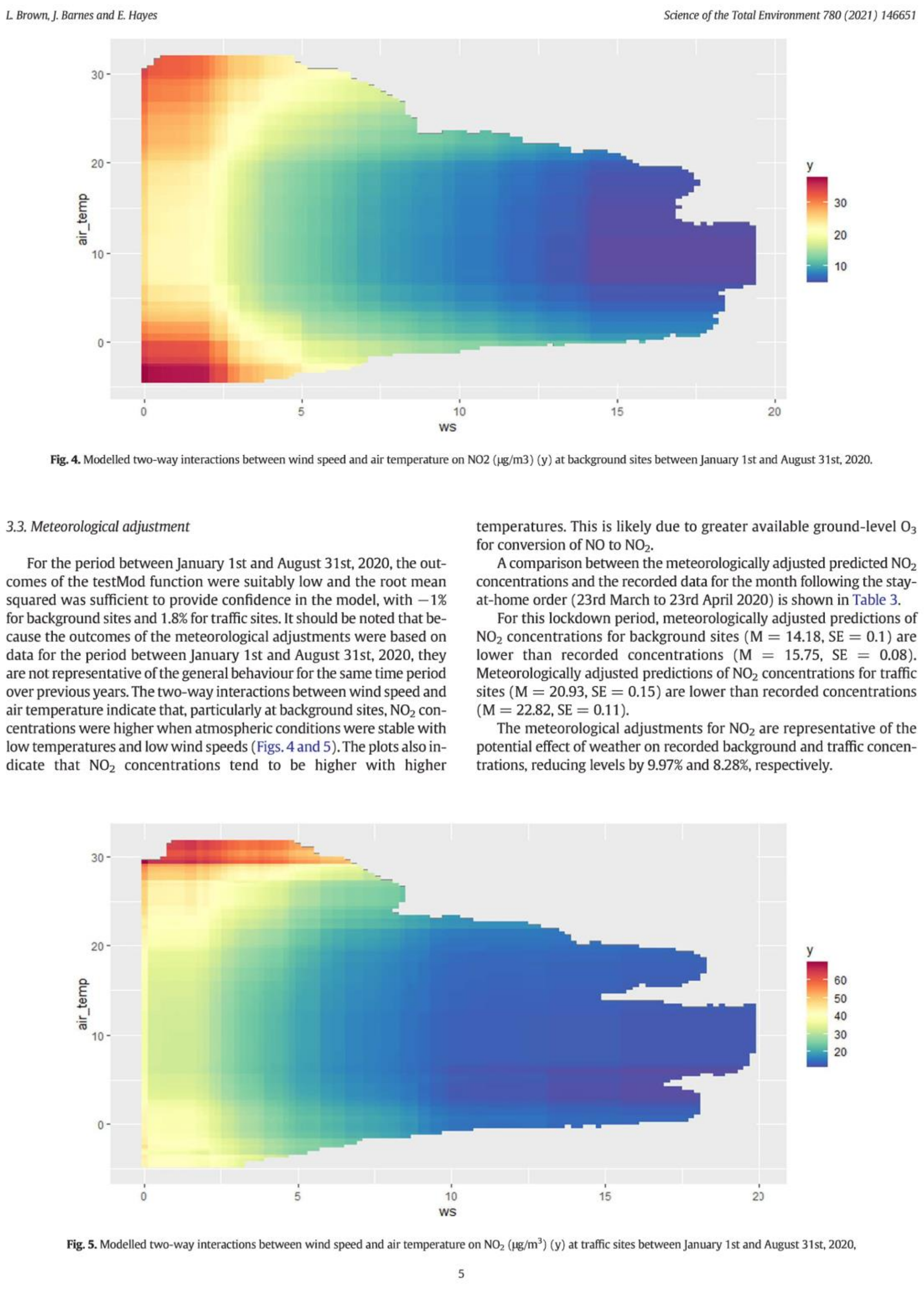

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**Fig. 4.** Modelled two-way interactions between wind speed and air temperature on NO2 (μg/m3) (y) at background sites between January 1st and August 31st, 2020.

### 3.3. Meteorological adjustment

For the period between January 1st and August 31st, 2020, the outcomes of the testMod function were suitably low and the root mean squared was sufficient to provide confidence in the model, with −1% for background sites and 1.8% for traffic sites. It should be noted that because the outcomes of the meteorological adjustments were based on data for the period between January 1st and August 31st, 2020, they are not representative of the general behaviour for the same time period over previous years. The two-way interactions between wind speed and air temperature indicate that, particularly at background sites, $NO_2$ concentrations were higher when atmospheric conditions were stable with low temperatures and low wind speeds (Figs. 4 and 5). The plots also indicate that $NO_2$ concentrations tend to be higher with higher temperatures. This is likely due to greater available ground-level $O_3$ for conversion of NO to $NO_2$.

A comparison between the meteorologically adjusted predicted $NO_2$ concentrations and the recorded data for the month following the stay-at-home order (23rd March to 23rd April 2020) is shown in Table 3.

For this lockdown period, meteorologically adjusted predictions of $NO_2$ concentrations for background sites ($M = 14.18$, $SE = 0.1$) are lower than recorded concentrations ($M = 15.75$, $SE = 0.08$). Meteorologically adjusted predictions of $NO_2$ concentrations for traffic sites ($M = 20.93$, $SE = 0.15$) are lower than recorded concentrations ($M = 22.82$, $SE = 0.11$).

The meteorological adjustments for $NO_2$ are representative of the potential effect of weather on recorded background and traffic concentrations, reducing levels by 9.97% and 8.28%, respectively.

**Fig. 5.** Modelled two-way interactions between wind speed and air temperature on $NO_2$ ($\mu g/m^3$) (y) at traffic sites between January 1st and August 31st, 2020,

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**Table 3**
Comparison of recorded (observed) and meteorologically adjusted (predicted) mean data between 23rd March and 23rd April 2020.

| $NO_2$ ($\mu g/m^3$) | Background | | Traffic | |
|---|---|---|---|---|
| | Observed | Predicted | Observed | Predicted |
| Count | 28,057 | 576 | 20,267 | 576 |
| Mean | 15.75 | 14.18 | 22.82 | 20.93 |
| Standard Deviation | 12.98 | 2.39 | 16.37 | 3.52 |
| Median | 11.67 | 13.53 | 18.43 | 19.89 |
| Standard Error | 0.08 | 0.1 | 0.11 | 0.15 |

## 4. Discussion

The analysis provides an overview of the air pollution changes as a consequence of the COVID-19 lockdown, and the reductions of $NO_2$ in the vicinity of schools in England. A significant reduction of $NO_2$ took place following the stay-at-home order on March 23rd and the trends indicated a sustained reduction of $NO_2$ at background and traffic sites for several months following the announcement.

Both traffic and background site data indicated significant reductions on schooldays. Around schools in England, $NO_2$ concentration reductions during lockdown when compared to the five-year historical mean for background and traffic sites ranged between 35.13% and 40.85%. Once the data for the time period (between January 1st and August 31st, 2020) was adjusted for meteorological influence, the potential reductions increased, although the range narrowed to between 41.60% and 45.75%. The general trends show a steep decline of $NO_2$ concentrations at both background and traffic sites at the start of the lockdown measures. However, it is noted that the outcomes of the meteorological adjustment only reflect the aforementioned time period and cannot be extrapolated to the general historical behaviour of this same time period.

Temporal trends for both site groups were similar, although a sharper reduction was visible at the traffic sites, indicating a lag between the traffic and background sites. This behaviour is to be expected when considering pollution from traffic sites, which are characteristically proximal to road sources, and background sites, which are further from those sources, and will take longer to be affected by any related changes. For the same reason, it is also understandable that diurnal traffic would not affect background sites as much as those near roadsides.

The lockdown $NO_2$ concentration means showed a reduction of 4.74 $\mu g/m^3$ for background sites and 7.01 $\mu g/m^3$ for traffic sites when compared to the pre-lockdown period. This trend continued into the post-lockdown period, with further respective reductions for background and traffic sites of 4.01 $\mu g/m^3$ and 3.02 $\mu g/m^3$, although an increase is observable towards the end of the period as restrictions become more relaxed. Analyses of the reduction support arguments for lower levels of traffic around schools to reduce potential child exposure to air pollutants. Policies that encourage active travel and discourage unnecessary vehicular use during peak traffic times can lower air pollution in the vicinity of schools when children are on the school run, but can also improve air quality for all of those who must travel at these particularly polluted periods of each day.

Improvements to traffic management can help to reduce pollution at the most congested periods of the day, which is particularly relevant for the reduction of child exposure to pollutants during peak traffic periods on weekday mornings. Indeed, policies and interventions that encourage active travel will be further benefitted by more general reductions in peak traffic and accompanying pollution. The study results support the position of research relating to measures for improved management of traffic, including school travel planning (Cairns et al., 2008), promotion of active travel (McDonald et al., 2014; Smith et al., 2015), walking school buses (Dirks et al., 2016), improved workplace travel initiatives and planning (Macmillan et al., 2013), improvements to public transport, school buses and related incentives (Schraufnagel et al., 2018), carpooling and car-sharing (Hasan et al., 2016), teleworking (Giovanis, 2018) and anti-idling campaigns (Eghbalnia et al., 2013; Ryan et al., 2013). The results indicate that practices such as working from home, active travel, and a reduction of non-essential travel can help to maintain these reductions outside of the lockdown, and the discouragement of driving to school during peak traffic times can also assist in the reduction of child exposure to harmful pollutants.

## 5. Conclusion

Due to their sensitivity, developing physiology and regular exposure to heavy traffic, children are an at-risk group who are particularly susceptible and vulnerable to high concentrations of traffic-related air pollution. Schools and associated travel present areas of interest for the reduction of traffic-related air pollution and the mitigation of child exposure. The current study has demonstrated that the measures taken as part of the UK stay-at-home order, such as teleworking, the reduction of non-essential travel and the removal of traffic related to school runs, have significantly reduced air pollution in the vicinity of schools in England. Limitations of the current study include the focus on $NO_2$ and schools in England. Future research should investigate the interactions between other traffic-related pollutants, including the effects of meteorology, and in different regions of the UK.

In order to maintain the pollution reductions highlighted in the current study, it is essential to develop and implement effective behavioural strategies towards the reduction of peak traffic. Whilst this can be partly achieved by a reduction of school-related traffic, it is also important to develop broader strategies to reduce overall levels of traffic to ensure that child exposure in active travel at peak times remains low.

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## CRediT authorship contribution statement

**Louis Brown:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Jo Barnes:** Conceptualization, Supervision, Methodology, Validation, Writing – review & editing, Project administration. **Enda Hayes:** Conceptualization, Supervision, Methodology, Validation, Writing – review & editing, Project administration.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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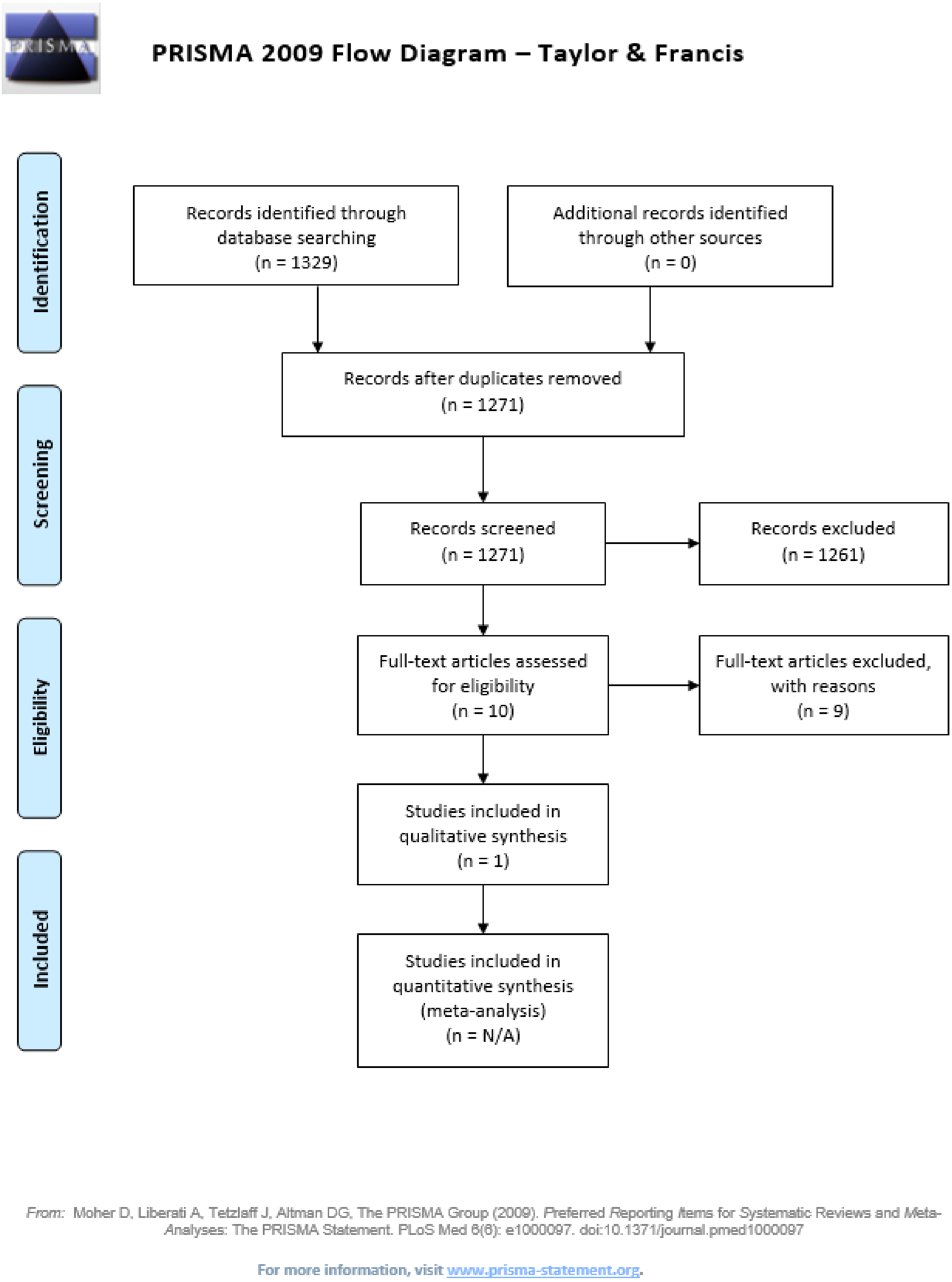
## Appendix B: PRISMA Flow Diagrams (PRISMA, 2022)



*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *Preferred Reporting Items for Systematic Reviews and Meta-Analyses*: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

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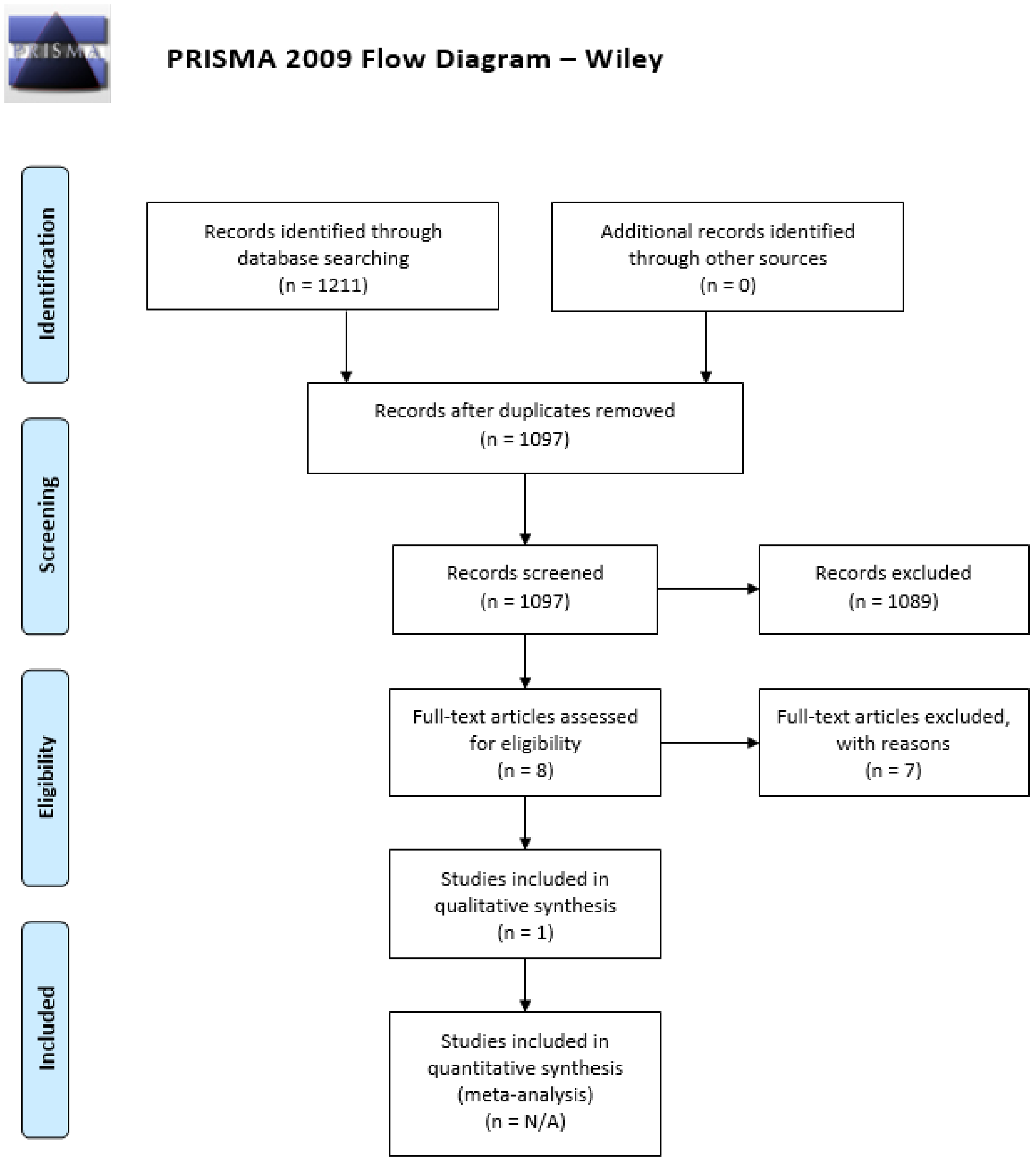
*Figure 174 PRISMA 2009 Flow Diagram for Taylor & Francis Database Search.*



*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

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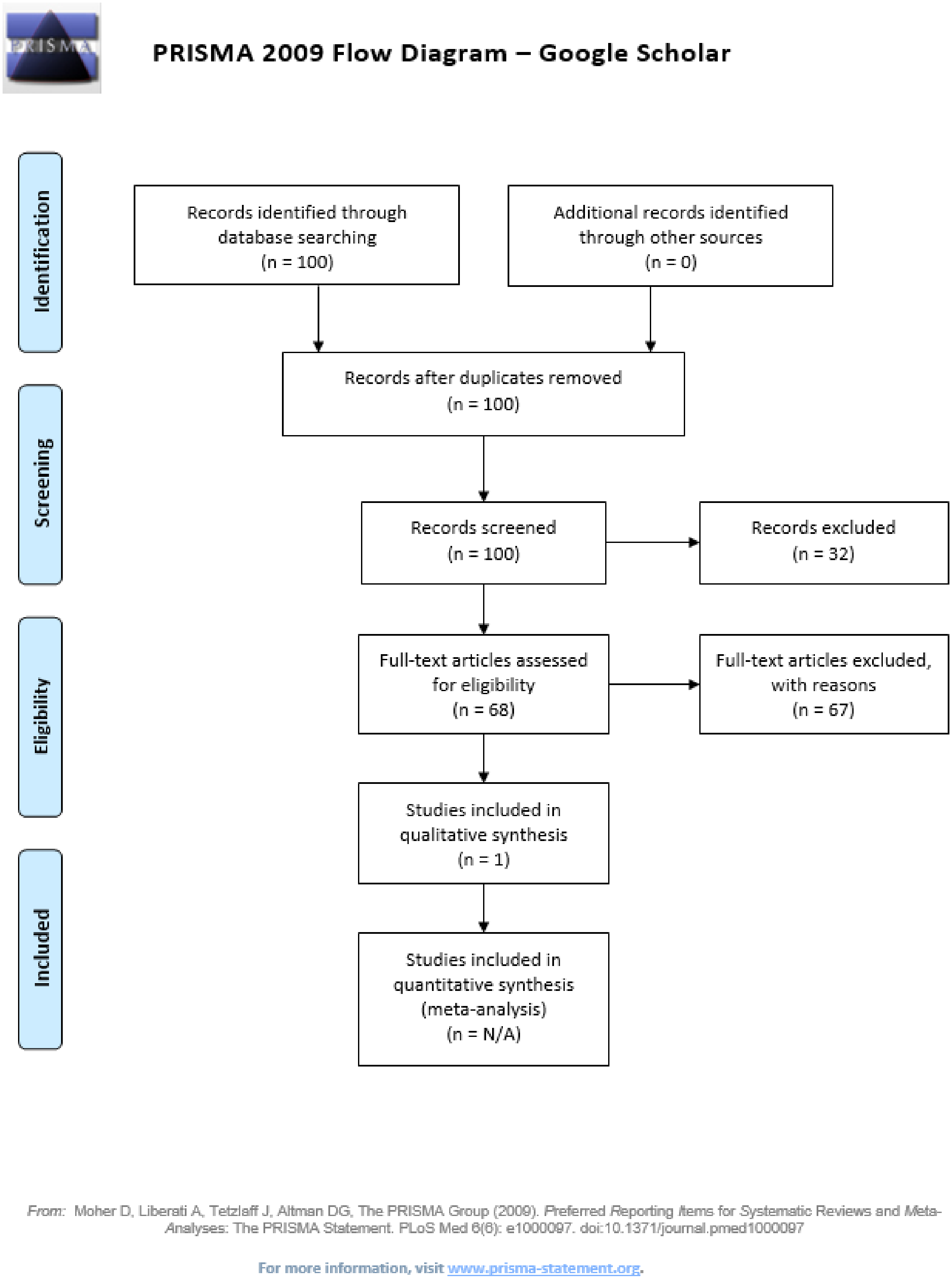
*Figure 175 PRISMA 2009 Flow Diagram for Wiley Database Search.*



PRISMA 2009 Flow Diagram – Google Scholar

*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

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*Figure 176 PRISMA 2009 Flow Diagram for Google Scholar Search.*

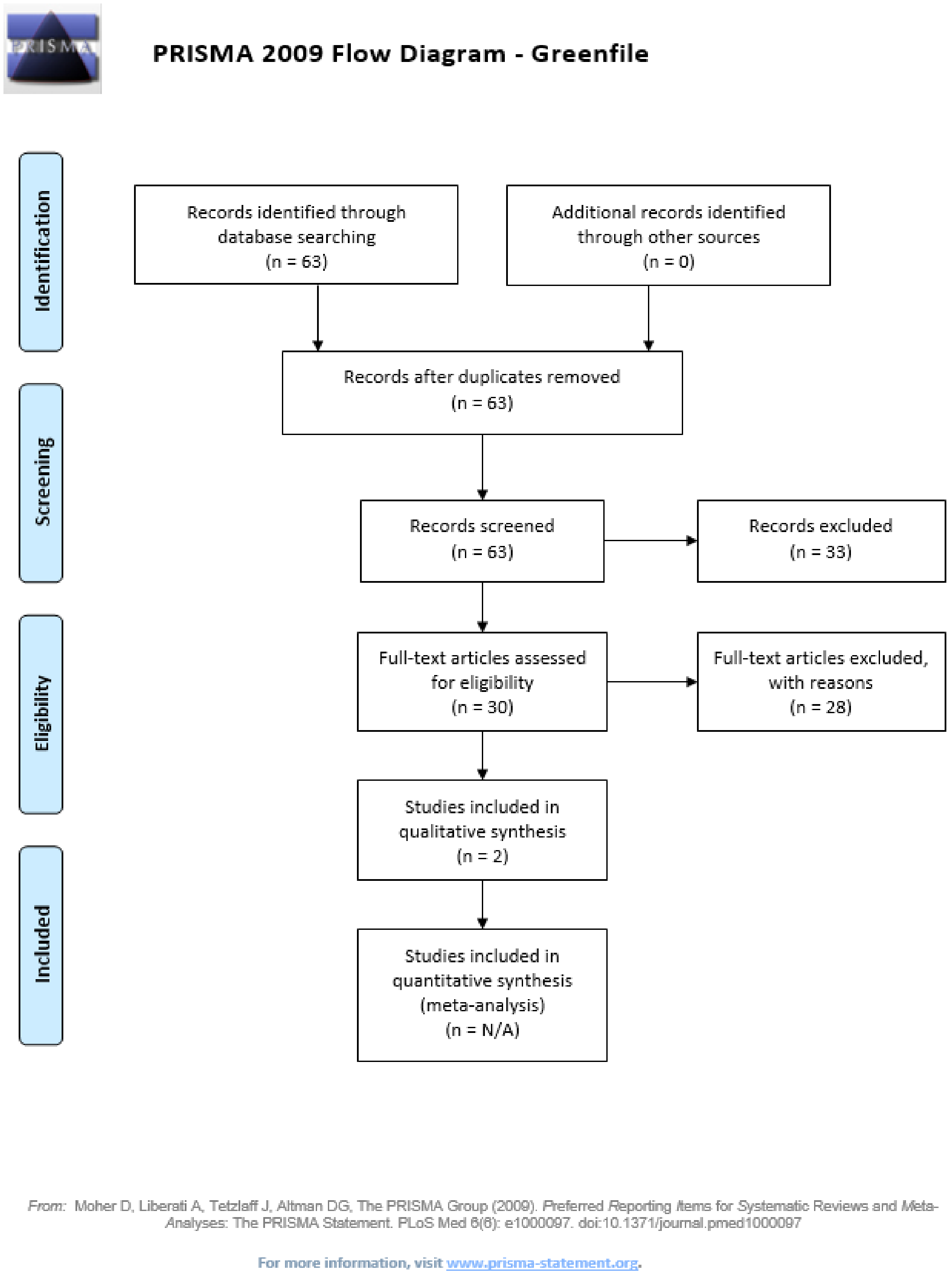


*Figure 177 PRISMA 2009 Flow Diagram for Greenfile Database Search.*

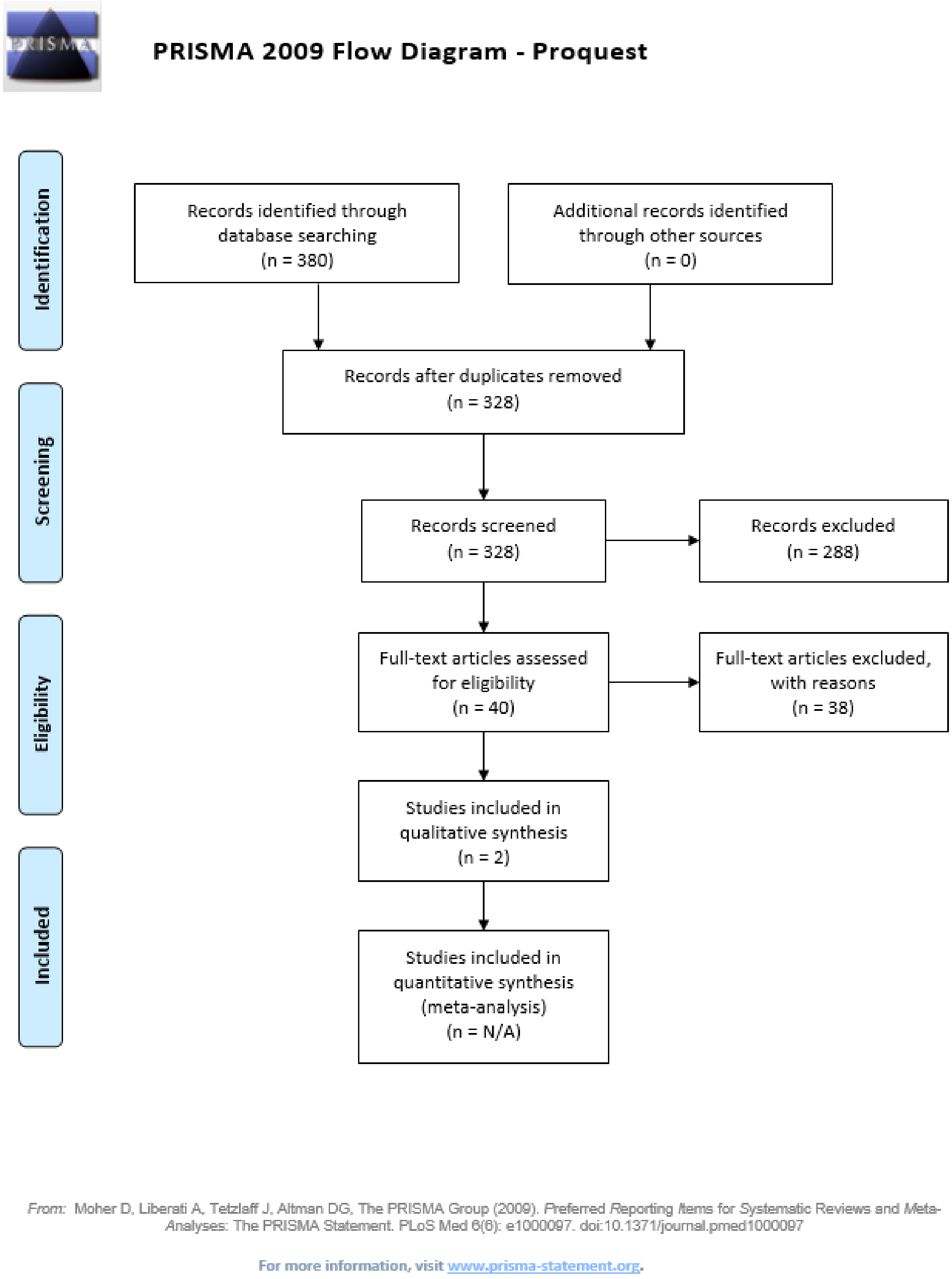
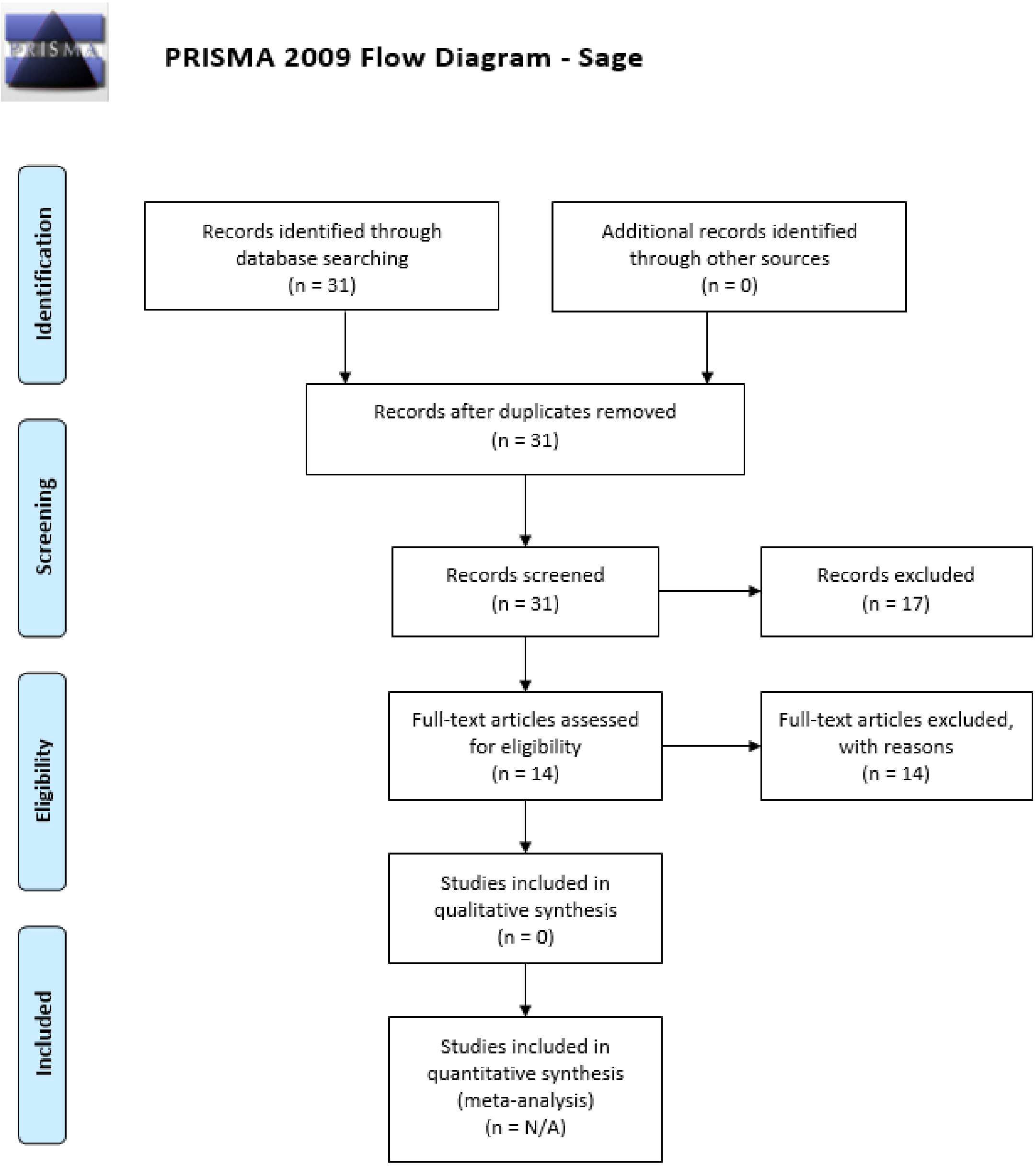


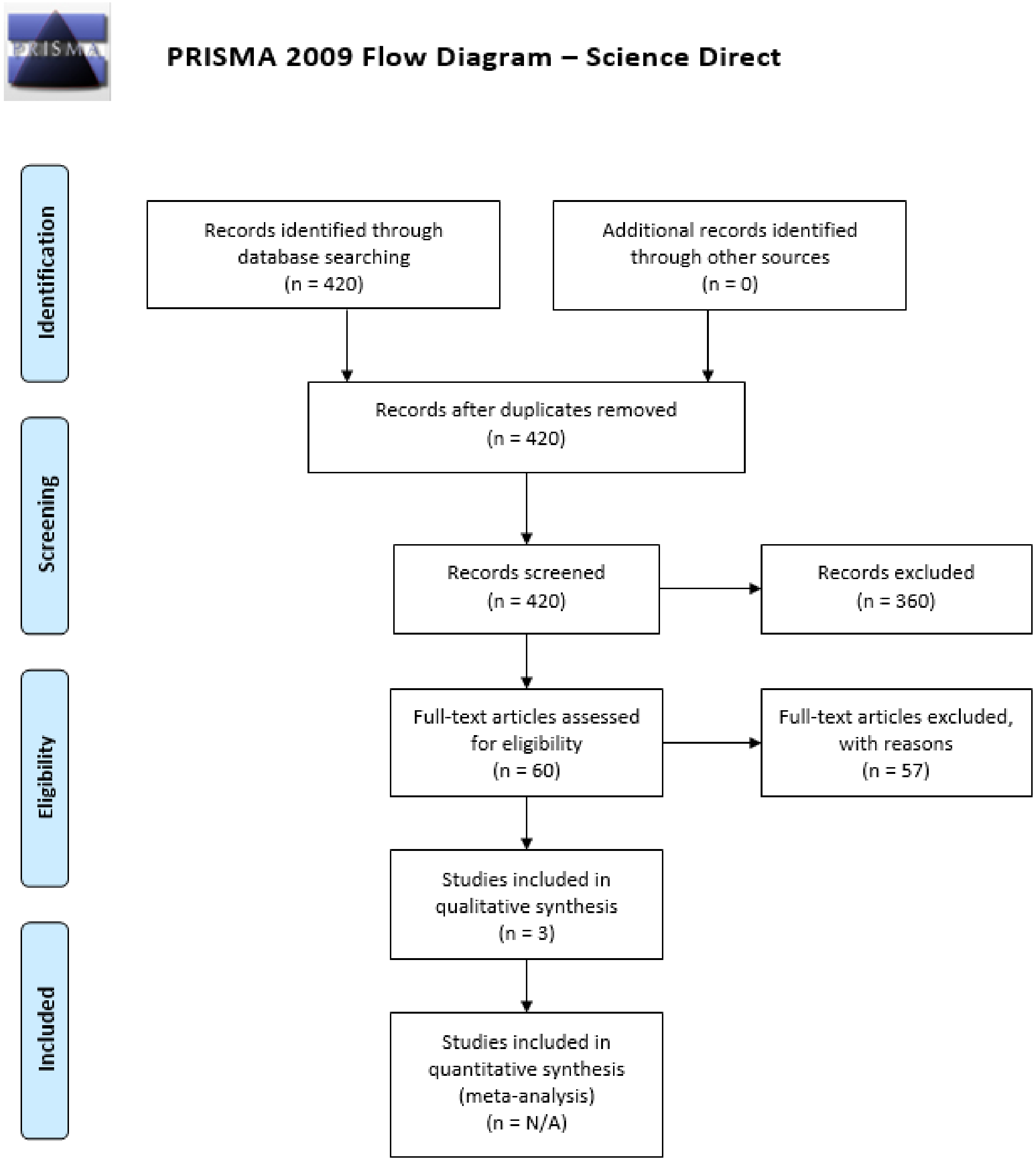
*Figure 178 PRISMA 2009 Flow Diagram for ProQuest Database Search.*



*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *Preferred Reporting Items for Systematic Reviews and Meta-Analyses*: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

**For more information, visit www.prisma-statement.org.**

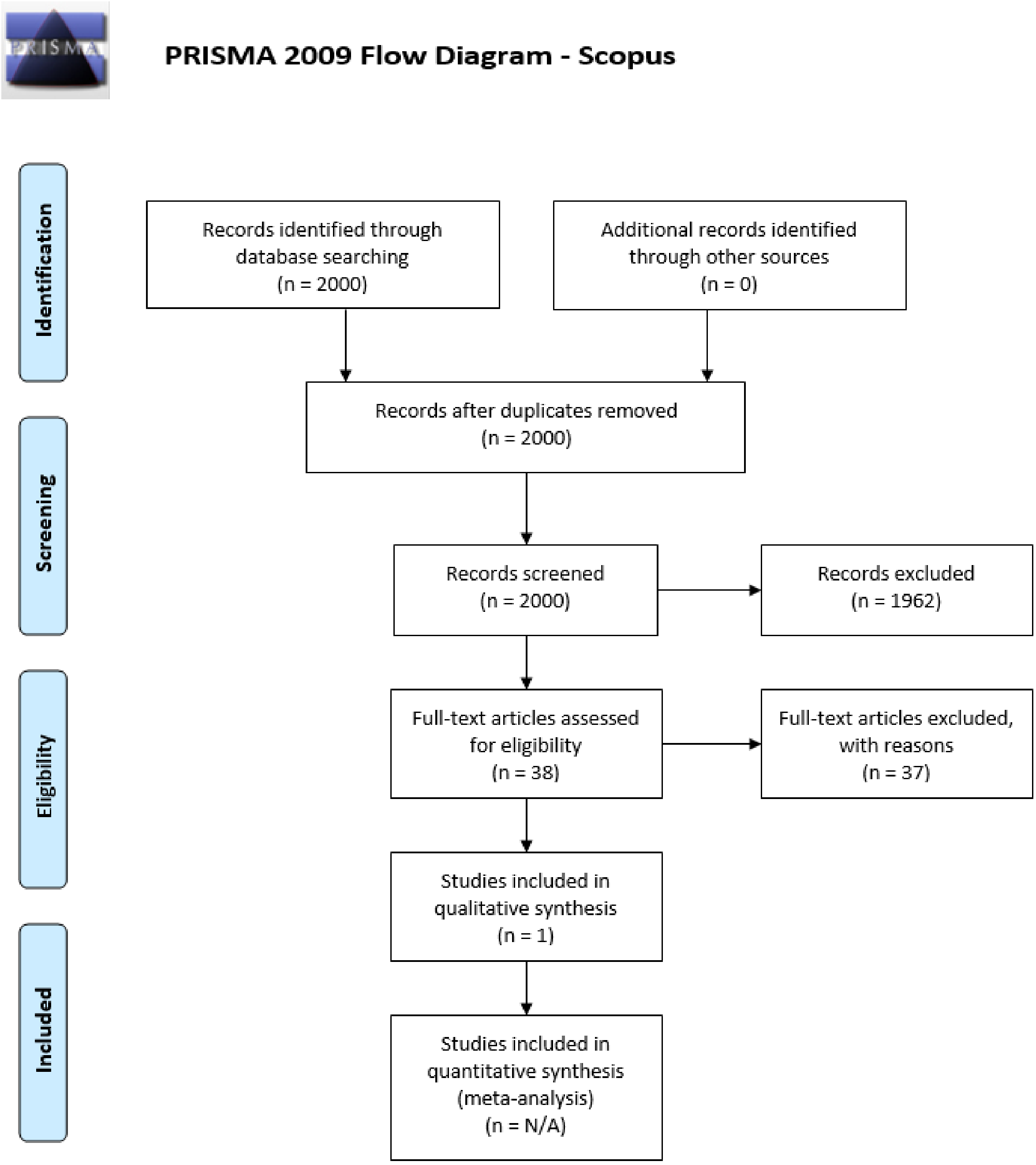
*Figure 179 PRISMA 2009 Flow Diagram for Sage Database Search.*



*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

**For more information, visit www.prisma-statement.org.**

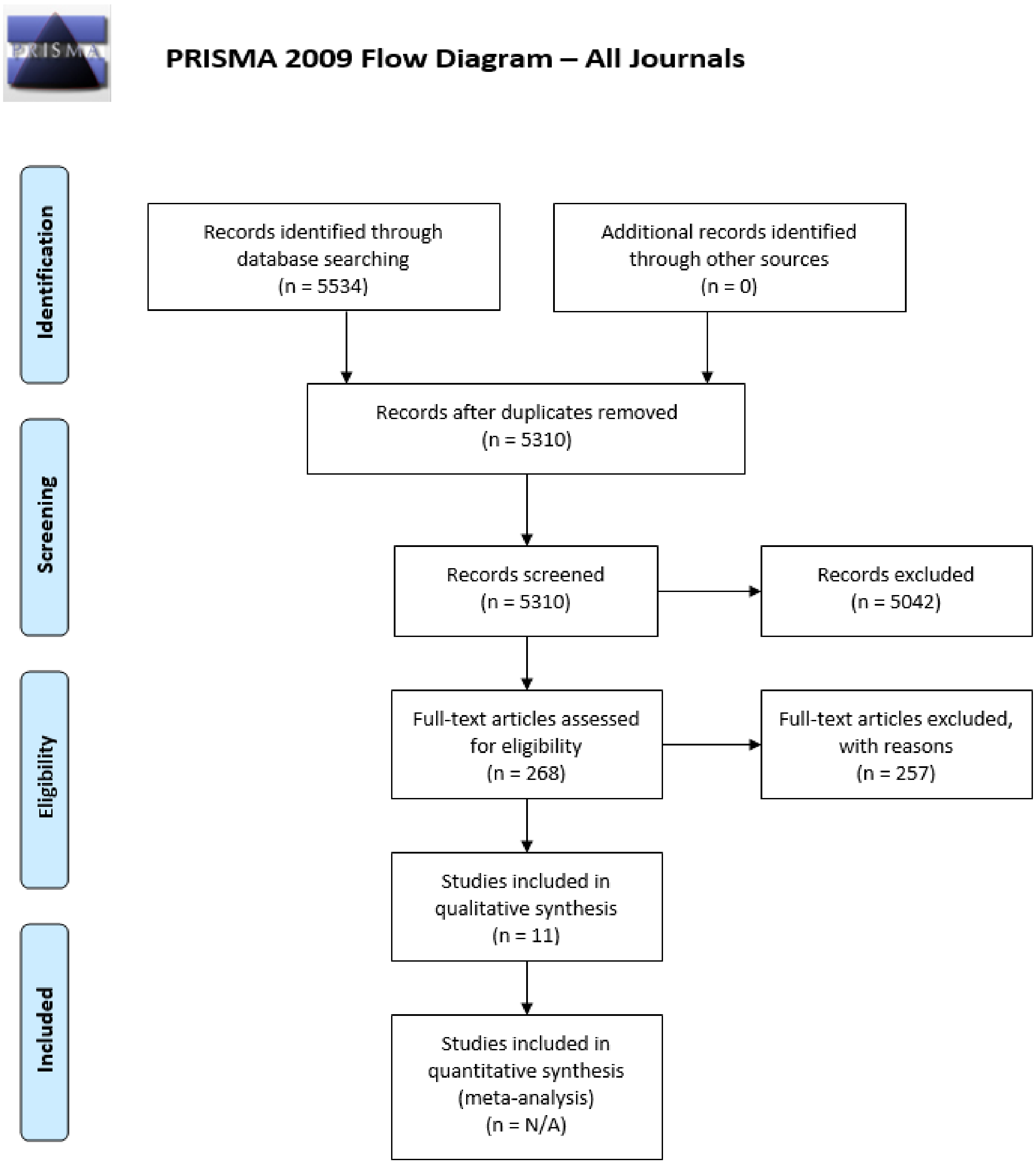
*Figure 180 PRISMA 2009 Flow Diagram for Science Direct Database Search.*



*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

**For more information, visit www.prisma-statement.org.**

*Figure 181 PRISMA 2009 Flow Diagram for Scopus Database Search.*



*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

**For more information, visit www.prisma-statement.org.**

*Figure 182 PRISMA 2009 Flow Diagram for All Journals.*

# Appendix C: 27-item Checklist (PRISMA, 2022)

| Section/topic | # | Checklist item |
|---|---|---|
| **TITLE** | | |
| Title | 1 | Identify the report as a systematic review, meta-analysis, or both. |
| **ABSTRACT** | | |
| Structured summary | 2 | Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number. |
| **INTRODUCTION** | | |
| Rationale | 3 | Describe the rationale for the review in the context of what is already known. |
| Objectives | 4 | Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS). |
| **METHODS** | | |
| Protocol and registration | 5 | Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number. |
| Eligibility criteria | 6 | Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale. |
| Information sources | 7 | Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched. |
| Search | 8 | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated. |
| Study selection | 9 | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis). |
| Data collection process | 10 | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators. |

| | | |
|---|---|---|
| Data items | 11 | List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made. |
| Risk of bias in individual studies | 12 | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis. |
| Summary measures | 13 | State the principal summary measures (e.g., risk ratio, difference in means). |
| Synthesis of results | 14 | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$) for each meta-analysis. |

*Figure 183 27-Item PRISMA Checklist (1/2).*

| **Section/topic** | **#** | **Checklist item** |
|---|---|---|
| Risk of bias across studies | 15 | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies). |
| Additional analyses | 16 | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified. |
| **RESULTS** | | |
| Study selection | 17 | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram. |
| Study characteristics | 18 | For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations. |
| Risk of bias within studies | 19 | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12). |
| Results of individual studies | 20 | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot. |
| Synthesis of results | 21 | Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency. |

|  |  |  |
|---|---|---|
| Risk of bias across studies | 22 | Present results of any assessment of risk of bias across studies (see Item 15). |
| Additional analysis | 23 | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]). |
| **DISCUSSION** |  |  |
| Summary of evidence | 24 | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers). |
| Limitations | 25 | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias). |
| Conclusions | 26 | Provide a general interpretation of the results in the context of other evidence, and implications for future research. |
| **FUNDING** |  |  |
| Funding | 27 | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review. |

*Figure 184 27-Item PRISMA Checklist (2/2).*

# Appendix D: ROBINS-I Risk of Bias Summaries

*Table 60 ROBINS-I Summary Table for Risk of Bias within Primary Studies.*

| Study | Citation | Bias due to confounding | Bias due to selection of participants | Bias in classification of interventions | Bias due to deviations from intended interventions | Bias due to missing data | Bias in measurement of outcomes | Bias in selection of the reported result | Overall | Weight |
|---|---|---|---|---|---|---|---|---|---|---|
| **Study 1** | Rojas-Rueda et al., 2012 | Moderate | Low | Low | Low | Moderate | Low | Low | Low | 1 |
| **Study 2** | Luo, Boriboonsomsin & Barth, 2018 | Moderate | Low | Moderate | Low | Low | Moderate | Low | Low | 1 |
| **Study 3** | Bistaffa et al., 2019 | Low | Low | High | Low | Low | Moderate | Low | Moderate | 1 |
| **Study 4** | Ryan et al., 2013 | Moderate | Low | Low | Low | Moderate | Low | Low | Moderate | 1 |
| **Study 5** | Borrego et al., 2012 | High | Moderate | Low | Low | Low | Low | Low | Moderate | 1 |
| **Study 6** | Duque et al., 2016 | High | Low | Low | Low | Low | Low | Low | Low | 1 |
| **Study 7** | Santos, Gómez-Losada & Pires, 2019 | High | Moderate | Moderate | Low | Low | Moderate | Low | Moderate | 1 |
| **Study 8** | Tonne et al., 2008 | Low | Low | Moderate | Low | Low | Moderate | Low | Low | 1 |
| **Study 9** | Pérez-Martínez et al., 2017 | Low | Low | Low | Low | Low | Moderate | Low | Low | 1 |
| **Study 10** | Al-Dabbous, Kumar & Prashant, 2014 | Moderate | Low | Moderate | Low | Low | Moderate | Low | Low | 1 |
| **Study 11** | Jeanjean et al., 2017 | High | Low | Low | Low | Low | Low | Low | Low | 1 |

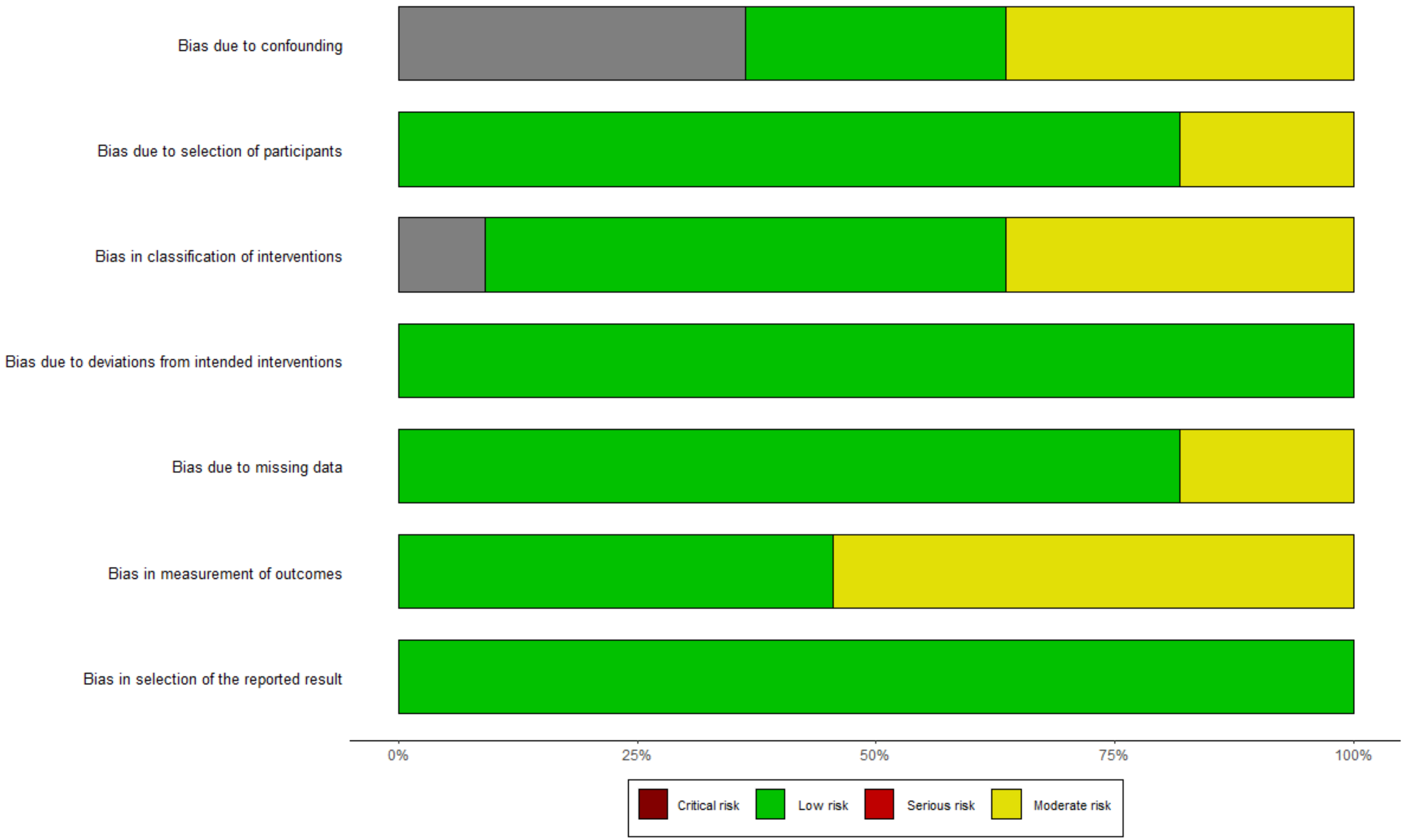
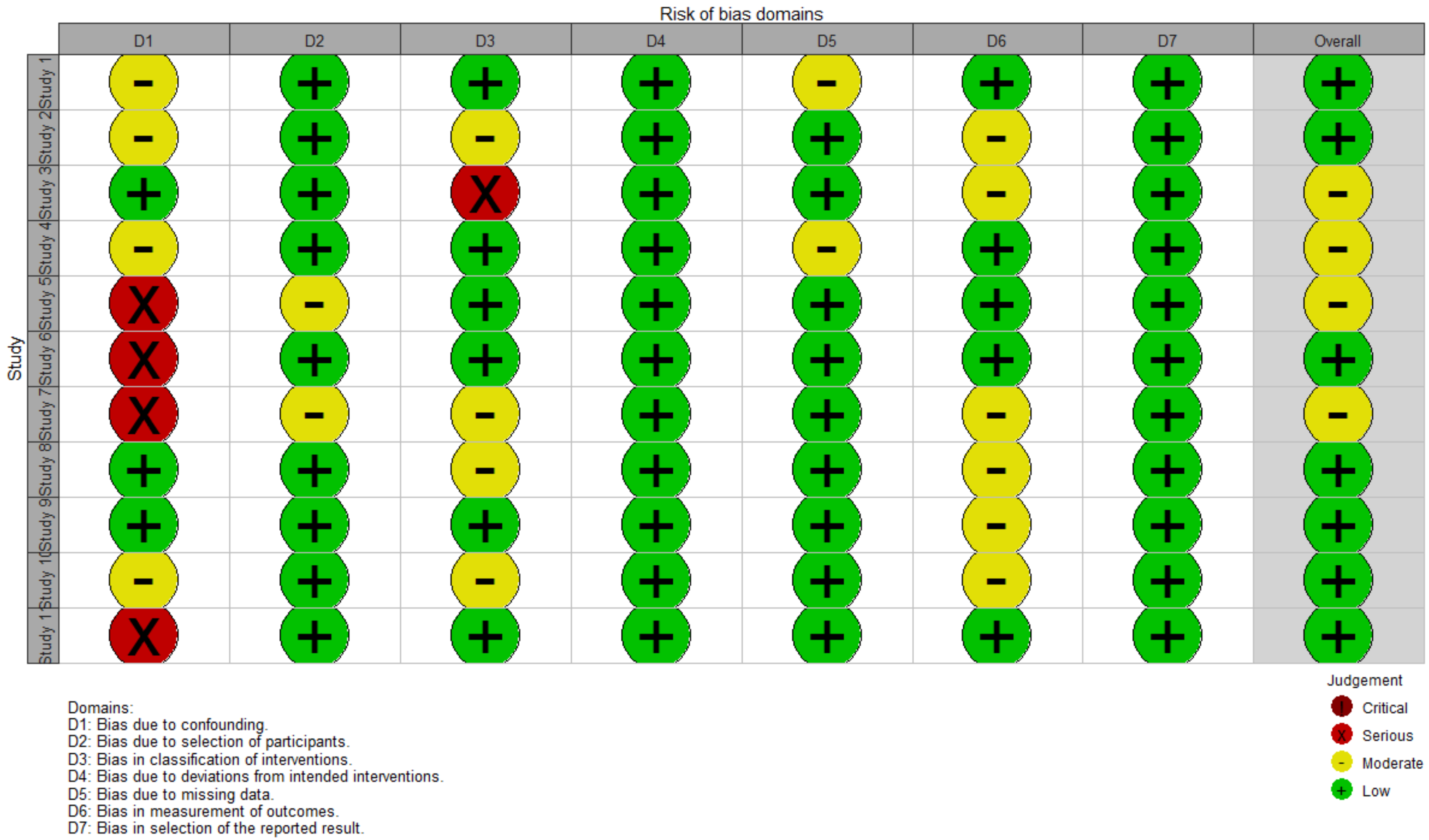


*Figure 185 ROBINS-I Summary Plot for Risk of Bias within Primary Studies.*



| Study | D1 | D2 | D3 | D4 | D5 | D6 | D7 | Overall |
|---|---|---|---|---|---|---|---|---|
| Study 1 | - | + | + | + | - | + | + | + |
| Study 2 | - | + | - | + | + | - | + | + |
| Study 3 | + | + | X | + | + | - | + | - |
| Study 4 | - | + | + | + | - | + | + | - |
| Study 5 | X | - | + | + | + | + | + | - |
| Study 6 | X | + | + | + | + | + | + | + |
| Study 7 | X | - | - | + | + | - | + | - |
| Study 8 | + | + | - | + | + | - | + | + |
| Study 9 | + | + | + | + | + | - | + | + |
| Study 10 | - | + | - | + | + | - | + | + |
| tudy 1 | X | + | + | + | + | + | + | + |

Domains:
D1: Bias due to confounding.
D2: Bias due to selection of participants.
D3: Bias in classification of interventions.
D4: Bias due to deviations from intended interventions.
D5: Bias due to missing data.
D6: Bias in measurement of outcomes.
D7: Bias in selection of the reported result.

*Figure 186 ROBINS-I Traffic Light Summary for Risk of Bias within Primary Studies.*

**Appendix E: Survey Flow & Skip/Response Logic**

# Air Quality Mitigation & Interventions Questionnaire

## Survey Flow

**Standard: Introduction (1 Question)**
**Standard: Demography (6 questions) (6 Questions)**
**Standard: Perceptions about air pollution at schools (6 questions) (9 Questions)**
**Standard: Block 3 (1 Question)**

---

Start of Block: Introduction

Introduction:

**An Investigation of Traffic-Related Air Pollution and Policy Interventions in the Vicinity of Schools in the UK**

This questionnaire is to help determine the most effective methods for the reduction of child exposure to air pollution at schools in the UK.

You have received this questionnaire because you have been identified as someone who may be interested in protecting child health from air pollution around schools, or have expressed interest in taking part.

The participant information sheet and privacy notice is available for download here: Participant Information and Privacy Notice.pdf .

Please answer in terms of the school with which you are most affiliated. If you are affiliated with more than one school, or no school at all, you may answer generally.

Should you wish to learn more about the study please feel free to view the researcher Louis Brown's research page (https://bit.ly/30iZuRv) or contact him directly (louis3.brown@live.uwe.ac.uk).

The questionnaire comprises 2 sections: 5 demographic questions followed by 6 questions about air pollution at schools.

All responses are anonymous, and your answers will only appear in aggregated form. Please feel comfortable answering honestly and openly - no identifying information will be gathered.

The entire questionnaire should take no longer than 5 minutes from start to finish.

**Consent**

If you are happy to take part in the questionnaire, please signify your consent to the following statements by clicking to proceed and begin:

I have read and understood the information provided above before being asked to signify consent;

- I have been provided with contact details of the researcher should I have any questions;
- I understand that all answers will be anonymous and no identifiable information will be requested;
- I agree that anonymised responses may be used in the reporting of this study;
- I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason;
- I agree to take part in the research.

Thank you very much for your participation.

**End of Block: Introduction**

---

Start of Block: Demography (6 questions)

Q1

What is your age?

- ○ Under 18 (1)
- ○ 18-24 (9)
- ○ 25-34 (2)
- ○ 35-44 (3)
- ○ 45-54 (4)
- ○ 55-64 (5)
- ○ 65 and over (6)

---

Q2 What is the first part of your school postcode? (You can be approximate, or if you don’t know then you can put your own)

Start typing in the box or click and scroll to select. (1)

▼ AB1 (1) ... ZE3 (3114)

Q3

Please choose one option that best describes your ethnic group or background.

▼ White: English/Welsh/Scottish/Northern Irish/British (1) ... Prefer not to say (19)

---

Q4 What is highest level of education you have completed?

▼ None (2) ... Trade/Apprenticeship (9)

Q5 What best describes your school affiliation?

○ Parent (1)

○ Teacher (11)

○ Teaching Assistant (5)

○ Other School Staff (6)

○ Governor (7)

○ Interest/Activist Group (8)

○ Other (please specify) (9)

________________________________________________

Q6 How many children do you have?

▼ None (1) ... 4 or more (5)

End of Block: Demography (6 questions)

Start of Block: Perceptions about air pollution at schools (6 questions)

Q7 How concerned are you about the effects of air pollution on the health of pupils at school?

