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An integrated tool to assess the role of new planting in PM_{10} capture and the human health benefits: A case study in London

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A combination of models can be used to estimate particulate matter concentrations before and after greenspace establishment and the resulting benefits to human health.

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ABSTRACT

The role of vegetation in mitigating the effects of PM_{10} pollution has been highlighted as one potential benefit of urban greenspace. An integrated modelling approach is presented which utilises air dispersion (ADMS-Urban) and particulate interception (UFORE) to predict the PM_{10} concentrations both before and after greenspace establishment, using a 10×10 km area of East London Green Grid (ELGG) as a case study. The corresponding health benefits, in terms of premature mortality and respiratory hospital admissions, as a result of the reduced exposure of the local population are also modelled. PM_{10} capture from the scenario comprising 75% grassland, 20% sycamore maple (*Acer pseudoplatanus* L.) and 5% Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) was estimated to be 90.41 t yr^{-1}, equating to 0.009 t ha^{-1} yr^{-1} over the whole study area. The human health modelling estimated that 2 deaths and 2 hospital admissions would be averted per year.

1. Introduction

Sources of PM_{10} (particles with a diameter of less than 10×10^{-6} m) within urban areas of the UK include road traffic, industry and power production (Dore et al., 2005). Results from numerous longitudinal investigations of human respiratory and other diseases show consistent statistical associations between human exposure to outdoor levels of PM_{10} and adverse health impacts. Health effects range from alveolar inflammation and respiratory-tract infection (specifically pneumonia) (Pope et al., 1995; Holgate, 1996; QUARG, 1996; Defra, 2007a) to acute cardiovascular disorders (Pope et al., 1995; Klemm et al., 2000; USEPA, 2004). These often lead to substantially increased morbidity and mortality, in particular among elderly individuals (Zelikoff et al., 2003). The adverse health effects of high ambient PM_{10} concentrations have resulted in the introduction of air quality standards which are designed to be protective of human health. When considered in an economic context, the health costs incurred by PM_{10} pollution in the UK have been estimated to range between £9.1 and 21.4 billion per annum (Defra, 2007a).

Although PM_{10} emissions in the UK have reduced in the last 30 years (Dore et al., 2005; Defra, 2007a), this trend is flattening or reversing in some major urban areas and along roads (Defra, 2007a). A range of measures have been introduced in an attempt to further reduce PM_{10} emissions, for example tightening of vehicle emissions standards and road pricing initiatives. However, a range of cost-effective abatement measures must be initiated if improvements in air quality are to be any more substantial (Defra, 2007a). Tree establishment in urban areas has been proposed as one measure to reduce ambient PM_{10} concentrations (Bealey et al., 2007; Nowak et al., 2006; McDonald et al., 2007). PM_{10} deposition to vegetation has been the subject of a number of recent investigations (Beckett et al., 1998; Gupta et al., 2004; Dammgen et al., 2005; Tiwary et al., 2006). However, the complexities involved in understanding the removal mechanisms for PM_{10} on different vegetation types, species, planting design and age class has resulted in a large degree of uncertainty regarding the level of reduction that could practically be achieved and how this would relate to human health. This uncertainty is exacerbated by the inherent assumptions and uncertainties in deposition models, where the

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interception mechanism is influenced by particle size, foliage density, terrain, and meteorological conditions (Ruijgrok et al., 1995; He et al., 2002).

Trees can serve as effective sinks for particulates at the canopy level, both via dry, wet and occult deposition mechanisms. For example, work on forest canopies (Peters and Eiden, 1992; Erisman et al., 1997; Freer-Smith et al., 1997; Decker et al., 2000; Urbat et al., 2004) found them to have high capturing efficiencies for airborne particles. The structure of trees and the rough surfaces that they provide increase the incidence of particle impaction and interception by disrupting the flow of air (Beckett et al., 1998), mainly at canopy height (Erisman et al., 1997). It has been suggested that the layered canopy structure of large trees provides a surface area for particulate deposition of between 2 and 12 times that of the area of land they cover (Broadmeadow and Freer-Smith, 1996). Fowler et al. (2004) found that woodlands in the West Midlands, England, collected three times more PM_{10} than grassland. The differences between tree species play an important role in estimating PM_{10} capture; leaves with complex shapes, large circumference-to-area ratios, waxy cuticles or fine hairs on their surfaces collect particles more efficiently. Conifers, which are also in leaf all year round, may be more effective than deciduous species (Freer-Smith et al., 2005).

Deposition models such as Urban Forest Effects model (UFORE) (Nowak, 1994) and FRAMES (Bealey et al., 2007) are available to assess the potential for particulate matter interception by trees. In UFORE, generic deposition values are assigned to trees due to a lack of empirical deposition data for specific species and for different wind speeds. However, recent reports have shown that tree species and wind speed account for large variations in deposition velocity (Beckett et al., 2000a,b; Freer-Smith et al., 2005). These variations suggest that the use of generic deposition velocities may produce imprecise estimates of PM_{10} flux if they are used to predict deposition where the species composition is different from that for which they have been derived. Recently published deposition velocities measured for specific tree species and wind speeds (Freer-Smith et al., 2004, 2005) allow more accurate PM_{10} flux estimations to be produced.

