Grant Agreement No: 265307
Project start date: 1st January 2011
Project end date: 30st June 2014

BROWSE

Bystanders, Residents, Operators and WorkerS Exposure models for plant protection products

SEVENTH FRAMEWORK PROGRAMME

Theme: Environment (including climate change)

Deliverable 3.4

Work Package 3: Models of exposure to agricultural pesticides for bystanders and residents

Title of Deliverable	Work Package 3: Models of exposure to agricultural pesticides for bystanders and residents
Deliverable number	D3.4 and D5.1
Related WP and Tasks	WP3 , WP5
Type of Document	Public Report
Authors	Clare Butler Ellis, Erik van den Berg, Marc Kennedy, Jan van de Zande, Georgios Fragkoulis, Christine O'Sullivan, Cor Jacobs, Marco Trevisan
Compiled by	Clare Butler Ellis
Date	12/09/2013

Project coordinator
Dr Andy Hart
Fera, United Kingdom
E-mail: andy.hart@fera.gsi.gov.uk
http://www.browseproject.eu

Work Package 3: Models of exposure to agricultural pesticides for bystanders and residents

Contents

Work Package 3: Models of exposure to agricultural pesticides for bystanders and residents

1 Summary

The aims of the BROWSE models of exposure for residents and bystanders are:

- To use the best of current knowledge and data to develop an improved exposure assessment for the selected scenarios;
- To provide a clear description of the population which the exposure assessment addresses;
- To include an assessment of the range of possible conditions to produce a probability distribution of exposures.

The models have three main components:

- The source (i.e. the quantity and characteristics of the active substance emitted into the air)
- The dispersion downwind
- The interaction with the bystander or resident to determine exposure.

The current BROWSE model for residents and bystanders includes exposure to spray drift from boom and orchard (air blast) sprayers during a spray application, as well as exposure to vapour and deposited spray drift following an application, assuming residents and bystanders are immediately downwind of the application.

The model is appropriate for a wide range of agricultural crops, including all outdoor field crops sprayed with a conventional boom, and fruit crops sprayed with an air blast sprayer.

It is possible to use the Browse model of bystander and resident exposure to follow a tiered approach. In the current version, the data required for a first tier relates to the application characteristics (dosage, concentration in product) and substance properties (such as vapour pressure). All other inputs can use default values. In the higher tier the user can enter alternative input data that may be more appropriate to the specific proposed use. Future developments may extend this tiered approach.

1.1 Boom sprayer

The source and dispersion of spray from a boom sprayer application are described by a mechanistic Spray Drift model. This is used to determine airborne concentrations at the required heights and distances downwind, as well as ground deposits. Due to the time required to run the model, it is not appropriate to include it directly in the BROWSE model. The Spray Drift model was therefore used to create an 'emulator' which mimics the operation of the model but can be run very fast. This allows multiple runs over a range of input values to determine a distribution of outputs.

The emulator operates with fewer variables than the original model, and the ranges are restricted. However, for maximum flexibility, the emulator used in the BROWSE model retains the most important variables influencing spray drift namely: sprayer boom height; spray quality; distance downwind; wind speed; crop height; and forward speed. Spray drift reduction is taken account of simply by a percentage reduction in spray drift. There is an empirical estimate of the effect of humidity in three categories of low, medium and high.

1.2 Orchard sprayer

There is currently no model available that can be used to predict airborne spray drift and ground deposition downwind of an orchard airblast sprayer. There is, however, a significant quantity of experimental data (from the Netherlands and UK) which can be used and therefore an empirical approach has been taken. The data are insufficient to determine the effect of some important variables (e.g. wind speed, crop size and structure) which can therefore only be captured as variability in the data. The variables that are retained in the model are sprayer type (cross flow or axial fan), growth stage (dormant, transition, full leaf) and spray drift reduction.

Field measurements of spray drift from the Netherlands and the UK are used to determine a potential distribution of airborne (at a single distance) and ground deposits (at a range of distances) of spray drift for a given sprayer type and growth stage. Empirical models are used to translate airborne spray to different distances, and both airborne and ground deposits to different levels of spray drift reduction.

1.3 Vapour

The emission of vapour from a treated field crop (the source) is described by the PEARL model. This model has been used since 2001 in the EU registration process for leaching to groundwater. The PEARL model has been tested in volatilisation studies against experimental data, so it is considered a suitable model for volatilisation exposure assessments under field conditions. The PEARL model has been coupled to a dispersion model, called OPS, which simulates the atmospheric process sequence of dispersion. The combination of PEARL and OPS is used to predict time-dependent air concentration at locations around and within the source field using real meteorological data from locations identified as worst case (90th percentile of average temperature across the growing season) within each EU regulatory zone.

1.4 Interaction with bystander and resident

Acute exposure over a period of up to 24 hours is considered for people who are adjacent (within 20 m) and downwind of the treated area. Longer term exposure is considered for people who are surrounded by fields on all sides within 20 m, and remain in that location for 365 days a year.

Both exposure types include residents and bystanders, who can be exposed through a number of routes:

1. Being present, adjacent to, and downwind of, an area (field or orchard) being treated with plant protection product. A plume of drifting spray will pass the person, who will become exposed through:
    a. Spray coming into contact with their skin (direct dermal exposure);
    b. Spray being inhaled (Inhalation exposure).

2. Being present, adjacent to, and downwind of, an area that has recently been treated with plant protection product. The person will become exposed through:
    a. Breathing in vapour which is emitted from the crop after application (inhalation exposure);
    b. Drifting spray settling on the ground followed by skin contact with the contaminated ground (indirect dermal exposure).

3. Dermal exposure on the hands may become ingested through hand-to-mouth contact (ingestion exposure), particularly for children, following exposure through either route 1 or route 2.

1.5 Model Inputs

The minimum (mandatory) inputs required to run the model are listed below, with defaults available for the large number of additional inputs required. Thus the model can be run very simply, or with greater degree of complexity depending on the knowledge of the user and the information provided relating to the product.

Minimum inputs required to calculate spray drift exposure	**Minimum inputs required to calculate vapour exposure**
Product dose Concentration of active substance in product Applied spray volume	Product dose Concentration of active substance in product Molar mass Saturated vapour pressure and temperature of measurement Water solubility and temperature of measurement Log_{10} Kom (soil applications only)

1.6 Example calculations

Some example calculations, based on the case studies used in the CRD Guidance (Chemicals Regulation Directorate), have been undertaken, and the comparisons are given in the tables below.

Example output from BROWSE model version 4.4 compared with CRD case study for boom sprayers. Exposures are mg/kg

	Acute - BROWSE centiles			Longer-term BROWSE centiles			CRD
	median	75th	95th	median	75th	95th	
adult							
direct dermal	1.51E-04	4.19E-04	1.77E-03	2.16E-05	5.99E-05	2.52E-04	1.77E-04
spray inhalation	3.32E-06	4.29E-06	6.30E-06	4.74E-07	6.13E-07	9.01E-07	1.04E-04
child							
direct dermal	6.41E-04	1.77E-03	7.57E-03	9.15E-05	2.53E-04	1.08E-03	7.08E-04
spray inhalation	3.12E-05	4.34E-05	6.95E-05	4.46E-06	6.21E-06	9.93E-06	4.16E-04

	Acute - BROWSE centiles			Longer-term BROWSE centiles			CRD
	median	75th	95th	median	75th	95th	
child							
indirect dermal	2.05E-04	5.59E-04	2.14E-03	4.61E-04	1.18E-03	3.89E-03	7.50E-05
indirect ingestion	1.18E-06	2.89E-06	9.77E-06	2.66E-06	6.04E-06	1.72E-05	1.65E-05

Example output from BROWSE model version 4.4 compared with CRD case study for orchard sprayers. Exposures are mg/kg

	Acute -BROWSE centiles			Longer-term - BROWSE centiles			CRD
	median	75th	95th	median	75th	95th	
adult							
direct dermal	1.64E-04	5.09E-04	2.52E-03	2.34E-05	7.25E-05	3.60E-04	3.28E-03
spray inhalation	1.46E-05	2.69E-05	5.94E-05	2.10E-06	3.85E-06	8.46E-06	1.04E-05
child							
direct dermal	6.78E-04	2.13E-03	1.05E-02	9.57E-05	3.02E-04	1.50E-03	1.31E-02
spray inhalation	1.35E-04	2.61E-04	5.72E-04	1.93E-05	3.73E-05	8.24E-05	4.16E-05

	Acute -BROWSE centiles			Longer-term - BROWSE centiles			CRD
	median	75th	95th	median	75th	95th	
child							
indirect dermal	1.44E-03	4.21E-03	1.66E-02	2.84E-03	7.48E-03	1.48E-01	1.98E-04
indirect ingestion	8.20E-06	2.19E-05	7.61E-05	1.64E-05	3.85E-05	1.11E-04	4.50E-05

Predicted exposures from a low volatility a.s. (vapour pressure = 0.0001 Pa at 20 C) for two locations

Exposures are µg/kg

	Northern			Southern (Spain)			
	median	75th centile	95th centile	median	75th centile	95th centile	CRD
adult acute	0.114	0.176	0.367	0.636	0.927	1.51	0.253
adult longer term	0.0416	0.0606	0.118	3.09	4.49	7.28	
child acute	0.553	0.846	1.76	0.25	0.324	0.452	0.6
child longer term	0.2	0.289	0.56	1.21	1.56	2.13	

1.7 Comparison between BROWSE and existing models of bystander and resident exposure

Comparing the results of the BROWSE model with exposure assessment models is not straightforward because of the different approaches taken.

A separate report has been provided by BPI which considered the comparison between the two main existing models (Germany and UK) and some results produced by the BROWSE model for boom sprayer applications. While this showed significantly greater exposures from BROWSE using a similar example calculation to that above, it is possible to run the BROWSE model using input values representative of the experimental conditions under which the data underlying the UK model were obtained, and to achieve very similar estimations of exposure. The main reason for the increased predicted exposure with BROWSE, compared with existing models, is because a scenario which is more representative of current practice (in some EU member states) is used as the default.

1.8 Benefits of the BROWSE model for bystander and resident exposure

There are a number of benefits of the BROWSE model over current models of bystander and resident exposure

- Mitigation measures to reduce exposure (such as spray drift reduction technology) can be taken into account if required
- The model is sufficiently flexible to allow the wide range of application practices around the EU to be addressed
- The model includes realistic scenarios – where data is available about current practice and behaviour, this is used and unrealistic cases are avoided.
- The use of probabilistic modelling avoids an over-conservative approach.

2 Introduction

There has been, in recent years, a number of reviews of the models for assessing the exposure of bystanders and residents to pesticides used in agricultural applications. Prompted by public concern, the UK government asked the Royal Commission on Environmental Pollution to undertake a study into the science used to assess risk to people from crop spraying, following which a report was produced (Royal Commission on Environmental Pollution, September 2005), focusing on the UK situation. There were many recommendations within this report, but the most important on relating to exposure assessment was that

> ...the current approach for assessing resident and bystander exposure should, with some urgency, be replaced with a computational model which is probabilistic, looks at a wider range of possible exposure routes and more robustly reflects worst-case outcomes...

The UK government then commissioned the BREAM project (Defra, 2006) in order to address this. The BREAM project finished in January 2010, and demonstrated the potential for underestimating exposure in some circumstances with the existing exposure models, as well as providing alternative models for some exposure routes.

In 2007, The European Food Safety Authority (EFSA) commissioned a review of the exposure assessment component of the risk, but to include all European member states and broadened to cover operators and workers. This report (Hamey, et al., 2008), contained a number of recommendations. Those specific to bystanders and residents were:

> **Bystander exposure**
> A scientifically robust collection of exposure data is not yet available to establish science based models that predict representative levels of exposure taking account of relevant uncertainties, therefore a protective approach is required.
>
> It is noted that in the UK a specific project aims to produce a model in early 2010, but in the meantime approaches proposed by the UK and Germany are similar and a harmonised approach can be proposed based on these two approaches.
>
> **Resident exposure**
> A scientifically robust collection of exposure data is not yet available to establish science based models that predict representative levels of exposure taking account of relevant uncertainties, therefore a protective approach is required.

> It is again noted that in the UK a project aims to produce a model in early 2010, but in the meantime approaches proposed by the UK and Germany for exposure to vapour are similar and a harmonised approach can be proposed based on these two approaches.
>
> In addition the approaches adopted by the UK, and Germany for exposure to drift fallout in area adjacent to treated sites, along with the Netherlands approach for exposure from treated lawns, are similar. Therefore harmonised approaches for assessing exposures to spray drift fallout and exposures of residents to lawn treatments should be produced.

A scientific opinion on the preparation of a guidance document on Pesticide Exposure Assessment for Workers, Operators, Bystanders and Residents was then published by EFSA (EFSA Panel on Plant Protection Products and their Residues (PPR), 2010) and at the time of preparing this report, the finalised Guidance Document itself has not yet been published, but is expected imminently.

At the start of the BROWSE project, the state-of-the-art in exposure assessment for bystanders and residents was reviewed (Butler Ellis, O'Sullivan, Fragkoulis, Trevisan, van den Berg, & Capri, 2010), and concluded that:

> The developments that can be made in the BROWSE project in relation to bystander and resident exposures are very dependent on the source of the exposure that is being considered, and will be very variable because of the level of data and the available models currently available:
>
> - Recent work on a model of exposure from boom sprayers will be readily incorporated into BROWSE
> - Although no recent exposure data has been obtained relating to orchard or other fruit sprayers, data and expert knowledge on spray drift from such machines will allow a new semi-empirical model to be developed for BROWSE
> - Significant effort is planned to make necessary improvements to our ability to predict volatilisation under field conditions: when combined with an existing dispersion model and an agreed resident behaviour model, there is scope for a new, much improved resident exposure model to be developed for BROWSE
> - Other sources of exposure – particularly contaminated dust – can be modelled in terms of dispersion and human behaviour in a similar way, but there will be limits to their accuracy depending on the data available relating to the magnitude of the emission source.

