The UDM. A Puff Model for Estimating Dispersion in Urban Areas

D.J. Hall[1], A.M. Spanton[2], I.H. Griffiths[3], M. Hargrave[3], S.Walker[4], C. John[2]
[1] *Envirobods Ltd, Stevenage, Herts SG2 8SR, UK*
[2] *DERA Porton Down, Salisbury SP4 0JQ, UK*
[3] *Riskaware Ltd, Bristol, UK BS1 5BT*
[4] *BRE Ltd, Garston, Watford, Herts WD2 7JR*

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1 Introduction

The paper describes the ‘Urban Dispersion Model’ (UDM)), which has been designed to estimate the dispersion of instantaneous releases (‘puffs’) of airborne contaminants at short ranges in urban areas, where the surface obstructions within the urban canopy (mainly buildings) modify the dispersion patterns. The model is designed to cope with multiple sources at the ground at distances between about 10m and 10km; beyond this distance, dispersing puffs tend to fill the whole boundary layer and the nature of the surface becomes less important to the dispersion.

2 Structure of the Model

The UDM has been developed to satisfy a requirement for a numerical model that predicts the dispersion of airborne contaminants through urban areas at ranges between about 10 m and 10 km. It was required to deal with single or multiple short term releases (‘puffs’) which might be variable in space and time. Using a succession of timed puffs (of varying size if necessary), releases in any desired format can be simulated; single or multiple; time dependent or continuous; static or moving. There was also the constraint that the calculations should be fast, for several reasons. Firstly, a wide variety of dispersion situations would be encountered within the large range of distances and surface characteristics likely to be encountered. This would require a multiplicity of calculation procedures within a single puff dispersion calculation. Secondly, the use of multiple puff sources implied a further multiplicity of calculations within a single model run. Thirdly, some applications of the model required that it be used in ‘real time’.

Models suitable for dealing with dispersion in urban areas were reviewed by Hall *et al* (1996a), who identified both suitable available modelling procedures and deficiencies in the research database. No acceptable model was found and it was concluded that a new model would have to be devised. This was first outlined in 1997; the model was coded shortly afterwards and has proved successful. The software is highly structured, so that all its components can be individually modified or developed as required and enhancements can be added easily. Recent developments have included:

- Enhancing the physics of the model and its range of application, based on a research programme providing new urban dispersion data from wind tunnel and field experiments;
- Enhancing the input and output routines, especially in the development of an effective graphical user interface (GUI), so that the model is easy to use, providing a high level of visual information on dispersion calculations;
- Extending the application of the model to complex terrain, via a seamless interface to a wind field calculation model (based on the RISO LINCOM model (Astrup *et al* (1999));
- Premilinary validation of the model output against independent field trials data (Griffiths *et al* 2000).

3 Physics of the Model

The single most important feature of the urban environment that must be accounted for in short range, near-ground dispersion models is the presence of surface obstacles, which are mainly buildings but also a variety of other types of structure whose size is large enough to directly affect puff dispersion patterns. Though there are a variety of modelling procedures to deal with individual facets of this situation, these do not cover all the needs of an urban dispersion model. Therefore, it has been necessary to devise modelling procedures for some of these situations.

In their review, Hall *et al* (1996) defined three main regimes, generally of increasing scale, within which different types of modelling procedure were required depending upon the relative scales of the dispersing puff and the surface obstacles and upon the occupational density of the surface obstacles. These regimes have formed the basis of the model described here.

3.1 Open/Interacting Regime

This regime represents a region of low obstacle occupational density (below 5%), generally at short ranges below 1km. Here, the dispersing puff is of small cross section compared to the scale of individual obstacles and the effects of these obstacles are the greatest influence on dispersion. The dispersing puff interacts with relatively large individual surface obstacles in succession as they intrude into its path and local effects of the airflows around the individual obstacles dominate the puff path and its dispersion. Dispersion patterns are highly individualistic for different sites and high levels of spatial and temporal variability in dispersion patterns are normally found. A puff only partially entrains into the wakes of any obstacles encountered, so that in the model the puff partitions into those parts which are respectively unaffected by the obstacle and those which are entrained into the obstacle wake.