The potential use of trees to improve local air quality has been recognised by the UK Government (e.g. Scottish Executive, 2006; Defra, 2007b; Royal Commission on Environmental Pollution, 2007). There is, however, a need for greenspace to be planned and implemented strategically at the landscape level in order to fulfil the potential benefits it can bring to urban environments. These benefits include those to air quality, climate amelioration, sustainable urban drainage, health and well-being. This study aims to estimate the potential for a greenspace initiative to reduce PM_{10} levels in an area of East London and the corresponding human health impacts on mortality and morbidity. It also aims to demonstrate how this type of integrated modelling approach, comprising environmental and health models, can be used as a tool by practitioners wishing to target greenspace development to areas where air quality is of concern.

2. Materials and methods

2.1. Study area

The East London Green Grid (ELGG; Fig. 1) (Greater London Authority, 2008) is the delivery mechanism of the 'Greening the Gateway' initiative in London. It is a proposed 'network of interlinked, multi-purpose and high quality open spaces that connect areas where people live and work with town centres, public transport, the countryside in the urban fringe and the River Thames' that will be created from both new and existing greenspace (Greater London Authority, 2006). The drivers behind the ELGG development are multi-faceted and, whilst PM_{10} reduction is not a primary driver the improvement of local air quality is seen as a potential benefit of the scheme (Greater London Authority, 2006).

This study used a 10 × 10 km region (Fig. 2; National Grid Reference TQ 401801, 51°30′N, 0°01′E) of the ELGG covering the London Boroughs of Newham and Greenwich. The ELGG within this area occupies 547 ha (5.5% of the total study area).

2.2. Overview of the integrated approach

The study area falls within a heavily urbanised region of the ELGG, characterised by heavy traffic, industrial activity and London City airport. Sources of PM_{10} from the whole of Greater London were modelled using ADMS-Urban (version 2.2, Cambridge Environmental Research Consultants, UK; CERC, 2006) to calculate hourly PM_{10} concentrations at 1.5 m height (human receptor level) for the 10,000 ha study area; a map of average PM_{10} concentrations was then produced. This process used emissions data from the London Atmospheric Emissions Inventory (GLA, 2006) and meteorological data for 2004 from Heathrow Airport, UK (Meteorological Office, 2006). ADMS-Urban allows a maximum of 10,000 output points in the calculation of spatial concentrations; these can be specified using a mix of regular output grid points and additional receptor points. For the presented study the grid resolution for the 10 km × 10 km study area was chosen as a mix of points on a 40 × 40 grid (0.25 × 0.25 m) and 18 specified receptor locations. The latter were used to sample the input upstream concentrations in order to calculate the potential flux from vegetation intervention.

A canopy PM_{10}-uptake model based on UFORE (Nowak, 1994) was then used to estimate the PM_{10} interception by the proposed ELGG within the study area. However, the ELGG does not yet have specific information available on the composition of the greenspaces, e.g. species choice, percentage tree cover or planting design. Therefore, a range of possible planting options for these greenspaces was modelled. The 'most realistic scenario' of PM_{10} interception by the ELGG within the study area was then used to reproduce the PM_{10} concentration map for the area for use in the human health modelling. This scenario was thought to be most realistic based on social considerations for urban greenspace design, where broadleaves, a range of habitats and areas of open space tend to be preferred by local communities (Lee, 2001). The interception of PM_{10} by the other scenarios is presented in order to demonstrate the importance of species selection if air quality improvement is an objective of greenspace design and the beneficial role of tree cover versus grassland.

The PM_{10} concentrations post-implementation of the ELGG were estimated in ADMS-Urban using two modifications to the pre-implementation scenario. Firstly, the source strength of each grid cell was adjusted by accounting for the modelled flux to vegetation using the GIS information on the presence of the corresponding vegetation in each grid cell. Secondly, the surface roughness (in metres) was altered to take account of changes to this parameter following greenspace establishment. ADMS-Urban parameterises the boundary layer structure based on the Monin-Obukhov length and the boundary layer height. Using the hourly sequential meteorological data a pre-processor code makes accurate estimation of the boundary layer height for each hour, based on the previous history.

The impact of the ELGG on human health from PM_{10} exposure was compared with a situation of no greenspace establishment. Two models were used to estimate the premature mortality and respiratory hospital admissions, as a result of PM_{10} exposure, of the populations within the London Boroughs of Newham and Greenwich.

2.3. The potential impact of the ELGG on PM_{10} concentration

Five scenarios were used to estimate the potential for PM_{10} interception by the ELGG. These were based on the premise that trees have a greater capacity for PM_{10} reduction than grassland and that conifers have a greater capacity than broadleaves. Data for sycamore maple (*Acer pseudoplatanus* L.) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) were selected to provide the 'best' and 'worst' case scenarios for PM_{10} interception by tree cover. *A. pseudoplatanus* produces very low deposition velocities due to its low particle capture efficiency and *P. menziesii* exhibits very high deposition velocities (Freer-Smith et al., 2004, 2005). The five scenarios used, based on a total land area of 547 ha, in the study were:

1. 100% grassland;
2. 50% grassland, 50% *A. pseudoplatanus*;
3. 100% *A. pseudoplatanus*;
4. 75% grassland, 20% *A. pseudoplatanus*, 5% *P. menziesii*;
5. 100% *P. menziesii*.

The PM_{10} flux (F; in g m $^{-2}$ s^{-1}) to each greenspace scenario is calculated as the product of the deposition velocity (V_d; in m s^{-1}) and the pollutant concentration (C; in g m^{-3}) according to the methodology outlined in Nowak (1994):

$$F = V_d C \quad (1)$$

Deposition velocity is calculated as the inverse of the sum of the aerodynamic (R_a), quasi-laminar boundary layer (R_b) and canopy (R_c) resistances (Baldocchi et al., 1987):