In practice, no model of exposure to dust has been developed, because of a lack of data that could be used to either support model development, to validate or test any model that might be developed, as well as a lack of input data for running such a model.

The work undertaken in BROWSE has therefore focused on the first three causes of exposure identified as having potential for improvement: boom sprayers, orchard sprayers and vapour emissions.

3 Scope and Aim

3.1 Scope

3.1.1 Scenarios included in the BROWSE model

The current BROWSE model for residents and bystanders includes exposure to spray drift from boom and orchard (air blast) sprayers during a spray application, as well as exposure to vapour and deposited spray drift following an application, assuming residents and bystanders are immediately downwind of the application.

The model is appropriate for a wide range of agricultural crops, including all outdoor field crops sprayed with a conventional boom, and fruit crops sprayed with an air blast sprayer.

The model does not explicitly include exposure to amenity applications (e.g. parks, golf courses) although the boom sprayer model can be extended to include operating conditions typical of many vehicle-mounted amenity applications.

The model does not include exposure from contact with treated agricultural crops (e.g. from walking through a recently sprayed cereal crop). This could be addressed, however, by using models of worker exposure, or by extending the resident and bystander model of exposure to turf contaminated with spray drift.

The model excludes exposure to dust from airborne soil, from drilling treated seeds or from harvesting crops because there was no data available at the start of the project, and still inadequate data for model development, for estimating the quantity of active substance emitted from these operations.

The model does not currently calculate exposure of residents and bystanders to emissions from protected crop structures.

3.1.2 Definition of Bystanders and Residents.

The models have been developed to assess the potential exposure of any member of the public who finds themselves in proximity to an agricultural pesticide spray application, regardless of whether they are present for a short time or live there permanently. Definitions of bystanders and residents have been provided in the EFSA Scientific Opinion (EFSA Panel on Plant Protection Products and their Residues (PPR), 2010) and were initially the basis for the models we developed.

- ***Bystanders*** *are: persons who could be located within or directly adjacent to the area where PPP application or treatment is in process or has recently been completed; whose presence is quite incidental and unrelated to work involving PPPs, but whose position might lead them to be exposed during a short period of time (acute exposure); and who take no action to avoid or control exposure.*

- ***Residents*** *are: persons who live, work or attend school or any other institution adjacent to an area that is or has been treated with a PPP; whose presence is quite incidental and unrelated to work involving PPPs but whose position might lead them to be exposed; who take no action to avoid or control exposure; and who might be in the location for 24 hours per day (longer term exposure).*

However, this terminology caused confusion at the BROWSE Stakeholder workshop held in 2013, with some stakeholders believing that acute resident exposure and long-term bystander exposure were not being appropriately addressed.

Our preferred definition, therefore, for the exposed population under consideration is:

- Residents and bystanders are *persons who could be located within or directly adjacent to the area where PPP application or treatment is in process or has recently been completed, because they live, work or attend school or any other institution adjacent to an area, or visit such an area; whose presence is quite incidental and unrelated to work involving PPPs, but whose position might lead them to be exposed; who take no action to avoid or control exposure.*

3.2 Aim

The aims of the BROWSE models of exposure for residents and bystanders are:

- To use the best of current knowledge and data to develop an improved exposure assessment for the selected scenarios;
- To provide a clear description of the population which the exposure assessment addresses;
- To include an assessment of the range of possible conditions to produce a probability distribution of exposures.

4 Model overview

The models have three main components:

- The source (i.e. the quantity and characteristics of the active substance emitted into the air)
- The dispersion downwind
- The interaction with the bystander or resident to determine exposure.

4.1 Source and dispersion

4.1.1 Boom sprayer model

The source and dispersion of spray from a boom sprayer application are described by the Silsoe Spray Drift model (Butler Ellis & Miller, 2010). This can be used to determine airborne concentrations at the required heights and distances downwind, as well as ground deposits. Because of the time taken to run the Silsoe model, it was not appropriate to include it directly in the BROWSE model. The Spray Drift model was therefore used to create an 'emulator' which mimics the operation of the model but can be run very fast. This allows multiple runs over a range of input values to determine a distribution of outputs (Kennedy, Butler Ellis, & Miller, 2012).

The emulator operates with fewer variables than the original model, and their ranges are restricted. However, for maximum flexibility, the emulator used in the BROWSE model retains the most important variables influencing spray drift – sprayer boom height, spray quality, wind speed, crop height and forward speed.

4.1.2 Orchard sprayer

There is currently no mechanistic model available that can be used to predict airborne spray drift and ground deposition downwind of an orchard air blast sprayer. There is, however, a significant quantity of experimental data which can be used and therefore an empirical approach has been taken, similar to that proposed by van de Zande (van de Zande, Wenneker, & Michielsen, 2010). There is, however, insufficient data to determine the effect of some important variables (e.g. wind speed, crop size and structure) which can therefore only be captured as variability in the data. The variables that are retained in the model are sprayer type (cross flow or axial fan), growth stage of the fruit trees (dormant, transition, full leaf) and spray drift reduction.

4.1.3 Vapour

The BROWSE model for vapour exposure is the first attempt that has been made to model mechanistically the process involved in bystander and resident exposure to vapours released from a treated field for risk assessment purposes. The mechanistic approach is based on the PEARL model, already developed as part of the FOCUS package for the risk assessment of surface water , for determining volatile losses to air, combined with OPS, a plume-dispersion model which simulates the downwind dispersion of the emitted vapour and the resulting concentrations in air.

The major challenge with this component of resident and bystander exposure has been defining the scenario(s) that are the basis for the vapour exposure models. Since there was no existing defined scenario (including, for example, meteorological conditions, field size and layout, location of bystander or resident, pattern of applications) there was a significant expenditure in time of developing ideas, and then attempting to put them into practice in the models. This is potentially the least 'finished' component of the resident and bystander exposure model because new ideas for improving the model were developed too late to be implemented. In particular, since this is a relatively complicated process, it may be appropriate to have a first tier simple approach, and then include a more sophisticated calculation, with additional input parameters, for higher tiers. A major restriction on developing more sophisticated scenarios was the time taken for the software to run. Stakeholder feedback was clear that the run time should be a few minutes at most, and this then limits the complexity of the model.

The main variables that influence exposure in the vapour model are physico-chemical properties of the active ingredient, size of treated area, location of the application (defined by meteorological conditions) and whether the application is to crop or soil.

4.2 Interaction with bystander and resident

The bystander and resident can be exposed through a number of routes:

1. Being present adjacent and downwind of an area (field or orchard) being treated with pesticide spray. A plume of drifting spray will pass the person, who will become exposed through
        - Spray contacting the skin (**direct dermal exposure**)
        - Spray breathed in (**spray Inhalation exposure**)

The drifting spray will also settle on the ground.

2. Being present, adjacent and downwind of an area that has recently been treated with pesticide. The person will become exposed through:
    - Breathing in vapour which is emitted from the crop after application (**vapour inhalation exposure**);
    - Contact of the skin with the contaminated ground (**indirect dermal exposure**).
3. Dermal exposure on the hands may become ingested through hand-to-mouth contact (ingestion exposure), particularly for children, following exposure through either route 1 (**direct ingestion**) or route 2 (**indirect ingestion**)

In order to determine the actual exposure arising from the emission and dispersion in air of pesticides, models have been developed of the above interactions. The models relating to indirect dermal and ingested exposure are similar to those currently used for bystander and resident exposure assessment. However, the values of parameters used in these models have been re-considered and alternative options are available.

The main variables relating to bystanders and residents that influence exposure are bodyweight and breathing rates, clothing, distance from sprayed area, and factors relating to the transfer from contaminated turf to the body.

5 Bystander and resident – exposed population

The population included in these models relates to people who spend time adjacent to agricultural outdoor spraying operations and/or the area that has been treated.

1. The duration of the resident or bystander being present is considered to be:

- Up to 24 hours, in the case of acute exposure. The routes of exposure defined in section 4.2 within a 24 hour period at a given location are included.
- 24 hours a day, 365 days a year, in the case of longer-term exposures. The routes of exposure defined in section 4.2 at a given location over a given period of time are included.

2. The distance from the treated area is considered to be, for both bystanders and residents:
   - Between 2 and 20 m downwind.

3. It is assumed that the resident or bystander can be surrounded on all sides by treated fields. However, all four fields cannot be both being treated and directly upwind of the resident or bystander simultaneously. Over a longer period of time, however, the wind direction is likely to change, and it is possible to be exposed to the emissions from more than one field. In the BROWSE model, therefore, the number of fields from which the pesticide emissions cause the exposure are:
   a. A single upwind field for acute exposure to spray drift, both direct and indirect;
   b. A single upwind field for longer term **direct** exposure to spray drift;
   c. Two upwind fields for longer term **indirect** exposure to spray drift;
   d. Treated fields on all four sides for exposure to vapour, although at any one time only one of these will be upwind of the bystander or resident. The use of real meteorological data ensures a realistic distribution of wind directions.

4. The people included in this populations are:
   - Adults and children. Children are treated as a separate population from adults because important factors such as breathing rate, bodyweight, height and activity differ significantly between these two groups. The height of the person and the height above ground of the breathing zone are fixed within the model at 2.0 m and 1.4 m respectively for adults, and 1.0 m and 0.7 m for children.
   - Male and female of these two groups are not treated separately, and where statistics are used, these relate to the combined population, therefore both women and men are included.

- Different age ranges within adults and children are not considered separately, but where age-specific information is available, the age range with the worst case behaviour is selected (e.g. highest breathing rate: bodyweight ratio).

Thus the population considered in the model includes the most vulnerable people who remain permanently close to the treated field – people who live surrounded by fields with no protective barrier between, do not spend time away from their home and spend all their time outdoors. While we cannot realistically model every type of behaviour, activity and set of circumstances that might occur in practice, by selecting the population for 'worst case' exposure, the model can be protective for all except in exceptional and unforeseeable circumstances.

6 User interface and model input data

The structure of the user interface of the version 3.92 is described, and suggested values for default model input data are given, together with the justification for these values. In general, the aim is to include recommended values from EFSA, and from the US EPA when appropriate.

Not all of the recommended defaults for running the models are captured in the current version of the software. This is for two reasons:

(a) The software is still under development, and

(b) The defaults aim to achieve a realistic worst case for risk assessment purposes, consistent with current practice. However, many input parameter are common to more than one model and there is sometimes a conflict – for example an input variable that is chosen to give a worst case exposure for a resident might then give an underestimate for an operator.

6.1 Assessment tab: general inputs – used in all work packages

There are two options for resident and bystander exposure calculations: those applied to field crops with a boom sprayer, and those applied to fruit crops with an air-blast sprayer. Hand-held applications are not currently included.

Input	Option 1	Option 2	Notes
Crop type	Arable and vegetables	Orchard	Orchard includes pome fruit, grapes, hops, other crops that use the same equipment
Application Technique	Vehicle mounted/drawn boom sprayer	Vehicle mounted/drawn air blast sprayer	Also includes self-propelled machines
Scenario	Boom spraying (field crops)	Orchard sprayers – broadcast air assisted	

Table 1. Other Inputs for Assessment tab

Input	**Units**	**Default**	**Range**	**Notes**
Formulation type		liquid	Liquid, solid	NOT USED IN Residents & Bystander (R&B) MODELS This relates to the type of product that is diluted in water, not the type of application – i.e. only liquid spray applications are included in the model
Container size				NOT USED IN R&B MODELS
Formulation				NOT USED IN R&B MODELS
Concentration (active substance) in product	g/L (liquid) g/kg (solid)	None		Quantity of active substance in product (L/ha or kg/ha)
Product dose	L/ha (liquid); kg/ha (solid)	None		Amount of product applied (L or kg) per ha
Acceptable Operator Exposure Level (AOEL)	mg/kg bodywt/day	None		
Acute AOEL	mg/kg bodywt/day	None		
Dermal absorption of product	%	None	0-100	Dermal absorption of the product
Dermal absorption of in-use dilution	%	None	0-100	Dermal absorption of the diluted product

Oral absorption	%	None	0-100	Absorption from ingestion exposure
Skin-to-mouth transfer factor	%	43	0 - 100	The percentage that can be removed from hands through contact with mouth. Based on data provided by WP1, and similar to that used in current models
Percentage of hand making contact with mouth	%	7	0-100	Based on data provided by WP1, and similar to that used in current models
Inhalation absorption	%	100	0-100	

6.2 Scenario tab: boom spraying scenario – inputs used in both operator and bystander and resident models

Table 2. Inputs for Scenario tab

Input	Units	Default	Range	Notes
Wind speed at 2.0 m above ground	m/s	2.8	0.5 - 10	Corresponds to approximately 7.5 km/h (4.5 mph) speed at boom height- at upper end, but within, UK code of practice. Based on analysis undertaken in Defra-funded project PS2030. Other EU states have different acceptable wind speeds
Crop Height	m	0.1	0.1, 0.5, 1.0, 1.5	For short crop, cut grass or bare soil, use 0.1.
Sprayed volume rate	l/ha	None		Total amount of spray liquid applied per unit area. Needs to be consistent with nozzles available and forward speed – see table 3 below for guidance
Tank volume				NOT USED IN R&B MODEL
Sprayed area				NOT USED IN R&B MODEL
Total spray volume				NOT USED IN R&B MODEL
Forward speed	Km/h	12	4-25	Operating speed of the sprayer. EFSA data: 8 km/h mean & median; 2% outside range of 4-25 (all slower). Max is 19 km/h. 90th percentile is 12 km/h. BROWSE survey data (UK only): 11 km/h mean; 10 km/h median; 1 sprayer outside range of 4-25 (faster) Max

				is 28 km/h; 90th percentile is 15 km/h
Tankfuls applied				NOT USED IN R&B MODEL
Concentration of active substance in spray liquid	g/l			Calculated from product dose, concentration of a.s. in product and applied spray volume
Sprayer Type				NOT USED IN BOOM SPRAYER MODEL
Spray quality	none	medium	Fine – very coarse	Default based on a flat fan “03” nozzle (F/110/1.2/3.0) at 3.0 bar spray pressure. This defines the boundary between Medium and Fine and is therefore a worst case for medium. Each of the other spray categories available are also based on the boundary with the next category, and are therefore also worst case (Southcome, 1997) The EFSA survey suggests 13% of nozzles whose spray quality could be estimated would be on the fine/medium boarder, and 12% would be finer. A realistic worst case could therefore be ‘fine’.
Spray drift reduction	%	0	50, 75, 90, 95,	Should be based on values available in UK, NL and German drift reduction schemes,
Nozzle output	l/min		0.4 to 4 l/min	Calculated from applied volume rate and forward speed.
Boom height above crop	m	0.7	0.2-1.2	Height of boom above the top of the crop. No meaningful data available – based on expert judgement (0.5 m is the recommended value for 110 degree nozzles, but is often increased to reduce the risk of boom damage)
Boom width (Assumes a nozzle spacing of 0.5 m)	m	24	6-48	EFSA survey suggests 94% of sprayers have boom widths within this range. Wider booms can be simulated, but for fewer passes, as the total number of nozzles is 960 (i.e. 10 passes x 96 nozzles)
Application type		single	Single, multiple	Applies only to longer term calculation
Applications made during longer term		1	any	Applies only to longer term calculation

exposure period				
Longer term exposure period		7 d	7 d, 14 d, 1 m, 3 m	Applies only to longer term calculation