○ Very (1)

○ Fairly (2)

○ Not very (3)

○ Not at all (4)

*Skip To: Q8 If Q7 = Not very*

*Skip To: Q8 If Q7 = Very*

*Skip To: Q8 If Q7 = Not at all*

*Skip To: Q8 If Q7 = Fairly*

*

Q8 Why are you concerned (select all that apply)?

☐ The school location is very congested (1)

☐ The school is near or on a busy main road (2)

☐ There are lots of idling cars outside the school (3)

☐ Air pollution monitors have shown that air pollution levels at the school are constantly high (4)

☐ Levels of respiratory illnesses (such as asthma) are rising among pupils at the school (5)

☐ General concerns due to media coverage, etc. (6)

☐ ⊗ Don’t know (7)

☐ Other (8) ________________________________________________

*Skip To: Q9 If Q8 = The school location is very congested*

*Skip To: Q9 If Q8 = The school is near or on a busy main road*

*Skip To: Q9 If Q8 = There are lots of idling cars outside the school*

*Skip To: Q9 If Q8 = Air pollution monitors have shown that air pollution levels at the school are constantly high*

*Skip To: Q9 If Q8 = Levels of respiratory illnesses (such as asthma) are rising among pupils at the school*

*Skip To: Q9 If Q8 = General concerns due to media coverage, etc.*

*Skip To: Q9 If Q8 = Don’t know*

*Skip To: Q9 If Q8 = Other*

*

Q8 Why are you unconcerned (select all that apply)?

☐ The school is in a rural area (1)

☐ There is very little traffic near the school (2)

☐ The majority of pupils use active travel modes (walking, scooting or cycling) to get to school (3)

☐ Air pollution monitoring has shown that air pollution levels at the school are consistently low (4)

☐ Levels of respiratory illnesses (such as asthma) are low among pupils at the school (5)

☐ ⊗Don’t know (6)

☐ Other (7) ________________________________________________

✱

Q9 What has your school/community/council/other done to improve school air quality? (please select all that apply)

☐ Promotion of active travel (cycling, scooting, walking) (1)

☐ Promotion of cleaner walking routes to school (2)

☐ Promotion of car sharing (3)

☐ Facemasks for air pollution protection (not specifically Covid-19) (4)

☐ Anti-idling campaign (6)

☐ Broader community awareness (7)

☐ Parent awareness (8)

☐ Pupil awareness (9)

☐ Closure of school roads during pick up and drop off times (13)

☐ Improved management of deliveries/visitors (14)

☐ Improved cycle & pedestrian environment (15)

☐ Low-emission vehicle promotion (16)

☐ Clean air zone (17)

☐ Green infrastructure on nearby roads (green screens, shrubs, trees, etc.) (18)

☐ Traffic calming measures (19)

☐ Green infrastructure at school (green screens, shrubs, trees, etc.) (20)

☐ Improved cycle/scooter parking (21)

☐ Ridesharing (22)

☐ Anti-idling zones (23)

☐ Air quality monitoring (24)

☐ ⊗Nothing (32)

☐ ⊗Don’t know (27)

☐ Other (29) ________________________________________________

Q10a What measures do you think would be effective for improving air quality at school? (please select all that apply)

☐ Promotion of active travel (cycling, scooting, walking) (1)

☐ Promotion of cleaner walking routes to school (2)

☐ Promotion of car sharing (3)

☐ Facemasks for air pollution protection (not specifically Covid-19) (4)

☐ Anti-idling campaign (6)

☐ Broader community awareness (7)

☐ Parent awareness (8)

☐ Pupil awareness (9)

☐ Improvement of fuel standards (10)

☐ Legislation & taxation of high emission vehicles (11)

☐ Fines to enforce anti-idling outside schools (12)

☐ Closure of school roads during pick up and drop off times (13)

☐ Improved management of deliveries/visitors (14)

☐ Improved cycle & pedestrian environment (15)

☐ Low-emission vehicle promotion (16)

☐ Clean air zone (17)

☐ Green infrastructure on nearby roads (green screens, shrubs, trees, etc.) (18)

☐ Traffic calming measures (19)

☐ Green infrastructure at school (green screens, shrubs, trees, etc.) (20)

☐ Improved cycle/scooter parking (21)

☐ Ridesharing (22)

☐ Anti-idling zones (23)

☐ Air quality monitoring (24)

☐ ⊗Don't know (26)

☐ Other (28) ________________________________________________

*Display This Question:*

*If Q10a != Don't know*

*And What measures do you think would be effective for improving air quality at school? (please select all that apply) q://QID27/SelectedChoicesCount Is Not Equal to 1*

*Carry Forward Selected Choices - Entered Text from "Q10a"*

Q10b What do you think would be the most effective measure for improving air quality at school? (please select one)

○ Promotion of active travel (cycling, scooting, walking) (1)

○ Promotion of cleaner walking routes to school (2)

○ Promotion of car sharing (3)

○ Facemasks for air pollution protection (not specifically Covid-19) (4)

○ Anti-idling campaign (5)

○ Broader community awareness (6)

○ Parent awareness (7)

○ Pupil awareness (8)

○ Improvement of fuel standards (9)

○ Legislation & taxation of high emission vehicles (10)

○ Fines to enforce anti-idling outside schools (11)

○ Closure of school roads during pick up and drop off times (12)

○ Improved management of deliveries/visitors (13)

○ Improved cycle & pedestrian environment (14)

○ Low-emission vehicle promotion (15)

○ Clean air zone (16)

○ Green infrastructure on nearby roads (green screens, shrubs, trees, etc.) (17)

○ Traffic calming measures (18)

○ Green infrastructure at school (green screens, shrubs, trees, etc.) (19)

○ Improved cycle/scooter parking (20)

○ Ridesharing (21)

○ Anti-idling zones (22)

○ Air quality monitoring (23)

○ ⊗ Don't know (24)

○ Other (25)

Q11a What are the biggest obstacles for improving air quality and/or reducing car use at school? (please select all that apply)

☐ Lack of parental support (1)

☐ Lack of staff support (2)

☐ Lack of safe cycling infrastructure (3)

☐ Lack of safe walking routes (4)

☐ Lack of staff time to implement suitable initiatives (5)

☐ No clear governmental//local authority guidance (6)

☐ School is close to busy or congested roads (13)

☐ Parents fear for the safety of their children (14)

☐ Children do not own bikes or scooters (15)

☐ Children live too far away (21)

☐ Driving is more convenient for many families (22)

☐ Children do not want to cycle, scoot or walk to school (23)

☐ ⊗Don’t know (11)

☐ Other (12) ________________________________________________

*Display This Question:*

*If Q11a != Don’t know*

*And What are the biggest obstacles for improving air quality and/or reducing car use at school? (please select all that apply) q://QID23/SelectedChoicesCount Is Not Equal to 1*

*Carry Forward Selected Choices - Entered Text from "Q11a"*

Q11b What is the biggest obstacle for improving air quality at school? (please select 1 answer)

○ Lack of parental support (1)

○ Lack of staff support (2)

○ Lack of safe cycling infrastructure (3)

○ Lack of safe walking routes (4)

○ Lack of staff time to implement suitable initiatives (5)

○ No clear governmental//local authority guidance (6)

○ School is close to busy or congested roads (7)

○ Parents fear for the safety of their children (8)

○ Children do not own bikes or scooters (9)

○ Children live too far away (10)

○ Driving is more convenient for many families (11)

○ Children do not want to cycle, scoot or walk to school (12)

○ ⊗ Don’t know (13)

○ Other (14)

Q12 Who do you consider to be the most important for supporting efforts to improve air quality at schools?

- ○ Local authorities (1)
- ○ Local community (2)
- ○ National government (3)
- ○ Parents (4)
- ○ Schools/Staff (5)
- ○ Campaign groups (6)
- ○ Other (10) ________________________________________________

End of Block: Perceptions about air pollution at schools (6 questions)

---

Start of Block: Block 3

QZ Thank you for completing this survey. Please feel free to add any additional comments below.

________________________________________________________________

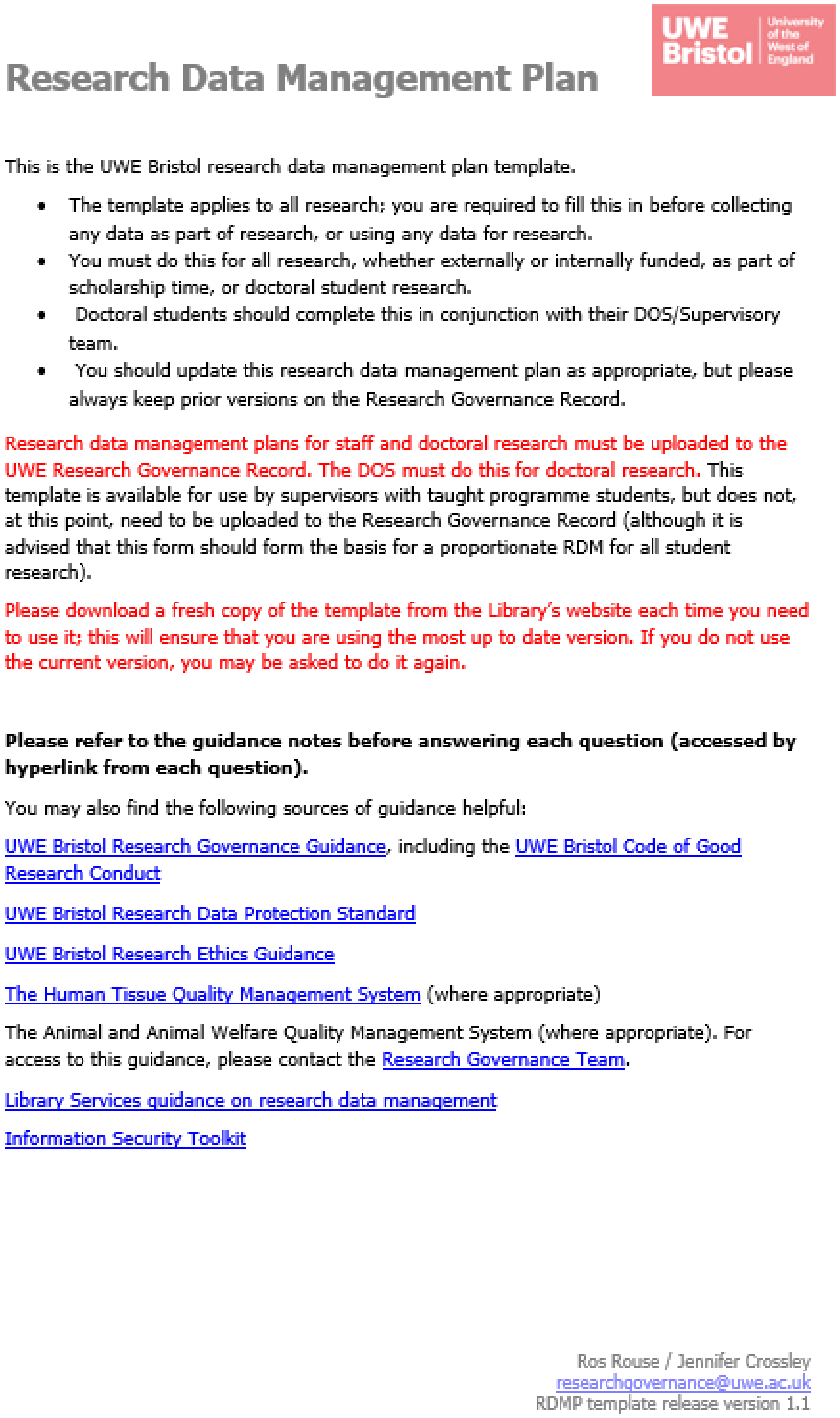
________________________________________________________________

________________________________________________________________

________________________________________________________________

________________________________________________________________

# Appendix F: Data Management Plan



## Research Data Management Plan

This is the UWE Bristol research data management plan template.

- The template applies to all research; you are required to fill this in before collecting any data as part of research, or using any data for research.
- You must do this for all research, whether externally or internally funded, as part of scholarship time, or doctoral student research.
- Doctoral students should complete this in conjunction with their DOS/Supervisory team.
- You should update this research data management plan as appropriate, but please always keep prior versions on the Research Governance Record.

Research data management plans for staff and doctoral research must be uploaded to the UWE Research Governance Record. The DOS must do this for doctoral research. This template is available for use by supervisors with taught programme students, but does not, at this point, need to be uploaded to the Research Governance Record (although it is advised that this form should form the basis for a proportionate RDM for all student research).

Please download a fresh copy of the template from the Library's website each time you need to use it; this will ensure that you are using the most up to date version. If you do not use the current version, you may be asked to do it again.

**Please refer to the guidance notes before answering each question (accessed by hyperlink from each question).**

You may also find the following sources of guidance helpful:

UWE Bristol Research Governance Guidance, including the UWE Bristol Code of Good Research Conduct

UWE Bristol Research Data Protection Standard

UWE Bristol Research Ethics Guidance

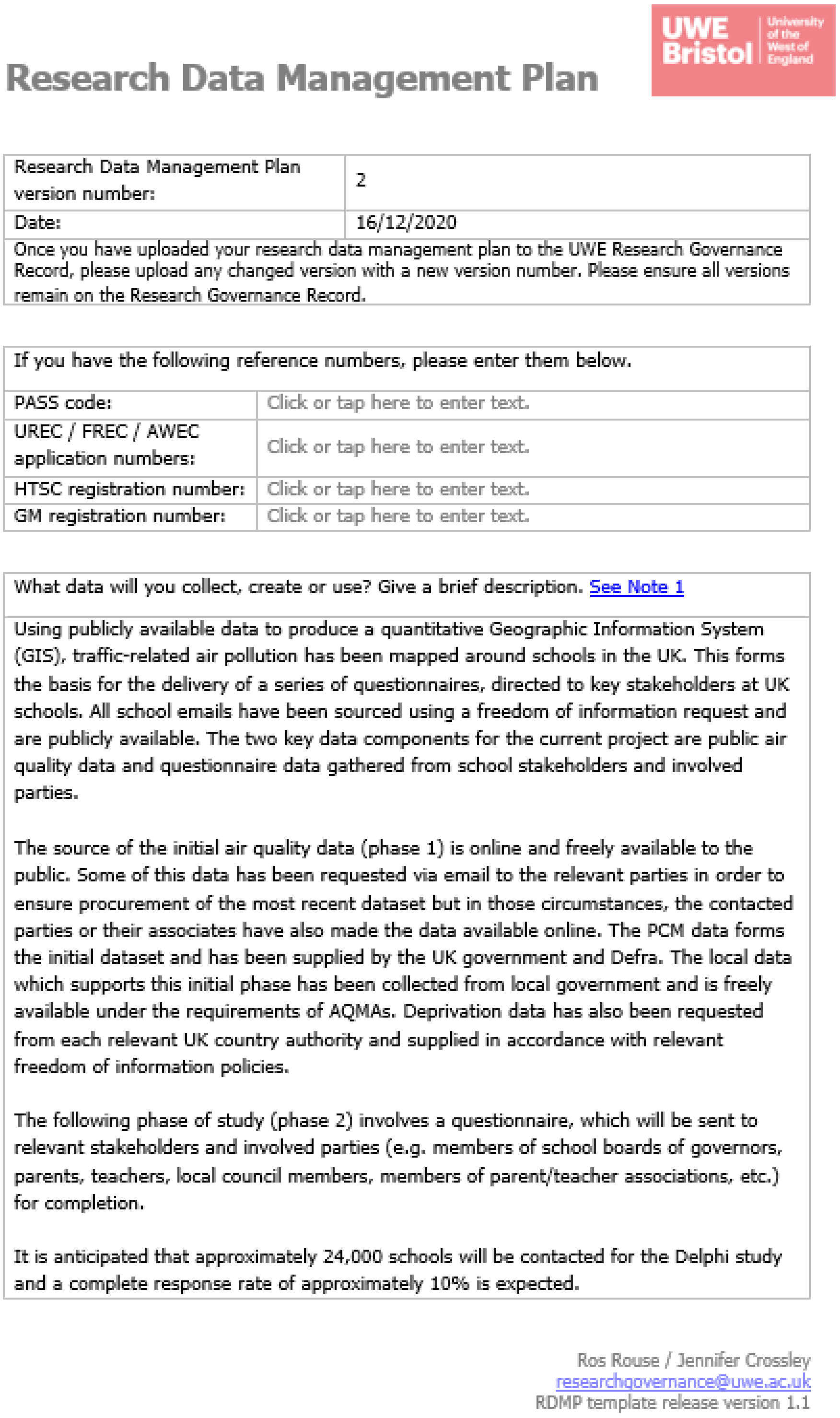
The Human Tissue Quality Management System (where appropriate)

The Animal and Animal Welfare Quality Management System (where appropriate). For access to this guidance, please contact the Research Governance Team.

Library Services guidance on research data management

Information Security Toolkit

Ros Rouse / Jennifer Crossley
researchgovernance@uwe.ac.uk
RDMP template release version 1.1



# Research Data Management Plan

UWE Bristol
University of the West of England

| | |
|---|---|
| Research Data Management Plan version number: | 2 |
| Date: | 16/12/2020 |
| Once you have uploaded your research data management plan to the UWE Research Governance Record, please upload any changed version with a new version number. Please ensure all versions remain on the Research Governance Record. | |

| | |
|---|---|
| If you have the following reference numbers, please enter them below. | |
| PASS code: | Click or tap here to enter text. |
| UREC / FREC / AWEC application numbers: | Click or tap here to enter text. |
| HTSC registration number: | Click or tap here to enter text. |
| GM registration number: | Click or tap here to enter text. |

What data will you collect, create or use? Give a brief description. See Note 1

Using publicly available data to produce a quantitative Geographic Information System (GIS), traffic-related air pollution has been mapped around schools in the UK. This forms the basis for the delivery of a series of questionnaires, directed to key stakeholders at UK schools. All school emails have been sourced using a freedom of information request and are publicly available. The two key data components for the current project are public air quality data and questionnaire data gathered from school stakeholders and involved parties.

The source of the initial air quality data (phase 1) is online and freely available to the public. Some of this data has been requested via email to the relevant parties in order to ensure procurement of the most recent dataset but in those circumstances, the contacted parties or their associates have also made the data available online. The PCM data forms the initial dataset and has been supplied by the UK government and Defra. The local data which supports this initial phase has been collected from local government and is freely available under the requirements of AQMAs. Deprivation data has also been requested from each relevant UK country authority and supplied in accordance with relevant freedom of information policies.

The following phase of study (phase 2) involves a questionnaire, which will be sent to relevant stakeholders and involved parties (e.g. members of school boards of governors, parents, teachers, local council members, members of parent/teacher associations, etc.) for completion.

It is anticipated that approximately 24,000 schools will be contacted for the Delphi study and a complete response rate of approximately 10% is expected.

Ros Rouse / Jennifer Crossley
researchgovernance@uwe.ac.uk
RDMP template release version 1.1

| |
|---|
| Given the status of the participants and their association with the subject matter, there will be no requirement to create or request any personal, sensitive or special category data. Each participant will be contacted via public email and their submissions to the online survey responses will be anonymised on entry, prior to any analyses. However, for the purposes of administration, the list of email addresses will be held by the researcher on the UWE Bristol OneDrive prior to and during the study. This information will be made available to the participants in their consent forms and information sheets prior to participation. |
| Please classify your data here as public, restricted or confidential. See Note 2 |
| Phase 1 data (PCM, deprivation data, school location data and local-level air pollution data) is all classified as 'public'. This is information that is available to any member of the public without restriction. However, this information is compiled into a series of GIS and will not necessarily be placed into the public domain, although all the information has been compiled at source for the public domain.<br>Phase 2 data (primary data) comprises the questionnaire responses. No personal information will be requested. The questionnaire response data will be anonymised at the point of entry and classified as 'restricted'. The information is non-confidential. |
| How will you collect, create or access the data? See Note 3 |
| Phase 1 data has been collected from government and local authority online sources and is all freely available to the public.<br>Phase 2 data will be gathered by questionnaires. To ensure data protection, a suitable online questionnaire service will be used (Qualtrics) and links will be emailed to the potential participants. Under instruction from UWE, the online software questionnaire solution used will be Qualtrics.<br>Consent for all participants will be gained from an initial consent form containing the UWE Bristol recommended Participant Privacy Notice, in addition to a participant information sheet. The data will be anonymised via the Qualtrics platform upon entry.<br>All information will be held for the duration of the study and any subsequent research based upon the data, as specified in the participant information sheet and consent form Access will be granted to the researcher and the supervisory team where necessary, as specified in the participant information sheet and consent form. |
| How will the data be stored and backed up at all stages during its life course? See Note 4 |

All data will be stored on the UWE Bristol OneDrive to ensure privacy and security is maintained throughout the project. A clear pathway for the transfer of data from the survey tool to OneDrive will be ensured and will involve the direct download of data to OneDrive, using only a UWE-supplied laptop. The laptop has been provided for sole access by the researcher and no-one else has access to the machine. Once the study is concluded, the machine will be re-imaged by ITS in order to ensure that any personal data is irretrievable.

How will the data be documented, described and maintained? See Note 5

Standard file versions will be maintained throughout the duration of the study. These include text and spreadsheet documents in accordance with Microsoft Office, and file types associated with ArcGIS. Both of these software packages are maintained by UWE Bristol and will dictate the formats in use. The widespread use of these formats ensure ongoing readability of the data.

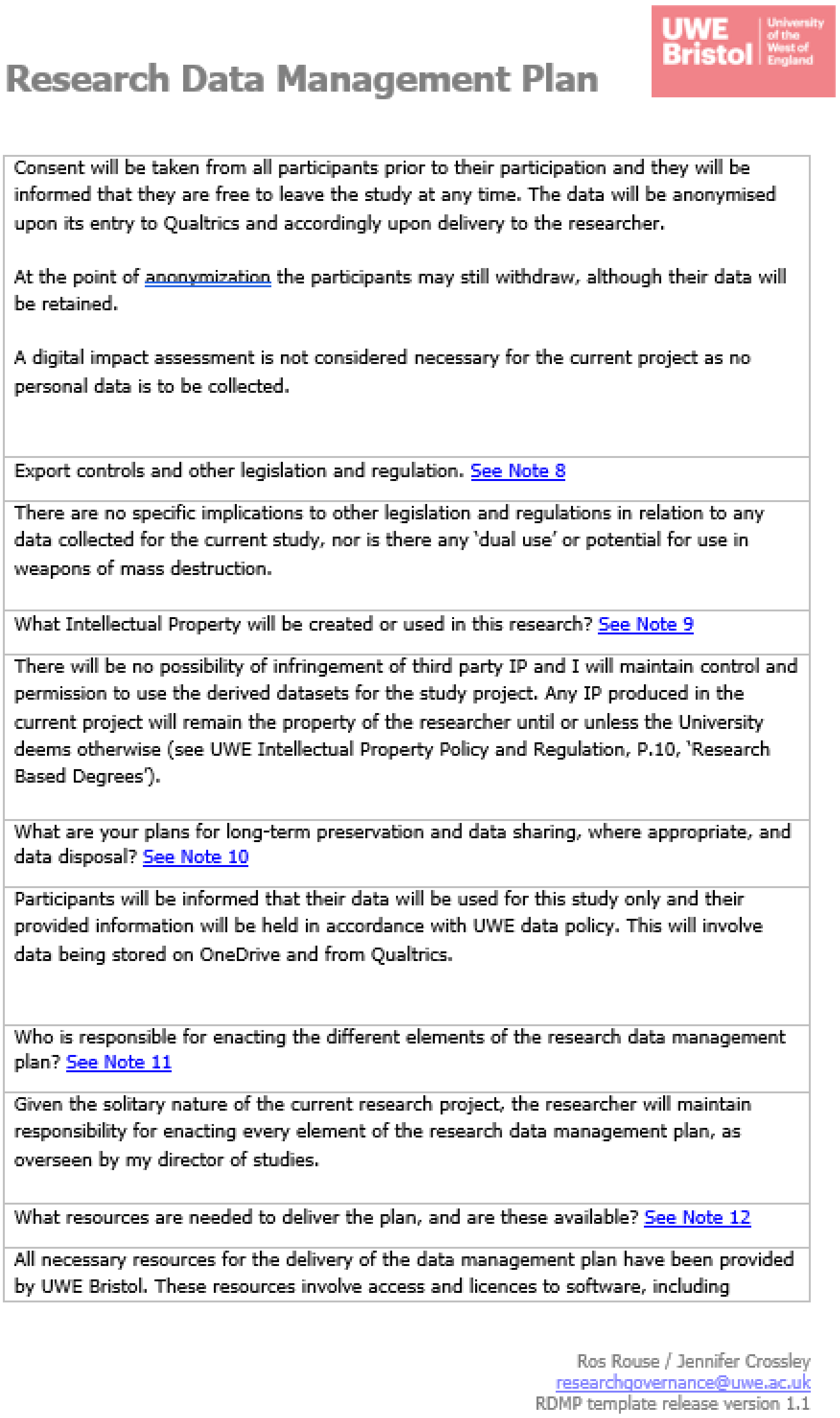
Information regarding the data will be recorded in accompaniment where possible and appropriate. Information including date, name, data purpose, the creator and information pertaining to any codes and abbreviations will be recorded as a minimum. This will commonly be held within the data itself or in a readme.txt with the data. However, no personal participant information will be stored. In addition, there will be no identifiable data requested, recorded or held with the questionnaire responses as outlined previously.

How will your data be processed? See Note 6

Data security measures will be in place throughout the duration of the study and are largely achieved through storage on the UWE Bristol OneDrive. However, all data will be handled carefully and legitimate access will only be granted to myself and my supervisory team, should it be deemed necessary. To ensure that only those who have a legitimate right to access, the data will be password protected and can only be accessed by myself in the first instance. Once data is collected for phase 2, it will be immediately stored to Bristol UWE OneDrive and removed from the third-party approved collection application (Qualtrics). The participant information and consent form will indicate permission to share information with the research supervisory team and used for published analyses but will express that the data will not be identifiable to the participant.

Does the Data Protection Act (2018) apply to your research? See Note 7

The GDPR states that lawfulness, fairness and transparency in relation to any data subjects must take place. Accordingly, all participants in the phase 2 data collection will be informed fully of their rights, the processing of the data and the intention of the study.



# Research Data Management Plan

| |
|---|
| Consent will be taken from all participants prior to their participation and they will be informed that they are free to leave the study at any time. The data will be anonymised upon its entry to Qualtrics and accordingly upon delivery to the researcher.<br>At the point of anonymization the participants may still withdraw, although their data will be retained.<br>A digital impact assessment is not considered necessary for the current project as no personal data is to be collected. |
| Export controls and other legislation and regulation. See Note 8 |
| There are no specific implications to other legislation and regulations in relation to any data collected for the current study, nor is there any 'dual use' or potential for use in weapons of mass destruction. |
| What Intellectual Property will be created or used in this research? See Note 9 |
| There will be no possibility of infringement of third party IP and I will maintain control and permission to use the derived datasets for the study project. Any IP produced in the current project will remain the property of the researcher until or unless the University deems otherwise (see UWE Intellectual Property Policy and Regulation, P.10, 'Research Based Degrees'). |
| What are your plans for long-term preservation and data sharing, where appropriate, and data disposal? See Note 10 |
| Participants will be informed that their data will be used for this study only and their provided information will be held in accordance with UWE data policy. This will involve data being stored on OneDrive and from Qualtrics. |
| Who is responsible for enacting the different elements of the research data management plan? See Note 11 |
| Given the solitary nature of the current research project, the researcher will maintain responsibility for enacting every element of the research data management plan, as overseen by my director of studies. |
| What resources are needed to deliver the plan, and are these available? See Note 12 |
| All necessary resources for the delivery of the data management plan have been provided by UWE Bristol. These resources involve access and licences to software, including |

ArcGIS, Microsoft Office, Qualtrics, SPSS and OneDrive. In addition, a UWE laptop has been provided for access to UWE services and completion of the project. Guidance in the use of security in relation to Qualtrics has already been actioned and the capabilities of the software for security are fully understood and appropriate for the outlined project.

## Appendix G: Participant Information and Privacy Notice

**Project Title: An Investigation of Traffic-Related Air Pollution and Policy Interventions in the Vicinity of Schools in the UK**

### Invitation:

You are invited to take part in research taking place at the University of the West of England, Bristol. It is funded by the researcher. Before you decide whether to take part, it is important for you to understand why the study is being done and what it will involve. Please read the following information carefully and if you have any queries or would like more information please contact the researcher, Louis Brown, Faculty of Environment & Technology, University of the West of England, Bristol [louis4.brown@uwe.ac.uk].

The project Researcher is Louis Brown. The Director of Studies is Dr Jo Barnes and the Supervisor is Professor Enda Hayes.

### Overview:

A questionnaire has been developed to determine solutions and strategies with key stakeholders for the mitigation of air pollution exposure risk in the vicinity of schools in the UK. The responses will be analysed to determine consensus on the issues relating to suitable strategies and mitigation measures.

### Research Aims:

The research concerns elevated concentrations of traffic-related air pollution around schools. The research questions are:

Q1 What are the baseline levels of traffic-related air pollution in the vicinity of selected schools in the UK?

Q2 What are the most effective interventions supported by evidence that are suitable for school vicinities?

Q3 What is the effectiveness of these interventions on air quality and risk of exposure?

To help answer these questions the researcher will conduct the aforementioned questionnaire.

The results of the study will be analysed and used for a PhD thesis made available on the University of the West of England’s open-access repository. The anonymised results may also be used in conference papers and peer-reviewed academic papers.

**Reason for Invitation:**

As a researcher I am interested in gaining information about your experience and views so the questionnaire will ask you about these things in relation to the research aims listed above. The purpose of the questions will be to develop an understanding of your views regarding the key issues surrounding the reduction of air pollution around schools in the UK, and to assist in the development of mitigation measures and strategies to facilitate a reduction.

**Participation:**

You do not have to take part in this research, and it is entirely up to you to decide whether or not you want to be involved. If you do decide to take part, you will be provided with a copy of this information sheet to keep and will be asked to signify your consent. If you decide to take part, you are able to withdraw from the research without giving a reason. All collected data will be anonymised automatically by the Qualtrics system and can therefore no longer be traced back to you.

If you change your mind while completing the questionnaire, simply exit the questionnaire without submitting it and you will be removed from the study and receive no further contact in relation to the research. Deciding not to take part or to withdraw from the study does not carry any penalty. Because the questionnaire is anonymous, you will not be able to withdraw from the study once you have submitted it.

**What the study requires:**

If you agree to take part, you will be asked to complete a short questionnaire.

The questionnaire is administered using the Qualtrics secure questionnaire solution, which is the supported and approved method of questionnaire delivery for UWE Bristol. The questionnaire will take approximately 5 minutes to complete but this may be more or less depending on your responses.

The subject and focus of the questionnaire are measures for the reduction of traffic-related air pollution around schools in the UK. Your answers will be fully anonymised and no identifiable data will be requested or recorded during the questionnaire process. Accordingly, your data will be anonymised at the point of collection by the researcher and will be analysed with questionnaire data from the other anonymised participants.

**Benefits of taking part:**

This work is being carried out to respond directly to the issue of elevated concentrations of traffic-related air pollution and daily child exposure to these toxins.  If you take part, you will be helping to gain a better understanding of the reasons why the issue persists and will be helping to influence measures that could be put in place to help reduce the likelihood of child exposure to traffic-related air pollution at school.

**Associated risks of participation:**

The researcher does not foresee or anticipate any risk to you in taking part in this study. If, however, you feel uncomfortable at any time you can desist from participation by the methods listed above and you will be removed from the study and receive no further contact regarding the research. If you need any support during or after the questionnaire, then the researcher will be able to put you in touch with suitable support agencies. The researcher and the supervisory team are experienced in conducting this form of study and are sensitive to the subject area. The questionnaire has been designed with these considerations in mind.

**Gathered information:**

All the information received from you will be treated in the strictest confidence.

All the information that you give will be kept confidential and anonymised at the point of entry. Your anonymised data will be analysed together with other questionnaire and file data, and I will ensure that there is no possibility of identification or re-identification from this point.

**Research results:**

A thesis will be written containing the research findings. This thesis will be available on the University of the West of England’s open-access Research Repository. The project is self-funded by the Researcher.

A digital copy of the thesis will be made available to all research participants if you would like to see it. Key findings will also be shared both within and outside the University of the West of England. Anonymous and non-identifying direct quotes may be used for publication and presentation purposes.

**Ethical approval:**

The project has been reviewed and approved by University of the West of England University Research Ethics Committee. Any comments, questions or complaints about the ethical conduct of this study can be addressed to the Research Ethics Committee at the University of the West of England at:

Researchethics@uwe.ac.uk

Concerns, queries and/or complaints will be handled. For students, this could be in the form of contacting your Director of Studies in the first instance. For staff, this may mean contacting the lead researcher, the ethics committee, the research governance manager or a line manager.

**For further enquiries:**

If you would like any further information about the research, please contact in the first instance:

Louis Brown, AQMRC. Faculty of Environment & Technology, University of the West of England, Frenchay Campus, Coldharbour Lane, Bristol, BS16 1QY. Email: louis4.brown@uwe.ac.uk.

For further information please feel free to view Louis Brown’s academic profile at the following link: https://bit.ly/30iZuRv

## Privacy Notice for Research Participants

### Purpose of the Privacy Notice

This privacy notice explains how the University of the West of England, Bristol (UWE) collects, manages and uses your personal data before, during and after you participate in An Investigation of Traffic-Related Air Pollution and Policy Interventions in the Vicinity of Schools in the UK. ‘Personal data’ means any information relating to an identified or identifiable natural person (the data subject). An ‘identifiable natural person’ is one who can be identified, directly or indirectly, including by reference to an identifier such as a name, an identification number, location data, an online identifier, or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.

This privacy notice adheres to the General Data Protection Regulation (GDPR) principle of transparency. This means it gives information about:

- How and why your data will be used for the research;
- What your rights are under GDPR; and
- How to contact UWE Bristol and the project lead in relation to questions, concerns or exercising your rights regarding the use of your personal data.

This Privacy Notice should be read in conjunction with the Participant Information Sheet and Consent Form provided to you before you agree to take part in the research.

**Why are we processing your personal data?**

UWE Bristol undertakes research under its public function to provide research for the benefit of society. As a data controller we are committed to protecting the privacy and security of your personal data in accordance with the (EU) 2016/679 the General Data Protection Regulation (GDPR), the Data Protection Act 2018 (or any successor legislation) and any other legislation directly relating to privacy laws that apply (together “the Data Protection Legislation”). General information on Data Protection law is available from the Information Commissioner’s Office (https://ico.org.uk/).

**How do we use your personal data?**

Your personal data will be used for research with appropriate safeguards in place on the lawful bases of fulfilling tasks in the public interest, and for archiving purposes in the public interest, for scientific or historical research purposes.

You will always be told about the information collected from you and how it will be used.

Your personal data will not be used for automated decision making about you or for profiling purposes.

Our research is governed by robust policies and procedures and, where human participants are involved, is subject to ethical approval from either UWE Bristol's Faculty or University Research Ethics Committees. This research has been approved by the Faculty for Environment and Technology Research Ethics Committee (Ethics Application Reference No: FET.19.08.003). The committee can be contacted at Researchethics@uwe.ac.uk for queries, comments or complaints. The research team adhere to the **Ethical guidelines of the British Educational Research Association (and/or the principles of the Declaration of Helsinki, 2013) and the principles of the General Data Protection Regulation (GDPR).**

For more information about UWE Bristol's research ethics approval process please see our Research Ethics webpages at:

www1.uwe.ac.uk/research/researchethics

**What data do we collect?**

The data we collect will vary from project to project. Researchers will only collect data that is essential for their project. The specific categories of personal data processed are described in the Participant Information Sheet provided to you with this Privacy Notice.

**Who do we share your data with?**

We will only share your personal data in accordance with the attached Participant Information Sheet and your Consent.

**How do we keep your data secure?**

We take a robust approach to protecting your information with secure electronic and physical storage areas for research data with controlled access. If you are participating in a particularly sensitive project UWE Bristol puts into place additional layers of security. UWE Bristol has Cyber Essentials information security certification.

Alongside these technical measures there are comprehensive and effective policies and processes in place to ensure that users and administrators of information are aware of their obligations and responsibilities for the data they have access to. By default, people are only granted access to the information they require to perform their duties. Mandatory data protection and information security training is provided to staff and expert advice available if needed.

**How long do we keep your data for?**

Your personal data will only be retained for as long as is necessary to fulfil the cited purpose of the research. The length of time we keep your personal data will depend on several factors including the significance of the data, funder requirements, and the nature of the study. Specific details are provided in the attached Participant Information Sheet. Anonymised data that falls outside the scope of data protection legislation as it contains no identifying or identifiable information may be stored in UWE Bristol's research data archive or another carefully selected appropriate data archive.

**Your Rights and how to exercise them**

Under the Data Protection legislation, you have the following **qualified** rights:

(1) The right to access your personal data held by or on behalf of the University;
(2) The right to rectification if the information is inaccurate or incomplete;
(3) The right to restrict processing and/or erasure of your personal data;
(4) The right to data portability;
(5) The right to object to processing;
(6) The right to object to automated decision making and profiling;
(7) The right to complain to the Information Commissioner's Office (ICO).

**Please note, however, that some of these rights do not apply when the data are being used for research purposes if appropriate safeguards have been put in place**.

We will always respond to concerns or queries you may have. If you wish to exercise your rights or have any other general data protection queries, please contact UWE Bristol's Data Protection Officer (dataprotection@uwe.ac.uk).

If you have any complaints or queries relating to the research in which you are taking part, please contact either the research project lead, whose details are in the attached Participant Information Sheet, UWE Bristol's Research Ethics Committees (research.ethics@uwe.ac.uk) or UWE Bristol's research governance manager (Ros.Rouse@uwe.ac.uk)

**Appendix H: Pilot Questionnaire**

# Air Quality Questionnaire - Pilot

## Survey Flow

**Standard: Introduction (1 Question)**

**Standard: Demography (5 questions) (5 Questions)**

**Standard: Perceptions about air pollution at schools (7 questions) (9 Questions)**

**Standard: Block 3 (1 Question)**

Page Break

---

**Start of Block: Introduction**

**Introduction**

**Project Title:  An Investigation of Traffic-Related Air Pollution and Policy Interventions in the Vicinity of Schools in the UK**

This questionnaire is to help determine the most effective methods for the reduction of child exposure to air pollution at schools in the UK.

You have received this questionnaire because you have been identified as someone who may be interested in protecting child health from air pollution around schools, or have expressed interest in taking part.

You should have received a participant information sheet and privacy notice. If you have not received this document, one is available for download here:

Participant Information and Privacy Notice.pdf .

If you are affiliated with more than one school, you may answer generally.

Should you wish to learn more about the study please feel free to view the researcher Louis Brown's research page (https://bit.ly/30iZuRv) or contact him directly (louis3.brown@live.uwe.ac.uk).

The questionnaire comprises 2 sections: 5 demographic questions followed by 6 questions about air pollution at schools.
All responses are anonymous, and your answers will only appear in aggregated form. Please feel comfortable answering honestly and openly - no identifying information will be gathered.

The entire questionnaire should take no longer than 5 minutes from start to finish.

**Consent**

If you are happy to take part in the questionnaire, please signify your consent to the following statements by clicking to proceed and begin:

- I have read and understood the information provided above before being asked to signify consent;
- I have been provided with contact details of the researcher should I have any questions;

- I understand that all answers will be anonymous and no identifiable information will be requested;
- I agree that anonymised responses may be used in the reporting of this study;
- I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason;
- I agree to take part in the research.

Thank you very much for your participation.

**End of Block: Introduction**

---

Start of Block: Demography (5 questions)

Q1 What is your age?

- ○ 18-24 (1)
- ○ 35-44 (3)
- ○ 45-54 (4)
- ○ 55-64 (5)
- ○ 65 and over (6)

---

Q2 What is the first part of your postcode?

Start typing in the box or click and scroll to select. (1)

▼ AB1 (1) ... ZE3 (3114)

---

Q3

Please choose one option that best describes your ethnic group or background.

▼ White: English/Welsh/Scottish/Northern Irish/British (1) ... Prefer not to say (19)

---

Q4 What is highest level of education you have completed?

▼ None (2) ... Trade/Apprenticeship (9)

---

Q5 How many children do you have?

▼ None (1) ... 4 or more (5)

**End of Block: Demography (5 questions)**

---

**Start of Block: Perceptions about air pollution at schools (7 questions)**

Q6 How concerned are you about the effects of air pollution on the health of pupils at your school?

○ Very (1)

○ Fairly (2)

○ Not very (3)

○ Not at all (4)

*Skip To: Q7 If Q6 = 3*

*Skip To: Q7 If Q6 = 4*

---

*

Q7 Why are you concerned (select all that apply)?

○ The school location is very congested (1)

○ The school is near or on a busy main road (2)

○ There are lots of idling cars outside the school (3)

○ Air pollution monitors have shown that air pollution levels at the school are constantly high (4)

○ Levels of respiratory illnesses (such as asthma) are rising among pupils at the school (5)

○ General concerns due to media coverage, etc. (6)

○ ⊗ Don’t know (7)

○ Other (8) ________________________________________________

Skip To: Q8 If Q7 = 1

Skip To: Q8 If Q7 = 2

Skip To: Q8 If Q7 = 3

Skip To: Q8 If Q7 = 4

Skip To: Q8 If Q7 = 5

Skip To: Q8 If Q7 = 6

Skip To: Q8 If Q7 = 7

Q7 Why are you unconcerned (select all that apply)?

○ The school is in a rural area (1)

○ There is very little traffic near the school (2)

○ The majority of pupils use active travel modes (walking, scooting or cycling) to get to school (3)

○ Air pollution monitoring has shown that air pollution levels at the school are consistently low (4)

○ Levels of respiratory illnesses (such as asthma) are low among pupils at the school (5)

○ ⊗ Don’t know (6)

○ Other (7) ________________________________________________

Q8 What has your school/community/council/other done to improve school air quality? (Please select all that apply)

○ Promotion of active travel (cycling, scooting, walking) (1)

○ Promotion of cleaner walking routes to school (2)

○ Promotion of car sharing (3)

○ Facemasks for air pollution protection (not specifically Covid-19) (4)

○ Anti-idling campaign (6)

○ Broader community awareness (7)

○ Parent awareness (8)

○ Pupil awareness (9)

○ Closure of school roads during pick up and drop off times (13)

○ Improved management of deliveries/visitors (14)

○ Improved cycle & pedestrian environment (15)

○ Low-emission vehicle promotion (16)

○ Clean air zone (17)

○ Green infrastructure on nearby roads (green screens, shrubs, trees, etc.) (18)

○ Traffic calming measures (19)

○ Green infrastructure at school (green screens, shrubs, trees, etc.) (20)

○ Improved cycle/scooter parking (21)

○ Ridesharing (22)

○ Anti-idling zones (23)

○ Air quality monitoring (24)

○ ⊗ Don’t know (27)

○ Other (29) ________________________________________________

*

Q9a What measures do you think would be effective for improving air quality at your school? (Please select all that apply)

- ○ Promotion of active travel (cycling, scooting, walking)  (1)
- ○ Promotion of cleaner walking routes to school  (2)
- ○ Promotion of car sharing  (3)
- ○ Facemasks for air pollution protection (not specifically Covid-19)  (4)
- ○ Anti-idling campaign  (6)
- ○ Broader community awareness  (7)
- ○ Parent awareness  (8)
- ○ Pupil awareness  (9)
- ○ Improvement of fuel standards  (10)
- ○ Legislation & taxation of high emission vehicles  (11)
- ○ Fines to enforce anti-idling outside schools  (12)
- ○ Closure of school roads during pick up and drop off times  (13)
- ○ Improved management of deliveries/visitors  (14)
- ○ Improved cycle & pedestrian environment  (15)
- ○ Low-emission vehicle promotion  (16)

○ Clean air zone  (17)

○ Green infrastructure on nearby roads (green screens, shrubs, trees, etc.)  (18)

○ Traffic calming measures  (19)

○ Green infrastructure at school (green screens, shrubs, trees, etc.)  (20)

○ Improved cycle/scooter parking  (21)

○ Ridesharing  (22)

○ Anti-idling zones  (23)

○ Air quality monitoring  (24)

○ ⊗ Don’t know  (26)

○ Other  (28) ________________________________________________

*Display This Question:*

*If Q9a != 26*

*And What measures do you think would be effective for improving air quality at your school? (Please s... q://QID27/SelectedChoicesCount Is Not Equal to  1*

*Carry Forward Selected Choices - Entered Text from "Q9a"*

Q9b What do you think would be the most effective measure for improving air quality at your school? (Please select one)

○ Promotion of active travel (cycling, scooting, walking)  (1)

○ Promotion of cleaner walking routes to school  (2)

○ Promotion of car sharing  (3)

○ Facemasks for air pollution protection (not specifically Covid-19)  (4)

○ Anti-idling campaign  (5)

○ Broader community awareness  (6)

○ Parent awareness  (7)

○ Pupil awareness  (8)

○ Improvement of fuel standards  (9)

○ Legislation & taxation of high emission vehicles  (10)

○ Fines to enforce anti-idling outside schools  (11)

○ Closure of school roads during pick up and drop off times  (12)

○ Improved management of deliveries/visitors  (13)

○ Improved cycle & pedestrian environment  (14)

○ Low-emission vehicle promotion  (15)

○ Clean air zone  (16)

○ Green infrastructure on nearby roads (green screens, shrubs, trees, etc.)  (17)

○ Traffic calming measures  (18)

○ Green infrastructure at school (green screens, shrubs, trees, etc.)  (19)

○ Improved cycle/scooter parking  (20)

○ Ridesharing  (21)

○ Anti-idling zones  (22)

○ Air quality monitoring (23)

○ ⊗Don’t know (24)

○ Other (25)

Q10a What are the biggest obstacles for improving air quality and/or reducing car use at your school? (Please select all that apply)

○ Lack of parental support (1)

○ Lack of staff support (2)

○ Lack of safe cycling infrastructure (3)

○ Lack of safe walking routes (4)

○ Lack of staff time to implement suitable initiatives (5)

○ No clear governmental//local authority guidance (6)

○ School is close to busy or congested roads (13)

○ Parents fear for the safety of their children (14)

○ Children do not own bikes or scooters (15)

○ Children live too far away (21)

○ Driving is more convenient for many families (22)

○ Children do not want to cycle, scoot or walk to school (23)

○ ⊗Don’t know (11)

○ Other (12) ________________________________________________

*Display This Question:*

*If Q10a != 11*

*And What are the biggest obstacles for improving air quality and/or reducing car use at your school? (Please select all that apply) q://QID23/SelectedChoicesCount Is Not Equal to 1*

*Carry Forward Selected Choices from "Q10a"*

X→

Q10b What is the biggest obstacle for improving air quality at your school? (Please select 1 answer)

○ Lack of parental support (1)

○ Lack of staff support (2)

○ Lack of safe cycling infrastructure (3)

○ Lack of safe walking routes (4)

○ Lack of staff time to implement suitable initiatives (5)

○ No clear governmental//local authority guidance (6)

○ School is close to busy or congested roads (7)

○ Parents fear for the safety of their children (8)

○ Children do not own bikes or scooters (9)

○ Children live too far away (10)

○ Driving is more convenient for many families (11)

○ Children do not want to cycle, scoot or walk to school (12)

○ ⊗Don’t know (13)

○ Other (14) ________________________________________________

Q11 Who do you consider to be the most important for supporting efforts to improve air quality around schools?

○ Local authorities (1)

○ Local community (2)

○ National government (3)

○ Parents (4)

○ Schools/Staff (5)

○ Campaign groups (6)

○ Other (10) ________________________________________________

**End of Block: Perceptions about air pollution at schools (7 questions)**

---

**Start of Block: Block 3**

QZ Thank you for completing this pilot survey. Please feel free to talk about your experience below and highlight any possible suggestions or improvements.

**End of Block: Block 3**

## Appendix I: Feedback from Pilot (provided in closing comments section)

*Feedback 1:*

Quick comments, please ignore if not helpful:

- Q1-5 is looking good. Perhaps add a title? Section 1: Demographic
- Perhaps then start section 2: Perception about air pollution at schools (7 questions)
- -*Not possible*
- Q8 has too much info to process, perhaps cluster separate them into 8a and 8b – one about what the school had done, and the other about initiatives by other stakeholders). So I think 8b needs to be different as you need to capture who did what, rather than just what was done (perhaps use a matrix/drop and match actors on one side and measures on the other?)
- *Matrix not possible for phone view*
- Q9 would be best if it mirrored 8b, as you are trying to unpack who the school thinks can help improve air quality and how?
- Q10 could be clubbed with 8a – this is where you are trying to capture the actions taken by the school and the barriers they face.
- Q11 – not sure if it is relevant for this study.
- Q12 needs to be linked to Q9 and 8b – I think if you asked Q12 first, followed by an understanding of what was done and by whom (Q8a) and what further could be done by whom and how (Q9)

*Feedback 2:*

A few comments on your survey:

- Have you had your front page approved by the ethics committee? We have had to provide links to a UWE privacy notice etc. for our projects in the past (and state the ethics # etc.). You also only ask for consent to use the data in a final report – will you not also be writing publications based on the data?
- Is ‘how many children do you have?’ relevant? What will it tell you? Do you want to know if they have school age children?

- I don’t know who the survey is going out to, but it might be worth having a question about the person’s role, e.g., teacher, headteacher, parent, local authority staff.
- Is the survey only interested in primary schools? I don’t think it says anywhere, but I assume that this is the case. Secondary and special schools will require many more options e.g., about public transport, dedicated school transport, kids not able to walk/cycle to school etc.
- Something funky is going on in Q9 – loads of the options are repeated!
- Q9 is also really long. I’m not sure how it will look once the repetitions have been removed, but it’s tough for people to choose or rank when the list is longer than 1 screen. Do you need to do it like this? Or could you ask people to select one from each of the subheadings and then present those for ranking?
- Q9 talks about “enforcing” idling – I think this is the opposite of what you mean.
- Q12 – I don’t know what you mean by “most responsible”, as in they cause the most pollution? They can have the biggest impact? They should pay for measures?
- The question number was incorrect on the final question, but probably because this is a pilot-specific question. Do you need question numbers at all, though? You provide a progress bar at the top and specify the number of questions in the intro, so it might just be increasing the risk of errors?

*Feedback 3:*

Currently it doesn’t allow you to rank at all – you can only select 6 options in one question, 3 in another, and then 1 in the final one.

Could you ask people to select all that apply, and then a sub question to select their main one?

Choosing only one option is very limiting and doesn’t let you get to the heart of the issue

## Appendix J: Generic Invitation Email

Subject: National Air Pollution and Schools Survey

Dear Sir/Madam,

I am contacting you to request your participation in a national survey to address air pollution at schools. The data collected from this survey will help to develop strategies to reduce child exposure to harmful air pollution.

Please could you circulate this email or the provided link to any relevant parties (such as to any affiliated staff, newsletters, noticeboards, via social media, and to any parents, teachers and governors, or to any other networks or contacts which may be available to you), as the more interested parties that participate the better.

The questionnaire is entirely anonymous, and no personal or identifiable information will be requested or recorded at any point.

The link below will take you to the questionnaire, which should take no more than a few minutes to complete.

Thanks very much for your time,

Louis Brown MA MSc
Researcher
Air Quality Management Resource Centre (AQMRC)
UWE Bristol,
Coldharbour Lane,
Bristol, BS16 1QY

## Appendix K: Email Invitation for Schools

Dear Sir/Madam,

I am contacting you to kindly request your participation in an important national survey (in conjunction with the University of the West of England, Bristol) to address air pollution at schools. The data collected from this survey will inform the development of strategies to reduce child exposure to harmful air pollution.

Please could you circulate this email or the provided link to any relevant parties (such as to any staff, newsletters, noticeboards, via social media, and to any parents, teachers and governors, or any other networks or contacts which may be available to you), as the more interested parties that participate the better.

The questionnaire is entirely anonymous, and no personal or identifiable information will be requested or recorded at any point.

The link below will take you to the questionnaire, which should take no more than a few minutes to complete.

https://uwe.eu.qualtrics.com/jfe/form/SV_9ZD2i6fXjKPNCFD

Thanks very much for your time,

Louis Brown.
Researcher,
Air Quality Management Resource Centre (AQMRC)
UWE, Bristol.
Coldharbour Lane, Bristol, BS16 1QY

Follow this link to the Survey:
${l://SurveyLink?d=Take the Survey}
Or copy and paste the URL below into your internet browser:
${l://SurveyURL}

Follow the link to opt out of future emails:
${l://OptOutLink?d=Click here to unsubscribe}

## Appendix L: Follow-up Email to Schools

Dear Sir/Madam,

You may remember I contacted you some weeks ago regarding a national survey to address air pollution at schools, in conjunction with the University of the West of England, Bristol. The survey has had a tremendous response and I would like to thank everyone who has been involved for your efforts.

The survey is now in its final month, and I would like to implore anyone who is yet to take part or share the survey to please do so at your earliest convenience. The data collected from this survey will inform the development of strategies to reduce child exposure to harmful air pollution. If you have already done so, then I would like to thank you again and please disregard this message. In any case, I can assure you that (unless otherwise requested) this is the last time you will be contacted regarding this matter.

Please could you circulate this email or the provided link to any relevant parties (such as to any staff, newsletters, noticeboards, via social media, and to any parents, teachers and governors, or any other networks or contacts which may be available to you), as the more interested parties that participate the better.

The questionnaire is entirely anonymous, and no personal or identifiable information will be requested or recorded at any point.

The link below will take you to the questionnaire, which should take no more than a few minutes to complete.

https://uwe.eu.qualtrics.com/jfe/form/SV_9ZD2i6fXjKPNCFD

Thanks very much for your time,

Louis Brown.
Researcher,
Air Quality Management Resource Centre (AQMRC)
UWE, Bristol.
Coldharbour Lane, Bristol, BS16 1QY

Follow this link to the Survey:
${l://SurveyLink?d=Take the Survey}
Or copy and paste the URL below into your internet browser:
${l://SurveyURL}

Follow the link to opt out of future emails:
${l://OptOutLink?d=Click here to unsubscribe}

## Appendix M: Generic Social Media Post Templates

*Iteration 1:*

Children are disproportionately affected by traffic-related air pollution. In conjunction with UWE Bristol, we are conducting a national survey on air pollution and schools.

No personal or identifiable information will be requested or recorded. Your views will help to develop strategies for the reduction of child exposure to harmful air pollution.

Please feel share this link!

https://bit.ly/3aIYM7x

#schools #LTNS #childhealth #cleanair #airpollution #breathe

*Iteration 2:*

Calling all parents, teachers & citizen scientists! Please complete my survey to inform strategies to reduce child exposure to air pollution:

https://uwe.eu.qualtrics.com/jfe/form/SV_9ZD2i6fXjKPNCFD

#schools #LTNS #childhealth #cleanair #airpollution #breathe #survey #Research

*Iteration 3:*

Please can you complete my survey to inform strategies to reduce child exposure to air pollution:

https://uwe.eu.qualtrics.com/jfe/form/SV_9ZD2i6fXjKPNCFD

Please leave a link to yours in the comments once done and I will happily complete!

#schools #LTNS #childhealth #cleanair #airpollution #breathe #survey #Research

## Appendix N: End of Survey Message

Thank you for taking part. Please circulate the following anonymous link if you anyone else who may be interested in helping protect child health from air pollution:

https://uwe.eu.qualtrics.com/jfe/form/SV_9ZD2i6fXjKPNCFD

This link is unable to track any identifying information and can be reused.

Thank you very much for your time.

## Appendix O: Survey Response Counts

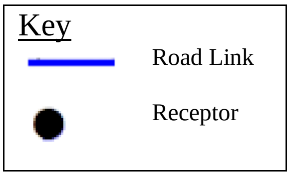
*Table 61 Response Counts.*

| Question | Count |
|---|---|
| Q1 - What is your age? | 1665 |
| Q2 - What is the first part of your school postcode? | 1665 |
| Q3 - Please choose one option that best describes your ethnic group or background. | 1665 |
| Q4 - What is highest level of education you have completed? | 1665 |
| Q5 - What best describes your school affiliation? | 1665 |
| Q6 - How many children do you have? | 1665 |
| Q7 - How concerned are you about the effects of air pollution on the health of pupils at school? | 1644 |
| Q8 - Why are you concerned (select all that apply)? | 1258 |
| Q8 - Why are you unconcerned (select all that apply)? | 365 |
| Q9 - What has your school/community/council/other done to improve school air quality? | 1555 |
| Q10a - What measures do you think would be effective for improving air quality at school? | 1503 |
| Q10b - What do you think would be the most effective measure for improving air quality at school? | 1391 |
| Q11a - What are the biggest obstacles for improving air quality and/or reducing car use at school? | 1480 |
| Q11b - What is the biggest obstacle for improving air quality at school? | 1146 |
| Q12 - Who do you consider to be the most important for supporting efforts to improve air quality at schools? | 1470 |

## Appendix P: Travel Routes & Receptors

### i. Overview & key for all diagrams

The current section details the placement of all receptors and road links for the ADMS modelling phase of the investigation. All images have been produced using ESRI's ArcMap (Version 10.8.1). Each concentric black circle surrounding a centre point indicates an additional 100-metre boundary from a school (starting at 200 metres, up to 500 metres). A key is provided and is consistent for all diagrams (Figure 187).



