Cost-Benefit Analysis of Reducing Particulate Emissions from Non-Road Mobile Machinery on the Olympic Park Construction Site

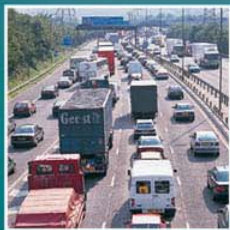
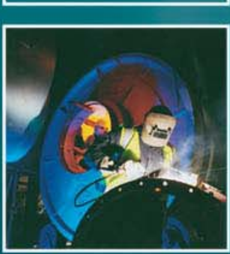
Final Report

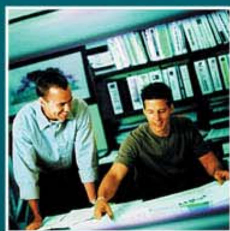
April 2010









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Final Report

April 2010

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Report for

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Executive Summary

Purpose of this Report

This report has been produced for the purpose of providing a technical evidence base to inform the ODA's decisions regarding the requirements of the Best Practice Guidance 'The Control of Dust and Emissions from Construction and Demolition' produced in partnership by the GLA and the London Councils.

Introduction

The ODA's Code of Construction Practice (CoCP) includes a number of measures to be considered for limiting dust and vehicle emissions. These measures are based on recommendations contained within the Best Practice Guidance for mitigating the effects of construction on sites deemed as "high risk". One of the mitigation measures which should be considered is the retro-fitting of diesel particulate filters (DPFs), or other exhaust after-treatment, to all Non-Road Mobile Machinery (NRMM) over 37 kW power rating. These filters, if fitted, would conform to a filtration efficiency of over 85 per cent (load/duty cycle permitting) and thus have the potential to lead to a significant reduction in the emissions of fine particles from construction plant and vehicles, which may lead to benefits in terms of local air quality. This requirement has been the subject of debate between engine manufacturers, plant hire companies, contractors, DPF manufacturers and lobby groups. The debate focuses on the costs and benefits of using this equipment.

This report summarises the work undertaken to assess the costs and benefits of using DPFs on the Olympic Park. The approach taken includes:

- The development of detailed inventory of plant operating on the Olympic Park Construction Site (OPCS);
- The development of an atmospheric dispersion model to calculate air pollutant concentrations at receptor locations around the boundary of the Olympic Park;
- Establishment of potential health benefits based on the reduction in concentrations of air pollutants at receptor locations;
- A review of costs in implementing on site measures; and
- A comparison of the costs of introducing these measures against to the associated health benefits.

Assessment Scenarios

To establish the effect of the particle emissions from the OPCS on air quality in the surrounding area, the exhaust emission from vehicles and plant operating on the OPCS have been quantified for the following three operational scenarios:

- Scenario 1: All machinery on site is operated without the use of Ultra Low Sulphur Gas Oil (ULSGO) or DPFs;
- Scenario 2: All machinery on site is operated with ULSGO but excluding DPFs (the existing baseline); and
- Scenario 3: All machinery on site is operated with ULSGO combined with the use of DPFs on plant >37kW achieving a 90% (mass) particle reduction efficiency.

Emissions Inventory

The geographic scope of the emissions inventory included the main work areas on the OPCS, including the primary haul roads. The emissions were calculated for the three scenarios presented above, in order to identify the emission reduction associated with the use of ULSGO in all diesel plant and the use of DPFs on all Non-Road Mobile Machinery over 37 kW.

The emissions inventory has shown the following annual emissions of PM_{10} and $PM_{2.5}$ from the OPCS for each of the assessment scenarios:

- Scenario 1 (no ULSGO) – 11,406 kg of PM_{10} and 10,735 kg of $PM_{2.5}$;
- Scenario 2 (ULSGO) – 8,186 kg of PM_{10} and 7,695 kg of $PM_{2.5}$; and
- Scenario 3 (ULSGO and DPFs) – 2,578 kg of PM_{10} and 2,396 kg of $PM_{2.5}$.

Dispersion Modelling

For the detailed dispersion modelling, the contribution of the OPCS emissions to concentrations of PM_{10} and $PM_{2.5}$ at locations around the boundary of the OPCS were not of sufficient magnitude to result in any exceedences of the annual mean air quality objectives at any of the modelled receptors. This was inclusive of the contribution of the road traffic emissions from the main roads in the area and the ambient background contribution. There were, however, exceedences identified at receptors close to the A11 and A12 which is consistent with the findings of the local authorities.

The receptor which experienced the greatest contribution of PM_{10} and $PM_{2.5}$ from the OPCS was located to the west of the site. The PM_{10} contribution at this receptor was 2.3 µg m^{-3} for the Scenario 1, reducing to 1.6 µg m^{-3} for

Scenario 2 and reducing further to 0.5 µg m^{-3} for Scenario 3. The $PM_{2.5}$ contribution at this receptor was 2.2 µg m^{-3} for the baseline scenario, reducing to 1.5 µg m^{-3} for Scenario 2 and reducing further to 0.4 µg m^{-3} for Scenario 3.

Population Weighted Mean Concentrations (PWMCs) have been calculated for each scenario based on the population in the surrounding area exposed within each concentration contour, i.e. the modelled concentrations of PM_{10} are overlaid on the population data to estimate exposure. This has been used in the benefits analysis.

Cost-Benefit Analysis

Costs

Capital (i.e. up-front) and ongoing operating (i.e. every year) costs of DPFs have been estimated based on data gathered direct from manufacturers, a review of relevant literature and data provided direct by the ODA (e.g. fuel costs). A range of costs has been applied in the analysis to reflect the wide variability in retrofit costs for different sizes and types of plant.

The following costs have been estimated:

- Total retrofit costs for installing DPFs on plant >37kW are expected to be £2.5-5.8 million with operating costs of £0.3-0.5 million per year. Operating costs include the additional costs of all plant using ULSGO (relative to standard gas oil) and are estimated to be approximately £100k per year; and
- Annualised costs for retro-fitting DPFs on plant >37kW are estimated to be £0.9-1.8 million depending on the range of cost data applied and if the capital costs are annualised over the lifetime of the equipment (5 years)[1].

Benefits

The Institute of Occupational Medicine (IOM) has undertaken a Health Impact Assessment of each of the scenarios based on the modelled PWMC data provided by Entec. This has been combined with the latest recommended exposure-response functions to estimate the health impacts to the local population associated with particulate emissions from NRMM on site. These impacts have then been monetised through the application of the Government's Interdepartmental Group on Costs and Benefits (IGCB) recommended values[2].

The following benefits have been estimated:

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[1] For sensitivity (to reflect the possible impacts to the ODA itself) the capital costs have also been annualised over the remaining lifetime of the build (i.e. 2 years). This increases annualised costs to £1.6-3.5 million.

[2] http://www.defra.gov.uk/environment/quality/air/airquality/panels/igcb/index.htm

- The emission reductions associated with the use of ULSGO by all plants are expected to result in benefits of approximately £0.4 million per year (sensitivity range of £0.3-0.6 million).

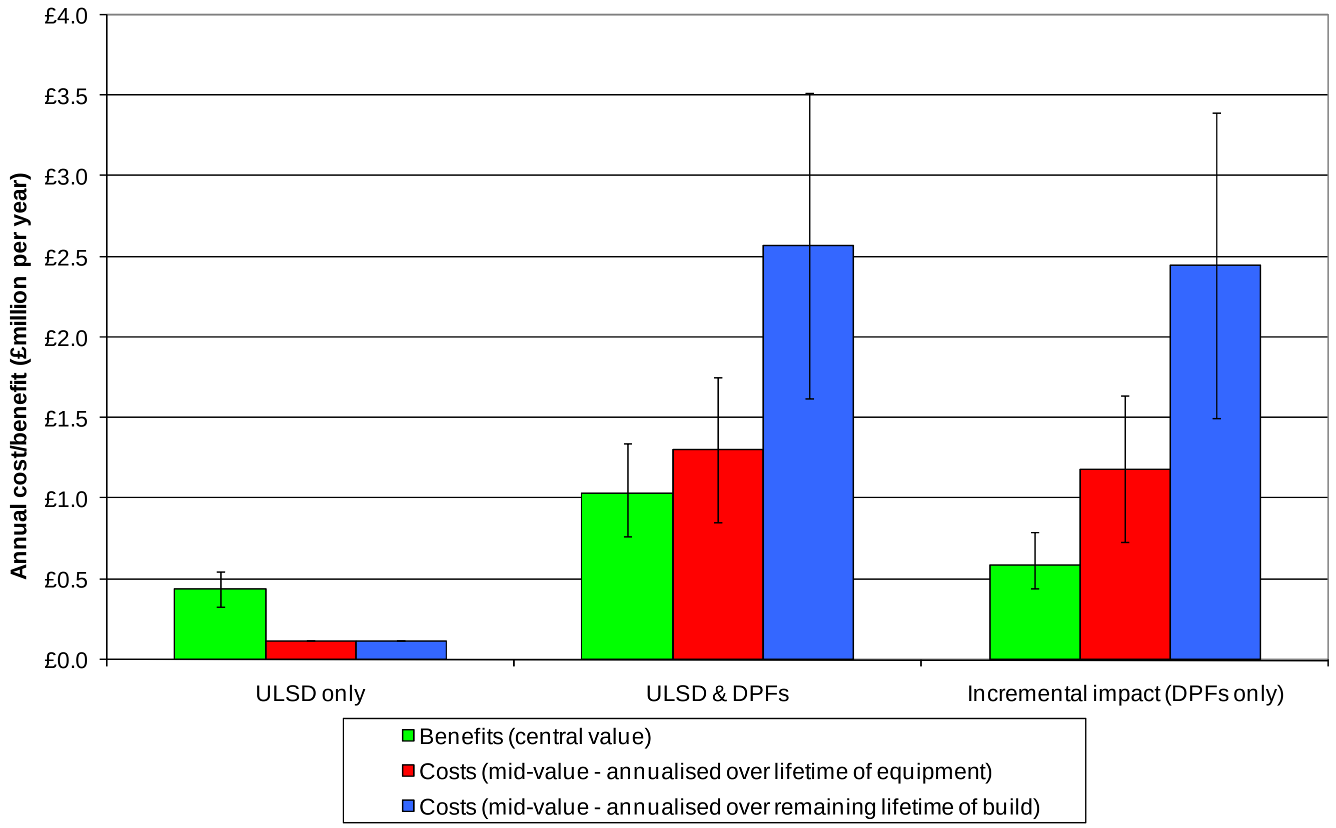
- The emission reductions associated with the use of ULSGO by all plants and DPFs by plants >37kW are expected to result in benefits of approximately £1.0 million per year (sensitivity range of £0.8-1.3 million) i.e. the retrofit of DPFs is expected to result in additional benefits (relative to ULSD alone) of approximately £0.6 million per year (sensitivity range of £0.4-0.8 million).

The health benefits associated with the use of ULSGO and the retrofit of DPFs are relatively low due to the geographical location of the site with limited population living very close to the site boundaries. In addition, the population density in the affected area is approximately 25% lower than the average density in the surrounding Boroughs.

Overview

The costs and benefits associated with each scenario are summarised in Figure 1 below (the error bars indicate the range of costs and benefits).

Figure 1 Summary of costs and benefits of each scenario



Conclusions

Impacts on Emissions and Air Quality

As would be expected, the inventory shows that emissions of PM_{10} and $PM_{2.5}$ reduce with the use of ULSGO and DPFs. The existing baseline (Scenario 2), based on compliance with the CoCP and the use of ULSGO provides a reduction in emissions of PM_{10} of approximately 28% compared to the use of standard gas oil (Scenario 1). The combination of ULSGO and the retrofitting of DPFs on all plant >37kW (Scenario 3) provides a further reduction of approximately 68% in total emissions of PM_{10}, a reduction in emissions of approximately 77% compared to Scenario 1.

The detailed dispersion modelling predicts that the emissions of pollutants from the machinery on the site are not having a significant effect on air quality in the local area and are unlikely to result in an exceedence of the annual mean air quality objectives for PM_{10} or $PM_{2.5}$. At locations close to the A11 and A12 there are exceedences predicted by the dispersion modelling but the contribution of the OPCS at these locations is small compared to the contribution from the road network and other background sources.

Cost-benefit Ratios

The following cost-benefit ratios have been estimated based on annual costs (spread over the lifetime of the equipment) and benefits:

- A ratio of 3.5:1 (sensitivity range of 2.6-4.4:1) has been estimated for the use of ULSGO alone relative to the baseline i.e. annual benefits are expected to be over three times higher than the annual costs.

- A ratio of 0.8:1 (sensitivity range of 0.4-1.6:1) has been estimated for the use of ULSGO and DPFs relative to the baseline i.e. annual benefits are expected to be approximately 20% lower than annual costs.

- The incremental impact of retro-fitting DPFs in addition to using ULSGO results in a ratio of 0.5:1 (sensitivity range of 0.3-1.1:1) i.e. the incremental annual benefits associated with retro-fitting DPFs are approximately half of the annual incremental costs.

The above cost-benefit ratios change significantly if the annual benefits are compared against annual costs spread over the remaining lifetime of the build rather than the lifetime of the equipment (i.e. 2 years as opposed to 5). In particular, the annual costs are significantly higher (by a factor of four) than the annual benefits associated with the use of DPFs (see Figure 1 above).

It should be noted that the cost-benefit analysis undertaken for this study is specific to the machinery on site and the location of the site in relation to the surrounding population. The findings, therefore, are not directly transferable to other sites. There are also a number of uncertainties which should be taken into consideration and these are summarised in Section 6.4.

Relevant Terminology

Term/Abbreviation	Description
AADT	Annual Average Daily Traffic (vehicles per day)
APPLE	London Air Pollution Planning and Local Environment Working Group
AQAP	Air Quality Action Plan
AQMA	Air Quality Management Area
AQO	Air Quality Objective
AQS	Air Quality Standards
Background	Background air quality is used in this report to mean the concentration of atmospheric pollutants that would prevail if no local sources of air pollution, such as local road traffic and industrial sources were present.
Baseline	Baseline air quality is used in this report to mean the likely air quality predicted without the changes due to the proposed development. This includes the contribution of existing local roads and point sources in addition to background pollutant concentrations.
CBA	Cost Benefit Analysis
CERC	Cambridge Environmental Research Centre
CoCP	Code of Construction Practice
COMEAP	Committee on the Medical Affects of Air Pollutants
Concentration	The amount of a polluting substance in a volume of air, typically expressed as a mass of pollutant per unit volume of air or a volume of gaseous pollutant per unit volume of air.
DPFs	Diesel Particulate Filters
EGR	Exhaust Gas Re-circulation
EIC	Environmental Industries Commission
Emission	Discharge or release of particulates or a gaseous pollutant into air
EU	European Union
Exceedence	A concentration of a pollutant greater than the appropriate Air Quality Objective.
GLA	Greater London Authority
g/kWh	Grams per kilowatt-hour
HDV / HGV	Heavy duty vehicle / Heavy goods vehicle
IGCB	Interdepartmental Group on Costs and Benefits
IOM	Institute of Occupational Medicine
kg	Kilograms
kW	Kilowatts
LAEI	London Atmospheric Emissions Inventory
LAQM	Local Air Quality Management

Term/Abbreviation	Description
LDV	Light duty vehicle
LPA	Local Planning Authority
Microgram (µg)	One millionth of a gram
$\mu g\ m^{-3}$	Micrograms per cubic metre of air
NAEI	National Atmospheric Emissions Inventory
Netcen	National Environmental Technology Centre
NO_X	Nitrogen Oxides
NRMM	Non Road Mobile Machinery
ODA	Olympic Delivery Authority
OPCS	Olympic Park Construction Site
PM_{10}	Particulate Matter with a diameter less than 10 microns
$PM_{2.5}$	Particulate Matter with a diameter of less than 2.5 microns
PM_1	Particulate Matter with a diameter of less than 1 micron
ppm	Parts per million
PWMC	Population Weighted Mean Concentration
Roadside	A site sampling between 1m of the kerbside of a busy road and the back of the pavement. Typically this will be within 5m of the road, but could be up to 15m.
SCR	Selective Catalytic Reduction
SDS	Sustainable Development Strategy
ULSGO	Ultra Low Sulphur Gas Oil. Can also be called Ultra Low Sulphur Diesel (ULSD)
Validation	Refers to model testing carried out by the model developers during model development.
Verification	Refers to the comparison of modelled pollutant concentrations against measured concentrations carried out during a modelling assessment.
WHO	World Health Organisation

Contents

1. Introduction

1.1 Background

Entec has been appointed by the Olympic Delivery Authority (ODA) to provide air quality consultancy support. The purpose of this support is to provide a technical evidence base to inform the ODA's decision regarding the requirements to meet aspects of the Best Practice Guidance 'The Control of Dust and Emissions from Construction and Demolition' produced in partnership by the GLA and the London Councils.

The ODA has put in place several measures to reduce the effect of vehicles and construction plant on air quality. The ODA's Code of Construction Practice (CoCP) includes a number of measures to be considered for limiting emissions and reducing dust, including the use of ultra low sulphur gas oil (ULSGO) by all of the plant and vehicles on site. The potential measures contained in the CoCP are based on recommendations contained within the Best Practice Guidance. In addition to the CoCP, the Sustainable Development Strategy (SDS) includes a target for transporting more than 50% of the materials to the site by sustainable means, thus reducing the number of road vehicles travelling to and from the site.

One of the measures to be considered by ODA contractors is retro-fitting of diesel particulate filters (DPFs), or other exhaust after-treatment, to all Non-Road Mobile Machinery (NRMM) with an engine power of >37kW. This measure is reflected in the ODA's Code of Construction Practice as a consideration (as one of a number of measures) for contractors. These filters, if fitted, would conform to a filtration efficiency of over 85 per cent (load/duty cycle permitting) and thus have the potential to lead to a significant reduction in the emissions of fine particles from construction plant and vehicles, that could lead to potential benefits in terms of local air quality.

There are a number of stakeholders which have lobbied the ODA to meet this perceived requirement. These stakeholders mainly represent manufacturers of appropriate exhaust after-treatment equipment (i.e. diesel particulate filters) and air quality lobby groups. Conversely, the construction industry and plant hire firms have concerns about the requirement. The concerns reflect the cost-effectiveness of the equipment and the potential impacts of retro-fitting the equipment on existing plant. Moreover, the industry states that all new plant will be required to meet higher emissions standards in the next 2 years as the result of changes to EU policy (Section 3.2).