Table 3. Boom sprayer: Spray volume applied, l/ha, at 3.0 bar, (43 psi) nozzle pressure and 50 cm nozzle spacing on the spray boom

	Nozzle size						
Forward speed, km/h	02	03	04	05	06	08	
6	160	240	320	400	480	640	
8	120	180	240	300	360	480	
10	96	144	192	240	288	384	
12	80	120	160	200	240	320	
14	69	103	137	171	206	274	
16	60	90	120	150	180	240	
18	53	80	107	133	160	213	

Spray quality with standard flat fan nozzle (*other qualities possible with other nozzle designs*)

Fine

Medium

Coarse

6.3 *Scenario tab: boom spraying scenario - Inputs specific to bystander and residents exposed to vapour*

These inputs do not need to be entered if exposure to vapour is not selected as an option. It can be de-selected on the Resident/Bystander tab. Also used for the worker model.

Table 4. Inputs for scenario tab – exposure to vapour

Input	**Units**	**Default**	**Range**	**Notes**
Crop/ meteorology combination		Northern	Northern (Denmark) Central (Germany or Hungary), Southern	Defines the meteorological data to be used for the calculation; in future developments could also take the crop structure into account but currently assumes

			(Spain or Italy)	100% crop interception and no losses of active substance apart from through volatilisation.
Treated area	m	200 x 200	200 x 200; 500 x 500; 2000 x 2000	Can relate to a large number of small fields that might have been treated with the same active substance at a similar time
Molar mass	g/mol	none		
Saturated vapour pressure	Pa	none		Data relating to saturated vapour pressure under field conditions is required: data obtained on the pure active substance under laboratory conditions may seriously underestimate volatilisation.
Temperature at which s.v.p. was measured	Celsius	None		
Water solubility	mg/l	None		
Temperature at which solubility was measured	Celsius	None		
Log10 of Kom		None		

6.4 Resident/Bystander tab: boom spraying scenario - Inputs specific to bystander and residents exposed to spray drift

Table 5. Inputs for Resident/Bystander tab – exposure to spray drift

Input	**Units**	**Default**	**Range**	**Notes**
Number of iterations to run		175,000		Increasing the number will increase run-time, but reduce variability of output between runs
Number of upwind passes	none	3	1 - 10	This defines the number of passes for which the bystander or resident is present downwind of the spray. No data available to define this – common sense suggests that for a small field, a sprayer will traverse quickly e.g. for a 240 m field length, sprayed at 12 km/h, it will take around 5 minutes for a sprayer to pass a fixed point 3 times. A worst case could be much higher for a bystander who doesn’t

				deliberately move away, but the first 3 swaths deliver the majority of the total spray
Standard deviation of boom height distribution	m	0.2 x boom height	0-1.0	Defined in BREAM project as a very worst case of 0.3 x boom height. Reduced slightly for BROWSE to 0.2 x boom height based on expert judgement. Further data needed to relate different types of boom suspension to this measure of stability
Droplet evaporation	none	None	None, moderate, high	Relates to wet bulb depression of 0 -3 C, 3 -7 C, >7 C. Greatest exposure from highest evaporation, but since droplet evaporation is also product-dependent, the effect of low humidity is relatively poorly understood
Vapour exposure parameters are duplicated here				
Bodyweight	kg	Distribution		Distributions based on EFSA data (Efsa Scientific Committee, 2012). EFSA-recommended or user-defined constant also possible
Short term (moderate activity) breathing rate	m^3/hour	Distribution		Assumes moderate activity. Distribution based on EPA data (US EPA) ch 6 ; US constant, EFSA-recommended or user-defined constant also possible
Long term average breathing rate	m^3/day	Distribution		Assumes daily average. Based on EPA data (US EPA) ch 6. US constant, EFSA-recommended or user-defined constant also possible
Clothing penetration	%	Distribution	0.1-1.0	Combines skin area uncovered with penetration through clothing, to give a single 'penetration' value. No data available. BROWSE survey data suggests few people would deliberately cover up because of nearby pesticide application, and it can be assumed that the people undertaking moderate to heavy activity will be wearing less than average level of clothing. Distribution also an option – a uniform distribution between 0.1 and 1.0
Closest distance	m	2	2-20	These define the range for the

to sprayed area				uniform distribution of distances for the bystander/resident. Can be set to equal to define a fixed position
Furthest distance from sprayed area	m	20	2-20	
Fraction of dermal exposure on hand		Distribution		The fraction of the direct dermal exposure that was measured on the hands – data from UK Defra project PS2006. User –input possible
Surface area of hand contacting mouth	m^2	0.002		Estimated for child (Martin, et al., 2008). User-input possible
Duration of exposure/activity (post-application)	hours	Distribution	US EPA distribution, EFSA constant, US EPA constant, user value	The duration for a person engaged in outdoor activities in contact with contaminated turf. Distribution based on EPA Exposure Factors Handbook ch16 (US EPA). EFSA and US recommendations are based on a curtailed distribution, giving an mean of 2.0 or 1.5 hours respectively. BROWSE survey data suggested much higher averages than this.
Half life of a.s. on adjacent vegetation	days	30	any	The half-life of the active substance on turf
Turf Transfer Residue	none	Distribution	US EPA values; EFSA values; distribution based on US EPA data; user value	Defines the fraction of the spray drift deposited on the turf which can be transferred to a person engaged in physical activity on the grass. No data available relating to spray drift, which will be present at the top of the grass sward, rather than penetrating into the turf as would be the case with a high-volume turf application, and more available for transfer. Suggested first tier default should be much higher than measurements made for high-volume turf applications. Data for turf applications also available from US (US EPA, February 2012) and European (Martin, et al., 2008) recommendations.
Transfer coefficient	m^2/h	US EPA distribution	US EPA distribution, US EPA constant,	Defines the area covered in an hour by a person engaged in physical activity on the grass.

			EFSA constant	Data available from US (US EPA, February 2012) and European (Martin, et al., 2008) recommendations. US data sufficiently detailed to allow a distribution of transfer coefficients to be used.
Frequency of hand-to-mouth contact	none	20	any	Estimated for child (Martin, et al., 2008)

6.5 *Scenario tab: orchard spraying scenario – inputs used in both operator and bystander and resident models*

Table 6. Inputs to scenario tab

Input	**Units**	**Default**	**Range**	**Notes**
Wind speed at 2.0 m above ground	m/s	2.8	0.5 - 10	NOT USED IN R&B CALCULATION FOR ORCHARDS
Crop Height				NOT RELEVANT FOR ORCHARDS – WILL BE REMOVED
Sprayed volume rate	l/ha	500	100-2000	
Tank volume				NOT USED IN R&B MODEL
Sprayed area				NOT USED IN R&B MODEL
Total spray volume				NOT USED IN R&B MODEL
Forward speed	Km/h	6	4-25	Default based on EU current practice.
Tankfuls applied				NOT USED IN R&B MODEL
Concentration of active substance in spray liquid	g/l			Calculated from product dose, concentration of a.s. in product and applied spray volume
Sprayer Type		Axial fan	Axial fan, cross flow	Cross flow fan machines used mostly in NL; other member states use primarily axial fan machines
Spray quality	none	Very fine	Very fine - medium	Default based on typical air blast sprayer nozzle and pressure. Operator model uses spray quality, whereas R&B model uses spray drift reduction. Very fine and fine = 0% d.r; medium = 50% d.r. Higher levels of d.r. use
Drift reduction	%	0	0, 50, 75, 90, 95	

				medium to run operator model (no data available for higher levels of d.r.)
Application type		single	Single, multiple	Applies only to longer term calculation
Applications made during longer term exposure period		1	any	Applies only to longer term calculation
Longer term exposure period		7 d	7 d, 14 d, 1 m, 3 m	Applies only to longer term calculation

6.6 Resident/Bystander tab: orchard spraying scenario - Inputs specific to bystander and residents exposed to spray drift

Table 7. Inputs for Resident/Bystander tab – exposure to spray drift

Input	**Units**	**Default**	**Range**	**Notes**
Number of iterations to run		175,000		Increasing the number will increase run-time, but reduce variability of output between runs
Growth stage		dormant	Dormant, transition, full leaf	
Add noise				To be removed in final version
Bodyweight	kg	Distribution		Distributions based on EFSA data (Efsa Scientific Committee, 2012). EFSA-recommended or user-defined constant also possible
Short term (moderate activity) breathing rate	m^3/hour	Distribution		Assumes moderate activity. Distribution based on EPA data (US EPA) ch 6 ; US constant, EFSA-recommended or user-defined constant also possible
Long term average breathing rate	m^3/day	Distribution		Assumes daily average. Based on EPA data (US EPA) ch 6. US constant, EFSA-recommended or user-defined constant also possible
Clothing penetration	%	Distribution	0.1-1.0	Combines skin area uncovered with penetration through clothing, to give a single ‘penetration’ value. No data available. BROWSE survey data suggests few people would deliberately cover up because of nearby pesticide application, and it can be assumed that the people

				undertaking moderate to heavy activity will be wearing less than average level of clothing. Distribution also an option – a uniform distribution between 0.1 and 1.0
Closest distance to sprayed area	m	2	2-20	These define the uniform distribution of distances for the bystander/resident. Can be set equal to define a fixed position
Furthest distance from sprayed area	m	20	2-20	
Fraction of dermal exposure on hand		Distribution		The fraction of the direct dermal exposure that was measured on the hands – data from UK Defra project PS2006. User –input possible
Surface area of hand contacting mouth	m^2	0.002		Estimated for child (Martin, et al., 2008). User-input possible
Duration of exposure/activity (post-application)	hours	Distribution	US EPA distribution, EFSA constant, US EPA constant, user value	The duration for a person engaged in outdoor activities in contact with contaminated turf. Distribution based on EPA Exposure Factors Handbook ch16 (US EPA). EFSA and US recommendations are based on a curtailed distribution, giving an mean of 2.0 or 1.5 hours respectively. BROWSE survey data suggested much higher averages than this.
Half life of a.s. on adjacent vegetation	days	30	any	The half-life of the active substance on turf
Turf Transfer Residue	none	Distribution	US EPA values; EFSA values; distribution based on US EPA data; user value	Defines the fraction of the spray drift deposited on the turf which can be transferred to a person engaged in physical activity on the grass. No data available relating to spray drift, which will be present at the top of the grass sward, rather than penetrating into the turf as would be the case with a high-volume turf application, and more available for transfer. Suggested first tier default should be much higher than measurements made for high-volume turf applications. Data for turf applications also

				available from US (US EPA, February 2012) and European (Martin, et al., 2008) recommendations.
Transfer coefficient	m^2/h	US EPA distribution	US EPA distribution, US EPA constant, EFSA constant	Defines the area covered in an hour by a person engaged in physical activity on the grass. Data available from US (US EPA, February 2012) and European (Martin, et al., 2008) recommendations. US data sufficiently detailed to allow a distribution of transfer coefficients to be used.
Frequency of hand-to-mouth contact	none	20	any	Estimated for child (Martin, et al., 2008)

7 Model details

7.1 *Model 1: Exposure to spray drift - Boom Spraying*

7.1.1 Model outline& conceptual model

A diagram of the conceptual model for the spray drift component, which describes the source and dispersion, is shown in Fig.1. The Silsoe Spray Drift Model (Butler Ellis & Miller, 2010) is a particle tracking model, which simulates the release of droplets from a moving boom and calculates their trajectory, subject to complex air flows close to the nozzle, and then assumes a random walk further away. This model was used to generate training runs across the range of input variables, from which a series of emulators is developed. A separate emulator was developed for each model output, and for each non-continuous variable.

Model outputs are

1. Ground deposits
2. Airborne spray (adult)
3. Airborne spray (child)
4. Inhalation factor (adult)

5. Inhalation factor (child)

The non-continuous, or categorical, variables are

1. Spray quality (fine, medium, coarse, very coarse)
2. Crop height (short crop/bare soil, defined as 0.1 m; 0.5 m; 1.0 m; 1.5 m)

There are, therefore 4 x 4 x 5 (=80) emulators contained within the model.

Model emulators

The emulator is an approximation to the Silsoe spray drift model to allow estimation of multiple exposure types under a variety of scenarios, which can also account for uncertainty and variability in input parameters. In order to achieve this, it is essential to produce a fast model that can be run many thousands of times for any user-specified conditions selected from a wide range. The approximation errors should be as small as possible, but this requirement must be balanced against the need for practical implementation and fast calculations during real-time use.

Outputs from the Silsoe Spray Drift model are required to model exposures to bystanders, residents and operators but, due to its complexity, it is not practical for use directly in the Browse tool. In Appendix 1 a model to approximate these outputs is described, so that an output value can be estimated for any required input parameter set.

