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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: PS2005
2. Project title: The development and validation of a Bystander and Resident Exposure Assessment Model (BREAM)
3. Contractor organisation(s):
   The Arable Group
   Morley Business Centre
   Deopham Road
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4. Total Defra project costs (agreed fixed price): £ 758,176
5. Project: start date .... 19 June 2006
   end date .... 31 January 2010

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Please confirm your agreement to do so.. **YES** ☒ **NO** ☐

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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

The aim of this project was to predict the potential exposure of people to pesticide, both as droplets and vapours, from an application site treated with a boom sprayer operating in the range of conditions likely to be encountered in the UK.

Exposure to spray drift

A new model has been developed specifically to predict human exposure to spray drift for scenarios considered relevant to risk assessment. A standard 'reference' nozzle (FF110/1.2/3.0) is included in the model, representing a typical application scenario and a good estimate of realistic levels of spray drift. Additional nozzles can be included in future developments of the model.

The effect of crop and field margin vegetation is not adequately represented in the model, potentially underestimating the filtering effect. Further experimental data and modelling effort will be needed to improve this. Crop height has been excluded as a parameter for predicting ground deposits for the first version of the BREAM model – only short vegetation (up to 0.1 m) can be considered

An emulator has been used to reproduce the behaviour of the spray drift model, but running significantly faster, so that it can be run many times for a distribution of inputs to give a distribution of exposures.The use of the emulator was not as successful as expected, possibly because of the large number of variables and because of complex model behaviour. Additional model runs will be necessary to improve the accuracy of the emulator

The Silsoe Spray Drift Model, on which the BREAM model is based, has been well validated for the reference nozzle, and there has been some validation of two other nozzles

The BREAM model has been validated with the standard flat fan nozzle for a range of conditions around a worst case. There is a tendency to under-predict with a tall crop which should be improved with better modelling of the relationship between airborne spray and bystander contamination and improvements in the emulation.

Exposure to vapour

A methodology for determining vapour concentrations has been developed using commercial plume dispersion software, ADMS. This uses real UK met data and although a wider range of sites and years would improve confidence in the predicted concentrations being protective, expert judgement suggests that the results obtained were likely to be appropriate for use in risk assessment.

A reliable model of vapour emissions was not found to be available for use in the BREAM project and therefore this remains the greatest source of uncertainty in the project. Further work is essential to develop this model.

Project findings

The work undertaken has demonstrated that the potential exposure of people at the time of a pesticide application could be significantly higher than that currently used in the regulatory risk assessment due to changes in application practice and to reducing the distance between bystander and sprayer used in the risk assessment scenario. The scenario that is used in the risk assessment is crucial to determining a more realistic level of exposure, and the BREAM model allows exposure for a range of scenarios, including distance, boom height and wind speed, to be predicted. For the higher-drift example given in this report, the one-off exposure, represented by the 95th percentile of the exposure distribution, was shown to be 29 times the current exposure assessment for an adult.

While the model predicts exposures from a single application event, the ability of the model to predict a distribution of exposures allows the model output to be used to represent longer-term exposures from multiple events by using, for example, 50th or 75th percentiles.

Without an improved model of vapour emissions, our ability to predict exposure to vapour for rural residents surrounded by fields is severely limited. However, this work has demonstrated that the current exposure assessment, based on a single concentration, is likely to be protective in many cases, since

- No measurements of vapour concentrations were made that exceeded this value, even in conditions that would be expected to give worst-case concentrations
- The highest possible concentration is proportional to the applied dose, and therefore the current trend for reducing applied doses will be helping to bring down the worst-case exposure

There is, however, a need to establish a robust model of emission rates of active ingredients under field conditions.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the scientific objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

Scientific Objectives

The primary objective of the work was to predict the potential exposure of people to pesticide, both as droplets and vapours, from an application site treated with a boom sprayer operating in the range of conditions likely to be encountered in the UK.

Specific objectives relate to:

1. Establishing a framework for the development of a predictive model of spray droplet and vapour transport from boom sprayers. This involved:
   1.1. A review of previous modelling approaches;
   1.2. An examination of the possible methods of modelling spray behaviour:

1.2.1. in the region around each nozzle;
1.2.2. in the immediate vicinity of the spray vehicle and boom assembly;
1.2.3. in an area downwind of an application site so as to account for meteorological and topographical features such as slopes and major obstacles to natural air flows and the wind;

1.3. The collation of the available experimental data that could be used to aid the formulation of components of a spray droplet and vapour transport model relevant to the operation of boom sprayers and/or that would be relevant to the validation of all or parts of the model output;
1.4. A definition of the laboratory/wind tunnel and field experiments required to support the development of sections of a transport model that will need to be formulated;
1.5. A definition of the approaches to be used for the modelling study of each of the zones defined in 1.2 above having evaluated all of the available options;
1.6. Collection of data relating to resident and bystander behaviour to include in exposure estimates within the model;
1.7. Convening a workshop in conjunction with representations of The Pesticides Safety Directorate to discuss and agree modelling approaches with technical experts from within the European Community particularly including those from research organisations, regulatory bodies and representative of chemical companies where appropriate.

2. Preliminary analysis of resident and bystander exposure risks
   2.1. Collation of preliminary model outputs.
   2.2. Collation of previous field trial data.
   2.3. Comparison of preliminary results with existing approaches used by The Pesticides Safety Directorate
3. Construction of a spray droplet and vapour transport model for:
   3.1. Downwind transport of droplet and vapour movement at the time of application;
   3.2. Downwind transport model for vapour losses for periods of up to 120 hours immediately post the application;
   3.3. Integrating predicted spatial and temporal dispersion distributions with data relating to resident and bystander behaviour.
4. Conducting experiments to generate data required for model formulation, involving:
   4.1. Laboratory/wind tunnel studies of spray behaviour close to the nozzle;
   4.2. Field studies to obtain information about spray movement on a larger scale around the application vehicle and into downwind areas.
5. Validation of the model using:
   5.1. Laboratory/wind tunnel experiments to validate key components of the model: this will involve at least one experiment to give data that can be used to validate each new section of the complete model.
   5.2. Field trials to validate model predictions at larger scales: at least three full-scale trials will be conducted the results from which can be compared with model predictions as part of the validation of the full model capabilities.
6. Use of the model to explore options for the improved management of drift and methods of minimising resident and bystander exposure by adjusting:
   6.1. Operational factors and the interaction with application timeliness;
   6.2. System variables relating to nozzle design and machine technologies (e.g. air assistance);
   6.3. Distances between the edge of treated areas and organisms/systems requiring protection from exposure.

1. Model of exposure to spray drift

1.1 Scenarios

Any modelling approach depends crucially on the scenarios that need to be modelled and therefore at an early stage in the project, these scenarios were discussed with CRD and were presented to the ACP for their input and comment. The agreed scenarios are given in Appendix 1. They can be summarised as

- Low drift, (air induction nozzle, low boom and low forward speed)
- Standard drift (low boom, reference flat fan nozzle and moderate forward speed)
- High drift (high boom, extended range nozzle and high forward speed)

Crop height, field margin vegetation and wind speed were also considered in the scenarios. Bystanders were considered to be stationary, upright and between 2 and 10 metres downwind of the sprayer.

1.2 Review of modelling approaches

There have been many attempts to model spray drift over the last 30 years and a number of different approaches have been taken, with models being developed that are appropriate for different purposes. A fuller review of modelling approaches that have been taken for spray drift is contained in a draft paper (Appendix 2) which will has been submitted to Biosystems Engineering

Plume dispersion models

These models are based on a Gaussian distribution of concentrations in the atmospheric boundary layer that is transported downwind by the prevailing air flow. These models have been developed over many years and are now commercially available in a variety of forms. In the UK for example, ADMS is routinely used in air quality modelling for a range of pollutants. The main advantage of this type of modelling is the computational efficiency, particularly over long distances. Their main deficiency is the difficulty of including specific details of the source term, such as nozzles or sprayer configuration.

Computational Fluid Dynamics models

In computational fluid dynamics (CFD), the spatial domain is divided into cells to form a volume mesh, and then a suitable algorithm is applied to solve flow equations. The advantage with CFD modelling is that relatively complex systems, such as spray nozzles, can be included. However, the consequence is that the computational effort required in setting up the model can be high, and the computing power and time needed to run a simulation of a complete sprayer over a reasonable distance will be significant. The practical limitations in using such models, which require some expertise, have not been amenable to their use by the regulatory authorities.

Droplet tracking models

An alternative approach is to solve equations of motion in an airstream for individual droplets. An early such model for spray drift was proposed by Thompson and Ley (1983) based on a random walk in the atmospheric boundary layer, which was then built on by Miller and Hadfield (1989) specifically for boom sprayers by adding a ballistic component near the nozzle. The advantage with such approaches is that the complex structure of flows near the nozzle can be taken into account, although this may be difficult to quantify without extensive measurements

Multiple regression models

There have also been some attempts to model spray drift based on empirical data. The disadvantage of this approach is the quantity of data needed because of the large number of variables known to influence drift

These varied models of spray drift have been produced for a wide range of purposes. The most challenging objective is to provide an estimate of absolute spray drift, either airborne or deposited on the ground, for regulatory risk assessment. Droplet tracking models have been used for this purpose in the US and the Netherlands, as well as multiple regression models in the US.

1.3 Modelling approach in BREAM

In developing a new drift model for estimating exposure for regulatory purposes, the advantages and disadvantages of each approach was considered. The distance over which we are concerned (< 20 m from the sprayed area) is a crucial factor – plume dispersion models are inappropriate for such small scales. A multiple regression model was not considered appropriate because of the limited data available relating to airborne spray. CFD models were also ruled out as a practical option for a non-specialist user. A particle tracking model was therefore seen as the best approach, because of its flexibility and its relatively high computation speed over short distances, as well as its previous success in producing sufficiently accurate predictions of absolute drift for regulatory purposes. The model originally developed by Miller and Hadfield (1989) was the basis for the new model.

The three-scale approach that was originally proposed (close to the nozzle, vehicle and landscape scales) was modified following the agreement of the main scenarios to be addressed and initial investigations using the different available models. A single model was proposed for spray drift that could include nozzle and, if necessary, vehicle scale effects. Separate CFD modelling investigations were undertaken by AEA Technology using Fire Dynamic Simulator (FDS) software (http://fire.nist.gov/fds/) to explore some vehicle and landscape effects.

1.4 Model development

A full description of the development of the model is to be published (Appendix 2). Modifications to the Miller and Hadfield model include:

- Multiple nozzles on a boom, with interactions between nozzles
- Forward speed
- Improvements to the air flows around the nozzle
- More sophisticated input data relating to droplet size and velocities.