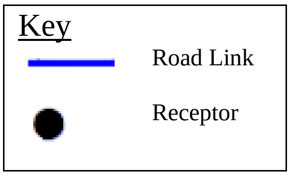


*Figure 187 Key for symbols on all receptor and link diagrams.*

## ii. Bristol St Paul’s: Receptors & Links

*Figure 188 Bristol St Paul’s Receptors & Links*

## iii. Bristol St Paul’s: Active Travel Routes

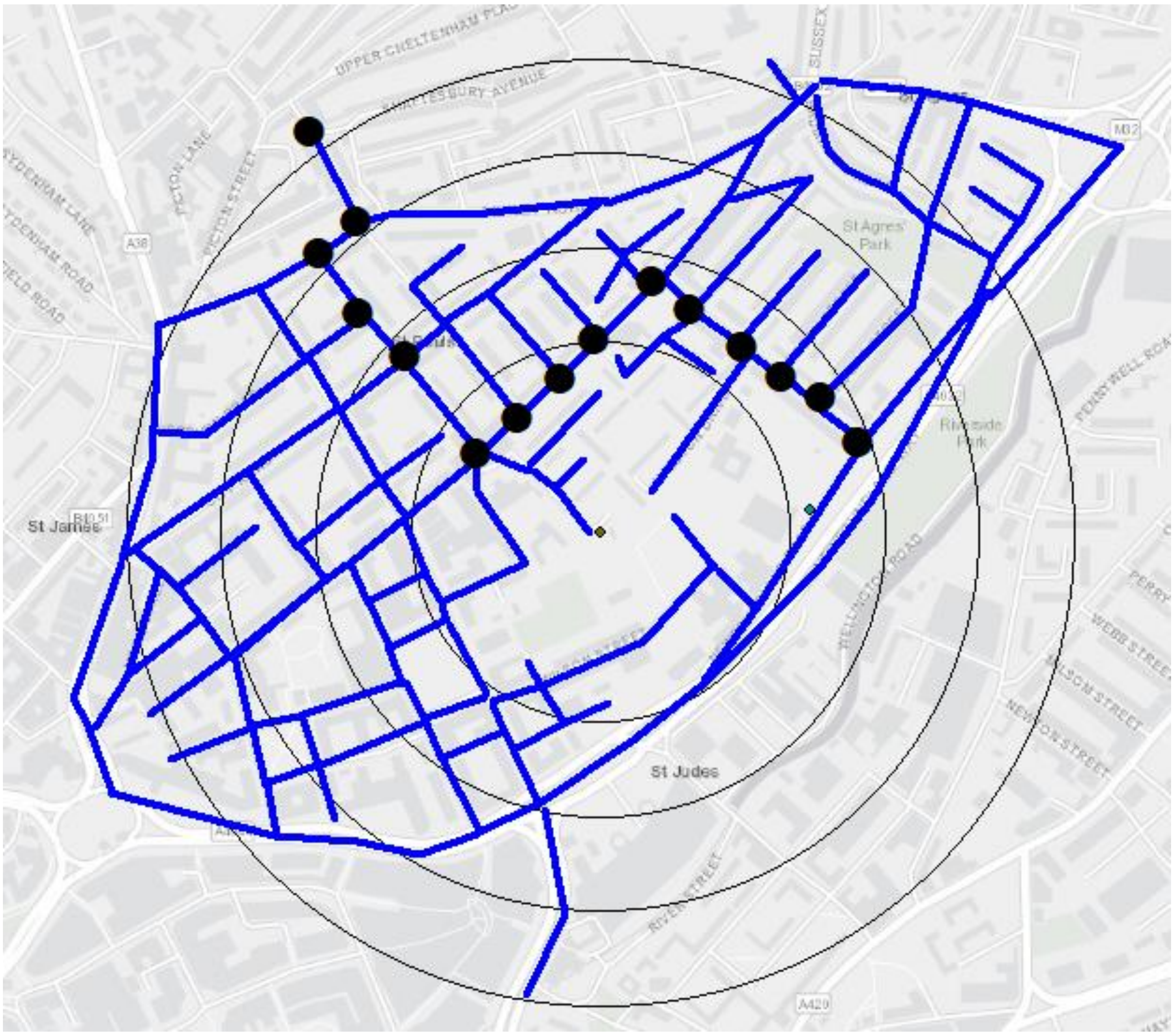


*Figure 189 Bristol St Paul’s Active Travel Routes: Ashley Road.*

*Figure 190 Bristol St Paul's Active Travel Routes: Stokes Croft*

*Figure 191 Bristol St Paul’s Active Travel Routes: St Agnes.*

*Figure 192 Bristol St Paul's Active Travel Routes: Bristol South.*

*Figure 193 Bristol St Paul's Active Travel Routes: Cheltenham Road.*

## iv. Bristol St Paul’s Improved Travel Routes

*Figure 194 Bristol St Paul’s Improved Travel Routes: Ashley Road.*

*Figure 195 Bristol St Paul's Improved Travel Routes: Stokes Croft.*

*Figure 196 Bristol St Paul's Improved Travel Routes: St Agnes.*

*Figure 197 Bristol St Paul's Improved Travel Routes: Bristol South.*

*Figure 198 Bristol St Paul's Improved Travel Routes: Cheltenham Road.*

### v. Bristol Bedminster: Receptors & Links

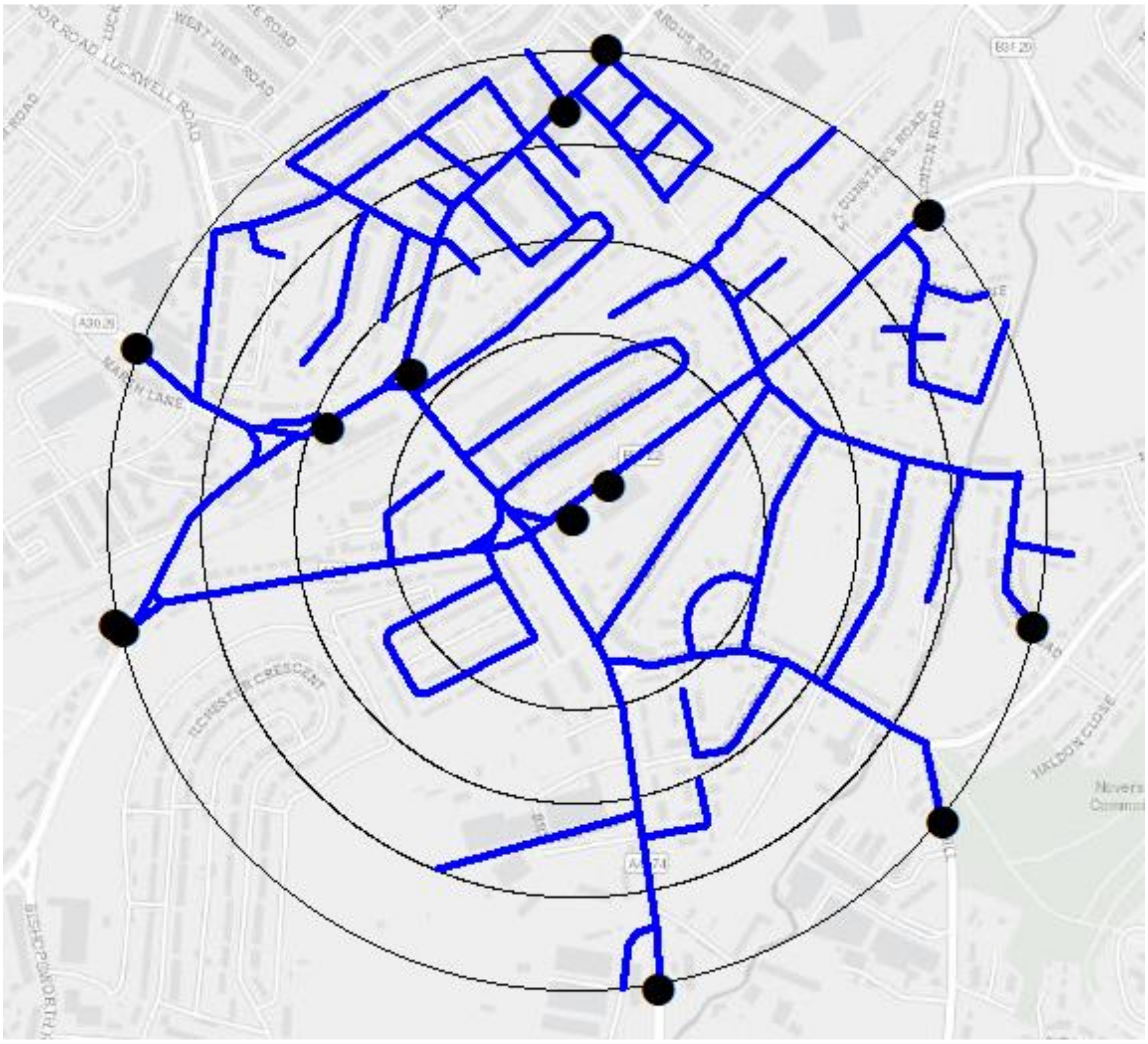


*Figure 199 Bristol Bedminster: Receptors & Links.*

## vi. Bristol Bedminster: Active Travel Routes

*Figure 200 Bristol Bedminster Active Travel Routes: Ashton Gate.*

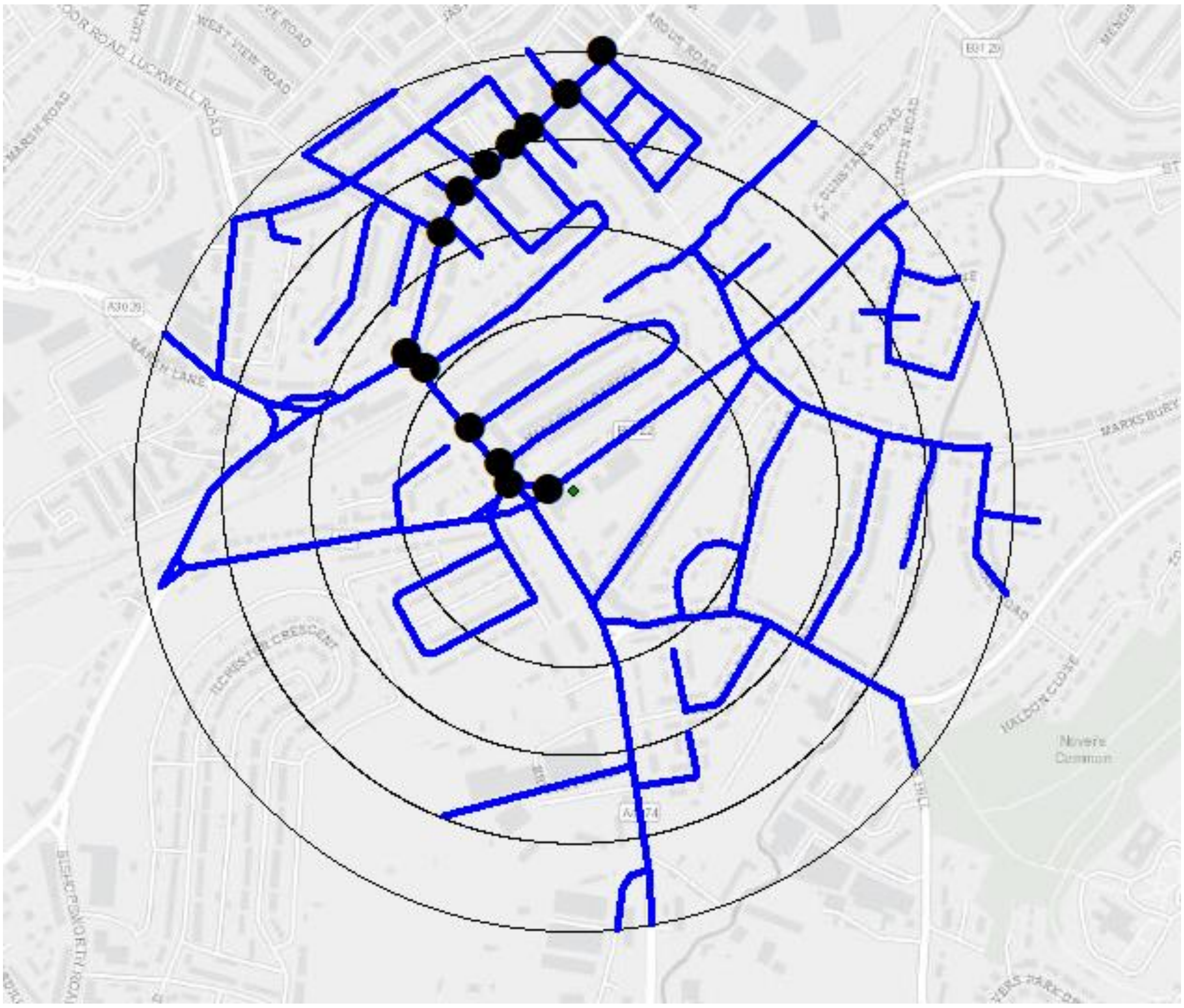


Figure 201 Bristol Bedminster Active Travel Routes: Bedminster.

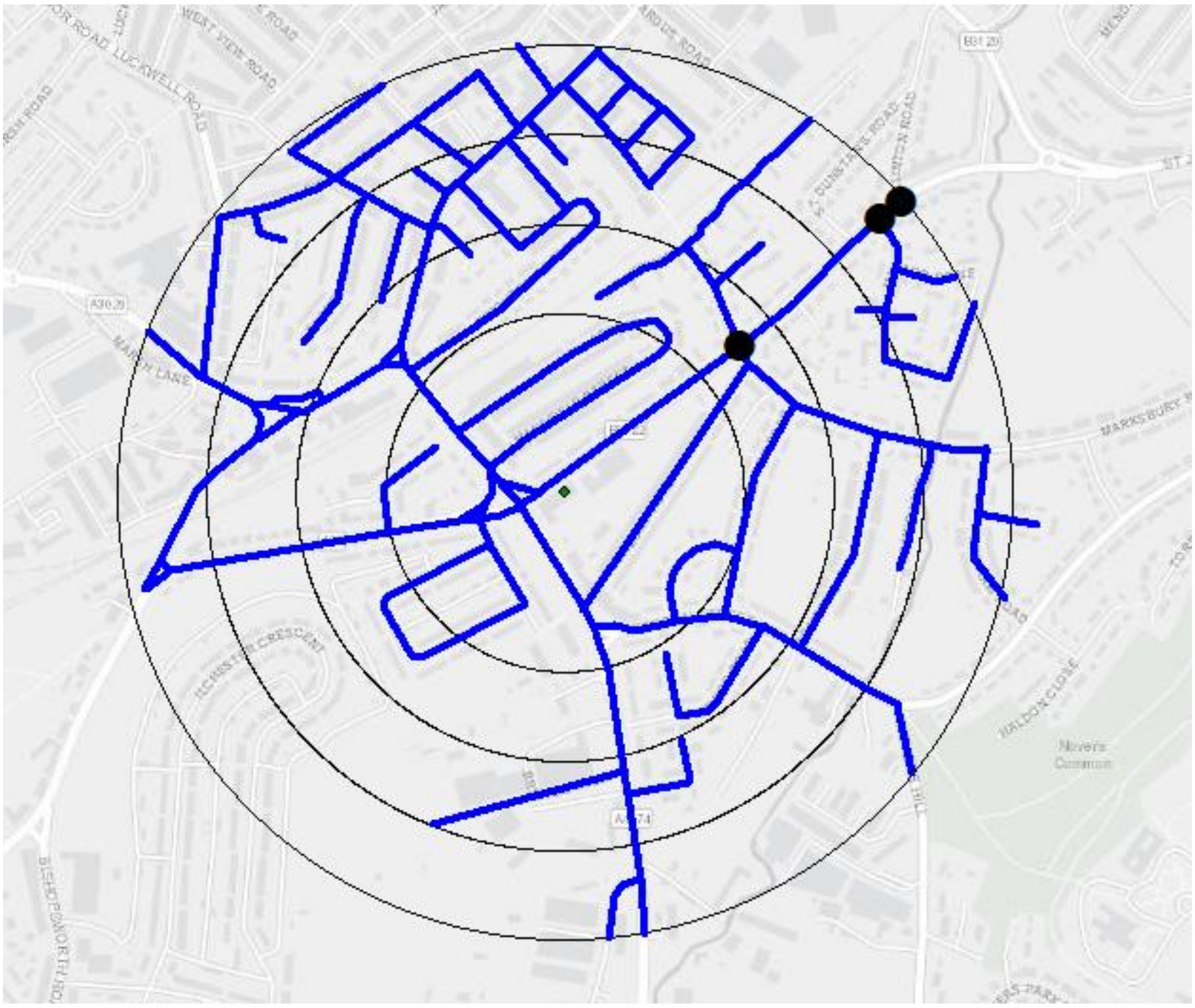


*Figure 202 Bristol Bedminster Active Travel Routes: Victoria Park.*

*Figure 203 Bristol Bedminster Active Travel Routes: Knowle West.*

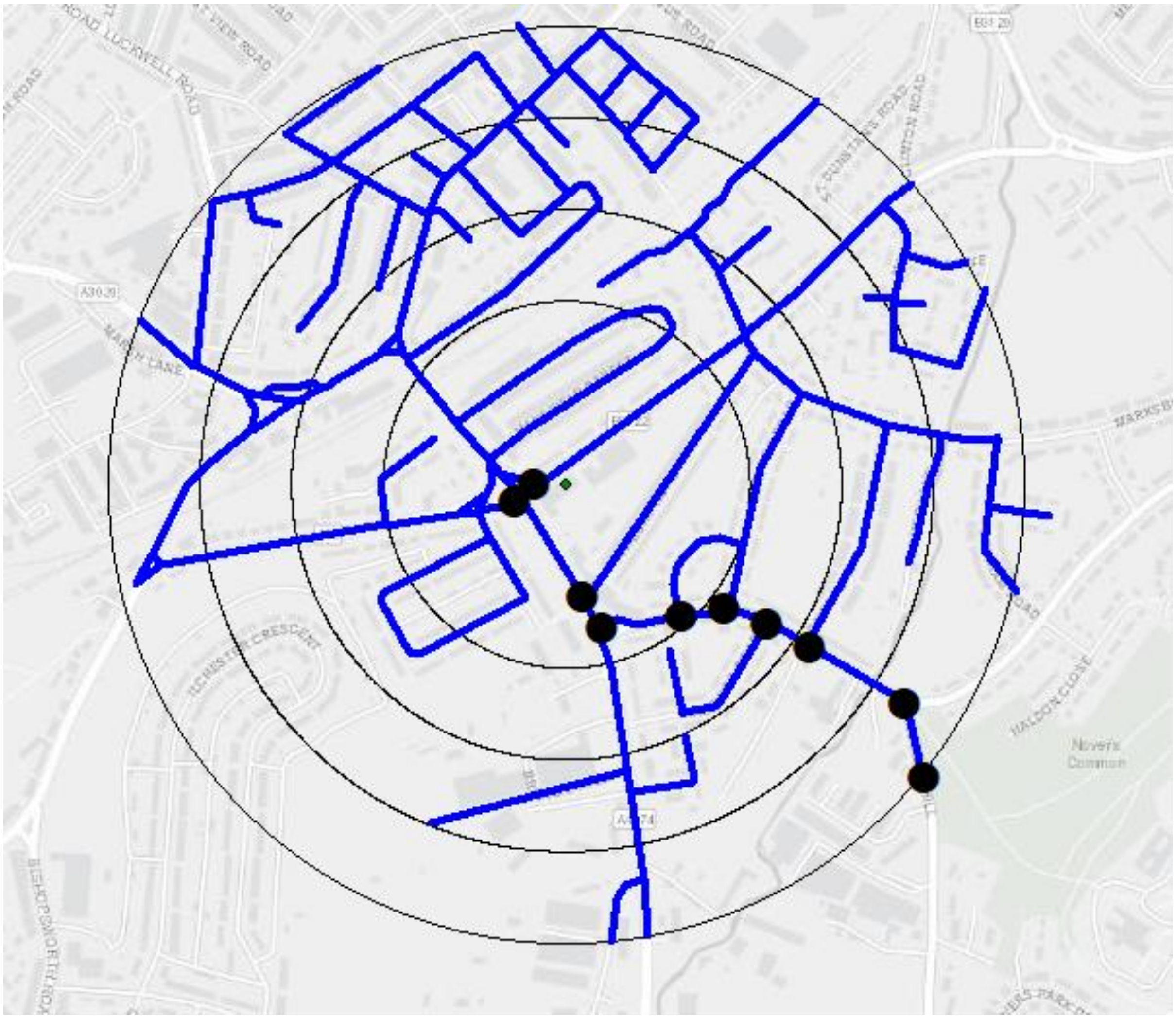


*Figure 204 Bristol Bedminster Active Travel Routes: Knowle West South.*

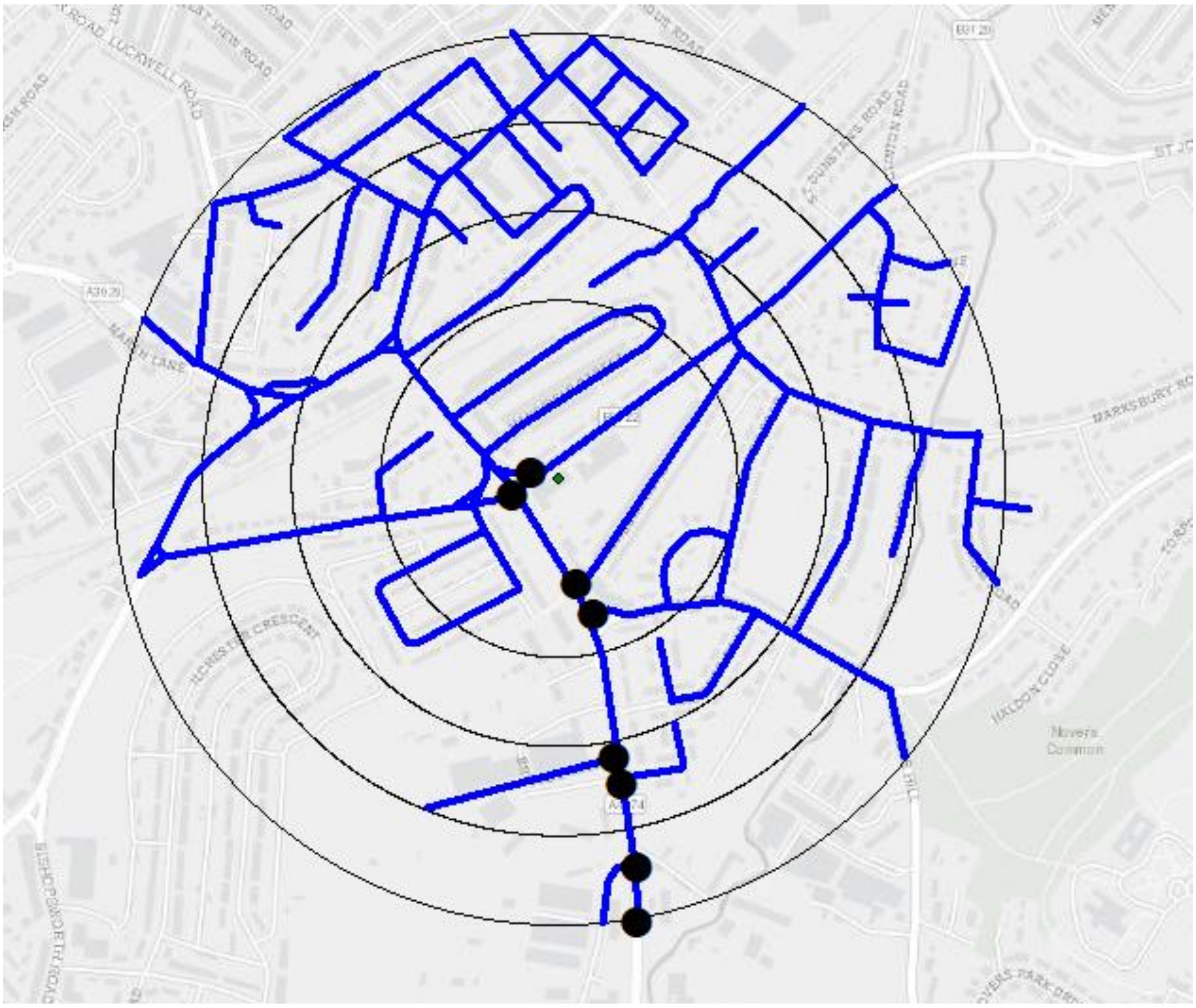


*Figure 205 Bristol Bedminster Active Travel Routes: Hartcliffe Way.*

*Figure 206 Bristol Bedminster Active Travel Routes: Bedminster Down.*

## vii. Bristol Bedminster: Improved Travel Routes

*Figure 207 Bristol Bedminster Improved Travel Routes: Ashton Gate.*

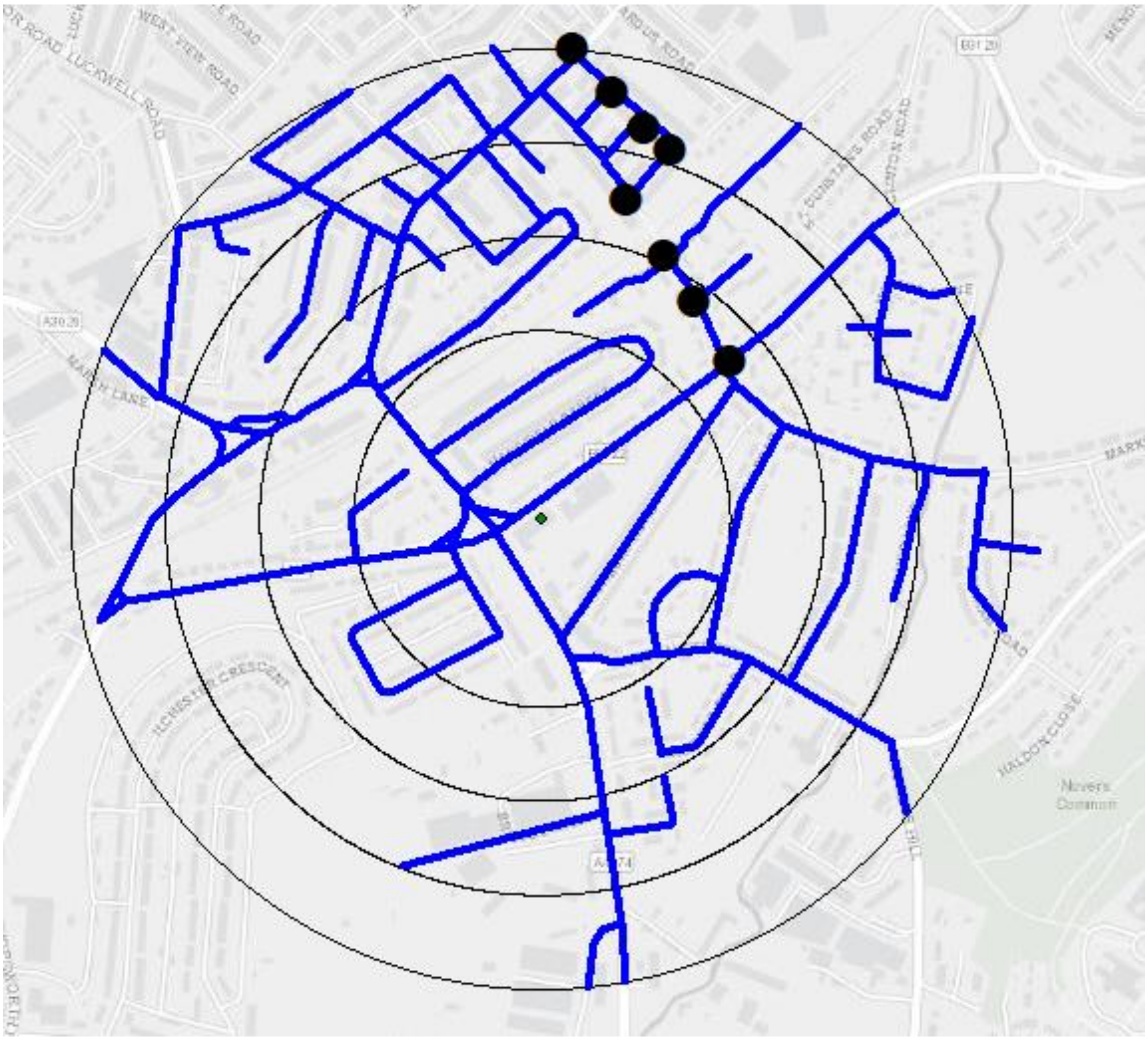


*Figure 208 Bristol Bedminster Improved Travel Routes: Bedminster.*

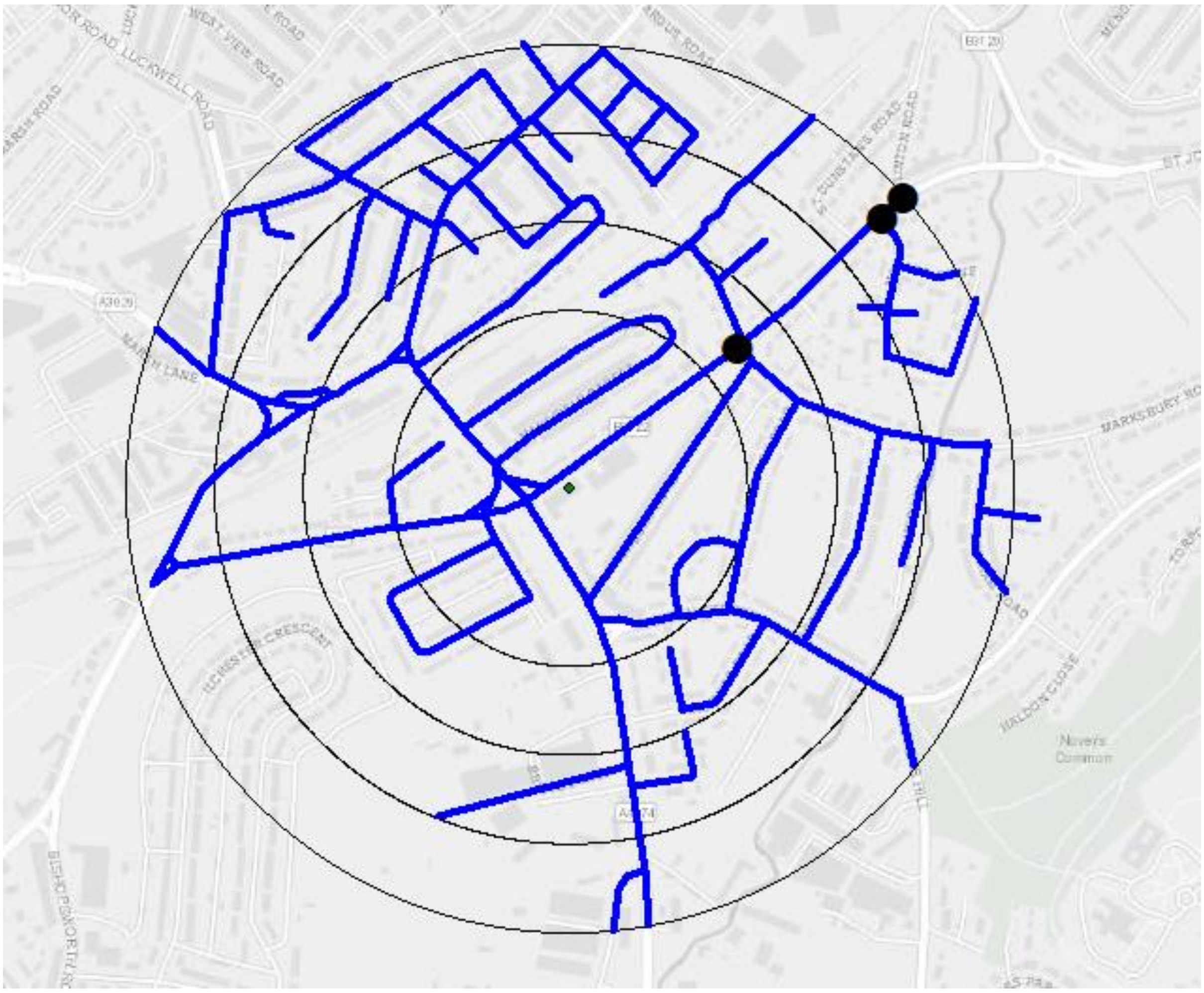


*Figure 209 Bristol Bedminster Improved Travel Routes: Victoria Park.*

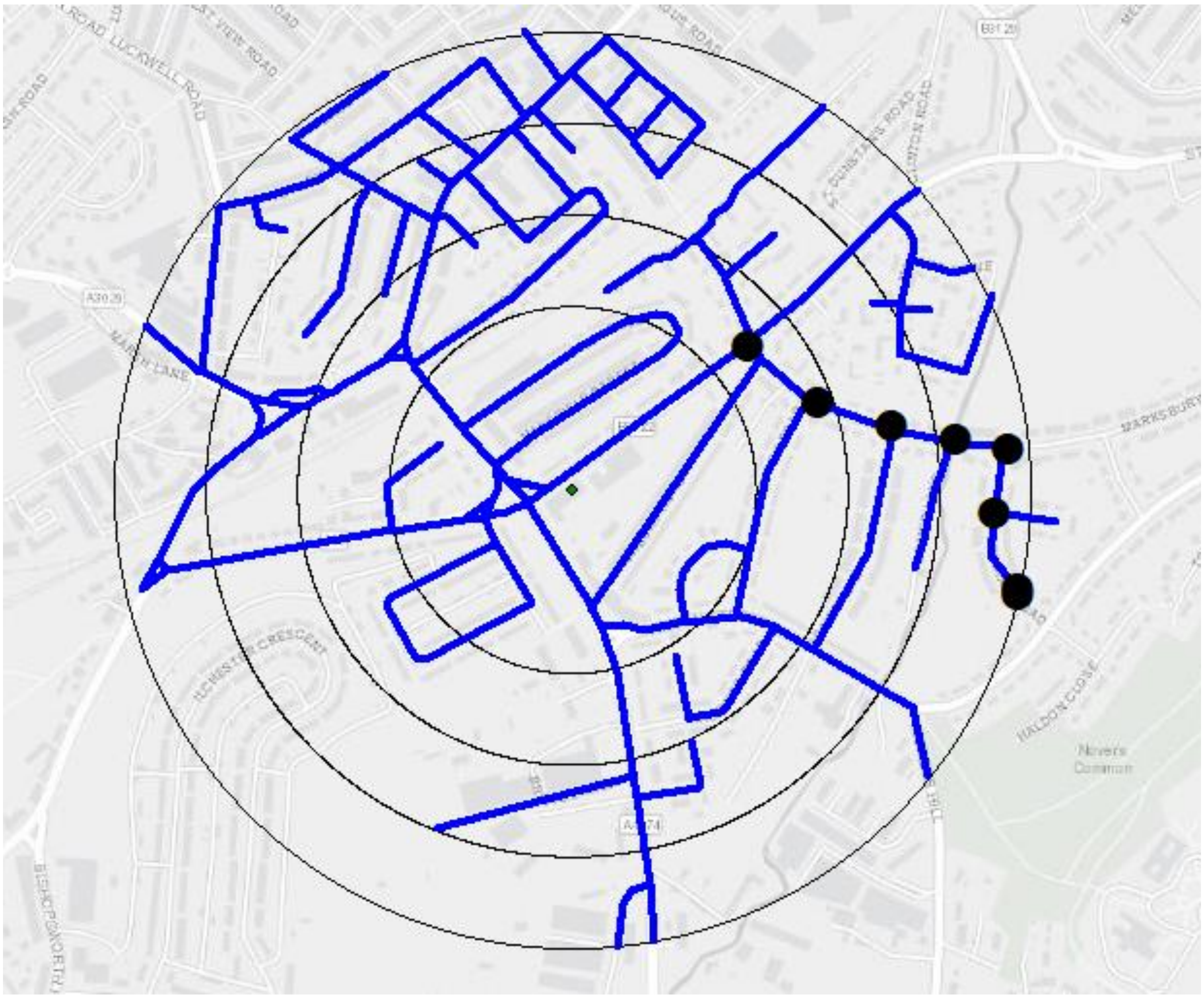


*Figure 210 Bristol Bedminster Improved Travel Routes: Knowle West.*

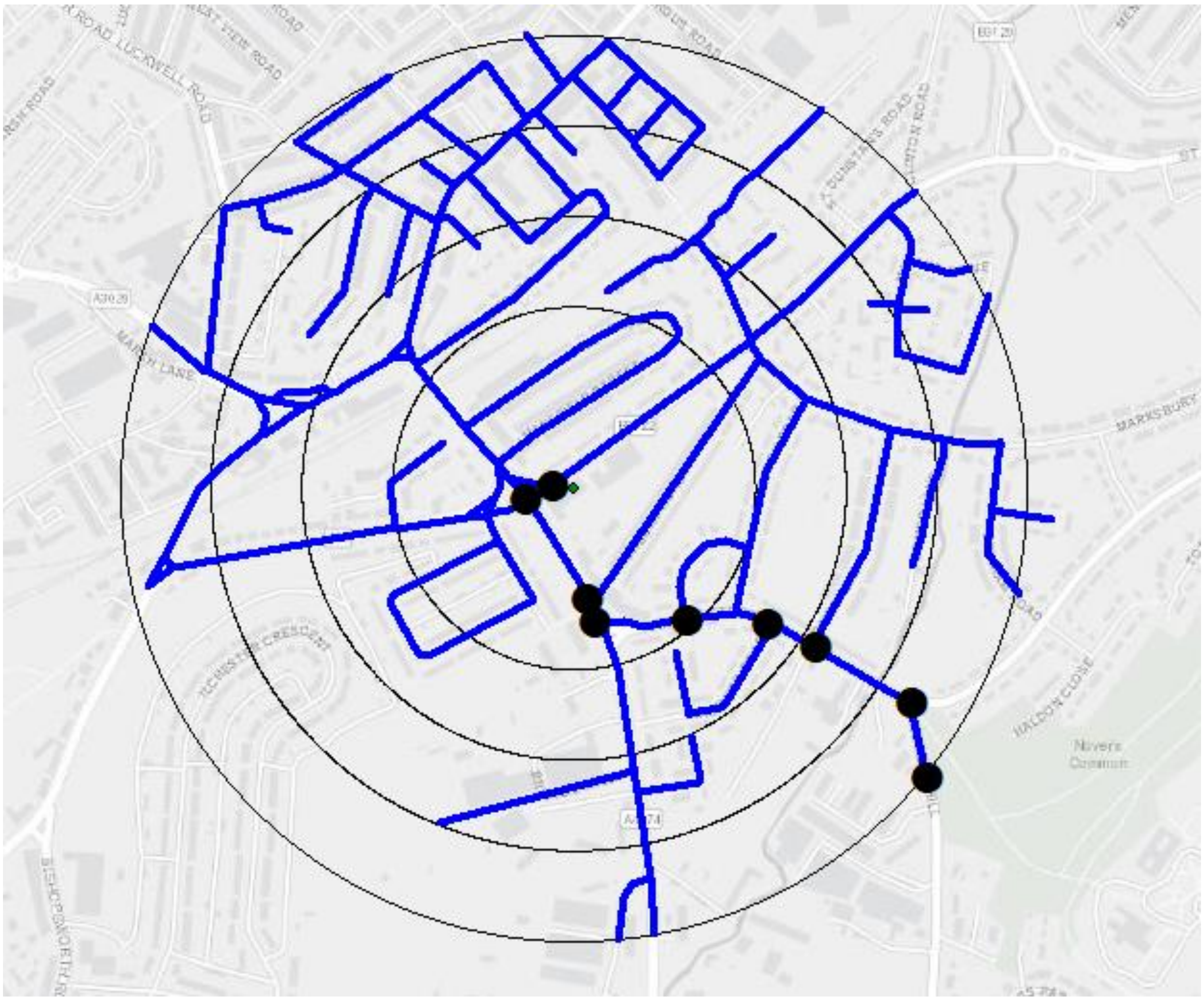


*Figure 211 Bristol Bedminster Improved Travel Routes: Knowle West South.*

*Figure 212 Bristol Bedminster Improved Travel Routes: Hartcliffe Way.*

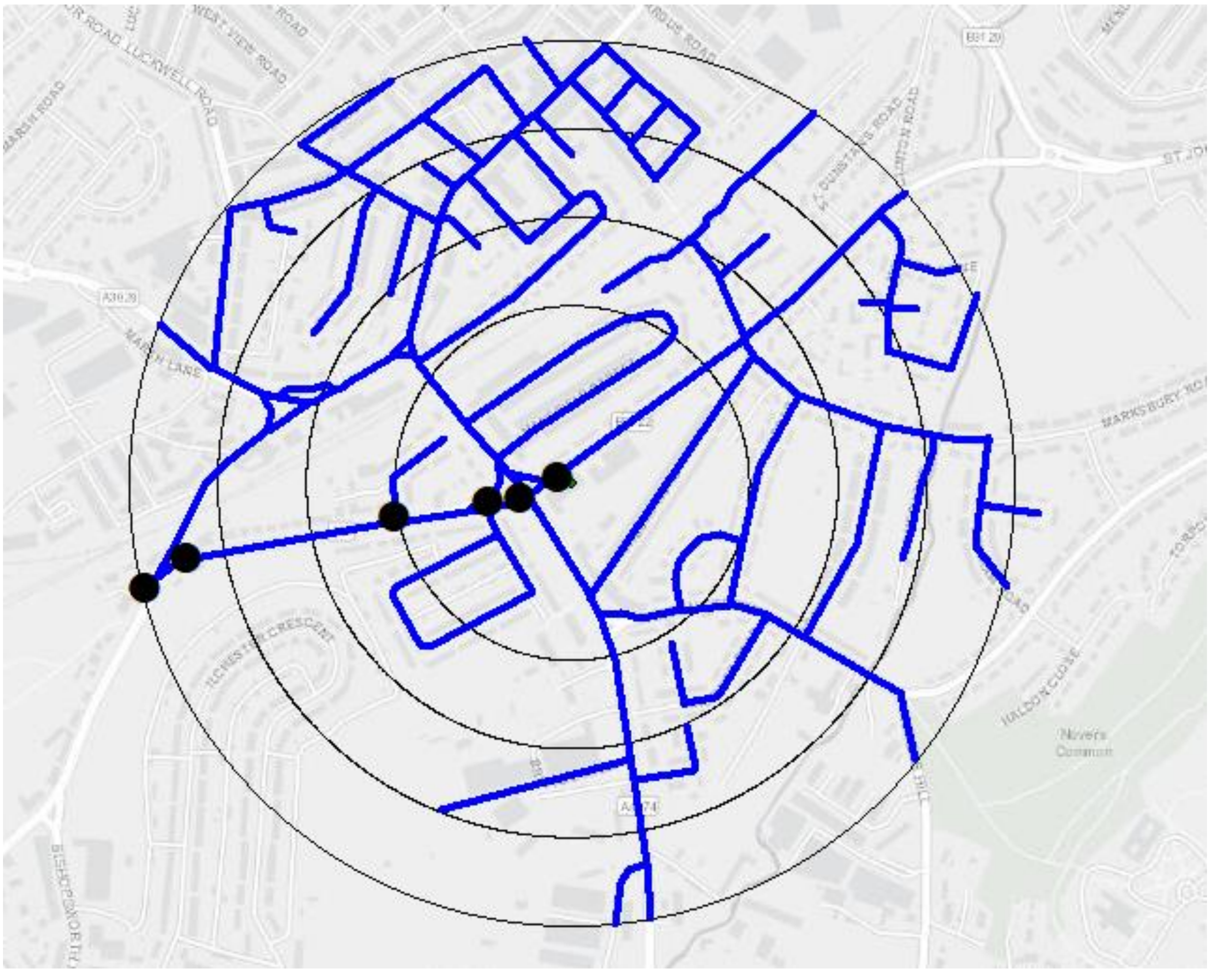


*Figure 213 Bristol Bedminster Improved Travel Routes: Bedminster Down.*

## viii. Coventry Binley: Receptors & Links

*Figure 214 Coventry Receptors & Links*

## ix. Coventry Binley: Active Travel Routes

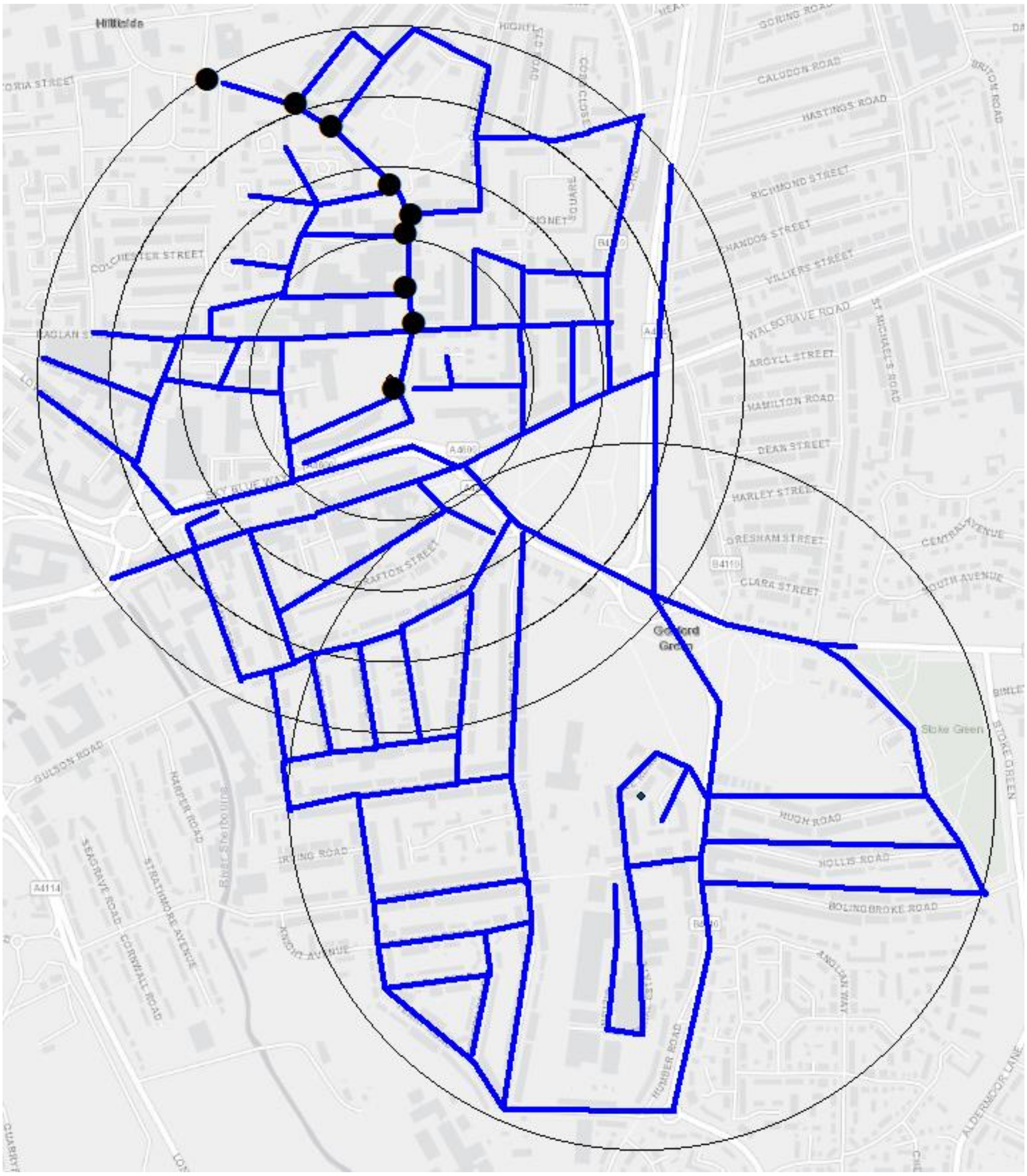


*Figure 215 Coventry Active Travel Routes: Bishopsgate Green.*

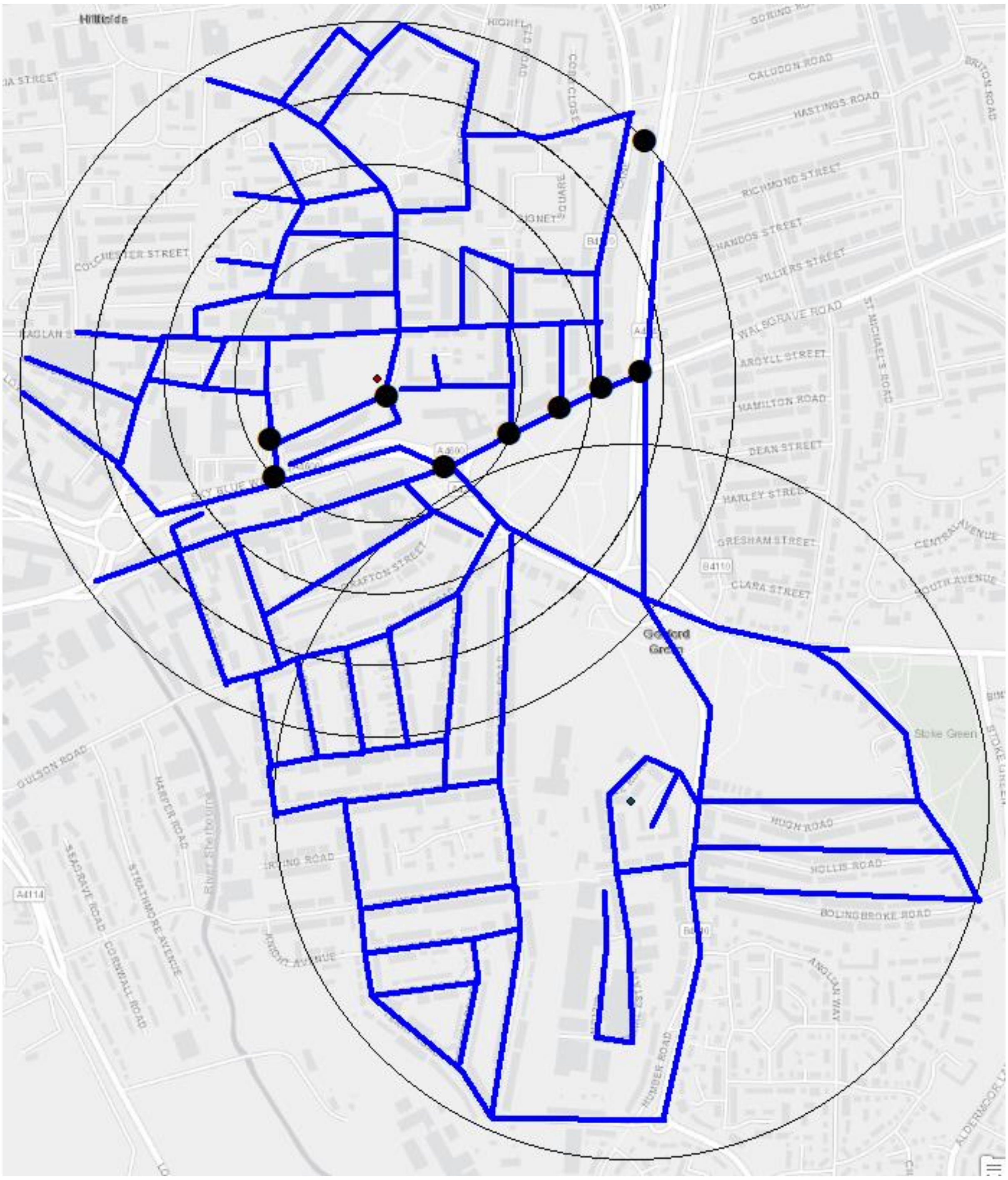


*Figure 216 Coventry Active Travel Routes: Baras Heath.*

*Figure 217 Coventry Active Travel Routes: Gosford Park.*

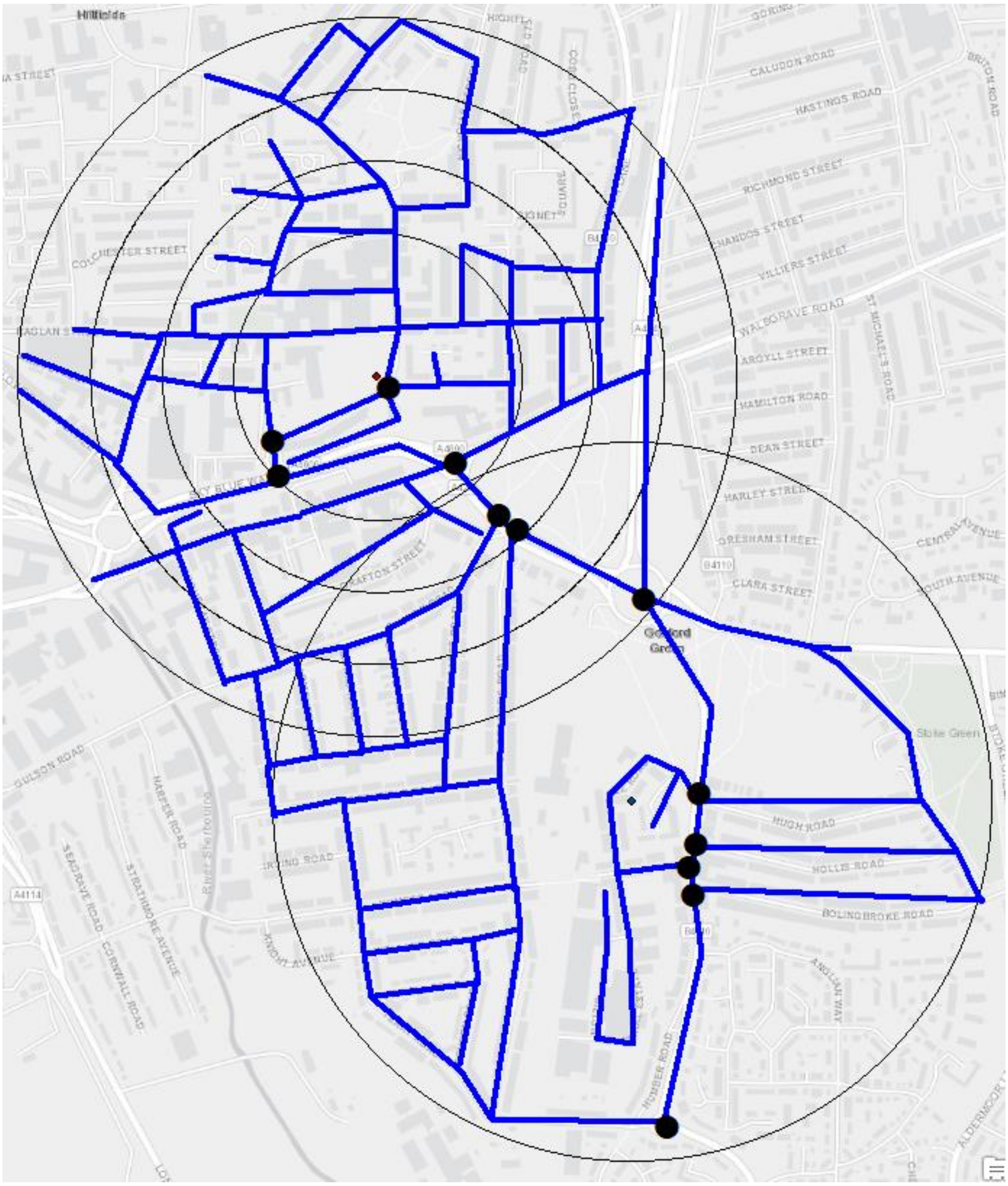


*Figure 218 Coventry Active Travel Routes: Stoke Aldermoor.*

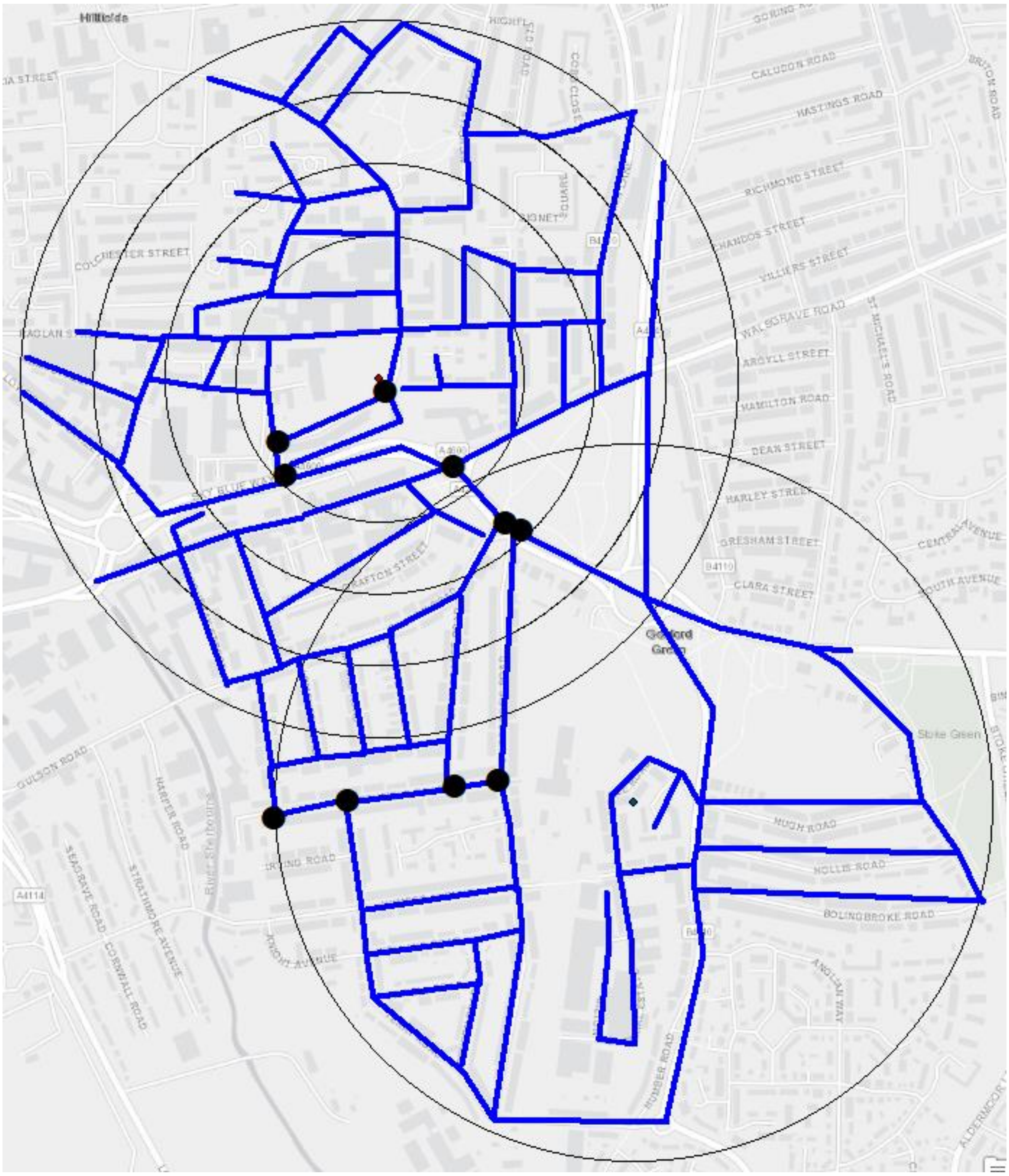


*Figure 219 Coventry Active Travel Routes: Charterhouse Park.*

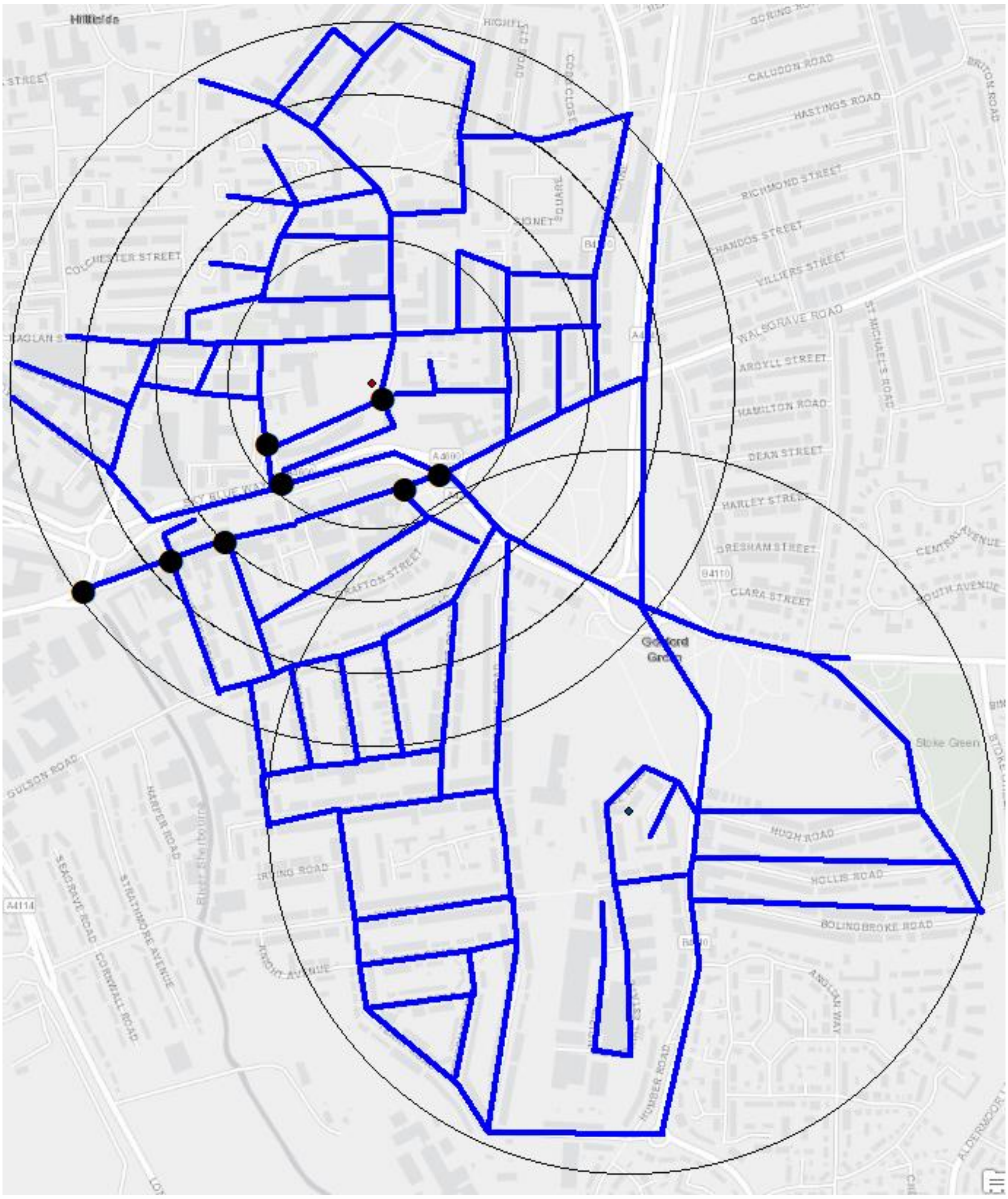


*Figure 220 Coventry Active Travel Routes: Callice Court.*

## x. Coventry Binley: Improved Travel Routes

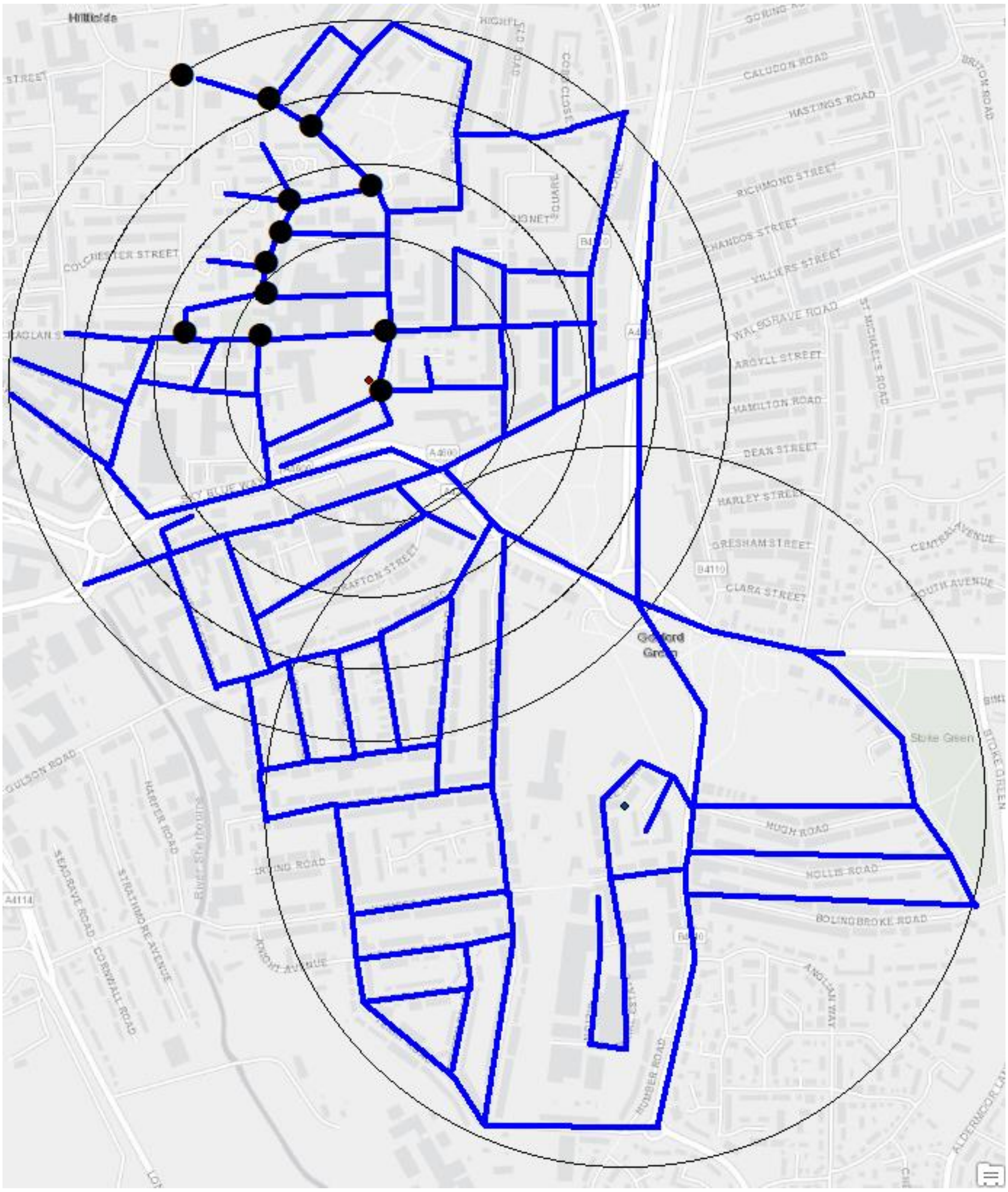


*Figure 221 Coventry Improved Travel Routes: Bishopsgate Green.*

*Figure 222 Coventry Improved Travel Routes: Baras Heath.*

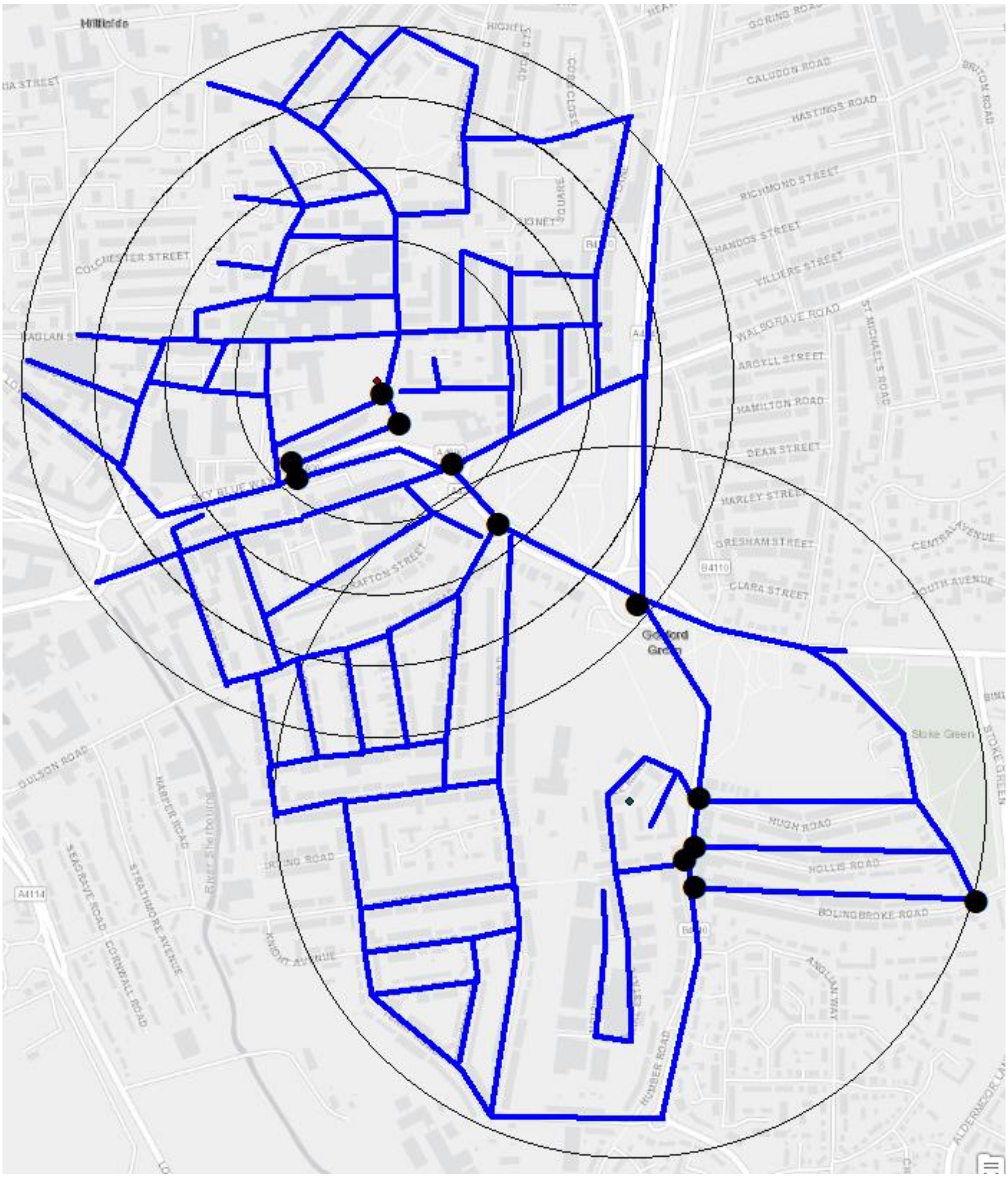


Figure 223 Coventry Improved Travel Routes: Gosford Park.