Though the broad characteristics of this type of dispersion are understood, the detailed flow behaviour can be quite complex and it is not practicable to model these details. An empirical model has to be based mainly on relatively simple rules governing the probability of occurrence of specific puff behaviour patterns. There were a number of significant deficiencies in both the types of simple model available and in the research database, but there was sufficient information to construct an acceptable simple dispersion model in the first instance. Some deficiencies, especially with regard to plume sources laterally displaced from the obstacle, have been the subject of field experiments reported on by Mavroidis(1996) and by Mavroidis and Griffiths(1996).

3.2 Urban Regime

An ‘urban’ regime exists in regions of high obstacle density (above 5%) and also generally at short ranges below 1km, where the puff cross section is large enough to encompass several obstacles. This situation will occur rapidly after the first row of obstacles in an urban array, even with sources within the urban obstacle array. In this regime, dispersion remains influenced by the effects of the shape and distribution of the local surface obstacles. Experimental evidence (Hall *et al* (1998)) has shown that the lateral and longitudinal puff concentration distributions are Gaussian, so that conventional dispersion modelling procedures can be used. However, the rates of dispersion depend on the ensemble properties of the surface obstacles rather than their individual characteristics.

No models dealt specifically with the urban regime and there were significant deficiencies in the dispersion research database. Wind tunnel and field studies were therefore commissioned to provide sufficient research data for an adequate model to be developed in the first instance. Some of this work has been reported by Hall *et al* (1998) and by Macdonald *et al* (1998) and the research programme is continuing. There has also been a survey of some representative UK urban areas by Spanton *et al* (1996) in order to classify their aerodynamic characteristics.

3.3 Long-Range Open Regime

A ‘longer range’ regime exists when the puff cross section becomes large compared with the scales of individual obstacles. The individual form of the surface obstacles loses its importance and rates

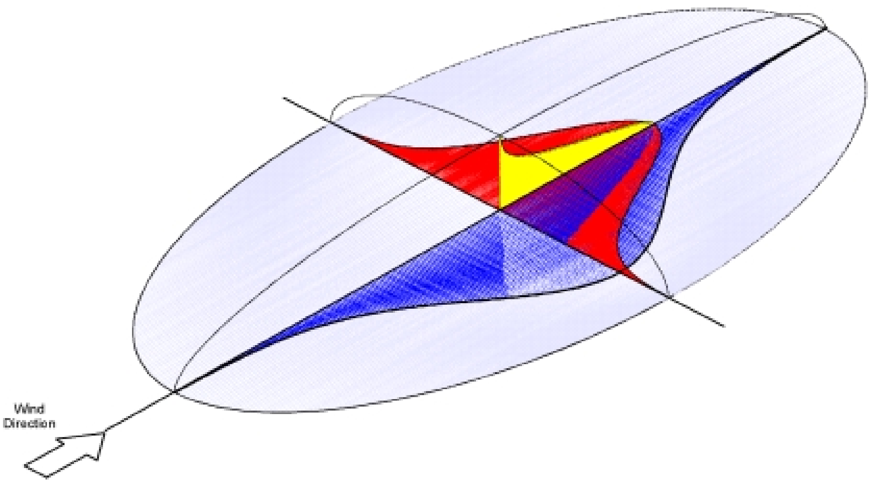

Figure 1 A Gaussian Puff.