1.5 Vehicle scale investigations

There were concerns that the wake created by a moving vehicle could potentially increase spray drift and have consequences for human exposure and therefore two small studies, one using CFD modelling and one making measurements in the field (section 2.1), were conducted

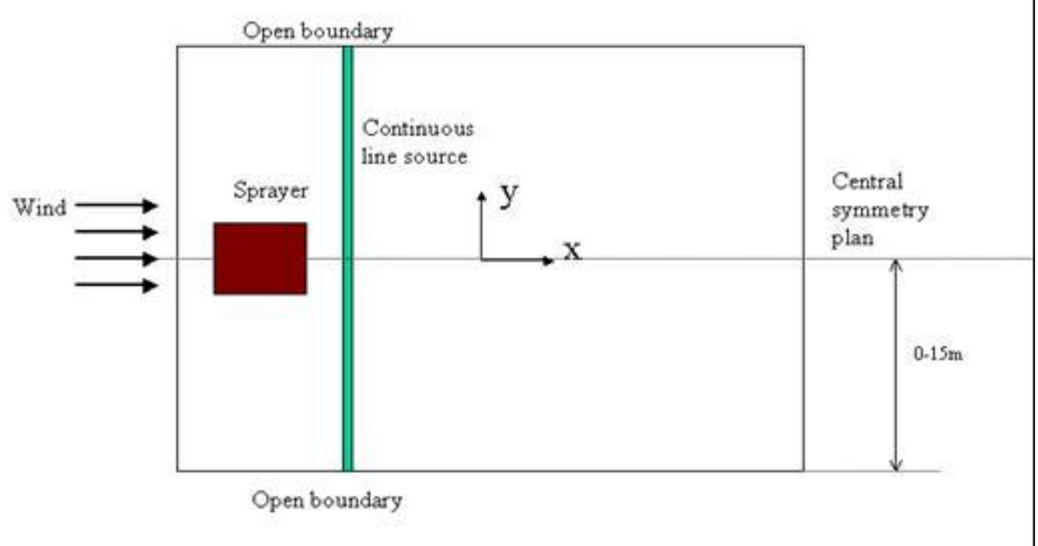
Figure 1a shows the set-up of the CFD computational domain. The sprayer is 2.5m wide, 3.0 m long and 2.5 m high and 2.0 m ahead of the continuous line source representing the boom. Three velocity components over vertical sections crossing the boom between 0.1-0.6 m above the ground were output for analysis:
U: the horizontal component in the wind direction (positive in the wind direction)
V: the horizontal component crossing the wind direction (positive in the y direction as shown in Figure 1)
W: The vertical component (positive for upward velocity).

The nozzles were represented by an idealised continuous line source, so the interactions between nozzles and wind were not represented directly in the simulation.

The results of the simulation can be summarised as:

- The region of the boom affected by the sprayer wake increases with air speed
- The U component of velocity is reduced by the sprayer, and is negative at some locations. This would result in a reduction in droplet detrainment in the spray, but might result in droplets being deposited on the back of the sprayer
- The V component of velocity is increased by the sprayer by a small amount – to around 0.6 m/s at some locations for a 4 m/s air speed and 0.3m/s in the same region for a 2m/s air speed. When no sprayer is present, the V components are generally negligibly small on all sections.
- The presence of the sprayer caused the vertical W component to change direction on the sections behind the sprayer. When there is no sprayer, the sections below the boom all have a small vertical velocity towards the ground due downward droplet motion. The W component is general positive behind the sprayer with a peak of 0.2m/s when the sprayer is included in the simulation. This upwards component could lead to increased dispersion, which was supported by the predictions of airborne concentrations downwind of the sprayer.

Figure 1a Plan view of the computational domain



These results suggested that spray drift was unlikely to be increased by the presence of the sprayer, and that the drifting spray was potentially dispersed higher into the air by the airflows generated by the sprayer, and reducing airborne concentrations and potential human exposure

1.6 Landscape effects -Downwind structures – investigation of the 'gap' effect

FDS software was also used to examine the potential for gaps between building-scale structures at the field margin to enhance the droplet deposition on a bystander/resident standing in the gap. An 'enhancement factor' (EF) was defined as the ratio of the droplet flux through an area representing an adult or child standing in the gap to the flux through the same area in the absence of the buildings. The dependence of EF on wind speed, building height and gap width was investigated. Fig 2 shows a plan view of the configuration of buildings, source and receptor, with the wind blowing left to right perpendicular to the source.

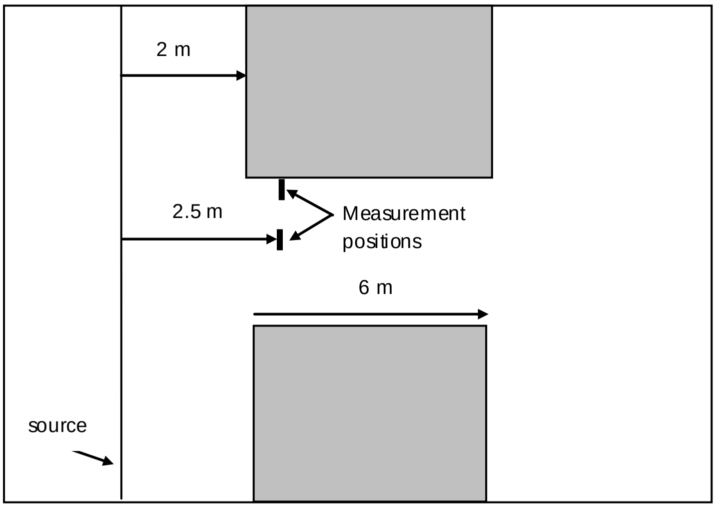


Figure 2. Relative position of source, buildings and receptors

Droplets of 60 μm diameter (non-evaporating) were released at a height of 0.7 m at constant rate from a line source perpendicular to the wind, with a speed equal to the wind speed at source height (in the absence of structures). The source was 2 m from the front face of the two cuboid buildings, which were 6.0 m deep in the direction of the wind. Outputs were defined in terms of the mass of droplets passing through a vertical rectangular area perpendicular to the wind, of width 0.5 m and of height either 1.0 m or 2.0 m representing a child or adult respectively. The receptor area sat within the gap between the buildings at 0.5 m back from the building face, either at the centre of the gap or immediately adjacent to the wall.

The parameter ranges spanned by the investigation were:
- wind speed at 2 m height (1 - 5 m/s),
- building height (1 - 10 m) and
- gap width (1 - 6 m).

The boundary layer developed in the simulation was allowed to approach a near-logarithmic wind speed profile upwind of the test domain where the source and buildings were located. In view of the long run times for the FDS simulations, an emulator was built by CSL to enable the multi-dimensional parameter space to be investigated using only 24 runs.

Key features of the results were:
- with only one exception, the EF values are greater than unity for both centre-line receptor areas, ranging up to about 3;
- for a given set of inputs, the ‘adult’ values of EF are greater than the ‘child’ values;
- for a given set of inputs, the centre-line EF value is greater than the corresponding edge value.

The presence of buildings and gap introduces a number of mechanisms, which are clearly seen in visualisations of the FDS simulations, including:
- ‘channelling’ of droplets into the gap, ie the diversion of streamlines such that droplets that would have missed a receptor area in the absence of buildings now pass through it;
- increased vertical dispersion as streamlines lose speed and diverge vertically in the approach to the flow barrier created by the buildings; this explains why the ‘child’ EFs are generally smaller than the ‘adult’ EFs;
- introduction of rotational flow components near the ground upwind of the buildings, thereby bringing some droplets closer to the ground (and thus more readily deposited) than in the absence of buildings;
- impingement droplets onto building surfaces, where they are assumed to be retained.

Use of the emulator showed that EF generally decreases with increasing gap width, increases with increasing wind speed but has a more complex dependence on building height. The dependence on building height resulted from competition between the vertical divergence of streamlines (and slow down) as the flow approaches the barrier created by tall buildings and the lateral channelling of some part of the overall flow through the gap.

In conclusion, droplet fluxes through an area representing a bystander/resident may be enhanced in a gap between buildings by up to a factor of around 3 for the range of parameters investigated. The enhancement factor increases with increasing wind speed, decreases with increasing gap width and tends to reach its greatest value for intermediate building heights.

2. Field measurements and validation – spray drift

2.1 Vehicle scale measurements

Measurements of the air flow around a spraying vehicle were made to assess the potential implications for spray drift and its prediction. The purpose of the study was to support the previous computer modelling study (section 1.5) and aimed to determine:
whether the presence of the vehicle or boom would result in high localised air velocities in the region of spray formation and hence increase the detrainment of small droplets;
the extent to which the air flow field behind the sprayer would be modified by the moving vehicle and the implications for airborne droplet transport.

Air flow measurements were made behind the vehicle and the boom on a Househam 3000 litre self-propelled sprayer with a 24 m boom set at 0.65 m above the ground. The machine was driven against and with the prevailing wind with the anemometers recording air velocities in three dimensions. Measurements of the wind conditions at the time of each experimental run were also made using an anemometer mounted statically adjacent to the track to be followed by the sprayer. In addition to air velocity measurements made at the rear of the vehicle, a series of measurements were also made with the sprayer driving over a stationary anemometer mounted on the ground such that the vehicle passed directly over the anemometer.

A total of 34 measurement runs were completed in mean wind speeds of between 2.68 and 5.53 m/s. Ultrasonic anemometers were so that measurements were made in two positions at the same height for each run, summarised in Table 1.

Table 1 - Positions of air velocity measurements

Height above ground level, mm	Position	
	Immediately behind the sprayer	On an outer boom section
400	Below the boom	Below the boom
800	Behind the boom structure	Behind the boom structure
1200	Above the boom	Above the boom
1600	Behind the upper part of the sprayer	-

The sprayer travelled at speeds of 8.0 and 16.0 km/h over bare ground conditions with no significant vegetation and without the nozzles operating so that airborne spray did not interfere with the anemometers.

Summary of results

Air velocities in the region immediately behind the sprayer and behind and above the boom structure were low (<2.0 m/s). When travelling into the wind and with no effect from the spraying vehicle or boom structure, air velocities would be expected to be approximately the sum of the mean wind and forward speeds The results obtained indicate that the spraying vehicle is tending to act as a bluff body, as expected, with a region of low pressure immediately behind the vehicle.

There was no evidence of substantial vertical air movement in the region behind the sprayer suggesting that any re-circulation was not attached to the vehicle. In the region below the boom, there was a substantial air velocity component in the direction of travel although velocities were only in the order of 50% of the sum of the forward speed and wind speed. This result indicated that there is some air flow beneath the spraying vehicle and that had the nozzles been operating then this flow would have interacted with the forming spray. Transverse velocities, across the sprayer, were small in both cases as expected since measurements were made along the centreline of the machine.

Air velocities recorded with a static anemometer mounted 250 mm above the ground (Figure 3) showed an increase in air velocities both in the direction of travel and vertically due to air movements in front of the vehicle. When the sprayer passed over the anemometers, air velocities in the direction of travel fell below the main wind speed for a period of approximately 5.0 – 8.0 seconds indicating that the vehicle wake structure had dimensions in the order of 20.0 m. Air velocities within the wake are likely to have been similar to the mean wind speed – up to 4.0 m/s in this case.