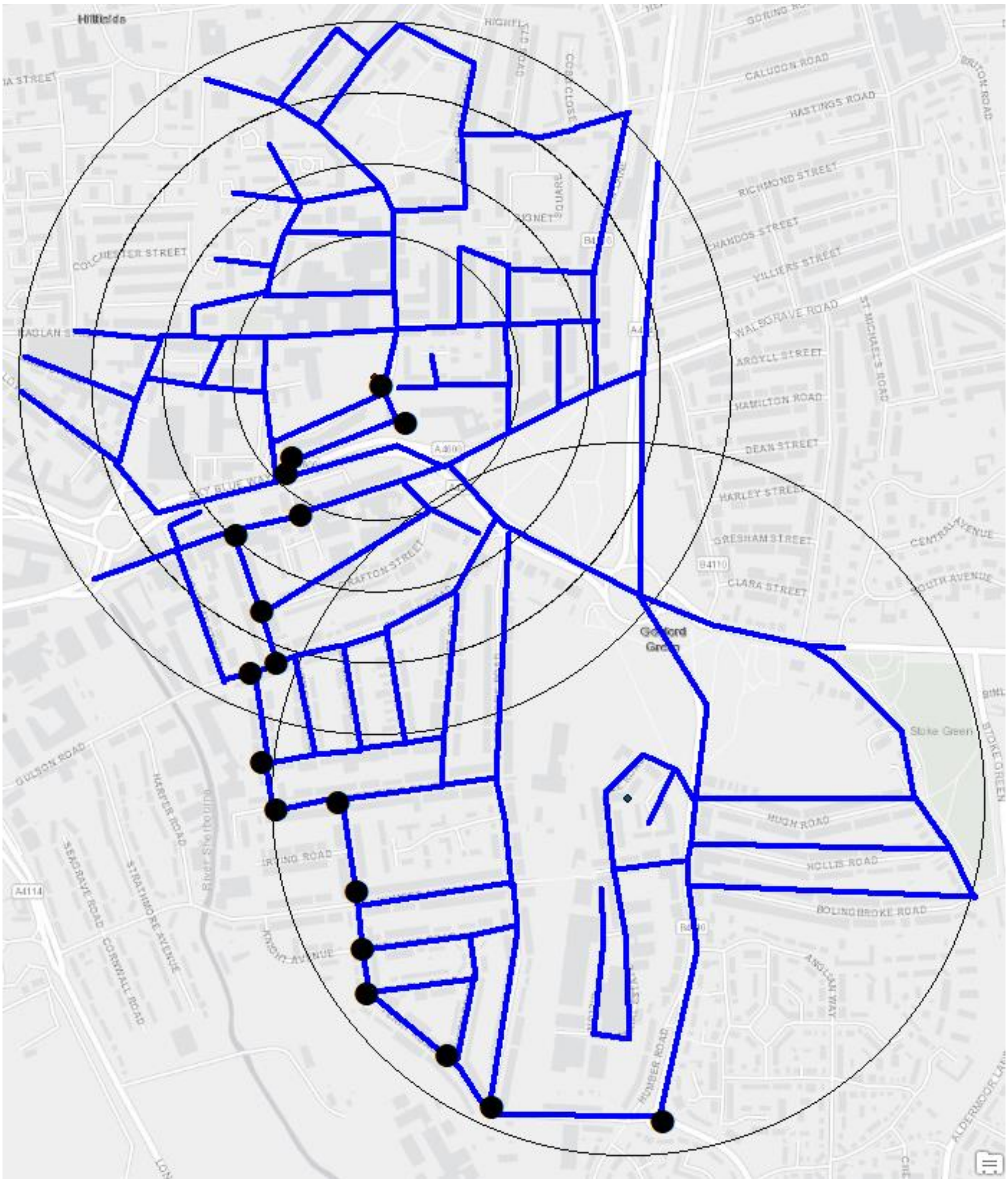


*Figure 224 Coventry Improved Travel Routes: Stoke Aldermoor.*

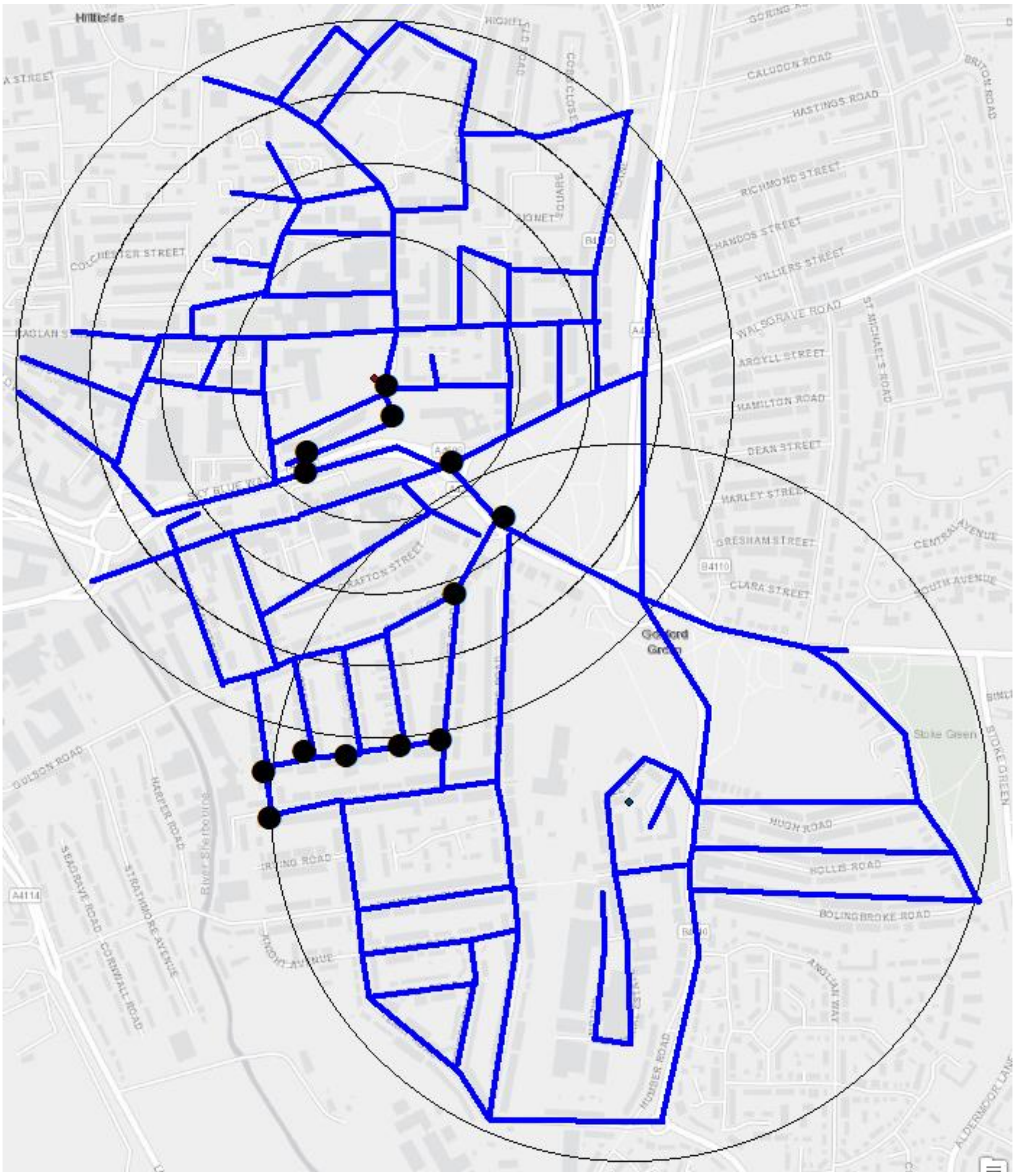


*Figure 225 Coventry Improved Travel Routes: Charterhouse Park.*

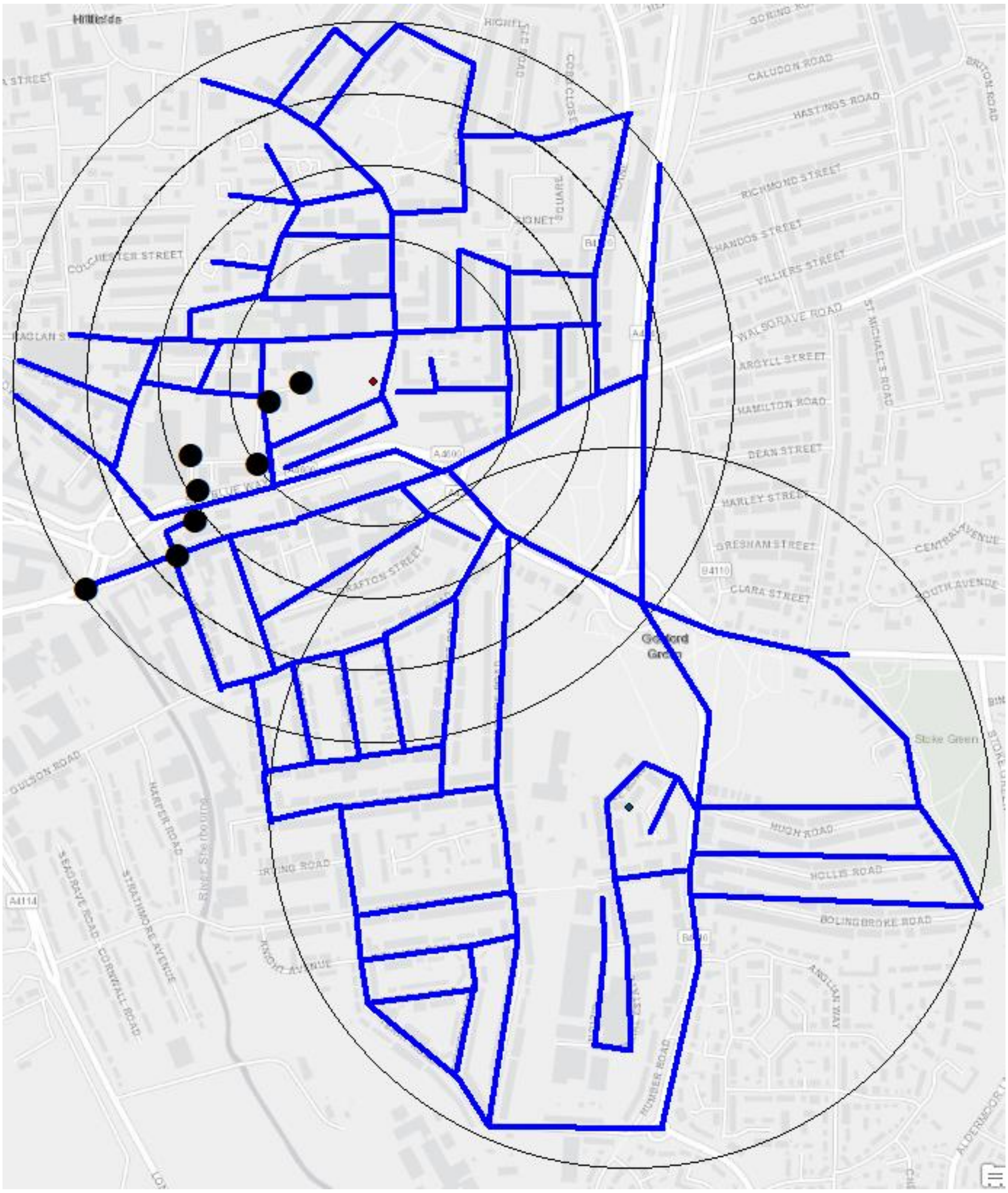


*Figure 226 Coventry Improved Travel Routes: Callice Court.*

## xi. Oxford St Ebbe's: Receptors & Links

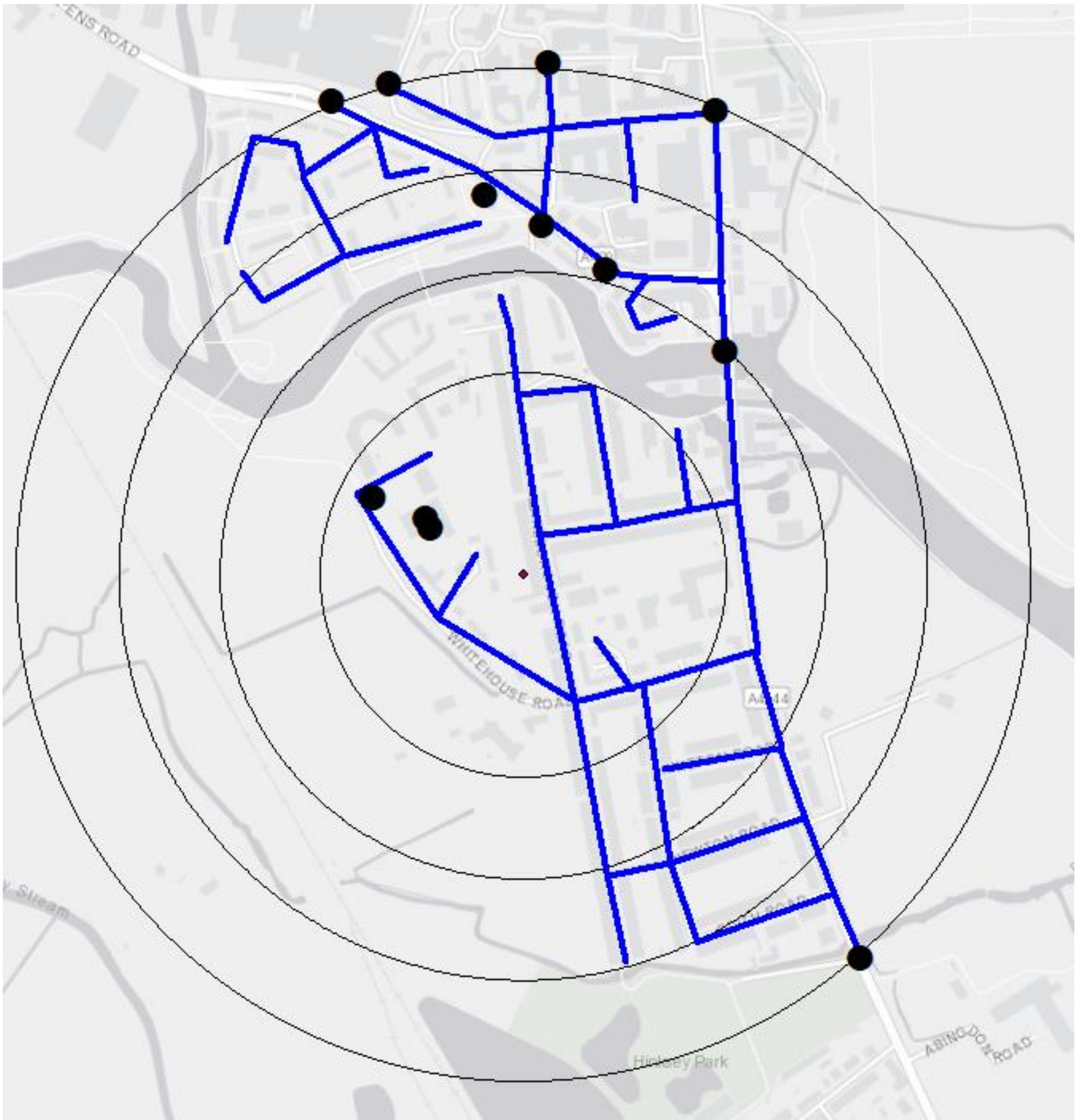


*Figure 227 Oxford Receptors & Links.*

## xii. Oxford St Ebbe’s: Active Travel Routes

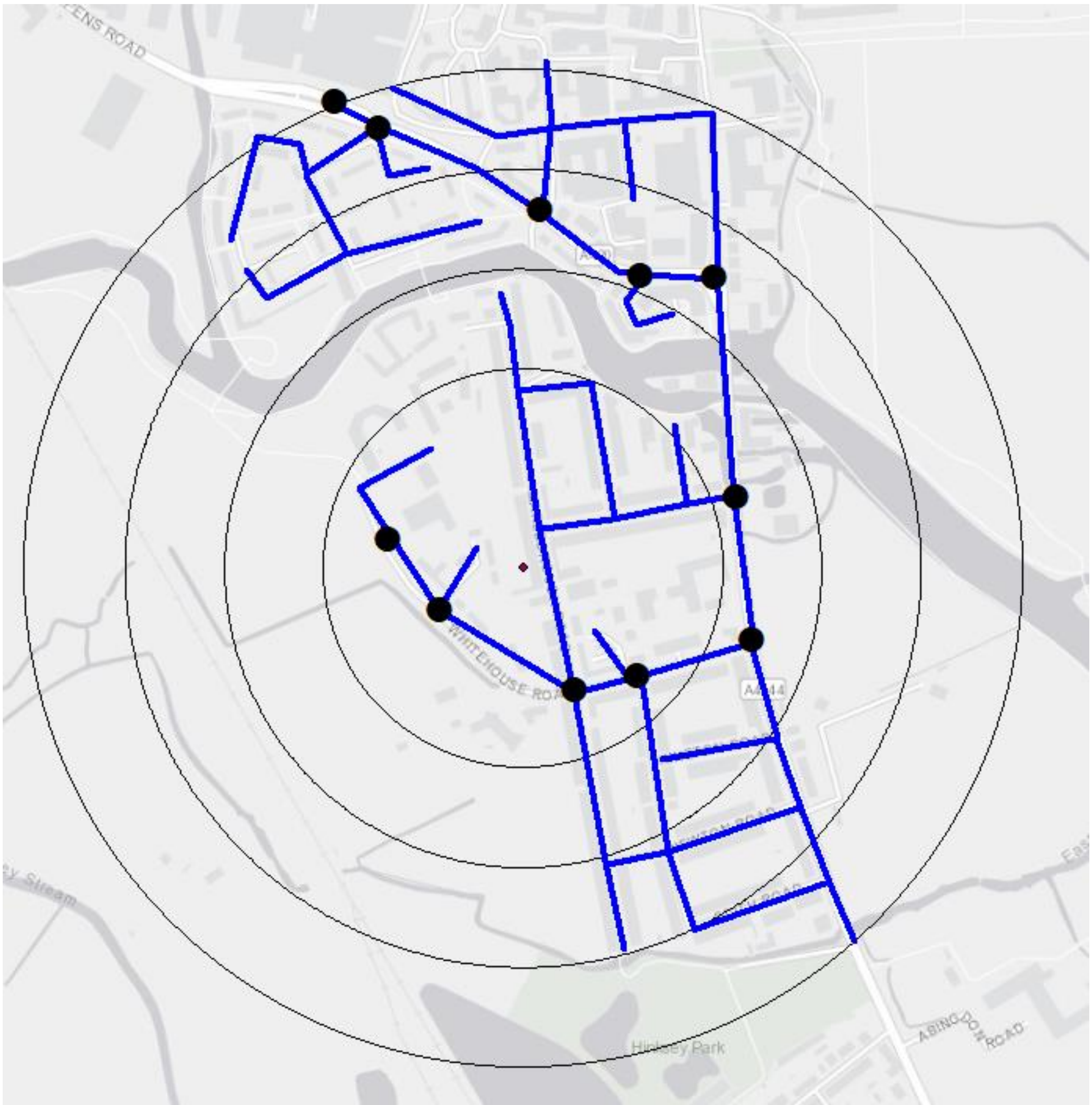


*Figure 228 Oxford Active Travel Routes: Westgate.*

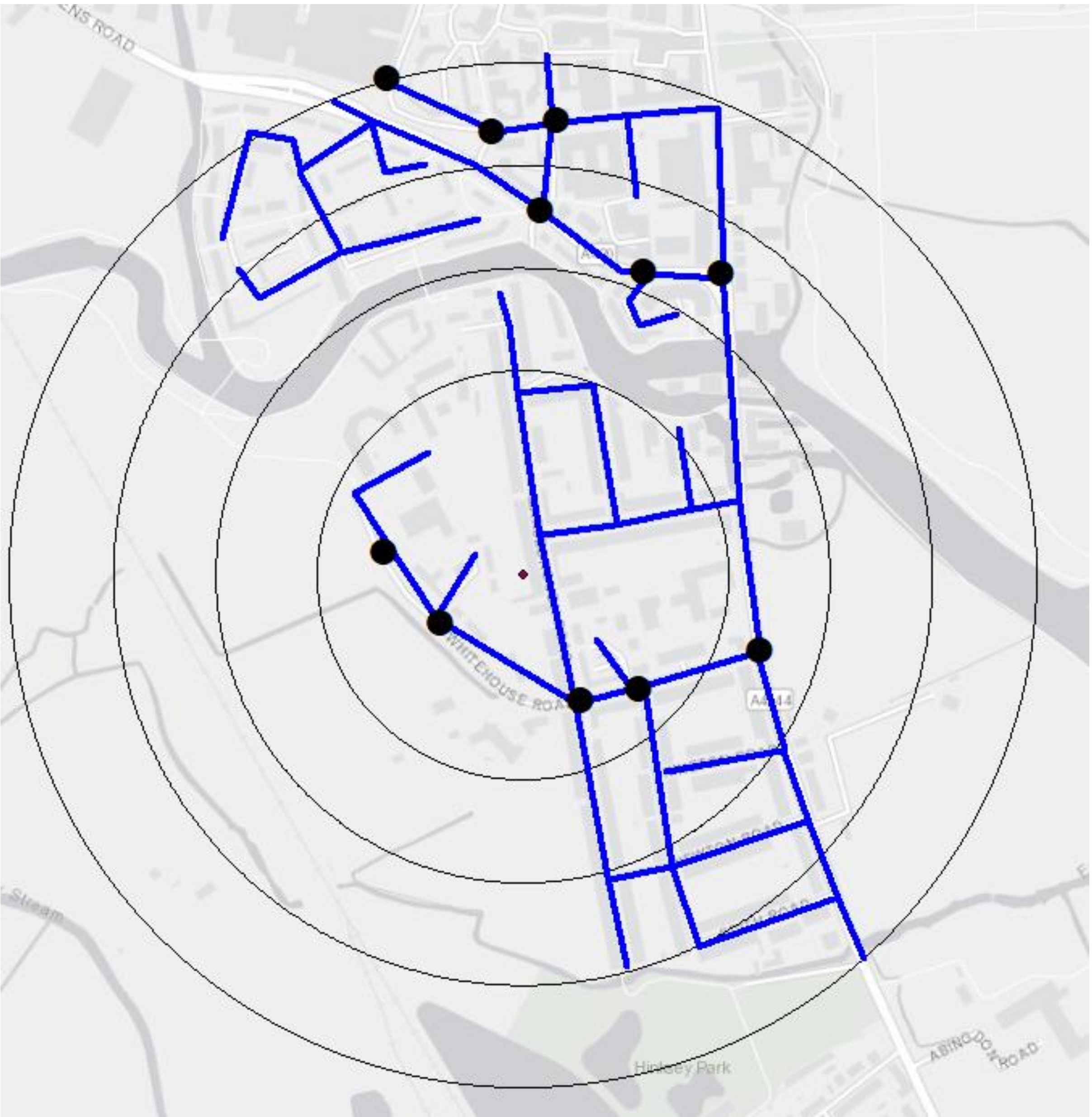


*Figure 229 Oxford Active Travel Routes: Gloucester Green.*

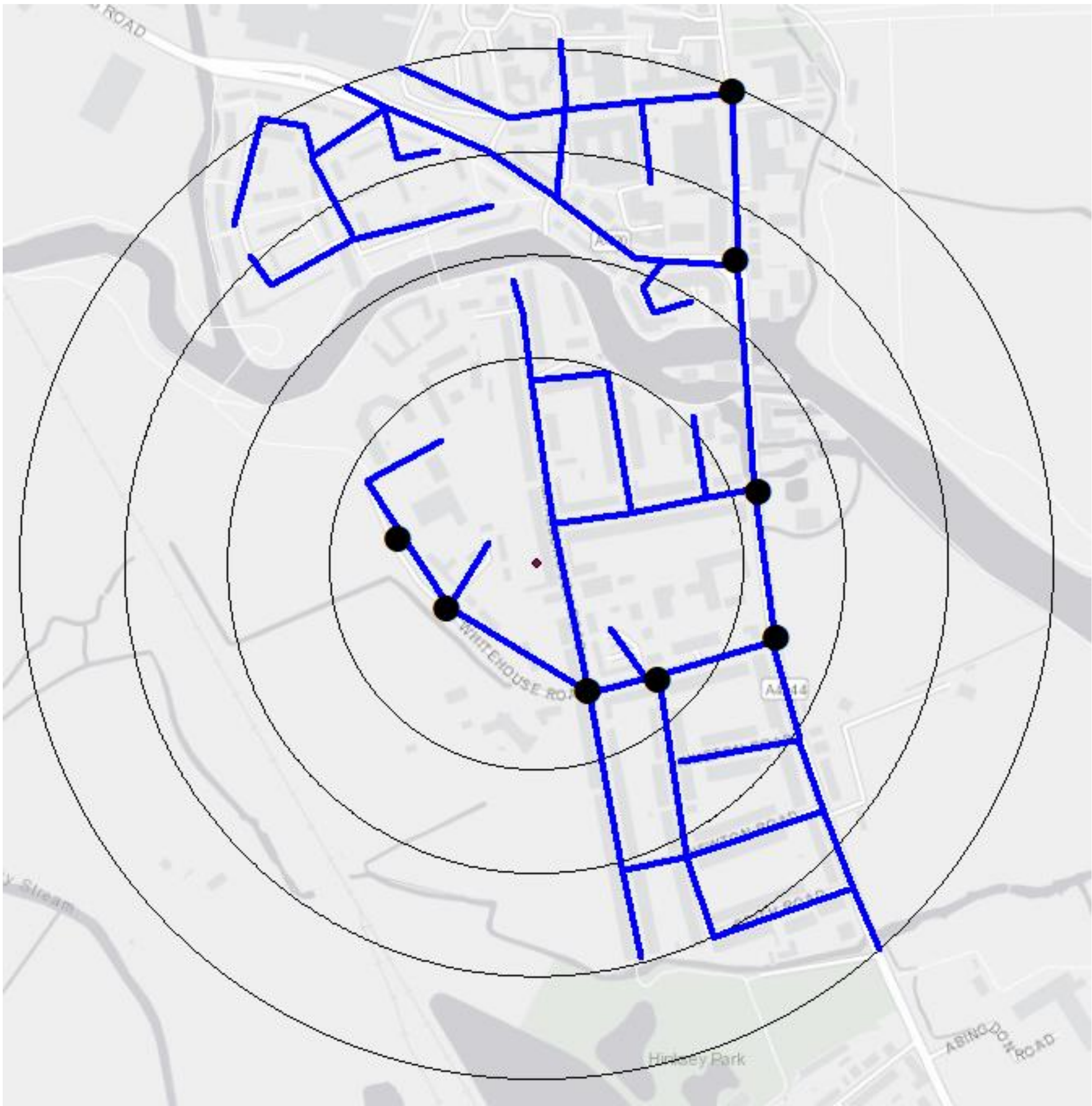


*Figure 230 Oxford Active Travel Routes: Christ Church.*

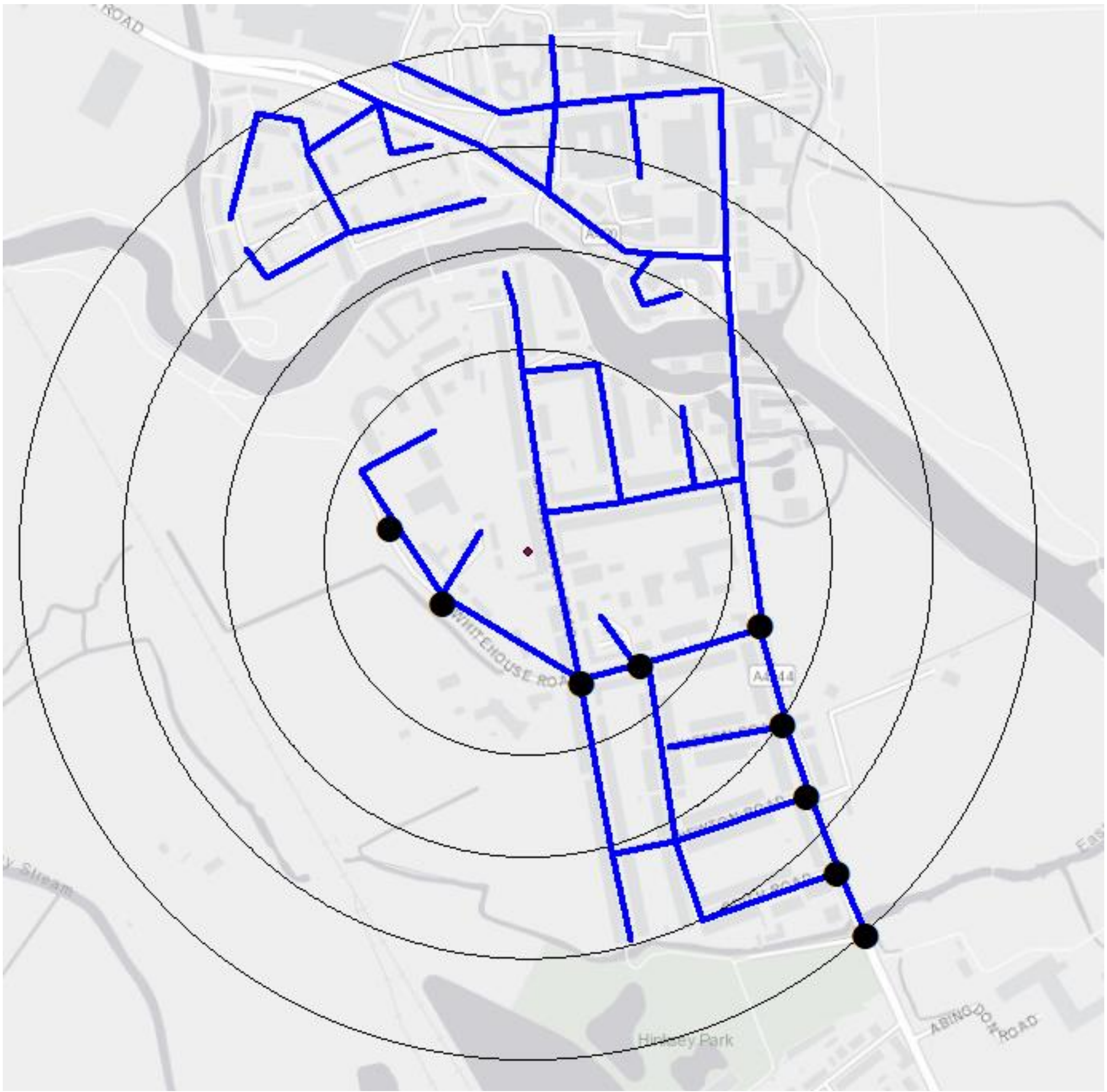


*Figure 231 Oxford Active Travel Routes:Hinksey*

## xiii. Oxford St Ebbe’s: Improved Travel Routes

*Figure 232 Oxford Improved Travel Routes: Westgate.*

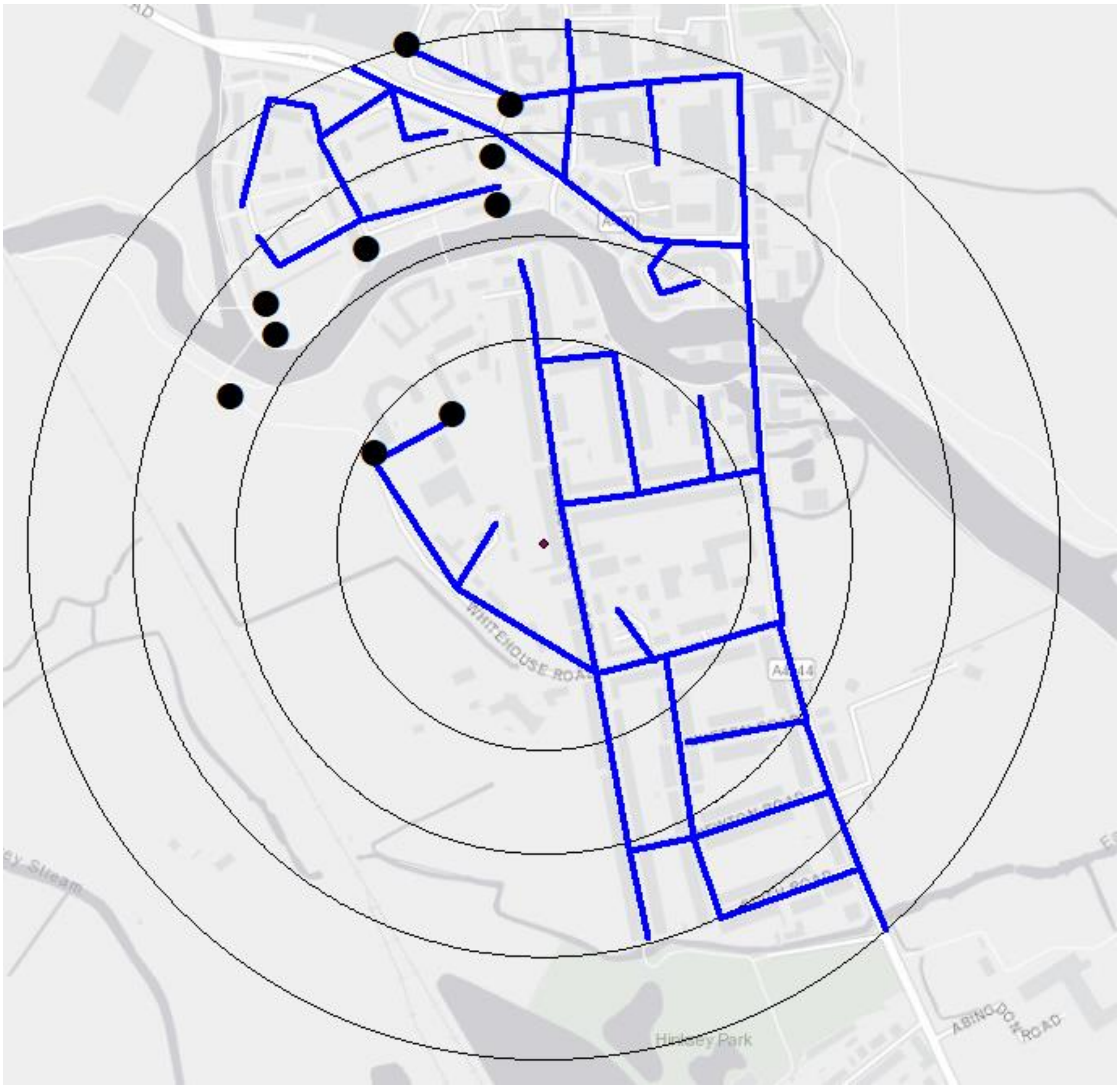


*Figure 233 Oxford Improved Travel Routes: Gloucester Green.*

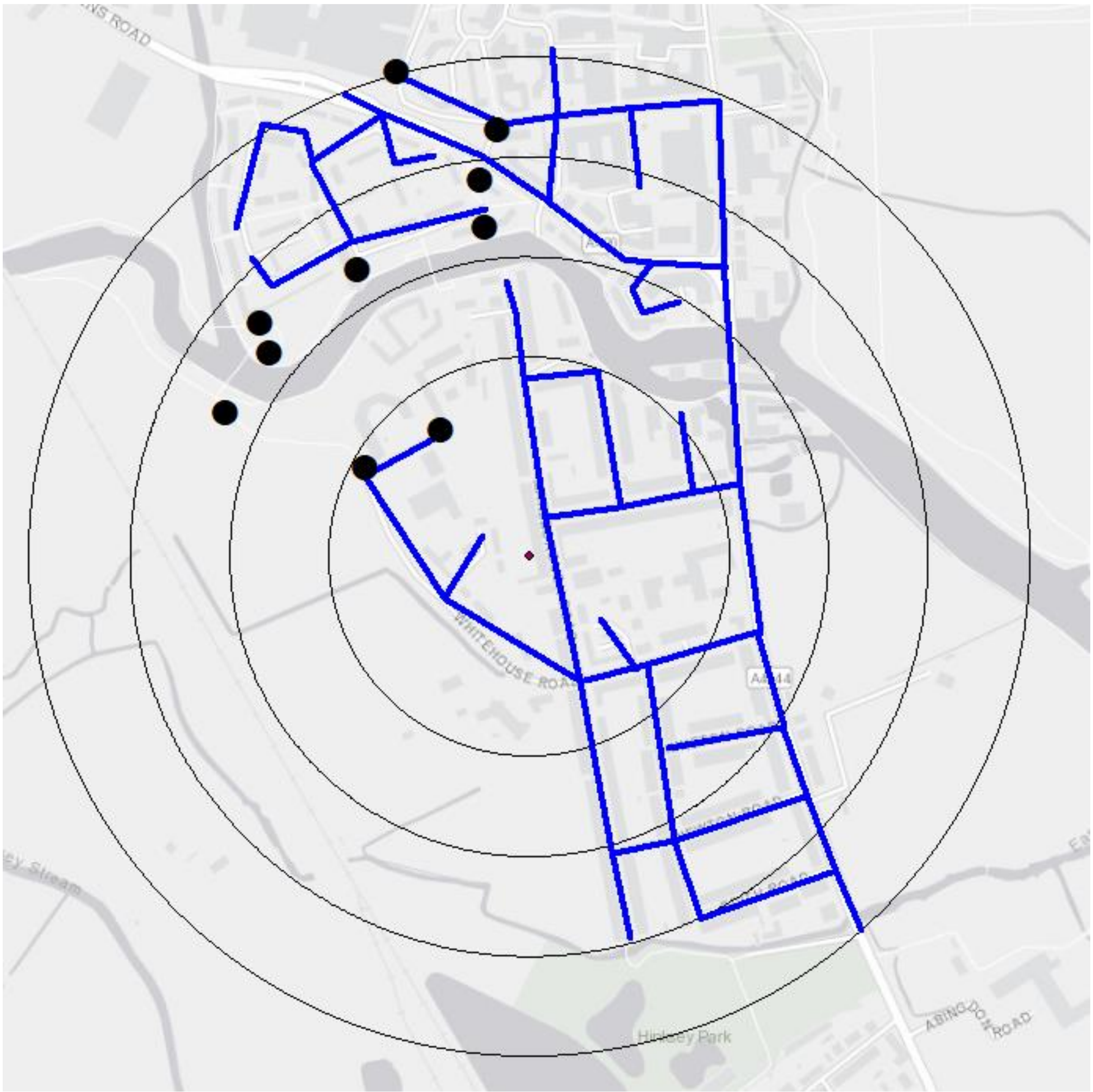


*Figure 234 Oxford Improved Travel Routes: Christ Church.*

*Figure 235 Oxford Improved Travel Routes: Hinksey.*

### xiv. Sheffield Tinsley: Receptors & Links

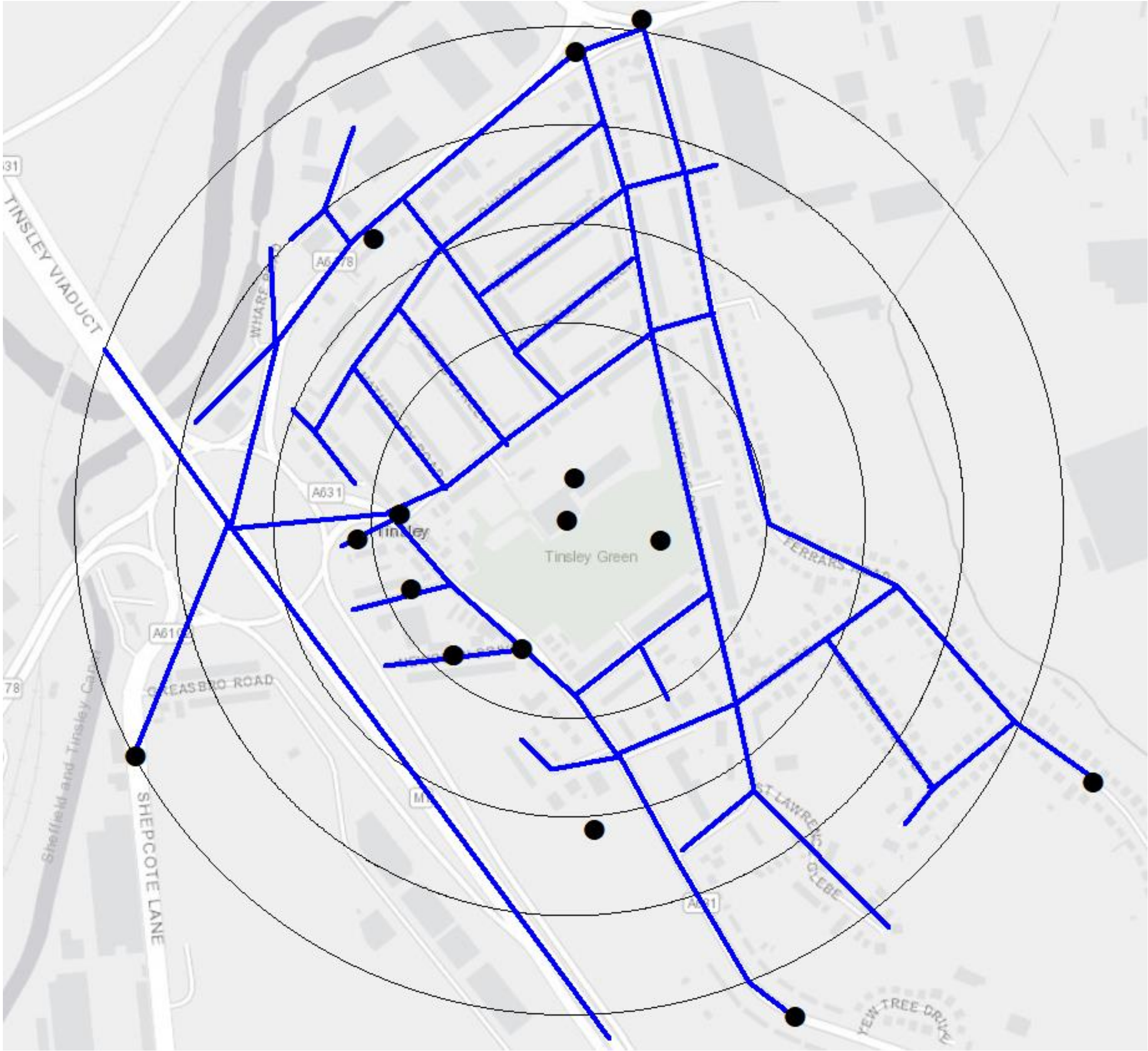


*Figure 236 Sheffield Receptors & Links.*

## xv. Sheffield Tinsley: Active Travel Routes

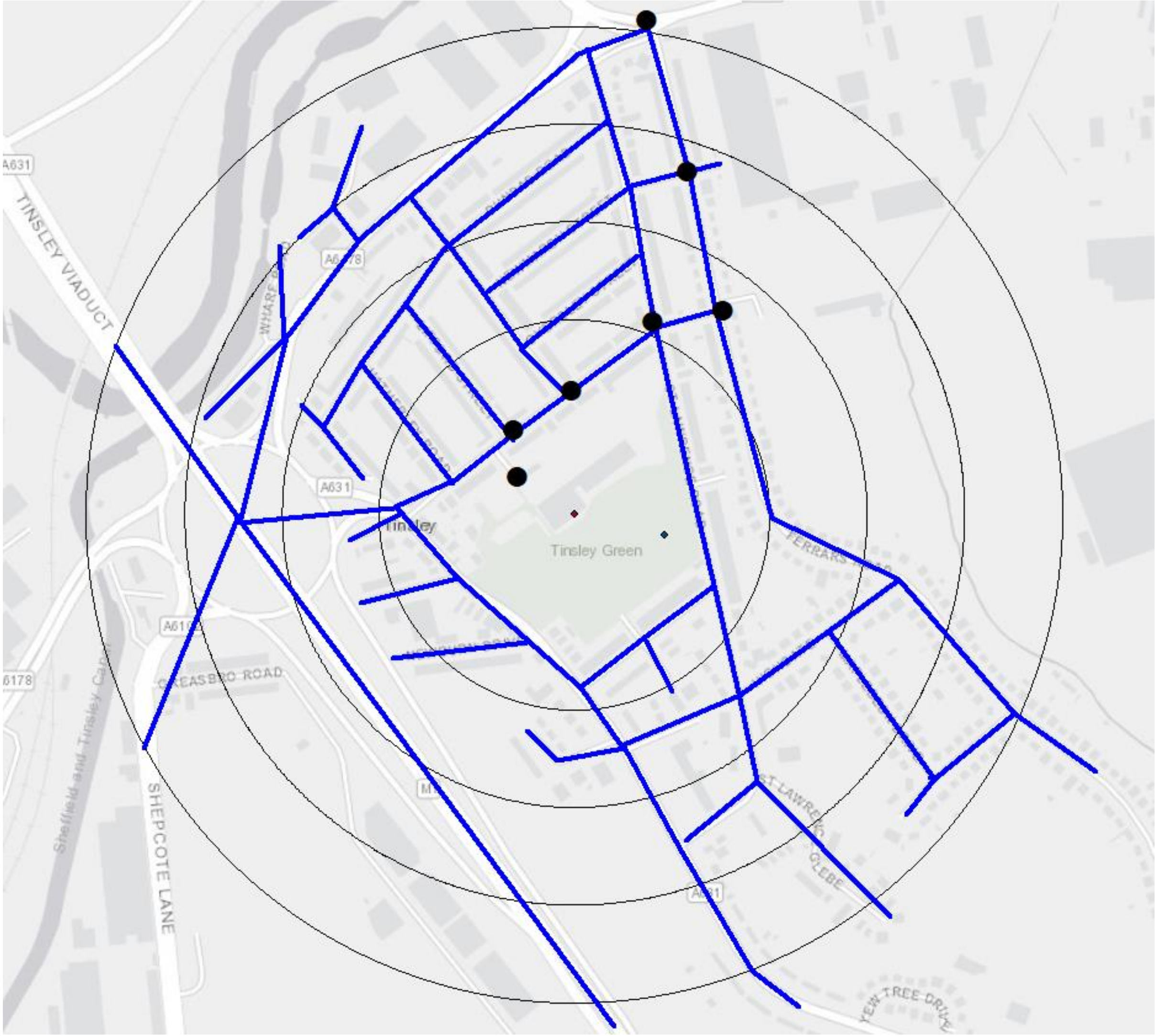


*Figure 237 Sheffield Active Travel Routes Blackburn Meadows.*

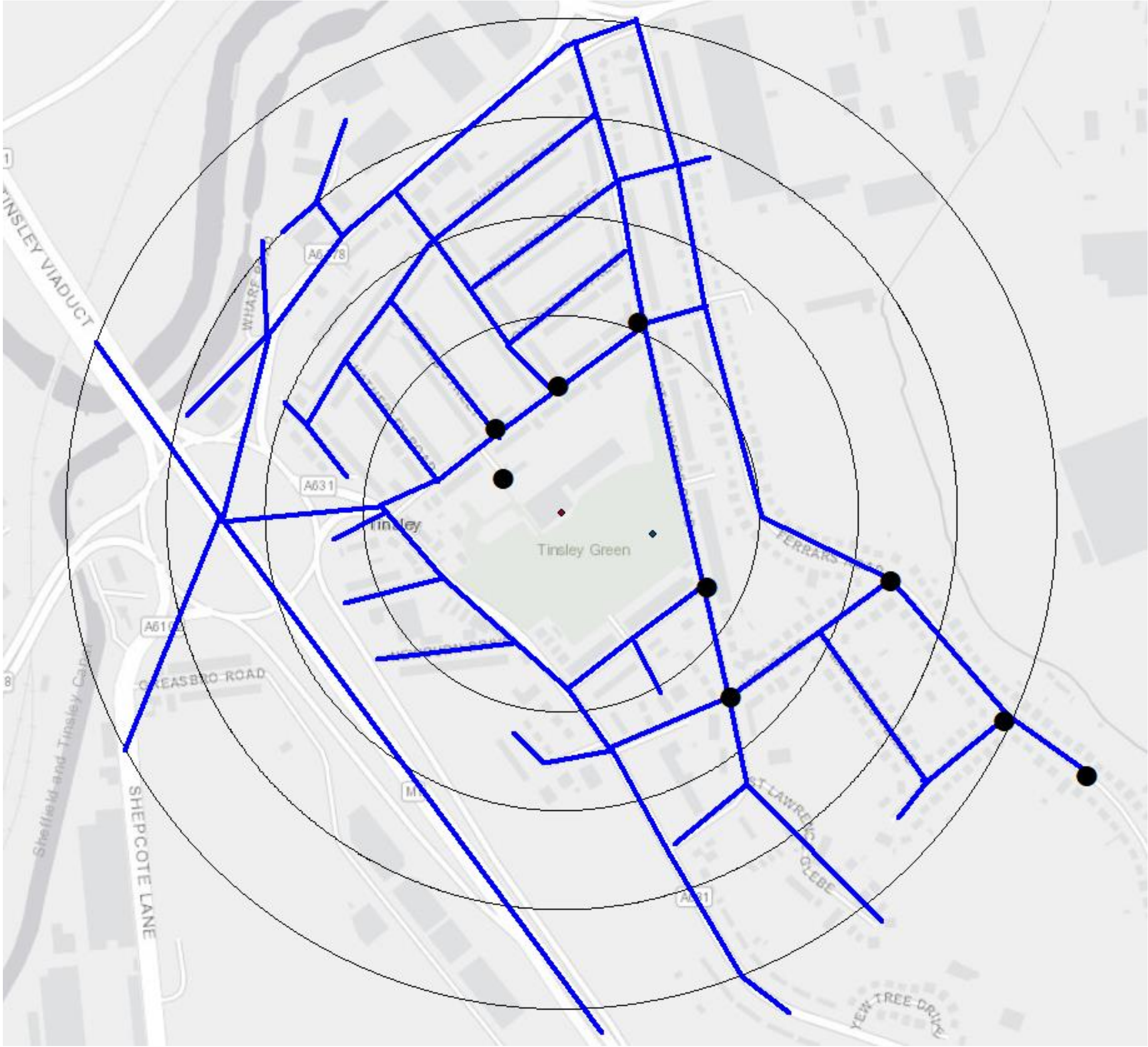


*Figure 238 Sheffield Active Travel Routes: Brinsworth.*

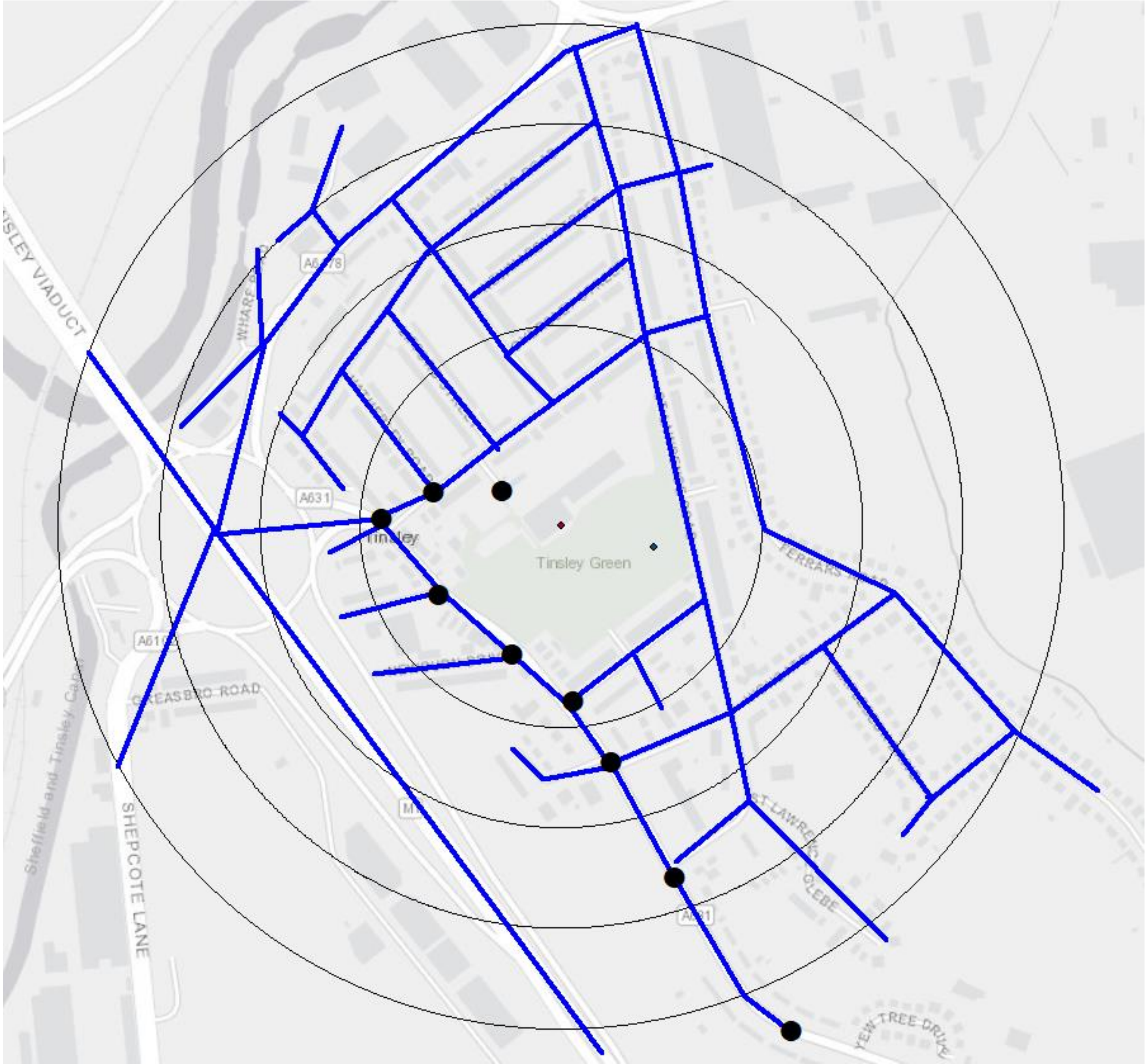


*Figure 239 Sheffield Active Travel Routes: Catcliffe.*

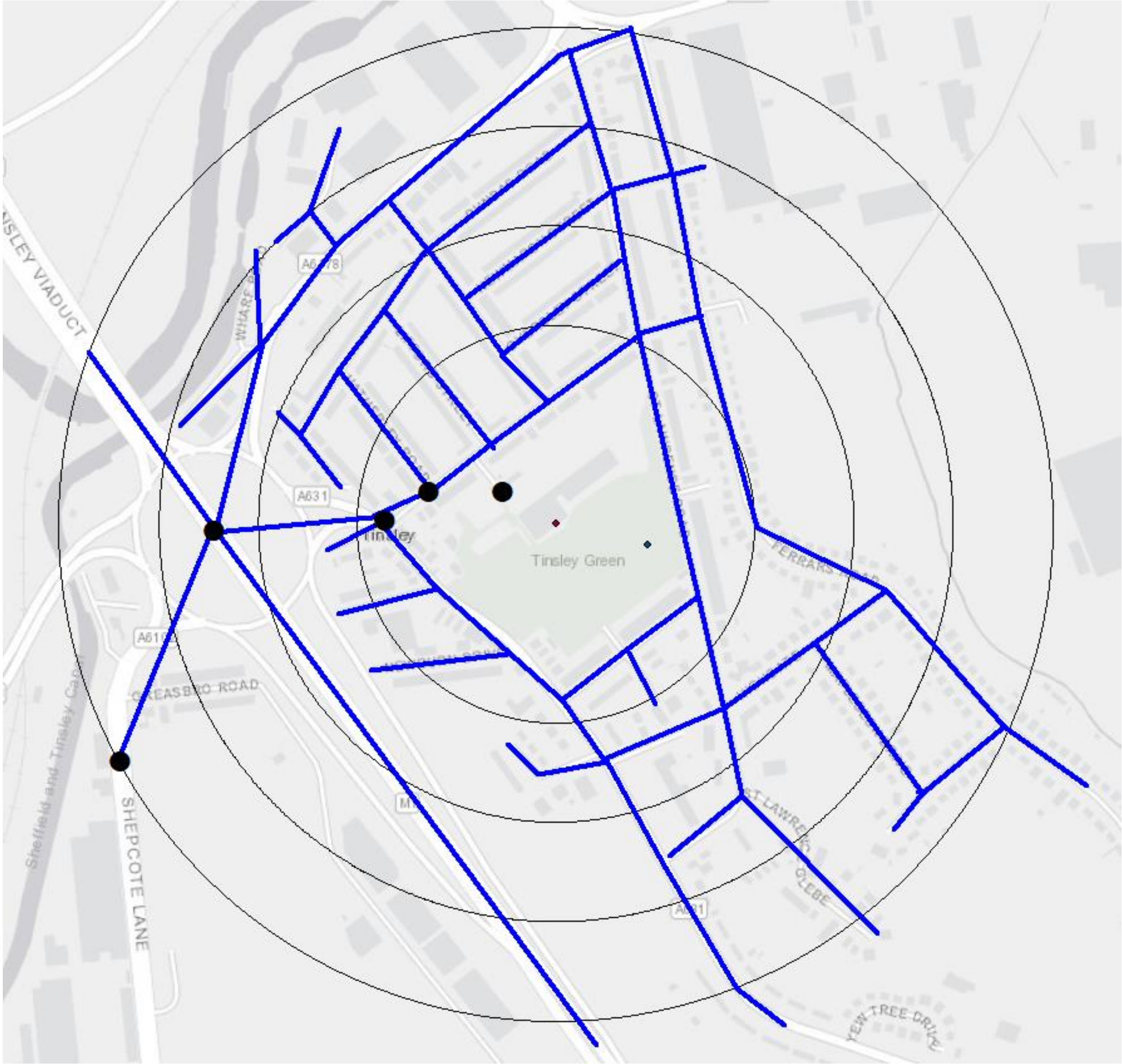


*Figure 240 Sheffield Active Travel Routes: Greenland.*

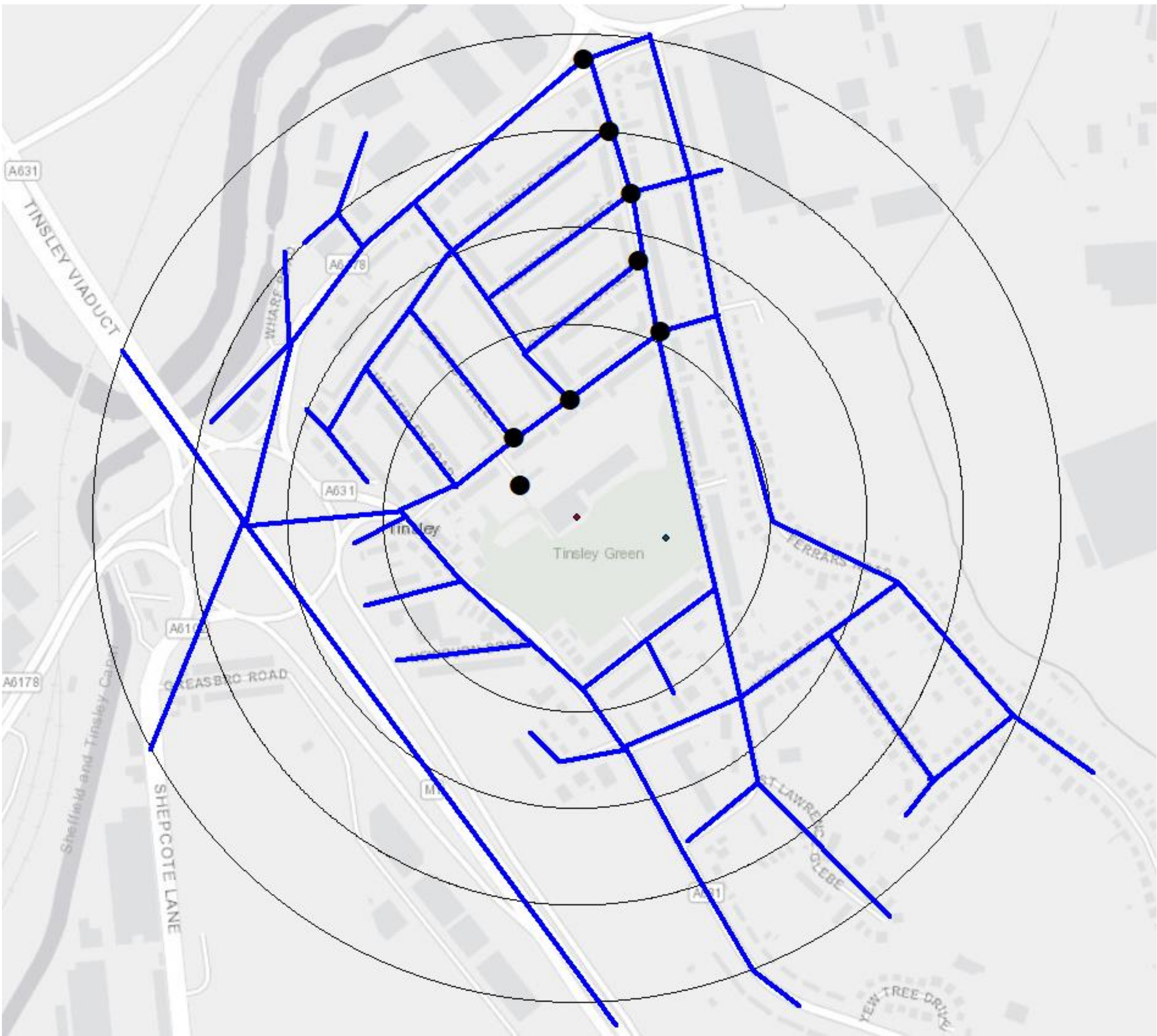


*Figure 241 Sheffield Active Travel Routes: Sheffield Rd.*

### xvi. Sheffield Tinsley: Improved Travel Routes

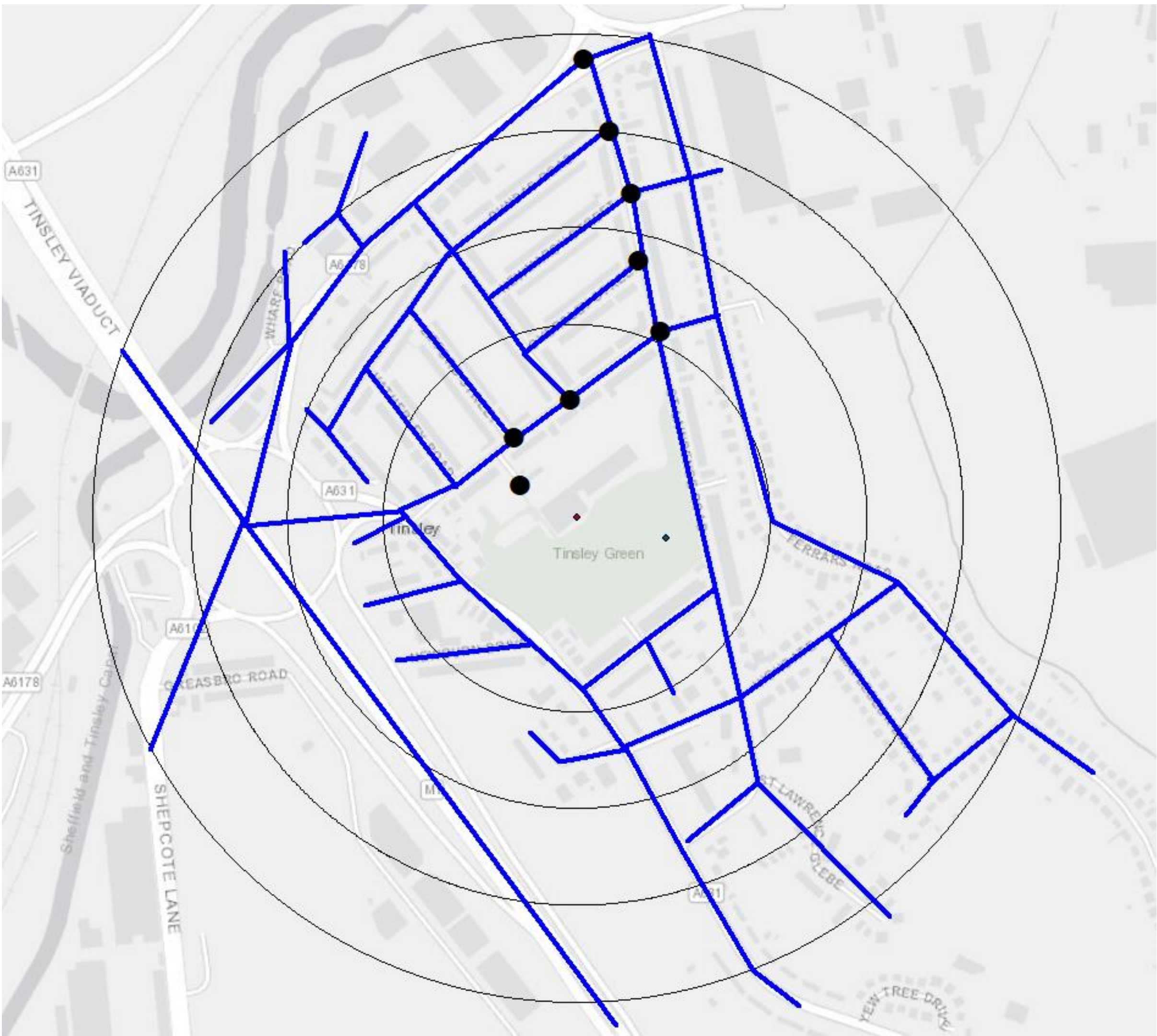


*Figure 242 Sheffield Improved Travel Routes: Blackburn Meadows.*

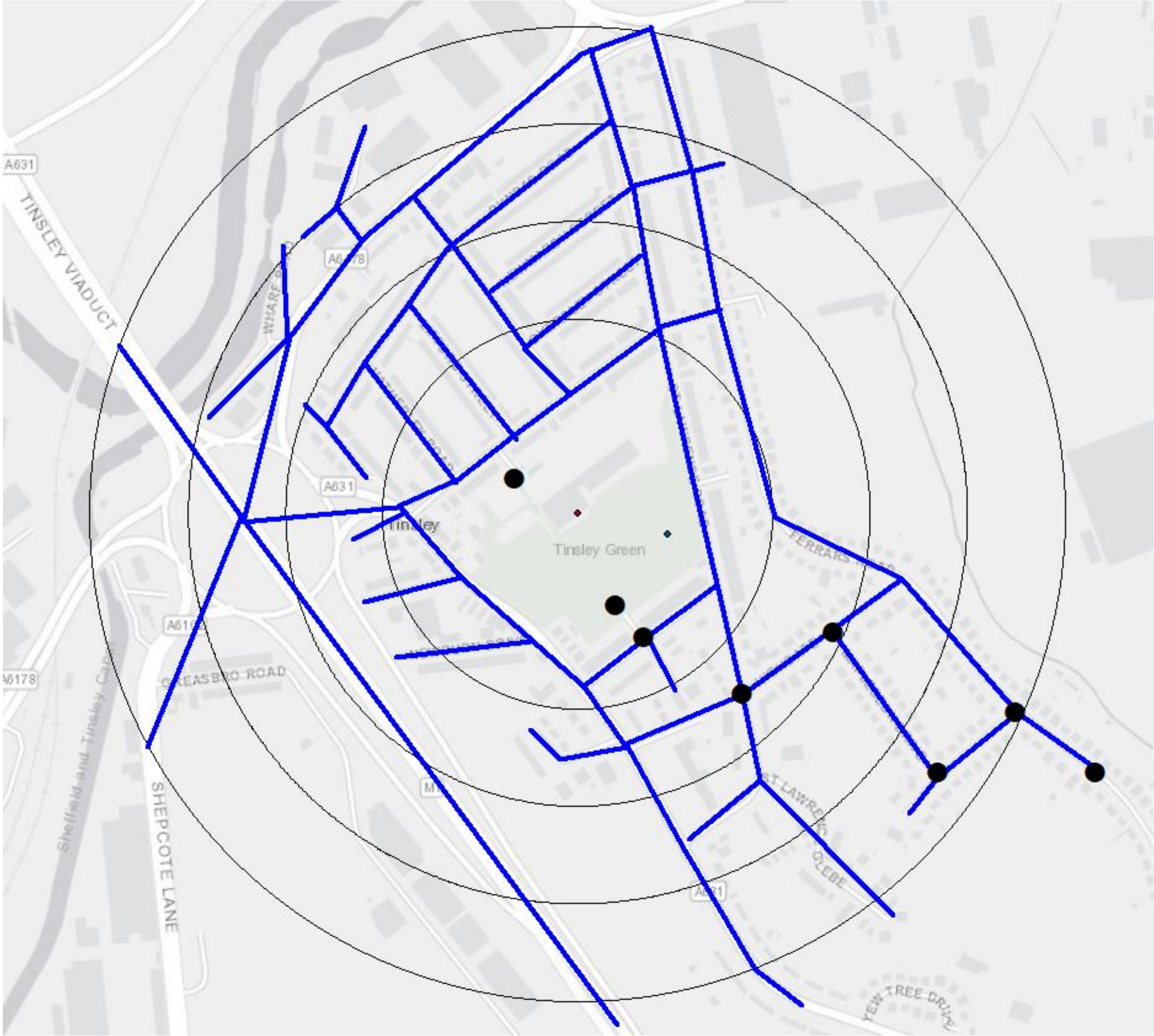


*Figure 243 Sheffield Improved Travel Routes Brinsworth.*

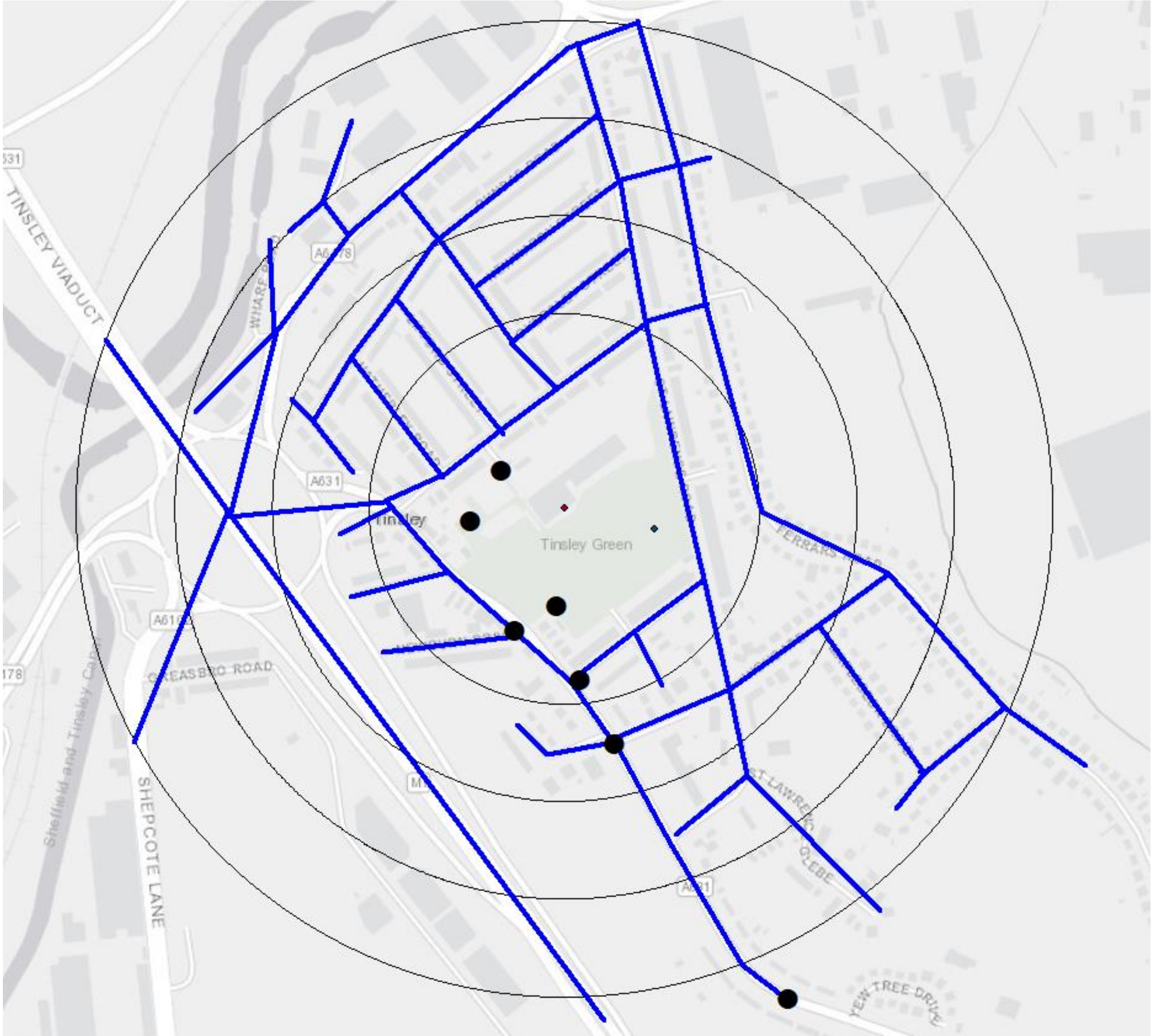


*Figure 244 Sheffield Improved Travel Routes Catcliffe.*

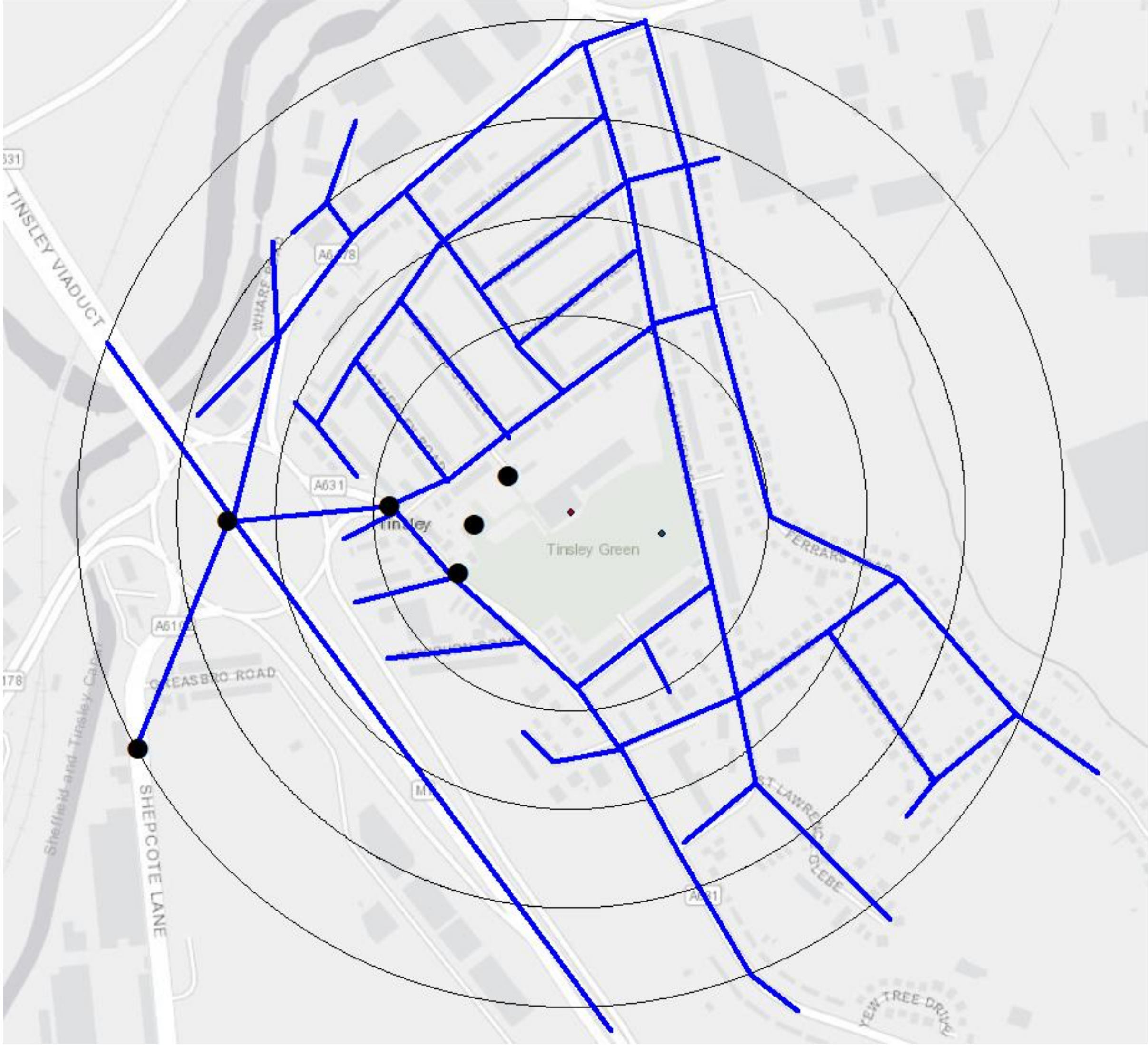


*Figure 245 Sheffield Improved Travel Routes: Greenland.*

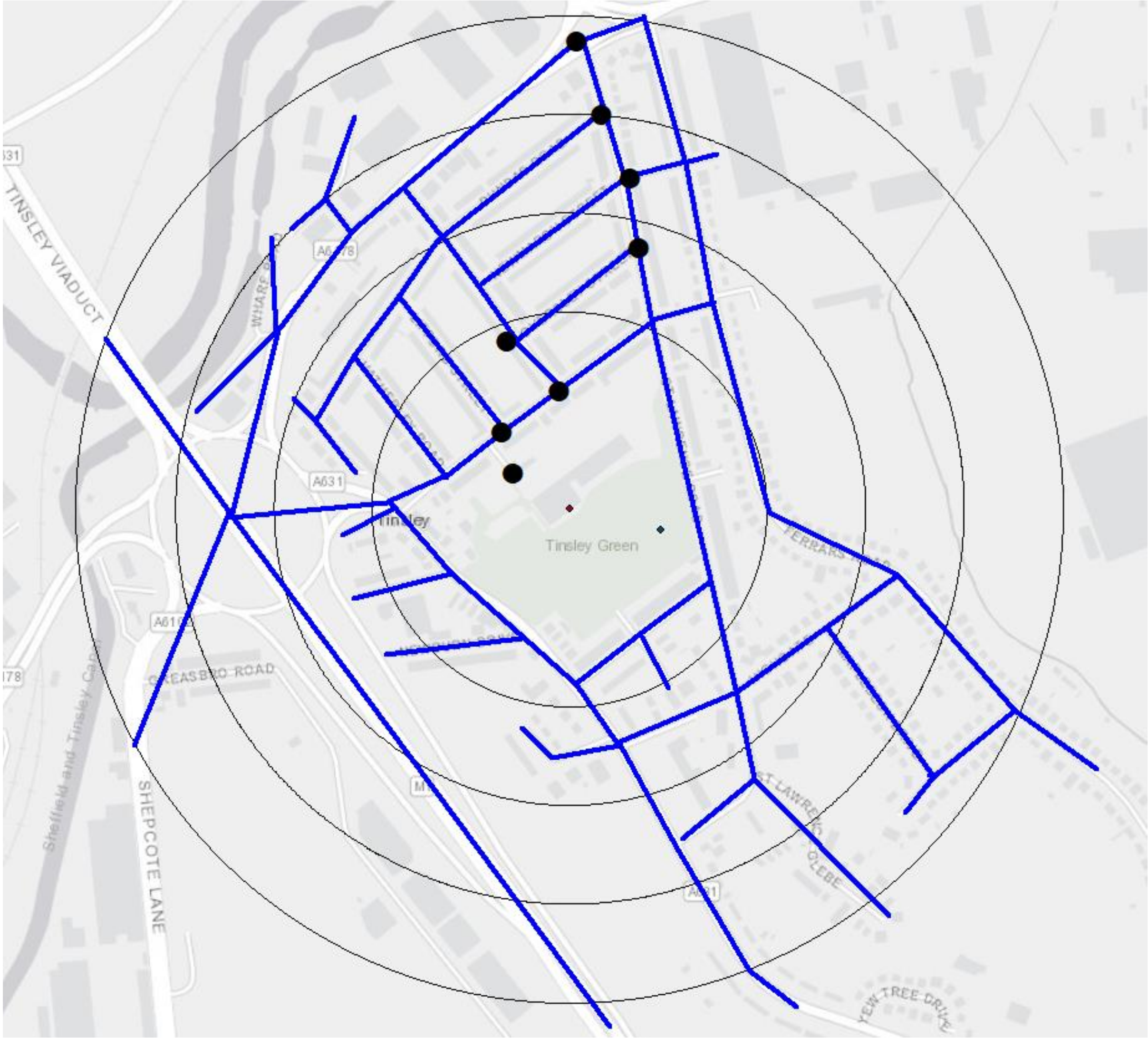


*Figure 246 Sheffield Improved Travel Routes: Sheffield Rd.*

# Appendix Q: Conversion Calculators

*Table 62 Conversion calculator parameters for all modelling locations for use with Defra's LAQM calculator (Defra, 2022d).*

| Parameters | Bristol St Paul's | Bristol Bedminster | Coventry Binley | Oxford St Ebbe's | Sheffield Tinsley |
|---|---|---|---|---|---|
| Year | 2019 | 2019 | 2019 | 2019 | 2019 |
| Local Authority | City of Bristol | City of Bristol | Coventry District | Oxford District | Sheffield District |
| Estimated regional concentrations above surface layer | | | | | |
| Ozone (µg/m$^3$) | 58.2 | 58.2 | 56.83 | 56.9 | 59.34 |
| Oxides of nitrogen (µg/m$^3$ as $NO_2$) | 11.5 | 11.5 | 13.69 | 13.2 | 9.2 |
| Nitrogen Dioxide (µg/m$^3$) | 8.9 | 8.9 | 10.37 | 10.0 | 7.12 |
| Traffic mix | All other urban UK traffic | | | | |
| Fraction $NO_x$ emitted from local road vehicles | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 |
| Regional fraction $NO_x$ emitted as $NO_2$ | 0.83 | 0.29 | 0.29 | 0.29 | 0.29 |

*Table 63 Bristol St Paul's $NO_X$ to $NO_2$ (µg/m$^3$) using Defra's LAQM calculator (Defra, 2022d).*

| Bristol St Paul's Receptor ID | Road increment $NO_x$ (µg m$^{-3}$) | Background $NO_2$ (µg m$^{-3}$) | Total $NO_2$ (µg m$^{-3}$) | Road $NO_2$ (µg m$^{-3}$) |
|---|---|---|---|---|
| Bristol St Paul's BRS8 AURN | 25.92 | 14.81 | 28.21 | 13.4 |
| Bristol Temple Way BR11 AURN | 34.51 | 14.81 | 32.33 | 17.51 |
| 15 Horsefair | 49.93 | 14.81 | 39.34 | 24.53 |
| 363 5102 facade | 29.39 | 14.81 | 29.89 | 15.08 |
| 22 Stokes Croft | 45.52 | 14.81 | 37.38 | 22.57 |
| 497 20 Ashley Road | 29.46 | 14.81 | 29.92 | 15.11 |
| 295 Lamppost 16 Ashley Rd St P | 52.86 | 14.81 | 40.62 | 25.81 |
| 374 St Paul St | 70.57 | 14.81 | 48.07 | 33.25 |
| 20 Newfoundland Way | 54.23 | 14.81 | 41.21 | 26.4 |
| 373 123 Newfoundland St facade | 40.44 | 14.81 | 35.08 | 20.26 |

*Table 64 Bristol Bedminster $NO_X$ to $NO_2$ (µg/m$^3$) using Defra's LAQM calculator (Defra, 2022d).*

| Bristol Bedminster Receptor ID | Road increment $NO_x$ (µg m$^{-3}$) | Background $NO_2$ (µg m$^{-3}$) | Total $NO_2$ (µg m$^{-3}$) | Road $NO_2$ (µg m$^{-3}$) |
|---|---|---|---|---|
| 215 Parson St School | 45.24 | 14.81 | 37.26 | 22.44 |
| 242 Parson St Bedminster Down Rd | 31.28 | 14.81 | 30.79 | 15.98 |
| 418 Bedminster Down Rc lamppost | 80.97 | 14.81 | 52.22 | 37.4 |
| 419 Parson St lamppost Scuba | 55.49 | 14.81 | 41.76 | 26.94 |
| 439 Parson St School | 41.09 | 14.81 | 35.37 | 20.56 |
| 474 Martial Arts West Street | 35.72 | 14.81 | 32.89 | 18.08 |

*Table 65 Coventry Binley $NO_X$ to $NO_2$ (μg/$m^3$) using Defra's LAQM calculator (Defra, 2022d).*

| Coventry Binley Receptor ID | Road increment $NO_x$ (μg $m^{-3}$) | Background $NO_2$ (μg $m^{-3}$) | Total $NO_2$ (μg $m^{-3}$) | Road $NO_2$ (μg $m^{-3}$) |
|---|---|---|---|---|
| Coventry Binley Road COBR AURN | 59.02 | 15.38 | 28.21 | 13.4 |
| Site FGS4 | 31.09 | 15.38 | 32.33 | 17.51 |
| Site FGS2 | 52.86 | 15.38 | 39.34 | 24.53 |
| Site BH1a | 24.48 | 15.38 | 29.89 | 15.08 |

*Table 66 Oxford St Ebbe's $NO_X$ to $NO_2$ (μg/$m^3$) using Defra's LAQM calculator (Defra, 2022d).*

| Oxford St Ebbe's Receptor ID | Road increment $NO_x$ (μg $m^{-3}$) | Background $NO_2$ (μg $m^{-3}$) | Total $NO_2$ (μg $m^{-3}$) | Road $NO_2$ (μg $m^{-3}$) |
|---|---|---|---|---|
| Oxford St Ebbe's OX8 AURN | 19.94 | 14.20 | 24.62 | 10.42 |
| DT63 Thames St Trinity | 19.64 | 14.20 | 24.47 | 10.27 |
| DT62 1 Blackfriars Rd | 20.62 | 14.20 | 24.97 | 10.76 |
| DT61 Friars Wharf | 20.50 | 14.20 | 24.9 | 10.7 |
| DT60 N Butterwyke Place Thames | 22.15 | 14.20 | 25.72 | 11.52 |
| DT59 Thames St | 23.97 | 14.20 | 26.62 | 12.42 |
| DT58 Folly Bridge | 24.27 | 14.20 | 26.77 | 12.57 |
| DT1 St Ebbe's First School | 20.57 | 14.20 | 24.94 | 10.74 |

*Table 67 Sheffield Tinsley $NO_X$ to $NO_2$ (μg/$m^3$) using Defra's LAQM calculator (Defra, 2022d).*

| Sheffield Tinsley Receptor ID | Road increment $NO_x$ (μg $m^{-3}$) | Background $NO_2$ (μg $m^{-3}$) | Total $NO_2$ (μg $m^{-3}$) | Road $NO_2$ (μg $m^{-3}$) |
|---|---|---|---|---|
| UKA00181 Sheffield Tinsley SHE AURN | 16.91 | 9.82 | 18.9 | 9.08 |
| Site Greasbro Rd | 18.46 | 9.82 | 19.7 | 9.87 |
| Site Town St | 26.42 | 9.82 | 23.72 | 13.89 |
| Site 7 Bawtry Gate | 26.43 | 9.82 | 23.72 | 13.9 |
| Site 47 Bawtry Rd | 31.25 | 9.82 | 26.09 | 16.27 |
| Site 30 Siemens Close | 19.60 | 9.82 | 20.29 | 10.46 |
| Site Tinsley Meadows Primary A | 16.56 | 9.82 | 18.72 | 8.9 |
| Site Ferrars Road | 20.62 | 9.82 | 20.81 | 10.98 |
| Site 109 Bawtry Rd | 30.39 | 9.82 | 25.67 | 15.85 |

# Appendix R: Verification & Adjustment

## i. Bristol St Paul's

*Table 68 Bristol St Paul's model outputs (µg/m$^3$) for verification & adjustment.*

| Receptor | Tot Mon NO$_2$ | Tot Mod NO$_2$ | % diff | Mod Rds. NO$_x$ | Mon Rd-NO$_x$ |
|---|---|---|---|---|---|
| Bristol St Paul's BRS8 AURN | 23.4 | 27.47 | 15% | 24.41 | 16.21 |
| Bristol Temple Way BR11 AURN | 39.2 | 26.09 | -50% | 21.62 | 49.87 |
| 15 Horsefair | 42.2 | 30.53 | -38% | 30.72 | 56.76 |
| 363 5102 facade | 34.0 | 28.54 | -19% | 26.60 | 38.2 |
| 22 Stokes Croft | 44.3 | 35.27 | -26% | 40.86 | 61.73 |
| 497 20 Ashley Road | 29.1 | 28.56 | -2% | 26.63 | 27.82 |