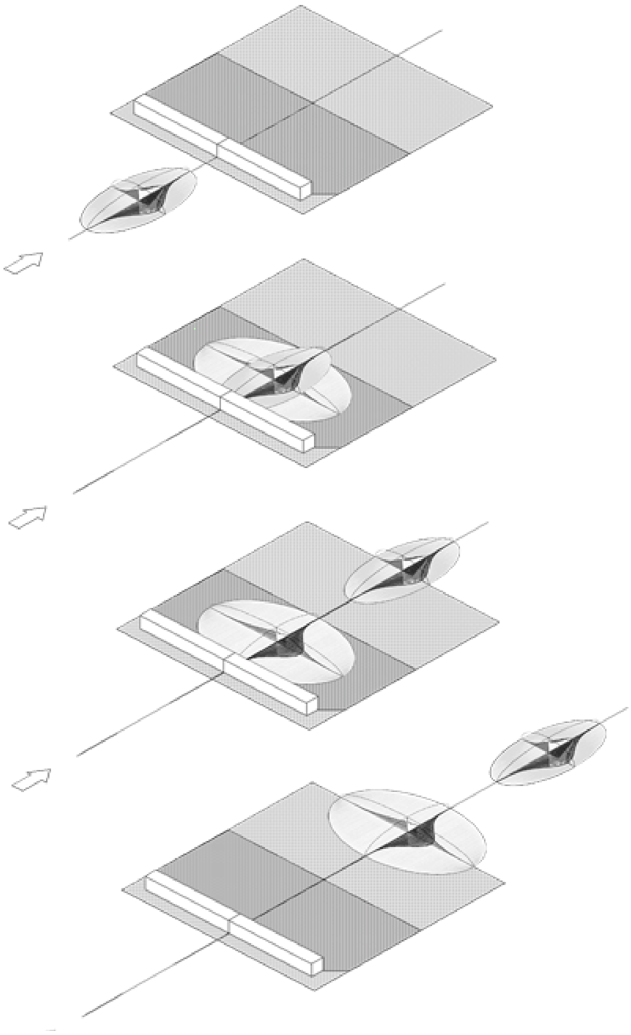

Figure 2 Diagram of Puff Partitioning Due to a Puff /Obstacle Interaction.

of dispersion then depend largely on the overall drag of the surface, usually expressed solely in terms of the aerodynamic roughness height, z_0,, and of the atmospheric stratification.

In this regime, conventional dispersion models are adequate for the present purposes, though some modifications are required to account more fully for the effects of urban roughness in modifying rates of dispersion. However, this is manageable, though imperfectly, with the existing database.

3.4 Modelling Approach

Additional research carried out to quantify some features of the urban regime has largely confirmed the advisability of this three-regime model. The UDM has therefore retained, and continues to follow, this pattern. However its practical application has required a more complex approach than this simple division. There are both additional constraints that apply between the different regimes and sub-regimes within them as well as some overlap in their use. The model is based on a conventional Gaussian puff in the Long-Range regime, as shown in Figure 1. On encountering a surface obstacle of significant size a puff is partitioned between entrained and unentrained fractions, as shown in Figure 2, which then become separate entities to the model. If the puff considers the obstacle as ‘small’, its effects are ignored and the calculation effectively continues as if in the long-range regime. Regions of high obstacle density, as in Figure 3, are regarded as ‘urban arrays’; here, puff dispersion characteristics, which depend on the array parameters, are defined from experimental data. Figure 4 shows a sample output of the UDM, in this case for a continuous release, in which the effects of the buildings on the modelled concentration pattern can be clearly observed.