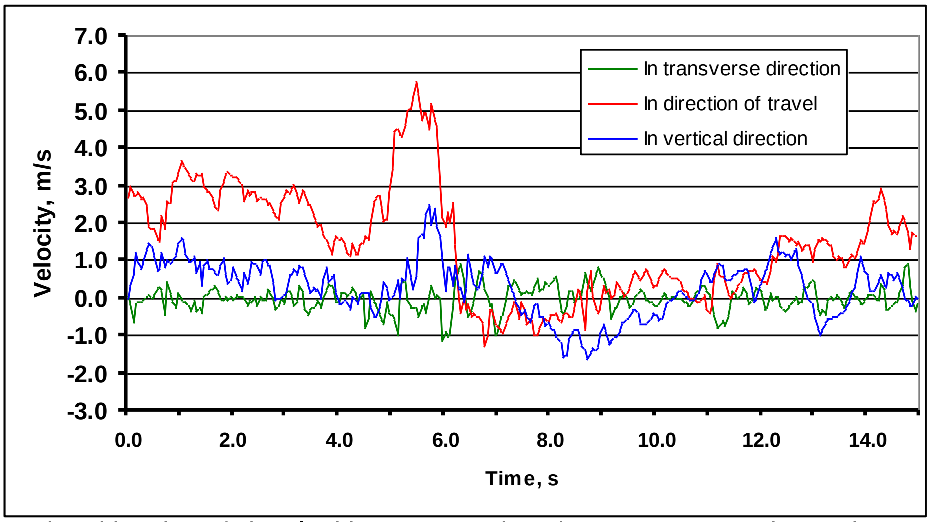


Figure 3. Time histories of air velocities measured as the sprayer passed over the anemometer

Air velocities around the boom at an outer section indicated that the boom structure had a substantial effect on the air flows around it. Air velocities in the direction of travel and immediately behind the boom were approximately 50% of those below the boom indicating that the boom, although visually very open and porous, had a substantial effect on the air flow in this region. This is likely to have implications for the movement of any airborne spray detrained from the main spray structure. In the region below the boom, measured velocities were close to the sum of the forward and natural wind velocities indicating that the boom structure was not resulting in a substantial increase in air movements in the region of spray formation.

Results from wind tunnel work have shown that the presence of the spray also acts to block the air flow in the direction of travel. It is therefore likely that air flows around a spraying vehicle will have an effect on the movement of airborne spray in the wake of the sprayer and is also likely to give differences in deposit distribution close to the sprayer. However, the results of this work and of the earlier CFD study support the conclusion that the presence of the sprayer is likely to reduce airborne concentrations of spray droplets and that excluding the effects of a sprayer in the BREAM model will potentially lead to an overestimate of bystander exposure by an amount that will reduce as the boom becomes wider (and the proportion that is affected becomes smaller).

2.2 Field measurements of drift and bystander contamination

Three experiments were conducted, one in November - December 2007, the second in March 09 and the final experiment in June 2009. The first two experiments were conducted over short grass at Wrest Park. The third experiment was conducted over a mature winter wheat canopy on a commercial farm in Bedfordshire.

In these experiments, data was obtained relating to bystander contamination, airborne spray, ground deposits and meteorological conditions.

Experimental Methods.

Similar protocols were employed for all three experiments. A 24 metre sprayer sprayed along a track at right angles to the predominant wind direction. Plots were laid out downwind of the sprayed area in which drift collectors, including bystanders, were placed at distances from the edge of the sprayed area. Either two or four passes were made along the same track by the sprayer to ensure that measurable quantities of spray liquid were deposited on the collectors. During the application, measurements were made of wind speed and direction at a height of 2.0 m above the ground.

Following the spray application, the collectors and bystander suits were allowed to dry and then placed in individual bags, sealed and stored in cool dark conditions. The tracer dye was recovered from each suit by washing in distilled water or other appropriate solvent. The concentration of dye in the solvent was compared, using spectrophotometry, with a sample of the spray tank to determine the quantity of original spray liquid. Fuller details have been published in Glass et al, 2010 and in a paper submitted for publication in Biosystems Engineering (Appendix 3)

November - December 2007

Adult and child mannequins were placed at 2 and 4 m downwind, and adult mannequins at 8 and 12 m downwind. Airborne and ground deposited drift were also collected at the same distances. The spray liquid was 0.1% v/v non-ionic surfactant plus a tracer dye (Brilliant Blue) at approximately 0.4% w/v. Adult and child mannequins were dressed in Tyvek coveralls (Large size for adult mannequins, and cut down sections of coveralls for child mannequins). Table 2 shows the individual runs undertaken.

Table 2. Treatments for Nov 07 spray drift experiment: all nozzles at 3.0 bar; boom height above short (<0.1 m) grass

Run no CSL Ref	Nozzle type	Boom Height (m)	Fwd speed (km/h)	Nominal application rate (l/ha)
07_01	Hypro F110	1.1	12	120
07_02	Hypro F110	1.1	16	90
07_03	Hypro F110	0.7	16	90
07_10	Hypro F110	0.7	16	90
07_11	Hypro F110	1.1	16	90
07_15	XR TeeJet 110-03 VS	1.1	12	120
07_16	XR TeeJet 110-03 VS	1.1	16	90
07_17	XR TeeJet 110-03 VS	0.7	16	90

March 2009

A 24 metre sprayer was used to spray a solution of 0.2% Green S and 0.1% Tween 20 surfactant. The nozzle/forward speed/ boom height treatments that were used are shown in Table 3. Measurements were made of ground deposit, airborne spray, bystander contamination on two adult volunteers and two child mannequins wearing paper overalls at 2.0 and 5.0 m downwind and wind velocity in three dimensions at 2.0 m above the ground using a sonic anemometer immediately upwind of the sprayer.

Table 3 - Treatments for March 09 spray drift experiment: all nozzles at 3.0 bar; boom height above short (<0.1 m) grass

Nozzle	Boom height, m	Forward speed, km/h	Number of repeat runs	Run numbers
FF 110 03	0.7	12	2	7,8
FF 110 03	0.7	16	2	9,10
XR 110 03	1.1	16	3	1,2,13
XR 110 03	0.7	12	2	11,12
BBJ 025	1.1	16	2	5,6
BBJ 025	0.7	12	2	3,4

June 2009

The 24 metre sprayer was used to spray a 20 m swath of a 0.65 m tall winter wheat crop. The end sections of the boom were turned off since the commercial crop was grown on a 20 m tramline spacing. Similar measurements were made to the March 2009 experiment, except there were no child mannequins included. The volunteer bystanders were situated on a track running along side the field, similar to many public footpaths across the UK. The bystander at 2.0 m was in the centre of the footpath, whereas the 5.0 m bystander was in the boundary vegetation, in a position where walkers would be unlikely to be found. Treatments are shown in Table 4.

Table 4. Treatments, nozzles at 3 bar, forward speed 12 km/h for all runs

Run no.	Nozzle	Boom height, m, above crop
1	FF 110 03	0.5
2	FF 110 03	0.5
3	FF 110 03	1.0
4	FF 110 03	1.0
5	XR 110 03	0.5
6	XR 110 03	0.5
7	XR 110 03	1.0
8	XR 110 03	1.0
9	XR 110 03	1.0
10	XR 110 03	0.5

Results

Results of airborne and ground spray are not given explicitly here, but are used in the validation of the Silsoe Spray Drift Model, shown in section 4.1. Bystander contamination values given in the tables 5-11 are ml spray liquid per bystander per pass of the sprayer. They are grouped according to nozzle type and distance from the sprayed area.

November - December 2007

Table 5. Spray deposit on Bystander mannequins, ml, with nozzle Hypro 03- F110 at 3.0 bar

Run no.	R1	R2	R3	R10	R11
Wind speed at 2m, m/s	3.4	3.6	2.3	2.7	3.1
2m adult	0.37	0.44	0.24	0.31	0.52
2m child	0.35	0.32	0.18	0.22	0.58
4m adult	0.23	0.32	0.14	0.34	0.21
4m child	0.07	0.16	0.10	0.15	0.29
8m adult	0.08	0.14	0.04	0.14	0.18
12m adult	0.07	0.11	0.04	0.07	0.12

Table 6. Spray deposit on Bystander Mannequins, ml, with nozzle XR TeeJet 110-03 VS at 3.0 bar

Run no.	R15	R16	R17
Wind speed at 2m, m/s	4.1	4.3	4.6
2m adult	1.02	0.87	0.44
2m child	1.59	0.72	0.26
4m adult	0.67	0.68	0.28
4m child	0.64	0.74	0.15
8m adult	0.35	0.43	0.15
12m adult	0.19	0.35	0.16

March 2009

Table 7. Spray deposit on Bystanders, ml, with XR TeeJet 110-03 VS nozzle at 3.0 bar

	wind speed,	child		adult	
	m/s	2m	5 m	2m	5 m
run 1	6.68	1.72	0.64	1.60	2.20
run 2	8.09	1.58	0.89	3.21	2.05
run 11	2.12	0.06	0.01	0.14	0.05
run 12	3.72	0.12	0.04	0.18	0.07
run 13	4.22	0.57	0.12	1.30	0.16

Table 8. Spray deposit on Bystanders, ml, with Hypro F110 - 03 nozzle at 3.0 bar

	wind speed,	child		adult	
	m/s	2m	5 m	2m	5 m
run 7	4.95	0.25	0.14	0.41	0.24
run 8	5.86	0.26	0.11	0.58	0.29
run 9	4.16	0.17	0.06	0.25	0.12
run 10	3.55	0.25	0.10	0.46	0.20

Table 9. Spray deposit on Bystanders, ml, with Billericay bubblejet 025 at 3.0 bar

	wind speed,	child		adult	
	m/s	2m	5 m	2m	5 m
run 3	8.18	0.29	0.18	0.41	0.38
run 4	7.14	0.19	0.13	0.41	0.27
run 5	6.04	0.24	0.09	0.56	0.19
run 6	5.43	0.24	0.05	0.39	0.15

June 2009

Table 10. Spray deposit on Bystanders, ml, with Hypro F110 - 03 nozzle at 3.0 bar

Run number	Windspeed at 2.0 m, m/s	2m	5m
R1	5.48	0.30	0.32

R2	6.05	0.37	0.49
R3	4.45	0.76	0.55
R4	4.34	0.89	0.48

Table 11. Spray deposit on Bystanders, ml, with XR TeeJet 110-03 VS nozzle at 3.0 bar

Run number	Windspeed at 2.0 m, m/s	2m	5m
R5	5.87	0.46	0.27
R6	5.01	0.45	0.26
R7	4.63	0.95	0.42
R8	6.09	1.09	0.48
R9	5.02	1.93	0.83
R10	5.42	0.27	0.22

All the bystander and airborne spray data was collated (Fig. 4). The first three data sets were used to define the relationship between bystander exposure and airborne spray The June 09 data could then be used as a true validation of the model.