The ODA has commissioned the study in response to the varied concerns of all stakeholders, elicited at an ODA Stakeholder Engagement Meeting in July of 2009, in order to ascertain what the benefits in air quality terms would be of a decision to implement exhaust gas after-treatment for NRMM on the OPCS.

1.2 Purpose

The primary scope of the technical assessment is to quantify the magnitude of particulate emission savings from the potential introduction of DPFs on selected plant and the cost / benefit of doing so. This includes the determination of the magnitude of change in emissions of particulate matter (PM_{10} and $PM_{2.5}$).

The scope also includes an assessment of the effectiveness of the air quality related mitigation measures contained in the Code of Construction Practice (CoCP) in comparison with a do-nothing scenario. This will focus on the assessment of the reduction in emissions of PM_{10} / $PM_{2.5}$ brought about by the use of ULSGO and DPFs in all plant and vehicles operating on the site.

Dispersion modelling has been undertaken in order to quantify the change in the potential exposure of sensitive receptor groups around the Olympic site to PM_{10} and $PM_{2.5}$ in the context of existing baseline concentrations of these key local air pollutants.

Entec, with support from the Institute of Occupational Medicine (IOM), has also conducted a Cost-Benefit Analysis (CBA) to provide a comparison of the costs of compliance in terms of retro-fitting DPFs against the wider health benefits for the local population.

Information provided in the air quality assessment and the CBA will be used by the ODA to determine the most cost effective way of safeguarding local air quality.

1.3 Objectives

The ODA’s objectives for this desk study were as follows:

- To determine the actual likely environmental benefit of implementing DPFs;
- To determine the most cost effective way of safeguarding air quality; and
- To determine the cost / benefit ratio of implementing DPFs.

The wider objectives of the GLA in this process were as follows:

"The GLA hopes to achieve consensus between stakeholders regarding the practical implementation of retro-fitting filters to onsite pieces of kit and machinery on the Olympic construction site. The GLA will seek to use the information from the retrofit pilot trial to inform future review and development of the Best Practice Guidance and the Mayor’s Air Quality Strategy; if it is proven and agreed that there are no significant practical barriers to fitting the filters then the GLA will seek to implement this more widely across London."

As can be seen from the above, the GLA’s focus is more to investigate issues associated with the retro-fitting of DPFs, as compared with the ODA’s focus which is firstly focused on the environmental benefits and costs associated with the retro-fitting and costs of the DPFs on the OPCS. The retrofit pilot study is outside of the scope of this assessment.

2. Nature, Sources and Emissions of Airborne Particles and their Health Effects

2.1 Nature and Source of Particles

The Airborne Particles Expert Group identifies that airborne PM_{10} is composed essentially of three fractions, each of which makes up approximately one-third of the total, as follows:

- Primary particle emissions, derived from combustion sources such as road traffic, power stations and industrial processes;
- Secondary particle emissions, formed by chemical reactions in the atmosphere (principally sulphate and nitrate compounds); and
- Coarse particles, from a wide range of sources, including traffic-suspended road dusts, construction work, mineral workings, wind blown dust and soil, marine aerosol and biological particles.

The fine particle fraction, below $PM_{2.5}$, comprises mainly primary and secondary particles, whilst particles in the $PM_{2.5}$ to PM_{10} range consist of coarse particles. The majority of particles arising from diesel exhaust emissions will be in the fine particle fraction, below $PM_{2.5}$.

2.2 Emissions of Particles

Traditionally, stationary combustion (mainly coal) and industrial processes were a major source of PM_{10} emissions, although the decline in the use of coal has led to a reduction in these emissions. From 1970-2007 an approximate 70% reduction in total annual emissions of PM_{10} has been achieved. Currently, the main sources of particulate emissions in the UK are road transport, stationary combustion and industrial processes (this includes bulk handling, mining, construction and quarrying). Total emissions of particles (PM_{10}) in 2007 in the UK amounted to 135,000 tonnes[3], of which road traffic, the main source of particles (PM_{10}), contributed approximately 25,000 tonnes or 19% to total emissions.

The London Atmospheric Emissions Inventory (LAEI) provides PM_{10} emission estimates for the London Boroughs for 2010. Total PM_{10} emissions from the London Boroughs is estimated to be 2,026 tonnes in 2010, with the majority (1,298 tonnes or 64%) emitted by road traffic. The London Borough of Newham, in which the majority of the Olympics Site is located, is estimated to contribute 57.7 tonnes of PM_{10} or 3% to the annual total across

[3] NAEI (National Emissions Inventory): http://www.naei.org.uk/emissions/emissions_2007/summary_tables.php?action=unece&page_name=PM1007.html

London. The greatest proportion of emissions in Newham is also due to road transport sources, which accounts for 66% of the total emissions (35.5 out of 57.7 tonnes).

Construction activities account for very little of this total, although as emissions from construction are more fugitive and temporary in nature, there is no separate category given for construction activities in the LAEI. In addition, particle emissions are likely to be from both dust and exhausts from stationary machinery as well as mobile machinery on site. These factors therefore make it particularly difficult to quantify annual emissions from construction sites across London.

The recently published Draft Mayor's Air Quality Strategy for London[4] provides further information regarding PM_{10} emissions in London. The Draft Strategy estimates that around 140 tonnes of PM_{10} was emitted in Central London in 2006. Of this 83% (116 tonnes) was from road transport. With implementation of the measures in the Mayor's Draft Air Quality Strategy for London, it is estimated that PM_{10} emissions will reduce by 20% in Greater London by 2012.

2.3 Health Effects of Particles

In recent years evidence has accumulated which shows that day to day variations in concentrations of airborne particles, including PM_{10}, $PM_{2.5}$ and black smoke, are associated with variations in a range of health indicators including hospital admissions (for treatment of both respiratory and cardiovascular diseases), symptoms amongst patients suffering from asthma and daily deaths.

Recent reviews by WHO and the Committee on the Medical Effects of Air Pollutants (COMEAP) have suggested exposure to a finer fraction of particles gives a stronger association with the observed ill-health effects, but also warn that there is evidence that the coarse fraction between $PM_{2.5}$ and PM_{10} also has some effects on health. Fine particulates such as $PM_{2.5}$ and PM_1 can be carried deep into the lungs where they can cause inflammation and lead to a worsening of the condition of people with heart and lung diseases. In addition they may also carry surface-absorbed carcinogenic and other toxic compounds into the lungs.

For that reason, the UK (as a result of revisions to existing European air quality legislation) has introduced Air Quality Objectives and an exposure reduction target for $PM_{2.5}$ to protect public health. These are national objectives and targets which are not included in the Local Air Quality Management Regulations (Chapter 3).

Further details on the health effects of particles are provided in IOM's Health Impact Assessment (Appendix C).

[4] The Mayor's draft Air Quality Strategy for consultation with the London Assembly and functional bodies. Clearing the Air. October 2009.

3. Policy, Legislation and Guidance

3.1 Overview

This section introduces the existing and future legislation in relation to the emissions of particles from internal combustion engines of non-road mobile machinery. It then details the existing legislation in relation to the protection of human health associated with concentrations of pollutants in ambient air.

3.2 Exhaust Emissions from NRMM

Directive 2002/88/EC[5], relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery, implements two stages of emission limit values for compression ignition engines. The two stages of emissions limits for new diesel engines set the maximum allowable emissions of NO_X, PM, hydrocarbons and carbon monoxide.

Stage I is already in force for all engine categories and Stage II has now entered into force for almost all engines (with the exception of small spark ignition hand held engines with a displacement $\geq 50cm^3$ installed before the 1st August 2008 and the machinery exempted from the implementation dates of Stage II emission limit requirements for a period of three years after the entry onto force of those limit requirements).

Directive 2004/26/EC of the European Parliament and of the Council amending Directive 97/68/EC (NRMM Directive) and Directive 2002/88/EC, implements 3 stages of future emissions limits (Stage IIIA, IIIB & IV) that apply to equipment already within the scope of Directive 97/68/EC. The emission limits are shown in Appendix A.

All engines installed that are not already available in the market will have to comply with the emission limits before 2015 (with the exception of Stage IV for engines other than constant speed engines with a production date prior to 31 December 2013 and 30 September 2014 where the compliance date may be postponed by two years).

Directive 98/70/EC as amended by Directive 2003/17/EC relating to the quality of petrol and diesel fuels establishes minimum specifications for petrol and diesel to be placed on the market in the EU, including gas oils intended for use by non-road mobile machinery. These are required to contain less than 2000 mg/kg of sulphur decreasing to 1000 mg/kg by 1 January 2008 at the latest.

For small engines (37-75kW), the predicted technology required to meet Stage IIIA controls includes engine modifications, adoption of electronic engine control, improved fuel pumps and limited, un-cooled Exhaust Gas Recirculation (EGR). For larger engines which already utilise electronic engine control, the predicted technology

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[5] Directive 2002/88/EC, amends Directive 97/68/EC

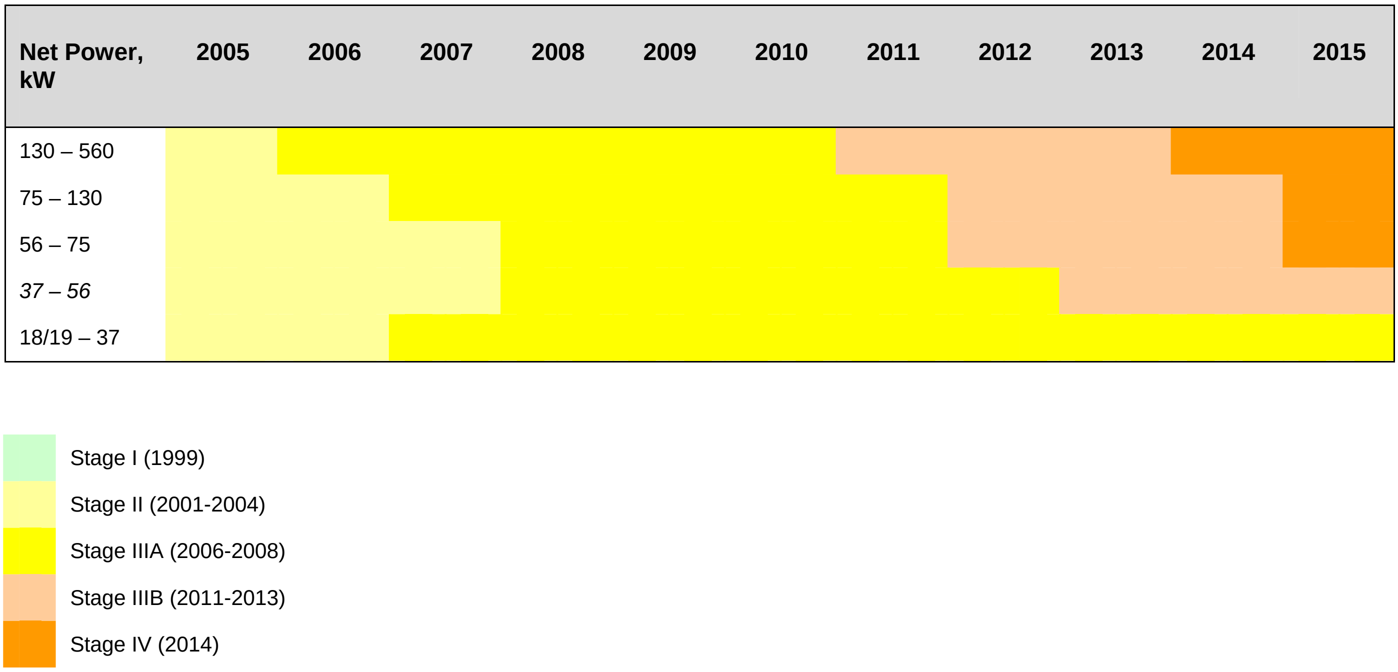
required is engine modifications, common rail injection, air-air charge cooling and limited, un-cooled EGR. Further reductions for small engines (i.e. 18 - 37kW) are considered impractical[6].

For engines to meet Stage IIIB controls it is expected that diesel particulate filters (DPFs) will be fitted. To ensure reliable operation of DPFs, the use of low sulphur content fuels would be needed (approximately 10 mg/kg sulphur, whilst gas oil had 2000 mg/kg sulphur, decreasing to 1000 mg/kg from 2008)[6].

Stage IV controls are expected to force the adoption of Selective Catalytic Reduction (SCR) de-NO_X after-treatment systems in addition to DPFs.

A summary of the implementation dates for the emission standards dates is presented Figure 3.1 below.

Figure 3.1 Summary of the Implementation Dates for NRMM Emission Standards



6 DfT (2006), Regulatory Impact Assessment (RIA) on NRMM emissions, Department for Transport.

3.3 Protection of Human Health

3.3.1 Air Quality Strategy

The 2007 Air Quality Strategy for England, Scotland, Wales and Northern Ireland[7], provides a framework for improving air quality at a national and local level. Central to the Air Quality Strategy are health-based standards for key air pollutants; these standards are based on medical and scientific reports on how and at what concentration each pollutant affects human health. The air quality objectives (AQOs) based on these standards were made statutory through the Air Quality Regulations 2000, as amended in 2002[8], and the Air Quality Standards Regulations 2007[9]. These include AQOs for PM_{10} and $PM_{2.5}$.

The Air Quality Standards Regulations 2007 seek to simplify air quality regulation and provide a new transposition of the Air Quality Framework Directive[10], First, Second and Third Daughter Directives and also transpose the Fourth Daughter Directive, relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. The Air Quality Limit Values are transposed into the updated Regulations as 'Air Quality Standards' (AQS) with attainment dates in line with the European Directives.

The AQOs are based on the Air Quality Limit Values, with interim target dates to help the UK move toward the achievement of the Air Quality Limit Values. The air quality objectives in the Air Quality Strategy are a statement of policy intentions or policy targets. As such, there is no legal requirement to meet these objectives except as far as these mirror any equivalent legally binding limit values in EU legislation.

Table 3.1 sets out the air quality objectives that are relevant to this assessment, and the dates by which they are to be achieved.

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[7] The Air Quality Strategy for England, Scotland, Wales and Northern Ireland. Department for Environment, Food and Rural Affairs in Partnership with the Scottish Executive, Welsh Assembly Government and Department of the Environment Northern Ireland. Stationary Office, July 2007.

[8] The Air Quality (England) Regulations 2000, Statutory Instrument 2000 No. 928, The Air Quality (England) (Amendment) Regulations 2002.

[9] The Air Quality Standards Regulations 2007, Statutory Instrument 2007 No. 64

[10] Council Directive 96/62/EC on ambient air quality assessment and management (OJ No L 296, 21.11.96, p55)

Table 3.1 National Air Quality Objectives and European Directive Limit and Target Values for the Protection of Human Health

Pollutant	Objective Value	Concentration Measured As	Date To Be Achieved And Maintained Thereafter	European Obligations	Date To Be Achieved and Maintained Thereafter
Particles (PM_{10}) (gravimetric)	50µg m^{-3} not to be exceeded more than 35 times a year.	24 hour mean	31 Dec 2004	50µg m^{-3} not to be exceeded more than 35 times a year.	01 Jan 2005
	40µg m^{-3}	Annual mean	31 Dec 2004	40µg m^{-3}	01 Jan 2005
$PM_{2.5}$ objectives (not included in Regulations)[1]					
Particles ($PM_{2.5}$)	25µg m^{-3}	Annual mean	2020	-	-
	Target of 15% reduction in concentration at urban background locations	3 year mean	Between 2010 and 2020.	-	-

Notes:

1: The UK Government and the Devolved administrations have set new national air quality objectives for particulate matter smaller than 2.5 micrometer diameter ($PM_{2.5}$). These objectives have not been incorporated into LAQM Regulations and authorities have no statutory obligation to review and assess air quality against them, although they are a national objective which is required to be met by the UK as a whole.

3.3.2 Local Air Quality Management

Part IV of the Environment Act 1995 requires local authorities to periodically review concentrations of the UK Air Quality Strategy pollutants within their areas and to identify areas where the AQOs may not be achieved by their relevant target dates. This process of Local Air Quality Management (LAQM) is an integral part of delivering the Government's AQOs detailed in the Regulations. When areas are identified where some or all of the objectives might potentially be exceeded and where there is relevant public exposure, i.e. where members of the public would regularly be exposed over the appropriate averaging period, the local authority has a duty to declare an Air Quality Management Area (AQMA) and to implement an Air Quality Action Plan (AQAP) to reduce air pollution levels so that the required AQOs are met. Furthermore, a key principle of LAQM is to fully integrate air quality into local planning processes.

The four London 2012 host Boroughs within the study area, of Hackney, Newham, Tower Hamlets and Waltham Forest have all declared AQMAs owing to predicted exceedences of the nitrogen dioxide (NO_2) and PM_{10} Air Quality Objectives. The London Borough of Newham has declared AQMAs close to the main roads in the Borough, while Hackney, Tower Hamlets and Waltham Forest have declared their whole boroughs as AQMAs.

3.4 GLA Best Practice Guidance

The GLA in association with London Councils has produced a best practice guide to control dust and emissions associated with construction and demolition activities within London[11]. The guide categorises development sites according to their size and recommends mitigation measures and practices which should take place on these sites to reduce the generation and subsequent migration offsite of emissions and dust. This document is currently scheduled for review later this year. The OPCS is classified, according to the guidance, as a "High Risk" site. High Risk sites are classified using the following criteria:

- Development of over 15,000 square metres of land, or;
- Development of over 150 properties, or;
- Major Development referred to the Mayor and /or the London Development Agency, or;
- Major Development defined by a London borough, or;
- Potential for emissions and site to have significant impact on sensitive receptors.

The OPCS could be classified as a "High Risk" site using a number of the criteria above.

Further planning guidance for London has been published by the London Air Pollution Planning and the Local Environment (APPLE) working group[12].

3.4.1 ODA Commitments

In its Sustainable Development Strategy, the ODA committed to follow the GLA Best Practice Guidance, which sets out a number of recommended measures for minimising construction effects on dust and air quality.

Through its CoCP, the ODA has identified the risk of air quality effects from the development and identified measures from the GLA Best Practice Guidance for mitigating the risks. These measures have been agreed with the Local Planning Authority (LPA). These measures include the hard surfacing of haul roads, dust suppression measures used on stockpiles and other open areas, use of Ultra Low Sulphur Gas Oil on all plant, street sweeping on and off Park and regular maintenance of plant/vehicles. A comprehensive monitoring strategy, which meets the requirements of the GLA's Best Practice Guidance, with an alert system is in place to ensure that any potential high levels of dust or pollutants are detected quickly to enable the source activity to be identified and improved mitigation to be employed or the activity stopped.