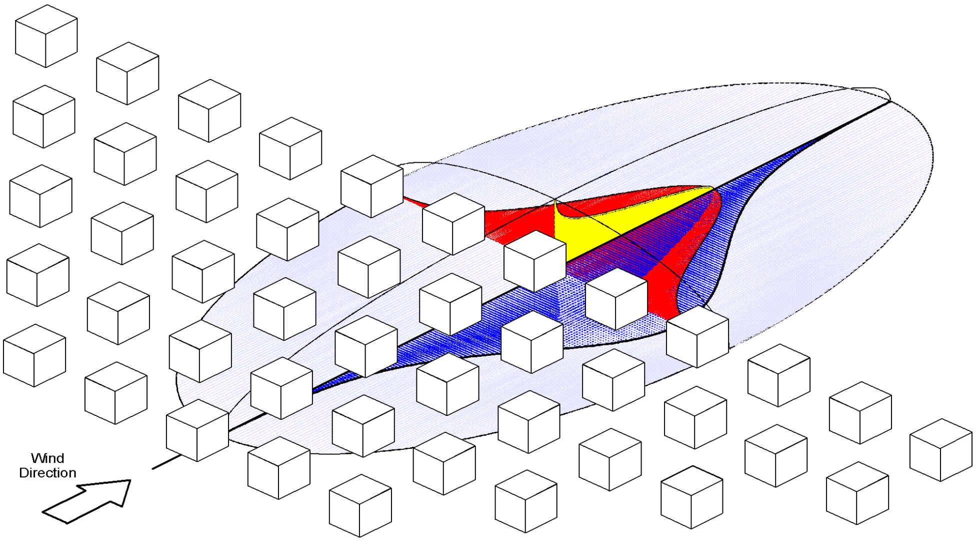

Figure 3 Diagram of Puff Dispersion in the Urban Regime, Where the Obstacle Density is High and the Plume is of Comparable Size to the Obstacle Array.

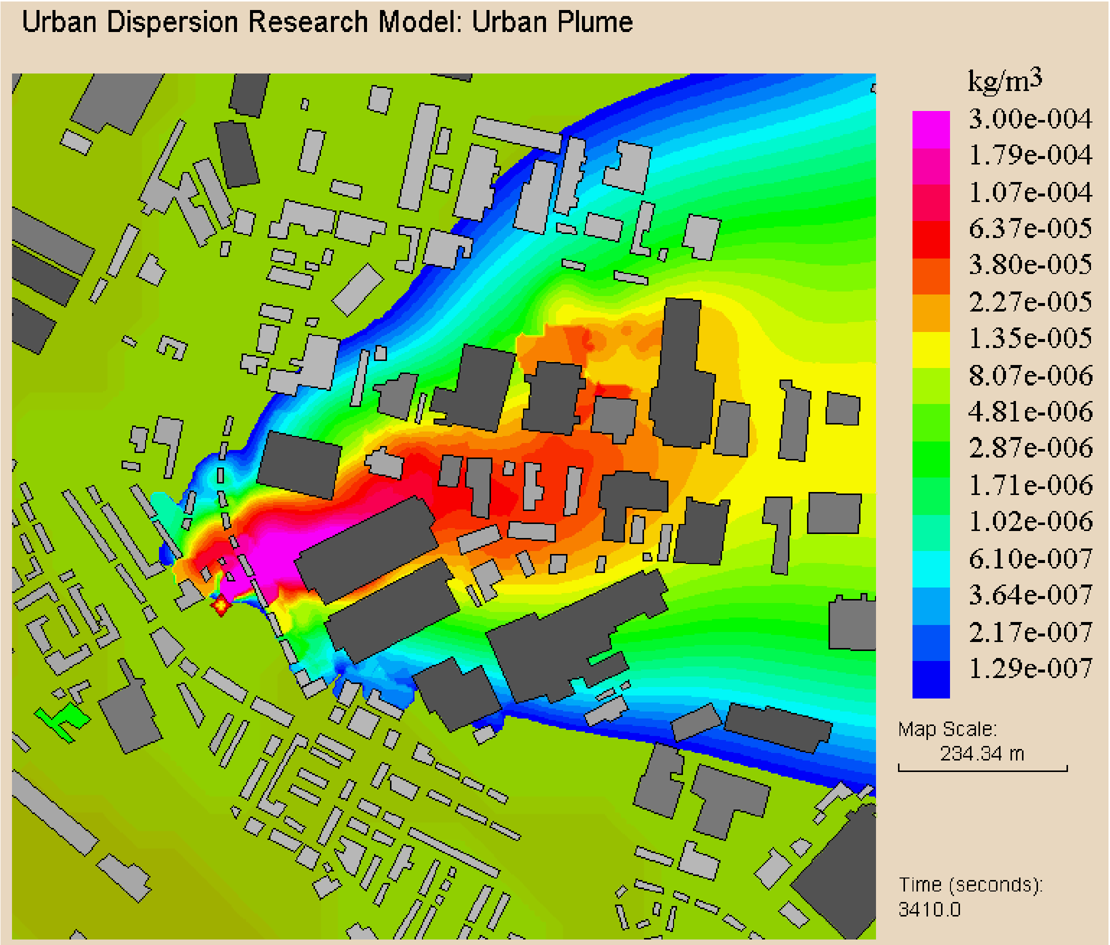

Figure 4 Screenshot of sample UDM output.

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