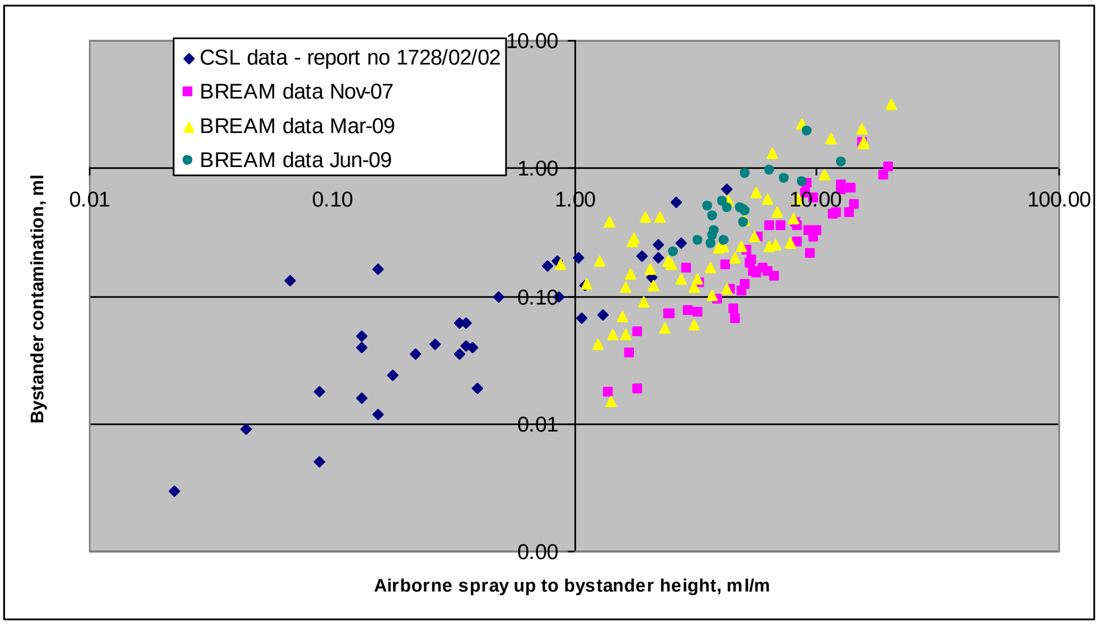


Figure 4. Relationship between mean airborne spray (ml/m2) x bystander height (m) and bystander contamination (ml)

3. Development of BREAM model

The Silsoe Spray Drift Model was combined with the empirical data relating spray drift to bystander contamination to produce a model specifically aimed at predicting human exposure to spray drift. A more detailed description of this work is currently being prepared for publication (Appendix 4)

3.1 Emulator and user interface

An emulator here refers to a statistical approximation to one of the Silsoe drift model outputs, built using a set of model training inputs using the GEM-SA software implementation of Kennedy (2005). The training inputs were designed to give an even coverage over the range of the 8 inputs of interest (inputs 2-9 in Table 1), with ranges chosen to represent feasible values. A total of 200 runs were used in the training samples, to cover the 8-dimensional input space. The 5 emulated outputs from the Silsoe spray drift model are ground deposit (G), adult inhalation factor (IFa), child inhalation factor (IFc), adult airborne spray (ASa), and child airborne spray (ASc). Separate emulators were developed for a short crop and for a variable height crop, since initial work showed that ground from the Silsoe drift model with a crop height above 0.1 m were not well represented by the emulator, due to a potential discontinuity. Initial plans involved developing emulators for three nozzle designs, but due to difficulties in ensuring that the emulators represented the drift model, it was only possible to include one nozzle, a conventional flat fan nozzle (FF/110/1.2/3.0 operated at 3.0 bar, Hypro Ltd). Therefore in total 10 emulators were created. which are embedded within the overall exposure modelling framework, which has 6 steps:

Step 1. The user selects appropriate values for inputs (1-8 and 10-12 in Table 12) For inputs 2 and 3 (wind speed and boom height), the selected value represents the mean.
Step 2. A Monte Carlo algorithm is used, first by simulating a large sample of values for inputs 2, 3, and 9, then computing the corresponding set of emulator outputs (with other inputs fixed at the values chosen in Step 1). For each of the 5 outputs (G, IFa, IFc, ASa, ASc), the sample of emulator runs is a sample from the probability distribution of that output. Summaries of these can be presented separately in Step 5, or used in subsequent probabilistic modelling in steps 3-4.
Step 3. A statistical model is used to relate measurements of airborne spray and bystander contamination. The model is fit using the data in Fig. 4, and includes a measure of variability in contamination for any given spray level (i.e. the spread about the mean line fitted to the data). As we have a large sample of ASa and ASc points from Step 2, the result is also a samples from the distributions of BCa and BCc.
Step 4. Calculate: Inhalation for adult and child (Ia = IFa . Ba, Ic = IFc . Bc); Dermal exposure for adult and child (Da = BCa . Abs, Dc = BCc . Abs).
Step 5. (Presentation of outputs). From the generated samples, the mean and 95th percentiles of distributions for G, Ia, Ic, Da, Dc, are calculated and reported.

Table 12 - Inputs to the user interface and/or emulators.

Input no.	***Inputs***	***Range for emulator***	***Comments related to user interface/model framework***
1	Nozzle type	FF 110 03 nozzle at 3.0 bar	Separate emulators needed for each nozzle type (XR, AI could be added in future work)
2	Wind speed at 3.0 m	0.5 – 25 km/h	Distribution assumed, user inputs mean
3	Boom height	0.1 – 1.5 m	Distribution assumed, user inputs mean
4	Forward speed (km/h)	4 – 25 km/h	User specifies single-value input
5	Number of nozzles	6 – 992 in units of 6	User specifies single-value input
6	Crop height	0.05 – 2.0 m	User specifies single-value input
7	Vegetation height	0.05 – 2.0 m	User specifies single-value input
8	Distance	1 – 15 m	User specifies single-value input
9	Wind angle	10 – 170 degrees	Distribution cannot be altered by user
10	Bystander type		User selects adult or child
11	Exposure route		User selects inhalation or dermal
12	Breathing rate for Adults (Ba) or Children (Bc) or dermal absorption (Abs)		User specifies single-value input

3.2 Distribution of inputs – boom height and wind speed and angle

Developing reliable estimates of the potential distributions for boom height and wind speed and angle were beyond the scope of this project and therefore an initial estimate of possible distributions were made, based on some limited available data. The methodology used is shown in Appendix 5.

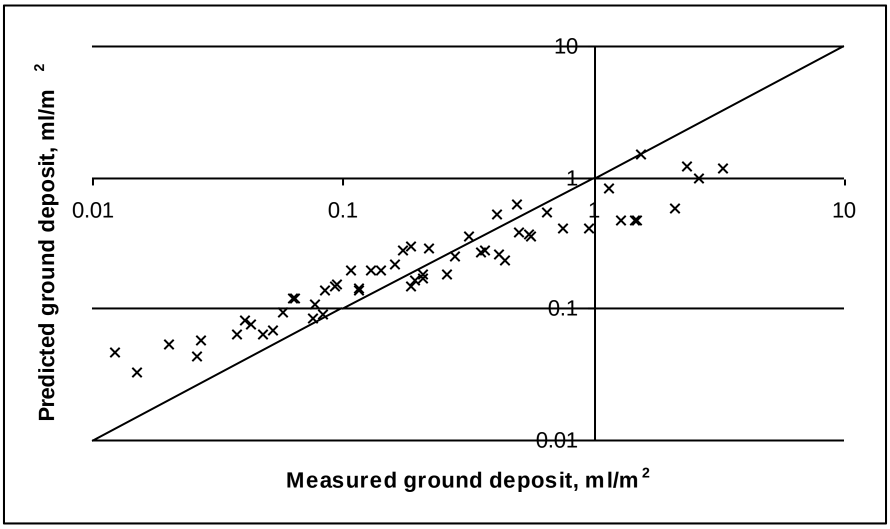
Wind speed, wind angle and boom height are all based on a normal distribution, with the mean defined by the user for wind speed and boom height, and set at 90 degrees for wind angle. The standard deviations are then calculated as follows:

Wind speed: standard deviation = 0.185 x mean windspeed + 0.0068
Wind angle: standard deviation = 10 degrees
Boom height: standard deviation = A x (mean boom height), where the default value of A is 0.3, but can be changed.

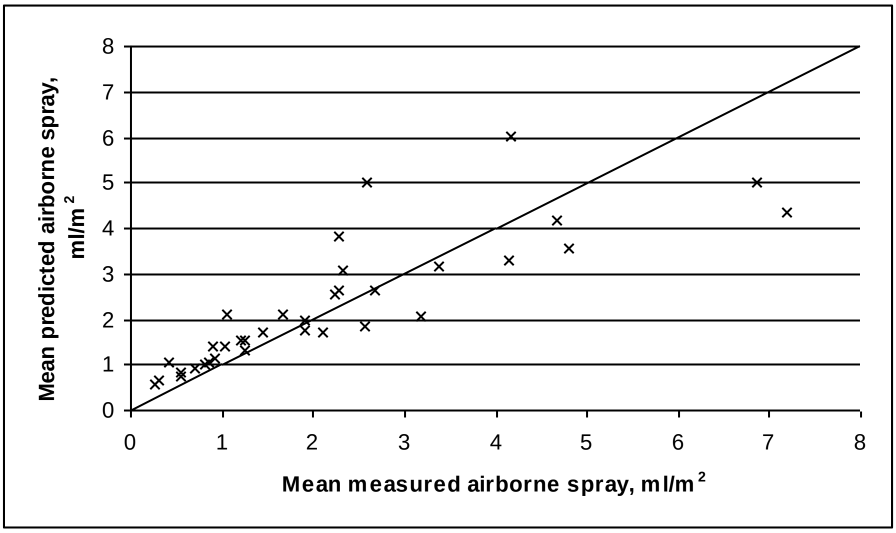
4. Validation

4.1 Validation of Silsoe Spray Drift Model

Results of the comparison between the three field experiments and model predictions are shown for a flat fan nozzle FF110/1.2/3.0 (Hypro EU) in Figs. 5-7.