| 295 Lamppost 16 Ashley Rd St | 48.1 | 28.05 | -72% | 25.60 | 70.97 |
| 374 St Paul St | 39.9 | 50.42 | 21% | 76.42 | 51.25 |
| 20 Newfoundland Way | 42.4 | 31.09 | -36% | 31.90 | 57.21 |
| 373 123 Newfoundland St facade | 31.2 | 29.14 | -7% | 27.84 | 32.13 |

*Table 69 Adjusted Bristol St Paul's model outputs (µg/m$^3$) for verification & adjustment.*

| Receptor | NO$_x$ ADJ Corr1 | Adj Rd-NO$_x$ | MODELLED Rd-NO$_2$ | Adj Tot-NO$_2$ | Tot Mon NO$_2$ |
|---|---|---|---|---|---|
| Bristol St Paul's BRS8 AURN | 0.66 | 29.09 | 13.4 | 28.21 | 23.4 |
| Bristol Temple Way BR11 AURN | 2.31 | 25.77 | 17.51 | 32.33 | 39.2 |
| 15 Horsefair | 1.85 | 36.62 | 24.53 | 39.34 | 42.2 |
| 363 5102 facade | 1.44 | 31.70 | 15.08 | 29.89 | 34.0 |
| 22 Stokes Croft | 1.51 | 48.70 | 22.57 | 37.38 | 44.3 |
| 497 20 Ashley Road | 1.04 | 31.74 | 15.11 | 29.92 | 29.1 |
| 295 Lamppost 16 Ashley Rd St | 2.77 | 30.51 | 25.81 | 40.62 | 48.1 |
| 374 St Paul St | 0.67 | 91.08 | 33.25 | 48.07 | 39.9 |
| 20 Newfoundland Way | 1.79 | 38.02 | 26.4 | 41.21 | 42.4 |
| 373 123 Newfoundland St facade | 1.15 | 33.18 | 20.26 | 35.08 | 31.2 |
| Regression | 1.19 | | | | |

*Table 70 Bristol St Paul's final site differences for verification & adjustment.*

| Site | Final NO$_2$ Difference | |
|---|---|---|
| | µg/m$^3$ | % |
| Bristol St Paul's BRS8 AURN | 4.86 | 20.80% |
| Bristol Temple Way BR11 AURN | -6.92 | -17.63% |
| 15 Horsefair | -2.89 | -6.84% |
| 363 5102 facade | -4.11 | -12.09% |
| 22 Stokes Croft | -6.95 | -15.68% |
| 497 20 Ashley Road | 0.82 | 2.82% |
| 295 Lamppost 16 Ashley Rd St | -7.51 | -15.60% |
| 374 St Paul St | 8.22 | 20.63% |
| 20 Newfoundland Way | -1.21 | -2.85% |
| 373 123 Newfoundland St facade | 3.92 | 12.58% |

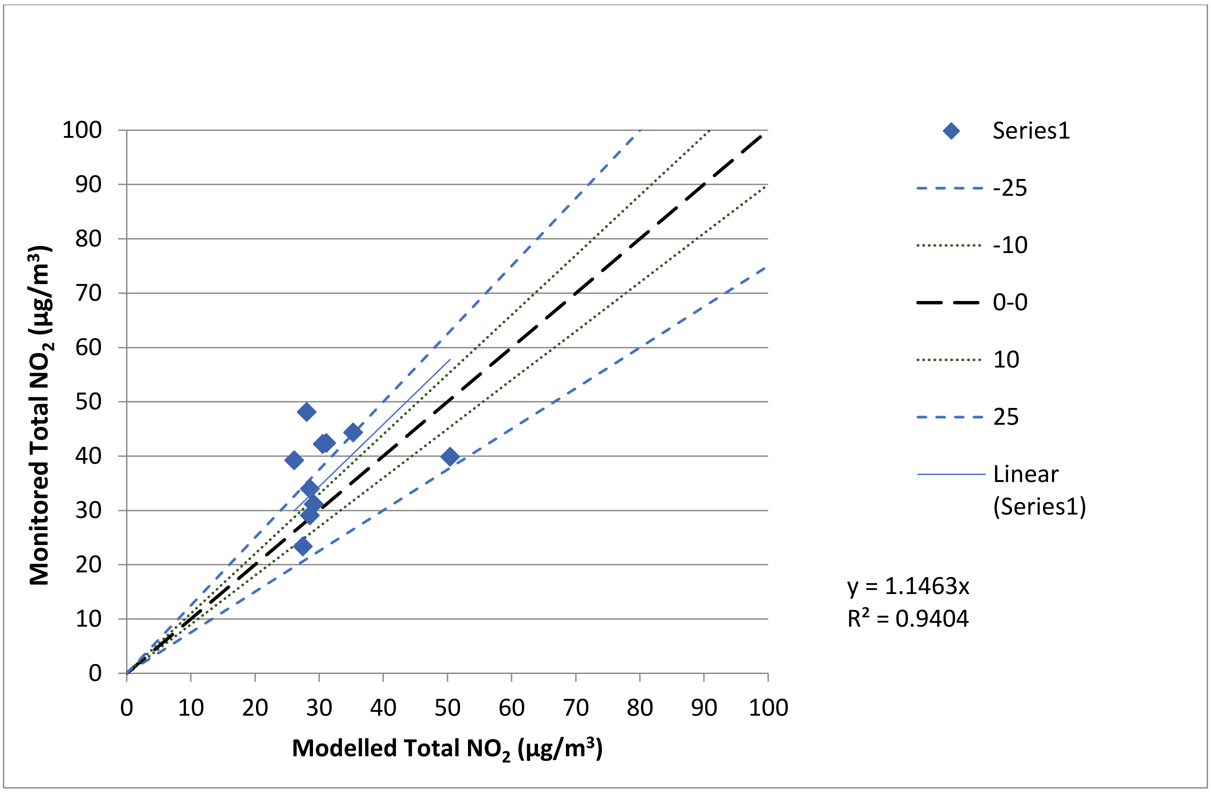


*Figure 247 Bristol St Paul's total NO$_2$ with deviation interval classes at 10 and 25 percent. Series 1 represents total monitored NO$_2$ against total modelled NO$_2$.*

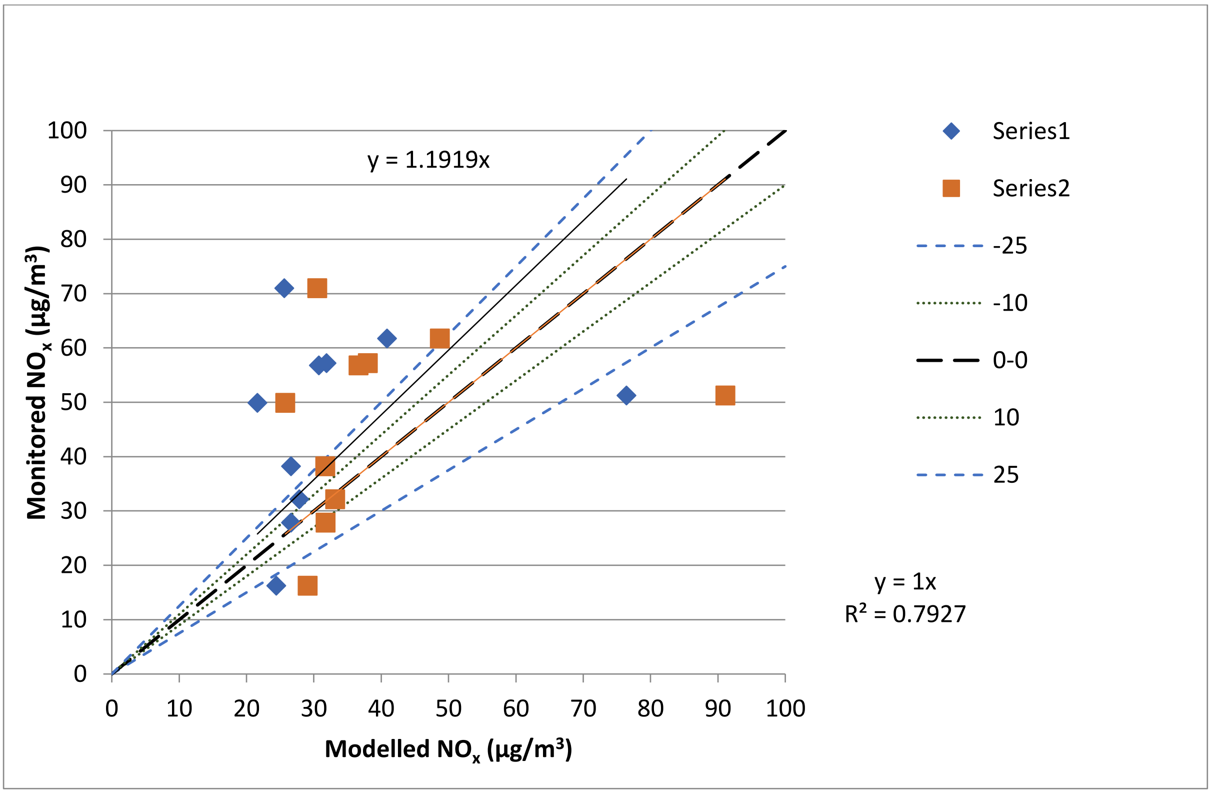


*Figure 248 Bristol St Paul's Road NO$_2$ with deviation interval classes at 10 and 25 percent. Series 1 represents total monitored road NO$_2$ and series 2 represents adjusted road NO$_X$.*

## ii. Bristol Bedminster

*Table 71 Bristol Bedminster model outputs (µg/m³) for verification & adjustment.*

| Receptor | Tot Mon $NO_2$ | Tot Mod $NO_2$ | % diff | Mod Rds. $NO_x$ | Mon Rd-$NO_x$ |
|---|---|---|---|---|---|
| 215 Parson St School | 32.9 | 35.06 | 6% | 40.40 | 35.75 |
| 242 Parson St Bedminster Down Rd | 41.1 | 26.8 | -53% | 23.05 | 53.85 |
| 418 Bedminster Down Rc lamppost | 51.1 | 32.98 | -55% | 35.92 | 78.19 |
| 419 Parson St lamppost Scuba | 39.1 | 45.31 | 14% | 63.88 | 49.28 |
| 439 Parson St School | 31.7 | 33.59 | 6% | 37.22 | 33.25 |
| 474 Martial Arts West Street | 29.1 | 38.86 | 25% | 48.85 | 27.83 |

*Table 72 Adjusted Bristol Bedminster model outputs (µg/m³) for verification & adjustment.*

| Receptor | $NO_x$ ADJ | | MODELLED | | Tot |
|---|---|---|---|---|---|
| | Corr1 | Adj Rd-$NO_x$ | Rd-$NO_2$ | Adj Tot-$NO_2$ | Mon $NO_2$ |
| 215 Parson St School | 0.88 | 40.16 | 22.44 | 37.26 | 32.9 |
| 242 Parson St Bedminster Down Rd | 2.34 | 22.92 | 15.98 | 30.79 | 41.1 |
| 418 Bedminster Down Rc lamppost | 2.18 | 35.70 | 37.4 | 52.22 | 51.1 |
| 419 Parson St lamppost Scuba | 0.77 | 63.51 | 26.94 | 41.76 | 39.1 |
| 439 Parson St School | 0.89 | 37.00 | 20.56 | 35.37 | 31.7 |
| 474 Martial Arts West Street | 0.57 | 48.56 | 18.08 | 32.89 | 29.1 |
| Regression | 0.99 | | | | |

*Table 73 Bristol Bedminster final site differences for verification & adjustment.*

| Receptor | Final $NO_2$ Difference | |
|---|---|---|
| | µg/m³ | % |
| 215 Parson St School | 4.35 | 13.23% |
| 242 Parson St Bedminster Down Rd | -10.26 | -24.99% |
| 418 Bedminster Down Rc lamppost | 1.10 | 2.15% |
| 419 Parson St lamppost Scuba | 2.71 | 6.94% |
| 439 Parson St School | 3.64 | 11.47% |
| 474 Martial Arts West Street | 3.75 | 12.87% |

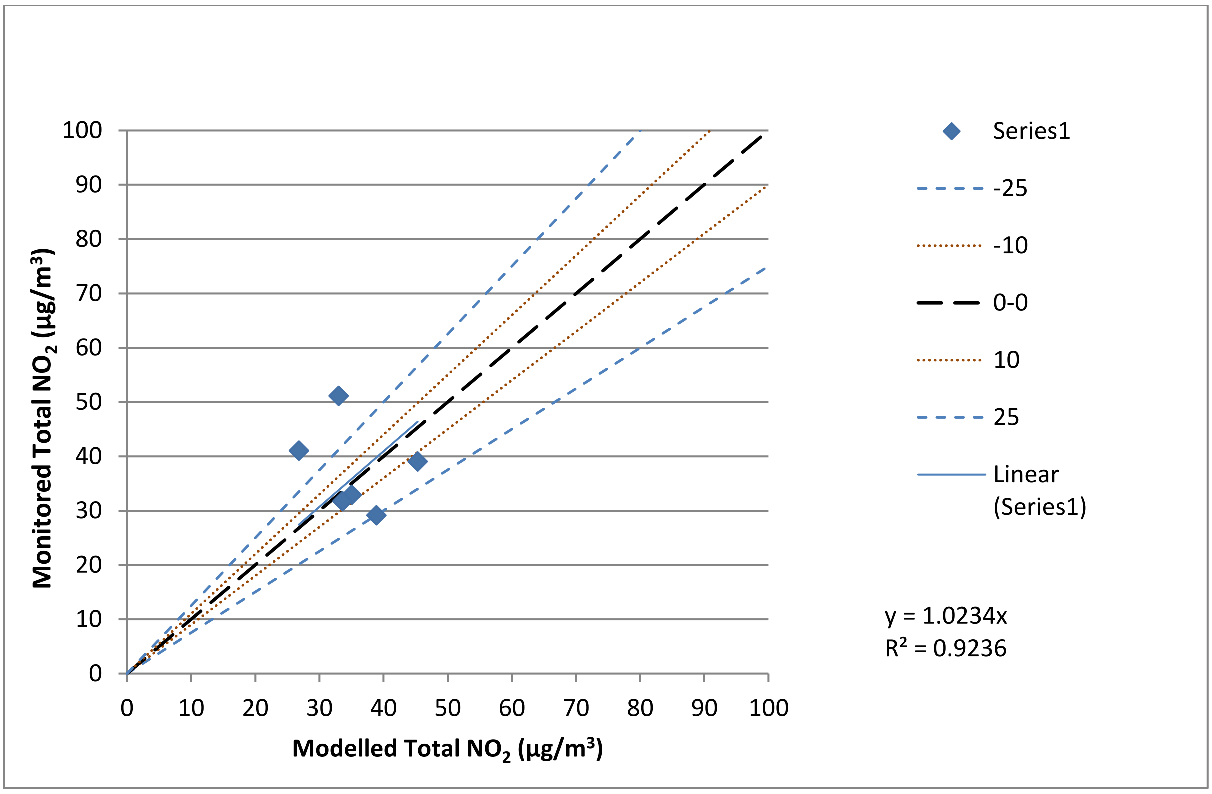


*Figure 249 Bristol Bedminster total NO$_2$ with deviation interval classes at 10 and 25 percent. Series 1 represents total monitored NO$_2$ against total modelled NO$_2$.*

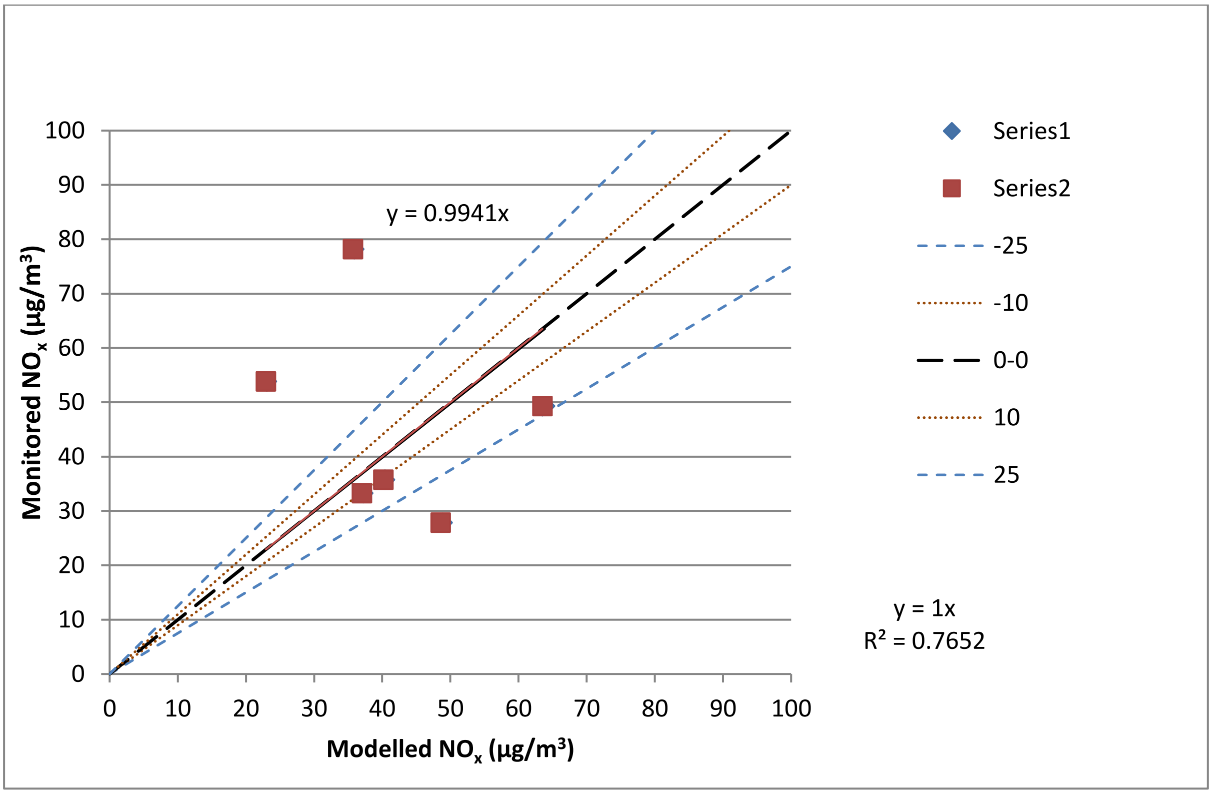


*Figure 250 Bristol Bedminster Road NO$_2$ with deviation interval classes at 10 and 25 percent. Series 1 represents total monitored road NO$_2$ and series 2 represents adjusted road NO$_X$.*

## iii. Coventry Binley

*Table 74 Coventry Binley model outputs (µg/m$^3$) for verification & adjustment.*

| **Receptor** | **Tot Mon NO$_2$** | **Tot Mod NO$_2$** | **% diff** | **Mod Rds. NO$_x$** | **Mon Rd-NO$_x$** |
|---|---|---|---|---|---|
| Coventry Binley Road COBR AURN | 30.9 | 33.43 | 7% | 35.89 | 30.64 |
| Site FGS4 | 36.9 | 27.77 | -33% | 24.00 | 43.66 |
| Site FGS2 | 32.9 | 30.31 | -8% | 29.27 | 34.80 |
| Site BH1a | 37.1 | 27.86 | -33% | 24.19 | 43.95 |

*Table 75 Adjusted Coventry Binley model outputs (µg/m$^3$) for verification & adjustment.*

| **Receptor** | **NO$_x$ ADJ** | | **MODELLED** | | **Tot** |
|---|---|---|---|---|---|
| | **Corr1** | **Adj Rd-NO$_x$** | **Rd-NO$_2$** | **Adj Tot-NO$_2$** | **Mon NO$_2$** |
| Coventry Binley Road COBR AURN | 0.85 | 45.91 | 28.27 | 43.65 | 50.5 |
| Site FGS4 | 1.82 | 30.70 | 15.79 | 31.18 | 37.6 |
| Site FGS2 | 1.19 | 37.44 | 25.64 | 41.02 | 42.9 |
| Site BH1a | 1.82 | 30.95 | 12.62 | 28 | 23.5 |
| Regression | 1.28 | | | | |

*Table 76 Coventry Binley final site differences for verification & adjustment.*

| **Receptor** | **Final NO$_2$ Difference** | |
|---|---|---|
| | **µg/m$^3$** | **%** |
| Coventry Binley Road COBR AURN | -6.85 | -13.56% |
| Site FGS4 | -6.42 | -17.07% |
| Site FGS2 | -1.91 | -4.45% |
| Site BH1a | 4.49 | 19.10% |

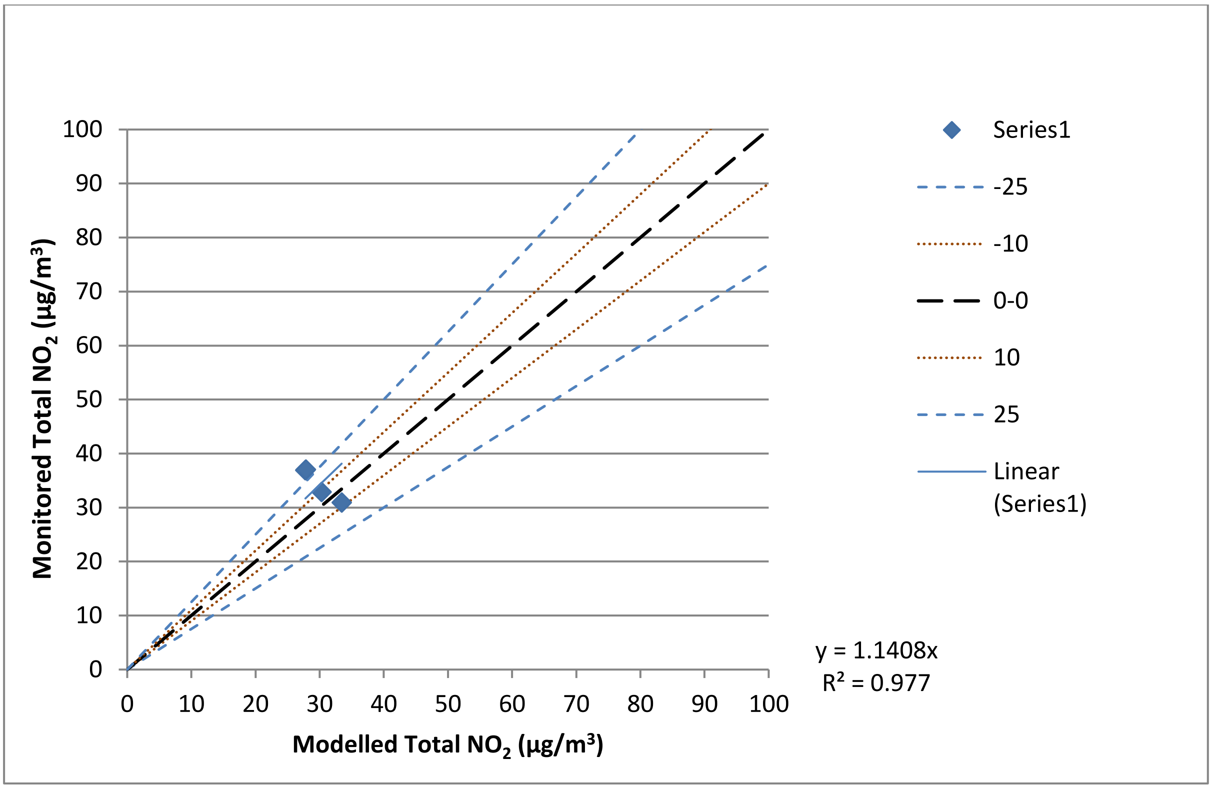


*Figure 251 Coventry Binley total $NO_2$ with deviation interval classes at 10 and 25 percent. Series 1 represents total monitored $NO_2$ against total modelled $NO_2$.*

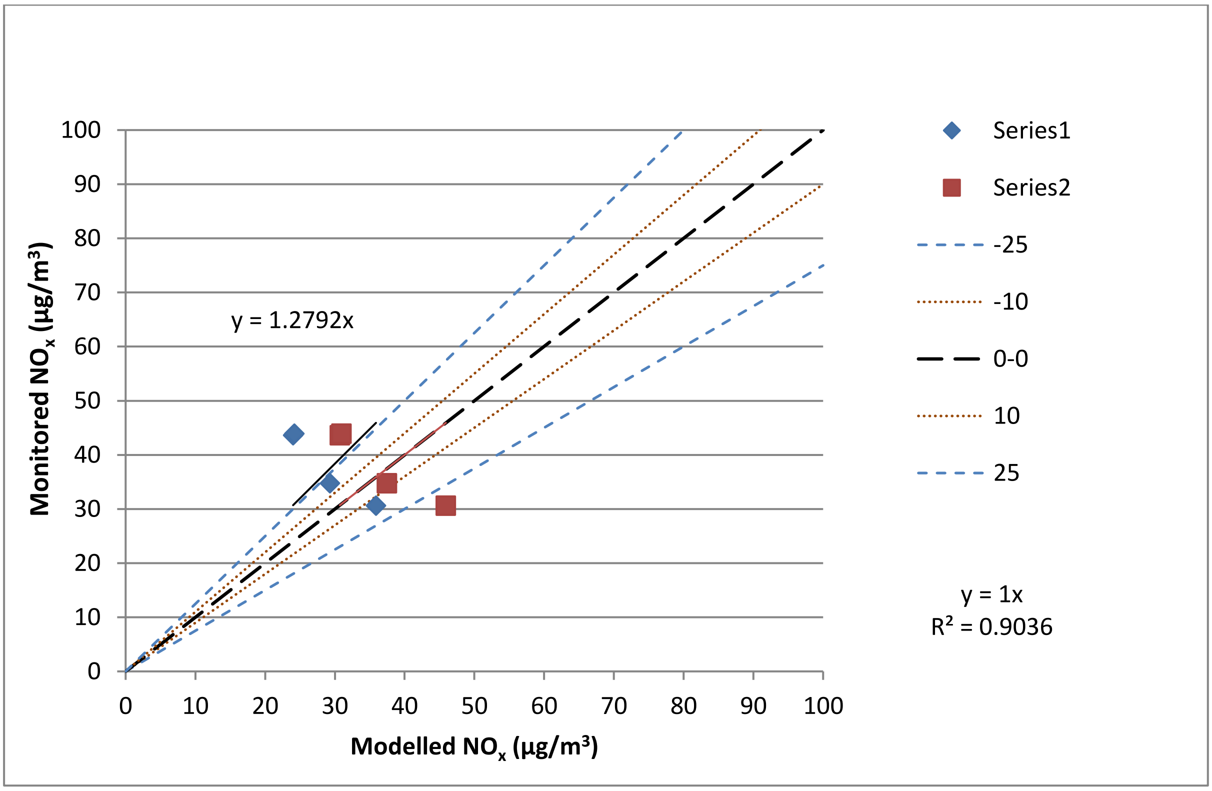


*Figure 252 Coventry Binley Road $NO_2$ with deviation interval classes at 10 and 25 percent. Series 1 represents total monitored road $NO_2$ and series 2 represents adjusted road $NO_X$.*

### iv. Oxford St Ebbe's

*Table 77 Oxford St Ebbe's model outputs (μg/m$^3$) for verification & adjustment.*

| **Receptor** | **Tot<br>Mon NO$_2$** | **Tot<br>Mod NO$_2$** | **% diff** | **Mod Rds. NO$_x$** | **Mon Rd-NO$_x$** |
|---|---|---|---|---|---|
| DT61 Friars Wharf | 20.0 | 24.9 | 20% | 20.50 | 10.9 |
| DT60 N Butterwyke Place Thames | 33.0 | 25.72 | -28% | 22.15 | 37.44 |
| DT59 Thames St | 26.0 | 26.62 | 2% | 23.97 | 22.76 |
| DT58 Folly Bridge | 34.0 | 26.77 | -27% | 24.27 | 39.62 |
| DT1 St Ebbe's First School | 16.0 | 24.94 | 36% | 20.57 | 3.32 |

*Table 78 Adjusted Oxford St Ebbe's model outputs (μg/m$^3$) for verification & adjustment.*

| **Receptor** | **NO$_x$ ADJ** | | **MODELLED** | | **Tot** |
|---|---|---|---|---|---|
| | **Corr1** | **Adj Rd-NO$_x$** | **Rd-NO$_2$** | **Adj Tot-NO$_2$** | **Mon NO$_2$** |
| DT61 Friars Wharf | 0.53 | 19.05 | 11.26 | 24.9 | 23.5 |
| DT60 N Butterwyke Place Thames | 1.69 | 20.59 | 11.78 | 25.72 | 23.5 |
| DT59 Thames St | 0.95 | 22.28 | 12.59 | 26.62 | 23.5 |
| DT58 Folly Bridge | 1.63 | 22.56 | 12.69 | 26.77 | 23.5 |
| DT1 St Ebbe's First School | 0.16 | 19.12 | 13.45 | 24.94 | 23.5 |
| Regression | 0.93 | | | | |

*Table 79 Oxford St Ebbe's final site differences for verification & adjustment.*

| **Receptor** | **Final NO$_2$ Difference** | |
|---|---|---|
| | μg/m$^3$ | % |
| DT61 Friars Wharf | 1.39 | 5.91% |
| DT60 N Butterwyke Place Thames | 2.21 | 9.40% |
| DT59 Thames St | 3.11 | 13.23% |
| DT58 Folly Bridge | 3.26 | 13.87% |
| DT1 St Ebbe's First School | 1.43 | 6.08% |