This approach is similar to that developed for the BREAM project (Defra, 2010) but with modifications to the Silsoe Spray Drift model, improved emulation and additional spray categories.

The conceptual model for the interaction between spray drift and the bystander or resident is shown in Figure 2. The approach used is similar to existing models of exposure for bystanders, taking account of alternative values for model parameters.

The model is run multiple times, selecting from inputs which are associated with distributions, to generate a distribution of outputs from which relevant percentiles of exposure can be determined. The model parameters which can be treated as distributions are shown in Table 8.

Table 8. Model parameters that can be distributions

Parameter	Distribution type	Source of data
Boom height	Normal	Estimated theoretically, following the method described in BREAM project (Defra, 2010), but standard deviation adjusted to 0.2 x boom height
Wind speed and angle	Normal	Based on experimental study collecting meteorological data; project funded by Defra (Defra, 2013)
Distance from treated area	Uniform	Defined by chosen population.
Bodyweight	Normal	EFSA recommendation (Efsa Scientific Committee, 2012)
Breathing rates	Normal	EPA exposure factors handbook, Ch 6 (US EPA)
Transfer coefficients	Normal	EPA recommendations (US EPA, February 2012)
Turf transfer residues	Normal	EPA recommendations (US EPA, February 2012)
Clothing protection	Uniform	Defined by practical considerations
Duration of exposure	Normal	EPA Exposure factors handbook Ch 16 (US EPA); supported by BROWSE survey data

7.1.2 Algorithms: Model inputs and outputs

Exposures are calculated from the outputs of emulators, which are based on the Silsoe Spray Drift Model.

These outputs are:

1. Ground deposit, G [ml/m^2]
2. Airborne spray (adult) [ml/m^2]
3. Airborne spray (child) [ml/m^2]
4. Inhalation factor for airborne spray (adult), If_a [ml/(m.s)]
5. Inhalation factor for airborne spray (child), If_c [ml/(m.s)]

7.1.2.1 Acute exposure

Components of exposure considered in the spray exposure models are

1. Spray inhalation
2. Direct dermal (airborne spray)

3. Direct ingestion (airborne spray collected on hands and then passed to mouth)
4. Indirect dermal (body contact with contaminated ground)
5. Indirect dermal (hand contact with contaminated ground and passed to mouth)

1. Spray Inhalation

Quantity of spray inhaled is given by

$$I = q(z)\ B / Ws \times \text{Inhalation absorption}/BW$$

- Where q(z) is the quantity of spray at height z [ml/m^2], Ws is the wind speed [m/s] and q(z)/Ws is the inhalation factor, I_f, [ml/(m.s)] output by the model – z is different for adults and children and therefore the inhalation factor is different for both.
- B is a breathing rate, also different for adults and children - use short term value or distribution, based on moderate activity. Units are [m^3/min] or [m^3/hour] and will need to be converted into [m^3/s] for this calculation
- IA - Inhalation absorption (%) – set as 100% default value
- BW – bodyweight (kg)

Therefore Inhalation exposure [ml] = I_f B x IA/BW ………………………………………… (1)

2. Direct Dermal/ 3. Ingested exposure

Dermal exposure [ml] = airborne spray (from emulator)[ml/m^2] x bystander height [m] x bystander collection efficiency [m^{-1}]

Bystander collection efficiency comes from the dataset used in the BREAM project relating mean airborne spray[ml/m^2] x bystander height [m] to bystander exposure [ml]) (Kennedy et al, 2012)

First calculate component which is ingested due to hand-to-mouth contact. If dermal absorption is greater than saliva extraction, then assume all exposure is dermal, as this is worst case.

If dermal absorption >= SE

Ingested exposure = 0 ………………………………………………………………………………… (2a)

If dermal absorption < SE

quantity ingested [ml] = Dermal exposure x Fh x Am/Ah x SE ………………………………..(2b)

- Where Fh is the fraction of dermal exposure on hands,
- Afh is the fraction of the area of hands making contact with the mouth – same value as for operators and workers (0.07)
- SE is saliva extraction factor (now called skin to mouth transfer factor)

Actual ingested exposure = quantity ingested x OA / BW ……………………………………….(2c)

where OA = Oral absorption (%) – set as 100% as a default

Actual dermal exposure [ml] = (dermal exposure – quantity ingested) x penetration of clothing x dermal absorption /BW ……………………………………………………………………….. (3)

Penetration of clothing is the fraction of dermal exposure that gets through to the skin (combination of the quantity of skin that is covered and the penetration of spray through clothing, although penetration expected to be small with the low levels of exposure compared with operator or worker)

4. Indirect Dermal/ 5. Ingested exposure

Indirect dermal exposure = G (from emulator) x TTR x TC x duration (H) x clothing penetration x dermal absorption/BW ……………………………………... (4)

- TTR – Turf Transfer Residue, fraction,
- TC – Transfer coefficient $[m^2/h]$
- H – from distribution (based on EFH and survey) [h]

Indirect Ingested exposure = G (from emulator) x TTR x SE x SA x Freq x H x OA /BW…………………. (5)

- SE – saliva extraction factor
- SA – surface area of hands in contact with mouth $[m^2]$
- Freq – frequency of hand-to-mouth contact, number per hour
- OA – Oral absorption (100%)

Get input data from user → select input data from distributions → run emulators for adult and child for 5 outputs (G, Meanair adult, Meanair child, I_f adult, I_f child → multiply by flowrate factor → multiply by wbd factors → multiply by spray drift reduction factor→ determine spray Inhalation (1), direct ingestion (2) direct dermal (3), indirect dermal (4)and indirect ingestion (5) exposure and add →repeat for next set of input data.

Also keep each component separate for user information.

Flowrate factors:

Multiply the output of the emulator by a factor determined by nozzle flow rate (l/min) and spray quality:

Fine	Flowrate/0.48
Medium	Flowrate/1.2
Coarse	Flowrate/1.94
Very Coarse	Flowrate/2.87

Spray drift reduction factors:

25% - 0.75

50% - 0.5

75% - 0.25

90% - 0.1

95% - 0.05

Wbd factors:

Multiply the output of the emulator by a factor determined by wet bulb depression:

0 – 3 °C	*1.0*
3 – 7 °C	*1.4*
> 7 °C	*1.9*

Numbers obtained from these equations relate to volume of spray liquid, Q_{sl} (ml). Need to turn into quantity of active ingredient, Q_{ai} (mg).

$$Q_{ai} = Q_{sl} \text{ x dose x conc / app vol}$$

where **dose** is litres/ha product,

conc is the concentration of active ingredient in product, g/l and

app vol is the volume of water used, litres/ha.

7.1.2.2 Longer term exposure

The routes of exposure considered in the long-term assessment are the same as for acute exposure. The main differences are that the indirect exposure from contact with contaminated ground is from applications to two fields, this contact is repeated daily, and spray deposit decays with time.

Direct dermal, inhalation and ingestion calculations are identical to those for the acute exposure.

Indirect Dermal/Ingested exposure

Nd = number of days over which the assessment is to be made

$T_{1/2}$ = half-life (d) of active ingredient on vegetation

G(on day d) = G (from emulator) x exp(-0.69 d / $T_{1/2}$) .... (6)

Other calculations are then the same as for acute exposure, but using a time-dependent value of G:

Indirect dermal exposure (on day d) = G (d) x TTR x TC x duration (H) x clothing penetration x dermal absorption/ BW .... (7)

- TTR – Turf Transfer Residue, fraction,
- TC – Transfer coefficient
- H – from distribution (based on EFH and survey)

Indirect Ingested exposure = G (d) x TTR x SE x SA x Freq x H x OA/BW .... (8)

- SE – saliva extraction factor
- SA – surface area of hands in contact with mouth
- Freq – frequency of hand-to-mouth contact, number per hour

Running model:-

Get input data from user → select input data from distributions, including two distances, x & y → calculate 6 outputs (G, Airborne adult, Airborne child, I_f adult, I_f child for x, and a second value of G for y, and add G(y) to G(x)→adjust for spray drift reduction →adjust for wet bulb depression→ determine spray Inhalation (1), direct ingestion (2) and dermal (3), →determine indirect dermal (7)and ingestion (8) exposure and add →repeat calculation of indirect exposure (7 & 8) for next day (d=d+1) until d=Nd, → calculate average 24 hour exposure over Nd days, → repeat for next set of input data to get a distribution of average exposures

Also keep each component separate for user information.

Values obtained from these equations relate to volume of spray liquid, Q_{sl} (ml). To evaluate quantity of active ingredient, Q_{ai} (mg):

$$Q_{ai} = Q_{sl} \text{ x dose x Na x conc / app vol}$$

where dose is litres/ha product,

conc is the concentration of active ingredient in product, g/l and

app vol is the volume of water used, litres/ha.

Na is the number of applications made in the period of Nd days.

Nd – number of days over which the assessment is to be made

$T_{1/2}$ – half life of active ingredient, days

7.2 Model 2: Vapour exposure

7.2.1 Model outline & basic concepts

The emission of vapour into the air after spraying the plant protection product on the crop or soil is computed by the PEARL model (**P**esticide **E**mission **A**ssessment at **R**egional and **L**ocal scales). The version of PEARL for BROWSE is based on the PEARL version currently being used (i.e. FOCUS_PEARL_444) to assess leaching to groundwater in the registration procedure at the EU level. This version includes the improved description of the volatilisation of plant protection products from crops as well as the description of competing processes on the plant surface, such as penetration into the plant tissue, wash-off and photo-transformation (Van den Berg & Leistra, 2004). Moreover, this version has an option to read meteorological data on an hourly basis, so the volatilisation can be assessed on an hourly basis.

The PEARL model has been coupled to the atmospheric dispersion model OPS (**O**perational Atmospheric Transport Model for **P**riority **S**ubstances) that simulates atmospheric concentration and dry deposition of pollutants in a given area of interest. OPS simulates the atmospheric process sequence of dispersion, transport, chemical conversion and finally deposition (Van Jaarsveld, 2004). The special high-resolution model version of OPS used for the BROWSE Scenarios, OPS-St (St for Short term) allows hour-to-hour variations in emissions to be included (Van Pul, Jaarsveld, J A, van den Broek, & Smits, 2008). OPS has been set up as a universal framework supporting the modeling of a wide variety of pollutants and specific applications.

OPS-St is able to compute the concentration at hourly time steps, using a variable surface source strength. The output is computed for receptor points to be specified by the user. The simulations take into account 1) the source characteristics and strength; 2) the meteorological conditions; 3) local land cover and land use in the area and at the specific receptor points. For BROWSE, the improved PEARL model was coupled to OPS-St to enable the prediction of time-dependent air concentrations at an hourly resolution at locations around and within the source field.

The coupled Pearl-OPS model determines the concentration at two heights for the layout and locations shown in Figure 3. Further details of Pearl are given in Appendix 2. The conceptual model for the interaction between the airborne vapour and the resident or bystander is the same as is used for spray drift (Figure 2) but includes only the inhalation component.

The treated area is a variable: either 200 m x 200 m, 500 m x 500 m or 2000 m x 2000 m. In regions where field sizes are small, there are likely to be groups of fields that are treated with the same chemical at a similar time, and so the area should be considered as a block of fields. The distance at which the exposure of residents and bystanders are assessed is fixed at 10 m. Unlike spray drift, the airborne concentrations of vapour are relatively insensitive to distance within the range 2 to 20 m for treated areas of 200 m x 200 m or more and therefore does not make a significant impact on the variability of exposure calculations.

In order to simulate the situation where the resident/bystander is surrounded on all sides by treated fields, so whichever way the wind is blowing, the bystander is always downwind, the receptor with the highest concentration during any one-hour period is selected.

For the scenarios for volatilisation from crops after spraying, a reference crop is assumed to be present throughout. The crop height is set to 0.1 m, which results in worst case concentration in air at short distances from the field.

The rate of volatilisation of a plant protection product from crops is strongly driven by vapour pressure. Because vapour pressure increases with temperature, locations with arable crops were identified in each EU zone with an average air temperature in the growing season (April-October) corresponding to the 90th percentile of the average temperatures within that zone (realistic worst case conditions). Sites were selected in the Northern zone (Denmark), Central zone (Germany and Hungary) and Southern zone (Spain and Italy). For each site meteorological data on an hourly basis for the period 2005 – 2009 were collected. Appendix 3 describes the methodology for defining the locations of the meteorological data, and Appendix 4 summarises the mean temperature and wind speeds for each site chosen.

The model is then run assuming a single application. An application of the pesticide is made every seven days from April – September; to avoid overlap in emission resulting from 2 consecutive applications, the residue of the compound was set to zero just before the next application. While in practice there could be a cumulative dose on the crop from sequential applications, it is unlikely as other processes, not currently taken into account in the BROWSE model, will increase the rate of loss from the crop. These processes include wash-off by rainfall, photodegradation and uptake by the plant.

The coupled PEARL-OPS models are run for five years of meteorological data to have a wide range of meteorological conditions at the time and on the days following each application. The outputs of Pearl-OPS are concentrations at each of the specified locations for each hour of five seasons. The output data is then processed to determine:

- The maximum 24 – hour mean concentration for each application.
- The long-term average concentration over 7 days for each application

The methodology for processing this output data is given in Appendix 5.

There is therefore a distribution of maximum 24-hour concentrations (associated with each application date across the five years) and a distribution of long-term average concentrations (associated with each set of application dates across the five years).

For the scenarios for volatilisation from bare soil, applications are assumed to be only possible in the period 1 October – 31 March. Data on soil profiles were taken from the EFSA soil persistence scenarios, since the soil profiles in these scenarios are low in organic matter content. A low organic matter content results in comparatively high concentrations in the liquid and/or gas phase, so this favours conditions for high volatilisation rates from the soil. For the first tier for BROWSE, transformation in soil is not considered. The substance can be transported down into the soil profile by downward water flow resulting from rainfall infiltrating the soil.