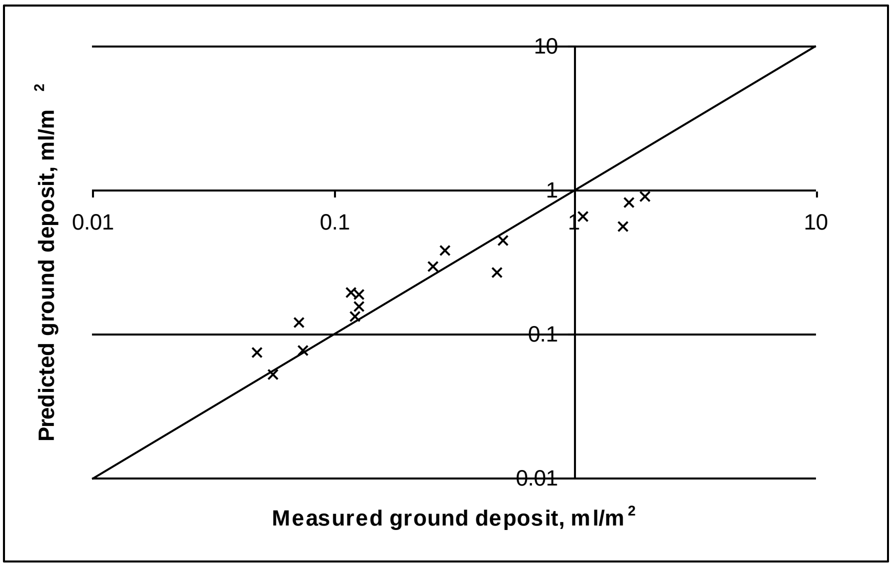


(a)

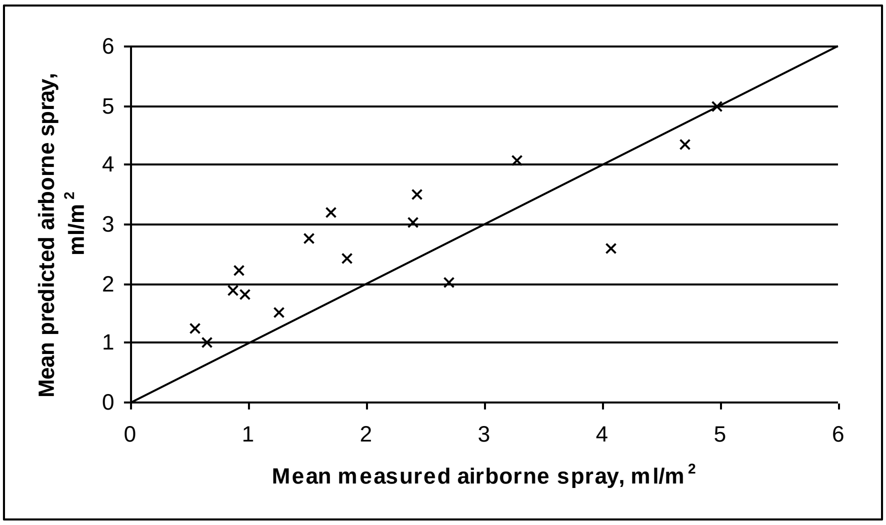


(b)

Figure 5. Comparison between measured and predicted spray drift between 2 and 20 m downwind for (a) ground deposits and (b) mean airborne spray from 0 – 2m above the ground. Flat fan nozzle (F/110/1.2/3.0) at 3.0 bar, 24 m boom, 12 and 16 km/h, boom height 0.7 – 1.1 m,

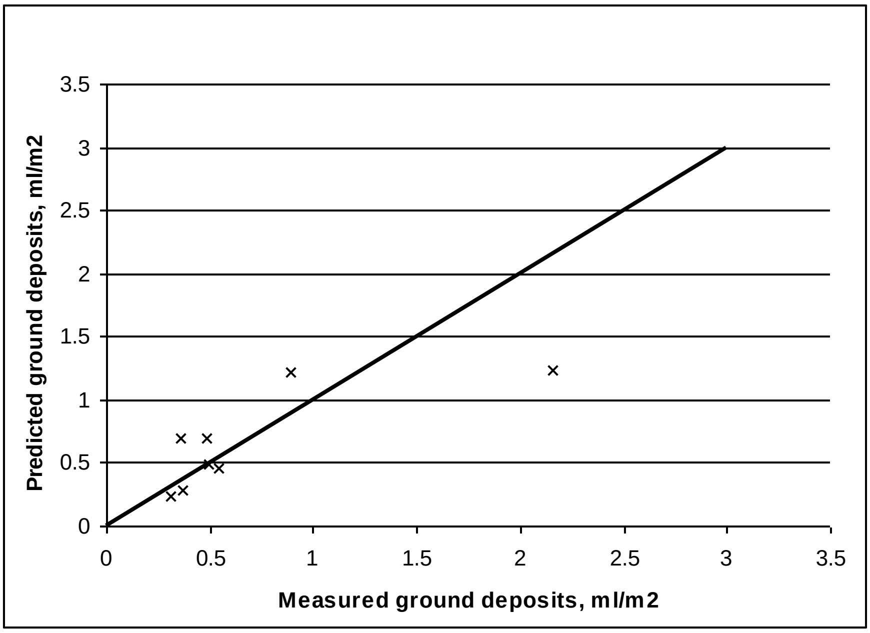


(a)

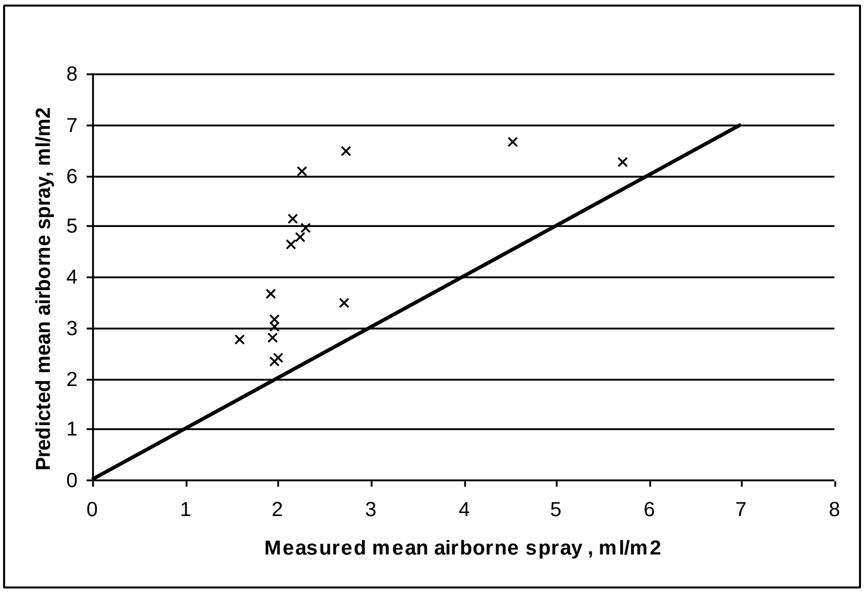


(b)

Figure 6. Comparison between measured and predicted spray drift between 2 and 20 m downwind for (a) ground deposits and (b) mean airborne spray from 0 – 2m above the ground. Flat fan nozzle (F/110/1.2/3.0) at 3.0 bar, 24 m boom, 12 and 16 km/h, boom height 0.7 – 1.1 m



(a)



(b)

Figure 7. Comparison between measured and predicted spray drift between 2 and 20 m downwind for (a) ground deposits and (b) mean airborne spray from 0 – 2.0 m above the ground. Flat fan nozzle (F/110/1.2/3.0) at 3.0 bar, 20 m boom, 12 km/h, boom height 0.7 – 1.1 m

Comparisons with data obtained from the experimental work over a mature winter wheat crop undertaken in June 09 showed that while predictions of ground deposit were reasonable, the predictions of airborne spray were significantly poorer than the previous experiments, which is likely to be due to the inadequacy of the simulation of droplets interacting with a crop canopy. Additional comparisons between previous data (CSL) obtained with a mature crop and model predictions showed similar results for airborne spray, but significantly poorer prediction (underestimated) of ground deposits.

4.2 Validation of BREAM model

Predictions of dermal exposure by the BREAM model were compared with measurements for all available datasets (Fig. 8), including previously obtained data (Glass et al, 2002). At the lowest measured values of dermal exposure, there is a tendency for the model to over-predict, while at the higher values there is a tendency to under-predict. The under-prediction is particularly noticeable for the data relating to a tall crop. Since the underlying model tends to over-predict airborne spray concentration for the tall crop, as shown in Figure 7, this under-prediction of bystander contamination is likely to be as a result of either errors in the emulation or in the mapping to bystander contamination.

Comparing the relationship between airborne spray and bystander contamination for both empirical data and model prediction (Fig. 9) it can be seen that the June 09 data is around the 95th percentile of predicted model exposure, based on predicted airborne spray. The June 09 data was not included in the data used to determine the relationship between the two, and therefore improvements in prediction would be obtained if it were to be added in. Improvements in modelling the relationship are also possible, through use of more sophisticated line-fitting procedures than have been used so far.

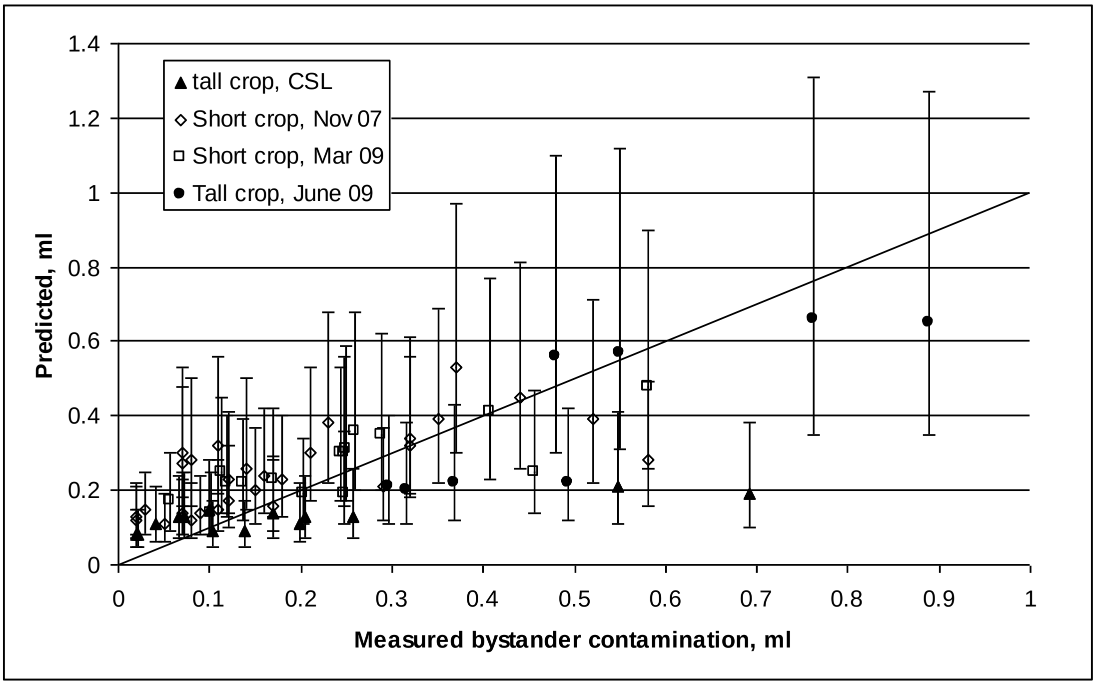


Figure 8. Comparison between measured bystander dermal contamination and that predicted by the BREAM model. Error bars refer to the 25th and 75th percentile predictions.