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[11] Greater London Authority and London Councils. Best Practice Guidance: The control of dust and emissions from construction and demolition. November 2006.

[12] London Councils, 2007. Air Quality and Planning Guidance.

4. Emission Quantification and Dispersion Modelling Methodology

4.1 Overview

As described in Section 1.2, the scope of the desk-based assessment includes the estimation of emissions from the OPCS related construction activity, the development of an atmospheric emissions inventory and subsequent dispersion modelling of these emissions to determine potential air quality effects at nearby sensitive receptor locations.

4.2 Phase 1 – OPCS Emissions Inventory

4.2.1 Construction Plant and Machinery

The first phase of this assessment has been the development of a detailed baseline atmospheric emissions inventory, which forms the basis of the dispersion modelling assessment and CBA.

The emissions inventory primarily includes on-site emissions from non-electric plant and machinery. It also includes other non-construction related site vehicles including staff buses and HGVs.

In its most basic form, the inventory is based on fuel consumption calculated bottom-up from plant schedules and activity rates, combined with published emission factors. The emission inventory disaggregates the emissions spatially, based on the geographical deployment of plant.

The emissions inventory was developed from fleet data provided by the contractors operating on the OPCS for the month of October 2009. October was selected for the base-month as this was the current month at the time the data was requested and also represented what was considered to be a peak month in terms of plant numbers and activity levels. In order to obtain an indication of plant turnover in both numbers and types of plant, additional plant data were requested for April 2009 as well as forecast fleet and activity data for April 2010. This historical and future data proved difficult to obtain and therefore, the October 2009 fleet data was used as the baseline for the assessment.

Information provided by each contractor included the number and types of plant and vehicles operating during October, the kW engine ratings of the plant and the percentage of time each item of plant was in use. Contractors and the ODA also provided information regarding the geographical areas of the OPCS where these plant were operational.

A summary of plant included in the assessment is shown in Table 4.1 below.

Table 4.1 Summary of Plant Schedule

Plant Type	Number of Plant
Off-Road truck	149
Buses / Trucks / HGVs	33
Crane	52
Dump Truck	124
Excavator	7
Forklift	51
Heavy Excavator	28
Large Generator	21
Medium Excavator	62
Medium Generator	71
Mini Excavator	85
Piling Rigs	3
Roller	57
Site Vehicle	310
Small Excavator	167
Small Plant	531
Tractor	25
TOTAL	1776

The derived fuel consumption estimates based on October activity data were compared against monthly fuel use data provided by the OPCS fuel distributor. This enabled the determination of the likely over or underestimation of emissions that were derived on the basis of calculated fuel consumption figures as opposed to actual fuel use data.

The pollutants included in the emission inventory are as follows:

- PM_{10}; and
- $PM_{2.5}$.

Emissions of nitrogen oxides or other pollutants associated with engine exhausts were not considered in the assessment as fuel consumption was assumed to remain constant under each assessment scenario and emissions of other pollutants would therefore remain constant.

4.2.2 Scenarios

From the baseline emissions inventory, a number of scenarios have been developed to assess the emission benefits from the adopted measures contained in the CoCP, as well as other emission reduction measures beyond those contained in the CoCP and subsequently adopted.

Primarily, the difference in on-site construction emissions with the CoCP measures in place is that all contractors are to use ULSGO with a sulphur content of 10ppm rather than standard gas oil. The Best Practice Guidance states that the introduction of ULSGO will reduce particulate emissions by 30%. The Best Practice Guidance also suggests the consideration of other emission reduction measures for High Risk sites, beyond those included in the CoCP. The principal recommendation for the reduction in exhaust emissions is for the consideration of the retro-fitting of diesel particulate filters (DPFs), or other exhaust after-treatment, to all Non Road Mobile Machinery (NRMM) above 37 kW.

In the absence of information regarding “in-use” emission factors, it has been assumed, as a worst-case, that emissions are equivalent to the Stage IIIA emission limits, although at reduced engine loads it would be anticipated that emissions (in units of g/kWh) would also reduce. Where there are no emission standards specified in the EU Directive, emission factors for the uncontrolled case have been applied[13]. It is recognised that different DPFs have different efficiencies and different operational constraints, however, the emission inventory has assumed a performance efficiency of DPFs of 90% from the Stage IIIA baseline.

The following scenarios have been included in the assessment:

- **Scenario 1 (pre CoCP Baseline):** No use of ULSGO or DPFs on site;
- **Scenario 2 (CoCP Baseline):** Use of ULSGO on site by all plant (assumed 30% reduction in particle emissions[11]) and no use of DPFs onsite; and
- **Scenario 3 (CoCP + DPFs):** Use of ULSGO on site by all plant (assumed 30% reduction in particle emissions) and use of DPFs with 90% efficiency for plant >37kW.

4.2.3 Other Local Emission Sources

Dust Emissions

During construction work, there may be potential for local annoyance related to emissions of dust. Dust deposition will only affect receptors when they are downwind of the source, although the closer the potentially sensitive receptors are to the emission sources, the greater the likelihood of annoyance.

[13] EMEP EEA Emission Inventory Guidebook, 2009. Non-road mobile sources and machinery.

Dust deposition rates of larger dust particles (greater than 30 μm in diameter) from construction activities fall off rapidly with distance from the source and research shows that these particles will largely deposit within 100m of sources. Intermediate sized particles (10-30 μm in diameter) are likely to travel up to 200-500m. Thus it is large and intermediate sized particles that mainly contribute to dust annoyance. However, smaller dust-borne PM_{10} particles (less than 10 μm in diameter) which typically make up a small proportion of emissions from construction activity, will be emitted in combination with those PM_{10} from exhaust emissions; these particles are deposited slowly and may travel 1000m or more from the emission source.

The CoCP identifies measures that are in place during the construction of the Olympic Park to manage potential emissions of dust associated with construction activities. These activities, with the combined effect of reducing emissions to the point beyond where effects would not be identified beyond the site boundary, are summarised below:

- Hard surfaced haul routes with effective cleaning and appropriate speed limits around site;
- Effective vehicle cleaning and specific fixed wheel washing at site egress points;
- Damping down of haul routes and stockpiles areas (including use of binding agent);
- Spray systems around high risk activities such as concrete crushers; and
- Implementation of a site-wide dust monitoring strategy to monitor deposited dust and particulate matter (PM_{10}).

With these mitigation measures in place, a significant reduction has been achieved at the OPCS in levels of airborne dust and fine particles. The ODA operates a number of air quality monitoring stations to ensure that the above mitigation measures are effective in controlling levels of airborne dust.

The quantification of dust emissions from construction activity and the modelling of its dispersion is not something that generally forms part of an air quality assessment.

Modelling of dust deposition rates has a high degree of inherent uncertainty, based not only on the limitations of the model, but also on the calculation of the emission rates from dust generating activity that are used by the model to determine dust deposition rates. The particle size distribution also determines the proportion of dust in the PM_{10} size fraction and this very much depends on local geology and soil conditions. Modelling of dust deposition is not routinely undertaken in the UK, as the preferred means by which to assess potential effects is often through a semi-quantitative risk based approach, or through direct monitoring at affected receptor locations. Furthermore, emissions of PM_{10} from dust and exhaust gases are likely to have different health effects; this study focuses on the health effects of particles from fuel combustion, thus it is not considered necessary or appropriate to consider non-combustion sources of particles.

Rail

Emissions from rail movements associated with the delivery of materials to site have not been included in the assessment of diesel particulate emissions. There are a limited number of daily train movements which are unlikely to result in emissions of diesel particles of a sufficient magnitude when compared to emissions from NRMM operating on the Olympic Park.

Non-Olympic Park Construction Activity

Within the area around the OPCS there are a large number of construction projects un-related to the OPCS, including Stratford City Development, Crossrail and several housing regeneration schemes. The dust and emissions from these schemes may also impact on the air quality in the area, but have not been included in this assessment.

4.2.4 Temporal Resolution

The Olympic Park construction programme is complex and multi-faceted. Thus, replicating construction activity to develop an emissions inventory and dispersion model requires a number of assumptions.

The emission inventory has been developed on the basis of historical site activity and fuel use data. This information was provided for the study by the OPCS contractors and fuel supplier, to fulfil an information request from Entec that was distributed to the contractors by the ODA. The data request focused on obtaining information regarding the types of plant operating on the OPCS, their age, engine size, fuel type, average engine load, working hours, utilisation and working areas. From this information it was possible to develop a detailed plant inventory from which fuel consumption and exhaust emissions could be calculated.

Plant data was provided by contractors for the month of October 2009, as this was the month this study commenced and it was considered to be less onerous for contractors to provide current plant data as opposed to historical information. Recognising that October 2009 was an above-average month in terms of construction and plant activity, the information request for contractors also required activity levels and plant fleet structures for April 2009 and forecasts for April 2010, which were considered more representative months in terms of overall site activity.

As expected, less detailed information was provided by contractors for April 2009 and 2010 and, from this information, it was not possible to develop a typical profile of plant types and numbers for each contractor that would have been more representative of historical and future expected working patterns. To derive annual emission levels for construction activities, fuel use data was used to scale activity rates, thus assuming that the fleet mix and numbers of plant remained constant and utilisation levels varied.

4.2.5 Spatial Resolution

The emissions have been estimated within 18 construction zones across the main OPCS, in addition to the internal haul road network and external roads (A11 and A12). The spatial resolution of site-based emissions has been very much dependent on the level of detail available from contractors in terms of the operational areas for each item of plant. Efforts in capturing such data have focused more towards construction zones that are more intensively worked, and/or those closest to the main site perimeter and therefore closer to sensitive receptors, which would have a greater potential to influence off-site particle concentrations.

4.3 Phase 2 – Detailed Dispersion Modelling

4.3.1 Overview

Following the development of the emissions inventory, detailed dispersion modelling has been undertaken to determine what effect particulate abatement would have on pollutant concentrations, particularly at sensitive receptor locations.

The primary focus of the dispersion modelling assessment was to provide appropriate outputs for use in the Health Impact Assessment and Cost-Benefit Analysis. The source contribution to ground-level pollutant concentration (i.e. the contribution of the OPCS only) and the incremental change in pollutant concentrations with each assessment scenario were therefore the required outputs.

Movements of vehicles on the principal local road network (A11 and A12), which include construction-related road traffic movements to and from the OPCS, have been included in the scope of the dispersion modelling. These emissions were included in order to identify the contribution of these road sources to local pollutant concentrations and to more fully consider the local pollution climate against which the significance of on-site OPCS activities could be assessed.

The detailed dispersion modelling has been undertaken using the ADMS 4.1 and ADMS-Roads computer software packages. ADMS 4.1 has been used for the modelling of site-based emissions and the ADMS-Roads model has been used for modelling road traffic emissions from the A11 and A12. These models have been extensively validated by the model developers, Cambridge Environmental Research Consultants (CERC), and are generally regarded as the models of choice in the UK for these types of assessments.

The modelling of site-based emissions using ADMS-4.1 considered the diurnal profile of emissions, whereby a time-varying profile was included in the model with all emissions occurring during site operational hours, rather than averaging daily emissions over a 24-hour period.

The focus of the modelling has been to determine ambient concentrations of annual mean PM_{10} and $PM_{2.5}$. To derive estimates of the number of days exceedence of the 24-hour mean PM_{10} objective, the approach presented in Defra's guidance LAQM.TG(09)[14] has been applied.

4.3.2 Meteorological Data

The modelling has incorporated hourly sequential meteorological data recorded at Heathrow. Predicted concentrations derived from dispersion modelling will be affected by the choice of meteorological data, in terms of the representativeness of the geographical location of the meteorological station to the study area, but also the choice of calendar year. Heathrow is considered to be the most representative location where suitable meteorological data is available, but to determine the calendar year that would be considered worst-case in terms of leading to the highest ground-level pollutant concentrations, a sensitivity analysis was undertaken.

Ordinarily, such a sensitivity analysis is undertaken for the last five full calendar years, in this case 2004 to 2008 inclusive. However, year 2003 data were also included in the analysis as during this year there were known to be unusual meteorological conditions, including summer months with above average temperatures, which led to poor dispersion of pollutants and a build up of background pollution; therefore monitored background and roadside pollutant concentrations increased in 2003 across the majority of the UK.

The sensitivity analysis showed that hourly sequential meteorological data from year 2003 produced the highest OPCS contribution to modelled concentrations of particulate matter at the most sensitive receptor locations. Therefore, the use of year 2003 data is considered to provide a worst-case assessment of concentrations for consideration in the cost-benefit analysis.

Year 2003 meteorological data have also been used in ADMS-Roads for modelling the dispersion of emissions from road traffic on the A11 and A12. Ordinarily, the selected meteorological year for road traffic modelling would be the most recent full year, and predicted concentrations would be verified against local air quality monitoring data for the same year. On the basis that no suitable monitoring of particulate matter is undertaken in the study area, it has not been possible to verify the modelled output against measurement data and 2003 meteorological data has been included in the modelling as it is most likely to lead to worst-case ground level pollutant concentrations. Figure 4.1 shows a windrose for Heathrow 2003 data, illustrating the strength of the prevailing south-westerly winds, and the presence of winds from other directions, including those from the East.

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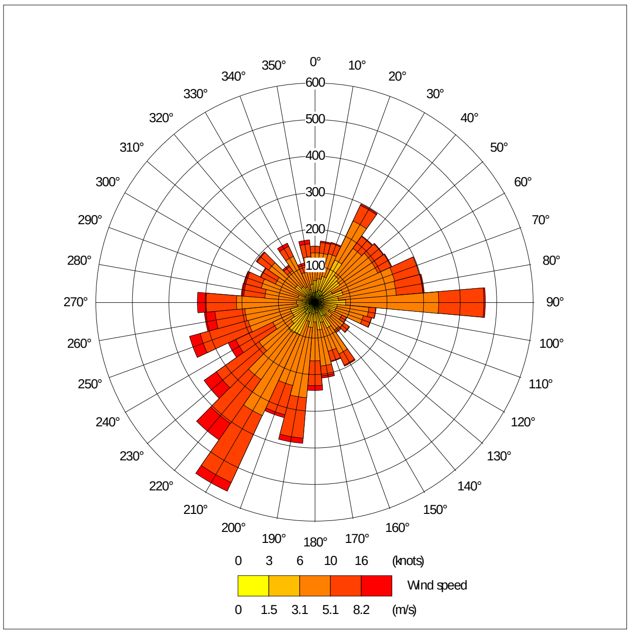
[14] Defra (2009) Local Air Quality Management, Technical Guidance LAQM.TG(09)

Figure 4.1 Windrose for Heathrow, 2003.



4.3.3 Receptors

Table 4.2 shows the receptor locations that have been included in the detailed dispersion modelling assessment; these have been modelled at a height of 1.5m above ground level, and generally represent the closest receptors to construction activity around the boundary of the OPCS. The locations of existing air quality monitoring stations around the OPCS have also been modelled to allow a comparison to be made between the modelled and monitored concentrations. In addition, a grid of receptors centred over the OPCS, with a grid point resolution of 30m, has been modelled; from this receptor grid, contours have been produced to show the spatial variation in ground-level concentrations of pollutants from OPCS activities.

Table 4.2 Receptor Locations

Receptor	X-Coordinate	Y-Coordinate
Ruckholt Close	537783	186038
Ruckholt Close 2	537866	186039
West Down Road	538254	185895
West Down Road 2	538240	185638
Crownfield Road	538499	185463
Alphabet Nursery School	538831	184768

Receptor	X-Coordinate	Y-Coordinate
Gibbons Road	538395	184096
Bisson Road	538268	183455
Baldock Street	537620	183173
Wick Lane	537313	183386
Meadow Close	536947	185039
Gainsborough Primary	537050	184902
Leabank Square	537088	184860
Omega Works	537323	184371
Gallery Flats	537252	184571
Cadogan Terrace	536813	184403
Monitoring Station 2	537029	184900
Monitoring Station 9	538260	184076
Monitoring Station 10a	537980	183336
Monitoring Station 11	538228	183763
Monitoring Station 12	538225	185638
Monitoring Station 14	537463	183926
Monitoring Station 15	537336	184327
Monitoring Station 16	538570	183664

4.3.4 Population-Weighted Mean Concentrations (PWMCs)

The output from the dispersion modelling assessment was used to assess potential exposure to adverse air quality by calculating population-weighted mean concentrations (PWMCs).

Entec provided IOM with population counts within a series of concentration contours, for both annual mean PM_{10} and $PM_{2.5}$. These population counts were derived from Ordnance Survey Address Point data. It was assumed that the average exposure of the population within each concentration band was equivalent to the midpoint concentration. The values for all contour bands were then summed and then divided by the total population to calculate the population-weighted mean concentration.

4.3.5 Model Verification

Model verification enables an estimation of uncertainty and systematic errors associated with the modelling components of a detailed air quality assessment to be considered. There are many explanations for these errors, which may stem from uncertainty in the modelled number of vehicles, speeds and vehicle fleet composition. Defra has provided guidance in terms of preferred methods for undertaking dispersion model verification which is based on the relationship between monitored and modelled concentrations and deriving a correction factor that is subsequently applied to the modelled results to bring the concentrations into line with measured concentrations.

Within this assessment there are two components of the dispersion modelling where verification of PM_{10} and $PM_{2.5}$ concentrations have been considered; the road traffic component (A11 and A12) and the OPCS contribution. It has not been possible to undertake verification of the modelled concentration contribution from the A11 and A12 as there is no suitable monitoring of PM_{10} or $PM_{2.5}$ undertaken in the study area within an appropriate distance from the modelled local road network.

In terms of verification of the OPCS contribution to concentrations of PM_{10} or $PM_{2.5}$, there is continuous measurement data available from monitoring stations at perimeter locations around the OPCS. These monitoring stations use a light-scattering method to measure ambient concentrations of particulate matter, which in itself is subject to additional uncertainty when compared to the European gravimetric reference sampler. The advantage of the equipment used by the ODA is that it is appropriate for measuring trends in particulate concentrations and identifying short-term peaks that could be linked back to construction activity; the equipment is not intended to measure concentrations within the same uncertainty limits as a gravimetric sampler. The Data Quality Objective for overall uncertainty as defined within the Air Quality Directive is +/- 25% and it would be expected that the monitoring equipment used by the ODA would be the subject of increased levels of uncertainty. Owing to the combined uncertainties with modelling and monitoring techniques, formal verification of modelled concentrations has not been undertaken, although a comparison between modelled and monitored data are presented in Section 5.3 of this report.