Ultimately, a tiered approach to the exposure assessment is proposed. The current BROWSE model includes only the first tier, where the sole mechanism removing the compound from the leaf surface is considered to be volatilisation. The input data required are the physico-chemical properties of the substance, such as the vapour pressure and the water solubility, application data, such as dosage, application interval (time between 2 consecutive applications) and size of treated area.

The calculated concentrations are used to determine acute and long-term exposure as follows:

Acute exposure (µg/day) = maximum 24-hour concentration, ug/m^3 x (short term breathing rate, m^3/hour x duration + long term breathing rate, m^3/hour x (24 - duration)) ……………..……………….(9)
where the short term breathing rate relates to 'moderate' activity and 'duration' is the length of time over which that moderate activity occurs.
Long term exposure (µg/day) = long term average concentration, ug/m^3 x long term breathing rate, m^3/day ……………. ……………………………………………….(10)

7.3 Calculating total exposure – boom spray and vapour

The separate routes of exposure given in section 4.2 are displayed individually in the model outputs and are also added together in the following way to determine a total exposure.

7.3.1 Acute exposure

1. Select the following inputs from distributions
   - Boom height
   - windspeed
   - distance from the edge of the field
2. Run the appropriate emulators
3. Select the following inputs from distributions
   - Clothing penetration
   - Turf transferable residue
   - Transfer coefficient
   - Breathing rate, long term & short term
   - duration
4. Calculate direct dermal, direct inhalation, direct ingestion, indirect dermal, indirect ingestion
5. Select from distribution of vapour concentration (acute, peak 24 hour mean)
6. Calculate vapour inhalation ((concentration, ug/m^3 x (short term breathing rate, m^3/hour x duration + long term breathing rate, m^3/hour x (24 – duration))

i.e. the bystander has a period of time of higher than average activity, so higher than average breathing rate, but this cannot last all day, but will continue to be exposed over the rest of the 24 hours.

7. Add all together – total exposure
8. Select bodyweight
9. Calculate exposure/bodyweight:
   - Direct dermal
   - Direct inhalation
   - Direct ingestion
   - Indirect dermal
   - Indirect ingestion
   - Vapour inalation
   - Total

7.3.2 Long term exposure

1. Select the following inputs from distributions
   - Boom height

- Wind speed
- Distance from the edge of the field

2. Run the Ground emulator – G1

3. Repeat the process for second value G2, and add G1+G2

4. Calculate total ground deposits for the subsequent N days

5. Select the following inputs from distributions. I assume that they do not change across the days, although it is arguable that they might change across the N days. I have made the assumption that an individual will behave similarly, and the characteristics of the deposit won't change, across the N days.

- Clothing penetration
- Turf transferable residue
- Transfer coefficient
- Breathing rate, long term
- duration

6. Calculate indirect dermal, indirect ingestion
7. Select from distribution of vapour concentration (long-term, N-day mean)
8. Calculate vapour inhalation.
9. Add all together – total exposure
10. Select bodyweight
11. Calculate exposure/bodyweight:

- Direct dermal
- Direct inhalation
- Direct ingestion
- Indirect dermal
- Indirect ingestion
- Vapour inhalation
- Total

From the resulting distribution of exposures, acute or longer term, specific target percentile exposures can be calculated for each individual exposure route and for the total exposure.

7.4 Model 3: Exposure to spray drift - Orchard spraying

The model for exposure to spray drift from orchard applications follows exactly the same structure as for boom spraying, but the outputs that are generated by an emulator for the boom sprayer model are determined from experimental spray drift data combined with some empirical relationships.

These outputs are:

1. Ground deposit, G [ml/m^2]
2. Airborne spray (adult) [ml/m^2]
3. Airborne spray (child) [ml/m^2]
4. Inhalation factor for airborne spray (adult), If_a [ml/(m.s)]
5. Inhalation factor for airborne spray (child), If_c [ml/(m.s)]

This section describes only how these outputs are determined from the available data, and the determination of exposures follows the procedures described in sections 7.1.2, 7.2 and 7.3.

Whereas in the boom sprayer model, the basic spray drift values were determined from emulators, in the Orchard Model, these will be determined largely from experimental data. **Note that the units of the experimental data for the orchard model are relative (i.e. % applied) whereas the emulators for the boom model give an absolute value, so the calculations will be slightly different in places.** There are six sets of data, relating to the two types of sprayer (cross flow and axial fan) and the three growth stages (dormant, transition and full leaf).

7.4.1 Determination of Ground deposit, G

Ground deposit data are available between 5 and 25 m downwind (Zande, 2014). Curves were fitted to each measurement set so that when a ground deposit is required for a particular distance downwind, a curve will be sampled at random from the appropriate sprayer/growth stage dataset, and the ground deposit at the required distance will be determined.

7.4.2 Determination of Airborne spray

The airborne spray will be derived from two sets of data, measured in different ways. A comparison of the two measurement techniques was made in (Butler Ellis M. C., 2014) which showed they were sufficiently similar to allow data to be combined.

1. The measured airborne spray at a single distance downwind for adult (0 – 2 m height) and child (0- 1 m height) for each of the six situations.

   For the UK data, this will be the value of the 0-1 m height measurement for children, and the average of the 0-1 m and the 1-2 m height measurements for adults;

For the NL data, it will be the average of the 0 and 1 m height values for children, and the average of 0, 1 and 2 m height values for adults.

2. A number of matrices relating airborne spray at the measured distance to airborne spray at another distance between 2 and 20 m downwind (adult, child, sprayer type, growth stage). This is based on data obtained by (Michelsen, 2007)

The adult (or child) airborne spray will be obtained by sampling randomly from the appropriate dataset in (1) and then adjusting according to the appropriate matrix in (2) to get the airborne spray at the required distance.

7.4.3 Determination of inhalation

Inhalation factors require knowledge of the wind speed at the location of the breathing zone of the bystander, but this information is not available, nor is it so easy to determine from the wind speed measurements that are. We have therefore taken a reasonable worst case – e.g. 1 m/s for adult and 0.5 m/s for a child. Since inhalation is small compared with the other sources, this simplistic approach is unlikely to contribute to over-conservatism in the total exposure.

(1) Inhalation is determined in a similar way as for airborne spray:

For UK data, the 0-1 m height value for children, and the 1 – 2 m height value for adults

For NL data, the average of the 0 and 1 m height values for children and the average of the 1 and 2 m height values for adults

Matrices for the variation of these values with distance are used to exptrapolate to different distances, but the ones for children' inhalation factors will be the same as those for airborne spray. i.e. three sets of matrices will be required in total, one for 0 -1 m height (airborne child, and inhalation child), one for 0 – 2 m height (airborne adult) and one for 1 – 2 m height (inhalation adult).

Inhalation factor with then be determined by sampling from the data and then adjusting according to the distance matrix and dividing by an estimate of wind speed as proposed above.

7.4.4 Adjustment for spray drift reduction

If there is any spray drift reduction (or a spray quality other than ’fine’ or ‘very fine’ selected) the value of G, Aa, Ac, Ifa, Ifc will be adjusted according to the appropriate spray drift reduction curve, which will give an adjustment factor as a function of distance.

In theory, there could be 150 of these curves (5 outputs x 2 sprayer types x 3 growth stages x 5 spray drift reduction classes) but in practice there is a smaller number of curves each covering a wider range of situations.

A detailed description of the statistical methods used in the orchard sprayer model is given in Appendix 7

8 Testing and validation

8.1 Testing of software

All code was peer-reviewed within the software team and then tested by partners to ensure it performed as intended, before release to the BROWSE Advisory Panel and stakeholders for further testing prior to the stakeholder workshop in October 2013. Changes to those models, and the addition of further models was then undertaken and a new programme of testing begun. This is likely to be ongoing as bugs are identified and corrected.

One objective of the testing was to ensure that this version ran with reasonable combinations of inputs, typical of those that we anticipate will be used in practice. We have aimed to ensure that it will run for at least all scenarios that can be considered good practice. Model outputs have been checked to ensure that, where we have good knowledge about the effect of input parameters, the responses to changes in inputs are as expected.

8.2 Comparison with existing exposure assessment

Comparing the results of the BROWSE model with exposure assessment models is not straightforward because of the different approaches taken.

- For a given scenario which determines a single exposure estimate when used in existing models, there is a wide range of possible exposure estimates from BROWSE, depending on the values used as other inputs.
- BROWSE produces a distribution of exposures, rather than a single value.
- Not only are there differences in the separate components of exposure between existing models and BROWSE, there are differences in the way these components are combined to produce acute and long-term exposure.
- In fact current exposure models do not explicitly calculate both long-term and acute exposures, but only one exposure which, since it is then compared to the AOEL, is presumed to be a long-term value.

A separate report was been provided by BPI which aims to consider the comparison between the two main existing models (Germany and UK) and some results produced by the BROWSE model, using the version made available for the October 2013 Stakeholder Workshop. (Charistou, 2013).

While this showed significantly greater exposures from BROWSE using the example calculation (see Figure 4), it is possible to run the BROWSE model using input values representative of the experimental conditions under which the data underlying the UK model were obtained, and to achieve very similar estimations of exposure. The main reason for the increased predicted exposure with BROWSE, compared with existing models, is because a scenario which is more representative of current practice (in some EU member states) is used as the default.

The case studies shown in section 11 below also include some comparisons between BROWSE predictions and the current exposure model used by the UK CRD.

8.3 *Validation against experimental data*

When the BROWSE model has been fully tested, it will be possible to test predictions against the available experimental data. For bystander dermal exposure, this includes some data that is part of the empirical component of the model (Butler Ellis, Lane, O'Sullivan, Miller, & Glass, 2010) and therefore would not be a true validation exercise. There is some data, however, that is not used in the model (Lloyd & Bell, 1983), (Lloyd J. , Bell, Samuels, Cross, & Berrie, 1987) is available, and these could be used in a more formal validation of the model.

For the model of exposure to vapour, a preliminary exercise has been undertaken to compare vapour concentrations predicted using PEARL-OPS with those measured in field experiments (Glass, Mathers, Hetmanski, Sehnalova, & Fussell, 2012). This showed reasonably good model predictions, given some of the simplifications and assumptions used. This study is given in Appendix 8.

9 Uncertainties and conservatism in the model

The degree of conservatism is, to a great extent, under the control of the user. The user can select the input values to manipulate the conditions under which the application is made and some elements of bystander or resident behaviour. Thus the model can be run to represent best practice, poor practice where this is known to occur, or to take account of unpredictable behaviour by operators and/or members of the public. The range of input values is not unlimited, as it is important to ensure that the model is not run outside its valid range.

Default values are provided which aim, overall, to represent a realistic case, tending towards worst case. However, each individual default input is not necessarily a worst case, as this would provide an over-conservative (and unrealistic) estimate.

A choice of alternative input values are provided based on current models, but the recommended default is, wherever possible, a distribution. This ensures that we do not propagate uncertainties and variability through the model in an unrealistic way. Wherever possible, the model also allows for manual over-ride so that should new data become available, it can be used in the model.

In the current first tier assessment for vapour exposure after application to crops, volatilisation is the only dissipation process considered. Competing processes on the crop canopy such photo-degradation, wash-off and penetration into the plant tissue are not considered. This results in conservative estimates of the emission into the air and consequently also of the vapour exposure.

There is a number of inputs that cannot be changed, and these are fixed as a reasonable worst case. These are listed in Table 9.

Table 9. Inputs to the model that cannot be varied

Input	Fixed value	Comments
Height of bystander	2.0 m for adults; 1.0 m for children	Worst case = higher values
Height of breathing zone above ground	1.4 m for adults; 0.7 m for children	Worst case = lower values
Nozzle spacing	0.5 m	Typical value – not a fundamental parameter influencing spray drift
Location for meteorological data for vapour exposure assessment	90th percentile for mean temperature across April – September, evaluated for crop-growing regions in the zone	Temperature is one of the biggest drivers for volatilisation; wind speed also influential, so a location with a lower temperature and a lower wind speed could give higher exposures, but the chosen locations give a reasonable worst case.
Crop height for vapour exposure	0.1 m	This is probably a worst case; future developments may include a higher tier approach where crop height can be varied.

When the model is run with the proposed default inputs, the exposure estimates relate to the population of residents and bystanders defined above, with the environmental and spray application conditions typical, but tending towards a worst case scenario, for Europe. The output represents a distribution of exposures within this population, taking account of variation and uncertainty due to: meteorological data; boom height fluctuations; efficiency of transfer of pesticide from air or ground to skin; location, clothing, duration of activity, bodyweight and breathing rates of the exposed people.

10 Data used in model development

A range of sources of data were used in the development of the models. Lists of model inputs, and the data that was used to define them, are given in Section 6.

The main datasets that are ‘embedded’ in the model, rather than being explicit model inputs, and are therefore not necessarily obvious to the user, are shown in Table 10.

Table 10. Data used in the model

Data	BROWSE scenario	Purpose in model	Source
Droplet size and velocity distributions	Spray drift exposure from boom sprayers	Used as input to the Silsoe Spray Drift model when creating emulators for the 'fine', 'medium, 'coarse' and 'very coarse' sprays	Generated at Silsoe Spray Applications Unit as part of the BREAM and BROWSE projects
Output from the Silsoe Spray Drift Model	Spray drift exposure from boom sprayers	Training data to develop the emulators for the boom sprayer model	Generated at Silsoe Spray Applications Unit as part of the BROWSE project
Data defining the relationship between airborne spray and bystander exposure	Spray drift exposure from boom sprayers and from orchard sprayers	To take model predictions of airborne spray concentration and extrapolate to the quantity deposited on a human body	Generated at Silsoe Spray Applications Unit as part of the BREAM project, and as part of UK Defra-funded project PS2032
Spray drift data from orchard sprayers	Spray drift exposure from orchard sprayers	To estimate airborne spray concentration and ground deposits for the orchard sprayer exposure model; the relationship between airborne spray and distance, and the effect of spray drift reduction	Data obtained over a number of years by WUR-PRI (NL) and Silsoe Research Insitute (UK)
Meteorological data – 5 years of hourly data per location	Vapour exposure – residents, bystanders and workers	To use as input to Pearl-OPS to calculate emission and dispersion	German data from the Deutsche Wetterdienst; the other data from FLUXNET

11 Case studies

11.1 Model 1: exposure to spray drift – boom spraying

An example calculation, based on the case study used in the CRD Guidance (Chemicals Regulation Directorate), summarised in Table 11, is shown in Figure 5.