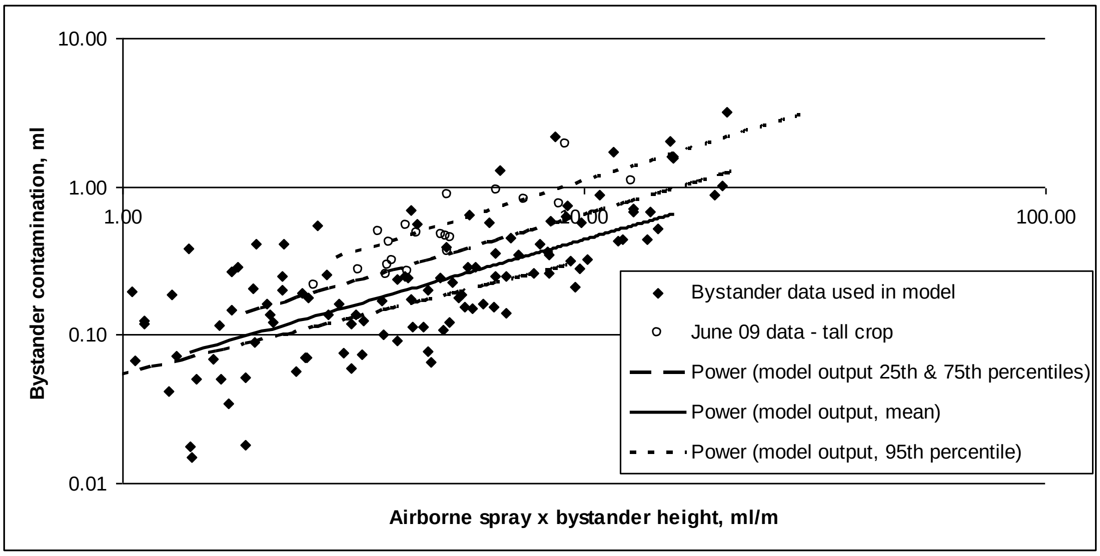


Figure 9. Relationship between airborne spray (ml/m2) x bystander height (m) and bystander contamination (ml) for experimental data and BREAM model output.

No comparisons were possible for inhaled spray because measurements undertaken in earlier work showed that measurements were generally below the level of detection (PS2006, PS2008, Lloyd and Bell, 1986). This was supported by model predictions which also were very low.

5. Examples of predicted exposure from spray drift

5.1 Typical scenario

Short crop/bare ground
FF 110 03 nozzle at 3.0 bar
96 nozzles (i.e. 2 passes of a 24 m boom)
0.7 m boom height
12 km/h forward speed
Applied volume = 120 l/ha
Active applied at 120 g/ha; concentration of active in tank = 1 g/l
Wind speed (at 3.0 m height) 2.5 m/s – top end of ‘ideal’ conditions (Defra, 2006)

Dermal absorption – 10%

Bystander at 2.0 m from sprayer

Table 13. Example exposure, mg active ingredient, typical scenario

		Mean	75th percentile	95th percentile
Adult	Dermal (external)	0.25	0.52	1.35
	Dermal (internal)	0.025	0.052	0.135
	Inhalation	6.3e-4	7.4e-4	8.9e-4
	Total	2.56e-02	5.27e-02	1.36e-01
Child	Dermal (external)	0.19	0.35	0.78
	Dermal (internal)	0.019	0.035	0.078
	Inhalation	8.5e-4	1.1e-3	1.4e-3
	Total	2.00e-02	3.61e-02	7.94e-02
Ground		0.51	0.70	1.07

5.2 Higher drift scenario

Short crop/bare ground
FF 110 03 nozzle at 3.0 bar
96 nozzles (i.e. 2 passes of a 24 m boom)
1.0 m boom height
16 km/h forward speed
Applied volume = 90 l/ha
Active applied at 120 g/ha; concentration of active in tank = 1.333 g/l
Wind speed (at 3.0 m height) 3.5 m/s – top end of 'risky' conditions (Defra, 2006)
Dermal absorption – 10%

Bystander at 2.0 m from sprayer

Table 14. Example exposure, mg active ingredient, higher drift scenario

		Mean	75th percentile	95th percentile
Adult	Dermal (external)	0.74	1.57	3.81
	Dermal (internal)	0.074	0.157	0.381
	Inhalation	9.90E-04	1.10E-03	2.00E-03
	Total	7.50E-02	1.58E-01	3.83E-01
Child	Dermal (external)	0.38	0.69	1.53
	Dermal (internal)	0.038	0.069	0.153
	Inhalation	1.60E-03	1.80E-03	2.70E-03
	Total	3.96E-02	7.08E-02	1.56E-01
Ground		1.21	1.6	1.79

6. Vapour Exposure

6.1 Field measurements

Two field experiments relating to vapour emissions from a crop: the first in July 2006 was reported in Butler Ellis and Miller (2008) (Appendix 6) and the second in June 2008 (Appendix 7) was reported in Butler Ellis et al (2010). These two experiments showed that:

- A low vapour pressure active ingredient can be emitted from the crop at the same rate as a much higher vapour pressure active ingredient
- 24-hour mean vapour concentrations very close to a treated plot did not exceed the current value used in regulatory exposure assessment, even when stable conditions and high temperatures were recorded
- The pattern of emissions over 24 hours following application followed a cycle that could not be wholly explained by wind speed and temperature.
- An investigation (PS2010) into whether contaminated particles could be a significant component of the measured airborne pesticide showed that this was not the case for the second experiment (Appendix 8)

6.2 Modelling approach

A fuller description of the approach taken is contained in a draft paper (Appendix 9) The concentration of vapours in the air downwind of an application is dependent on the location, the emission of vapours from the treated area and the dispersion of vapours in the environment. The exposure of a person at that location depends upon breathing rate and duration for which they remain at that location. There are, therefore, three sections to the exposure process which need to be modelled: emission, dispersion and human behaviour.

Existing models of emission rates as well as experimental data were reviewed to identify the most appropriate route for determining emissions. A plume dispersion model, ADMS, was selected to predict the concentration of airborne pesticide vapour at different positions within the landscape, and a simple model of worst-case human behaviour was employed

6.3 Review of emission

From both a review of information in the literature and our own field studies in the BREAM project, it is apparent that while some of the factors that influence the volatilisation rate of pesticides from a crop or soil can be identified, there is insufficient understanding to be able to use this knowledge to predict likely volatilisation rates. It has become clear that:

- while there is a correlation between vapour pressure of an active ingredient and evaporation rate under controlled laboratory conditions, this relationship appeared to break down under realistic field conditions for one of the active ingredients investigated;
- a model that relies on vapour pressure of the active ingredient as the sole chemical property driving volatilisation cannot reliably be used;
- volatilisation rates in field conditions tend to be higher than those in controlled laboratory tests.

It was not planned within the BREAM project to explore the factors influencing volatilisation and to develop a new model and the inadequacy of existing mechanistic and empirical models has resulted in an unavoidable gap in our ability to predict emission rates. However, it is possible to estimate a worst case emission rate based on applied dose. An analysis of the available field data (Smit et al, 1998) showed that the volatilisation over 24 hours, as a percentage of the applied dose, has a relatively uniform distribution between 0 and 100%. An appropriate worst case might therefore be 95% of the applied dose in 24 hours.

6.4 Modelling vapour dispersion

A series of preliminary sensitivity studies were carried out to establish some basic principles for establishing appropriate risk assessment ‘scenarios’ and it was found that:

- the highest concentrations occurred under stable meteorological conditions (e.g. overnight with low wind speeds);
- the highest concentrations occurred with flat terrain – hills and other topographical features tended to increase turbulence and thereby increase dispersion;
- the parameters relating to the way the source was modelled had only a small effect on the resulting concentration;
- the area of the source, and in particular the length of upwind fetch, was very important in determining the concentration at any point downwind. The larger the source, the higher the concentration and the slower it would dissipate with distance downwind (Figure 10).

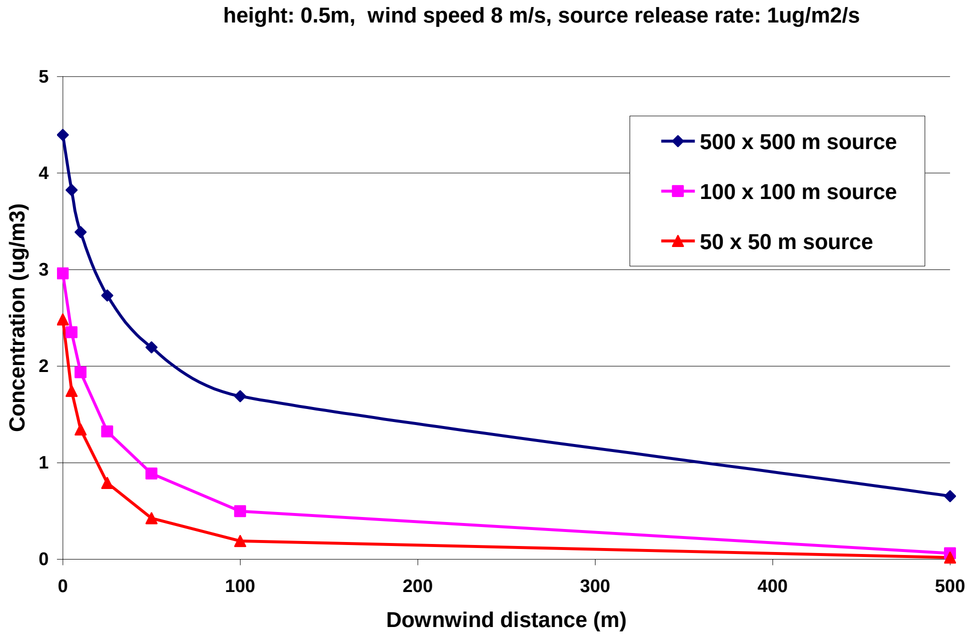


Figure 10 Decline of airborne concentration with distance downwind for different source (field) sizes.

The 'worst case' meteorological conditions which would give rise to the highest concentrations of pesticide in air for a given emission rate occur for probably only a few percent of the time, and therefore basing the risk assessment for exposure to vapours solely on these conditions would potentially lead to an overestimate, particularly for repeated, long-term exposures. It was agreed, therefore, to use real meteorological data for sites in typical arable areas to determine the distribution of concentrations that could occur in practice.

The robustness of the analysis will increase with the number of datasets – different years and sites – that are included. There has been no work undertaken as part of BREAM to determine the optimum number of sites and years that should be included. Two datasets (two years at the Andrewsfield site in East Anglia, which gave the highest concentrations) were used for the final analysis. While we believe that the results of the analysis are likely to be a reasonable estimate of the same analysis over a wider range of sites and years, we cannot be certain that these results are representative. We would recommend that, in order to satisfy potential critics, the analysis is repeated using data for five sites over five years. Some analysis of the year-to-year and site-to-site variation would then be possible.