4.4 Assumptions and Uncertainties

With any assessment of this nature, where a number of data are combined, each with an uncertainty attached, the uncertainty in the total emission or concentration estimates involves a combination of the contributing uncertainties.

The approach to collating fleet and operational information from individual contractors has the potential to lead to uncertainty. Data returns from contractors were generally comprehensive but a number of assumptions, generally based on the average statistics calculated from data that had been provided, were applied where data fields were not populated. The fleet profile and site activity levels were based on data for October 2009, with plant activity rates adjusted on the basis of fuel-use data that were available from the OPCS fuel supplier for October and the previous 12-month period. This approach is likely to lead to uncertainties, but within the time scale of this assessment, it was not possible to develop a comprehensive plant schedule that would be able to simulate the dynamic nature of the construction programme in terms of the geographical locations of activity and also the change in demand for different types of plant and vehicles.

The emission quantification element of the assessment has also adopted a conservative approach to the quantification of emissions, which has generally led to a series of worst-case assumptions that would lead to a

general over-estimation of total emissions. Such assumptions include utilisation and load factors for individual plant operating on the OPCS and the use of emission limits for each item of plant rather than in-use emission factors. Uncertainties also relate to the effect of the use of ULSGO on the emissions of fine particles and the particulate removal efficiency of DPFs.

The site fuel usage figures for the 12 month period up to October 2009, provided by the OPCS fuel supplier, have been utilised to provide a cross check of actual fuel use against calculated fuel consumption for the plant operating on the OPCS. As expected, there were differences between the figures, with the calculated figures from the study producing fuel consumption estimates that were in some cases approximately 50% higher than those provided by the OPCS fuel supplier. Some of the difference between these figures may be the result of some plant being re-fuelled off site (i.e. hire plant) and some mobile vehicles which can travel off site, being re-fuelled elsewhere, although the main reason is likely to be that the calculation of fuel consumption from the inventory is based on published fuel consumption figures and assumed plant operational data for a peak month in terms of both numbers of plant and activity levels. This level of over-estimation in terms of fuel consumption will also be reflected in total site emissions.

The effect of emissions on modelled concentrations at receptor locations around the site boundary will not necessary be directly proportional to total site emissions owing to the varied distribution of the emissions across the site. For example, the primary haul road is to the centre of the OPCS and emissions from plant trafficking the haul road will contribute only a small proportion to total OPCS modelled concentrations at receptor locations that may be several hundred metres away.

Aside from assumptions required in development of the emission inventory and the inevitable uncertainties that arise, there are also uncertainties introduced from the use of a dispersion model to generate pollutant concentrations data from the site emissions. Throughout the assessment uncertainties in the dispersion modelling have been minimised as far as possible and comparisons have been made with monitoring data available from the ODA to ensure that outputs are reliable and within expected ranges.

The effects of these uncertainties are further discussed in Chapter 6, in the context of their implications for the cost-benefit analysis.

5. Results – Emissions and Concentrations

5.1 Emissions from Plant Operating on the OPCS

The estimated mass of particulate matter emissions from plant and machinery operating at the OPCS is presented in the following section.

The figures show the annual emissions (kg) of PM_{10} and $PM_{2.5}$ aggregated for all of the construction areas on the OPCS, for each of the following assessment scenarios:

- **Scenario 1:** No use of ULSGO or DPFs;
- **Scenario 2:** Use of ULSGO only by all plant; and
- **Scenario 3:** Use of ULSGO by all plant and DPFs for plant >37kW.

Table 5.1 and Table 5.2 present the emissions of PM_{10} and $PM_{2.5}$ for each scenario, differentiating between those emissions from non-road plant and machinery (Table 5.1) and road-going vehicles (Table 5.2). Table 5.3 presents the data disaggregated by plant type.

As would be expected, Table 5.1 shows a reduction of 30% in emissions of PM_{10} between Scenario 1 and Scenario 2, from 10,737 kg to 7,516 kg, owing to the introduction of ULSGO. There is a further reduction in Scenario 3 of approximately 75%, to 1,908 kg of particulate emissions where DPFs with a 90% removal efficiency are retrofitted to all plant >37kW. The same trend is shown for emissions of $PM_{2.5}$, where emissions reduce from 10,133 kg in Scenario 1 to 7,093 kg in Scenario 2 and 1,796 kg in Scenario 3. Total emissions of $PM_{2.5}$ from off road plant are approximately 94% of the equivalent PM_{10} value.

Table 5.1 Estimated Exhaust Emissions of PM_{10} and $PM_{2.5}$ from NRMM at the OPCS, Year 2009.

Pollutant	Scenario 1	Scenario 2	Scenario 3
PM_{10}	10,737	7,516	1,908
$PM_{2.5}$	10,133	7,093	1,796

Table 5.2 shows the PM_{10} and $PM_{2.5}$ exhaust emissions from road-going plant in use on the OPCS. There are currently no published $PM_{2.5}$ road vehicle exhaust emission factors and it has therefore been assumed that 90% of PM_{10} emissions were as $PM_{2.5}$. The results show that the emissions of PM_{10} and $PM_{2.5}$ from road vehicles operating on site were 669 kg and 602 kg, respectively, for each of the scenarios. Reductions in emissions do not occur under Scenarios 2 and 3 as it was assumed that these vehicles would operate on standard road diesel as opposed to a higher sulphur gas oil or ULSGO. These vehicles comply with the emission standards for road vehicles as opposed to the emission standards for NRMM.

In Scenario 1 road vehicles account for approximately 6% of total PM_{10} emissions on the OPCS, increasing to 8% in Scenario 2, when other plant switch fuel to ULSGO and reduce emissions. In Scenario 3, when all plant >37 kW are considered to include a 90% reduction in emissions of particulates with the use of DPFs, the road vehicle contribution to total emissions increases to 26%.

Table 5.2 Estimated Exhaust Emissions of PM_{10} and $PM_{2.5}$ from Road Vehicles at the OPCS, Year 2009.

Pollutant	Scenario 1	Scenario 2	Scenario 3
PM_{10}	669	669	669
$PM_{2.5}$	602	602	602

Table 5.3 shows the disaggregation of total PM_{10} and $PM_{2.5}$ emissions by plant type.

In Scenario 1, Off-Road Trucks are the main emissions source (2,439 kg of PM_{10}) representing approximately 21% of total site emissions. With the introduction of ULSGO in Scenario 2 and DPFs in Scenario 3, the contribution from Off-Road Trucks to total emissions reduces to 20% (Scenario 2) and 7% (Scenario 3). While emissions from all NRMM >37 kW reduce in Scenario 3, emissions from road vehicles and NRMM <37 kW operating on the site remain the same and their proportional contribution to total emissions increases.

Table 5.3 Total Annual Emissions of PM_{10} and $PM_{2.5}$ by Plant Type

Plant Type	Scenario 1 PM_{10} (kg)	Scenario 2 PM_{10} (kg)	Scenario 3 PM_{10} (kg)	Scenario 1 $PM_{2.5}$ (kg)	Scenario 2 $PM_{2.5}$ (kg)	Scenario 3 $PM_{2.5}$ (kg)
Off-Road truck	2,439	1,708	171	2,318	1,622	162
Buses / HDVs / HGVs	342	342	342	307	307	307
Crane	493	345	35	469	328	33
Dump Truck	872	625	131	824	590	121
Excavator	90	63	6	84	59	6
Forklift	473	331	45	448	314	43
Heavy Excavator	473	331	33	449	314	31
Large Generator	248	174	17	235	165	16
Medium Excavator	800	560	56	749	524	52
Medium Generator	611	428	146	575	402	137
Mini Excavator	479	335	178	451	316	166
Piling Rigs	62	43	4	59	41	4
Roller	267	187	58	251	176	54
Site Vehicle	280	280	280	252	252	252
Small Excavator	1,865	1,306	142	1,749	1,224	133
Small Plant	1,319	923	914	1,241	869	860
Tractor	293	205	20	274	192	19
TOTAL	11,406	8,186	2578	10,735	7,695	2396

5.2 Modelled Concentrations of Particulate Matter

5.2.1 Results of Detailed Dispersion Modelling – OPCS Only

As described in Section 4.3, detailed dispersion modelling has been undertaken to determine the effects of the reduction in emissions from NRMM in each of three assessment scenarios, and the effect the emission reductions would have in terms of local air quality and population exposure. The annual mean PM_{10} and $PM_{2.5}$ concentrations for the three scenarios at the selected receptors are shown in Table 5.4.

Contours to show the concentration contribution from the OPCS for the three scenarios are contained in Appendix B. Also included on these figures are the locations of the modelled receptors.

PM_{10} Concentrations – OPCS Contribution

As shown in Table 5.4, the predicted annual mean PM_{10} concentrations at the receptors range from 0.5 to 2.3 µg m^{-3} for Scenario 1. These concentrations then reduce to between 0.4 and 1.6 µg m^{-3} for Scenario 2, reducing further to between 0.1 and 0.5 µg m^{-3} for Scenario 3. The annual mean Air Quality Objective for PM_{10} is 40 µg m^{-3}.

The results show the highest annual mean concentration of PM_{10} from the site activities is predicted at the 'Gallery Flats' receptor (2.3 µg m^{-3}). This is located on the banks of the River Lee Navigation opposite the OPCS. The receptors of 'Leabank Square' and 'Gainsborough Primary School' are also located on the banks of the River Lee Navigation opposite the OPCS and show similar concentrations, albeit slightly lower, to those predicted at the 'Gallery Flats' (2.0 and 1.9 µg m^{-3} respectively). These locations are also predicted to experience the highest concentrations of PM_{10} for Scenarios 2 and 3. The 'Gallery Flats' receptor was predicted to experience an annual mean concentration of PM_{10} of 1.6 µg m^{-3} in Scenario 2 and 0.5 µg m^{-3} in Scenario 3.

$PM_{2.5}$ Concentrations – OPCS Contribution

The predicted annual mean $PM_{2.5}$ concentrations at the receptors in Table 5.4 show a similar trend to the PM_{10} concentrations, although these are lower than the PM_{10} concentrations. The highest predicted $PM_{2.5}$ concentration is experienced at the 'Gallery Flats' receptor, with a concentration of 2.2 µg m^{-3} for Scenario 1, 1.5 µg m^{-3} for scenario 2, and 0.4 µg m^{-3} for Scenario 3. The annual mean national Air Quality Objective for $PM_{2.5}$ is 25 µg m^{-3}.

Table 5.4 Annual average concentrations of PM_{10} and $PM_{2.5}$ at selected receptors for each scenario – OPCS contribution only ($\mu g\ m^{-3}$)

Receptor	PM_{10} Scenario 1 (Baseline)	PM_{10} Scenario 2 (With ULSGO no DPFs)	PM_{10} Scenario 3 (With ULSGO and DPFs – 90%)	$PM_{2.5}$ Scenario 1 (Baseline)	$PM_{2.5}$ Scenario 2 (With ULSGO no DPFs)	$PM_{2.5}$ Scenario 3 (With ULSGO and DPFs – 90%)
Ruckholt Close	1.1	0.8	0.2	1.0	0.7	0.2
Ruckholt Close 2	1.0	0.7	0.2	1.0	0.7	0.2
West Down Road	0.8	0.6	0.2	0.8	0.6	0.2
West Down Road 2	1.5	1.0	0.3	1.4	1.0	0.3
Crownfield Road	1.2	0.8	0.3	1.1	0.8	0.2
Alphabet Nursery Sch	0.6	0.4	0.1	0.6	0.4	0.1
Gibbons Road	1.6	1.1	0.4	1.5	1.0	0.3
Bisson Road	0.9	0.6	0.2	0.8	0.6	0.2
Baldock Street	0.5	0.4	0.1	0.5	0.3	0.1
Wick Lane	1.0	0.7	0.1	0.9	0.6	0.1
Meadow Close	1.6	1.1	0.4	1.5	1.1	0.4
Gainsborough Primary	1.9	1.4	0.5	1.8	1.3	0.4
Leabank Square	2.0	1.4	0.5	1.9	1.3	0.4
Omega Works	1.9	1.3	0.4	1.8	1.2	0.3
Gallery Flats	2.3	1.6	0.5	2.2	1.5	0.4
Cadogan Terrace	0.7	0.5	0.1	0.6	0.4	0.1

5.2.2 Results of Detailed Dispersion Modelling – OPCS, Road Traffic & Background Sources Combined

Although not a requirement of the cost-benefit analysis, estimates of background concentrations of PM_{10} and $PM_{2.5}$ have been combined with the modelled concentration contribution from the OPCS and the A11 and the A12 in order that a comparison of total concentrations can be made with the Air Quality Objectives. It is important to note that for some receptors, this approach may underestimate total concentrations of PM_{10} and $PM_{2.5}$ where receptor locations may be affected by other local emissions that have not been explicitly modelled.

PM_{10} Concentrations – All Sources

As shown in Table 5.5, combining the predicted concentrations of annual mean PM_{10} from the OPCS and the principal road network with Netcen ambient background concentrations (excluding 'A' roads in each 1x1 km grid cell) gives a range of total PM_{10} concentrations at the receptors locations of between 22.2 – 44.6 µg m^{-3} in Scenario 1, 22.0 – 45.5 µg m^{-3} in Scenario 2 and 21.7-44.2 µg m^{-3} in Scenario 3. The Baldock Street receptor is the only receptor that shows an exceedence of the 40 µg m^{-3} Air Quality Objective. The concentration contribution from the OPCS is shown to be a small proportion of total concentrations at each receptor, with the contribution reducing with distance from the OP. At the 'Gallery Flats' receptor, the location with the highest predicted concentration contribution from the OPCS, the OPCS contribution to total concentrations of PM_{10} represents 8.6% in Scenario 1, 6.2% in Scenario 2 and 1.9% in Scenario 3.

The 24-hour average Air Quality Objective for PM_{10} is 50 µg m^{-3}, not to be exceeded more than 35 times a year. The approach to estimate the number of days exceedence of the 24-hour mean Objective from the annual average PM_{10} concentration, detailed in Defra's Technical Guidance, LAQM.TG(09), has been applied in this assessment. As shown in Table 5.6, the number of days exceedence of the 50 µg m^{-3} Objective ranges from 7-115 days in Scenario 1, 6-114 days in Scenario 2 and from 6-111 days in Scenario 3. The maximum reduction in the number of days exceedence between Scenario 1 and 3 is 6 days, while the maximum reduction between Scenario 2 and 3 is 4 days. Predicted exceedences of the PM_{10} 24-hour mean Air Quality Objective are shown at the receptors located closest to the A11 and A12 and are therefore connected with the volume of traffic on the road network and not the OPCS; predicted concentration at the receptors located in close proximity to the OPCS boundary are predicted to be comfortably within the Air Quality Objective.

$PM_{2.5}$ Concentrations – All Sources

Table 5.7 presents the $PM_{2.5}$ results. Combining the predicted concentrations of annual mean $PM_{2.5}$ from the OPCS and the principal road network with Netcen ambient background concentrations gives a range of total $PM_{2.5}$ concentrations at the receptors locations of between 15.5 – 35.0 µg m^{-3} in Scenario 1, 15.3 – 34.9 µg m^{-3} in Scenario 2 and 15.0 – 34.6 µg m^{-3} in Scenario 3. Six of the modelled receptors have predicted $PM_{2.5}$ concentrations in excess of the 25 µg m^{-3} national Air Quality Objective for $PM_{2.5}$. The concentration contribution from the OPCS is shown to be a small proportion of total concentrations at each receptor, with the contribution reducing with distance from the OP. At the ‘Gallery Flats’ receptor, the location with the highest predicted concentration contribution from the OPCS, the OPCS contribution to total concentrations of $PM_{2.5}$ represents 11.0% in Scenario 1, 8.0% in Scenario 2 and 2.4% in Scenario 3.

Table 5.5 Annual Average PM_{10} Concentrations from Modelled sources and Ambient Background, 2009 ($\mu g\ m^{-3}$).

Receptor	2009 Ambient Back-ground PM_{10} ($\mu g\ m^{-3}$)	A11 / A12 PM_{10} S1,2 & 3 ($\mu g\ m^{-3}$)	OPCS PM_{10} S1 ($\mu g\ m^{-3}$)	OPCS PM_{10} S2 ($\mu g\ m^{-3}$)	OPCS PM_{10} S3 ($\mu g\ m^{-3}$)	Total PM_{10} S1 ($\mu g\ m^{-3}$)	Total PM_{10} S2 ($\mu g\ m^{-3}$)	Total PM_{10} S3 ($\mu g\ m^{-3}$)
Ruckholt Close	20.7	2.6	1.1	0.8	0.2	24.4	24.1	23.5
Ruckholt Close 2	20.7	2.8	1.0	0.7	0.2	24.5	24.2	23.7
West Down Road	21.1	14.8	0.8	0.6	0.2	36.8	36.6	36.1
West Down Road 2	21.1	4.4	1.5	1.0	0.3	27.0	26.5	25.8
Crownfield Road	21.1	1.5	1.2	0.8	0.3	23.8	23.5	22.9
Alphabet Nursery Sch	20.7	0.9	0.6	0.4	0.1	22.2	22.0	21.7
Gibbons Road	20.7	2.1	1.6	1.1	0.4	24.4	23.9	23.2
Bisson Road	21.2	15.8	0.9	0.6	0.2	37.8	37.6	37.1
Baldock Street	22.6	21.5	0.5	0.4	0.1	44.6	44.5	44.2
Wick Lane	22.6	13.2	1.0	0.7	0.1	36.7	36.4	35.9
Meadow Close	21.2	14.3	1.6	1.1	0.4	37.2	36.7	35.9
Gainsborough Primary	20.6	5.6	1.9	1.4	0.5	28.2	27.6	26.7
Leabank Square	20.6	4.8	2.0	1.4	0.5	27.4	26.8	25.9
Omega Works	20.6	3.8	1.9	1.3	0.4	26.3	25.7	24.8
Gallery Flats	20.6	3.6	2.3	1.6	0.5	26.5	25.8	24.7
Cadogan Terrace	21.9	13.5	0.7	0.5	0.1	36.0	35.8	35.5

Table 5.6 Number of Days Exceedence of 24-hour Average PM_{10} Air Quality Objective (Including all modelled sources and Background Concentrations, 2009.