Table 11 Input values for example calculation. All other inputs were model defaults as defined in Tables 1,2 and 5.

Single application with a test product	Dermal absorption = 17%
Concentration of a.s. in product = 125 g/l	Inhalation absorption =100%
Applied dose = 1 L product per ha	Oral absorption = 100%

Applied water volume = 200 L/ha	

A distribution of outputs is calculated, and a number of different centiles of the distributions can be selected by the user. The relative importance of each component of exposure is shown in Figure 5 for median values, and it can be seen that dermal exposure for this scenario was the largest for both acute and longer term exposures. Direct dermal exposure is greatest for acute exposure, and indirect dermal exposure is greatest for longer-term, as it is repeated daily.

Table 12 shows the median, 75th and 95th percentile of the output distribution for exposures, compared with the CRD case study. (Note that this case study used double the applied dose to determine the indirect exposures, shown in the lower half of the table for a child only, and we have therefore halved the CRD figures for comparison).

It can be seen that the BROWSE model acute exposure distribution has a median that is similar to the existing CRD exposure assessment for direct dermal exposure, but the 95th percentile (recommended by EFSA for acute exposure calculations) is significantly higher. Spray inhalation exposure is lower in the BROWSE model, however, because the CRD model uses the limit of detection of experimental data, whereas BROWSE attempts a realistic estimate.

The BROWSE indirect exposure calculation shows a greater longer-term exposure than the acute exposure, which is counter-intuitive. For indirect exposure, it is assumed that (a) the exposure occurs daily, and in this case study, the half life of the pesticide on the turf is 30 d so there is little decay over the 7 d exposure period, leading to a similar exposure to that for the acute calculation; and (b) there are two neighbouring fields that have contributed to the exposure, rather than a single field that is used for the acute calculation.

Indirect dermal exposure is higher in the BROWSE model than the CRD calculation, largely because a more realistic estimate of ground deposits are used by BROWSE and because there has been a revision in the default values for input parameters, compared with those used by CRD. Indirect ingestion exposure is similar to the CRD calculation.

Table 12. Example output from BROWSE model version 4.4 compared with CRD case study for boom sprayers. Exposures are mg/kg

	Acute - BROWSE centiles			Longer-term BROWSE centiles			CRD
	median	75th	95th	median	75th	95th	
adult							
direct dermal	1.51E-04	4.19E-04	1.77E-03	2.16E-05	5.99E-05	2.52E-04	1.77E-04
spray inhalation	3.32E-06	4.29E-06	6.30E-06	4.74E-07	6.13E-07	9.01E-07	1.04E-04
child							
direct dermal	6.41E-04	1.77E-03	7.57E-03	9.15E-05	2.53E-04	1.08E-03	7.08E-04
spray inhalation	3.12E-05	4.34E-05	6.95E-05	4.46E-06	6.21E-06	9.93E-06	4.16E-04

	Acute - BROWSE centiles			Longer-term BROWSE centiles			CRD
	median	75th	95th	median	75th	95th	
child							
indirect dermal	2.05E-04	5.59E-04	2.14E-03	4.61E-04	1.18E-03	3.89E-03	7.50E-05
indirect ingestion	1.18E-06	2.89E-06	9.77E-06	2.66E-06	6.04E-06	1.72E-05	1.65E-05

11.2 Model 2: exposure to spray drift – orchard spraying

An example calculation, based on the case study used in the CRD Guidance (Chemicals Regulation Directorate), summarised in Table 13, is shown in Figure 6.

Table 13. Input values for example calculation. All other inputs were model defaults as defined in Tables 1, 6 and 7.

Single application with a test product	Dermal absorption = 17%
Concentration of a.s. in product = 125 g/l	Inhalation absorption =100%
Applied dose = 1 L product per ha (2 L/ha for indirect exposure calculation)	Oral absorption = 100%
Applied water volume = 200 L/ha	Forward speed 12 km/h

A distribution of outputs is calculated, and a number of different centiles of the distributions can be selected by the user. The relative importance of each component of exposure is shown in Figure 6 for median values, and it can be seen that indirect dermal exposure for this scenario was the largest for both acute and longer term exposures.

Table 14 shows the median, 75th and 95th percentile of the output distribution for exposures, compared with the CRD case study. (Note that this case study used six times the applied dose to determine the indirect exposures, shown in the lower half of the table for a child only, and we have therefore divided the CRD figures by six for comparison).

Table 14. Example output from BROWSE model version 4.4 compared with CRD case study for orchard sprayers. Exposures are mg/kg

	Acute -BROWSE centiles			Longer-term - BROWSE centiles			CRD
	median	75th	95th	median	75th	95th	
adult							
direct dermal	1.64E-04	5.09E-04	2.52E-03	2.34E-05	7.25E-05	3.60E-04	3.28E-03
spray inhalation	1.46E-05	2.69E-05	5.94E-05	2.10E-06	3.85E-06	8.46E-06	1.04E-05
child							
direct dermal	6.78E-04	2.13E-03	1.05E-02	9.57E-05	3.02E-04	1.50E-03	1.31E-02
spray inhalation	1.35E-04	2.61E-04	5.72E-04	1.93E-05	3.73E-05	8.24E-05	4.16E-05

	Acute -BROWSE centiles			Longer-term - BROWSE centiles			CRD
	median	75th	95th	median	75th	95th	
child							
indirect dermal	1.44E-03	4.21E-03	1.66E-02	2.84E-03	7.48E-03	1.48E-01	1.98E-04
indirect ingestion	8.20E-06	2.19E-05	7.61E-05	1.64E-05	3.85E-05	1.11E-04	4.50E-05

It can be seen that the BROWSE model acute exposure distribution has a 95th percentile that is similar to the existing CRD exposure assessment for direct dermal exposure. Spray inhalation exposure is comparable to the median in the BROWSE model, however. This may be because of the conservative approach to estimating the wind speed at bystander height, which directly influences the inhalation exposure.

Indirect dermal exposure is significantly higher than in the CRD calculation, largely because of an increase in ground deposits and in the transfer coefficient from turf to a human, whereas indirect ingestion is comparable to the 75th percentile of the acute distribution.

11.3 Exposure to vapour – boom and orchard sprayer models

Much less is known about how input parameters to the vapour exposure model influence exposures than for the spray drift models. Prior to comparing the results of the BROWSE vapour exposure model with the CRD model, some evaluations of the effects of the input parameters on predicted exposures were undertaken, therefore, to improve our understanding of the underlying processes.

Figure 7 shows the effect of vapour pressure on exposure. While an increase in vapour pressure results in an increase in the volatilisation rate, this does not necessarily translate into an increase in exposure because exposure also depends on the duration of the exposure period. For a high volatilisation rate, the duration can be short, and therefore the exposure will be reduced. The blue shaded area in Figure 7 relates to vapour pressures that are denoted ‘moderately volatile’ in Efsa guidance (EFSA Panel on Plant Protection Products and their Residues (PPR), 2010). This shows that the proposed EFSA classification might be misleading as the highest exposures do not necessarily occur with the highest vapour pressures. These simulations were undertaken using meteorological data for the Northern zone (i.e. lower temperatures than sites in the other zones. The results are different for the alternative sites: an example for the site in Spain is shown in Figure 8.

The effect of weather conditions is also not intuitive. A high temperature increases the volatilisation rate but the highest temperatures do not necessarily translate into the highest exposures if the duration is reduced. This is shown in Figure 9 for a relatively high vapour pressure active substance and a lower one. The Southern locations with the highest temperatures only give the highest exposures for the lower vapour pressure substance (see appendix 4 for details of temperatures for the different locations). For a ‘moderately volatile’ active substance, the meteorological data for the sites in the central zone gave the highest exposures.

To compare outputs of the BROWSE model with current exposure models, again the UK CRD model is used as an example case study. Table 15 shows the input values used. Tables 16 and 17 show the predicted exposures compared with those used in the CRD examples for a moderate and a low volatility active substance at two sites.

Table 15 Input values for example calculation. All other inputs were model defaults as defined in Tables 1,2 and 5.

Single application with a test product	7 d exposure period
Concentration of a.s. in product = 250 g/l	Inhalation absorption =100%
Applied dose = 2 L/ha	Northern Zone and Southern zone (Spain)
500 m x 500 m treated area	Vapour pressures 0.005 Pa and 0.0001 Pa measured at 20 C
Water solubility 100 mg/l at 20 C	

Table 16. Predicted exposures from a moderately volatile a.s. (vapour pressure = 0.005 Pa at 20 C) for two locations

	Northern			Southern (Spain)			
	median	75th centile	95th centile	median	75th centile	95th centile	CRD
adult acute	1.4	1.89	3.01	0.947	1.4	2.93	3.8
adult longer term	0.189	0.244	0.385	0.137	0.179	0.335	
child acute	6.81	9.12	14.3	4.57	6.69	14.1	9
child longer term	0.905	1.16	1.8	0.658	0.845	1.59	

Table 17. Predicted exposures from a low volatility a.s. (vapour pressure = 0.0001 Pa at 20 C) for two locations. Exposures are μg/kg.

	Northern			Southern (Spain)			
	median	75th centile	95th centile	median	75th centile	95th centile	CRD
adult acute	0.114	0.176	0.367	0.636	0.927	1.51	0.253
adult longer term	0.0416	0.0606	0.118	0.25	0.324	0.452	
child acute	0.553	0.846	1.76	3.09	4.49	7.28	0.6
child longer term	0.2	0.289	0.56	1.21	1.56	2.13	

The CRD calculation is of a similar order of magnitude to the BROWSE predictions, but the BROWSE model gives higher values for some situations, particularly when higher percentiles are used. The greatest difference between the two in the case study above was for exposure to a low volatility pesticide in the southern zone.

11.4 Relative importance of vapour and spray exposures

The relative importance of the different routes of exposure for residents and bystanders depends on too many factors to be able to definitively say that any route is less important to consider in an exposure assessment than the others. The same boom sprayer scenario that was simulated in Fig 6 was repeated, but this time including vapour exposure to a low volatility pesticide in the central zone over a 500 x 500 m treated area. It can be seen in Figure 10 that the main contributors to the total exposure are inhaled vapour, direct dermal and indirect dermal exposure. Spray inhalation and ingestion contribute relatively low amounts.

12 Stakeholder input

Stakeholder input was solicited at the start of the project at a workshop (Frewer, et al., 2011) and again when the first models were available in October 2013. Other stakeholder inputs, including from the Advisory Panel, were received over the course of the project. The stakeholder comments specific to work package 3, i.e. resident and bystander exposure models, are given in Appendix 8, together with the project responses to those comments.

There were a significant number of comments and questions relating to the definitions of ‘resident’ and ‘bystander’, and of ‘acute’ and ‘longer term’ exposures. In order to reduce the likelihood of confusion arising from a lack of clarity, the models now relate to a single group of ‘residents and bystanders’ who are people who can be present for any length of time, adjacent to agricultural land that is treated with pesticides.

There were also some comments relating to the routes of exposure that are included in long-term exposures. In the initial models made available for the October 2013 stakeholder workshop, it was assumed that, by definition, a single direct exposure to spray drift during an application event was an ‘acute’ exposure, and was not therefore included in the longer-term exposure calculation. In response to a direct question about this from the project team during the workshop, a number of stakeholders suggested that this was not reasonable, and therefore the revised models include direct exposure to spray drift in the longer-term exposure calculation.

It is suggested that further discussion on this would be fruitful – the model now assumes that a single high exposure on one day is equivalent to a lower exposure repeated over a number of days, and this might not be a scientifically justifiable approach.

13 Conclusions

A model has been developed for estimating the exposure of residents and bystanders to pesticides used in agriculture. The model takes a probabilistic approach by, wherever possible, using distributions of model inputs rather than single values.

The models currently predict the following exposure routes:

- Dermal exposure to spray drift
- Inhaled exposure to spray drift
- Inhaled exposure to vapour
- Dermal exposure from contact with contaminated land
- Oral exposure from hand-to-mouth contact.

The models include spray drift from boom and orchard sprayers, and therefore are applicable to a wide range of outdoor crops, and vapour emissions from all outdoor crops.

The benefits of the BROWSE model are that:

- Mitigation measures to reduce exposure (such as drift reduction technology) can be taken into account if required
- The model is sufficiently flexible to allow the wide range of application practices around the EU to be addressed
- The model includes realistic scenarios – where data is available about current practice and behaviour, this is used and unrealistic cases are avoided.
- The use of probabilistic modelling avoids an over-conservative approach.

In example calculations conducted to date, the greatest contributions to exposure from boom sprayer applications was seen to arise from direct and indirect dermal exposure, and inhaled vapour. Exposure from Inhaled and ingested spray appeared to be relatively insignificant.

Comparison with existing models was not straightforward because of the significant differences in the approaches. However, an initial comparison showed that, while the BROWSE example calculation showed greater exposures in some circumstances than current UK and German exposure models, it is possible to run the BROWSE model using input values representative of the experimental conditions under which the data underlying the UK model were obtained, and to achieve very similar estimations of exposure. The main reason for the increased predicted exposure with BROWSE, compared with existing models, is because a scenario which is more representative of current practice (in some EU member states) is used as the default, and the use of 75th and 95th percentiles further increases estimated exposures. Further model developments have taken place since this comparison was undertaken, and initial tests suggest that this remains true for exposure estimates for boom sprayer applications.

14 Bibliography

Arapaki, N., & Charistou, A. (2013). *Example scenarios for testing BROWSE models and comparison with the existing models.* BROWSE, internal working document.