The scenario for ADMS simulations was a volume source of size 1.5 km square in a flat terrain, representing a block of fields with the bystander/resident in the centre. The emission rate of the source is 1 ug/m2/s.

6.5 Model predictions

Table 15(a) shows the distribution of concentrations predicted by ADMS using the scenario described above and two years of Andrewsfield meteorological data, assuming an emission rate of 1 µg/m2/s. Table 15(b) shows the distribution of potential concentrations, given a product appliled at 100 g/ha of which 95% volatilises in 24 hours. Table 15(c) shows the distribution of potential exposures for defined breathing rates of adults and children.

Table 15(a). Distributions of concentrations of vapour in air.

Distribution		Mean	75th percentile	95th percentile
Concentration per unit emission	Adult	43.0	64.8	127.0
(µg m-3 / µg m-2 s-1)	Child	52.9	80.0	160.3

(b)Example for a product applied at100 g/ha; 95% volatilisation in 24 hours.

Distribution		Mean	75th percentile	95th percentile
Concentration	Adult	5.2	7.8	15.2
(µg m-3)	Child	6.3	9.6	19.2

(c) 24-hour intake based on breathing rates of 17.0 and 8.3 m3/day for adult and child respectively

Distribution		Mean	75th percentile	95th percentile
Dose, (µg)	Adult	88.4	132.6	258.4

Child	52.3	79.7	159.4

7. Sources of uncertainty

7.1 Spray drift exposure

Spray drift is an inherently variable process, caused by random fluctuations in the emission of droplets and by natural air turbulence. Therefore while there are still a number of uncertainties that could be reduced by further work, this natural variability may still dominate.

Table 16. Sources of uncertainty in the BREAM prediction of exposure to spray drift

Source of uncertainty	Over (+) or under (-) prediction	Comments
Silsoe Spray Drift Model	+/-	
Emulator	++/--	Additional model runs are needed to build a more reliable emulator; particularly poor performance at the edges of the range of variables
Relationship between airborne spray and bystander exposure	+/-	Very wide variability
Bystander behaviour	+/-	Bystander movement not accounted for, duration of exposure probably worst case, inhalation includes all droplet sizes
Model inputs	+/-	
Wind speed variability	-	Only relatively short-term variability included
Boom height variability	+	Assumes entire boom oscillates, rather than pivoting.
Downwind structures	++/--	CFD work showed highest factor of 3 increase, but other structures could reduce exposure
Vegetation	+	Limited evidence suggests that vegetation filters more than model predicts

7.2 Vapour drift

Table 17. Sources of uncertainty in the BREAM prediction of exposure to vapour

Source of uncertainty	Over (+) or under (-) prediction	Comments
ADMS	+/-	The well-validated model of dispersion reduces uncertainties, but still provides an 'on average' prediction and cannot deal with local effects.
Emission processes	+/-	Depends on whether or not a worst case (such as 95% in 24 hours) is taken
Field size	+/-	
Met data	+/-	Additional sites/years could change predicted concentrations, but probably not by more than 10%
Bystander behaviour	+	Bystander unlikely to remain so close to downwind field edge for a prolonged period

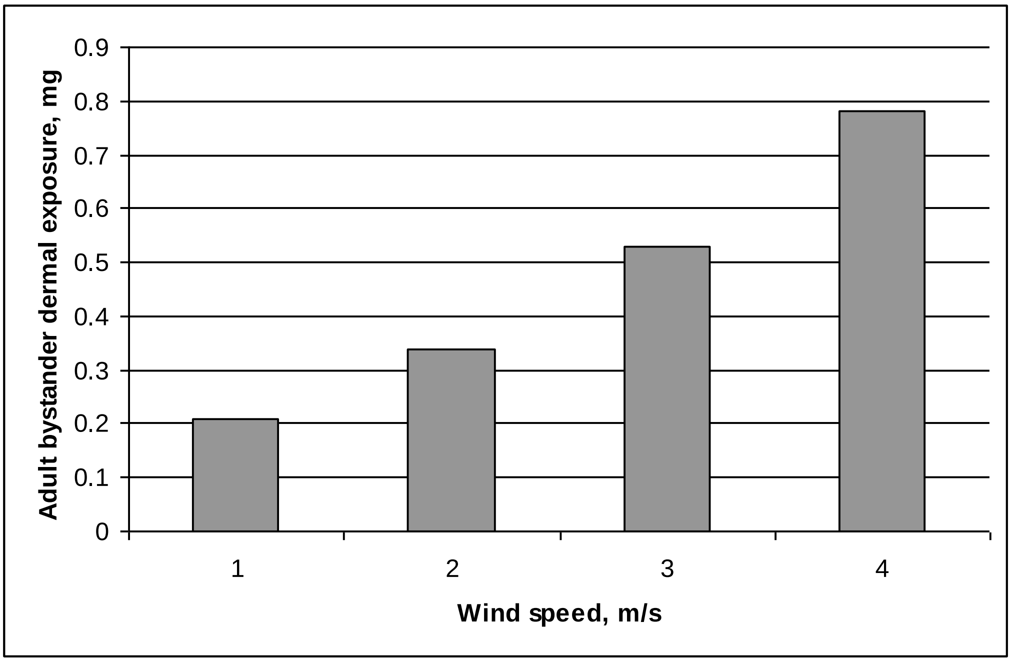
8. Options for drift management

The effect of application parameters on spray drift have been studied over many years and the main variables influencing drift are well known. The BREAM model can be used to explore how these variables influence potential bystander exposure to spray drift.

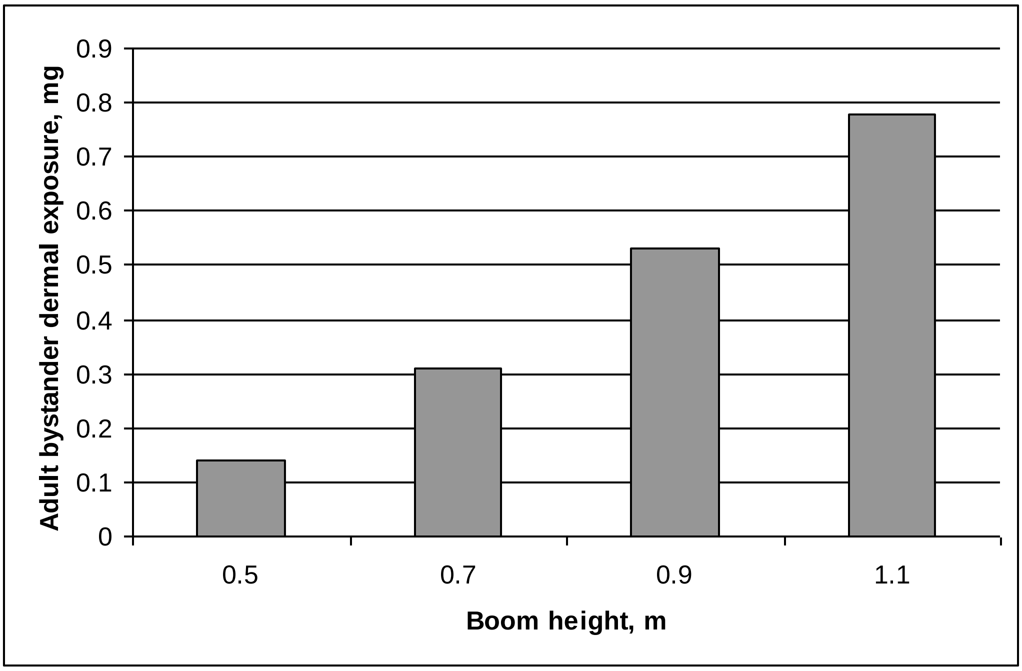
The variables which were investigated were boom height, wind speed, forward speed and distance from the sprayer. Nozzle design cannot be included at this stage since there is currently only one nozzle available in the model.

8.1 *Effect of wind speed and boom height*

Figs 11(a) and (b) show the effect of wind speed and boom height on mean adult bystander dermal exposure, based on the following scenario:
96 nozzles; 12 km/h forward speed, short crop, 2.0 m downwind, tank concentration of a.i., 1 g/l, boom height 0.9 m, wind speed 3 m/s.



(a)

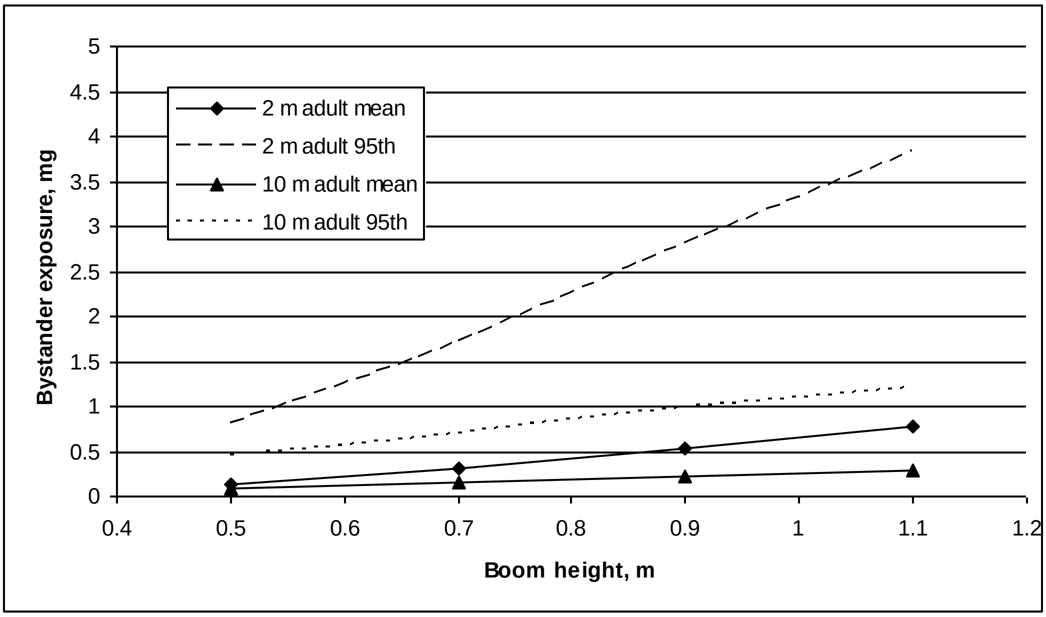


(b)