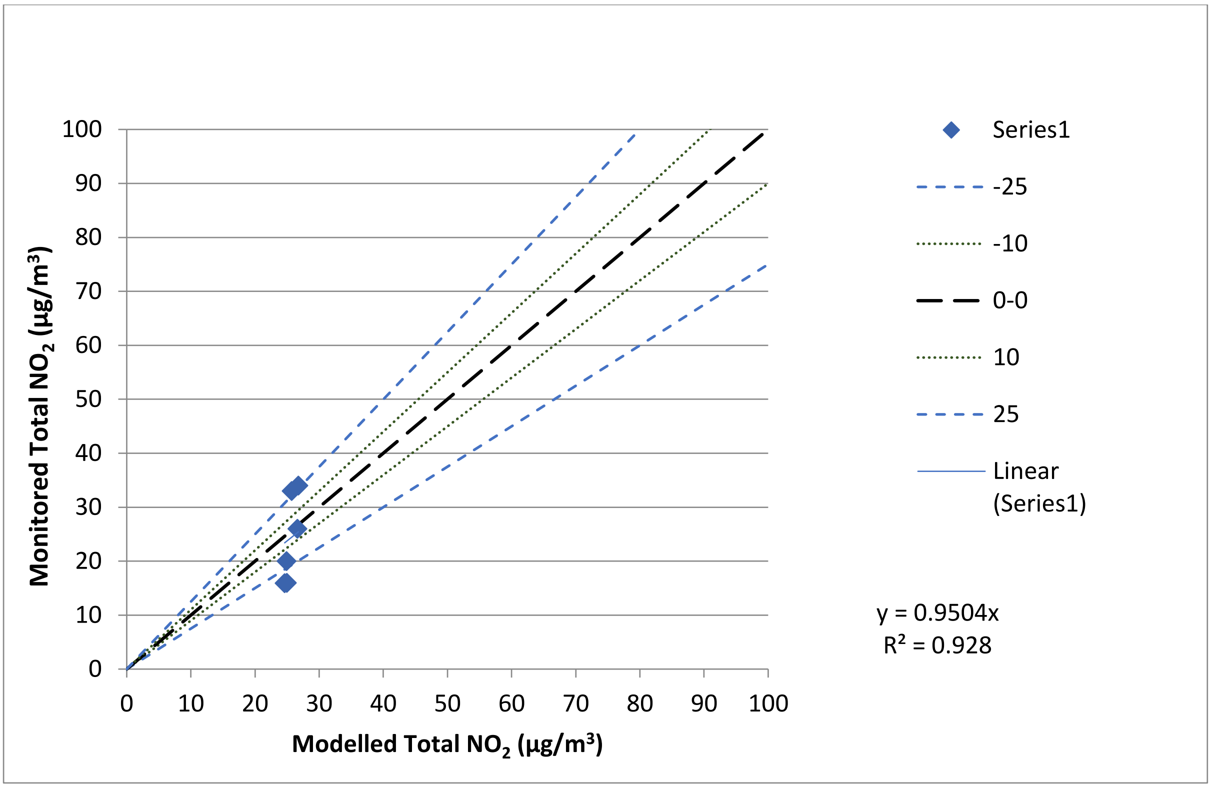


*Figure 253 Oxford St Ebbe's total $NO_2$ with deviation interval classes at 10 and 25 percent. Series 1 represents total monitored $NO_2$ against total modelled $NO_2$.*

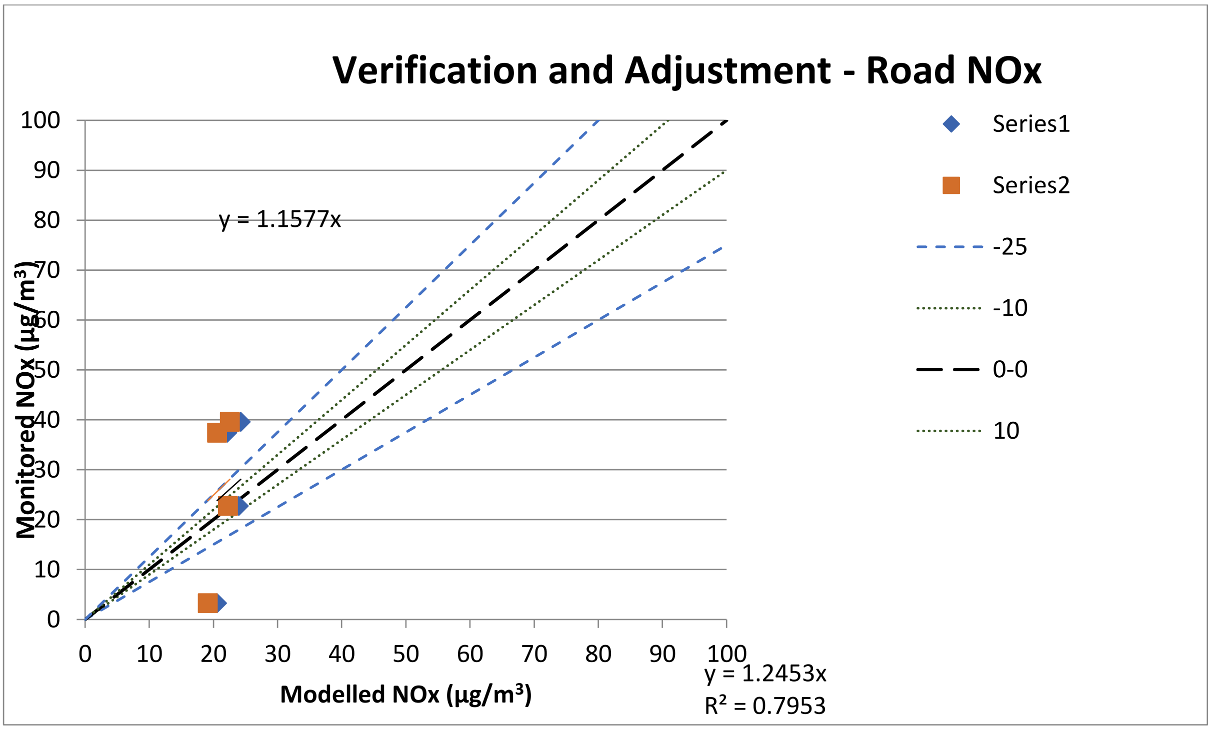


*Figure 254 Oxford St Ebbe's road $NO_2$ with deviation interval classes at 10 and 25 percent. Series 1 represents total monitored road $NO_2$ and series 2 represents adjusted road $NO_X$.*

## v. Sheffield Tinsley

Table 80 Sheffield Tinsley model outputs (μg/m$^3$) for verification & adjustment.

| Receptor | Tot<br>Mon $NO_2$ | Tot<br>Mod $NO_2$ | % diff | Mod Rds. $NO_x$ | Mon Rd-$NO_x$ |
|---|---|---|---|---|---|
| Site 7 Bawtry Gate | 39.0 | 20.12 | -94% | 19.28 | 59.49 |
| Site 47 Bawtry Rd | 44.0 | 23.1 | -90% | 25.17 | 71.37 |
| Site 30 Siemens Close | 44.0 | 18.92 | -133% | 16.94 | 71.37 |
| Site Tinsley Meadows Primary A | 38.0 | 18.27 | -108% | 15.70 | 57.18 |
| Site Ferrars Road | 33.0 | 20.43 | -62% | 19.89 | 45.94 |
| Site 109 Bawtry Rd | 35.0 | 25.01 | -40% | 29.05 | 50.37 |

Table 81 Adjusted Sheffield Tinsley model outputs (μg/m$^3$) for verification & adjustment.

| Receptor | $NO_x$ ADJ | | MODELLED | | Tot |
|---|---|---|---|---|---|
| | Corr1 | Adj Rd-$NO_x$ | Rd-$NO_2$ | Adj Tot-$NO_2$ | Mon $NO_2$ |
| Site 7 Bawtry Gate | 3.08 | 50.94 | 13.64 | 23.47 | 23.5 |
| Site 47 Bawtry Rd | 2.84 | 66.49 | 15.91 | 25.73 | 23.5 |
| Site 30 Siemens Close | 4.21 | 44.76 | 10.36 | 20.18 | 23.5 |
| Site Tinsley Meadows Primary A | 3.64 | 41.49 | 8.83 | 18.66 | 23.5 |
| Site Ferrars Road | 2.31 | 52.54 | 10.93 | 20.75 | 23.5 |
| Site 109 Bawtry Rd | 1.73 | 76.73 | 15.8 | 25.63 | 23.5 |
| Regression | 2.64 | | | | |

Table 82 Sheffield Tinsley final site differences for verification & adjustment.

| Receptor | Final $NO_2$ Difference | |
|---|---|---|
| | μg/m$^3$ | % |
| Site 7 Bawtry Gate | -0.04 | -0.17% |
| Site 47 Bawtry Rd | 2.22 | 9.44% |
| Site 30 Siemens Close | -3.33 | -14.16% |
| Site Tinsley Meadows Primary A | -4.85 | -20.63% |
| Site Ferrars Road | -2.76 | -11.74% |
| Site 109 Bawtry Rd | 2.12 | 9.02% |

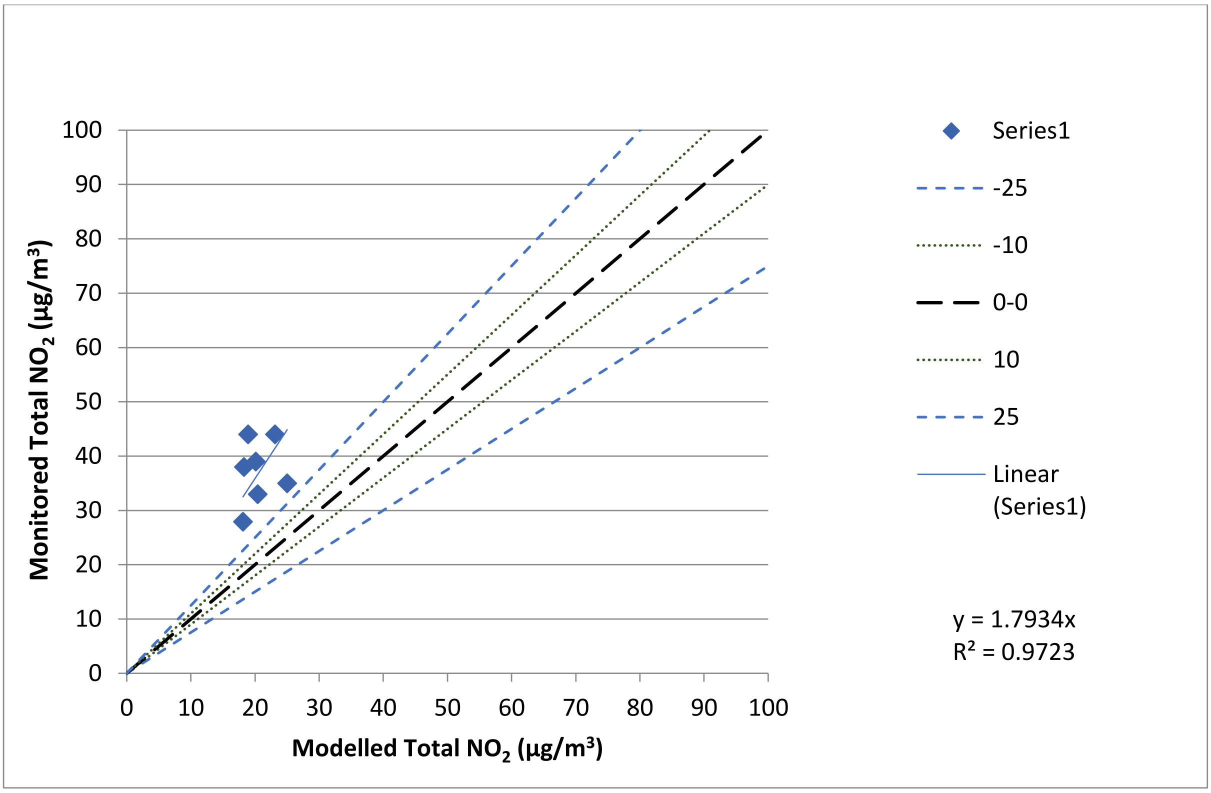


*Figure 255 Sheffield Tinsley total $NO_2$ with deviation interval classes at 10 and 25 percent. Series 1 represents total monitored $NO_2$ against total modelled $NO_2$.*

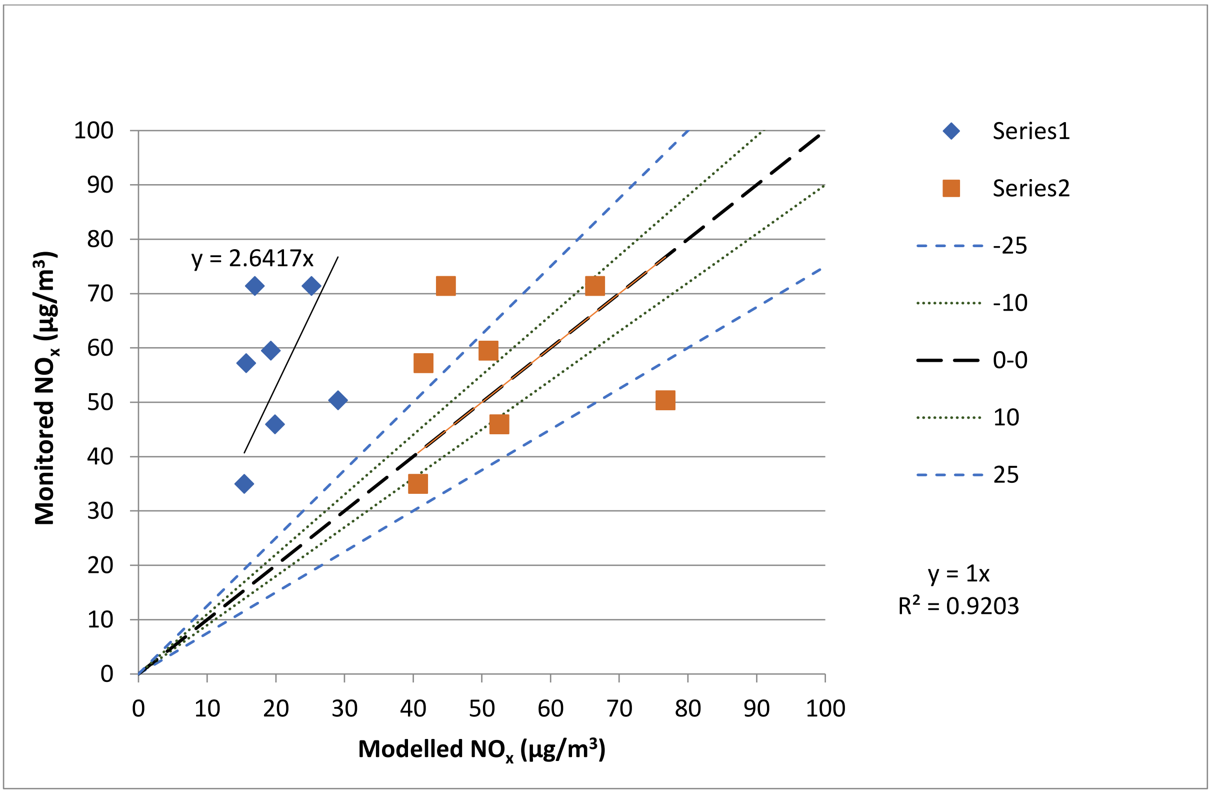


*Figure 256 Sheffield Tinsley Road $NO_2$ with deviation interval classes at 10 and 25 percent. Series 1 represents total monitored road $NO_2$ and series 2 represents adjusted road $NO_X$.*

# Appendix S: Establishment Type Groups

*Table 83 Establishment Type Group categories (GOV.UK, 2022b).*

| **Category** | **Type** |
|---|---|
| Academies | Academy alternative provision converter |
| | Academy alternative provision sponsor led |
| | Academy converter |
| | Academy special converter |
| | Academy special sponsor led |
| | Academy sponsor led |
| Children’s Centres | Children’s centre |
| | Children’s centre linked site |
| Colleges | Further education |
| Free Schools | Free schools |
| | Free schools 16 to 19 |
| | Free schools alternative provision |
| Independent Schools | City technology college |
| | Free schools special |
| | Non-maintained special school |
| | Other independent school |
| LA Maintained | Academy 16-19 converter |
| | Community school |
| | Foundation school |
| | Higher education institutions |
| | Local authority nursery school |
| | Miscellaneous |
| | Other independent special school |
| | Pupil referral unit |
| Other Types | Secure units |
| | Service children’s education |
| | Sixth form centres |
| | Special post 16 institution |
| Special Schools | Community special school |
| | Foundation special school |
| | Studio schools |
| | University technical college |
| | Voluntary aided school |
| Universities | Voluntary controlled school |

# Appendix T: Dispersion Modelling Site Input Parameters

## i. Bristol St Paul’s

*Table 84 Source Emission Rates for Bristol St Paul’s.*

| Source name | Emission rate ($NO_2$) | Emission rate ($NO_X$) | Comments |
|---|---|---|---|
| Ashley Rd A | 0.03 | 0.12 | g/km/s |
| Ashley Rd B | 0.03 | 0.12 | g/km/s |
| Ashley Rd C | 0.03 | 0.12 | g/km/s |
| Ashley Rd D | 0.03 | 0.12 | g/km/s |
| Ashley Rd E | 0.03 | 0.11 | g/km/s |
| Ashley Rd F | 0.03 | 0.11 | g/km/s |
| Ashley Rd G | 0.03 | 0.11 | g/km/s |
| Ashley Rd H | 0.08 | 0.55 | g/km/s |
| Ashley Rd I | 0.08 | 0.55 | g/km/s |
| Ashley Rd J | 0.08 | 0.55 | g/km/s |
| Ashley Rd K | 0.08 | 0.55 | g/km/s |
| Newfoundland Way A | 0.12 | 1.01 | g/km/s |
| Newfoundland Way B | 0.12 | 1.01 | g/km/s |
| Newfoundland Way C | 0.11 | 0.82 | g/km/s |
| Newfoundland Way D | 0.11 | 0.82 | g/km/s |
| Newfoundland Way E | 0.11 | 0.82 | g/km/s |
| Newfoundland Way G | 0.11 | 0.82 | g/km/s |
| Newfoundland Way H | 0.11 | 0.82 | g/km/s |
| Newfoundland Way I | 0.11 | 0.82 | g/km/s |
| Newfoundland Rd A | 0.00 | 0.02 | g/km/s |
| Newfoundland Rd B | 0.00 | 0.02 | g/km/s |
| Newfoundland Rd C | 0.00 | 0.01 | g/km/s |
| Badminton Rd A | 0.03 | 0.26 | g/km/s |
| Badminton Rd B | 0.03 | 0.26 | g/km/s |
| Cheltenham Rd A | 0.02 | 0.09 | g/km/s |
| Cheltenham Rd B | 0.02 | 0.09 | g/km/s |
| Cheltenham Rd C | 0.02 | 0.09 | g/km/s |
| Cheltenham Rd D | 0.02 | 0.09 | g/km/s |
| Cheltenham Rd E | 0.02 | 0.09 | g/km/s |
| Hepburn Rd | 0.02 | 0.12 | g/km/s |
| Gwyn St | 0.00 | 0.01 | g/km/s |
| Drummand Rd A | 0.01 | 0.06 | g/km/s |
| Drummand Rd B | 0.01 | 0.06 | g/km/s |
| Wellington Ave | 0.00 | 0.01 | g/km/s |
| Barnabas St | 0.00 | 0.00 | g/km/s |
| Campbell St | 0.00 | 0.01 | g/km/s |
| Grosvenor Rd A | 0.00 | 0.00 | g/km/s |
| Grosvenor Rd B | 0.00 | 0.01 | g/km/s |
| Grosvenor Rd C | 0.00 | 0.00 | g/km/s |
| Grosvenor Rd D | 0.00 | 0.00 | g/km/s |
| Grosvenor Rd E | 0.00 | 0.00 | g/km/s |
| Grosvenor Rd F | 0.00 | 0.00 | g/km/s |
| Grosvenor Rd G | 0.00 | 0.00 | g/km/s |
| Wilder St A | 0.00 | 0.00 | g/km/s |
| Wilder St B | 0.00 | 0.00 | g/km/s |
| Wilder St C | 0.00 | 0.00 | g/km/s |
| Wilder St D | 0.00 | 0.00 | g/km/s |
| Wilder St E | 0.00 | 0.00 | g/km/s |
| Wilder St F | 0.00 | 0.00 | g/km/s |
| William St | 0.00 | 0.00 | g/km/s |
| Denbigh St | 0.00 | 0.00 | g/km/s |
| Brigstocke Rd A | 0.03 | 0.11 | g/km/s |
| Brigstocke Rd B | 0.04 | 0.13 | g/km/s |
| Brigstocke Rd C | 0.03 | 0.11 | g/km/s |
| Brigstocke Rd D | 0.03 | 0.11 | g/km/s |
| Brigstocke Rd E | 0.03 | 0.11 | g/km/s |
| Winkworth Pl A | 0.00 | 0.00 | g/km/s |

| | | | |
|---|---|---|---|
| Winkworth Pl B | 0.00 | 0.00 | g/km/s |
| Winkworth Pl C | 0.00 | 0.00 | g/km/s |
| Winkworth Pl D | 0.00 | 0.00 | g/km/s |
| City Rd A | 0.06 | 0.42 | g/km/s |
| City Rd B | 0.05 | 0.38 | g/km/s |
| City Rd C | 0.05 | 0.38 | g/km/s |
| City Rd D | 0.05 | 0.38 | g/km/s |
| City Rd E | 0.06 | 0.39 | g/km/s |
| Upper York St A | 0.00 | 0.01 | g/km/s |
| Upper York St B | 0.00 | 0.01 | g/km/s |
| Upper York St C | 0.00 | 0.01 | g/km/s |
| Upper York St D | 0.00 | 0.01 | g/km/s |
| Backfields | 0.00 | 0.01 | g/km/s |
| Moon St A | 0.00 | 0.01 | g/km/s |
| Moon St B | 0.00 | 0.01 | g/km/s |
| Upper York St E | 0.00 | 0.01 | g/km/s |
| Cumberland St | 0.00 | 0.01 | g/km/s |
| York St A | 0.01 | 0.06 | g/km/s |
| York St B | 0.01 | 0.07 | g/km/s |
| Backfields Ln | 0.00 | 0.01 | g/km/s |
| Brunswick St A | 0.00 | 0.01 | g/km/s |
| Brunswick St B | 0.00 | 0.01 | g/km/s |
| Newfoundland Way F | 0.06 | 0.41 | g/km/s |
| Little Bishop Rd | 0.00 | 0.00 | g/km/s |
| Princes Rd A | 0.00 | 0.00 | g/km/s |
| Princes Rd B | 0.00 | 0.00 | g/km/s |
| Princes Rd C | 0.00 | 0.00 | g/km/s |
| Burnell Dr | 0.00 | 0.00 | g/km/s |
| Beggarswell Cl | 0.00 | 0.00 | g/km/s |
| Bishop St | 0.00 | 0.00 | g/km/s |
| Dean St A | 0.02 | 0.06 | g/km/s |
| Dean St B | 0.02 | 0.06 | g/km/s |
| Dean St C | 0.02 | 0.06 | g/km/s |
| Cave St A | 0.04 | 0.12 | g/km/s |
| Cave St B | 0.03 | 0.11 | g/km/s |
| Cave St C | 0.03 | 0.12 | g/km/s |
| Portland Square A | 0.04 | 0.21 | g/km/s |
| Portland Square B | 0.04 | 0.21 | g/km/s |
| Dean St D | 0.01 | 0.04 | g/km/s |
| Chapter St | 0.02 | 0.09 | g/km/s |
| St Nicholas Rd A | 0.04 | 0.21 | g/km/s |
| St Nicholas Rd B | 0.04 | 0.23 | g/km/s |
| St Nicholas Rd C | 0.04 | 0.23 | g/km/s |
| St Nicholas Rd D | 0.04 | 0.23 | g/km/s |
| St Nicholas Rd E | 0.04 | 0.23 | g/km/s |
| St Nicholas Rd F | 0.04 | 0.23 | g/km/s |
| Ludlow Cl A | 0.00 | 0.02 | g/km/s |
| Ludlow Cl B | 0.00 | 0.00 | g/km/s |
| Corey Cl | 0.00 | 0.00 | g/km/s |
| Halston Dr | 0.00 | 0.01 | g/km/s |
| Dove Ln A | 0.00 | 0.02 | g/km/s |
| Wilson St A | 0.00 | 0.01 | g/km/s |
| Wilson St B | 0.00 | 0.01 | g/km/s |
| St Paul St A | 0.01 | 0.04 | g/km/s |
| St Paul St B | 0.01 | 0.04 | g/km/s |
| Morgan St | 0.00 | 0.01 | g/km/s |
| Thomas St A | 0.00 | 0.01 | g/km/s |
| Tudor Rd | 0.02 | 0.18 | g/km/s |
| Lower Ashley Rd A | 0.08 | 0.52 | g/km/s |
| Lower Ashely Rd B | 0.08 | 0.52 | g/km/s |
| Lower Ashley Rd C | 0.08 | 0.52 | g/km/s |
| Lower Ashley Rd D | 0.08 | 0.52 | g/km/s |
| Newfoundland Rd D | 0.00 | 0.01 | g/km/s |
| Newfloundland Rd E | 0.00 | 0.01 | g/km/s |
| Byron St | 0.00 | 0.00 | g/km/s |
| Fern St | 0.00 | 0.00 | g/km/s |
| Dermot St | 0.00 | 0.00 | g/km/s |

|  |  |  |  |
|---|---|---|---|
| Davey St | 0.00 | 0.01 | g/km/s |
| Franklyn St | 0.00 | 0.01 | g/km/s |
| Franklyn Ln | 0.00 | 0.00 | g/km/s |
| Ashfield Pl | 0.00 | 0.00 | g/km/s |
| Badminton Rd C | 0.03 | 0.19 | g/km/s |
| London Rd A | 0.03 | 0.28 | g/km/s |
| London Rd B | 0.03 | 0.28 | g/km/s |
| Argyle Rd A | 0.00 | 0.00 | g/km/s |
| Argyle Rd B | 0.00 | 0.00 | g/km/s |
| Brunswick Sq A | 0.00 | 0.01 | g/km/s |
| Brunswick Sq B | 0.00 | 0.01 | g/km/s |
| Brunswick Sq C | 0.00 | 0.01 | g/km/s |
| Gloucester St | 0.00 | 0.00 | g/km/s |
| Pritchard St A | 0.00 | 0.01 | g/km/s |
| Pritchard St B | 0.00 | 0.01 | g/km/s |
| Pritchard St C | 0.00 | 0.01 | g/km/s |
| Orange St A | 0.00 | 0.02 | g/km/s |
| Orange St B | 0.00 | 0.02 | g/km/s |
| Lemon Ln A | 0.00 | 0.00 | g/km/s |
| Lemon Ln B | 0.00 | 0.00 | g/km/s |
| Norfolk Ave | 0.00 | 0.01 | g/km/s |
| Surrey St | 0.00 | 0.01 | g/km/s |
| Pembroke St | 0.00 | 0.01 | g/km/s |
| Dove Ln B | 0.00 | 0.01 | g/km/s |
| Bond St South | 0.06 | 0.37 | g/km/s |

*Table 85 Traffic dataset (EFT v9.0 (2 VC)) for Bristol St Paul's.*

| **Source name** | **Road width (m)** | **Canyon height (m)** | **Traffic flows used** | **Traffic flow year** | **Traffic flow road type** |
|---|---|---|---|---|---|
| Ashley Rd A | 8 | 10 | Yes | 2019 | England (urban) |
| Ashley Rd B | 8 | 10 | Yes | 2019 | England (urban) |
| Ashley Rd C | 8 | 10 | Yes | 2019 | England (urban) |
| Ashley Rd D | 8 | 10 | Yes | 2019 | England (urban) |
| Ashley Rd E | 8 | 10 | Yes | 2019 | England (urban) |
| Ashley Rd F | 8 | 10 | Yes | 2019 | England (urban) |
| Ashley Rd G | 8 | 10 | Yes | 2019 | England (urban) |
| Ashley Rd H | 8 | 10 | Yes | 2019 | England (urban) |
| Ashley Rd I | 8 | 10 | Yes | 2019 | England (urban) |
| Ashley Rd J | 8 | 10 | Yes | 2019 | England (urban) |
| Ashley Rd K | 8 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Way A | 20 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Way B | 20 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Way C | 20 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Way D | 20 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Way E | 20 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Way G | 20 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Way H | 20 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Way I | 20 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Rd A | 20 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Rd B | 20 | 10 | Yes | 2019 | England (urban) |
| Newfoundland Rd C | 20 | 10 | Yes | 2019 | England (urban) |
| Badminton Rd A | 10 | 18 | Yes | 2019 | England (urban) |
| Badminton Rd B | 10 | 18 | Yes | 2019 | England (urban) |
| Cheltenham Rd A | 13 | 10 | Yes | 2019 | England (urban) |
| Cheltenham Rd B | 13 | 10 | Yes | 2019 | England (urban) |
| Cheltenham Rd C | 13 | 10 | Yes | 2019 | England (urban) |
| Cheltenham Rd D | 13 | 10 | Yes | 2019 | England (urban) |
| Cheltenham Rd E | 13 | 10 | Yes | 2019 | England (urban) |
| Hepburn Rd | 5 | 8 | Yes | 2019 | England (urban) |
| Gwyn St | 6 | 8 | Yes | 2019 | England (urban) |
| Drummand Rd A | 5 | 8 | Yes | 2019 | England (urban) |
| Drummand Rd B | 5 | 8 | Yes | 2019 | England (urban) |
| Wellington Ave | 4 | 8 | Yes | 2019 | England (urban) |
| Barnabas St | 4 | 5 | Yes | 2019 | England (urban) |

| | | | | | |
|---|---|---|---|---|---|
| Campbell St | 3 | 8 | Yes | 2019 | England (urban) |
| Grosvenor Rd A | 7 | 9 | Yes | 2019 | England (urban) |
| Grosvenor Rd B | 7 | 9 | Yes | 2019 | England (urban) |
| Grosvenor Rd C | 7 | 9 | Yes | 2019 | England (urban) |
| Grosvenor Rd D | 7 | 9 | Yes | 2019 | England (urban) |
| Grosvenor Rd E | 7 | 9 | Yes | 2019 | England (urban) |
| Grosvenor Rd F | 7 | 9 | Yes | 2019 | England (urban) |
| Grosvenor Rd G | 7 | 9 | Yes | 2019 | England (urban) |
| Wilder St A | 5 | 9 | Yes | 2019 | England (urban) |
| Wilder St B | 5 | 9 | Yes | 2019 | England (urban) |
| Wilder St C | 5 | 9 | Yes | 2019 | England (urban) |
| Wilder St D | 5 | 9 | Yes | 2019 | England (urban) |
| Wilder St E | 5 | 9 | Yes | 2019 | England (urban) |
| Wilder St F | 5 | 9 | Yes | 2019 | England (urban) |
| William St | 5 | 10 | Yes | 2019 | England (urban) |
| Denbigh St | 5 | 7 | Yes | 2019 | England (urban) |
| Brigstocke Rd A | 7 | 9 | Yes | 2019 | England (urban) |
| Brigstocke Rd B | 7 | 9 | Yes | 2019 | England (urban) |
| Brigstocke Rd C | 7 | 9 | Yes | 2019 | England (urban) |
| Brigstocke Rd D | 7 | 9 | Yes | 2019 | England (urban) |
| Brigstocke Rd E | 7 | 9 | Yes | 2019 | England (urban) |
| Winkworth Pl A | 5 | 7 | Yes | 2019 | England (urban) |
| Winkworth Pl B | 5 | 7 | Yes | 2019 | England (urban) |
| Winkworth Pl C | 5 | 7 | Yes | 2019 | England (urban) |
| Winkworth Pl D | 5 | 7 | Yes | 2019 | England (urban) |
| City Rd A | 7 | 8 | Yes | 2019 | England (urban) |
| City Rd B | 7 | 8 | Yes | 2019 | England (urban) |
| City Rd C | 7 | 8 | Yes | 2019 | England (urban) |
| City Rd D | 7 | 8 | Yes | 2019 | England (urban) |
| City Rd E | 7 | 8 | Yes | 2019 | England (urban) |
| Upper York St A | 6 | 16 | Yes | 2019 | England (urban) |
| Upper York St B | 6 | 16 | Yes | 2019 | England (urban) |
| Upper York St C | 6 | 16 | Yes | 2019 | England (urban) |
| Upper York St D | 6 | 16 | Yes | 2019 | England (urban) |
| Backfields | 6 | 15 | Yes | 2019 | England (urban) |
| Moon St A | 6 | 6 | Yes | 2019 | England (urban) |
| Moon St B | 6 | 6 | Yes | 2019 | England (urban) |
| Upper York St E | 6 | 16 | Yes | 2019 | England (urban) |
| Cumberland St | 6 | 12 | Yes | 2019 | England (urban) |
| York St A | 6 | 13 | Yes | 2019 | England (urban) |
| York St B | 6 | 13 | Yes | 2019 | England (urban) |
| Backfields Ln | 4 | 8 | Yes | 2019 | England (urban) |
| Brunswick St A | 3 | 8 | Yes | 2019 | England (urban) |
| Brunswick St B | 3 | 8 | Yes | 2019 | England (urban) |
| Newfoundland Way F | 20 | 10 | Yes | 2019 | England (urban) |
| Little Bishop Rd | 9 | 6 | Yes | 2019 | England (urban) |
| Princes Rd A | 6 | 9 | Yes | 2019 | England (urban) |
| Princes Rd B | 6 | 9 | Yes | 2019 | England (urban) |
| Princes Rd C | 6 | 9 | Yes | 2019 | England (urban) |
| Burnell Dr | 5 | 4 | Yes | 2019 | England (urban) |
| Beggarswell Cl | 5 | 2 | Yes | 2019 | England (urban) |
| Bishop St | 7 | 14 | Yes | 2019 | England (urban) |
| Dean St A | 5 | 11 | Yes | 2019 | England (urban) |
| Dean St B | 10 | 11 | Yes | 2019 | England (urban) |
| Dean St C | 10 | 11 | Yes | 2019 | England (urban) |
| Cave St A | 4 | 14 | Yes | 2019 | England (urban) |
| Cave St B | 4 | 14 | Yes | 2019 | England (urban) |
| Cave St C | 4 | 14 | Yes | 2019 | England (urban) |
| Portland Square A | 9 | 20 | Yes | 2019 | England (urban) |
| Portland Square B | 9 | 20 | Yes | 2019 | England (urban) |
| Dean St D | 10 | 11 | Yes | 2019 | England (urban) |
| Chapter St | 5 | 16 | Yes | 2019 | England (urban) |
| St Nicholas Rd A | 8 | 6 | Yes | 2019 | England (urban) |
| St Nicholas Rd B | 8 | 6 | Yes | 2019 | England (urban) |
| St Nicholas Rd C | 8 | 6 | Yes | 2019 | England (urban) |
| St Nicholas Rd D | 8 | 6 | Yes | 2019 | England (urban) |
| St Nicholas Rd E | 8 | 6 | Yes | 2019 | England (urban) |

| | | | | | |
|---|---|---|---|---|---|
| St Nicholas Rd F | 8 | 6 | Yes | 2019 | England (urban) |
| Ludlow Cl A | 7 | 3 | Yes | 2019 | England (urban) |
| Ludlow Cl B | 7 | 3 | Yes | 2019 | England (urban) |
| Corey Cl | 4 | 8 | Yes | 2019 | England (urban) |
| Halston Dr | 6 | 6 | Yes | 2019 | England (urban) |
| Dove Ln A | 5 | 0 | Yes | 2019 | England (urban) |
| Wilson St A | 4 | 8 | Yes | 2019 | England (urban) |
| Wilson St B | 4 | 8 | Yes | 2019 | England (urban) |
| St Paul St A | 5 | 18 | Yes | 2019 | England (urban) |
| St Paul St B | 5 | 18 | Yes | 2019 | England (urban) |
| Morgan St | 4 | 8 | Yes | 2019 | England (urban) |
| Thomas St A | 4 | 7 | Yes | 2019 | England (urban) |
| Tudor Rd | 5 | 11 | Yes | 2019 | England (urban) |
| Lower Ashley Rd A | 6 | 8 | Yes | 2019 | England (urban) |
| Lower Ashely Rd B | 6 | 8 | Yes | 2019 | England (urban) |
| Lower Ashley Rd C | 6 | 8 | Yes | 2019 | England (urban) |
| Lower Ashley Rd D | 6 | 8 | Yes | 2019 | England (urban) |
| Newfoundland Rd D | 20 | 10 | Yes | 2019 | England (urban) |
| Newfloundland Rd E | 20 | 10 | Yes | 2019 | England (urban) |
| Byron St | 4 | 8 | Yes | 2019 | England (urban) |
| Fern St | 4 | 8 | Yes | 2019 | England (urban) |
| Dermot St | 4 | 8 | Yes | 2019 | England (urban) |
| Davey St | 5 | 6 | Yes | 2019 | England (urban) |
| Franklyn St | 5 | 6 | Yes | 2019 | England (urban) |
| Franklyn Ln | 3 | 6 | Yes | 2019 | England (urban) |
| Ashfield Pl | 3 | 8 | Yes | 2019 | England (urban) |
| Badminton Rd C | 10 | 18 | Yes | 2019 | England (urban) |
| London Rd A | 5 | 8 | Yes | 2019 | England (urban) |
| London Rd B | 5 | 8 | Yes | 2019 | England (urban) |
| Argyle Rd A | 5 | 10 | Yes | 2019 | England (urban) |
| Argyle Rd B | 5 | 10 | Yes | 2019 | England (urban) |
| Brunswick Sq A | 4 | 8 | Yes | 2019 | England (urban) |
| Brunswick Sq B | 4 | 8 | Yes | 2019 | England (urban) |
| Brunswick Sq C | 4 | 8 | Yes | 2019 | England (urban) |
| Gloucester St | 6 | 15 | Yes | 2019 | England (urban) |
| Pritchard St A | 5 | 15 | Yes | 2019 | England (urban) |
| Pritchard St B | 5 | 15 | Yes | 2019 | England (urban) |
| Pritchard St C | 5 | 15 | Yes | 2019 | England (urban) |
| Orange St A | 4 | 17 | Yes | 2019 | England (urban) |
| Orange St B | 4 | 17 | Yes | 2019 | England (urban) |
| Lemon Ln A | 3 | 13 | Yes | 2019 | England (urban) |
| Lemon Ln B | 3 | 13 | Yes | 2019 | England (urban) |
| Norfolk Ave | 5 | 15 | Yes | 2019 | England (urban) |
| Surrey St | 6 | 15 | Yes | 2019 | England (urban) |
| Pembroke St | 6 | 11 | Yes | 2019 | England (urban) |
| Dove Ln B | 5 | 0 | Yes | 2019 | England (urban) |
| Bond St South | 14 | 20 | Yes | 2019 | England (urban) |

*Table 86 Traffic data for Bristol St Paul's.*

| **Source name** | **Vehicle category** | **Average speed (km/hr)** | **Vehicle count (vehicles/hour)** | **Percent uphill** |
|---|---|---|---|---|
| Ashley Rd A | light duty vehicle | 14 | 695 | 50 |
| Ashley Rd A | heavy duty vehicle | 10 | 20 | 50 |
| Ashley Rd B | light duty vehicle | 14 | 695 | 50 |
| Ashley Rd B | heavy duty vehicle | 10 | 18 | 50 |
| Ashley Rd C | light duty vehicle | 14 | 695 | 50 |
| Ashley Rd C | heavy duty vehicle | 10 | 18 | 50 |
| Ashley Rd D | light duty vehicle | 14 | 695 | 50 |
| Ashley Rd D | heavy duty vehicle | 10 | 20 | 50 |
| Ashley Rd E | light duty vehicle | 14 | 595 | 50 |
| Ashley Rd E | heavy duty vehicle | 10 | 20 | 50 |
| Ashley Rd F | light duty vehicle | 14 | 595 | 50 |
| Ashley Rd F | heavy duty vehicle | 10 | 20 | 50 |

| | | | | |
|---|---|---|---|---|
| Ashley Rd G | light duty vehicle | 14 | 595 | 50 |
| Ashley Rd G | heavy duty vehicle | 10 | 20 | 50 |
| Ashley Rd H | light duty vehicle | 10 | 995 | 50 |
| Ashley Rd H | heavy duty vehicle | 6 | 160 | 50 |
| Ashley Rd I | light duty vehicle | 10 | 995 | 50 |
| Ashley Rd I | heavy duty vehicle | 6 | 160 | 50 |
| Ashley Rd J | light duty vehicle | 10 | 995 | 50 |
| Ashley Rd J | heavy duty vehicle | 6 | 160 | 50 |
| Ashley Rd K | light duty vehicle | 10 | 995 | 50 |
| Ashley Rd K | heavy duty vehicle | 6 | 160 | 50 |
| Newfoundland Way A | light duty vehicle | 18 | 1294 | 50 |
| Newfoundland Way A | heavy duty vehicle | 12 | 622 | 50 |
| Newfoundland Way B | light duty vehicle | 18 | 1294 | 50 |
| Newfoundland Way B | heavy duty vehicle | 12 | 622 | 50 |
| Newfoundland Way C | light duty vehicle | 20 | 1294 | 50 |
| Newfoundland Way C | heavy duty vehicle | 16 | 622 | 50 |
| Newfoundland Way D | light duty vehicle | 20 | 1294 | 50 |
| Newfoundland Way D | heavy duty vehicle | 16 | 622 | 50 |
| Newfoundland Way E | light duty vehicle | 20 | 1294 | 50 |
| Newfoundland Way E | heavy duty vehicle | 16 | 622 | 50 |
| Newfoundland Way G | light duty vehicle | 20 | 1294 | 50 |
| Newfoundland Way G | heavy duty vehicle | 16 | 622 | 50 |
| Newfoundland Way H | light duty vehicle | 20 | 1294 | 50 |
| Newfoundland Way H | heavy duty vehicle | 16 | 622 | 50 |
| Newfoundland Way I | light duty vehicle | 20 | 1294 | 50 |
| Newfoundland Way I | heavy duty vehicle | 16 | 622 | 50 |
| Newfoundland Rd A | light duty vehicle | 20 | 80 | 50 |
| Newfoundland Rd A | heavy duty vehicle | 14 | 10 | 50 |
| Newfoundland Rd B | light duty vehicle | 24 | 80 | 50 |
| Newfoundland Rd B | heavy duty vehicle | 18 | 10 | 50 |
| Newfoundland Rd C | light duty vehicle | 24 | 40 | 50 |
| Newfoundland Rd C | heavy duty vehicle | 20 | 5 | 50 |
| Badminton Rd A | light duty vehicle | 10 | 400 | 50 |
| Badminton Rd A | heavy duty vehicle | 6 | 80 | 50 |
| Badminton Rd B | light duty vehicle | 10 | 400 | 50 |
| Badminton Rd B | heavy duty vehicle | 6 | 80 | 50 |
| Cheltenham Rd A | light duty vehicle | 18 | 600 | 50 |
| Cheltenham Rd A | heavy duty vehicle | 14 | 10 | 50 |
| Cheltenham Rd B | light duty vehicle | 18 | 600 | 50 |
| Cheltenham Rd B | heavy duty vehicle | 14 | 10 | 50 |
| Cheltenham Rd C | light duty vehicle | 18 | 600 | 50 |
| Cheltenham Rd C | heavy duty vehicle | 14 | 10 | 50 |
| Cheltenham Rd D | light duty vehicle | 18 | 600 | 50 |
| Cheltenham Rd D | heavy duty vehicle | 14 | 10 | 50 |
| Cheltenham Rd E | light duty vehicle | 18 | 600 | 50 |
| Cheltenham Rd E | heavy duty vehicle | 12 | 10 | 50 |
| Hepburn Rd | light duty vehicle | 14 | 400 | 50 |
| Hepburn Rd | heavy duty vehicle | 10 | 40 | 50 |
| Gwyn St | light duty vehicle | 18 | 40 | 50 |
| Gwyn St | heavy duty vehicle | 12 | 2 | 50 |
| Drummand Rd A | light duty vehicle | 14 | 120 | 50 |
| Drummand Rd A | heavy duty vehicle | 10 | 30 | 50 |
| Drummand Rd B | light duty vehicle | 14 | 120 | 50 |
| Drummand Rd B | heavy duty vehicle | 10 | 30 | 50 |
| Wellington Ave | light duty vehicle | 18 | 45 | 50 |
| Wellington Ave | heavy duty vehicle | 12 | 2 | 50 |
| Barnabas St | light duty vehicle | 16 | 20 | 50 |
| Barnabas St | heavy duty vehicle | 5 | 0 | 50 |
| Campbell St | light duty vehicle | 20 | 40 | 50 |
| Campbell St | heavy duty vehicle | 14 | 2 | 50 |
| Grosvenor Rd A | light duty vehicle | 18 | 30 | 50 |
| Grosvenor Rd A | heavy duty vehicle | 14 | 1 | 50 |
| Grosvenor Rd B | light duty vehicle | 24 | 30 | 50 |
| Grosvenor Rd B | heavy duty vehicle | 20 | 2 | 50 |
| Grosvenor Rd C | light duty vehicle | 24 | 10 | 50 |
| Grosvenor Rd C | heavy duty vehicle | 20 | 1 | 50 |
| Grosvenor Rd D | light duty vehicle | 24 | 10 | 50 |

| | | | | |
|---|---|---|---|---|
| Grosvenor Rd D | heavy duty vehicle | 20 | 1 | 50 |
| Grosvenor Rd E | light duty vehicle | 24 | 10 | 50 |
| Grosvenor Rd E | heavy duty vehicle | 20 | 1 | 50 |
| Grosvenor Rd F | light duty vehicle | 24 | 10 | 50 |
| Grosvenor Rd F | heavy duty vehicle | 20 | 1 | 50 |
| Grosvenor Rd G | light duty vehicle | 24 | 10 | 50 |
| Grosvenor Rd G | heavy duty vehicle | 20 | 1 | 50 |
| Wilder St A | light duty vehicle | 22 | 10 | 50 |
| Wilder St A | heavy duty vehicle | 18 | 1 | 50 |
| Wilder St B | light duty vehicle | 22 | 10 | 50 |
| Wilder St B | heavy duty vehicle | 18 | 1 | 50 |
| Wilder St C | light duty vehicle | 22 | 10 | 50 |
| Wilder St C | heavy duty vehicle | 18 | 1 | 50 |
| Wilder St D | light duty vehicle | 22 | 10 | 50 |
| Wilder St D | heavy duty vehicle | 18 | 1 | 50 |
| Wilder St E | light duty vehicle | 22 | 10 | 50 |
| Wilder St E | heavy duty vehicle | 18 | 1 | 50 |
| Wilder St F | light duty vehicle | 22 | 10 | 50 |
| Wilder St F | heavy duty vehicle | 18 | 1 | 50 |
| William St | light duty vehicle | 16 | 20 | 50 |
| William St | heavy duty vehicle | 12 | 1 | 50 |
| Denbigh St | light duty vehicle | 20 | 20 | 50 |
| Denbigh St | heavy duty vehicle | 14 | 1 | 50 |
| Brigstocke Rd A | light duty vehicle | 20 | 870 | 50 |
| Brigstocke Rd A | heavy duty vehicle | 16 | 9 | 50 |
| Brigstocke Rd B | light duty vehicle | 14 | 870 | 50 |
| Brigstocke Rd B | heavy duty vehicle | 10 | 9 | 50 |
| Brigstocke Rd C | light duty vehicle | 24 | 870 | 50 |
| Brigstocke Rd C | heavy duty vehicle | 20 | 9 | 50 |
| Brigstocke Rd D | light duty vehicle | 24 | 870 | 50 |
| Brigstocke Rd D | heavy duty vehicle | 20 | 9 | 50 |
| Brigstocke Rd E | light duty vehicle | 22 | 870 | 50 |
| Brigstocke Rd E | heavy duty vehicle | 18 | 9 | 50 |
| Winkworth Pl A | light duty vehicle | 24 | 20 | 50 |
| Winkworth Pl A | heavy duty vehicle | 20 | 1 | 50 |
| Winkworth Pl B | light duty vehicle | 24 | 20 | 50 |
| Winkworth Pl B | heavy duty vehicle | 20 | 1 | 50 |
| Winkworth Pl C | light duty vehicle | 24 | 20 | 50 |
| Winkworth Pl C | heavy duty vehicle | 20 | 1 | 50 |
| Winkworth Pl D | light duty vehicle | 24 | 20 | 50 |
| Winkworth Pl D | heavy duty vehicle | 20 | 1 | 50 |
| City Rd A | light duty vehicle | 20 | 800 | 50 |
| City Rd A | heavy duty vehicle | 16 | 300 | 50 |
| City Rd B | light duty vehicle | 24 | 800 | 50 |
| City Rd B | heavy duty vehicle | 18 | 300 | 50 |
| City Rd C | light duty vehicle | 24 | 800 | 50 |
| City Rd C | heavy duty vehicle | 18 | 300 | 50 |
| City Rd D | light duty vehicle | 24 | 800 | 50 |
| City Rd D | heavy duty vehicle | 18 | 300 | 50 |
| City Rd E | light duty vehicle | 20 | 800 | 50 |
| City Rd E | heavy duty vehicle | 18 | 300 | 50 |
| Upper York St A | light duty vehicle | 24 | 60 | 50 |
| Upper York St A | heavy duty vehicle | 20 | 2 | 50 |
| Upper York St B | light duty vehicle | 24 | 60 | 50 |
| Upper York St B | heavy duty vehicle | 18 | 2 | 50 |
| Upper York St C | light duty vehicle | 24 | 60 | 50 |
| Upper York St C | heavy duty vehicle | 18 | 2 | 50 |
| Upper York St D | light duty vehicle | 20 | 60 | 50 |
| Upper York St D | heavy duty vehicle | 16 | 2 | 50 |
| Backfields | light duty vehicle | 22 | 40 | 50 |
| Backfields | heavy duty vehicle | 18 | 4 | 50 |
| Moon St A | light duty vehicle | 24 | 40 | 50 |
| Moon St A | heavy duty vehicle | 20 | 2 | 50 |
| Moon St B | light duty vehicle | 24 | 40 | 50 |
| Moon St B | heavy duty vehicle | 20 | 2 | 50 |
| Upper York St E | light duty vehicle | 20 | 60 | 50 |
| Upper York St E | heavy duty vehicle | 16 | 2 | 50 |

| | | | | |
|---|---|---|---|---|
| Cumberland St | light duty vehicle | 24 | 40 | 50 |
| Cumberland St | heavy duty vehicle | 20 | 2 | 50 |
| York St A | light duty vehicle | 24 | 80 | 50 |
| York St A | heavy duty vehicle | 20 | 60 | 50 |
| York St B | light duty vehicle | 20 | 80 | 50 |
| York St B | heavy duty vehicle | 16 | 60 | 50 |
| Backfields Ln | light duty vehicle | 20 | 40 | 50 |
| Backfields Ln | heavy duty vehicle | 14 | 1 | 50 |
| Brunswick St A | light duty vehicle | 22 | 40 | 50 |
| Brunswick St A | heavy duty vehicle | 14 | 2 | 50 |
| Brunswick St B | light duty vehicle | 22 | 40 | 50 |
| Brunswick St B | heavy duty vehicle | 18 | 2 | 50 |
| Newfoundland Way F | light duty vehicle | 24 | 890 | 50 |
| Newfoundland Way F | heavy duty vehicle | 18 | 320 | 50 |
| Little Bishop Rd | light duty vehicle | 26 | 10 | 50 |
| Little Bishop Rd | heavy duty vehicle | 20 | 1 | 50 |
| Princes Rd A | light duty vehicle | 26 | 10 | 50 |
| Princes Rd A | heavy duty vehicle | 20 | 1 | 50 |
| Princes Rd B | light duty vehicle | 26 | 10 | 50 |
| Princes Rd B | heavy duty vehicle | 20 | 1 | 50 |
| Princes Rd C | light duty vehicle | 26 | 10 | 50 |
| Princes Rd C | heavy duty vehicle | 20 | 1 | 50 |
| Burnell Dr | light duty vehicle | 22 | 4 | 50 |
| Burnell Dr | heavy duty vehicle | 18 | 0 | 50 |
| Beggarswell Cl | light duty vehicle | 14 | 5 | 50 |
| Beggarswell Cl | heavy duty vehicle | 5 | 0 | 50 |
| Bishop St | light duty vehicle | 20 | 30 | 50 |
| Bishop St | heavy duty vehicle | 14 | 1 | 50 |
| Dean St A | light duty vehicle | 22 | 460 | 50 |
| Dean St A | heavy duty vehicle | 16 | 5 | 50 |
| Dean St B | light duty vehicle | 22 | 460 | 50 |
| Dean St B | heavy duty vehicle | 18 | 5 | 50 |
| Dean St C | light duty vehicle | 20 | 460 | 50 |
| Dean St C | heavy duty vehicle | 16 | 5 | 50 |
| Cave St A | light duty vehicle | 16 | 860 | 50 |
| Cave St A | heavy duty vehicle | 12 | 9 | 50 |
| Cave St B | light duty vehicle | 20 | 860 | 50 |
| Cave St B | heavy duty vehicle | 14 | 9 | 50 |
| Cave St C | light duty vehicle | 18 | 860 | 50 |
| Cave St C | heavy duty vehicle | 14 | 9 | 50 |
| Portland Square A | light duty vehicle | 14 | 860 | 50 |
| Portland Square A | heavy duty vehicle | 10 | 60 | 50 |
| Portland Square B | light duty vehicle | 14 | 860 | 50 |
| Portland Square B | heavy duty vehicle | 10 | 60 | 50 |
| Dean St D | light duty vehicle | 20 | 120 | 50 |
| Dean St D | heavy duty vehicle | 14 | 20 | 50 |
| Chapter St | light duty vehicle | 22 | 401 | 50 |
| Chapter St | heavy duty vehicle | 16 | 40 | 50 |
| St Nicholas Rd A | light duty vehicle | 16 | 800 | 50 |
| St Nicholas Rd A | heavy duty vehicle | 12 | 80 | 50 |
| St Nicholas Rd B | light duty vehicle | 16 | 800 | 50 |
| St Nicholas Rd B | heavy duty vehicle | 10 | 80 | 50 |
| St Nicholas Rd C | light duty vehicle | 16 | 800 | 50 |
| St Nicholas Rd C | heavy duty vehicle | 10 | 80 | 50 |
| St Nicholas Rd D | light duty vehicle | 16 | 800 | 50 |
| St Nicholas Rd D | heavy duty vehicle | 10 | 80 | 50 |
| St Nicholas Rd E | light duty vehicle | 16 | 800 | 50 |
| St Nicholas Rd E | heavy duty vehicle | 10 | 80 | 50 |
| St Nicholas Rd F | light duty vehicle | 16 | 800 | 50 |
| St Nicholas Rd F | heavy duty vehicle | 10 | 80 | 50 |
| Ludlow Cl A | light duty vehicle | 16 | 40 | 50 |
| Ludlow Cl A | heavy duty vehicle | 12 | 10 | 50 |
| Ludlow Cl B | light duty vehicle | 16 | 0 | 50 |
| Ludlow Cl B | heavy duty vehicle | 12 | 0 | 50 |
| Corey Cl | light duty vehicle | 18 | 20 | 50 |
| Corey Cl | heavy duty vehicle | 12 | 1 | 50 |
| Halston Dr | light duty vehicle | 18 | 20 | 50 |

| | | | | |
|---|---|---|---|---|
| Halston Dr | heavy duty vehicle | 12 | 2 | 50 |
| Dove Ln A | light duty vehicle | 22 | 100 | 50 |
| Dove Ln A | heavy duty vehicle | 18 | 10 | 50 |
| Wilson St A | light duty vehicle | 22 | 50 | 50 |
| Wilson St A | heavy duty vehicle | 18 | 5 | 50 |
| Wilson St B | light duty vehicle | 22 | 50 | 50 |
| Wilson St B | heavy duty vehicle | 18 | 5 | 50 |
| St Paul St A | light duty vehicle | 22 | 300 | 50 |
| St Paul St A | heavy duty vehicle | 18 | 10 | 50 |
| St Paul St B | light duty vehicle | 24 | 300 | 50 |
| St Paul St B | heavy duty vehicle | 18 | 10 | 50 |
| Morgan St | light duty vehicle | 22 | 40 | 50 |
| Morgan St | heavy duty vehicle | 18 | 2 | 50 |
| Thomas St A | light duty vehicle | 20 | 40 | 50 |
| Thomas St A | heavy duty vehicle | 18 | 2 | 50 |
| Tudor Rd | light duty vehicle | 10 | 180 | 50 |
| Tudor Rd | heavy duty vehicle | 6 | 60 | 50 |
| Lower Ashley Rd A | light duty vehicle | 8 | 1095 | 50 |
| Lower Ashley Rd A | heavy duty vehicle | 6 | 140 | 50 |
| Lower Ashely Rd B | light duty vehicle | 8 | 1095 | 50 |
| Lower Ashely Rd B | heavy duty vehicle | 6 | 140 | 50 |
| Lower Ashley Rd C | light duty vehicle | 8 | 1095 | 50 |
| Lower Ashley Rd C | heavy duty vehicle | 6 | 140 | 50 |
| Lower Ashley Rd D | light duty vehicle | 8 | 1095 | 50 |
| Lower Ashley Rd D | heavy duty vehicle | 6 | 140 | 50 |
| Newfoundland Rd D | light duty vehicle | 22 | 40 | 50 |
| Newfoundland Rd D | heavy duty vehicle | 18 | 2 | 50 |
| Newfloundland Rd E | light duty vehicle | 20 | 40 | 50 |
| Newfloundland Rd E | heavy duty vehicle | 16 | 2 | 50 |
| Byron St | light duty vehicle | 24 | 20 | 50 |
| Byron St | heavy duty vehicle | 18 | 1 | 50 |
| Fern St | light duty vehicle | 22 | 20 | 50 |
| Fern St | heavy duty vehicle | 16 | 1 | 50 |
| Dermot St | light duty vehicle | 26 | 20 | 50 |
| Dermot St | heavy duty vehicle | 16 | 1 | 50 |
| Davey St | light duty vehicle | 22 | 40 | 50 |
| Davey St | heavy duty vehicle | 18 | 2 | 50 |
| Franklyn St | light duty vehicle | 22 | 40 | 50 |
| Franklyn St | heavy duty vehicle | 18 | 2 | 50 |
| Franklyn Ln | light duty vehicle | 18 | 10 | 50 |
| Franklyn Ln | heavy duty vehicle | 5 | 0 | 50 |
| Ashfield Pl | light duty vehicle | 18 | 20 | 50 |
| Ashfield Pl | heavy duty vehicle | 5 | 0 | 50 |
| Badminton Rd C | light duty vehicle | 18 | 400 | 50 |
| Badminton Rd C | heavy duty vehicle | 14 | 120 | 50 |
| London Rd A | light duty vehicle | 14 | 400 | 50 |
| London Rd A | heavy duty vehicle | 8 | 120 | 50 |
| London Rd B | light duty vehicle | 14 | 400 | 50 |
| London Rd B | heavy duty vehicle | 8 | 120 | 50 |
| Argyle Rd A | light duty vehicle | 20 | 30 | 50 |
| Argyle Rd A | heavy duty vehicle | 16 | 1 | 50 |
| Argyle Rd B | light duty vehicle | 22 | 30 | 50 |
| Argyle Rd B | heavy duty vehicle | 18 | 1 | 50 |
| Brunswick Sq A | light duty vehicle | 22 | 60 | 50 |
| Brunswick Sq A | heavy duty vehicle | 18 | 1 | 50 |
| Brunswick Sq B | light duty vehicle | 22 | 60 | 50 |
| Brunswick Sq B | heavy duty vehicle | 20 | 1 | 50 |
| Brunswick Sq C | light duty vehicle | 22 | 60 | 50 |
| Brunswick Sq C | heavy duty vehicle | 18 | 1 | 50 |
| Gloucester St | light duty vehicle | 20 | 30 | 50 |
| Gloucester St | heavy duty vehicle | 16 | 1 | 50 |
| Pritchard St A | light duty vehicle | 22 | 30 | 50 |
| Pritchard St A | heavy duty vehicle | 18 | 2 | 50 |
| Pritchard St B | light duty vehicle | 20 | 30 | 50 |
| Pritchard St B | heavy duty vehicle | 16 | 2 | 50 |
| Pritchard St C | light duty vehicle | 20 | 30 | 50 |
| Pritchard St C | heavy duty vehicle | 16 | 2 | 50 |

| | | | | |
|---|---|---|---|---|
| Orange St A | light duty vehicle | 16 | 60 | 50 |
| Orange St A | heavy duty vehicle | 10 | 10 | 50 |
| Orange St B | light duty vehicle | 16 | 60 | 50 |
| Orange St B | heavy duty vehicle | 10 | 10 | 50 |
| Lemon Ln A | light duty vehicle | 12 | 10 | 50 |
| Lemon Ln A | heavy duty vehicle | 8 | 1 | 50 |
| Lemon Ln B | light duty vehicle | 16 | 10 | 50 |
| Lemon Ln B | heavy duty vehicle | 10 | 1 | 50 |
| Norfolk Ave | light duty vehicle | 22 | 40 | 50 |
| Norfolk Ave | heavy duty vehicle | 18 | 2 | 50 |
| Surrey St | light duty vehicle | 22 | 40 | 50 |
| Surrey St | heavy duty vehicle | 18 | 2 | 50 |
| Pembroke St | light duty vehicle | 22 | 40 | 50 |
| Pembroke St | heavy duty vehicle | 18 | 2 | 50 |
| Dove Ln B | light duty vehicle | 22 | 25 | 50 |
| Dove Ln B | heavy duty vehicle | 18 | 10 | 50 |
| Bond St South | light duty vehicle | 12 | 800 | 50 |
| Bond St South | heavy duty vehicle | 8 | 140 | 50 |