Butler Ellis, M. C. (2014). Bystander and Resident exposure to spray drift from orchard application: field measurements, including a comparison of spray drift collectors. *International Advances in Pesticide Application, Aspects of Applied Biology vol 122*, (pp. 187-194).

Butler Ellis, M. C., & Miller, P. C. (2010). The Silsoe Spray Drift Model: A model of spray drift for the assessment of non-target exposures to pesticides. *Biosystems Engineering , 107*, 169-177.

Butler Ellis, M. C., Lane, A. G., O'Sullivan, C. M., Miller, P. C., & Glass, R. G. (2010). Bystander exposure to pesticide spray drift: New data for model development and validation. *Biosystems Engineering, 107* , 162-168.

Butler Ellis, M. C., O'Sullivan, C. M., Fragkoulis, G., Trevisan, M., van den Berg, F., & Capri, E. (2010). *Overview of currently used and emerging exposure models and data.* BROWSE Project.

Charistou, A. (2013). *Sub-report to the report "Work Package 3: Models of exposure to agricultural pesticides for bystanders and residents": Comparison with existing boom sprayer models.* BROWSE project.

Chemicals Regulation Directorate. (n.d.). *Bystander Exposure Guidance.* Retrieved Sept 2014, from Health and Safety Executive - Pesticides: http://www.pesticides.gov.uk/Resources/CRD/Migrated-Resources/Documents/B/Bystander-exposure-guidance.pdf

Defra. (2006). *PS2005*. Retrieved 2013, from http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=1

4534&FromSearch=Y&Publisher=1&SearchText=BREAM&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

Defra. (2010). *PS2005 Final report. The development and validation of a Bystander and Resident Exposure Assessment Model (BREAM).*

Defra. (2013). *PS2030*. Retrieved 2013, from http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17935&FromSearch=Y&Publisher=1&SearchText=spray drift&GridPage=1&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

EFSA Panel on Plant Protection Products and their Residues (PPR). (2010). Scientific opinion on preparation of a Guidance Document on pesticide exposure assessment for Workers, Operators, Bystanders and Residents. *Efsa Journal , 8* (2), 65pp.

Efsa Scientific Committee. (2012). Guidance on selected default values to be used by the Efsa Scientific Committees, Scientific Panels and Units in the absence of actual measured data. *The Efsa Journal , 10* (3), 32pp.

Frewer, L., Brennan, M., Remoundou, K., Spanoghe, P., Butler Ellis, C., Glass, R., et al. (2011). *Report on initial stakeholder workshop.*

Glass, C. R., Mathers, J. J., Hetmanski, M. T., Sehnalova, M., & Fussell, R. J. (2012). Development of techniques to measure vapour concentrations of pesticides to determine potential bystander and resident exposure. *Aspects of Applied Biology 114, International Advances in Pesticide Application* (pp. 87 - 90). Association of Applied Biologists.

Hamey, P., Byron, N., Hanley, L., Leslie, W., Morgan, N., Steurbaut, W., et al. (2008). *Project to assess current approaches and knowledge with a view to develop a Guidance Document for pesticide exposure assessment for workers, operators, bystanders and residents.* European Food Safety Authority.

Kennedy, M. C., Butler Ellis, M. C., & Miller, P. C. (2012). BREAM: A probabilistic Bystander and Resident Exposure Assessment Model of spray drift from an agricultural boom sprayer. *Computers and Electronics in Agriculture , 88*, 63-71.

Lloyd, G. A., & Bell, G. J. (1983). *Hydraulic nozzles: comparative drift study.* MAFF report SC7704.

Lloyd, J., Bell, G. J., Samuels, S. W., Cross, J. V., & Berrie, A. M. (1987). *Orchard sprayers: comparative operator exposure and spray drift study.* MAFF report.

Martin, S., Westphal, D., Erdtmann-Vourliotis, M., Dechet, F., Schulze-Rosario, C., Stauber, F., et al. (2008). Guidance for exposure and risk evaluation for bystanders and residents exposed to plant protection products during and after application. *Journal of consumer protection and food safety , 3*, 272-281.

Michielsen, J. M.G.P., Wenneker M, Zande J C van de, Heijne B (2007). Contribution of individual row sprayings to airborne drift spraying an apple orchard. *In: E. Gil, F. Solanelles, S. Planas, J.R. Rossell & L. Val (eds). Book of abstracts, VIII Workshop on Spray Application Techniques in Fruit Growing, Barcelona:*, (pp. 37-46). Barcelona.

Royal Commission on Environmental Pollution. (September 2005). *Crop Spraying and the Health of Residents and Bystanders.* London: Royal Commission on Environmental Pollution.

US EPA. *Exposure Factors Handbook.*

US EPA. (February 2012). *Standard Operating Procedures for Residential Pesticide Exposure Assessment.* Washington, DC: Health Effects Division, Office of Pesticide Programs, Office of Chemical Safety and Pollution Prevention, US Environmental Protection Agency.

van de Zande, J. C., Wenneker, M., & Michielsen, J. M. (2010). Risk estimation of bystander and residential exposure from orchard spraying based on measured spray drift data. *Aspects of Applied Biology 99: International Advances in Pesticide Application* (pp. 149-156). Warwick: Association of Applied Biologists.

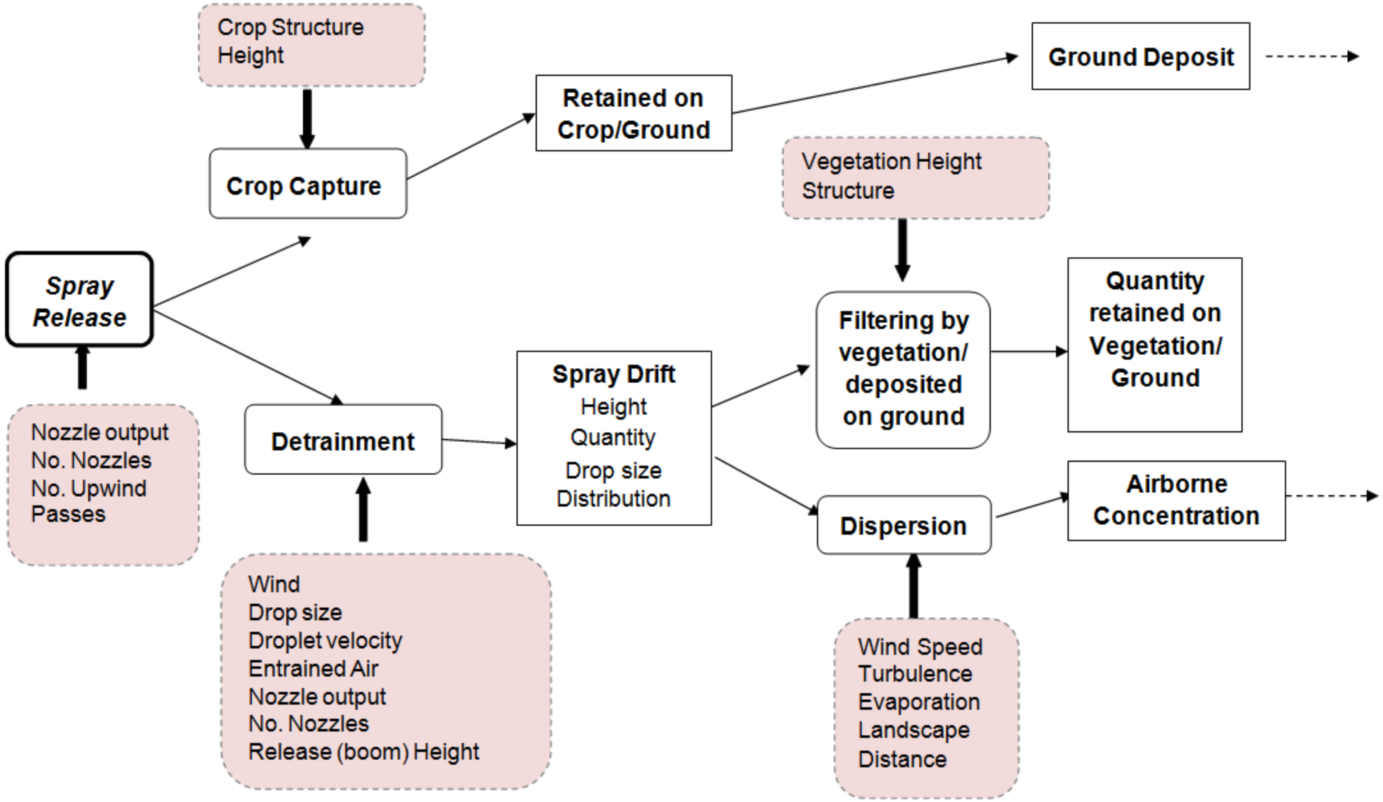
Van den Berg, F., & Leistra, M. (2004). *Improvement of the model concept for volatilisation of pesticides from soils and plant surfaces in PEARL. Description and user's guide for PEARL 2.1.1-C1FOCUS_AIR_PEARL.PDF.* Retrieved from http://www.pearl.pesticidemodels.nl/pdf/FOCUS_AIR_PEARL.pdf

Van Jaarsveld, J. A. (2004). *The Operational Priority Substances model: Description and validation of OPS-Pro 4.1.* Bilthoven: RIVM.

Van Pul, W. A., Jaarsveld, v., J A, V. O., van den Broek, M., & Smits, M. C. (2008). The VELD experiment: an evaluation of the ammonia emissions and concentrations in an agricultural area. *Atmospheric Environment , 11:42* (34), 8086-95.

15 Figures

Figure 1. Conceptual model for spray drift from a boom sprayer (Silsoe Spray Drift model)



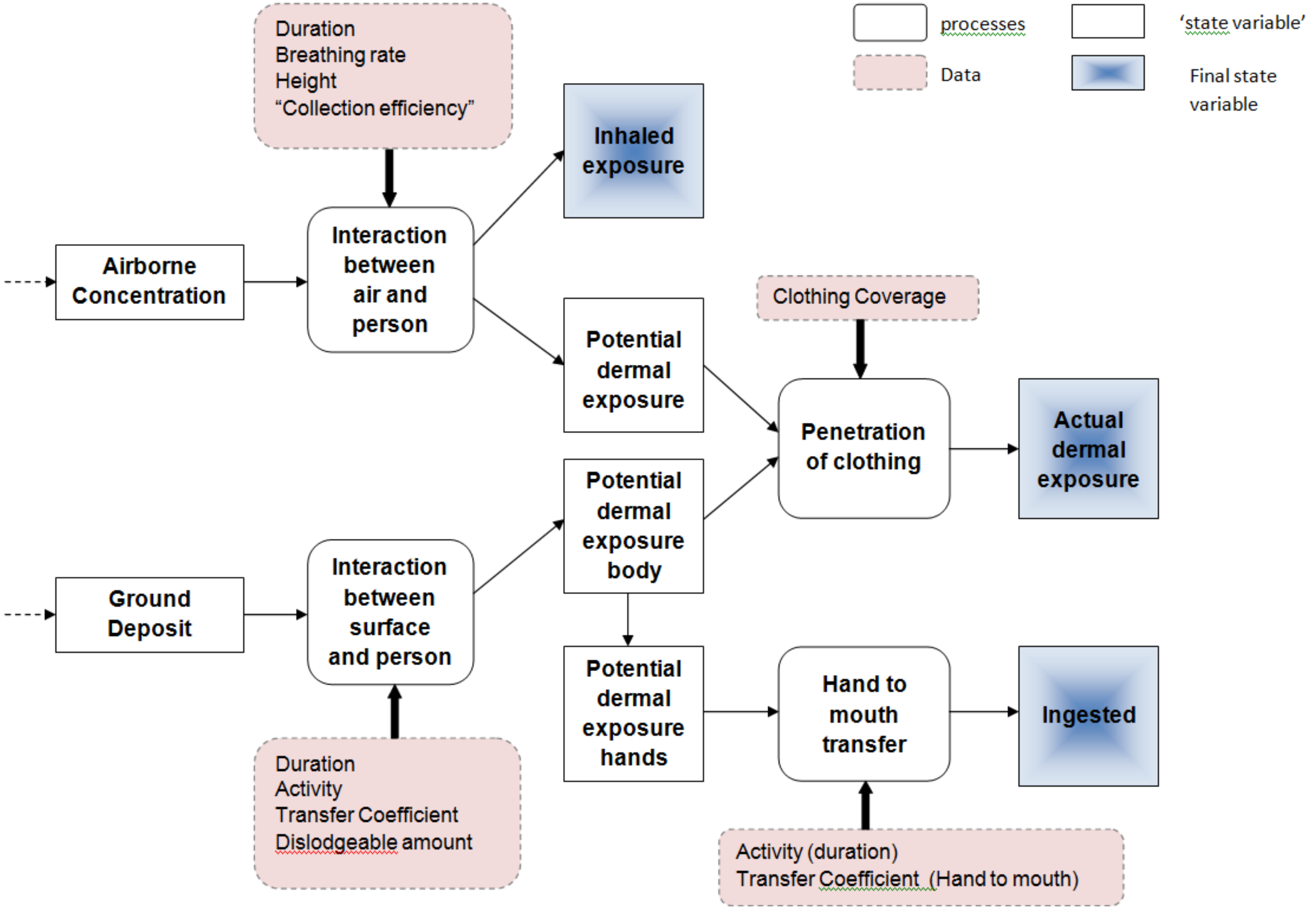


Figure 2. Conceptual model for bystander/resident interaction with spray drift.