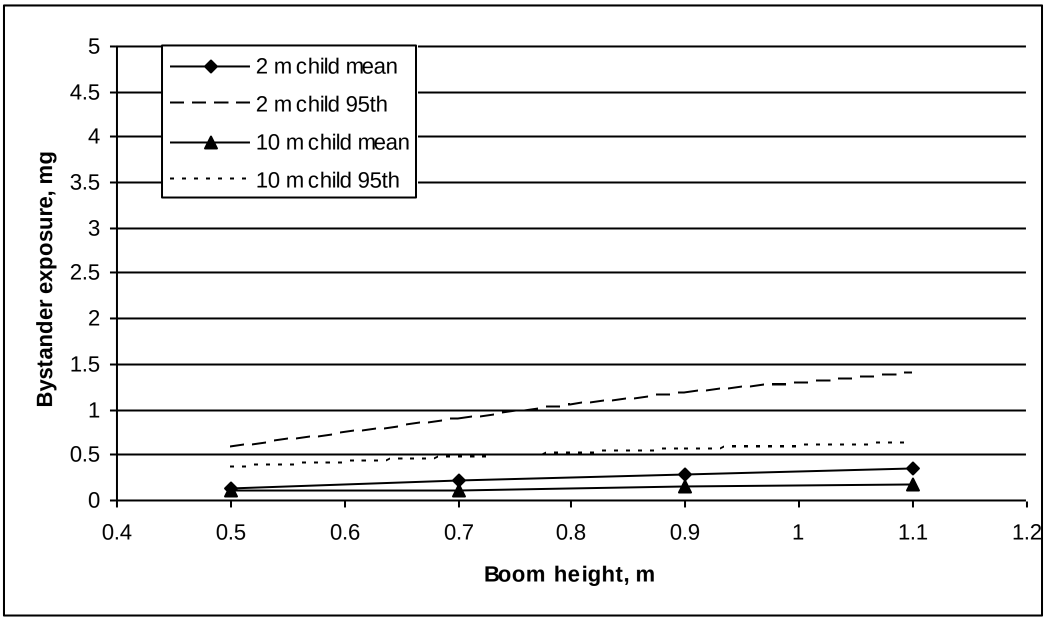
Fig. 11. The effect of (a) wind speed and (b) boom height on mean adult bystander dermal exposure, predicted at 2.0 m downwind.

Bystander exposure is sensitive to both boom height and wind speed, with a doubling in wind speed giving an approximate doubling in drift, and a doubling in boom height giving an approximate 4-fold increase in drift. This is consistent with both field and wind tunnel measurements of drift.

Figures 12 (a) and (b) show that the 95th percentile predicted by the model is even more sensitive to boom height, and that the sensitivity is reduced for children and for greater distances from the sprayer, probably due to a greater proportion of the drifting spray passing over the head of the bystander.



(a)



(b)

Fig 12. Effect of boom height on predicted levels of bystander dermal exposure. (a) adult; (b) child.

8.2 Effect of forward speed and distance from the sprayer

The model suggests that forward speed has a very small effect on bystander contamination. This does not, however, take into account the effect of fluctuations in speed that occur during an application, which result in compensating fluctuations in nozzle pressure. These would potentially increase drift, although again the effect is known to be relatively small. Restricting forward speed is not therefore a useful means of controlling drift directly, although if as a consequence of a lower speed the boom height is more stable and can be reduced, this would have an impact on drift reduction.

Figure 13 shows the effect of distance from the sprayer on bystander exposure and ground deposits. The model suggests a greater decrease in ground deposits with distance than bystander dermal exposure. For example, a distance of 15.0 m results in around 15% of the ground deposits at 2.0 m, but around 40% of the bystander dermal exposure. This suggests that larger buffer zones could be needed for reducing bystander exposure than those which are currently used for protecting surface water, if similar levels of reduction are required. However, it can be seen that a six meter distance has a significant effect on reducing both mean and 95th percentiles of bystander exposure and could therefore play an important role in reducing the risk to the public.

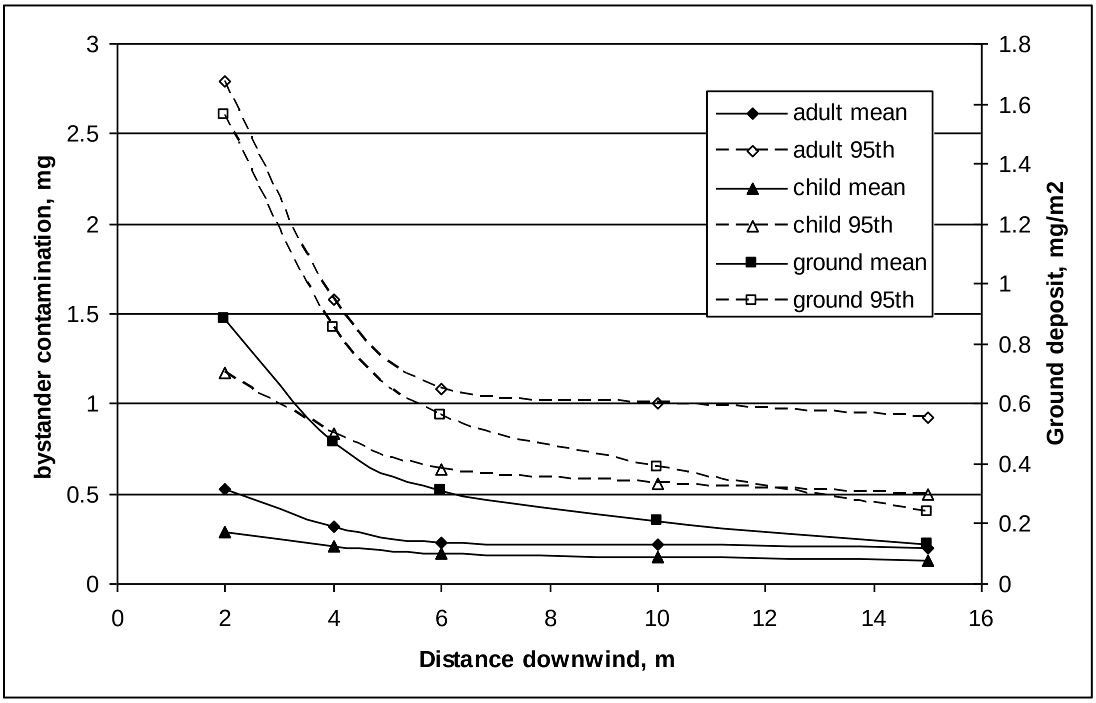


Fig 13. Model predictions of reduction in bystander dermal exposure and ground deposits with distance from the sprayer

9. Extent to which objectives have been met

A new model has been developed specifically to predict human exposure to spray drift for scenarios considered relevant to risk assessment.

Only one of the three nozzles originally proposed is available in the model, but this is the nozzle that is generally used as a standard ‘reference’ nozzle and therefore provides a good estimate of realistic levels of spray drift Including the other nozzles is problematic because their drift depends strongly on the manufacturer, and were the nozzles to be included in the model, the results would apply only to that specific model and make.

The effect of crop and field margin vegetation is not adequately represented in the model, potentially underestimating the filtering effect. Further experimental data and modelling effort will be needed to improve this.

The use of the emulator to reproduce model behaviour has not been as successful as expected, possibly because of the large number of variables and because of the complex behaviour
Crop height has been excluded as a parameter for predicting ground deposits for the first version of the BREAM model – only short vegetation (up to 0.1 m) can be considered
Additional model runs will be necessary to improve the accuracy of the emulator

The spray drift model on which the BREAM model is based has been well validated for the reference nozzle, and there has been some validation of two other nozzles

The BREAM model has been validated with the standard flat fan nozzle for a range of conditions around a worst case. There is a tendency to under-predict with a tall crop which should be improved with better modelling of the relationship between airborne spray and bystander contamination and improvements in the emulation.

The range of variables for which the BREAM model can be run is shown in Table 12. However, the greatest confidence in the model output relates to where the validation has been undertaken and shown to give good predictions, i.e.

- Distances from 2 to 10 m
- Wind speeds 2 - 5 m/s
- Boom height 0.5 - 1.1 m
- Forward speed 12 - 16 km/h
- Short crop/bare ground - both for the sprayed swath and downwind
- 48 nozzles (single swath)
- Wind at 90 degrees (± 15 degrees) to forward direction

A methodology for determining vapour concentrations has been developed using commercial plume dispersion software, ADMS. This uses real UK met data and although a wider range of sites and years would improve confidence in the predicted concentrations being protective, expert judgement suggests that the results obtained were likely to be appropriate for use in risk assessment.

A reliable model of vapour emissions was not found to be available for use in the BREAM project and therefore this remains the greatest source of uncertainty in the project. Further work is essential to develop this model.

10. Implication of findings

10.1 Bystander and resident exposure to spray drift

The work undertaken in the BREAM project has demonstrated that the potential exposure of people at the time of a pesticide application could be significantly higher than that currently used in the regulatory risk assessment due to changes in application practice and to reducing the distance between bystander and sprayer used in the risk assessment scenario. The scenario that is used in the risk assessment is crucial to determining a more realistic level of exposure, and the BREAM model allows exposure for a range of scenarios, including distance, boom height and wind speed, to be predicted. For the higher-drift example given in this report the one-off exposure, represented by the 95th percentile of the exposure distribution, was shown to be 29 times the current exposure assessment for an adult (i.e. 3.81 µg compared with the current exposure assessment of 0.133 µg), which is undertaken only for long-term exposures. A number of factors (such as downwind structures, different nozzle designs, spray liquid properties) could increase the estimate of exposure further.

While the model predicts exposures from a single application event, the ability of the model to predict a distribution of exposures allows the model output to be used to represent longer-term exposures from multiple events by using, for example, 50th or 75th percentiles. However, there is little evidence to suggest that direct multiple exposures to spray drift occur in practice, even for rural residents, since single events are relatively rare, and therefore the most valuable use of the model will be to explore potential one-off exposures.

10.2 Longer term exposure to vapours

Without an improved model of vapour emissions, our ability to predict exposure to vapour for rural residents surrounded by fields is severely limited. However, this work has demonstrated that the current exposure assessment, based on a single concentration, is likely to be protective in many cases, since

- No measurements of vapour concentrations were made that exceeded this value, even in conditions that would be expected to give worst-case concentrations
- The highest possible concentration is proportional to the applied dose, and therefore the current trend for reducing applied doses will be helping to bring down the worst-case exposure

There is, however, a need to establish a robust model of emission rates of active ingredients under field conditions.

11. Possible future work

Further developments of the modelling approaches would be valuable to ensure improved correlation between measured and predicted spray drift exposure and that the remaining uncertainties are reduced. In particular

- Development of a better understanding of the factors influencing volatilisation in field conditions, leading to improved volatilisation models is essential
- Improvements in the emulation of the Silsoe Spray Drift Model and in mapping from airborne spray to bystander exposure would increase the accuracy of the BREAM model
- Improved estimates of distributions of inputs, based on real data, would ensure that 95th percentiles are not over-estimated and that improvements in boom stability can be taken into account
- Further modifications to the Silsoe Spray Drift Model would allow
  - the effect of crop and field margin vegetation to be more reliably predicted
  - more nozzles to be included as inputs

The use of the Silsoe Spray Drift model to predict off-target exposure in a wider range of situations – for example surface water, non-target arthropods – would ensure all regulatory risk assessment is consistent and appropriate to current spraying practice.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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