### ii. Bristol Bedminster

*Table 87 Source Emission Rates for Bristol Bedminster.*

| **Source name** | **Emission rate ($NO_2$)** | **Emission rate ($NO_X$)** | **Comments** |
|---|---|---|---|
| Bedminster Rd A | 0.03 | 0.16 | g/km/s |
| Bedminster Rd B | 0.03 | 0.12 | g/km/s |
| Bedminster Rd C | 0.03 | 0.12 | g/km/s |
| Bedminster Rd D | 0.03 | 0.12 | g/km/s |
| Bedminster Rd E | 0.03 | 0.12 | g/km/s |
| Bedminster Rd F | 0.03 | 0.16 | g/km/s |
| West St A | 0.03 | 0.19 | g/km/s |
| West St B | 0.03 | 0.14 | g/km/s |
| West St C | 0.03 | 0.14 | g/km/s |
| West St D | 0.03 | 0.14 | g/km/s |
| West St E | 0.03 | 0.14 | g/km/s |
| West St F | 0.03 | 0.14 | g/km/s |
| West St G | 0.03 | 0.14 | g/km/s |
| West St H | 0.03 | 0.14 | g/km/s |
| West St I | 0.03 | 0.14 | g/km/s |
| West St J | 0.03 | 0.14 | g/km/s |
| West St K | 0.03 | 0.14 | g/km/s |
| West St L | 0.03 | 0.14 | g/km/s |
| West St M | 0.03 | 0.14 | g/km/s |
| West St N | 0.03 | 0.20 | g/km/s |
| Parson St A | 0.04 | 0.19 | g/km/s |
| Bedminster Down Rd A | 0.04 | 0.20 | g/km/s |
| Parson St B | 0.03 | 0.15 | g/km/s |
| Parson St C | 0.05 | 0.25 | g/km/s |
| Parson St D | 0.06 | 0.28 | g/km/s |
| Parson St E | 0.06 | 0.30 | g/km/s |
| Parson St F | 0.06 | 0.30 | g/km/s |
| Parson St G | 0.06 | 0.30 | g/km/s |
| Bedminster Rd G | 0.03 | 0.12 | g/km/s |
| Parson St H | 0.04 | 0.18 | g/km/s |
| Bedminster Rd H | 0.03 | 0.12 | g/km/s |
| Bedminster Rd I | 0.03 | 0.12 | g/km/s |
| Bedminster Rd J | 0.03 | 0.12 | g/km/s |
| Bedminster Rd K | 0.04 | 0.20 | g/km/s |
| Bedminster Rd L | 0.07 | 0.68 | g/km/s |
| Bedminster Rd M | 0.07 | 0.68 | g/km/s |
| Bedminster Rd N | 0.07 | 0.56 | g/km/s |
| Bedminster Down Rd B | 0.02 | 0.16 | g/km/s |
| Bedminster Down Rd C | 0.06 | 0.36 | g/km/s |
| Winterstoke Close | 0.06 | 0.35 | g/km/s |

|  |  |  |  |
|---|---|---|---|
| Bedminster Down Rd D | 0.08 | 0.61 | g/km/s |
| Bedminster Down Rd E | 0.08 | 0.61 | g/km/s |
| Bedminster Down Rd F | 0.07 | 0.42 | g/km/s |
| Bedminster Down Rd G | 0.07 | 0.48 | g/km/s |
| Bedminster Down Rd H | 0.08 | 0.61 | g/km/s |
| Winterstoke Rd A | 0.06 | 0.38 | g/km/s |
| Winterstoke Rd B | 0.06 | 0.38 | g/km/s |
| Winterstoke Rd C | 0.06 | 0.38 | g/km/s |
| Winterstoke Rd D | 0.06 | 0.38 | g/km/s |
| Winterstoke Rd E | 0.06 | 0.38 | g/km/s |
| Parson St I | 0.05 | 0.27 | g/km/s |
| Hartcliffe Way A | 0.05 | 0.24 | g/km/s |
| Hartcliffe Way B | 0.04 | 0.20 | g/km/s |
| Hartcliffe Way C | 0.04 | 0.20 | g/km/s |
| Hartcliffe Way D | 0.05 | 0.25 | g/km/s |
| Vale Lane | 0.00 | 0.02 | g/km/s |
| Stanley St South A | 0.00 | 0.02 | g/km/s |
| Stanley St South B | 0.00 | 0.02 | g/km/s |
| Stanley Terrace | 0.00 | 0.01 | g/km/s |
| Bartletts Rd A | 0.00 | 0.02 | g/km/s |
| Bartletts Rd B | 0.00 | 0.01 | g/km/s |
| Bartletts Rd C | 0.00 | 0.01 | g/km/s |
| Chapel Barton | 0.00 | 0.00 | g/km/s |
| Churchlands Rd | 0.00 | 0.01 | g/km/s |
| Osbourne Terrace | 0.00 | 0.01 | g/km/s |
| Brighton Terrace | 0.00 | 0.01 | g/km/s |
| Temple St | 0.00 | 0.02 | g/km/s |
| Brighton Crescent | 0.01 | 0.02 | g/km/s |
| Harptree Grove | 0.00 | 0.01 | g/km/s |
| Ireton Rd | 0.01 | 0.02 | g/km/s |
| Chessel St | 0.00 | 0.02 | g/km/s |
| Avonleigh Rd A | 0.00 | 0.02 | g/km/s |
| Avonleigh Rd B | 0.00 | 0.02 | g/km/s |
| Hengaston St A | 0.00 | 0.02 | g/km/s |
| Kingdom View | 0.00 | 0.01 | g/km/s |
| Palmyra Rd A | 0.00 | 0.01 | g/km/s |
| Palmyra Rd B | 0.00 | 0.01 | g/km/s |
| Palmyra Rd C | 0.00 | 0.01 | g/km/s |
| Paylmyra Rd D | 0.00 | 0.01 | g/km/s |
| Elmdale Rd | 0.00 | 0.01 | g/km/s |
| Avonleigh Rd C | 0.00 | 0.02 | g/km/s |
| Avonleigh Rd D | 0.00 | 0.02 | g/km/s |
| Derry Rd | 0.00 | 0.01 | g/km/s |
| Luckwell Rd | 0.00 | 0.01 | g/km/s |
| Thanet Rd | 0.00 | 0.01 | g/km/s |
| Highridge Rd | 0.01 | 0.02 | g/km/s |
| Willada Close | 0.00 | 0.01 | g/km/s |
| Hall St | 0.00 | 0.01 | g/km/s |
| Mansfield St | 0.00 | 0.01 | g/km/s |
| Honeywick Close A | 0.00 | 0.01 | g/km/s |
| Honeywick Close B | 0.00 | 0.01 | g/km/s |
| Honeywick Close C | 0.00 | 0.01 | g/km/s |
| Shepton Walk A | 0.00 | 0.01 | g/km/s |
| Shepton Walk B | 0.00 | 0.01 | g/km/s |
| Marksbury Rd A | 0.01 | 0.03 | g/km/s |
| Marksbury Rd B | 0.01 | 0.03 | g/km/s |
| Marksbury Rd C | 0.01 | 0.03 | g/km/s |
| Marksbury Rd D | 0.01 | 0.04 | g/km/s |
| Highbury Rd | 0.01 | 0.06 | g/km/s |
| Parson St J | 0.02 | 0.09 | g/km/s |
| Parson St K | 0.02 | 0.09 | g/km/s |
| Martock Rd A | 0.00 | 0.02 | g/km/s |
| Martock Rd B | 0.00 | 0.02 | g/km/s |
| Martock Crescent | 0.00 | 0.01 | g/km/s |
| Parson St L | 0.04 | 0.17 | g/km/s |
| Parson St M | 0.04 | 0.18 | g/km/s |
| Somermead | 0.00 | 0.01 | g/km/s |

|  |  |  |  |
|---|---|---|---|
| Parson St N | 0.02 | 0.09 | g/km/s |
| Parson St O | 0.02 | 0.09 | g/km/s |
| Novers Hill | 0.01 | 0.05 | g/km/s |
| Aylesbury Rd A | 0.00 | 0.01 | g/km/s |
| Aylesbury Rd B | 0.00 | 0.01 | g/km/s |
| Aylesbury Crescent | 0.00 | 0.01 | g/km/s |
| Hastings Close | 0.00 | 0.01 | g/km/s |
| Hastings Rd | 0.00 | 0.01 | g/km/s |
| Wimborne Rd | 0.00 | 0.01 | g/km/s |
| Malago Drive A | 0.00 | 0.01 | g/km/s |
| Malago Drive B | 0.00 | 0.01 | g/km/s |
| Malago Drive C | 0.00 | 0.01 | g/km/s |
| Malago Drive D | 0.00 | 0.01 | g/km/s |
| Malago Drive E | 0.00 | 0.01 | g/km/s |
| Malago Drive F | 0.00 | 0.01 | g/km/s |
| Somer Lane | 0.00 | 0.00 | g/km/s |
| Bristol Vale | 0.00 | 0.00 | g/km/s |
| Buckingham St | 0.00 | 0.00 | g/km/s |
| Beaufort St | 0.00 | 0.00 | g/km/s |
| Malego Drive G | 0.00 | 0.01 | g/km/s |
| Brixham Rd | 0.00 | 0.01 | g/km/s |
| Lydford Walk | 0.00 | 0.00 | g/km/s |

*Table 88 Traffic dataset (EFT v9.0 (2 VC)) for Bristol Bedminster.*

| **Source name** | **Road width (m)** | **Canyon height (m)** | **Traffic flows used** | **Traffic flow year** | **Traffic flow road type** |
|---|---|---|---|---|---|
| Bedminster Rd A | 17 | 5 | Yes | 2019 | England (urban) |
| Bedminster Rd B | 12 | 5 | Yes | 2019 | England (urban) |
| Bedminster Rd C | 9 | 5 | Yes | 2019 | England (urban) |
| Bedminster Rd D | 12 | 5 | Yes | 2019 | England (urban) |
| Bedminster Rd E | 11 | 5 | Yes | 2019 | England (urban) |
| Bedminster Rd F | 11 | 5 | Yes | 2019 | England (urban) |
| West St A | 16 | 3 | Yes | 2019 | England (urban) |
| West St B | 11 | 3 | Yes | 2019 | England (urban) |
| West St C | 14 | 3 | Yes | 2019 | England (urban) |
| West St D | 12 | 3 | Yes | 2019 | England (urban) |
| West St E | 14 | 3 | Yes | 2019 | England (urban) |
| West St F | 11 | 3 | Yes | 2019 | England (urban) |
| West St G | 11 | 3 | Yes | 2019 | England (urban) |
| West St H | 12 | 3 | Yes | 2019 | England (urban) |
| West St I | 11 | 3 | Yes | 2019 | England (urban) |
| West St J | 10 | 3 | Yes | 2019 | England (urban) |
| West St K | 13 | 3 | Yes | 2019 | England (urban) |
| West St L | 17 | 3 | Yes | 2019 | England (urban) |
| West St M | 14 | 3 | Yes | 2019 | England (urban) |
| West St N | 11 | 3 | Yes | 2019 | England (urban) |
| Parson St A | 12 | 8 | Yes | 2019 | England (urban) |
| Bedminster Down Rd A | 13 | 0 | Yes | 2019 | England (urban) |
| Parson St B | 17 | 8 | Yes | 2019 | England (urban) |
| Parson St C | 16 | 8 | Yes | 2019 | England (urban) |
| Parson St D | 20 | 8 | Yes | 2019 | England (urban) |
| Parson St E | 21 | 8 | Yes | 2019 | England (urban) |
| Parson St F | 7 | 8 | Yes | 2019 | England (urban) |
| Parson St G | 16 | 8 | Yes | 2019 | England (urban) |
| Bedminster Rd G | 9 | 7 | Yes | 2019 | England (urban) |
| Parson St H | 9 | 8 | Yes | 2019 | England (urban) |
| Bedminster Rd H | 6 | 7 | Yes | 2019 | England (urban) |
| Bedminster Rd I | 7 | 7 | Yes | 2019 | England (urban) |
| Bedminster Rd J | 8 | 7 | Yes | 2019 | England (urban) |
| Bedminster Rd K | 13 | 7 | Yes | 2019 | England (urban) |
| Bedminster Rd L | 14 | 7 | Yes | 2019 | England (urban) |
| Bedminster Rd M | 11 | 7 | Yes | 2019 | England (urban) |
| Bedminster Rd N | 12 | 7 | Yes | 2019 | England (urban) |
| Bedminster Down Rd B | 15 | 7 | Yes | 2019 | England (urban) |

| | | | | | |
|---|---|---|---|---|---|
| Bedminster Down Rd C | 15 | 7 | Yes | 2019 | England (urban) |
| Winterstoke Close | 9 | 0 | Yes | 2019 | England (urban) |
| Bedminster Down Rd D | 14 | 7 | Yes | 2019 | England (urban) |
| Bedminster Down Rd E | 9 | 7 | Yes | 2019 | England (urban) |
| Bedminster Down Rd F | 12 | 7 | Yes | 2019 | England (urban) |
| Bedminster Down Rd G | 14 | 7 | Yes | 2019 | England (urban) |
| Bedminster Down Rd H | 9 | 7 | Yes | 2019 | England (urban) |
| Winterstoke Rd A | 11 | 4 | Yes | 2019 | England (urban) |
| Winterstoke Rd B | 10 | 4 | Yes | 2019 | England (urban) |
| Winterstoke Rd C | 11 | 4 | Yes | 2019 | England (urban) |
| Winterstoke Rd D | 17 | 4 | Yes | 2019 | England (urban) |
| Winterstoke Rd E | 14 | 4 | Yes | 2019 | England (urban) |
| Parson St I | 17 | 8 | Yes | 2019 | England (urban) |
| Hartcliffe Way A | 18 | 9 | Yes | 2019 | England (urban) |
| Hartcliffe Way B | 13 | 9 | Yes | 2019 | England (urban) |
| Hartcliffe Way C | 17 | 9 | Yes | 2019 | England (urban) |
| Hartcliffe Way D | 15 | 9 | Yes | 2019 | England (urban) |
| Vale Lane | 12 | 7 | Yes | 2019 | England (urban) |
| Stanley St South A | 8 | 7 | Yes | 2019 | England (urban) |
| Stanley St South B | 9 | 7 | Yes | 2019 | England (urban) |
| Stanley Terrace | 8 | 8 | Yes | 2019 | England (urban) |
| Bartletts Rd A | 9 | 9 | Yes | 2019 | England (urban) |
| Bartletts Rd B | 9 | 9 | Yes | 2019 | England (urban) |
| Bartletts Rd C | 9 | 9 | Yes | 2019 | England (urban) |
| Chapel Barton | 5 | 8 | Yes | 2019 | England (urban) |
| Churchlands Rd | 9 | 8 | Yes | 2019 | England (urban) |
| Osbourne Terrace | 8 | 8 | Yes | 2019 | England (urban) |
| Brighton Terrace | 8 | 7 | Yes | 2019 | England (urban) |
| Temple St | 9 | 5 | Yes | 2019 | England (urban) |
| Brighton Crescent | 9 | 6 | Yes | 2019 | England (urban) |
| Harptree Grove | 8 | 6 | Yes | 2019 | England (urban) |
| Ireton Rd | 8 | 8 | Yes | 2019 | England (urban) |
| Chessel St | 12 | 6 | Yes | 2019 | England (urban) |
| Avonleigh Rd A | 9 | 2 | Yes | 2019 | England (urban) |
| Avonleigh Rd B | 11 | 2 | Yes | 2019 | England (urban) |
| Hengaston St A | 8 | 2 | Yes | 2019 | England (urban) |
| Kingdom View | 5 | 9 | Yes | 2019 | England (urban) |
| Palmyra Rd A | 10 | 8 | Yes | 2019 | England (urban) |
| Palmyra Rd B | 9 | 8 | Yes | 2019 | England (urban) |
| Palmyra Rd C | 10 | 8 | Yes | 2019 | England (urban) |
| Paylmyra Rd D | 9 | 8 | Yes | 2019 | England (urban) |
| Elmdale Rd | 11 | 8 | Yes | 2019 | England (urban) |
| Avonleigh Rd C | 11 | 7 | Yes | 2019 | England (urban) |
| Avonleigh Rd D | 9 | 7 | Yes | 2019 | England (urban) |
| Derry Rd | 8 | 8 | Yes | 2019 | England (urban) |
| Luckwell Rd | 14 | 6 | Yes | 2019 | England (urban) |
| Thanet Rd | 9 | 9 | Yes | 2019 | England (urban) |
| Highridge Rd | 8 | 6 | Yes | 2019 | England (urban) |
| Willada Close | 7 | 4 | Yes | 2019 | England (urban) |
| Hall St | 9 | 7 | Yes | 2019 | England (urban) |
| Mansfield St | 9 | 8 | Yes | 2019 | England (urban) |
| Honeywick Close A | 7 | 4 | Yes | 2019 | England (urban) |
| Honeywick Close B | 8 | 4 | Yes | 2019 | England (urban) |
| Honeywick Close C | 8 | 4 | Yes | 2019 | England (urban) |
| Shepton Walk A | 9 | 6 | Yes | 2019 | England (urban) |
| Shepton Walk B | 7 | 6 | Yes | 2019 | England (urban) |
| Marksbury Rd A | 12 | 7 | Yes | 2019 | England (urban) |
| Marksbury Rd B | 12 | 7 | Yes | 2019 | England (urban) |
| Marksbury Rd C | 12 | 7 | Yes | 2019 | England (urban) |
| Marksbury Rd D | 11 | 7 | Yes | 2019 | England (urban) |
| Highbury Rd | 10 | 6 | Yes | 2019 | England (urban) |
| Parson St J | 10 | 8 | Yes | 2019 | England (urban) |
| Parson St K | 11 | 8 | Yes | 2019 | England (urban) |
| Martock Rd A | 10 | 8 | Yes | 2019 | England (urban) |
| Martock Rd B | 10 | 8 | Yes | 2019 | England (urban) |
| Martock Crescent | 10 | 7 | Yes | 2019 | England (urban) |
| Parson St L | 12 | 8 | Yes | 2019 | England (urban) |

| | | | | | |
|---|---|---|---|---|---|
| Parson St M | 11 | 8 | Yes | 2019 | England (urban) |
| Somermead | 11 | 8 | Yes | 2019 | England (urban) |
| Parson St N | 13 | 8 | Yes | 2019 | England (urban) |
| Parson St O | 13 | 8 | Yes | 2019 | England (urban) |
| Novers Hill | 8 | 5 | Yes | 2019 | England (urban) |
| Aylesbury Rd A | 11 | 7 | Yes | 2019 | England (urban) |
| Aylesbury Rd B | 9 | 7 | Yes | 2019 | England (urban) |
| Aylesbury Crescent | 12 | 7 | Yes | 2019 | England (urban) |
| Hastings Close | 16 | 6 | Yes | 2019 | England (urban) |
| Hastings Rd | 10 | 6 | Yes | 2019 | England (urban) |
| Wimborne Rd | 8 | 8 | Yes | 2019 | England (urban) |
| Malago Drive A | 15 | 9 | Yes | 2019 | England (urban) |
| Malago Drive B | 11 | 9 | Yes | 2019 | England (urban) |
| Malago Drive C | 12 | 9 | Yes | 2019 | England (urban) |
| Malago Drive D | 12 | 9 | Yes | 2019 | England (urban) |
| Malago Drive E | 12 | 9 | Yes | 2019 | England (urban) |
| Malago Drive F | 34 | 9 | Yes | 2019 | England (urban) |
| Somer Lane | 6 | 2 | Yes | 2019 | England (urban) |
| Bristol Vale | 6 | 7 | Yes | 2019 | England (urban) |
| Buckingham St | 9 | 6 | Yes | 2019 | England (urban) |
| Beaufort St | 10 | 7 | Yes | 2019 | England (urban) |
| Malego Drive G | 10 | 8 | Yes | 2019 | England (urban) |
| Brixham Rd | 10 | 7 | Yes | 2019 | England (urban) |
| Lydford Walk | 10 | 7 | Yes | 2019 | England (urban) |

*Table 89 Traffic data for Bristol St Bedminster.*

| Source name | Vehicle category | Average speed (km/hr) | Vehicle count (vehicles/hour) | Percent uphill |
|---|---|---|---|---|
| Bedminster Rd A | light duty vehicle | 22 | 688 | 50 |
| Bedminster Rd A | heavy duty vehicle | 18 | 83 | 50 |
| Bedminster Rd B | light duty vehicle | 34 | 688 | 50 |
| Bedminster Rd B | heavy duty vehicle | 30 | 83 | 50 |
| Bedminster Rd C | light duty vehicle | 34 | 688 | 50 |
| Bedminster Rd C | heavy duty vehicle | 28 | 83 | 50 |
| Bedminster Rd D | light duty vehicle | 34 | 688 | 50 |
| Bedminster Rd D | heavy duty vehicle | 30 | 83 | 50 |
| Bedminster Rd E | light duty vehicle | 34 | 688 | 50 |
| Bedminster Rd E | heavy duty vehicle | 30 | 83 | 50 |
| Bedminster Rd F | light duty vehicle | 22 | 688 | 50 |
| Bedminster Rd F | heavy duty vehicle | 18 | 83 | 50 |
| West St A | light duty vehicle | 22 | 580 | 50 |
| West St A | heavy duty vehicle | 18 | 124 | 50 |
| West St B | light duty vehicle | 32 | 580 | 50 |
| West St B | heavy duty vehicle | 28 | 124 | 50 |
| West St C | light duty vehicle | 32 | 580 | 50 |
| West St C | heavy duty vehicle | 28 | 124 | 50 |
| West St D | light duty vehicle | 32 | 580 | 50 |
| West St D | heavy duty vehicle | 28 | 124 | 50 |
| West St E | light duty vehicle | 32 | 580 | 50 |
| West St E | heavy duty vehicle | 28 | 124 | 50 |
| West St F | light duty vehicle | 32 | 583 | 50 |
| West St F | heavy duty vehicle | 28 | 124 | 50 |
| West St G | light duty vehicle | 32 | 580 | 50 |
| West St G | heavy duty vehicle | 28 | 124 | 50 |
| West St H | light duty vehicle | 32 | 580 | 50 |
| West St H | heavy duty vehicle | 28 | 124 | 50 |
| West St I | light duty vehicle | 32 | 580 | 50 |
| West St I | heavy duty vehicle | 28 | 124 | 50 |
| West St J | light duty vehicle | 32 | 580 | 50 |
| West St J | heavy duty vehicle | 28 | 124 | 50 |
| West St K | light duty vehicle | 32 | 580 | 50 |
| West St K | heavy duty vehicle | 28 | 124 | 50 |
| West St L | light duty vehicle | 32 | 580 | 50 |
| West St L | heavy duty vehicle | 28 | 124 | 50 |

| | | | | |
|---|---|---|---|---|
| West St M | light duty vehicle | 32 | 580 | 50 |
| West St M | heavy duty vehicle | 28 | 124 | 50 |
| West St N | light duty vehicle | 22 | 580 | 50 |
| West St N | heavy duty vehicle | 16 | 124 | 50 |
| Parson St A | light duty vehicle | 22 | 800 | 50 |
| Parson St A | heavy duty vehicle | 18 | 100 | 50 |
| Bedminster Down Rd A | light duty vehicle | 22 | 1015 | 50 |
| Bedminster Down Rd A | heavy duty vehicle | 18 | 79 | 50 |
| Parson St B | light duty vehicle | 32 | 800 | 50 |
| Parson St B | heavy duty vehicle | 28 | 100 | 50 |
| Parson St C | light duty vehicle | 36 | 1325 | 50 |
| Parson St C | heavy duty vehicle | 30 | 200 | 50 |
| Parson St D | light duty vehicle | 30 | 1325 | 50 |
| Parson St D | heavy duty vehicle | 26 | 200 | 50 |
| Parson St E | light duty vehicle | 30 | 1325 | 50 |
| Parson St E | heavy duty vehicle | 22 | 200 | 50 |
| Parson St F | light duty vehicle | 30 | 1325 | 50 |
| Parson St F | heavy duty vehicle | 22 | 200 | 50 |
| Parson St G | light duty vehicle | 30 | 1325 | 50 |
| Parson St G | heavy duty vehicle | 22 | 200 | 50 |
| Bedminster Rd G | light duty vehicle | 34 | 688 | 50 |
| Bedminster Rd G | heavy duty vehicle | 28 | 83 | 50 |
| Parson St H | light duty vehicle | 30 | 1125 | 50 |
| Parson St H | heavy duty vehicle | 28 | 100 | 50 |
| Bedminster Rd H | light duty vehicle | 36 | 688 | 50 |
| Bedminster Rd H | heavy duty vehicle | 28 | 83 | 50 |
| Bedminster Rd I | light duty vehicle | 34 | 688 | 50 |
| Bedminster Rd I | heavy duty vehicle | 28 | 83 | 50 |
| Bedminster Rd J | light duty vehicle | 34 | 688 | 50 |
| Bedminster Rd J | heavy duty vehicle | 28 | 83 | 50 |
| Bedminster Rd K | light duty vehicle | 18 | 688 | 50 |
| Bedminster Rd K | heavy duty vehicle | 12 | 83 | 50 |
| Bedminster Rd L | light duty vehicle | 8 | 688 | 50 |
| Bedminster Rd L | heavy duty vehicle | 5 | 183 | 50 |
| Bedminster Rd M | light duty vehicle | 8 | 688 | 50 |
| Bedminster Rd M | heavy duty vehicle | 5 | 183 | 50 |
| Bedminster Rd N | light duty vehicle | 10 | 688 | 50 |
| Bedminster Rd N | heavy duty vehicle | 6 | 183 | 50 |
| Bedminster Down Rd B | light duty vehicle | 10 | 100 | 50 |
| Bedminster Down Rd B | heavy duty vehicle | 8 | 80 | 50 |
| Bedminster Down Rd C | light duty vehicle | 10 | 1015 | 50 |
| Bedminster Down Rd C | heavy duty vehicle | 6 | 84 | 50 |
| Winterstoke Close | light duty vehicle | 10 | 1015 | 50 |
| Winterstoke Close | heavy duty vehicle | 6 | 80 | 50 |
| Bedminster Down Rd D | light duty vehicle | 10 | 1015 | 50 |
| Bedminster Down Rd D | heavy duty vehicle | 6 | 184 | 50 |
| Bedminster Down Rd E | light duty vehicle | 10 | 1015 | 50 |
| Bedminster Down Rd E | heavy duty vehicle | 6 | 184 | 50 |
| Bedminster Down Rd F | light duty vehicle | 14 | 1015 | 50 |
| Bedminster Down Rd F | heavy duty vehicle | 10 | 184 | 50 |
| Bedminster Down Rd G | light duty vehicle | 12 | 1015 | 50 |
| Bedminster Down Rd G | heavy duty vehicle | 8 | 184 | 50 |
| Bedminster Down Rd H | light duty vehicle | 10 | 1015 | 50 |
| Bedminster Down Rd H | heavy duty vehicle | 6 | 184 | 50 |
| Winterstoke Rd A | light duty vehicle | 8 | 810 | 50 |
| Winterstoke Rd A | heavy duty vehicle | 4 | 80 | 50 |
| Winterstoke Rd B | light duty vehicle | 8 | 810 | 50 |
| Winterstoke Rd B | heavy duty vehicle | 4 | 80 | 50 |
| Winterstoke Rd C | light duty vehicle | 8 | 810 | 50 |
| Winterstoke Rd C | heavy duty vehicle | 4 | 80 | 50 |
| Winterstoke Rd D | light duty vehicle | 8 | 810 | 50 |
| Winterstoke Rd D | heavy duty vehicle | 4 | 80 | 50 |
| Winterstoke Rd E | light duty vehicle | 8 | 810 | 50 |
| Winterstoke Rd E | heavy duty vehicle | 4 | 80 | 50 |
| Parson St I | light duty vehicle | 30 | 1325 | 50 |
| Parson St I | heavy duty vehicle | 28 | 200 | 50 |
| Hartcliffe Way A | light duty vehicle | 26 | 1162 | 50 |

| | | | | |
|---|---|---|---|---|
| Hartcliffe Way A | heavy duty vehicle | 20 | 130 | 50 |
| Hartcliffe Way B | light duty vehicle | 34 | 1162 | 50 |
| Hartcliffe Way B | heavy duty vehicle | 28 | 130 | 50 |
| Hartcliffe Way C | light duty vehicle | 34 | 1162 | 50 |
| Hartcliffe Way C | heavy duty vehicle | 28 | 130 | 50 |
| Hartcliffe Way D | light duty vehicle | 24 | 1162 | 50 |
| Hartcliffe Way D | heavy duty vehicle | 20 | 130 | 50 |
| Vale Lane | light duty vehicle | 30 | 130 | 50 |
| Vale Lane | heavy duty vehicle | 28 | 3 | 50 |
| Stanley St South A | light duty vehicle | 24 | 130 | 50 |
| Stanley St South A | heavy duty vehicle | 20 | 3 | 50 |
| Stanley St South B | light duty vehicle | 28 | 130 | 50 |
| Stanley St South B | heavy duty vehicle | 26 | 3 | 50 |
| Stanley Terrace | light duty vehicle | 28 | 40 | 50 |
| Stanley Terrace | heavy duty vehicle | 24 | 1 | 50 |
| Bartletts Rd A | light duty vehicle | 26 | 100 | 50 |
| Bartletts Rd A | heavy duty vehicle | 22 | 5 | 50 |
| Bartletts Rd B | light duty vehicle | 30 | 100 | 50 |
| Bartletts Rd B | heavy duty vehicle | 26 | 5 | 50 |
| Bartletts Rd C | light duty vehicle | 28 | 100 | 50 |
| Bartletts Rd C | heavy duty vehicle | 22 | 5 | 50 |
| Chapel Barton | light duty vehicle | 18 | 30 | 50 |
| Chapel Barton | heavy duty vehicle | 14 | 1 | 50 |
| Churchlands Rd | light duty vehicle | 18 | 80 | 50 |
| Churchlands Rd | heavy duty vehicle | 16 | 2 | 50 |
| Osbourne Terrace | light duty vehicle | 18 | 60 | 50 |
| Osbourne Terrace | heavy duty vehicle | 14 | 2 | 50 |
| Brighton Terrace | light duty vehicle | 18 | 60 | 50 |
| Brighton Terrace | heavy duty vehicle | 14 | 2 | 50 |
| Temple St | light duty vehicle | 28 | 140 | 50 |
| Temple St | heavy duty vehicle | 24 | 3 | 50 |
| Brighton Crescent | light duty vehicle | 18 | 140 | 50 |
| Brighton Crescent | heavy duty vehicle | 16 | 3 | 50 |
| Harptree Grove | light duty vehicle | 18 | 60 | 50 |
| Harptree Grove | heavy duty vehicle | 14 | 2 | 50 |
| Ireton Rd | light duty vehicle | 24 | 140 | 50 |
| Ireton Rd | heavy duty vehicle | 18 | 3 | 50 |
| Chessel St | light duty vehicle | 28 | 140 | 50 |
| Chessel St | heavy duty vehicle | 22 | 3 | 50 |
| Avonleigh Rd A | light duty vehicle | 26 | 130 | 50 |
| Avonleigh Rd A | heavy duty vehicle | 20 | 4 | 50 |
| Avonleigh Rd B | light duty vehicle | 26 | 130 | 50 |
| Avonleigh Rd B | heavy duty vehicle | 22 | 4 | 50 |
| Hengaston St A | light duty vehicle | 28 | 120 | 50 |
| Hengaston St A | heavy duty vehicle | 24 | 3 | 50 |
| Kingdom View | light duty vehicle | 26 | 80 | 50 |
| Kingdom View | heavy duty vehicle | 22 | 2 | 50 |
| Palmyra Rd A | light duty vehicle | 24 | 100 | 50 |
| Palmyra Rd A | heavy duty vehicle | 20 | 2 | 50 |
| Palmyra Rd B | light duty vehicle | 26 | 100 | 50 |
| Palmyra Rd B | heavy duty vehicle | 20 | 2 | 50 |
| Palmyra Rd C | light duty vehicle | 26 | 100 | 50 |
| Palmyra Rd C | heavy duty vehicle | 22 | 2 | 50 |
| Paylmyra Rd D | light duty vehicle | 26 | 100 | 50 |
| Paylmyra Rd D | heavy duty vehicle | 22 | 2 | 50 |
| Elmdale Rd | light duty vehicle | 26 | 100 | 50 |
| Elmdale Rd | heavy duty vehicle | 22 | 2 | 50 |
| Avonleigh Rd C | light duty vehicle | 26 | 130 | 50 |
| Avonleigh Rd C | heavy duty vehicle | 22 | 4 | 50 |
| Avonleigh Rd D | light duty vehicle | 26 | 130 | 50 |
| Avonleigh Rd D | heavy duty vehicle | 22 | 4 | 50 |
| Derry Rd | light duty vehicle | 26 | 60 | 50 |
| Derry Rd | heavy duty vehicle | 22 | 1 | 50 |
| Luckwell Rd | light duty vehicle | 26 | 110 | 50 |
| Luckwell Rd | heavy duty vehicle | 22 | 2 | 50 |
| Thanet Rd | light duty vehicle | 26 | 70 | 50 |
| Thanet Rd | heavy duty vehicle | 22 | 2 | 50 |

| | | | | |
|---|---|---|---|---|
| Highridge Rd | light duty vehicle | 18 | 120 | 50 |
| Highridge Rd | heavy duty vehicle | 14 | 4 | 50 |
| Willada Close | light duty vehicle | 18 | 80 | 50 |
| Willada Close | heavy duty vehicle | 14 | 2 | 50 |
| Hall St | light duty vehicle | 18 | 80 | 50 |
| Hall St | heavy duty vehicle | 14 | 4 | 50 |
| Mansfield St | light duty vehicle | 28 | 80 | 50 |
| Mansfield St | heavy duty vehicle | 24 | 4 | 50 |
| Honeywick Close A | light duty vehicle | 18 | 40 | 50 |
| Honeywick Close A | heavy duty vehicle | 14 | 2 | 50 |
| Honeywick Close B | light duty vehicle | 18 | 40 | 50 |
| Honeywick Close B | heavy duty vehicle | 14 | 2 | 50 |
| Honeywick Close C | light duty vehicle | 18 | 40 | 50 |
| Honeywick Close C | heavy duty vehicle | 14 | 2 | 50 |
| Shepton Walk A | light duty vehicle | 18 | 80 | 50 |
| Shepton Walk A | heavy duty vehicle | 14 | 2 | 50 |
| Shepton Walk B | light duty vehicle | 18 | 80 | 50 |
| Shepton Walk B | heavy duty vehicle | 14 | 2 | 50 |
| Marksbury Rd A | light duty vehicle | 24 | 120 | 50 |
| Marksbury Rd A | heavy duty vehicle | 20 | 20 | 50 |
| Marksbury Rd B | light duty vehicle | 24 | 120 | 50 |
| Marksbury Rd B | heavy duty vehicle | 20 | 20 | 50 |
| Marksbury Rd C | light duty vehicle | 24 | 120 | 50 |
| Marksbury Rd C | heavy duty vehicle | 20 | 20 | 50 |
| Marksbury Rd D | light duty vehicle | 18 | 100 | 50 |
| Marksbury Rd D | heavy duty vehicle | 14 | 20 | 50 |
| Highbury Rd | light duty vehicle | 24 | 260 | 50 |
| Highbury Rd | heavy duty vehicle | 20 | 40 | 50 |
| Parson St J | light duty vehicle | 28 | 581 | 50 |
| Parson St J | heavy duty vehicle | 24 | 31 | 50 |
| Parson St K | light duty vehicle | 28 | 581 | 50 |
| Parson St K | heavy duty vehicle | 24 | 31 | 50 |
| Martock Rd A | light duty vehicle | 24 | 100 | 50 |
| Martock Rd A | heavy duty vehicle | 20 | 10 | 50 |
| Martock Rd B | light duty vehicle | 24 | 100 | 50 |
| Martock Rd B | heavy duty vehicle | 20 | 10 | 50 |
| Martock Crescent | light duty vehicle | 18 | 60 | 50 |
| Martock Crescent | heavy duty vehicle | 14 | 2 | 50 |
| Parson St L | light duty vehicle | 24 | 1015 | 50 |
| Parson St L | heavy duty vehicle | 20 | 60 | 50 |
| Parson St M | light duty vehicle | 22 | 1015 | 50 |
| Parson St M | heavy duty vehicle | 18 | 60 | 50 |
| Somermead | light duty vehicle | 24 | 60 | 50 |
| Somermead | heavy duty vehicle | 20 | 4 | 50 |
| Parson St N | light duty vehicle | 24 | 581 | 50 |
| Parson St N | heavy duty vehicle | 20 | 31 | 50 |
| Parson St O | light duty vehicle | 24 | 581 | 50 |
| Parson St O | heavy duty vehicle | 20 | 31 | 50 |
| Novers Hill | light duty vehicle | 24 | 280 | 50 |
| Novers Hill | heavy duty vehicle | 20 | 26 | 50 |
| Aylesbury Rd A | light duty vehicle | 18 | 80 | 50 |
| Aylesbury Rd A | heavy duty vehicle | 14 | 2 | 50 |
| Aylesbury Rd B | light duty vehicle | 18 | 80 | 50 |
| Aylesbury Rd B | heavy duty vehicle | 14 | 2 | 50 |
| Aylesbury Crescent | light duty vehicle | 18 | 80 | 50 |
| Aylesbury Crescent | heavy duty vehicle | 14 | 2 | 50 |
| Hastings Close | light duty vehicle | 18 | 40 | 50 |
| Hastings Close | heavy duty vehicle | 14 | 2 | 50 |
| Hastings Rd | light duty vehicle | 18 | 80 | 50 |
| Hastings Rd | heavy duty vehicle | 14 | 2 | 50 |
| Wimborne Rd | light duty vehicle | 18 | 40 | 50 |
| Wimborne Rd | heavy duty vehicle | 14 | 2 | 50 |
| Malago Drive A | light duty vehicle | 18 | 80 | 50 |
| Malago Drive A | heavy duty vehicle | 16 | 2 | 50 |
| Malago Drive B | light duty vehicle | 18 | 80 | 50 |
| Malago Drive B | heavy duty vehicle | 14 | 2 | 50 |
| Malago Drive C | light duty vehicle | 18 | 80 | 50 |

| | | | | |
|---|---|---|---|---|
| Malago Drive C | heavy duty vehicle | 14 | 2 | 50 |
| Malago Drive D | light duty vehicle | 18 | 80 | 50 |
| Malago Drive D | heavy duty vehicle | 14 | 2 | 50 |
| Malago Drive E | light duty vehicle | 18 | 80 | 50 |
| Malago Drive E | heavy duty vehicle | 14 | 2 | 50 |
| Malago Drive F | light duty vehicle | 18 | 80 | 50 |
| Malago Drive F | heavy duty vehicle | 12 | 2 | 50 |
| Somer Lane | light duty vehicle | 18 | 40 | 50 |
| Somer Lane | heavy duty vehicle | 14 | 0 | 50 |
| Bristol Vale | light duty vehicle | 18 | 40 | 50 |
| Bristol Vale | heavy duty vehicle | 14 | 0 | 50 |
| Buckingham St | light duty vehicle | 18 | 20 | 50 |
| Buckingham St | heavy duty vehicle | 14 | 0 | 50 |
| Beaufort St | light duty vehicle | 18 | 20 | 50 |
| Beaufort St | heavy duty vehicle | 14 | 0 | 50 |
| Malego Drive G | light duty vehicle | 18 | 80 | 50 |
| Malego Drive G | heavy duty vehicle | 14 | 0 | 50 |
| Brixham Rd | light duty vehicle | 18 | 60 | 50 |
| Brixham Rd | heavy duty vehicle | 14 | 1 | 50 |
| Lydford Walk | light duty vehicle | 18 | 40 | 50 |
| Lydford Walk | heavy duty vehicle | 14 | 0 | 50 |

### iii. Coventry Binley

*Table 90 Source Emission Rates for Coventry Binley.*

| Source name | Emission rate ($NO_2$) | Emission rate ($NO_X$) | Comments |
|---|---|---|---|
| Sky Blue Way A | 0.07 | 0.33 | g/km/s |
| Sky Blue Way B | 0.07 | 0.33 | g/km/s |
| Sky Blue Way C | 0.08 | 0.37 | g/km/s |
| Sky Blue Way D | 0.08 | 0.37 | g/km/s |
| Binley Rd A | 0.02 | 0.07 | g/km/s |
| Binley Rd B | 0.02 | 0.07 | g/km/s |
| Binley Rd C | 0.02 | 0.07 | g/km/s |
| A444 A | 0.00 | 0.02 | g/km/s |
| A444 B | 0.00 | 0.02 | g/km/s |
| A4600 A | 0.05 | 0.25 | g/km/s |
| A4600 B | 0.01 | 0.04 | g/km/s |
| A4600 C | 0.01 | 0.04 | g/km/s |
| A4600 D | 0.01 | 0.04 | g/km/s |
| Lower Ford St A | 0.02 | 0.06 | g/km/s |
| Lower Ford St B | 0.02 | 0.06 | g/km/s |
| Humber Rd A | 0.00 | 0.01 | g/km/s |
| Humber Rd B | 0.00 | 0.01 | g/km/s |
| Humber Rd C | 0.00 | 0.01 | g/km/s |
| Humber Rd D | 0.00 | 0.01 | g/km/s |
| Humber Rd E | 0.00 | 0.01 | g/km/s |
| Humber Rd F | 0.00 | 0.01 | g/km/s |
| Oxford St A | 0.00 | 0.01 | g/km/s |
| All Saints Lane | 0.00 | 0.00 | g/km/s |
| Paynes Ln A | 0.00 | 0.01 | g/km/s |
| East St A | 0.00 | 0.01 | g/km/s |
| East St B | 0.00 | 0.01 | g/km/s |
| East St C | 0.00 | 0.01 | g/km/s |
| Raglan St A | 0.00 | 0.00 | g/km/s |
| Raglan St B | 0.00 | 0.00 | g/km/s |
| Vauxhall St A | 0.00 | 0.01 | g/km/s |
| Vauxhall St B | 0.00 | 0.01 | g/km/s |
| Vauxhall St C | 0.00 | 0.01 | g/km/s |
| Vauxhall St D | 0.00 | 0.01 | g/km/s |
| Vauxhall St E | 0.00 | 0.01 | g/km/s |
| Swan Ln A | 0.00 | 0.01 | g/km/s |
| Swan Ln B | 0.00 | 0.01 | g/km/s |

| | | | |
|---|---|---|---|
| Swan Ln C | 0.00 | 0.01 | g/km/s |
| Days Close | 0.00 | 0.00 | g/km/s |
| Vauxhall Close | 0.00 | 0.01 | g/km/s |
| Brook Close | 0.00 | 0.01 | g/km/s |
| Britannia St A | 0.01 | 0.03 | g/km/s |
| Britannia St B | 0.01 | 0.03 | g/km/s |
| Britannia St C | 0.01 | 0.03 | g/km/s |
| Britannia St D | 0.01 | 0.03 | g/km/s |
| Wren St | 0.00 | 0.01 | g/km/s |
| King Richard St A | 0.00 | 0.01 | g/km/s |
| Mowbray St | 0.00 | 0.01 | g/km/s |
| LansdowneSt A | 0.00 | 0.00 | g/km/s |
| LansdowneSt B | 0.00 | 0.00 | g/km/s |
| Brunel Cl | 0.00 | 0.00 | g/km/s |
| King Richard St B | 0.00 | 0.01 | g/km/s |
| King Richard St C | 0.00 | 0.01 | g/km/s |
| Grantham St | 0.00 | 0.01 | g/km/s |
| Paynes Ln B | 0.00 | 0.01 | g/km/s |
| Paynes Ln C | 0.00 | 0.01 | g/km/s |
| Paynes Ln D | 0.00 | 0.01 | g/km/s |
| Paynes Ln E | 0.00 | 0.01 | g/km/s |
| Days Ln | 0.00 | 0.00 | g/km/s |
| Sparkbrook St | 0.00 | 0.00 | g/km/s |
| Catherine St | 0.02 | 0.06 | g/km/s |
| Berry St A | 0.00 | 0.01 | g/km/s |
| Berry St B | 0.00 | 0.01 | g/km/s |
| Berry St C | 0.00 | 0.01 | g/km/s |
| Coronation Rd A | 0.00 | 0.01 | g/km/s |
| Alexandra Rd | 0.00 | 0.00 | g/km/s |
| King Edward Rd | 0.00 | 0.01 | g/km/s |
| Hood St A | 0.00 | 0.01 | g/km/s |
| Hood St B | 0.00 | 0.01 | g/km/s |
| Hood St C | 0.00 | 0.01 | g/km/s |
| Anna St | 0.00 | 0.01 | g/km/s |
| South St A | 0.00 | 0.01 | g/km/s |
| South St B | 0.00 | 0.01 | g/km/s |
| Read St A | 0.00 | 0.01 | g/km/s |
| Read St B | 0.00 | 0.01 | g/km/s |
| Napier St | 0.00 | 0.00 | g/km/s |
| Thackhall St A | 0.00 | 0.01 | g/km/s |
| Thackhall St B | 0.00 | 0.01 | g/km/s |
| Thackhall St C | 0.00 | 0.01 | g/km/s |
| Thackhall St D | 0.00 | 0.01 | g/km/s |
| Nicholls St | 0.01 | 0.05 | g/km/s |
| Augustus Rd | 0.00 | 0.00 | g/km/s |
| Coronation Rd B | 0.00 | 0.01 | g/km/s |
| Ribble Rd A | 0.00 | 0.01 | g/km/s |
| Ribble Rd B | 0.00 | 0.01 | g/km/s |
| Ribble Rd C | 0.00 | 0.01 | g/km/s |
| Ribble Rd D | 0.00 | 0.01 | g/km/s |
| Ribble Rd E | 0.00 | 0.01 | g/km/s |
| Ribble Rd F | 0.00 | 0.01 | g/km/s |
| Ribble Rd G | 0.00 | 0.01 | g/km/s |
| Ribble Rd H | 0.00 | 0.01 | g/km/s |
| School Cl | 0.00 | 0.00 | g/km/s |
| Humber Ave A | 0.07 | 0.29 | g/km/s |
| Hugh Rd | 0.00 | 0.00 | g/km/s |
| Holilis Rd | 0.00 | 0.00 | g/km/s |
| Bolingbroke Rd | 0.00 | 0.01 | g/km/s |
| Stoke Grn A | 0.01 | 0.04 | g/km/s |
| Stoke Grn B | 0.01 | 0.04 | g/km/s |
| Stoke Grn C | 0.01 | 0.04 | g/km/s |
| Stoke Grn D | 0.01 | 0.04 | g/km/s |
| Stoke Grn E | 0.01 | 0.05 | g/km/s |
| Far Gosford St A | 0.07 | 0.35 | g/km/s |
| Far Gosford St B | 0.07 | 0.35 | g/km/s |
| Far Gosford St C | 0.07 | 0.35 | g/km/s |

| | | | |
|---|---|---|---|
| Far Gosford St D | 0.07 | 0.35 | g/km/s |
| Far Gosford St E | 0.07 | 0.35 | g/km/s |
| Binley Rd D | 0.01 | 0.06 | g/km/s |
| Binley Rd E | 0.01 | 0.06 | g/km/s |
| Gulson Rd A | 0.01 | 0.03 | g/km/s |
| Gulson Rd B | 0.01 | 0.03 | g/km/s |
| Gulson Rd C | 0.01 | 0.03 | g/km/s |
| Gulson Rd D | 0.01 | 0.03 | g/km/s |
| Gulson Rd E | 0.01 | 0.03 | g/km/s |
| Gulson Rd F | 0.01 | 0.03 | g/km/s |
| Gulson Rd G | 0.01 | 0.03 | g/km/s |
| St Georges Rd A | 0.12 | 0.45 | g/km/s |
| St Georges Rd B | 0.11 | 0.39 | g/km/s |
| St Georges Rd C | 0.10 | 0.37 | g/km/s |
| St Georges Rd D | 0.11 | 0.39 | g/km/s |
| St Georges Rd E | 0.11 | 0.41 | g/km/s |
| Terry Rd A | 0.04 | 0.21 | g/km/s |
| Terry Rd B | 0.04 | 0.20 | g/km/s |
| Terry Rd C | 0.04 | 0.19 | g/km/s |
| Terry Rd D | 0.04 | 0.21 | g/km/s |
| Terry Rd E | 0.04 | 0.21 | g/km/s |
| Terry Rd F | 0.04 | 0.21 | g/km/s |
| St Margaret Rd A | 0.00 | 0.00 | g/km/s |
| St Margaret Rd B | 0.00 | 0.00 | g/km/s |
| Northfield Rd A | 0.00 | 0.01 | g/km/s |
| Northfield Rd B | 0.00 | 0.01 | g/km/s |
| Northfield Rd C | 0.00 | 0.01 | g/km/s |
| David Rd A | 0.00 | 0.00 | g/km/s |
| David Rd B | 0.00 | 0.00 | g/km/s |
| David Rd C | 0.00 | 0.00 | g/km/s |
| David Rd D | 0.00 | 0.00 | g/km/s |
| Charterhouse Rd A | 0.00 | 0.01 | g/km/s |
| Charterhouse Rd B | 0.00 | 0.01 | g/km/s |
| Carmelite Rd | 0.00 | 0.00 | g/km/s |
| Monks Rd | 0.00 | 0.00 | g/km/s |
| Botoner Rd | 0.00 | 0.00 | g/km/s |
| Severn Rd A | 0.00 | 0.01 | g/km/s |
| Severn Rd B | 0.00 | 0.01 | g/km/s |
| Orwell Rd | 0.00 | 0.01 | g/km/s |
| Welland Rd A | 0.00 | 0.01 | g/km/s |
| Welland Rd B | 0.00 | 0.01 | g/km/s |
| Humber Ave B | 0.02 | 0.08 | g/km/s |
| Grafton St | 0.00 | 0.00 | g/km/s |
| Bramble St A | 0.00 | 0.01 | g/km/s |
| Bramble St B | 0.00 | 0.01 | g/km/s |
| Vecqueray St | 0.02 | 0.09 | g/km/s |
| Harnell Row | 0.01 | 0.06 | g/km/s |

*Table 91 Traffic dataset (EFT v9.0 (2 VC)) for Coventry Binley.*

| **Source name** | **Road width (m)** | **Canyon height (m)** | **Traffic flows used** | **Traffic flow year** | **Traffic flow road type** |
|---|---|---|---|---|---|
| Sky Blue Way A | 19 | 20 | Yes | 2019 | England (urban) |
| Sky Blue Way B | 19 | 20 | Yes | 2019 | England (urban) |
| Sky Blue Way C | 19 | 8 | Yes | 2019 | England (urban) |
| Sky Blue Way D | 19 | 8 | Yes | 2019 | England (urban) |
| Binley Rd A | 23 | 9 | Yes | 2019 | England (urban) |
| Binley Rd B | 23 | 9 | Yes | 2019 | England (urban) |
| Binley Rd C | 23 | 9 | Yes | 2019 | England (urban) |
| A444 A | 22 | 6 | Yes | 2019 | England (urban) |
| A444 B | 22 | 6 | Yes | 2019 | England (urban) |
| A4600 A | 9 | 3 | Yes | 2019 | England (urban) |
| A4600 B | 9 | 3 | Yes | 2019 | England (urban) |
| A4600 C | 9 | 3 | Yes | 2019 | England (urban) |

| | | | | | |
|---|---|---|---|---|---|
| A4600 D | 9 | 3 | Yes | 2019 | England (urban) |
| Lower Ford St A | 12 | 6 | Yes | 2019 | England (urban) |
| Lower Ford St B | 12 | 6 | Yes | 2019 | England (urban) |
| Humber Rd A | 16 | 7 | Yes | 2019 | England (urban) |
| Humber Rd B | 16 | 7 | Yes | 2019 | England (urban) |
| Humber Rd C | 16 | 7 | Yes | 2019 | England (urban) |
| Humber Rd D | 16 | 7 | Yes | 2019 | England (urban) |
| Humber Rd E | 16 | 7 | Yes | 2019 | England (urban) |
| Humber Rd F | 16 | 7 | Yes | 2019 | England (urban) |
| Oxford St A | 11 | 15 | Yes | 2019 | England (urban) |
| All Saints Lane | 5 | 2 | Yes | 2019 | England (urban) |
| Paynes Ln A | 8 | 7 | Yes | 2019 | England (urban) |
| East St A | 8 | 6 | Yes | 2019 | England (urban) |
| East St B | 8 | 6 | Yes | 2019 | England (urban) |
| East St C | 8 | 6 | Yes | 2019 | England (urban) |
| Raglan St A | 8 | 7 | Yes | 2019 | England (urban) |
| Raglan St B | 8 | 7 | Yes | 2019 | England (urban) |
| Vauxhall St A | 9 | 6 | Yes | 2019 | England (urban) |
| Vauxhall St B | 9 | 6 | Yes | 2019 | England (urban) |
| Vauxhall St C | 9 | 6 | Yes | 2019 | England (urban) |
| Vauxhall St D | 9 | 6 | Yes | 2019 | England (urban) |
| Vauxhall St E | 9 | 6 | Yes | 2019 | England (urban) |
| Swan Ln A | 11 | 7 | Yes | 2019 | England (urban) |
| Swan Ln B | 11 | 7 | Yes | 2019 | England (urban) |
| Swan Ln C | 11 | 7 | Yes | 2019 | England (urban) |
| Days Close | 5 | 6 | Yes | 2019 | England (urban) |
| Vauxhall Close | 6 | 6 | Yes | 2019 | England (urban) |
| Brook Close | 6 | 6 | Yes | 2019 | England (urban) |
| Britannia St A | 7 | 8 | Yes | 2019 | England (urban) |
| Britannia St B | 7 | 8 | Yes | 2019 | England (urban) |
| Britannia St C | 7 | 8 | Yes | 2019 | England (urban) |
| Britannia St D | 7 | 8 | Yes | 2019 | England (urban) |
| Wren St | 6 | 8 | Yes | 2019 | England (urban) |
| King Richard St A | 7 | 8 | Yes | 2019 | England (urban) |
| Mowbray St | 6 | 8 | Yes | 2019 | England (urban) |
| LansdowneSt A | 10 | 0 | Yes | 2019 | England (urban) |
| LansdowneSt B | 10 | 0 | Yes | 2019 | England (urban) |
| Brunel Cl | 10 | 0 | Yes | 2019 | England (urban) |
| King Richard St B | 7 | 8 | Yes | 2019 | England (urban) |
| King Richard St C | 7 | 8 | Yes | 2019 | England (urban) |
| Grantham St | 10 | 0 | Yes | 2019 | England (urban) |
| Paynes Ln B | 8 | 7 | Yes | 2019 | England (urban) |
| Paynes Ln C | 8 | 7 | Yes | 2019 | England (urban) |
| Paynes Ln D | 8 | 7 | Yes | 2019 | England (urban) |
| Paynes Ln E | 8 | 7 | Yes | 2019 | England (urban) |
| Days Ln | 5 | 7 | Yes | 2019 | England (urban) |
| Sparkbrook St | 8 | 7 | Yes | 2019 | England (urban) |
| Catherine St | 5 | 8 | Yes | 2019 | England (urban) |
| Berry St A | 9 | 0 | Yes | 2019 | England (urban) |
| Berry St B | 9 | 0 | Yes | 2019 | England (urban) |
| Berry St C | 9 | 10 | Yes | 2019 | England (urban) |
| Coronation Rd A | 5 | 9 | Yes | 2019 | England (urban) |
| Alexandra Rd | 9 | 8 | Yes | 2019 | England (urban) |
| King Edward Rd | 6 | 8 | Yes | 2019 | England (urban) |
| Hood St A | 9 | 5 | Yes | 2019 | England (urban) |
| Hood St B | 9 | 5 | Yes | 2019 | England (urban) |
| Hood St C | 9 | 5 | Yes | 2019 | England (urban) |
| Anna St | 8 | 12 | Yes | 2019 | England (urban) |
| South St A | 8 | 5 | Yes | 2019 | England (urban) |
| South St B | 8 | 5 | Yes | 2019 | England (urban) |
| Read St A | 8 | 12 | Yes | 2019 | England (urban) |
| Read St B | 8 | 5 | Yes | 2019 | England (urban) |
| Napier St | 8 | 6 | Yes | 2019 | England (urban) |
| Thackhall St A | 10 | 9 | Yes | 2019 | England (urban) |
| Thackhall St B | 10 | 9 | Yes | 2019 | England (urban) |
| Thackhall St C | 10 | 9 | Yes | 2019 | England (urban) |
| Thackhall St D | 10 | 9 | Yes | 2019 | England (urban) |

| | | | | | |
|---|---|---|---|---|---|
| Nicholls St | 8 | 9 | Yes | 2019 | England (urban) |
| Augustus Rd | 10 | 9 | Yes | 2019 | England (urban) |
| Coronation Rd B | 5 | 9 | Yes | 2019 | England (urban) |
| Ribble Rd A | 12 | 4 | Yes | 2019 | England (urban) |
| Ribble Rd B | 12 | 9 | Yes | 2019 | England (urban) |
| Ribble Rd C | 12 | 9 | Yes | 2019 | England (urban) |
| Ribble Rd D | 12 | 9 | Yes | 2019 | England (urban) |
| Ribble Rd E | 12 | 9 | Yes | 2019 | England (urban) |
| Ribble Rd F | 12 | 9 | Yes | 2019 | England (urban) |
| Ribble Rd G | 12 | 9 | Yes | 2019 | England (urban) |
| Ribble Rd H | 12 | 9 | Yes | 2019 | England (urban) |
| School Cl | 6 | 5 | Yes | 2019 | England (urban) |
| Humber Ave A | 10 | 9 | Yes | 2019 | England (urban) |
| Hugh Rd | 8 | 9 | Yes | 2019 | England (urban) |
| Holilis Rd | 10 | 8 | Yes | 2019 | England (urban) |
| Bolingbroke Rd | 10 | 9 | Yes | 2019 | England (urban) |
| Stoke Grn A | 8 | 7 | Yes | 2019 | England (urban) |
| Stoke Grn B | 8 | 7 | Yes | 2019 | England (urban) |
| Stoke Grn C | 8 | 7 | Yes | 2019 | England (urban) |
| Stoke Grn D | 8 | 7 | Yes | 2019 | England (urban) |
| Stoke Grn E | 8 | 7 | Yes | 2019 | England (urban) |
| Far Gosford St A | 10 | 7 | Yes | 2019 | England (urban) |
| Far Gosford St B | 10 | 7 | Yes | 2019 | England (urban) |
| Far Gosford St C | 10 | 7 | Yes | 2019 | England (urban) |
| Far Gosford St D | 10 | 7 | Yes | 2019 | England (urban) |
| Far Gosford St E | 10 | 7 | Yes | 2019 | England (urban) |
| Binley Rd D | 16 | 6 | Yes | 2019 | England (urban) |
| Binley Rd E | 16 | 6 | Yes | 2019 | England (urban) |
| Gulson Rd A | 11 | 10 | Yes | 2019 | England (urban) |
| Gulson Rd B | 11 | 10 | Yes | 2019 | England (urban) |
| Gulson Rd C | 11 | 10 | Yes | 2019 | England (urban) |
| Gulson Rd D | 11 | 10 | Yes | 2019 | England (urban) |
| Gulson Rd E | 11 | 10 | Yes | 2019 | England (urban) |
| Gulson Rd F | 11 | 10 | Yes | 2019 | England (urban) |
| Gulson Rd G | 11 | 10 | Yes | 2019 | England (urban) |
| St Georges Rd A | 10 | 10 | Yes | 2019 | England (urban) |
| St Georges Rd B | 10 | 10 | Yes | 2019 | England (urban) |
| St Georges Rd C | 10 | 10 | Yes | 2019 | England (urban) |
| St Georges Rd D | 10 | 10 | Yes | 2019 | England (urban) |
| St Georges Rd E | 10 | 10 | Yes | 2019 | England (urban) |
| Terry Rd A | 12 | 5 | Yes | 2019 | England (urban) |
| Terry Rd B | 12 | 5 | Yes | 2019 | England (urban) |
| Terry Rd C | 12 | 5 | Yes | 2019 | England (urban) |
| Terry Rd D | 12 | 5 | Yes | 2019 | England (urban) |
| Terry Rd E | 12 | 5 | Yes | 2019 | England (urban) |
| Terry Rd F | 12 | 5 | Yes | 2019 | England (urban) |
| St Margaret Rd A | 10 | 8 | Yes | 2019 | England (urban) |
| St Margaret Rd B | 10 | 8 | Yes | 2019 | England (urban) |
| Northfield Rd A | 9 | 10 | Yes | 2019 | England (urban) |
| Northfield Rd B | 9 | 10 | Yes | 2019 | England (urban) |
| Northfield Rd C | 9 | 10 | Yes | 2019 | England (urban) |
| David Rd A | 8 | 7 | Yes | 2019 | England (urban) |
| David Rd B | 8 | 7 | Yes | 2019 | England (urban) |
| David Rd C | 8 | 7 | Yes | 2019 | England (urban) |
| David Rd D | 8 | 7 | Yes | 2019 | England (urban) |
| Charterhouse Rd A | 7 | 8 | Yes | 2019 | England (urban) |
| Charterhouse Rd B | 7 | 8 | Yes | 2019 | England (urban) |
| Carmelite Rd | 8 | 8 | Yes | 2019 | England (urban) |
| Monks Rd | 8 | 8 | Yes | 2019 | England (urban) |
| Botoner Rd | 9 | 9 | Yes | 2019 | England (urban) |
| Severn Rd A | 8 | 8 | Yes | 2019 | England (urban) |
| Severn Rd B | 8 | 8 | Yes | 2019 | England (urban) |
| Orwell Rd | 11 | 7 | Yes | 2019 | England (urban) |
| Welland Rd A | 9 | 8 | Yes | 2019 | England (urban) |
| Welland Rd B | 9 | 8 | Yes | 2019 | England (urban) |
| Humber Ave B | 10 | 9 | Yes | 2019 | England (urban) |
| Grafton St | 9 | 8 | Yes | 2019 | England (urban) |

| | | | | | |
|---|---|---|---|---|---|
| Bramble St A | 11 | 8 | Yes | 2019 | England (urban) |
| Bramble St B | 11 | 8 | Yes | 2019 | England (urban) |
| Vecqueray St | 10 | 9 | Yes | 2019 | England (urban) |
| Harnell Row | 10 | 6 | Yes | 2019 | England (urban) |