Receptor	Scenario 1	Scenario 2	Scenario 3	difference between S1 and S2	difference between S1 and S3	difference between S2 and S3
Ruckholt Close	11	10	9	1	2	1
Ruckholt Close 2	11	11	10	0	1	1
West Down Road	59	58	56	1	3	2
West Down Road 2	18	16	14	2	4	2
Crownfield Road	10	9	8	1	2	1
Alphabet Nursery Sch	7	6	6	1	1	0
Gibbons Road	11	10	8	1	3	2
Bisson Road	65	64	61	1	4	3
Baldock Street	115	114	111	1	4	3
Wick Lane	59	57	54	2	5	3
Meadow Close	61	59	55	2	6	4
Gainsborough Primary	21	19	17	2	4	2
Leabank Square	19	17	15	2	4	2
Omega Works	16	14	12	2	4	2
Gallery Flats	16	14	12	2	4	2
Cadogan Terrace	55	54	52	1	3	2

Table 5.7 Annual Average $PM_{2.5}$ Concentrations from Modelled sources and Ambient Background, 2009 ($\mu g\ m^{-3}$).

Receptor	2009 Ambient Back-ground $PM_{2.5}$ ($\mu g\ m^{-3}$)	A11 / A12 $PM_{2.5}$ S1,2 & 3 ($\mu g\ m^{-3}$)	OPCS $PM_{2.5}$ S1 ($\mu g\ m^{-3}$)	OPCS $PM_{2.5}$ S2 ($\mu g\ m^{-3}$)	OPCS $PM_{2.5}$ S3 ($\mu g\ m^{-3}$)	Total $PM_{2.5}$ S1 ($\mu g\ m^{-3}$)	Total $PM_{2.5}$ S2 ($\mu g\ m^{-3}$)	Total $PM_{2.5}$ S3 ($\mu g\ m^{-3}$)
Ruckholt Close	14.2	2.3	1.0	0.7	0.2	17.5	17.2	16.7
Ruckholt Close 2	14.2	2.5	1.0	0.7	0.2	17.6	17.4	16.9
West Down Road	14.4	13.4	0.8	0.6	0.2	28.6	28.3	27.9
West Down Road 2	14.4	3.9	1.4	1.0	0.3	19.7	19.3	18.6
Crownfield Road	14.4	1.4	1.1	0.8	0.2	16.9	16.6	16.0
Alphabet Nursery Sch	14.1	0.8	0.6	0.4	0.1	15.5	15.3	15.0
Gibbons Road	14.1	1.9	1.5	1.0	0.3	17.5	17.1	16.4
Bisson Road	14.5	14.2	0.8	0.6	0.2	29.6	29.3	28.9
Baldock Street	15.1	19.4	0.5	0.3	0.1	35.0	34.9	34.6
Wick Lane	15.1	11.8	0.9	0.6	0.1	27.9	27.6	27.1
Meadow Close	14.4	12.9	1.5	1.1	0.4	28.8	28.3	27.6
Gainsborough Primary	14.2	5.1	1.8	1.3	0.4	21.1	20.6	19.7
Leabank Square	14.2	4.3	1.9	1.3	0.4	20.4	19.9	19.0
Omega Works	14.2	3.4	1.8	1.2	0.3	19.4	18.9	18.0
Gallery Flats	14.2	3.3	2.2	1.5	0.4	19.6	19.0	17.9
Cadogan Terrace	14.8	12.2	0.6	0.4	0.1	27.6	27.4	27.1

5.3 Comparison of Modelled and Measured Concentrations

Dispersion modelling is itself an uncertain tool and cannot be expected to produce precise estimates of concentrations. It should also be appreciated that there will also be imprecision in the estimation of the background concentrations, which will contribute to the overall uncertainty in predicting total PM_{10} concentrations. Guidance given in LAQM TG (09) suggests that where monitored and modelled concentrations are within 25% of each other, further adjustment of the modelled results (verification) is not necessary.

Table 5.8 shows the total modelled concentrations of PM_{10} for Scenario 2, compared to the actual monitored concentrations at those sites. Scenario 2 was chosen as this represents the likely particulate emissions being generated on the site at present owing to the use of ULSGO.

The results in the table show that the modelled concentrations range from 19% less than monitored concentrations to 30% more that monitored concentrations. At PM10_015 and PM10_016, less than 12 months of data is available which will lead to uncertainty in the annual mean value stated in the table. This spread of results compared to the actual measurement data is not unusual.

Table 5.9 presents the same modelled versus monitored data for $PM_{2.5}$. The model is shown to be significantly overestimating concentrations of $PM_{2.5}$, which is most likely a feature of the assumed background concentrations from Netcen. These assumed background concentrations of $PM_{2.5}$ are in the order of 15 $\mu g\ m^{-3}$ as an annual mean, compared to local measured annual mean concentrations that range from 7.8 to 11.8 $\mu g\ m^{-3}$. The cost-benefit analysis is based on the modelled only concentrations (i.e. the OPCS contribution only) and, on this basis, the apparent poor relationship between modelled and measured concentrations is not considered to be a key issue for this assessment.

Table 5.8 Annual average PM_{10} modelled concentrations Vs 2009 Annual Average PM_{10} monitoring concentrations ($\mu g\ m^{-3}$)

Monitoring Location	Modelled Concentration ($\mu g\ m^{-3}$)	Monitored Concentration ($\mu g\ m^{-3}$)	Difference between Modelled and Monitored ($\mu g\ m^{-3}$)	% Difference between Modelled and Monitored
PM10_002	27.0	22.6	4.4	-19.4
PM10_009	25.0	32.7	-7.7	23.7
PM10_010a	29.1	32.4	-3.3	10.1
PM10_011	25.4	34.7	-9.3	26.9
PM10_012	26.1	37.5	-11.4	30.3
PM10_014	27.7	23.3	4.4	-19.0
PM10_015**	24.7	22.6	2.1	-9.4
PM10_016^	25.3	28.4	-3.1	10.8

Notes:

** This monitor has only been in place since April 2009 and therefore, the annual mean reflects a period of less than 12 months

^ This monitor has only been in place since September 2009.

Table 5.9 Annual average $PM_{2.5}$ modelled concentrations Vs 2009 Annual Average PM_{10} monitoring concentrations ($\mu g\ m^{-3}$)

Monitoring Location	Modelled Concentration ($\mu g\ m^{-3}$)	Monitored Concentration ($\mu g\ m^{-3}$)	Difference between Modelled and Monitored ($\mu g\ m^{-3}$)	% Difference between Modelled and Monitored
PM10_002	20.0	8.4	11.6	-138
PM10_009	18.1	9.4	8.7	-92
PM10_010a	21.1	10.4	10.7	-103
PM10_011	18.3	10.5	7.8	-75
PM10_012	19.0	11.8	7.2	-61
PM10_014	19.9	9.4	10.5	-111
PM10_015**	17.9	7.8	10.1	-130
PM10_016^	18.3	10.9	7.4	-68

Notes:

** This monitor has only been in place since April 2009 and therefore, the annual mean reflects a period of less than 12 months

^ This monitor has only been in place since September 2009.

6. Cost-Benefit Analysis

6.1 Overview

This section provides an overview of the cost-benefit analysis that has been undertaken for this study. This has been carried out by Entec with support from the Institute of Occupational Medicine (IOM) to undertake a health impact assessment. The analysis has been undertaken in line with guidance from HM Treasury and the Interdepartmental Group on Costs and Benefits (IGCB)[15].

It should be noted that the cost-benefit analysis undertaken for this study is specific to the machinery on site and surrounding population.

6.2 Costs

6.2.1 Approach

Capital (i.e. up-front) and ongoing operating (i.e. every year) costs of DPFs have been estimated based on data gathered direct from manufacturers and the Environmental Industries Commission (EIC), a review of relevant literature and data provided direct by the ODA e.g. fuel costs. A range of costs has been applied in the analysis to reflect the wide variability in retrofit costs for different sizes and types of plant. Plant type, capacity and utilisation data are based directly on the data gathered from the inventory/air quality modelling phase of the work.

Other key assumptions include the following:

- All cost data is presented in current prices (2009 prices).
- Transfer payments are excluded in the analysis (e.g. VAT and fuel duty) as recommended by the HM Treasury Green Book[16].
- Given uncertainties over future prices (e.g. over fuel prices in particular), current prices are used only (2009 prices). The effects of inflation have not been included in the analysis. Given the short time periods used for the analysis this assumption is expected to have limited impacts on the overall results.
- It is assumed that all NRMM >37kW using gas oil are retrofitted with Diesel Particulate Filters (DPFs) in the initial year, rather than over several years. Plant with no gas oil consumption (e.g. electrically driven) are assumed to not require DPFs.

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[15] http://www.defra.gov.uk/environment/quality/air/airquality/panels/igcb/index.htm

[16] HM Treasury, The Green Book - Appraisal and Evaluation in Central Government.

- All annualised costs are discounted using a discount rate of 3.5% as recommended by the HM Treasury Green Book.

- Capital costs have been annualised in two ways:

  a) According to the expected lifetime of the plant i.e. assumed to be 5 years.

  b) As a sensitivity we have also annualised costs on the basis that the ODA would bear all the costs over the remaining lifetime of the build i.e. 2 years.

- The analysis is based on a snapshot of plant on site and does not take into account possible turnover which could result in an increase in the number that may need to be retrofitted.

The following range of cost data has been applied in the analysis based on the minimum and maximum estimates provided (Table 6.1).

Table 6.1 Overview of cost data used in the analysis

Plant capacity	One-off capital costs (£ per unit including installation)	Annual operating costs (£ per year)
37-56 kW	2,300-4,910	230-340
56-75 kW	2,500-4,910	230-380
75-130 kW	2,650-7,175	230-440
130-250 kW	3,600-8,900	230-540
250-560 kW	9,000-15,850	230-760
> 560 kW	12,000-15,850	230-910

In addition a price premium of 1.5 pence per litre has been assumed for ULSGO (relative to standard gas oil)[17].

The following scenarios have been considered for the costs analysis:

- Scenario 1 - Baseline – assuming use of standard gas oil and no DPFs (i.e. no additional costs);

- Scenario 2 - Ultra Low Sulphur Gas Oil (ULSGO) only for all plant (additional fuel costs only);

- Scenario 3a - Use of ULSGO by all plant & DPFs for plant >37kW – with NO FUEL PENALTY [capital costs annualised according to equipment lifetime i.e. 5 years];

- Scenario 3b - Use of ULSGO by all plant & DPFs for plant >37kW – with a FUEL PENALTY = 5% [capital costs annualised according to equipment lifetime i.e. 5 years];

[17] Personal communication from the ODA, 25th January 2010 (based on data provided by OPCS fuel suppliers).

- Scenario 4a - Use of ULSGO by all plant & DPFs for plant >37kW – with NO FUEL PENALTY [capital costs annualised according to ODA bearing full cost i.e. 2 years]; and
- Scenario 4b - Use of ULSGO by all plant & DPFs for plant >37kW – with a FUEL PENALTY = 5% [capital costs annualised according to ODA bearing full cost i.e. 2 years].

6.2.2 Results

Table 6.2 below provides an overview of the costs calculated for each scenario.

Table 6.2 Costs summary (2009 prices)

Scenario	Capital cost (£m)			Annualised capital cost (£m/year)			Operating costs (£m/year)			Fuel penalty (£m/year)			Total annual costs (£m/year)		
	Low		High	Low		High	Low		High	Low		High	Low		High
Scenario 2		N/A			N/A		£0.1	-	£0.1		N/A		£0.1	-	£0.1
Scenario 3a	£2.5	-	£5.8	£0.6	-	£1.3	£0.3	-	£0.5		N/A		£0.9	-	£1.8
Scenario 3b	£2.5	-	£5.8	£0.6	-	£1.3	£0.3	-	£0.5	£0.01	-	£0.01	£0.9	-	£1.8
Scenario 4a	£2.5	-	£5.8	£1.3	-	£3.0	£0.3	-	£0.5		N/A		£1.6	-	£3.5
Scenario 4b	£2.5	-	£5.8	£1.3	-	£3.0	£0.3	-	£0.5	£0.01	-	£0.01	£1.6	-	£3.5

Note: Figures rounded for presentational purposes.

The costs can be summarised as follows:

- Total retrofit costs for installing DPFs on plant >37kW are expected to be £2.5-5.8 million with operating costs of £0.3-0.5 million per year. Operating costs include the additional cost of all plant using ULSGO (relative to standard gas oil) which is estimated to be approximately £100k per year.
- Annualised costs for retro-fitting DPFs on plant >37kW are estimated to be £0.9-1.8 million depending on the range of cost data applied and if the capital costs are annualised over the lifetime of the equipment (5 years). Annualised costs are approximately double if the capital costs are annualised over the remaining lifetime of the build (2 years).
- The possible impacts of a fuel penalty (if realised) are minimal, i.e. less than £7k per year.

6.3 Benefits

6.3.1 Approach

There are two main approaches for assessing the benefits associated with reductions of emissions of air pollutants:

1. **Damage cost methodology** – this is a quick and simple approach using damage cost functions developed by the IGCB[18] which are defined as values that *"…measure the marginal external costs caused by each additional tonne of pollutant emitted - or conversely the benefits of reducing a pollutant emitted by one tonne*", i.e. £ per tonne of pollutant emitted/reduced. However, damage costs do not take into account the exact source and location of emissions and therefore the IGCB does not recommend using them *"…when air quality improvements are not **the main objective of the policy."***

2. **Impact pathway approach** – the IGCB recommend the use of this approach for valuing air quality impacts "*…as it uses a more detailed, location-specific approach to quantifying and valuing the impact of air pollution changes.*" This involves a detailed site-specific assessment of changes in emissions and air quality, an estimation of exposure of the local population, estimating health impacts based on exposure response functions and the monetisation of these impacts using recommended health values. For these reasons, this approach has been taken for modelling the health impacts associated with reductions in emissions from the OPCS (estimates using damage cost functions are presented in Appendix E for comparison).

The following steps have been taken in order to estimate and monetise the potential health impacts associated with the use of ULSD and DPFs by NRMM on the OPCS:

- Quantification of impacts on emissions from NRMM under each scenario and associated air quality modelling (see Section 4 for further details).

- Estimation of Population Weighted Mean Concentrations (PWMC) for each scenario i.e. the average exposure of the surrounding population to emissions from NRMM on the site. For the analysis, all other sources have been excluded as these are assumed to remain constant between scenarios e.g. local road traffic.

- IOM have undertaken a health impact assessment of each of the scenarios based on the modelled PWMC data provided by Entec. This has been combined with the latest recommended exposure-response functions to estimate the health impacts to the local population associated with particulate emissions from NRMM on site. The main health impacts that have been considered include:

  - Acute and chronic mortality

  - Respiratory and cardiovascular hospital admissions.

- These impacts have then been monetised through the application of IGCB recommended health values i.e. £ per unit of health impact.

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[18] Available from http://www.defra.gov.uk/environment/quality/air/airquality/panels/igcb/guidance/index.htm

Following discussions with the ODA, potential impacts on workers have not been included in the analysis. This is because of uncertainties over actual exposure due to turnover and location of workers as well as other considerations such as personal protective measures (e.g. filters on operator cabs) and existing occupational health requirements.

6.3.2 Results

IOM's health impact assessment is presented in Appendix C of this report. This includes further details on the health effects of exposure to particulate matter, the approach that has been taken and the health impacts associated with each scenario. In addition, the IGCB recommended health values that have been applied to the impacts estimated by IOM are provided in Appendix D. A summary of the monetised benefits are presented in Table 6.3 below.

Table 6.3 Benefits summary (2009 prices)

Scenario	Annual benefits (central value, £m per year)	Annual benefits (sensitivity, £m per year)
Scenario 2: ULSD only – all plant	£0.4	£0.3-0.6
Scenario 3: ULSD for all plant and DPFs for plant >37kW (90% abatement efficiency)	£1.0	£0.8-1.3

Note: Figures rounded for presentational purposes.

The benefits can be summarised as follows:

- The emission reductions associated with the use of ULSGO by all plant are expected to result in benefits of approximately £0.4 million per year (sensitivity range of £0.3-0.6 million).
- The emission reductions associated with the use of ULSGO by all plant and DPFs by plant >37kW are expected to result in benefits of approximately £1.0 million per year (sensitivity range of £0.8-1.3 million) i.e. the retrofit of DPFs is expected to result in additional benefits (relative to ULSGO alone) of approximately £0.6 million per year (sensitivity range of £0.4-0.8 million).
- The impacts of a potential fuel penalty are minimal and have therefore not been presented separately.

The health benefits associated with the use of ULSGO and the retrofit of DPFs are relatively low due to the geographical location of the site with limited population living very close to the site boundaries. In addition, the population density in the affected area is approximately 25% lower than the average density in the surrounding local authorities[19].

In addition, it should be noted that the monetised figures above do not include all possible health benefits associated with reductions in particulate emissions due to a lack of available IGCB recommended health values e.g. for wider impacts on asthmatics and new cases of bronchitis. However, these impacts are expected to be limited.

6.4 Uncertainties and limitations

The main uncertainties related to the CBA include the following:

- Uncertainties related to the capital costs of retro-fitting NRMM with DPFs. The actual cost will be dependent on the type of plant. As it was not possible within the scope of this study to consider costs on a plant-by-plant basis we have applied a range of costs to different capacity plant to reflect this uncertainty. Key assumptions for the costs analysis are presented in Section 6.2.1.

- The emissions inventory, air quality modelling and CBA are based on historical site activity and fuel use data for April 2009 and October 2009 as well as forecast data for April 2010. Costs and, to a lesser extent benefits, will vary according to how much turnover there is in the plant on site.

- Estimates for fuel consumption developed by the model are conservative (relative to actual reported data). Therefore total emissions (and reductions) and benefits will have been overestimated in the analysis.

- Assumptions have been made (based on a survey of operators) on the locations where each plant primarily operates to inform the emissions and air quality modelling. Changes in plant location (and emissions) can affect the dispersion of, and exposure to, particulate matter which would have knock-on effects on the benefits analysis.

- Uncertainties related to the health impacts of exposure to particulate matter (see IOM's health impact assessment in Appendix C for further details).

- Uncertainties related to the valuation of health impacts. In line with IGCB guidance we have presented monetised benefits based on central and sensitivity values to reflect this uncertainty.

- Impacts on workers have not been included in the benefits assessment.

- Costs and benefits have been presented on an annual basis for comparison. Whilst the remaining lifetime of the build at the Olympics site is two years there is considerable uncertainty as to where the plant retrofitted with DPFs may operate afterwards.