*Table 92 Traffic data for Coventry Binley.*

| **Source name** | **Vehicle category** | **Average speed (km/hr)** | **Vehicle count (vehicles/hour)** | **Percent uphill** |
|---|---|---|---|---|
| Sky Blue Way A | light duty vehicle | 20 | 1585 | 50 |
| Sky Blue Way A | heavy duty vehicle | 14 | 114 | 50 |
| Sky Blue Way B | light duty vehicle | 20 | 1585 | 50 |
| Sky Blue Way B | heavy duty vehicle | 14 | 114 | 50 |
| Sky Blue Way C | light duty vehicle | 18 | 1585 | 50 |
| Sky Blue Way C | heavy duty vehicle | 10 | 114 | 50 |
| Sky Blue Way D | light duty vehicle | 18 | 1585 | 50 |
| Sky Blue Way D | heavy duty vehicle | 10 | 114 | 50 |
| Binley Rd A | light duty vehicle | 32 | 580 | 50 |
| Binley Rd A | heavy duty vehicle | 30 | 14 | 50 |
| Binley Rd B | light duty vehicle | 32 | 580 | 50 |
| Binley Rd B | heavy duty vehicle | 30 | 14 | 50 |
| Binley Rd C | light duty vehicle | 28 | 580 | 50 |
| Binley Rd C | heavy duty vehicle | 26 | 14 | 50 |
| A444 A | light duty vehicle | 28 | 120 | 50 |
| A444 A | heavy duty vehicle | 24 | 14 | 50 |
| A444 B | light duty vehicle | 30 | 120 | 50 |
| A444 B | heavy duty vehicle | 26 | 14 | 50 |
| A4600 A | light duty vehicle | 28 | 1320 | 50 |
| A4600 A | heavy duty vehicle | 24 | 140 | 50 |
| A4600 B | light duty vehicle | 30 | 320 | 50 |
| A4600 B | heavy duty vehicle | 26 | 14 | 50 |
| A4600 C | light duty vehicle | 30 | 320 | 50 |
| A4600 C | heavy duty vehicle | 26 | 14 | 50 |
| A4600 D | light duty vehicle | 28 | 320 | 50 |
| A4600 D | heavy duty vehicle | 24 | 14 | 50 |
| Lower Ford St A | light duty vehicle | 30 | 500 | 50 |
| Lower Ford St A | heavy duty vehicle | 26 | 15 | 50 |
| Lower Ford St B | light duty vehicle | 32 | 500 | 50 |
| Lower Ford St B | heavy duty vehicle | 28 | 15 | 50 |
| Humber Rd A | light duty vehicle | 36 | 50 | 50 |
| Humber Rd A | heavy duty vehicle | 32 | 1 | 50 |
| Humber Rd B | light duty vehicle | 40 | 50 | 50 |
| Humber Rd B | heavy duty vehicle | 36 | 1 | 50 |
| Humber Rd C | light duty vehicle | 40 | 50 | 50 |
| Humber Rd C | heavy duty vehicle | 36 | 1 | 50 |
| Humber Rd D | light duty vehicle | 40 | 50 | 50 |
| Humber Rd D | heavy duty vehicle | 36 | 1 | 50 |
| Humber Rd E | light duty vehicle | 36 | 50 | 50 |
| Humber Rd E | heavy duty vehicle | 32 | 1 | 50 |
| Humber Rd F | light duty vehicle | 36 | 50 | 50 |
| Humber Rd F | heavy duty vehicle | 32 | 1 | 50 |
| Oxford St A | light duty vehicle | 40 | 60 | 50 |
| Oxford St A | heavy duty vehicle | 34 | 1 | 50 |
| All Saints Lane | light duty vehicle | 34 | 20 | 50 |
| All Saints Lane | heavy duty vehicle | 5 | 0 | 50 |
| Paynes Ln A | light duty vehicle | 28 | 112 | 50 |
| Paynes Ln A | heavy duty vehicle | 24 | 3 | 50 |
| East St A | light duty vehicle | 34 | 50 | 50 |
| East St A | heavy duty vehicle | 30 | 1 | 50 |
| East St B | light duty vehicle | 34 | 50 | 50 |
| East St B | heavy duty vehicle | 30 | 1 | 50 |
| East St C | light duty vehicle | 34 | 50 | 50 |
| East St C | heavy duty vehicle | 30 | 1 | 50 |
| Raglan St A | light duty vehicle | 36 | 40 | 50 |
| Raglan St A | heavy duty vehicle | 30 | 1 | 50 |

|  |  |  |  |  |
|---|---|---|---|---|
| Raglan St B | light duty vehicle | 36 | 40 | 50 |
| Raglan St B | heavy duty vehicle | 30 | 1 | 50 |
| Vauxhall St A | light duty vehicle | 26 | 50 | 50 |
| Vauxhall St A | heavy duty vehicle | 22 | 1 | 50 |
| Vauxhall St B | light duty vehicle | 36 | 50 | 50 |
| Vauxhall St B | heavy duty vehicle | 30 | 1 | 50 |
| Vauxhall St C | light duty vehicle | 36 | 50 | 50 |
| Vauxhall St C | heavy duty vehicle | 30 | 1 | 50 |
| Vauxhall St D | light duty vehicle | 36 | 50 | 50 |
| Vauxhall St D | heavy duty vehicle | 30 | 1 | 50 |
| Vauxhall St E | light duty vehicle | 26 | 50 | 50 |
| Vauxhall St E | heavy duty vehicle | 20 | 1 | 50 |
| Swan Ln A | light duty vehicle | 40 | 60 | 50 |
| Swan Ln A | heavy duty vehicle | 36 | 1 | 50 |
| Swan Ln B | light duty vehicle | 42 | 60 | 50 |
| Swan Ln B | heavy duty vehicle | 38 | 1 | 50 |
| Swan Ln C | light duty vehicle | 40 | 60 | 50 |
| Swan Ln C | heavy duty vehicle | 36 | 1 | 50 |
| Days Close | light duty vehicle | 26 | 20 | 50 |
| Days Close | heavy duty vehicle | 5 | 0 | 50 |
| Vauxhall Close | light duty vehicle | 28 | 40 | 50 |
| Vauxhall Close | heavy duty vehicle | 18 | 1 | 50 |
| Brook Close | light duty vehicle | 26 | 40 | 50 |
| Brook Close | heavy duty vehicle | 20 | 1 | 50 |
| Britannia St A | light duty vehicle | 22 | 200 | 50 |
| Britannia St A | heavy duty vehicle | 18 | 10 | 50 |
| Britannia St B | light duty vehicle | 26 | 200 | 50 |
| Britannia St B | heavy duty vehicle | 22 | 10 | 50 |
| Britannia St C | light duty vehicle | 26 | 200 | 50 |
| Britannia St C | heavy duty vehicle | 22 | 10 | 50 |
| Britannia St D | light duty vehicle | 24 | 200 | 50 |
| Britannia St D | heavy duty vehicle | 20 | 10 | 50 |
| Wren St | light duty vehicle | 24 | 30 | 50 |
| Wren St | heavy duty vehicle | 20 | 10 | 50 |
| King Richard St A | light duty vehicle | 26 | 30 | 50 |
| King Richard St A | heavy duty vehicle | 22 | 10 | 50 |
| Mowbray St | light duty vehicle | 28 | 40 | 50 |
| Mowbray St | heavy duty vehicle | 24 | 5 | 50 |
| LansdowneSt A | light duty vehicle | 30 | 30 | 50 |
| LansdowneSt A | heavy duty vehicle | 20 | 1 | 50 |
| LansdowneSt B | light duty vehicle | 30 | 30 | 50 |
| LansdowneSt B | heavy duty vehicle | 20 | 1 | 50 |
| Brunel Cl | light duty vehicle | 26 | 20 | 50 |
| Brunel Cl | heavy duty vehicle | 22 | 1 | 50 |
| King Richard St B | light duty vehicle | 28 | 30 | 50 |
| King Richard St B | heavy duty vehicle | 24 | 10 | 50 |
| King Richard St C | light duty vehicle | 28 | 30 | 50 |
| King Richard St C | heavy duty vehicle | 24 | 10 | 50 |
| Grantham St | light duty vehicle | 30 | 40 | 50 |
| Grantham St | heavy duty vehicle | 20 | 1 | 50 |
| Paynes Ln B | light duty vehicle | 36 | 112 | 50 |
| Paynes Ln B | heavy duty vehicle | 30 | 3 | 50 |
| Paynes Ln C | light duty vehicle | 36 | 112 | 50 |
| Paynes Ln C | heavy duty vehicle | 32 | 3 | 50 |
| Paynes Ln D | light duty vehicle | 36 | 112 | 50 |
| Paynes Ln D | heavy duty vehicle | 30 | 3 | 50 |
| Paynes Ln E | light duty vehicle | 34 | 112 | 50 |
| Paynes Ln E | heavy duty vehicle | 30 | 3 | 50 |
| Days Ln | light duty vehicle | 36 | 30 | 50 |
| Days Ln | heavy duty vehicle | 30 | 2 | 50 |
| Sparkbrook St | light duty vehicle | 36 | 20 | 50 |
| Sparkbrook St | heavy duty vehicle | 30 | 1 | 50 |
| Catherine St | light duty vehicle | 30 | 460 | 50 |
| Catherine St | heavy duty vehicle | 20 | 10 | 50 |
| Berry St A | light duty vehicle | 44 | 112 | 50 |
| Berry St A | heavy duty vehicle | 38 | 3 | 50 |
| Berry St B | light duty vehicle | 36 | 112 | 50 |

| | | | | |
|---|---|---|---|---|
| Berry St B | heavy duty vehicle | 32 | 3 | 50 |
| Berry St C | light duty vehicle | 34 | 112 | 50 |
| Berry St C | heavy duty vehicle | 32 | 3 | 50 |
| Coronation Rd A | light duty vehicle | 36 | 80 | 50 |
| Coronation Rd A | heavy duty vehicle | 32 | 4 | 50 |
| Alexandra Rd | light duty vehicle | 38 | 30 | 50 |
| Alexandra Rd | heavy duty vehicle | 34 | 1 | 50 |
| King Edward Rd | light duty vehicle | 30 | 60 | 50 |
| King Edward Rd | heavy duty vehicle | 20 | 6 | 50 |
| Hood St A | light duty vehicle | 34 | 60 | 50 |
| Hood St A | heavy duty vehicle | 30 | 1 | 50 |
| Hood St B | light duty vehicle | 34 | 60 | 50 |
| Hood St B | heavy duty vehicle | 32 | 1 | 50 |
| Hood St C | light duty vehicle | 34 | 60 | 50 |
| Hood St C | heavy duty vehicle | 32 | 1 | 50 |
| Anna St | light duty vehicle | 30 | 40 | 50 |
| Anna St | heavy duty vehicle | 20 | 1 | 50 |
| South St A | light duty vehicle | 26 | 60 | 50 |
| South St A | heavy duty vehicle | 20 | 2 | 50 |
| South St B | light duty vehicle | 26 | 60 | 50 |
| South St B | heavy duty vehicle | 20 | 2 | 50 |
| Read St A | light duty vehicle | 36 | 40 | 50 |
| Read St A | heavy duty vehicle | 32 | 2 | 50 |
| Read St B | light duty vehicle | 36 | 40 | 50 |
| Read St B | heavy duty vehicle | 32 | 2 | 50 |
| Napier St | light duty vehicle | 34 | 40 | 50 |
| Napier St | heavy duty vehicle | 30 | 1 | 50 |
| Thackhall St A | light duty vehicle | 28 | 60 | 50 |
| Thackhall St A | heavy duty vehicle | 24 | 2 | 50 |
| Thackhall St B | light duty vehicle | 30 | 60 | 50 |
| Thackhall St B | heavy duty vehicle | 26 | 2 | 50 |
| Thackhall St C | light duty vehicle | 30 | 60 | 50 |
| Thackhall St C | heavy duty vehicle | 26 | 2 | 50 |
| Thackhall St D | light duty vehicle | 36 | 60 | 50 |
| Thackhall St D | heavy duty vehicle | 30 | 2 | 50 |
| Nicholls St | light duty vehicle | 34 | 460 | 50 |
| Nicholls St | heavy duty vehicle | 30 | 10 | 50 |
| Augustus Rd | light duty vehicle | 36 | 40 | 50 |
| Augustus Rd | heavy duty vehicle | 30 | 1 | 50 |
| Coronation Rd B | light duty vehicle | 36 | 80 | 50 |
| Coronation Rd B | heavy duty vehicle | 30 | 2 | 50 |
| Ribble Rd A | light duty vehicle | 30 | 50 | 50 |
| Ribble Rd A | heavy duty vehicle | 20 | 1 | 50 |
| Ribble Rd B | light duty vehicle | 32 | 50 | 50 |
| Ribble Rd B | heavy duty vehicle | 22 | 1 | 50 |
| Ribble Rd C | light duty vehicle | 32 | 50 | 50 |
| Ribble Rd C | heavy duty vehicle | 22 | 1 | 50 |
| Ribble Rd D | light duty vehicle | 32 | 50 | 50 |
| Ribble Rd D | heavy duty vehicle | 22 | 1 | 50 |
| Ribble Rd E | light duty vehicle | 32 | 50 | 50 |
| Ribble Rd E | heavy duty vehicle | 22 | 1 | 50 |
| Ribble Rd F | light duty vehicle | 32 | 50 | 50 |
| Ribble Rd F | heavy duty vehicle | 22 | 1 | 50 |
| Ribble Rd G | light duty vehicle | 32 | 50 | 50 |
| Ribble Rd G | heavy duty vehicle | 22 | 1 | 50 |
| Ribble Rd H | light duty vehicle | 32 | 50 | 50 |
| Ribble Rd H | heavy duty vehicle | 22 | 1 | 50 |
| School Cl | light duty vehicle | 32 | 20 | 50 |
| School Cl | heavy duty vehicle | 20 | 1 | 50 |
| Humber Ave A | light duty vehicle | 5 | 1200 | 50 |
| Humber Ave A | heavy duty vehicle | 5 | 30 | 50 |
| Hugh Rd | light duty vehicle | 32 | 30 | 50 |
| Hugh Rd | heavy duty vehicle | 28 | 1 | 50 |
| Holilis Rd | light duty vehicle | 32 | 30 | 50 |
| Holilis Rd | heavy duty vehicle | 28 | 1 | 50 |
| Bolingbroke Rd | light duty vehicle | 36 | 40 | 50 |
| Bolingbroke Rd | heavy duty vehicle | 32 | 2 | 50 |

|  |  |  |  |  |
|---|---|---|---|---|
| Stoke Grn A | light duty vehicle | 40 | 400 | 50 |
| Stoke Grn A | heavy duty vehicle | 36 | 10 | 50 |
| Stoke Grn B | light duty vehicle | 42 | 400 | 50 |
| Stoke Grn B | heavy duty vehicle | 38 | 10 | 50 |
| Stoke Grn C | light duty vehicle | 42 | 400 | 50 |
| Stoke Grn C | heavy duty vehicle | 38 | 10 | 50 |
| Stoke Grn D | light duty vehicle | 42 | 400 | 50 |
| Stoke Grn D | heavy duty vehicle | 38 | 10 | 50 |
| Stoke Grn E | light duty vehicle | 32 | 400 | 50 |
| Stoke Grn E | heavy duty vehicle | 30 | 10 | 50 |
| Far Gosford St A | light duty vehicle | 24 | 1400 | 50 |
| Far Gosford St A | heavy duty vehicle | 18 | 200 | 50 |
| Far Gosford St B | light duty vehicle | 24 | 1400 | 50 |
| Far Gosford St B | heavy duty vehicle | 18 | 200 | 50 |
| Far Gosford St C | light duty vehicle | 24 | 1400 | 50 |
| Far Gosford St C | heavy duty vehicle | 18 | 200 | 50 |
| Far Gosford St D | light duty vehicle | 24 | 1400 | 50 |
| Far Gosford St D | heavy duty vehicle | 18 | 200 | 50 |
| Far Gosford St E | light duty vehicle | 24 | 1400 | 50 |
| Far Gosford St E | heavy duty vehicle | 18 | 200 | 50 |
| Binley Rd D | light duty vehicle | 26 | 180 | 50 |
| Binley Rd D | heavy duty vehicle | 20 | 40 | 50 |
| Binley Rd E | light duty vehicle | 26 | 180 | 50 |
| Binley Rd E | heavy duty vehicle | 20 | 40 | 50 |
| Gulson Rd A | light duty vehicle | 28 | 210 | 50 |
| Gulson Rd A | heavy duty vehicle | 22 | 10 | 50 |
| Gulson Rd B | light duty vehicle | 28 | 210 | 50 |
| Gulson Rd B | heavy duty vehicle | 22 | 10 | 50 |
| Gulson Rd C | light duty vehicle | 28 | 210 | 50 |
| Gulson Rd C | heavy duty vehicle | 22 | 10 | 50 |
| Gulson Rd D | light duty vehicle | 28 | 210 | 50 |
| Gulson Rd D | heavy duty vehicle | 22 | 10 | 50 |
| Gulson Rd E | light duty vehicle | 28 | 210 | 50 |
| Gulson Rd E | heavy duty vehicle | 22 | 10 | 50 |
| Gulson Rd F | light duty vehicle | 28 | 210 | 50 |
| Gulson Rd F | heavy duty vehicle | 22 | 10 | 50 |
| Gulson Rd G | light duty vehicle | 28 | 210 | 50 |
| Gulson Rd G | heavy duty vehicle | 22 | 10 | 50 |
| St Georges Rd A | light duty vehicle | 26 | 3272 | 50 |
| St Georges Rd A | heavy duty vehicle | 22 | 109 | 50 |
| St Georges Rd B | light duty vehicle | 36 | 3272 | 50 |
| St Georges Rd B | heavy duty vehicle | 30 | 109 | 50 |
| St Georges Rd C | light duty vehicle | 38 | 3272 | 50 |
| St Georges Rd C | heavy duty vehicle | 36 | 109 | 50 |
| St Georges Rd D | light duty vehicle | 34 | 3272 | 50 |
| St Georges Rd D | heavy duty vehicle | 32 | 109 | 50 |
| St Georges Rd E | light duty vehicle | 30 | 3272 | 50 |
| St Georges Rd E | heavy duty vehicle | 28 | 109 | 50 |
| Terry Rd A | light duty vehicle | 36 | 1131 | 50 |
| Terry Rd A | heavy duty vehicle | 32 | 169 | 50 |
| Terry Rd B | light duty vehicle | 38 | 1131 | 50 |
| Terry Rd B | heavy duty vehicle | 36 | 169 | 50 |
| Terry Rd C | light duty vehicle | 40 | 1131 | 50 |
| Terry Rd C | heavy duty vehicle | 38 | 169 | 50 |
| Terry Rd D | light duty vehicle | 36 | 1131 | 50 |
| Terry Rd D | heavy duty vehicle | 32 | 169 | 50 |
| Terry Rd E | light duty vehicle | 36 | 1131 | 50 |
| Terry Rd E | heavy duty vehicle | 32 | 169 | 50 |
| Terry Rd F | light duty vehicle | 36 | 1131 | 50 |
| Terry Rd F | heavy duty vehicle | 32 | 169 | 50 |
| St Margaret Rd A | light duty vehicle | 36 | 10 | 50 |
| St Margaret Rd A | heavy duty vehicle | 34 | 1 | 50 |
| St Margaret Rd B | light duty vehicle | 36 | 10 | 50 |
| St Margaret Rd B | heavy duty vehicle | 34 | 1 | 50 |
| Northfield Rd A | light duty vehicle | 36 | 40 | 50 |
| Northfield Rd A | heavy duty vehicle | 34 | 2 | 50 |
| Northfield Rd B | light duty vehicle | 36 | 40 | 50 |

|  |  |  |  |  |
|---|---|---|---|---|
| Northfield Rd B | heavy duty vehicle | 34 | 2 | 50 |
| Northfield Rd C | light duty vehicle | 36 | 40 | 50 |
| Northfield Rd C | heavy duty vehicle | 34 | 2 | 50 |
| David Rd A | light duty vehicle | 32 | 30 | 50 |
| David Rd A | heavy duty vehicle | 28 | 1 | 50 |
| David Rd B | light duty vehicle | 32 | 30 | 50 |
| David Rd B | heavy duty vehicle | 28 | 1 | 50 |
| David Rd C | light duty vehicle | 32 | 30 | 50 |
| David Rd C | heavy duty vehicle | 28 | 1 | 50 |
| David Rd D | light duty vehicle | 32 | 30 | 50 |
| David Rd D | heavy duty vehicle | 28 | 1 | 50 |
| Charterhouse Rd A | light duty vehicle | 28 | 50 | 50 |
| Charterhouse Rd A | heavy duty vehicle | 22 | 2 | 50 |
| Charterhouse Rd B | light duty vehicle | 28 | 50 | 50 |
| Charterhouse Rd B | heavy duty vehicle | 22 | 2 | 50 |
| Carmelite Rd | light duty vehicle | 28 | 10 | 50 |
| Carmelite Rd | heavy duty vehicle | 22 | 1 | 50 |
| Monks Rd | light duty vehicle | 28 | 10 | 50 |
| Monks Rd | heavy duty vehicle | 22 | 1 | 50 |
| Botoner Rd | light duty vehicle | 28 | 10 | 50 |
| Botoner Rd | heavy duty vehicle | 22 | 1 | 50 |
| Severn Rd A | light duty vehicle | 28 | 80 | 50 |
| Severn Rd A | heavy duty vehicle | 22 | 5 | 50 |
| Severn Rd B | light duty vehicle | 28 | 80 | 50 |
| Severn Rd B | heavy duty vehicle | 22 | 5 | 50 |
| Orwell Rd | light duty vehicle | 28 | 50 | 50 |
| Orwell Rd | heavy duty vehicle | 22 | 2 | 50 |
| Welland Rd A | light duty vehicle | 28 | 50 | 50 |
| Welland Rd A | heavy duty vehicle | 22 | 2 | 50 |
| Welland Rd B | light duty vehicle | 28 | 50 | 50 |
| Welland Rd B | heavy duty vehicle | 22 | 2 | 50 |
| Humber Ave B | light duty vehicle | 28 | 600 | 50 |
| Humber Ave B | heavy duty vehicle | 22 | 20 | 50 |
| Grafton St | light duty vehicle | 28 | 30 | 50 |
| Grafton St | heavy duty vehicle | 22 | 1 | 50 |
| Bramble St A | light duty vehicle | 28 | 60 | 50 |
| Bramble St A | heavy duty vehicle | 22 | 2 | 50 |
| Bramble St B | light duty vehicle | 28 | 60 | 50 |
| Bramble St B | heavy duty vehicle | 22 | 2 | 50 |
| Vecqueray St | light duty vehicle | 28 | 360 | 50 |
| Vecqueray St | heavy duty vehicle | 22 | 60 | 50 |
| Harnell Row | light duty vehicle | 34 | 400 | 50 |
| Harnell Row | heavy duty vehicle | 30 | 40 | 50 |

## iv. Oxford St Ebbe’s

*Table 93 Source Emission Rates for Oxford St Ebbe’s.*

| Source name | Emission rate (NO$_2$) | Emission rate (NO$_X$) | Comments |
|---|---|---|---|
| Thames St A | 0.02 | 0.06 | g/km/s |
| Thames St B | 0.02 | 0.06 | g/km/s |
| Thames St C | 0.00 | 0.01 | g/km/s |
| Thames St D | 0.02 | 0.07 | g/km/s |
| Thames St E | 0.02 | 0.07 | g/km/s |
| Abingdon Rd A | 0.01 | 0.03 | g/km/s |
| Abingdon Rd B | 0.01 | 0.03 | g/km/s |
| Abingdon Rd C | 0.01 | 0.03 | g/km/s |
| Abingdon Rd D | 0.01 | 0.03 | g/km/s |
| Abingdon Rd E | 0.01 | 0.03 | g/km/s |
| Abingdon Rd F | 0.01 | 0.03 | g/km/s |
| Marlborough Rd A | 0.01 | 0.03 | g/km/s |
| Marlborough Rd B | 0.01 | 0.03 | g/km/s |
| Marlborough Rd C | 0.01 | 0.03 | g/km/s |

| | | | |
|---|---|---|---|
| Marlborough Rd D | 0.01 | 0.03 | g/km/s |
| Marlborough Rd E | 0.01 | 0.03 | g/km/s |
| Marlborough Rd F | 0.01 | 0.03 | g/km/s |
| Whitehouse Rd A | 0.02 | 0.11 | g/km/s |
| Whitehouse Rd B | 0.02 | 0.11 | g/km/s |
| Long Ford Close | 0.01 | 0.05 | g/km/s |
| Whitehouse Rd C | 0.01 | 0.02 | g/km/s |
| Whitehouse Rd D | 0.00 | 0.02 | g/km/s |
| Western Rd A | 0.00 | 0.01 | g/km/s |
| Western Rd B | 0.00 | 0.01 | g/km/s |
| Western Rd C | 0.00 | 0.01 | g/km/s |
| Hodges Court | 0.00 | 0.00 | g/km/s |
| Newton Rd A | 0.00 | 0.01 | g/km/s |
| Newton Rd B | 0.00 | 0.01 | g/km/s |
| Chilswell Rd A | 0.00 | 0.01 | g/km/s |
| Chilswell Rd B | 0.00 | 0.01 | g/km/s |
| Chilswell Rd C | 0.00 | 0.01 | g/km/s |
| Edith Rd | 0.00 | 0.01 | g/km/s |
| Kineton Rd | 0.00 | 0.01 | g/km/s |
| Brook St | 0.00 | 0.00 | g/km/s |
| Cobden Cres | 0.00 | 0.00 | g/km/s |
| Buckingham St | 0.00 | 0.00 | g/km/s |
| Salter Close | 0.02 | 0.09 | g/km/s |
| Speedwell St A | 0.01 | 0.02 | g/km/s |
| Speedwell St B | 0.01 | 0.02 | g/km/s |
| Speedwell St C | 0.01 | 0.02 | g/km/s |
| Speedwell St D | 0.01 | 0.02 | g/km/s |
| Cromwell St | 0.00 | 0.00 | g/km/s |
| St Aldates | 0.00 | 0.00 | g/km/s |
| Butterwycke Place | 0.00 | 0.01 | g/km/s |
| Albion Pl | 0.00 | 0.01 | g/km/s |
| Friars Wharf | 0.01 | 0.05 | g/km/s |
| Dale Cl | 0.01 | 0.03 | g/km/s |
| Blackfriars Rd | 0.00 | 0.01 | g/km/s |
| Preachers Ln | 0.01 | 0.04 | g/km/s |
| Trinity St A | 0.01 | 0.04 | g/km/s |
| Trinity St B | 0.01 | 0.04 | g/km/s |
| Shirelake Cl | 0.00 | 0.00 | g/km/s |

*Table 94 Traffic dataset (EFT v9.0 (2 VC)) for Oxford St Ebbe's.*

| Source name | Road width (m) | Canyon height (m) | Traffic flows used | Traffic flow year | Traffic flow road type |
|---|---|---|---|---|---|
| Thames St A | 14 | 9 | Yes | 2019 | England (urban) |
| Thames St B | 14 | 9 | Yes | 2019 | England (urban) |
| Thames St C | 14 | 9 | Yes | 2019 | England (urban) |
| Thames St D | 14 | 9 | Yes | 2019 | England (urban) |
| Thames St E | 14 | 9 | Yes | 2019 | England (urban) |
| Abingdon Rd A | 13 | 6 | Yes | 2019 | England (urban) |
| Abingdon Rd B | 13 | 6 | Yes | 2019 | England (urban) |
| Abingdon Rd C | 13 | 6 | Yes | 2019 | England (urban) |
| Abingdon Rd D | 13 | 6 | Yes | 2019 | England (urban) |
| Abingdon Rd E | 13 | 6 | Yes | 2019 | England (urban) |
| Abingdon Rd F | 13 | 6 | Yes | 2019 | England (urban) |
| Marlborough Rd A | 6 | 9 | Yes | 2019 | England (urban) |
| Marlborough Rd B | 6 | 9 | Yes | 2019 | England (urban) |
| Marlborough Rd C | 6 | 9 | Yes | 2019 | England (urban) |
| Marlborough Rd D | 6 | 9 | Yes | 2019 | England (urban) |
| Marlborough Rd E | 6 | 9 | Yes | 2019 | England (urban) |
| Marlborough Rd F | 6 | 9 | Yes | 2019 | England (urban) |
| Whitehouse Rd A | 11 | 8 | Yes | 2019 | England (urban) |
| Whitehouse Rd B | 11 | 8 | Yes | 2019 | England (urban) |
| Long Ford Close | 8 | 6 | Yes | 2019 | England (urban) |
| Whitehouse Rd C | 11 | 8 | Yes | 2019 | England (urban) |
| Whitehouse Rd D | 11 | 8 | Yes | 2019 | England (urban) |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| Western Rd A | 9 | 8 | Yes | 2019 | England (urban) |
| Western Rd B | 9 | 8 | Yes | 2019 | England (urban) |
| Western Rd C | 9 | 8 | Yes | 2019 | England (urban) |
| Hodges Court | 8 | 6 | Yes | 2019 | England (urban) |
| Newton Rd A | 8 | 7 | Yes | 2019 | England (urban) |
| Newton Rd B | 8 | 7 | Yes | 2019 | England (urban) |
| Chilswell Rd A | 6 | 7 | Yes | 2019 | England (urban) |
| Chilswell Rd B | 6 | 7 | Yes | 2019 | England (urban) |
| Chilswell Rd C | 6 | 7 | Yes | 2019 | England (urban) |
| Edith Rd | 6 | 8 | Yes | 2019 | England (urban) |
| Kineton Rd | 8 | 8 | Yes | 2019 | England (urban) |
| Brook St | 8 | 10 | Yes | 2019 | England (urban) |
| Cobden Cres | 6 | 8 | Yes | 2019 | England (urban) |
| Buckingham St | 7 | 8 | Yes | 2019 | England (urban) |
| Salter Close | 7 | 7 | Yes | 2019 | England (urban) |
| Speedwell St A | 9 | 6 | Yes | 2019 | England (urban) |
| Speedwell St B | 9 | 6 | Yes | 2019 | England (urban) |
| Speedwell St C | 9 | 6 | Yes | 2019 | England (urban) |
| Speedwell St D | 9 | 6 | Yes | 2019 | England (urban) |
| Cromwell St | 7 | 15 | Yes | 2019 | England (urban) |
| St Aldates | 12 | 11 | Yes | 2019 | England (urban) |
| Butterwycke Place | 8 | 8 | Yes | 2019 | England (urban) |
| Albion Pl | 9 | 10 | Yes | 2019 | England (urban) |
| Friars Wharf | 6 | 12 | Yes | 2019 | England (urban) |
| Dale Cl | 7 | 8 | Yes | 2019 | England (urban) |
| Blackfriars Rd | 7 | 7 | Yes | 2019 | England (urban) |
| Preachers Ln | 7 | 8 | Yes | 2019 | England (urban) |
| Trinity St A | 6 | 7 | Yes | 2019 | England (urban) |
| Trinity St B | 6 | 7 | Yes | 2019 | England (urban) |
| Shirelake Cl | 7 | 9 | Yes | 2019 | England (urban) |

*Table 95 Traffic data for Oxford St Ebbe's.*

| Source name | Vehicle category | Average speed (km/hr) | Vehicle count (vehicles/hour) | Percent uphill |
|---|---|---|---|---|
| Thames St A | light duty vehicle | 28 | 521 | 50 |
| Thames St A | heavy duty vehicle | 22 | 8 | 50 |
| Thames St B | light duty vehicle | 28 | 521 | 50 |
| Thames St B | heavy duty vehicle | 22 | 8 | 50 |
| Thames St C | light duty vehicle | 44 | 121 | 50 |
| Thames St C | heavy duty vehicle | 40 | 8 | 50 |
| Thames St D | light duty vehicle | 44 | 616 | 50 |
| Thames St D | heavy duty vehicle | 40 | 24 | 50 |
| Thames St E | light duty vehicle | 44 | 616 | 50 |
| Thames St E | heavy duty vehicle | 40 | 24 | 50 |
| Abingdon Rd A | light duty vehicle | 48 | 328 | 50 |
| Abingdon Rd A | heavy duty vehicle | 40 | 10 | 50 |
| Abingdon Rd B | light duty vehicle | 48 | 328 | 50 |
| Abingdon Rd B | heavy duty vehicle | 40 | 10 | 50 |
| Abingdon Rd C | light duty vehicle | 48 | 328 | 50 |
| Abingdon Rd C | heavy duty vehicle | 40 | 10 | 50 |
| Abingdon Rd D | light duty vehicle | 48 | 328 | 50 |
| Abingdon Rd D | heavy duty vehicle | 40 | 10 | 50 |
| Abingdon Rd E | light duty vehicle | 48 | 328 | 50 |
| Abingdon Rd E | heavy duty vehicle | 40 | 10 | 50 |
| Abingdon Rd F | light duty vehicle | 48 | 328 | 50 |
| Abingdon Rd F | heavy duty vehicle | 40 | 10 | 50 |
| Marlborough Rd A | light duty vehicle | 28 | 160 | 50 |
| Marlborough Rd A | heavy duty vehicle | 24 | 20 | 50 |
| Marlborough Rd B | light duty vehicle | 28 | 160 | 50 |
| Marlborough Rd B | heavy duty vehicle | 24 | 20 | 50 |
| Marlborough Rd C | light duty vehicle | 28 | 160 | 50 |
| Marlborough Rd C | heavy duty vehicle | 24 | 20 | 50 |
| Marlborough Rd D | light duty vehicle | 28 | 160 | 50 |
| Marlborough Rd D | heavy duty vehicle | 24 | 20 | 50 |

| | | | | |
|---|---|---|---|---|
| Marlborough Rd E | light duty vehicle | 28 | 160 | 50 |
| Marlborough Rd E | heavy duty vehicle | 24 | 20 | 50 |
| Marlborough Rd F | light duty vehicle | 28 | 160 | 50 |
| Marlborough Rd F | heavy duty vehicle | 24 | 20 | 50 |
| Whitehouse Rd A | light duty vehicle | 22 | 520 | 50 |
| Whitehouse Rd A | heavy duty vehicle | 18 | 50 | 50 |
| Whitehouse Rd B | light duty vehicle | 22 | 520 | 50 |
| Whitehouse Rd B | heavy duty vehicle | 18 | 50 | 50 |
| Long Ford Close | light duty vehicle | 22 | 250 | 50 |
| Long Ford Close | heavy duty vehicle | 18 | 20 | 50 |
| Whitehouse Rd C | light duty vehicle | 22 | 140 | 50 |
| Whitehouse Rd C | heavy duty vehicle | 18 | 5 | 50 |
| Whitehouse Rd D | light duty vehicle | 26 | 120 | 50 |
| Whitehouse Rd D | heavy duty vehicle | 22 | 5 | 50 |
| Western Rd A | light duty vehicle | 26 | 50 | 50 |
| Western Rd A | heavy duty vehicle | 22 | 2 | 50 |
| Western Rd B | light duty vehicle | 28 | 50 | 50 |
| Western Rd B | heavy duty vehicle | 24 | 2 | 50 |
| Western Rd C | light duty vehicle | 26 | 50 | 50 |
| Western Rd C | heavy duty vehicle | 24 | 2 | 50 |
| Hodges Court | light duty vehicle | 25 | 20 | 50 |
| Hodges Court | heavy duty vehicle | 20 | 1 | 50 |
| Newton Rd A | light duty vehicle | 26 | 40 | 50 |
| Newton Rd A | heavy duty vehicle | 20 | 2 | 50 |
| Newton Rd B | light duty vehicle | 26 | 40 | 50 |
| Newton Rd B | heavy duty vehicle | 20 | 2 | 50 |
| Chilswell Rd A | light duty vehicle | 26 | 60 | 50 |
| Chilswell Rd A | heavy duty vehicle | 20 | 2 | 50 |
| Chilswell Rd B | light duty vehicle | 26 | 60 | 50 |
| Chilswell Rd B | heavy duty vehicle | 20 | 2 | 50 |
| Chilswell Rd C | light duty vehicle | 26 | 60 | 50 |
| Chilswell Rd C | heavy duty vehicle | 20 | 2 | 50 |
| Edith Rd | light duty vehicle | 20 | 50 | 50 |
| Edith Rd | heavy duty vehicle | 14 | 1 | 50 |
| Kineton Rd | light duty vehicle | 24 | 40 | 50 |
| Kineton Rd | heavy duty vehicle | 20 | 1 | 50 |
| Brook St | light duty vehicle | 20 | 20 | 50 |
| Brook St | heavy duty vehicle | 5 | 0 | 50 |
| Cobden Cres | light duty vehicle | 20 | 20 | 50 |
| Cobden Cres | heavy duty vehicle | 16 | 1 | 50 |
| Buckingham St | light duty vehicle | 20 | 20 | 50 |
| Buckingham St | heavy duty vehicle | 16 | 1 | 50 |
| Salter Close | light duty vehicle | 20 | 520 | 50 |
| Salter Close | heavy duty vehicle | 14 | 20 | 50 |
| Speedwell St A | light duty vehicle | 26 | 200 | 50 |
| Speedwell St A | heavy duty vehicle | 22 | 2 | 50 |
| Speedwell St B | light duty vehicle | 26 | 200 | 50 |
| Speedwell St B | heavy duty vehicle | 22 | 2 | 50 |
| Speedwell St C | light duty vehicle | 26 | 200 | 50 |
| Speedwell St C | heavy duty vehicle | 22 | 2 | 50 |
| Speedwell St D | light duty vehicle | 24 | 200 | 50 |
| Speedwell St D | heavy duty vehicle | 20 | 2 | 50 |
| Cromwell St | light duty vehicle | 20 | 20 | 50 |
| Cromwell St | heavy duty vehicle | 14 | 1 | 50 |
| St Aldates | light duty vehicle | 14 | 20 | 50 |
| St Aldates | heavy duty vehicle | 10 | 1 | 50 |
| Butterwycke Place | light duty vehicle | 28 | 60 | 50 |
| Butterwycke Place | heavy duty vehicle | 22 | 2 | 50 |
| Albion Pl | light duty vehicle | 28 | 50 | 50 |
| Albion Pl | heavy duty vehicle | 22 | 2 | 50 |
| Friars Wharf | light duty vehicle | 28 | 160 | 50 |
| Friars Wharf | heavy duty vehicle | 24 | 40 | 50 |
| Dale Cl | light duty vehicle | 16 | 120 | 50 |
| Dale Cl | heavy duty vehicle | 5 | 5 | 50 |
| Blackfriars Rd | light duty vehicle | 20 | 40 | 50 |
| Blackfriars Rd | heavy duty vehicle | 14 | 2 | 50 |
| Preachers Ln | light duty vehicle | 20 | 140 | 50 |

| | | | | |
|---|---|---|---|---|
| Preachers Ln | heavy duty vehicle | 14 | 20 | 50 |
| Trinity St A | light duty vehicle | 20 | 140 | 50 |
| Trinity St A | heavy duty vehicle | 14 | 20 | 50 |
| Trinity St B | light duty vehicle | 20 | 140 | 50 |
| Trinity St B | heavy duty vehicle | 14 | 20 | 50 |
| Shirelake Cl | light duty vehicle | 20 | 40 | 50 |
| Shirelake Cl | heavy duty vehicle | 5 | 0 | 50 |

## v. Sheffield Tinsley

*Table 96 Source Emission Rates for Sheffield Tinsley.*

| **Source name** | **Emission rate ($NO_2$)** | **Emission rate ($NO_X$)** | **Comments** |
|---|---|---|---|
| M1 A | 0.06 | 0.26 | g/km/s |
| M1 B | 0.06 | 0.26 | g/km/s |
| A6178 A | 0.05 | 0.22 | g/km/s |
| A631 A | 0.07 | 0.28 | g/km/s |
| A631 B | 0.03 | 0.09 | g/km/s |
| A631 C | 0.03 | 0.09 | g/km/s |
| A631 D | 0.03 | 0.09 | g/km/s |
| A631 E | 0.03 | 0.09 | g/km/s |
| A6178 B | 0.02 | 0.06 | g/km/s |
| A6178 C | 0.01 | 0.05 | g/km/s |
| A6178 D | 0.01 | 0.05 | g/km/s |
| Ferrars Rd A | 0.01 | 0.03 | g/km/s |
| Ferrars Rd B | 0.01 | 0.03 | g/km/s |
| Ferrars Rd C | 0.01 | 0.03 | g/km/s |
| Ferrars Rd D | 0.01 | 0.03 | g/km/s |
| Ferrars Rd E | 0.01 | 0.03 | g/km/s |
| Sheffield Rd | 0.02 | 0.06 | g/km/s |
| Vantage Rd A | 0.00 | 0.01 | g/km/s |
| Vantage Rd B | 0.00 | 0.01 | g/km/s |
| Vantage Rd C | 0.00 | 0.01 | g/km/s |
| St Lawrence Rd A | 0.01 | 0.03 | g/km/s |
| St Lawrence Rd B | 0.01 | 0.03 | g/km/s |
| St Lawrence Rd C | 0.01 | 0.03 | g/km/s |
| St Lawrence Rd D | 0.01 | 0.03 | g/km/s |
| St Lawrence Rd E | 0.01 | 0.03 | g/km/s |
| St Lawrence Rd F | 0.01 | 0.03 | g/km/s |
| St Lawrence Rd G | 0.01 | 0.03 | g/km/s |
| St Lawrence Rd H | 0.01 | 0.03 | g/km/s |
| A631 F | 0.03 | 0.10 | g/km/s |
| A631 G | 0.03 | 0.10 | g/km/s |
| Raby St A | 0.00 | 0.01 | g/km/s |
| Raby St B | 0.00 | 0.01 | g/km/s |
| Raby St C | 0.00 | 0.01 | g/km/s |
| Raby St D | 0.00 | 0.01 | g/km/s |
| St Lawrence Glebe | 0.08 | 0.37 | g/km/s |
| Dundas Rd A | 0.08 | 0.38 | g/km/s |
| Dundas Rd B | 0.09 | 0.40 | g/km/s |
| Dundas Rd C | 0.09 | 0.40 | g/km/s |
| Dundas Rd D | 0.09 | 0.40 | g/km/s |
| Town St A | 0.04 | 0.21 | g/km/s |
| Town St B | 0.04 | 0.21 | g/km/s |
| Newmarch St A | 0.01 | 0.04 | g/km/s |
| Newmarch St B | 0.01 | 0.04 | g/km/s |
| Oversly St | 0.01 | 0.04 | g/km/s |
| Norborough Rd A | 0.01 | 0.04 | g/km/s |
| Norborough Rd B | 0.01 | 0.04 | g/km/s |
| Norborough Rd C | 0.01 | 0.04 | g/km/s |
| Norborough Rd D | 0.01 | 0.04 | g/km/s |
| Norborough Rd E | 0.01 | 0.04 | g/km/s |
| Lifford St | 0.01 | 0.04 | g/km/s |

| | | | |
|---|---|---|---|
| Hatherley Rd | 0.00 | 0.02 | g/km/s |
| Wharf Rd | 0.00 | 0.02 | g/km/s |
| Highgate C | 0.02 | 0.08 | g/km/s |
| Ingfield Ave | 0.00 | 0.01 | g/km/s |
| Harrowden Rd A | 0.00 | 0.02 | g/km/s |
| Harrowden Rd B | 0.00 | 0.02 | g/km/s |
| Harrowden Ct | 0.00 | 0.01 | g/km/s |
| Highgate A | 0.02 | 0.07 | g/km/s |
| Highgate B | 0.02 | 0.08 | g/km/s |
| Maplebeck Dr | 0.00 | 0.01 | g/km/s |
| Maplebeck Rd A | 0.00 | 0.01 | g/km/s |
| Maplebeck Rd B | 0.00 | 0.01 | g/km/s |
| Newmarch St C | 0.00 | 0.02 | g/km/s |
| Seimens Cl | 0.00 | 0.01 | g/km/s |
| Newburn Dr | 0.00 | 0.01 | g/km/s |
| Bawtry Gate | 0.00 | 0.01 | g/km/s |

*Table 97 Traffic dataset (EFT v9.0 (2 VC)) for Sheffield Tinsley.*

| Source name | Road width (m) | Canyon height (m) | Traffic flows used | Traffic flow year | Traffic flow road type |
|---|---|---|---|---|---|
| M1 A | 49.00 | 0.00 | Yes | 2019 | England (motorway) |
| M1 B | 49.00 | 14.00 | Yes | 2019 | England (motorway) |
| A6178 A | 26.30 | 0.00 | Yes | 2019 | England (urban) |
| A631 A | 20.70 | 2.00 | Yes | 2019 | England (urban) |
| A631 B | 16.40 | 8.00 | Yes | 2019 | England (urban) |
| A631 C | 16.40 | 8.00 | Yes | 2019 | England (urban) |
| A631 D | 16.40 | 8.00 | Yes | 2019 | England (urban) |
| A631 E | 16.40 | 4.00 | Yes | 2019 | England (urban) |
| A6178 B | 17.80 | 0.00 | Yes | 2019 | England (urban) |
| A6178 C | 17.80 | 3.00 | Yes | 2019 | England (urban) |
| A6178 D | 17.80 | 9.00 | Yes | 2019 | England (urban) |
| Ferrars Rd A | 13.60 | 9.00 | Yes | 2019 | England (urban) |
| Ferrars Rd B | 13.60 | 9.00 | Yes | 2019 | England (urban) |
| Ferrars Rd C | 13.60 | 9.00 | Yes | 2019 | England (urban) |
| Ferrars Rd D | 13.60 | 9.00 | Yes | 2019 | England (urban) |
| Ferrars Rd E | 13.60 | 9.00 | Yes | 2019 | England (urban) |
| Sheffield Rd | 10.30 | 3.00 | Yes | 2019 | England (urban) |
| Vantage Rd A | 9.60 | 10.00 | Yes | 2019 | England (urban) |
| Vantage Rd B | 10.00 | 10.00 | Yes | 2019 | England (urban) |
| Vantage Rd C | 10.00 | 10.00 | Yes | 2019 | England (urban) |
| St Lawrence Rd A | 9.50 | 5.00 | Yes | 2019 | England (urban) |
| St Lawrence Rd B | 9.50 | 5.00 | Yes | 2019 | England (urban) |
| St Lawrence Rd C | 9.50 | 5.00 | Yes | 2019 | England (urban) |
| St Lawrence Rd D | 9.50 | 5.00 | Yes | 2019 | England (urban) |
| St Lawrence Rd E | 9.50 | 5.00 | Yes | 2019 | England (urban) |
| St Lawrence Rd F | 9.50 | 5.00 | Yes | 2019 | England (urban) |
| St Lawrence Rd G | 9.50 | 5.00 | Yes | 2019 | England (urban) |
| St Lawrence Rd H | 9.50 | 5.00 | Yes | 2019 | England (urban) |
| A631 F | 16.00 | 3.00 | Yes | 2019 | England (urban) |
| A631 G | 16.00 | 3.00 | Yes | 2019 | England (urban) |
| Raby St A | 5.40 | 8.00 | Yes | 2019 | England (urban) |
| Raby St B | 5.40 | 8.00 | Yes | 2019 | England (urban) |
| Raby St C | 5.40 | 8.00 | Yes | 2019 | England (urban) |
| Raby St D | 5.40 | 8.00 | Yes | 2019 | England (urban) |
| St Lawrence Glebe | 9.00 | 6.00 | Yes | 2019 | England (urban) |
| Dundas Rd A | 9.30 | 8.00 | Yes | 2019 | England (urban) |
| Dundas Rd B | 9.30 | 8.00 | Yes | 2019 | England (urban) |
| Dundas Rd C | 9.30 | 8.00 | Yes | 2019 | England (urban) |
| Dundas Rd D | 9.30 | 8.00 | Yes | 2019 | England (urban) |
| Town St A | 7.60 | 8.00 | Yes | 2019 | England (urban) |
| Town St B | 7.60 | 8.00 | Yes | 2019 | England (urban) |
| Newmarch St A | 4.80 | 8.00 | Yes | 2019 | England (urban) |
| Newmarch St B | 4.80 | 8.00 | Yes | 2019 | England (urban) |
| Oversly St | 5.50 | 8.00 | Yes | 2019 | England (urban) |

| | | | | | |
|---|---|---|---|---|---|
| Norborough Rd A | 6.60 | 9.00 | Yes | 2019 | England (urban) |
| Norborough Rd B | 6.60 | 9.00 | Yes | 2019 | England (urban) |
| Norborough Rd C | 6.60 | 9.00 | Yes | 2019 | England (urban) |
| Norborough Rd D | 6.60 | 9.00 | Yes | 2019 | England (urban) |
| Norborough Rd E | 6.60 | 9.00 | Yes | 2019 | England (urban) |
| Lifford St | 6.30 | 7.00 | Yes | 2019 | England (urban) |
| Hatherley Rd | 5.00 | 7.00 | Yes | 2019 | England (urban) |
| Wharf Rd | 3.20 | 1.00 | Yes | 2019 | England (urban) |
| Highgate C | 8.00 | 8.00 | Yes | 2019 | England (urban) |
| Ingfield Ave | 5.80 | 8.00 | Yes | 2019 | England (urban) |
| Harrowden Rd A | 5.50 | 4.00 | Yes | 2019 | England (urban) |
| Harrowden Rd B | 5.50 | 4.00 | Yes | 2019 | England (urban) |
| Harrowden Ct | 4.90 | 12.00 | Yes | 2019 | England (urban) |
| Highgate A | 8.00 | 8.00 | Yes | 2019 | England (urban) |
| Highgate B | 8.00 | 8.00 | Yes | 2019 | England (urban) |
| Maplebeck Dr | 5.80 | 8.00 | Yes | 2019 | England (urban) |
| Maplebeck Rd A | 6.90 | 8.00 | Yes | 2019 | England (urban) |
| Maplebeck Rd B | 6.90 | 8.00 | Yes | 2019 | England (urban) |
| Newmarch St C | 9.10 | 9.00 | Yes | 2019 | England (urban) |
| Seimens Cl | 9.70 | 5.00 | Yes | 2019 | England (urban) |
| Newburn Dr | 7.50 | 9.00 | Yes | 2019 | England (urban) |
| Bawtry Gate | 5.40 | 5.00 | Yes | 2019 | England (urban) |

*Table 98 Traffic data for Sheffield Tinsley.*

| **Source name** | **Vehicle category** | **Average speed (km/hr)** | **Vehicle count (vehicles/hour)** | **Percent uphill** |
|---|---|---|---|---|
| M1 A | light duty vehicle | 40 | 1554 | 50 |
| M1 A | heavy duty vehicle | 30 | 180 | 50 |
| M1 B | light duty vehicle | 40 | 1554 | 50 |
| M1 B | heavy duty vehicle | 30 | 180 | 50 |
| A6178 A | light duty vehicle | 36 | 1485 | 50 |
| A6178 A | heavy duty vehicle | 28 | 118 | 50 |
| A631 A | light duty vehicle | 30 | 1824 | 50 |
| A631 A | heavy duty vehicle | 26 | 133 | 50 |
| A631 B | light duty vehicle | 42 | 824 | 50 |
| A631 B | heavy duty vehicle | 38 | 33 | 50 |
| A631 C | light duty vehicle | 42 | 824 | 50 |
| A631 C | heavy duty vehicle | 38 | 33 | 50 |
| A631 D | light duty vehicle | 42 | 824 | 50 |
| A631 D | heavy duty vehicle | 38 | 33 | 50 |
| A631 E | light duty vehicle | 42 | 824 | 50 |
| A631 E | heavy duty vehicle | 38 | 33 | 50 |
| A6178 B | light duty vehicle | 40 | 485 | 50 |
| A6178 B | heavy duty vehicle | 34 | 18 | 50 |
| A6178 C | light duty vehicle | 42 | 485 | 50 |
| A6178 C | heavy duty vehicle | 36 | 18 | 50 |
| A6178 D | light duty vehicle | 42 | 485 | 50 |
| A6178 D | heavy duty vehicle | 36 | 18 | 50 |
| Ferrars Rd A | light duty vehicle | 28 | 200 | 50 |
| Ferrars Rd A | heavy duty vehicle | 26 | 10 | 50 |
| Ferrars Rd B | light duty vehicle | 28 | 200 | 50 |
| Ferrars Rd B | heavy duty vehicle | 26 | 10 | 50 |
| Ferrars Rd C | light duty vehicle | 28 | 200 | 50 |
| Ferrars Rd C | heavy duty vehicle | 26 | 10 | 50 |
| Ferrars Rd D | light duty vehicle | 28 | 200 | 50 |
| Ferrars Rd D | heavy duty vehicle | 26 | 10 | 50 |
| Ferrars Rd E | light duty vehicle | 28 | 200 | 50 |
| Ferrars Rd E | heavy duty vehicle | 26 | 10 | 50 |
| Sheffield Rd | light duty vehicle | 40 | 485 | 50 |
| Sheffield Rd | heavy duty vehicle | 34 | 18 | 50 |
| Vantage Rd A | light duty vehicle | 36 | 40 | 50 |
| Vantage Rd A | heavy duty vehicle | 30 | 5 | 50 |
| Vantage Rd B | light duty vehicle | 26 | 40 | 50 |
| Vantage Rd B | heavy duty vehicle | 22 | 5 | 50 |

| | | | | |
|---|---|---|---|---|
| Vantage Rd C | light duty vehicle | 26 | 40 | 50 |
| Vantage Rd C | heavy duty vehicle | 22 | 5 | 50 |
| St Lawrence Rd A | light duty vehicle | 28 | 200 | 50 |
| St Lawrence Rd A | heavy duty vehicle | 22 | 5 | 50 |
| St Lawrence Rd B | light duty vehicle | 26 | 200 | 50 |
| St Lawrence Rd B | heavy duty vehicle | 20 | 5 | 50 |
| St Lawrence Rd C | light duty vehicle | 26 | 200 | 50 |
| St Lawrence Rd C | heavy duty vehicle | 22 | 5 | 50 |
| St Lawrence Rd D | light duty vehicle | 28 | 200 | 50 |
| St Lawrence Rd D | heavy duty vehicle | 24 | 5 | 50 |
| St Lawrence Rd E | light duty vehicle | 28 | 200 | 50 |
| St Lawrence Rd E | heavy duty vehicle | 24 | 5 | 50 |
| St Lawrence Rd F | light duty vehicle | 24 | 200 | 50 |
| St Lawrence Rd F | heavy duty vehicle | 20 | 5 | 50 |
| St Lawrence Rd G | light duty vehicle | 24 | 200 | 50 |
| St Lawrence Rd G | heavy duty vehicle | 20 | 5 | 50 |
| St Lawrence Rd H | light duty vehicle | 24 | 200 | 50 |
| St Lawrence Rd H | heavy duty vehicle | 20 | 5 | 50 |
| A631 F | light duty vehicle | 40 | 824 | 50 |
| A631 F | heavy duty vehicle | 36 | 33 | 50 |
| A631 G | light duty vehicle | 40 | 824 | 50 |
| A631 G | heavy duty vehicle | 36 | 33 | 50 |
| Raby St A | light duty vehicle | 28 | 60 | 50 |
| Raby St A | heavy duty vehicle | 24 | 2 | 50 |
| Raby St B | light duty vehicle | 28 | 60 | 50 |
| Raby St B | heavy duty vehicle | 24 | 2 | 50 |
| Raby St C | light duty vehicle | 28 | 60 | 50 |
| Raby St C | heavy duty vehicle | 24 | 2 | 50 |
| Raby St D | light duty vehicle | 26 | 60 | 50 |
| Raby St D | heavy duty vehicle | 22 | 2 | 50 |
| St Lawrence Glebe | light duty vehicle | 26 | 2000 | 50 |
| St Lawrence Glebe | heavy duty vehicle | 24 | 200 | 50 |
| Dundas Rd A | light duty vehicle | 26 | 2000 | 50 |
| Dundas Rd A | heavy duty vehicle | 22 | 200 | 50 |
| Dundas Rd B | light duty vehicle | 24 | 2000 | 50 |
| Dundas Rd B | heavy duty vehicle | 20 | 200 | 50 |
| Dundas Rd C | light duty vehicle | 24 | 2000 | 50 |
| Dundas Rd C | heavy duty vehicle | 20 | 200 | 50 |
| Dundas Rd D | light duty vehicle | 24 | 2000 | 50 |
| Dundas Rd D | heavy duty vehicle | 20 | 200 | 50 |
| Town St A | light duty vehicle | 28 | 1100 | 50 |
| Town St A | heavy duty vehicle | 24 | 120 | 50 |
| Town St B | light duty vehicle | 28 | 1100 | 50 |
| Town St B | heavy duty vehicle | 24 | 120 | 50 |
| Newmarch St A | light duty vehicle | 30 | 200 | 50 |
| Newmarch St A | heavy duty vehicle | 20 | 20 | 50 |
| Newmarch St B | light duty vehicle | 30 | 200 | 50 |
| Newmarch St B | heavy duty vehicle | 20 | 20 | 50 |
| Oversly St | light duty vehicle | 30 | 200 | 50 |
| Oversly St | heavy duty vehicle | 20 | 20 | 50 |
| Norborough Rd A | light duty vehicle | 30 | 200 | 50 |
| Norborough Rd A | heavy duty vehicle | 20 | 20 | 50 |
| Norborough Rd B | light duty vehicle | 30 | 200 | 50 |
| Norborough Rd B | heavy duty vehicle | 20 | 20 | 50 |
| Norborough Rd C | light duty vehicle | 30 | 200 | 50 |
| Norborough Rd C | heavy duty vehicle | 20 | 20 | 50 |
| Norborough Rd D | light duty vehicle | 30 | 200 | 50 |
| Norborough Rd D | heavy duty vehicle | 20 | 20 | 50 |
| Norborough Rd E | light duty vehicle | 30 | 200 | 50 |
| Norborough Rd E | heavy duty vehicle | 20 | 20 | 50 |
| Lifford St | light duty vehicle | 30 | 200 | 50 |
| Lifford St | heavy duty vehicle | 20 | 20 | 50 |
| Hatherley Rd | light duty vehicle | 30 | 100 | 50 |
| Hatherley Rd | heavy duty vehicle | 20 | 10 | 50 |
| Wharf Rd | light duty vehicle | 30 | 60 | 50 |
| Wharf Rd | heavy duty vehicle | 20 | 10 | 50 |
| Highgate C | light duty vehicle | 30 | 600 | 50 |

|  |  |  |  |  |
|---|---|---|---|---|
| Highgate C | heavy duty vehicle | 20 | 20 | 50 |
| Ingfield Ave | light duty vehicle | 30 | 40 | 50 |
| Ingfield Ave | heavy duty vehicle | 20 | 5 | 50 |
| Harrowden Rd A | light duty vehicle | 30 | 80 | 50 |
| Harrowden Rd A | heavy duty vehicle | 20 | 10 | 50 |
| Harrowden Rd B | light duty vehicle | 30 | 80 | 50 |
| Harrowden Rd B | heavy duty vehicle | 20 | 10 | 50 |
| Harrowden Ct | light duty vehicle | 30 | 40 | 50 |
| Harrowden Ct | heavy duty vehicle | 20 | 2 | 50 |
| Highgate A | light duty vehicle | 30 | 600 | 50 |
| Highgate A | heavy duty vehicle | 26 | 15 | 50 |
| Highgate B | light duty vehicle | 28 | 600 | 50 |
| Highgate B | heavy duty vehicle | 24 | 15 | 50 |
| Maplebeck Dr | light duty vehicle | 30 | 60 | 50 |
| Maplebeck Dr | heavy duty vehicle | 20 | 2 | 50 |
| Maplebeck Rd A | light duty vehicle | 30 | 50 | 50 |
| Maplebeck Rd A | heavy duty vehicle | 20 | 5 | 50 |
| Maplebeck Rd B | light duty vehicle | 30 | 50 | 50 |
| Maplebeck Rd B | heavy duty vehicle | 20 | 5 | 50 |
| Newmarch St C | light duty vehicle | 30 | 100 | 50 |
| Newmarch St C | heavy duty vehicle | 20 | 10 | 50 |
| Seimens Cl | light duty vehicle | 30 | 40 | 50 |
| Seimens Cl | heavy duty vehicle | 20 | 1 | 50 |
| Newburn Dr | light duty vehicle | 30 | 40 | 50 |
| Newburn Dr | heavy duty vehicle | 20 | 1 | 50 |
| Bawtry Gate | light duty vehicle | 30 | 50 | 50 |
| Bawtry Gate | heavy duty vehicle | 20 | 5 | 50 |