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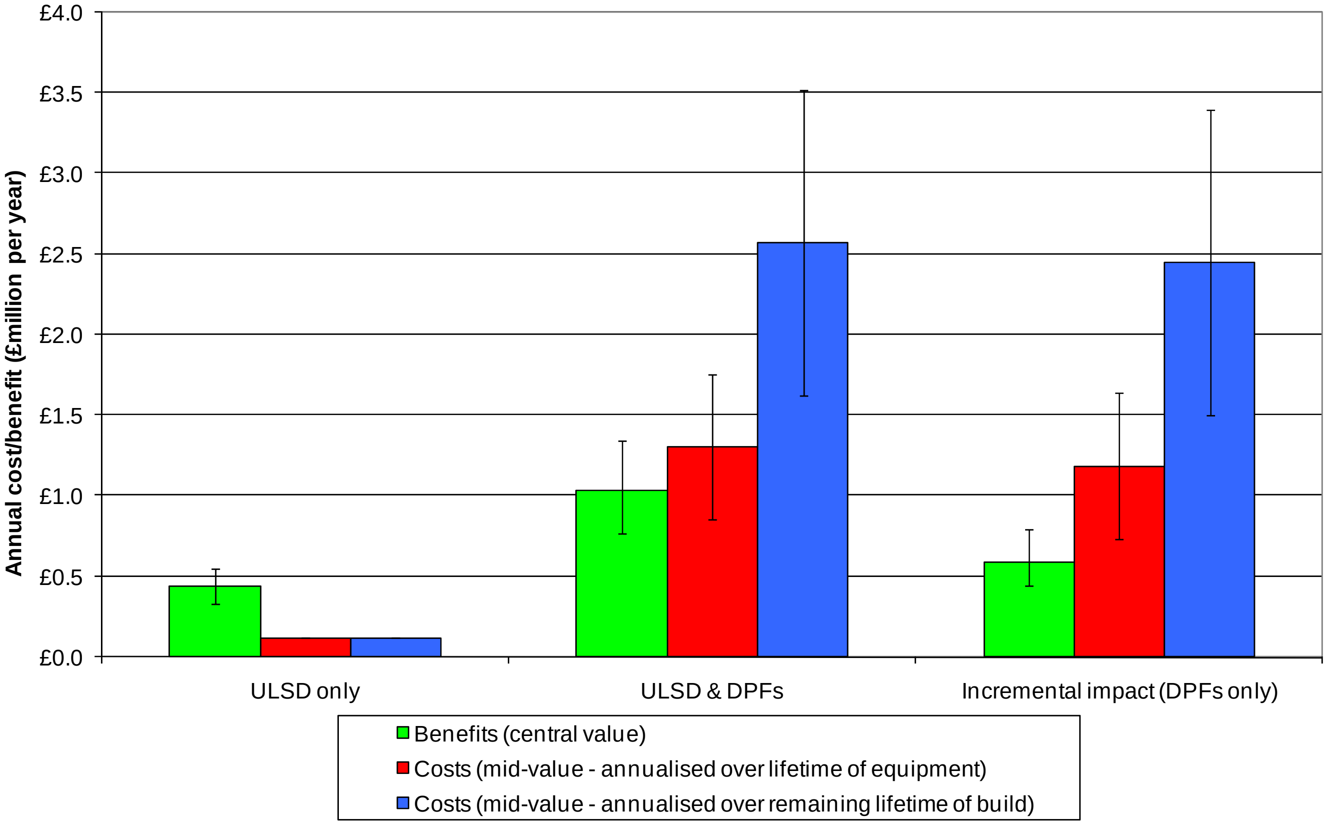
[19] Based on data extracted from the ONS Neighbourhood Statistics (2001 Census) – available from http://www.neighbourhood.statistics.gov.uk/dissemination/LeadHome.do

6.5 Summary

The costs and benefits associated with each scenario are summarised in Figure 6.1 below (the error bars indicate the range of costs and benefits).

Figure 6.1 Summary of costs and benefits of each scenario



As the error bars on the figure above demonstrate there is uncertainty associated with both the assessment of costs and benefits.

7. Conclusions

In line with the ODA's objectives for this desk study, the assessment has included:

- Determination of the actual likely environmental benefit of implementing DPFs;
- Determination of the most cost effective way of safeguarding air quality; and
- Determination of the cost / benefit ratio of implementing DPFs.

The approach to fulfilling these objectives involved developing a detailed plant emission inventory for the OPCS and undertaking a detailed dispersion modelling assessment to quantify concentrations of PM_{10} and $PM_{2.5}$ beyond the perimeter of the OPCS. This enabled the quantification of population exposure under each assessment scenario, upon which the cost-benefit analysis was based.

7.1 Air Quality Assessment

This report summarises the approach to develop a detailed inventory of plant operating on the OPCS, from which exhaust emissions were calculated. These emissions were entered into an atmospheric dispersion model to calculate air pollutant concentrations of PM_{10} and $PM_{2.5}$ at receptor locations around the boundary of the Olympic Park.

The change in exposure of these receptors to pollutant concentrations with the introduction of ULSGO and DPFs were quantified.

The emissions inventory has shown that the total emissions for Scenario 1 (no ULSGO or DPFs) were 11.4 tonnes of PM_{10}, reducing to 8.2 tonnes in Scenario 2 (ULSGO) and 2.6 tonnes in Scenario 3 (ULSGO and DPFs). Total emissions of $PM_{2.5}$ from off road plant were approximately 94% of the equivalent PM_{10} value.

The detailed dispersion modelling assessment has shown that the contribution of the OPCS together with the background concentrations (Netcen) and the emissions from the main roads in the areas are not predicted to significantly affect concentrations of PM_{10} or $PM_{2.5}$ at receptors close to the boundary of the Olympic Park. There are no predicted exceedences of the PM_{10} or $PM_{2.5}$ Air Quality Objectives at the receptors around the boundary of the Olympic Park. The receptor which experienced the greatest contribution of PM_{10} and $PM_{2.5}$ from the OPCS was located to the west of the site. The PM_{10} contribution at this receptor was 2.3 $\mu g\ m^{-3}$ for Scenario 1, reducing to 1.6 $\mu g\ m^{-3}$ for Scenario 2 and reducing further to 0.5 $\mu g\ m^{-3}$ for Scenario 3. The $PM_{2.5}$ contribution at this receptor was 2.2 $\mu g\ m^{-3}$ for the Scenario 1, reducing to 1.5 $\mu g\ m^{-3}$ for Scenario 2 and reducing further to 0.4 $\mu g\ m^{-3}$ for Scenario 3. Exceedences of the Air Quality Objectives were identified at receptors located in close proximity to the A11 and A12, findings which are consistent with those of local authorities and due primarily from road traffic emissions. The output of the dispersion modelling, in terms of the OPCS contribution to ground level concentrations of PM_{10} and $PM_{2.5}$, has been used in the cost-benefit analysis.

7.2 Cost-Benefit Assessment

Figure 6.1 in Section 6.5 provides an overview of the estimated costs and benefits associated with each scenario.

The following cost-benefit ratios have been estimated based on annual costs (spread over the lifetime of the equipment) and benefits:

- A ratio of 3.5:1 (sensitivity range of 2.6-4.4:1) has been estimated for the use of ULSGO alone relative to the baseline, i.e. annual benefits are expected to be over three times higher than the annual costs.
- A ratio of 0.8:1 (sensitivity range of 0.4-1.6:1) has been estimated for the use of ULSGO and DPFs relative to the baseline, i.e. annual benefits are expected to be approximately 20% lower than annual costs.
- The incremental impact of retro-fitting DPFs in addition to using ULSGO results in a ratio of 0.5:1 (sensitivity range of 0.3-1.1:1), i.e. the incremental annual benefits associated with retro-fitting DPFs are approximately half of the annual incremental costs.

The above cost-benefit ratios change significantly if the annual benefits are compared against annual costs spread over the remaining lifetime of the build rather than the lifetime of the equipment (i.e. 2 years as opposed to 5). In particular, the annual costs are significantly higher (by a factor of four) than the annual benefits associated with the use of DPFs (see Figure 6.1 for further details).

It should be noted that the cost-benefit analysis undertaken for this study is specific to the machinery on site and the location of the site in relation to the surrounding population. The findings, therefore, are not directly transferable to other sites.

Appendix A
EU Emission Limits

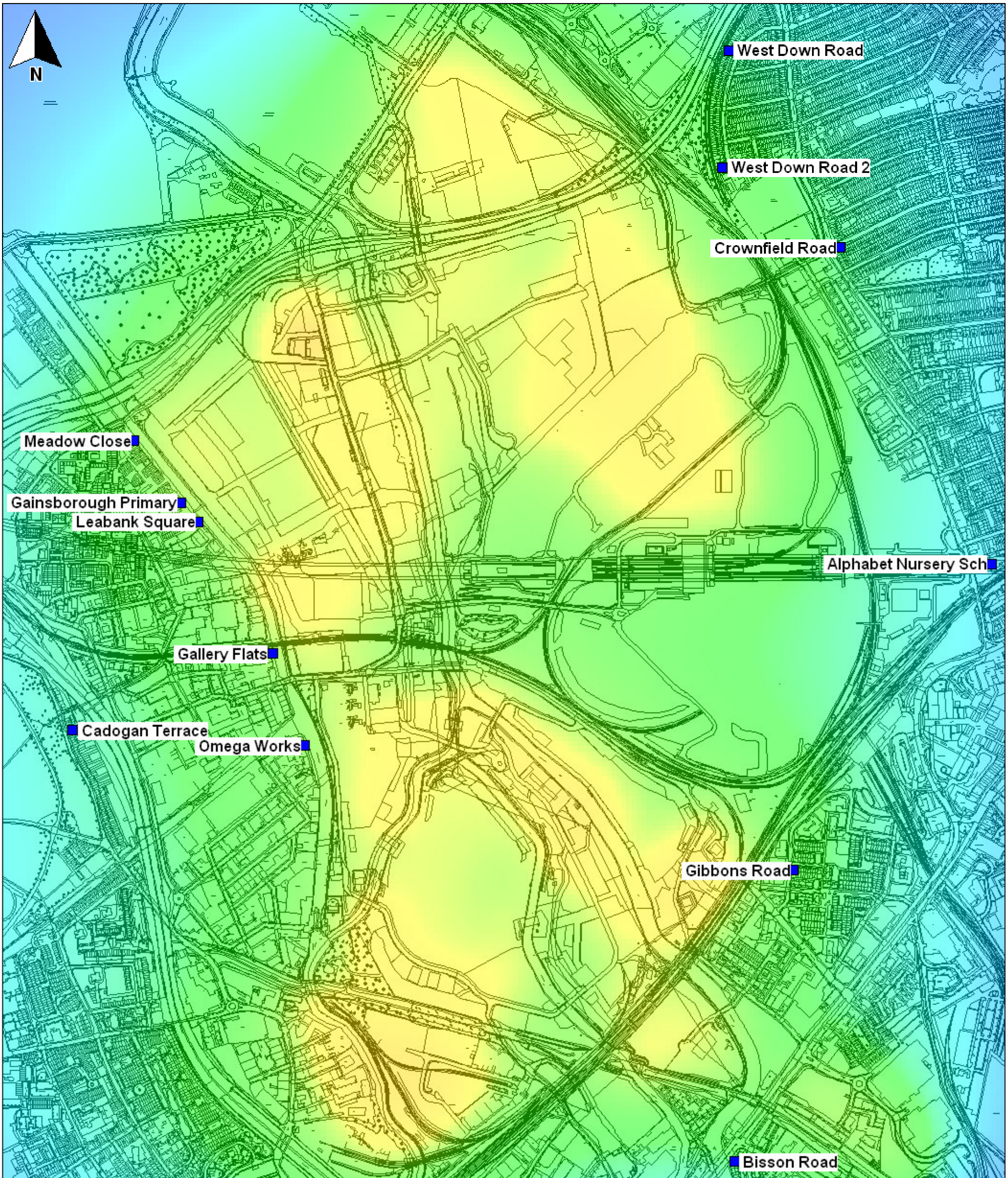
Table A1. Emission limits in Directive 97/68/EC on non-road mobile machinery

Net Power, KW	Stage	Emission limit – CO – g/kWh	Emission limit – HC – g/kWh	Emission limit – NOx – g/kWh	Emission limit – PM – g/kWh
130 – 560	I	5.0	1.3	9.2	0.54
75 – 130	I	5.0	1.3	9.2	0.7
37 – 75	I	6.5	1.3	9.2	0.85
130 – 560	II	3.5	1.0	6.0	0.2
75 – 130	II	5.0	1.0	6.0	0.3
37 – 75	II	5.0	1.3	7.0	0.4
18 – 37	II	5.5	1.5	8.0	0.8

Table A2 Emission limits in Directive 2004/26/EC for engines for use in applications other than propulsion of inland waterway vessels, locomotives and railcars

Net Power, KW	Stage	Emission limit – CO – g/kWh	Emission limit – HC & NOx - g/kWh	Emission limit – HC – g/kWh	Emission limit – NOx – g/kWh	Emission limit – PM – g/kWh	Net Power, KW
130 – 560	IIIA	3.5	4.0	-	-	0.2	130 – 560
75 – 130	IIIA	5.0	4.0	-	-	0.3	75 – 130
37 – 75	IIIA	5.0	4.7	-	-	0.4	37 – 75
19 – 37	IIIA	5.5	7.5	-	-	0.6	19 – 37
130 – 560	IIIB	3.5	-	0.19	2.0	0.025	130 – 560
75 – 130	IIIB	5.0	-	0.19	3.3	0.025	75 – 130
56 – 75	IIIB	5.0	-	0.19	3.3	0.025	56 – 75
37 – 56	IIIB	5.0	4.7	-	-	0.025	37 – 56
130 – 560	IV	3.5	-	0.19	0.4	0.025	130 – 560
56 – 130	IV	5.0	-	0.19	0.4	0.025	56 – 130

Appendix B
Contour Plots



Key:

Receptor Point

ugm-3

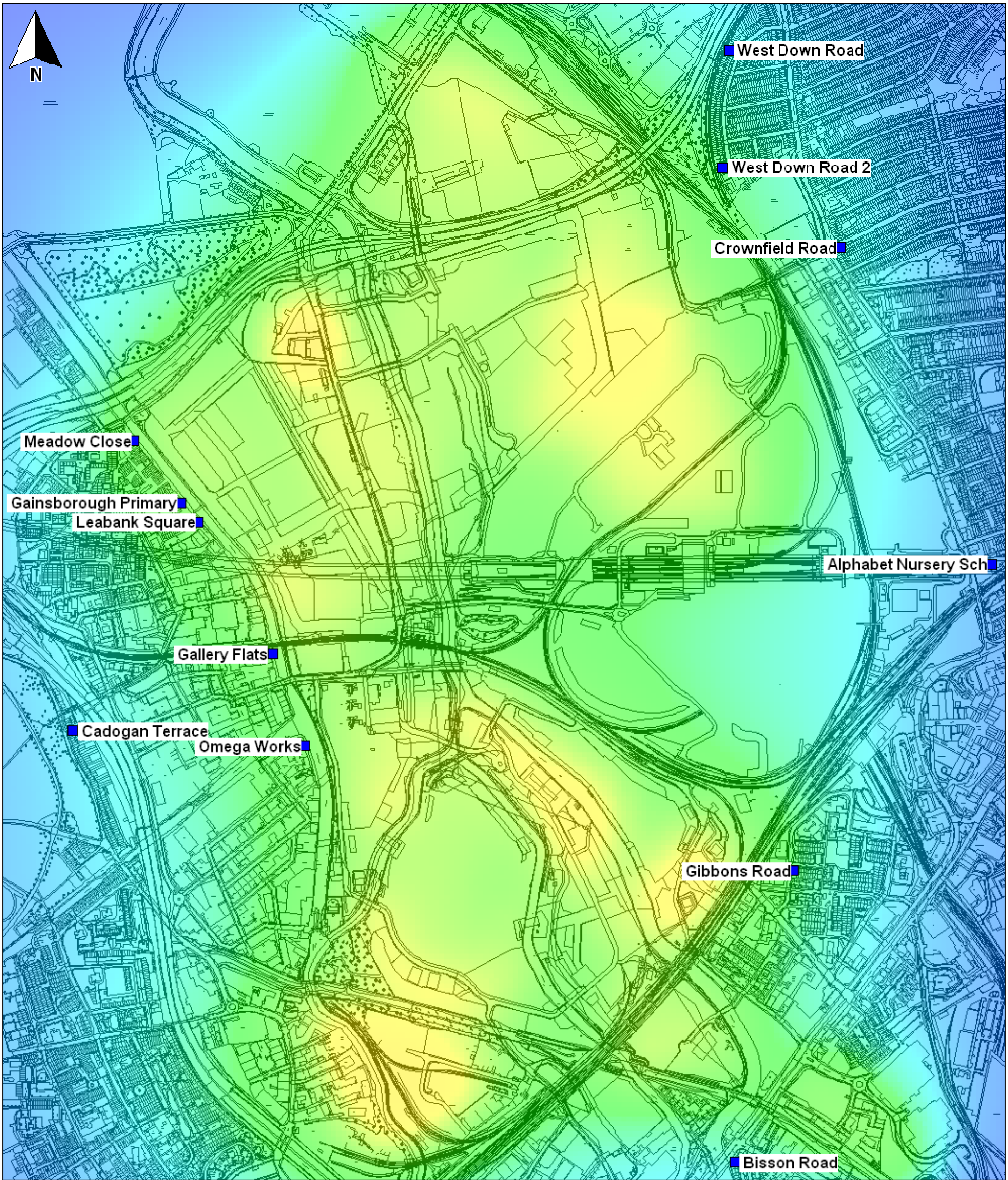
- 20
- 15
- 10
- 5
- 1
- 0.5
- 0.1

Cost-Benefit Analysis of Reducing Particulate Emissions from Non-Road Mobile Machinery on the Olympic Park Construction Site (OPCS)

Figure B1
Scenario 1
(No ULSGO and no DPFs)
OPCS contribution to Annual Mean PM10 Concentrations

March 2010
26160-01 hinda

Entec



Key:

- Receptor Point

ug m-3

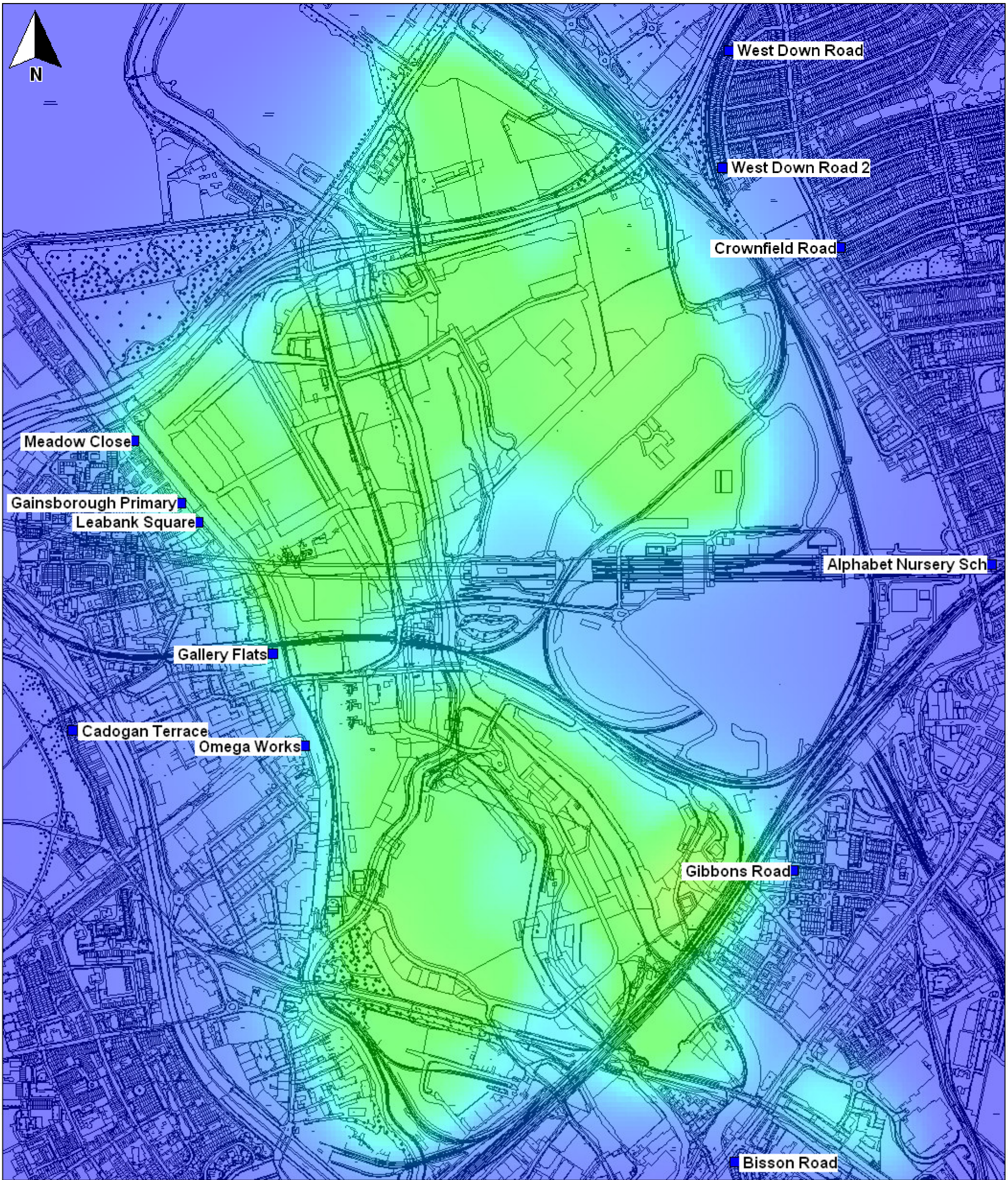
- 20
- 15
- 10
- 5
- 1
- 0.5
- 0.1

Cost-Benefit Analysis of Reducing Particulate Emissions from Non-Road Mobile Machinery on the Olympic Park Construction Site (OPCS)

Figure B2
Scenario 2
(ULSGO and no DPFs)
OPCS contribution to Annual Mean PM10 Concentrations

March 2010
26160-01 hinda

Entec



Key:

Receptor Point

ug m-3

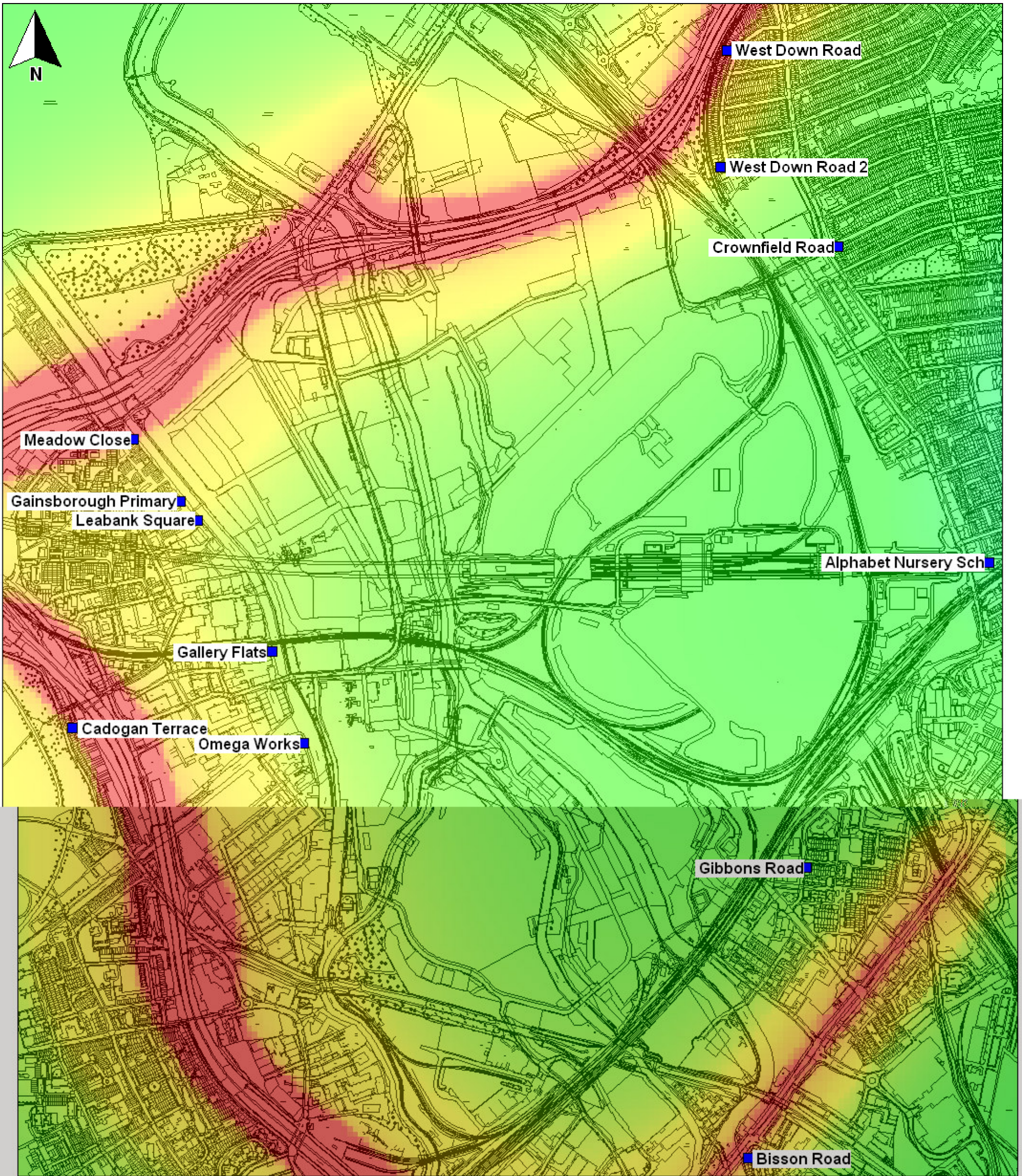
20
15
10
5
1
0.5
0.1

Cost-Benefit Analysis of Reducing Particulate Emissions from Non-Road Mobile Machinery on the Olympic Park Construction Site (OPCS)

Figure B3
Scenario 3
(ULSGO and DPFs)
OPCS contribution to Annual Mean PM10 Concentrations

March 2010
26160-01 hinda

Entec



Key:

Receptor Point

ug m-3

20
15
10
5
1
0.5
0.1

Cost-Benefit Analysis of Reducing Particulate Emissions from Non-Road Mobile Machinery on the Olympic Park Construction Site (OPCS)

Figure B4
A11/A12 road traffic contribution to Annual Mean PM10 Concentrations

March 2010
26160-01 hinda

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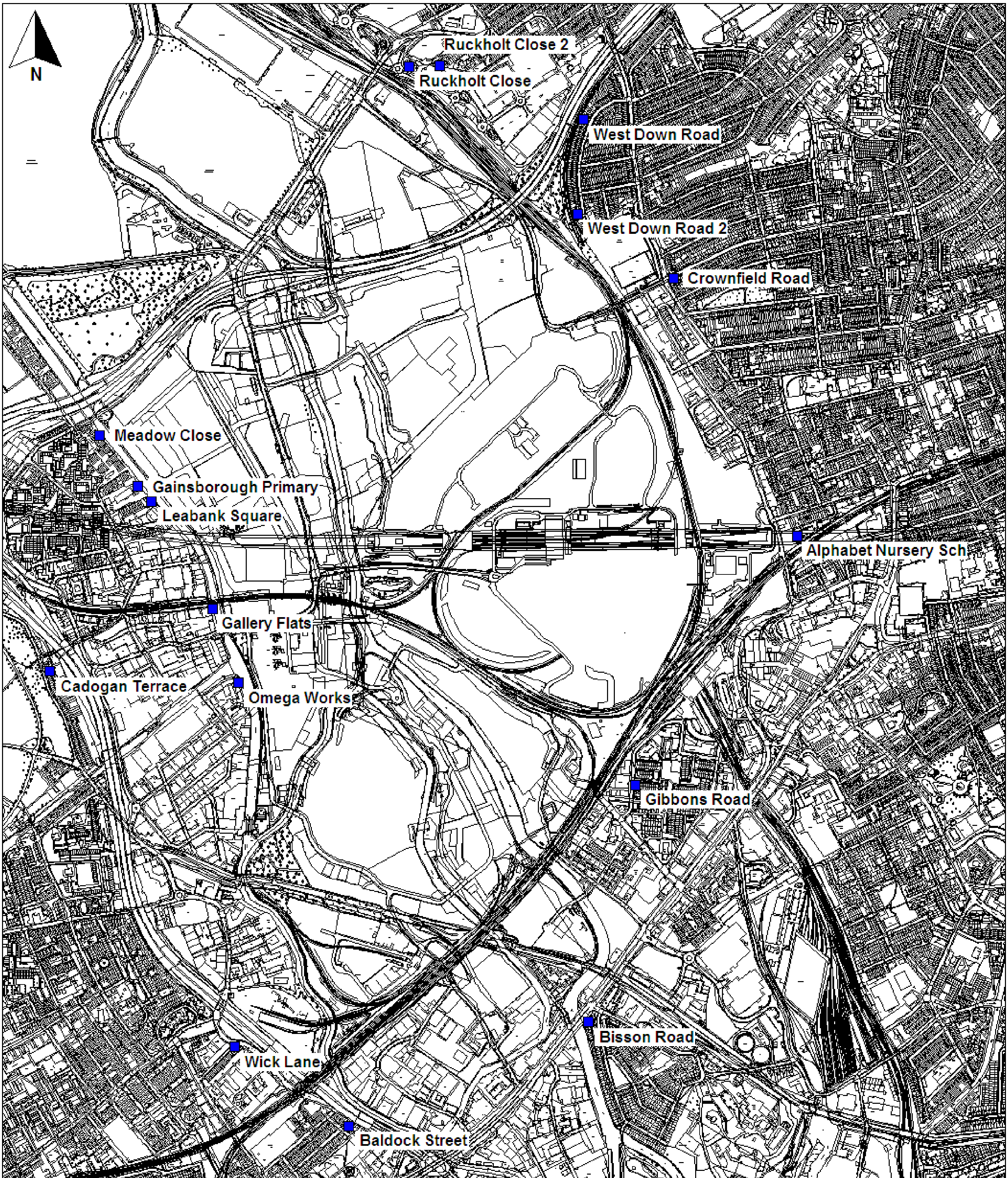

Key:

■ Receptor Point

Cost-Benefit Analysis of Reducing Particulate Emissions from Non-Road Mobile Machinery on the Olympic Park Construction Site (OPCS)

Figure B5
Receptor Locations

April 2010
26160-01 hinda

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Creating the environment for business

Appendix C
Health Impact Assessment (Institute of Occupational Medicine)

WORKING FOR A HEALTHY FUTURE

Health impact assessment for the Olympic Delivery Authority (ODA)

Final report prepared by: Alison Searl BSc (Hons), PhD, MEnvS
Date: 18th March 2010
IOM Contract no: 611-00432

INTRODUCTION

This document describes the estimated health effects associated with baseline emissions (i.e. no Ultra Low Sulphur Diesel (ULSD) or Diesel Particulate Filters (DPFs)) of particles and nitrogen oxides from NRMM operating at the Olympic Park in London and those associated with two alternative scenarios (scenario 1: ULSD only and 2: ULSD and DPFs). This is based on the population and concentration information provided by Entec. This document describes the methods used in the impact assessment and the outcome of the analysis.

Exposure to air pollution is associated with adverse cardiovascular and respiratory effects as discussed in more detail in the Appendix. The main cause of adverse effects is believed to be airborne particulate. The fractions of airborne particulate that are believed to be of greatest relevance to health are PM_{10}, the thoracic fraction which is able to penetrate the lungs, and $PM_{2.5}$, the high risk respirable fraction which can penetrate to the gas exchange region of the lungs in people with compromised respiratory health. There is growing evidence that $PM_{2.5}$ is more harmful to cardiovascular health than coarser particles within the PM_{10} size range but these coarser particles may be particularly associated with some respiratory health effects.

The impacts of air pollution on health are greater if the exposed population is relatively more deprived, more elderly and/or has poorer baseline health than the national average. These factors all confer increased sensitivity to air pollution giving rise to a greater percentage increase in effect per unit of air pollution. They are also associated with higher background rates of mortality and healthcare demand so that any percentage increase due to air pollution leads to proportionately more cases than the same percentage increase in more affluent and fitter population.

METHODS

Exposure

Population Weighted Mean exposure Concentrations (PWMC) for PM_{10} and $PM_{2.5}$ due to NRMM emissions from the Olympic Park were estimated by assuming that the average exposure of the population within each concentration band was equivalent to the midpoint concentration. The mean exposure concentration for the population above and below the highest and lowest concentration contours, was estimated by assuming that the interval above or below the contour was equivalent to half the interval between contours. For example, for the contours, <1.0, 1.0-1.5, 1.5-2.0, 2.0-2.5, 2.5-3.0, 3.0-3.5, 3.5+ ugm^{-3}, the mean exposure concentrations for each population group were estimated as: 0.75, 1.25, 2.25, 2.75, 3.25, 3.75 ugm^{-3}. If the population were evenly dispersed around the source, this would lead to a small over estimation of mean exposure and associated impact. Given that there are uncertainties in the exposure-response information and in relation to the sensitivity of the exposed population to the effects of air pollution, this potential slight over-estimation of impact is unlikely to have a significant impact on the conclusions of the HIA.

Concentration-response information

Concentration-response information is available for a variety of health endpoints for PM_{10} and a smaller number of health endpoints for $PM_{2.5}$.

The major effect of exposure to air pollution is loss of life expectancy associated with exposure to airborne particulates and estimation of life expectancy impacts played an important role in the Interdepartmental Group on Costs and Benefits (IGCB) 2007 study to support the development of the UK National Air Quality Strategy. The loss of life expectancy was calculated from an estimated change in mortality hazard reported in epidemiological studies of 0.6% per ugm^{-3} $PM_{2.5}$ (95% Confidence Interval (CI) 0.2-1.1%). Mortality risks are age dependent and the population impact of particulates is linked to population demographics. For England & Wales, the ICGB calculations suggest a loss of life expectancy of at least 0.2606 days per person per year of exposure per ugm^{-3} $PM_{2.5}$. Other important impacts of exposure to airborne particles include short term effects on mortality rate and hospital admissions for respiratory and cardiovascular illness. The concentration-response information for these endpoints is associated with a relatively low degree of uncertainty and was also used in the regulatory impact analysis undertaken by IGCB (2007).

Concentration-response information for other health effects arising from particle exposure such as increased rates of GP consultation for respiratory symptoms, increased symptoms in people with asthma, and days of mild illness that could lead to individuals modifying their daily routine (restricted activity days) is less certain. This reflects the difficulties in defining the health endpoints of interest, in identifying a study population and gaining co-operation to undertake studies and the very large number of different influences on respiratory health. IGCB did not consider the available exposure response functions sufficiently reliable for inclusion in regulatory impact analysis. The exclusion of these additional health endpoints, however, arguably leads to an underestimation of overall impact as a very much larger number of individuals may experience increased respiratory symptoms than will be admitted to hospital on high pollution days. Concentration-response relationships for other endpoints are available from an earlier IOM study undertaken for the UK Scottish Executive (Searl et al, 2003; AEAT, 2005.). The concentration-response function for chronic bronchitis was taken from the quantification methodology developed for the Clean Air for Europe (CAFE) programme (AEAT, 2005).

Although the numbers of individuals experiencing increased respiratory symptoms as the result of air pollution are likely to be considerably greater than those admitted to hospital or seeking primary care, there is considerable uncertainty in the estimation of impact.

Where effects have been calculated separately for adults and children, the age structure of the population has been assumed to be similar to that of London as a whole as recorded in the 2001 census.

Adjustment for local health status

The study area is largely in Newham but takes in parts of Tower Hamlets, Hackney and Waltham Forrest. Data from the 2001 census suggests that the self-rated population of these areas was slightly poorer than the national average and more recent information from the 2009 area Health Profiles for these boroughs suggests that life expectancy is generally slightly poorer than the national average. With the exception of Hackney, death rates are also slightly higher in these boroughs (Table 1).

Table 1: Baseline health in study area compared with national average

Measure		**Newham**	**Tower Hamlets**	**Hackney**	**Waltham Forest**	**England**
2001 Census, self-rated health %adults	Good	67.95	67.89	68.36	68.60	68.95
	Fairly Good	21.90	21.79	20.99	22.44	22.21
	Not Good	10.14	10.32	10.65	8.97	9.03
	Long term limiting illness	17.32	17.19	18.07	16.57	17.93
Life expectancy at birth 2005-7	Male	75.3	74.9	75.7	75.9	77.9
	Female	79.3	80.4	82.1	81.0	81.8
Standardised Mortality Ratio 2008		115	112	99	104	100

The impacts were initially calculated using English national rates for mortality and hospital admission, although the rates of GP consultation and A&E admissions were derived from London-based studies. The potential impact of a poorer health baseline on the baseline incidence and predicted increase in health effects was estimated using a factor of 1.15 as for the main analysis. This factor of 1.15 was based on the standardised mortality ratio for Newham for 2008 as being reasonably representative of the study area as a whole.

RESULTS

The results of the main analysis are presented in Tables 2 to 5 below. These tables show the health endpoints for which IGCB considered that there was sufficient evidence to include them in the cost-benefit analysis used in the development of the National Air Quality Strategy. Table 2 shows the calculated acute (short term) effects of particle exposure based on national mortality and hospital admission rates. Table 3 shows the predicted impact adjusted to take account of the below average health of the population of the study population. Table 4 shows the calculated impact on life expectancy based on national life expectancy and adjusted to take account of the higher local mortality rate.

Table 2: Acute effects based on national incidence rates

	Baseline	**Scenario 1**	**Scenario 2**
PM_{10} PWMC (NRMM exhaust contribution only, μgm^{-3})	0.83	0.54	0.14
Population in study area	58,532	58,532	58,532
Total deaths/year in study area	579	579	579
Predicted deaths brought forward due to emissions	**0.36**	**0.23**	**0.06**
Annual respiratory hospital admissions in study area	573	573	573
Predicted additional admissions/year arising from emissions	**0.38**	**0.25**	**0.07**
Annual cardiac hospital admissions in study area	574	574	574
Predicted additional admissions/year arising from emissions	**0.38**	**0.25**	**0.07**

Table 3: Predicted acute effects adjusted to take account of lower baseline health status in study area than in England and Wales as a whole

	Baseline	**Scenario 1**	**Scenario 2**
Predicted deaths brought forward due to emissions	**0.42**	**0.27**	**0.07**
Predicted additional admissions/year arising from emissions	**0.44**	**0.28**	**0.08**
Predicted additional admissions/year arising from emissions	**0.44**	**0.28**	**0.08**

Table 4: Predicted chronic effects associated with exposure to $PM_{2.5}$

	Baseline	**Scenario 1**	**Scenario 2**
Population in study area	58,532	58,532	58,532
$PM_{2.5}$ PWMC (NRMM exhaust contribution only, μgm^{-3})	0.78	0.51	0.14
Loss of life expectancy - days per year of exposure per person based on national mortality rate	0.20	0.13	0.04
Loss of life expectancy - days per year of exposure across population based on national mortality rate	**11,965**	**7,720**	**2,114**
Loss of life expectancy - days per year of exposure per person – adjusted estimate to take account of local health status	0.24	0.15	0.04
Loss of life expectancy - days per year of exposure across population – adjusted estimate to take account of local health status	**13,760**	**8,878**	**2,431**

Tables 5 and 6 show the results of the additional analysis that was undertaken for health endpoints not considered by IGCB. The estimated impacts shown in Table 5 are unadjusted to take account of local health status, where the estimated impacts for the same health endpoints that are shown in Table 6 have been adjusted to take account of the poorer health of the population in the study area compared with England as whole.

Table 5: Estimated effects based on incidence rates for England and Wales

	Baseline	**Scenario 1**	**Scenario 2**
PM_{10} PWMC (NRMM exhaust contribution only, μgm^{-3})	0.83	0.54	0.14
Population in study area	58,532	58,532	58,532
A&E visits respiratory illness/year	657	657	657
Predicted additional A&E visits/year arising from emissions	**0.55**	**0.35**	**0.10**
GP visits asthma/year	2,692	2,692	2,692
Predicted additional GP visits for asthma/year arising from emissions	**8.06**	**5.19**	**1.40**
GP visits lower respiratory symptoms/year	11,815	11,815	11,815
Predicted number of additional GP visits for lower respiratory symptoms arising from emissions	**3.93**	**2.53**	**0.69**
Increase days/year per asthmatic due to emissions	0.14	0.09	0.02
Total additional symptom-days adults	**654**	**421**	**114**
Increase days/year per asthmatic child due to emissions	0.11	0.07	0.02
Total additional symptom-days children	**194**	**125**	**34**
Total additional symptom days adults and children	**848**	**545**	**148**
Additional RADs per adult due to emissions	0.02	0.013	0.004
Total additional RADs in adults due to emissions	**975**	**545**	**170**
New cases of chronic bronchitis per year due to emissions	**1.03**	**0.66**	**0.18**

Adults 80.1% population 16+ (London), assume 10% asthmatic
Children (<16 years), 19.9% population, assume 15% asthmatic Acute effects based on incidence rates for England and Wales

Table 6: Estimated effects allowing for poorer baseline health of population in study area compared with the national average

	Baseline	**Scenario 1**	**Scenario 2**
Predicted additional A&E visits/year arising from emissions	**0.63**	**0.40**	**0.11**
Predicted additional GP visits for asthma/year arising from emissions	**9.27**	**5.96**	**1.62**
Predicted number of additional GP visits for lower respiratory symptoms arising from emissions	**4.52**	**2.91**	**0.79**
Total additional symptom days adults and children	**975**	**627**	**170**
Total additional RADs in adults due to emissions	**1,122**	**627**	**195**
New cases of chronic bronchitis per year due to emissions	**1.19**	**0.76**	**0.21**

Adults 80.1% population 16+ (London), assume 10% asthmatic

Children (<16 years), 19.9% population, assume 15% asthmatic Acute effects based on incidence rates for England and Wales

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HEALTH EFFECTS OF FINE PARTICULATES

The fractions of airborne particulate that are believed to be of greatest relevance to health are PM_{10}, the thoracic fraction which is able to penetrate the lungs, and $PM_{2.5}$, the high risk respirable fraction which can penetrate to the gas exchange region of the lungs in people with compromised respiratory health.

Studies of the effects of PM_{10} in large urban populations have found associations between PM_{10} and small changes in daily death rates, numbers of hospital admissions for cardiovascular and respiratory illness and increased GP consultations for respiratory illness (COMEAP, 1998; WHO 2000). Other studies of selected panels of individuals have shown associations between PM_{10} and increases in respiratory symptoms, particularly in those with pre-existing respiratory illnesses such as asthma (COMEAP 1998; WHO, 2000). In addition, associations have been found between variations in daily mean concentrations of PM_{10} or ultrafine particles and various circulatory parameters that help to substantiate the association with heart disease (eg Gold *et al*, 2000). The effects on daily death rate are well understood whereas those on respiratory symptoms are relatively poorly understood. This is because only small numbers of individuals can be studied in investigations of respiratory symptoms and the severity of respiratory symptoms is difficult to quantify. In addition, there are a large number of other influences on respiratory health including infections and exposure to allergens which mask the relatively small impact of air pollution. In contrast, death is an indisputable endpoint and mortality data is available for all developed nations.

The effects of long term exposure to air pollution are more difficult to quantify than those associated with changes in daily concentrations of PM_{10}, but are believed to be of greater importance than the effects of individual high pollution events (COMEAP, 2009a; 1998; WHO 2005). Several US studies have found an association between lifetime exposure to PM_{10} and a reduction in life expectancy. The estimated increase in mortality risk associated with long term exposure to an increment in concentration of $PM_{2.5}$ of 10 ugm^{-3} is 6% (COMEAP, 2009). The increase in risk of dying of cardiovascular causes is steeper than for all-cause mortality, with an increase in risk of about 15% per 10 ugm^{-3} for long term exposure. There is a substantial body of evidence linking exposure to $PM_{2.5}$ to nonfatal adverse cardiovascular effects (COMEAP, 2006). Long term exposure to $PM_{2.5}$ is also associated with an increased risk of respiratory cancers with the increase in lung cancer risk being about 8% per 10 ugm^{-3} increase in $PM_{2.5}$ (COMEAP, 2009a). There is some evidence that long term exposure to PM_{10} is associated with the development of bronchitis (Abbey *et al*, 1995; Dockery *et al*, 1989) although effects are poorly quantified.

EPAQS (2001) reported that the results of some epidemiological investigations (eg Mar *et al*, 2000; Schwartz *et al*, 1996; 1999) and toxicological studies have suggested that the adverse effects of PM_{10} are more strongly associated with the particles less than 1 um in diameter than with coarser particles within the PM_{10} size range. Subsequent epidemiological studies have provided further evidence that $PM_{2.5}$ has a greater influence on health than PM_{10}. For example, Kan *et al* (2007) showed the effects of $PM_{2.5}$ on daily mortality were considerably greater than those of PM_{10}. In a US study of hospital admissions for cardiovascular and respiratory diseases, Peng *et al* (2008) reported that, after adjusting for the impacts of $PM_{2.5}$ there were no statistically significant associations between coarse particulates and hospital admissions for cardiovascular and respiratory diseases. In another US study, Haley *et al* (2009) concluded that 3.1% of hospital admissions for heart failure were attributable to short-term $PM_{2.5}$ -exposure over background levels of 5 ugm^{-3} with older adults being more susceptible than younger adults. In a German study, Stolzel *et al* (2007) reported statistically significant associations between elevated concentrations of PM_1 (i.e. particles less than 1 um in diameter) and daily mortality for both total and cardio-respiratory causes. No association was found between $PM_{2.5}$ and daily mortality suggesting that fresh combustion particles were the most important component of airborne particulate in relation to cardiovascular health. Adverse effects of ultrafine ambient particulate on cardiovascular function are not confined to older people. In a study of the effects of PM_1 exposure during exercise, 16 intercollegiate athletes performed 30 minutes of exercise while inhaling low or high PM_1. Exposure to PM_1 was associated with adverse effects on both systemic conduit artery function and microcirculation with reduced blood flow in the muscle microvasculature (Rundell *et al*, 2007).

In contrast, however, Brauner *et al* (2008) found no evidence of adverse effects (detectable systemic inflammation, lipid or protein oxidation, altered haemostasis or microvascular function) in a volunteer study in which young healthy adults were exposed to urban particulate at ambient concentrations for two hours.

Several studies have identified the relative importance of the combustion generated component of $PM_{2.5}$ in giving rise to adverse effects. In a Californian study, Ostro *et al* (2008) reported that the daily death rate for cardiovascular causes was associated with components of $PM_{2.5}$ arising from combustion including elemental and organic carbon nitrates, sulphates, potassium, copper and iron. In a Finnish study, Lanki *et al* (2006) investigated the impact of $PM_{2.5}$ on exercise induced ischemia in a group of 45 elderly nonsmoking persons with stable coronary heart disease. Effects were most strongly associated with $PM_{2.5}$ originating from local traffic and long-range transport. In multipollutant models, only elemental carbon, an indicator of local traffic and other combustion, was associated with significant effects. In a recent Canadian study Cakmak *et al* (2009) reported that the chemical characteristics of $PM_{2.5}$ most strongly associated with impacts of daily mortality were consistent with vehicle exhaust emissions whereas soil derived particles had a much smaller impact on daily mortality risks. Yue *et al* (2007) investigated the associations between five particle source factors (airborne soil, local traffic-related ultrafine particles, combustion-generated aerosols, diesel traffic-related particles, and secondary aerosols) and markers of altered cardiac function and systemic inflammation in patients with coronary artery disease. Their results suggested that traffic-related and combustion-generated particles have a greater adverse impact on cardiac health than particles from other sources.

In addition to the evidence linking combustion-generated $PM_{2.5}$ to adverse cardiovascular outcomes, there is rather more limited evidence that exposure to PM_1 may cause relatively greater damage to the respiratory system than $PM_{2.5}$ or PM_{10}. In a study of lung function in Austrian school children aged 7-10, Moshammer *et al* (2006) reported a decrement in most lung function parameters of about 1% per 10 ugm^{-3} (both for particles and for NO_2). The greatest impact on lung function was observed for NO_2 which is a marker of traffic pollution and hence ultrafine particles, followed by PM_1, $PM_{2.5}$ and PM_{10}, while exposure to coarse dust ($PM_{10-2.5}$ - particles within the PM_{10} size range but outside of the $PM_{2.5}$ size range) did not significantly affect lung function.

Although the results of many studies suggest that the adverse effects of airborne particulate matter appear to be more strongly linked to $PM_{2.5}$ than PM_{10}, there is clear evidence that larger particles within the PM_{10} range are also harmful (eg studies by Lippmann *et al*, 2000; Ostro *et al* 1999). In a major review, Brunekreef and Fosberg (2005) concluded that there is no evidence that exposure to the coarse component of PM_{10} has an impact on life expectancy, although some studies have suggested an impact on daily mortality. However, In studies of chronic obstructive pulmonary disease, asthma and respiratory admissions, coarse PM has a stronger or as strong short-term effect as fine PM and there is some evidence of a link between coarse PM and emergency hospital admissions for cardiovascular illness. In a recent Finnish study, Halonen *et al* (2009) found associations between daily concentrations of all the investigated particle size fractions (0.03 um, 0.03-0.1 um, 0.1-0.29 um, 2.5-10 um particles, $PM_{2.5}$) and increased risk of hospital admission for respiratory illness in the elderly. A Californian study of heart rate variability in older adults with coronary artery disease Lipsett *et al* (2006) reported that decrements in several measures of heart rate variability were consistently associated with both PM_{10} and $PM_{10-2.5}$ but found little evidence of a relationship with $PM_{2.5}$ concentrations.

Overall, the evidence from the epidemiological studies undertaken to date indicates that that both fine and coarser particles within the PM_{10} size range are potentially harmful to health. Particles within the $PM_{2.5}$ size range, particularly within the PM_1 size range appear to be more strongly associated with adverse effects on cardiovascular health relative to coarser particles. There is however, evidence that exposure to the coarser component of PM_{10} also adversely affects cardiovascular health and there is some evidence to suggest that the composition of the coarse fraction may strongly affect its potential toxicity. Larger particles within the PM_{10} size range may be particularly strongly linked with adverse respiratory effects.

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Appendix D
IGCB Recommended Health Values

The impacts on human health have been quantified and are presented in IOM's report included previously in Appendix C. The main health impacts have been monetised using IGCB recommended health values taken from Chapter 2 of the IGCB report "Economic Analysis to inform the Air Quality Strategy, July 2007"[20]. The values applied are replicated in the table below.

Table D1. IGCB Recommended Health Values

Health effect	Form of measurement to which the valuations apply	Central value (2004 prices)	Sensitivity
Acute mortality	Number of years of life lost due to air pollution, assuming 2-6 months loss of life expectancy for every death brought forward. Life expectancy losses assumed to be in poor health.	£15,000	10% and 15% of life years valued at £29,000 instead of £15,000 (to account for the avoidance of sudden cardiac deaths in those in apparently good health.
Chronic mortality	Number of years of life lost due to air pollution. Life expectancy losses assumed to be in normal health.	£29,000	£21,700-£36,200 (sensitivity around the 95% confidence interval)
Respiratory hospital admissions	Case of a hospital admission of average duration 8 days.	£1,900-9,100	£1,900-£9,600
Cardiovascular hospital admissions	Case of a hospital admission of average duration 9 days.	£2,000-9,200	£2,000-£9,800

These recommended values have been converted to 2009 prices, assuming an inflation rate of 2.5%. This is in line with IGCB and Treasury Green Book Guidance.

[20] http://www.defra.gov.uk/environment/airquality/publications/stratreview-analysis/chap-2-icgb.pdf

Appendix E
Benefits Analysis: Damage Cost Functions

For sensitivity, indicative benefits are presented in this appendix based on the damage cost approach (i.e. £ per tonne of pollutant reduced – not site-specific) using values developed by the IGCB. For further details on the way in which they have been developed, the impacts they include and uncertainties/limitations please refer to supporting IGCB guidance[21]. A number of damage cost functions have been developed for particulate matter (PM) depending on the emission source. These are summarised in the table below.

Table E1. IGCB damage cost functions (2009 prices)

Source	Central Estimate (1)	Sensitivities	
		Low Central Range (2)	High Central Range (2)
PM Domestic	£25,744	£20,157	£29,255
PM Agriculture	£8,877	£6,951	£10,088
PM Waste	£19,086	£14,944	£21,689
PM Industry	£23,081	£18,071	£26,228
PM Electricity Supply Industry	£2,219	£1,738	£2,522
PM Transport Average	£44,386	£34,753	£50,439
PM Transport Central London	£202,847	£158,820	£230,508
PM Transport Inner London	£208,617	163,338	£237,065
PM Transport Outer London	£136,267	£106,691	£154,849
PM Transport Inner Conurbation	£107,860	£84,449	£122,568
PM Transport Outer Conurbation	£67,023	£52,478	£76,163
PM Transport Urban Big	£79,896	£62,555	£90,791
PM Transport Urban Large	£64,361	£50,391	£73,137
PM Transport Urban Medium	£50,601	£39,618	£57,501
PM Transport Urban Small	£31,958	£25,022	£36,316
PM Rural	£13,760	£10,773	£15,636

(1) The central damage cost is derived from the lag probability distribution developed for Monte Carlo analysis to reflect the fact that, although evidence is limited, COMEAP tend towards a greater proportion of the health effect occurring in the years sooner after the pollution rather than later. This estimate is intended for use only where a single point estimate is necessary and should always be accompanied by the central range.

(2) Variation between the central values reflect uncertainty about the lag between exposure and the associated health impact. The presented figures show the range between a 0 and 40 year lag. This sensitivity should be reported as the central sensitivity.

[21] Available from: http://www.defra.gov.uk/environment/quality/air/airquality/panels/igcb/guidance/index.htm

None of the IGCB damage cost functions directly match the source or location of emissions under consideration in this study. However, for illustrative purposes indicative benefits have been estimated based on the "PM Transport Outer London" and "PM Transport Inner London" values.

Table E2. Indicative benefits per year

PM Transport Outer London	Central (£m per year)	Low (£m per year)	High (£m per year)
Scenario 1: ULSD only	£0.4	£0.4	£0.5
Scenarios 2&3: ULSD & DPFs (90% efficiency)	£1.2	£1.0	£1.4
PM Transport Inner London	**Central (£m per year)**	**Low (£m per year)**	**High (£m per year)**
Scenario 1: ULSD only	£0.7	£0.5	£0.8
Scenarios 2&3: ULSD & DPFs (90% efficiency)	£1.9	£1.5	£2.1

The figure below presents these values alongside the benefits estimated for the study using the full impact pathway approach and the annual costs (the error bars indicate the range of costs and benefits).

Figure E1. Overview of costs and benefits