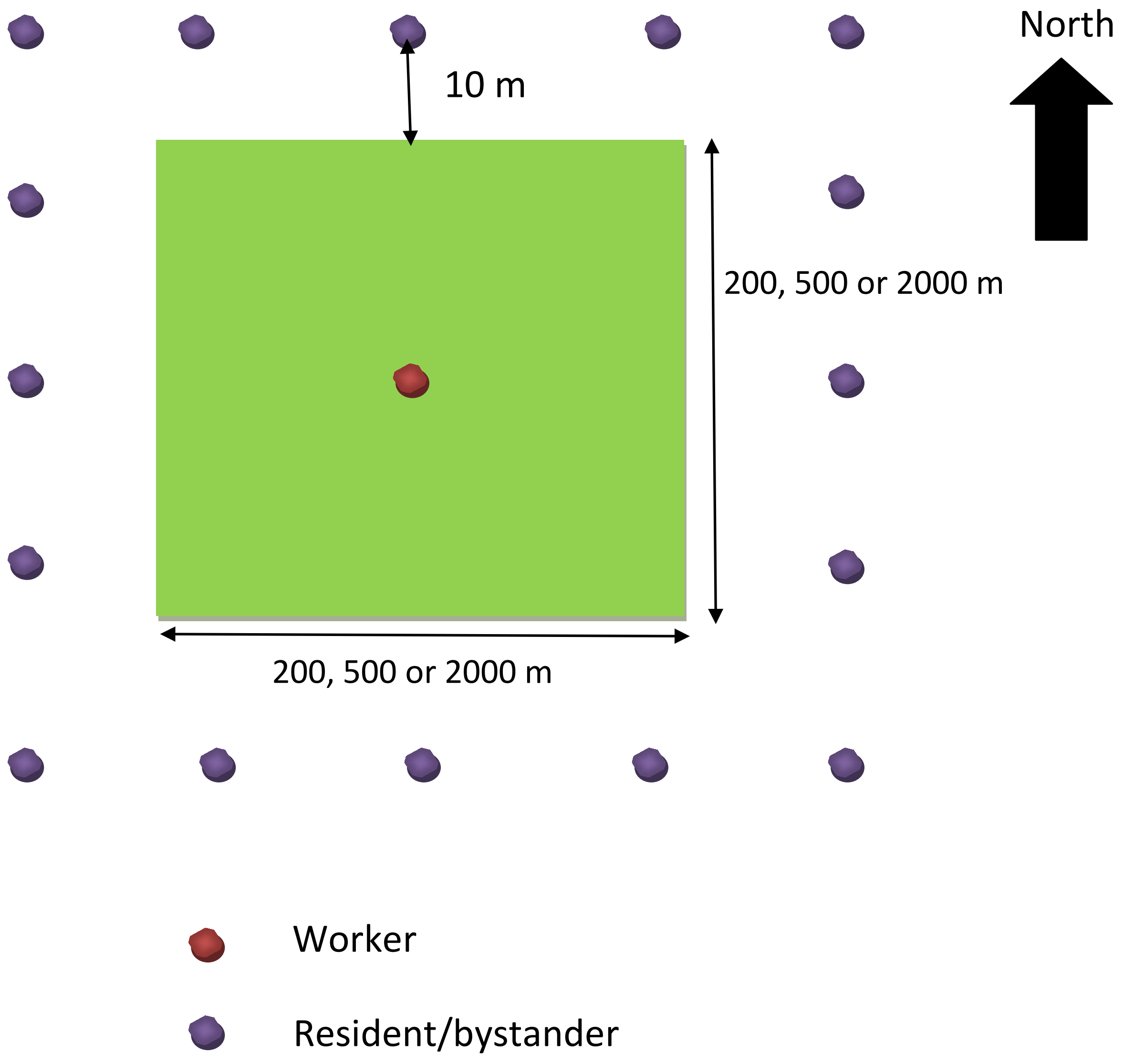


Figure 3. Layout of source (field) and receptors (workers, residents and bystanders) for modelling vapour exposure (not to scale)

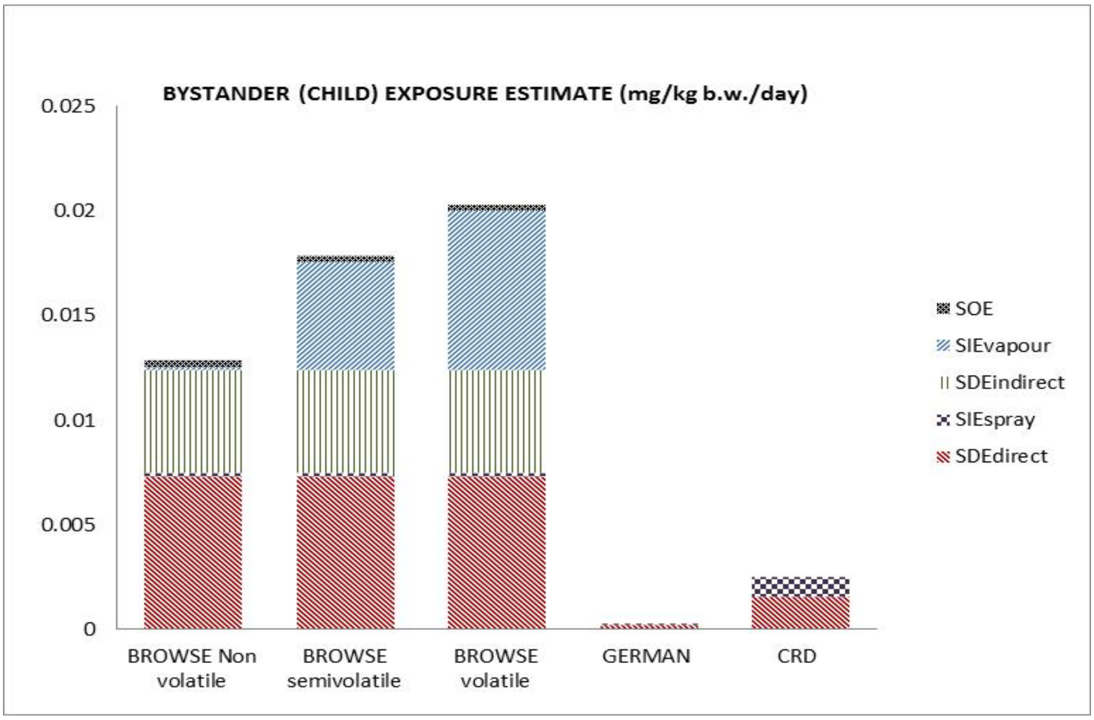
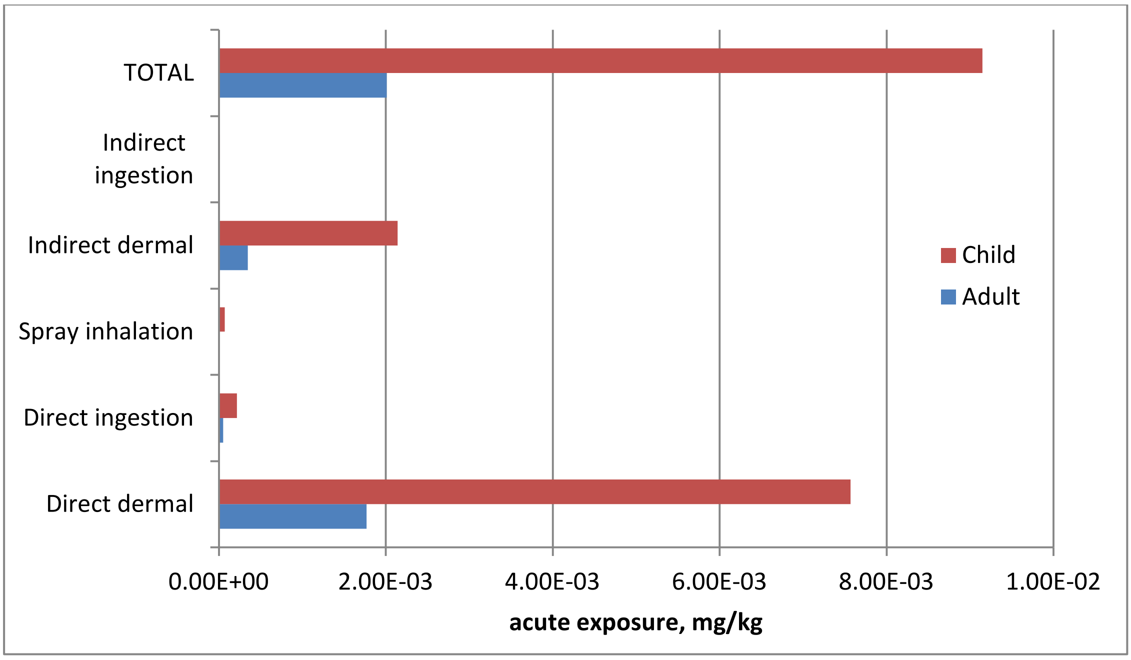


Figure 4. Example of a comparison between BROWSE, UK (CRD) and German bystander exposure models for a child, for one scenario. SOE = systemic oral exposure (hand-to-mouth); SIEvapour = systemic inhaled exposure to vapour; SDEindirect = indirect systemic dermal exposure (from contact with drift-contaminated land); SIEspray = systemic inhaled spray (from direct exposure to the airborne spray plume); SDEdirect = systemic dermal exposure (from direct exposure to the airborne spray plume).



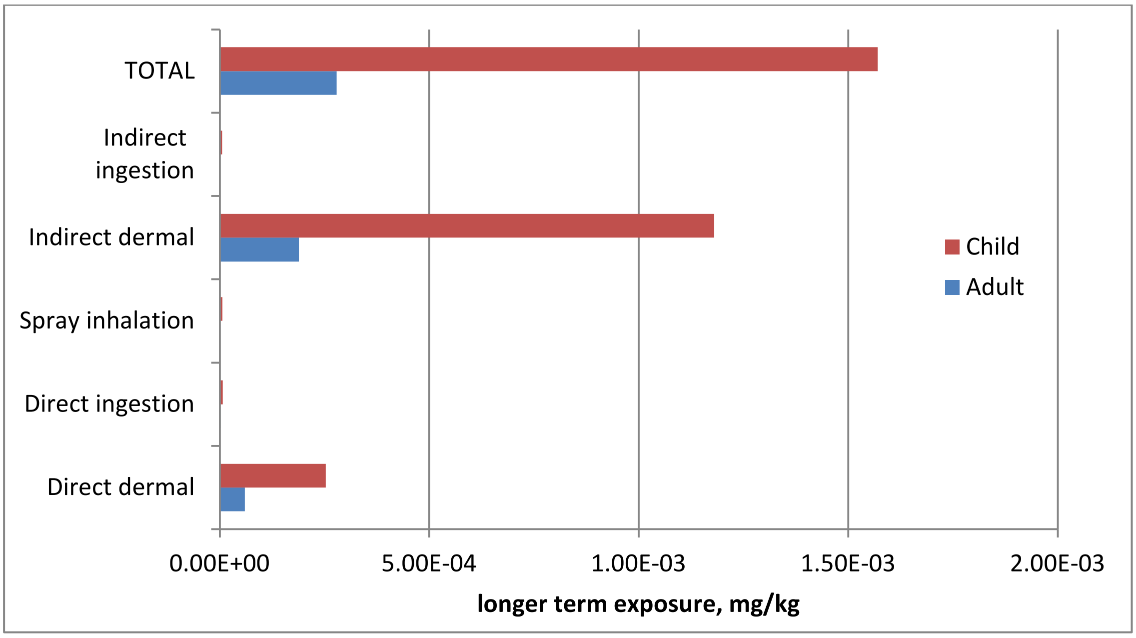
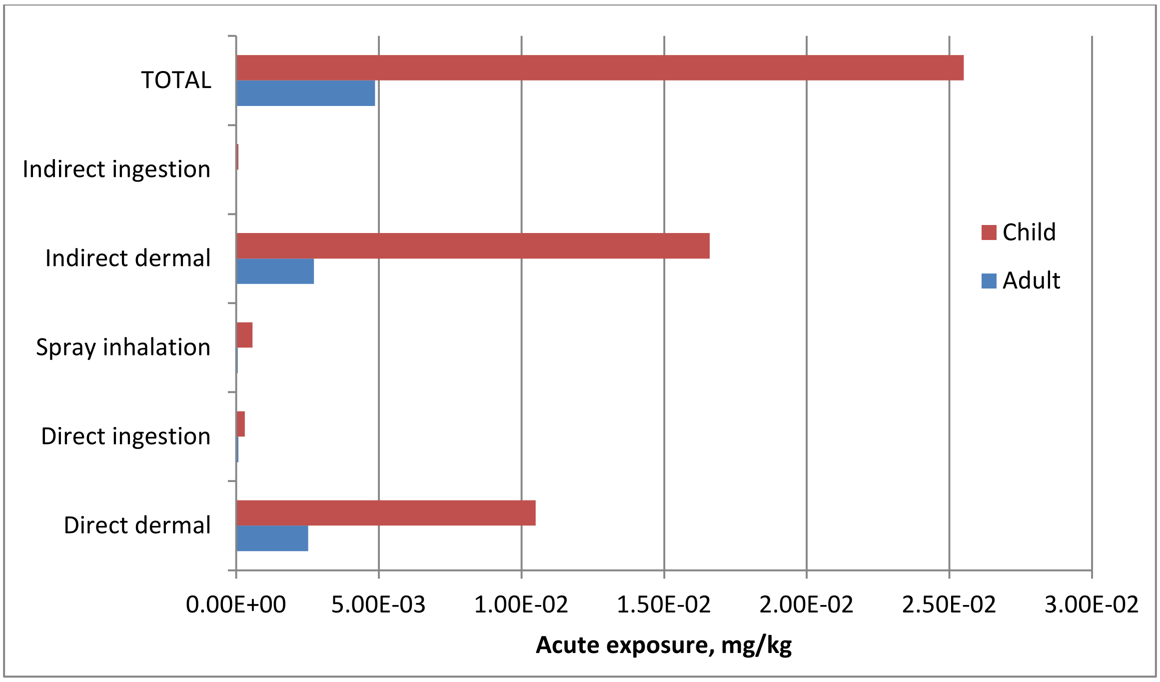


Figure 5. Relative importance of exposure routes to spray from boom applications for adult and child exposure for the example scenario given in section 11.1. Acute exposure is based on the 95th percentile, longer term exposure on 75th percentile, from BROWSE v4.4



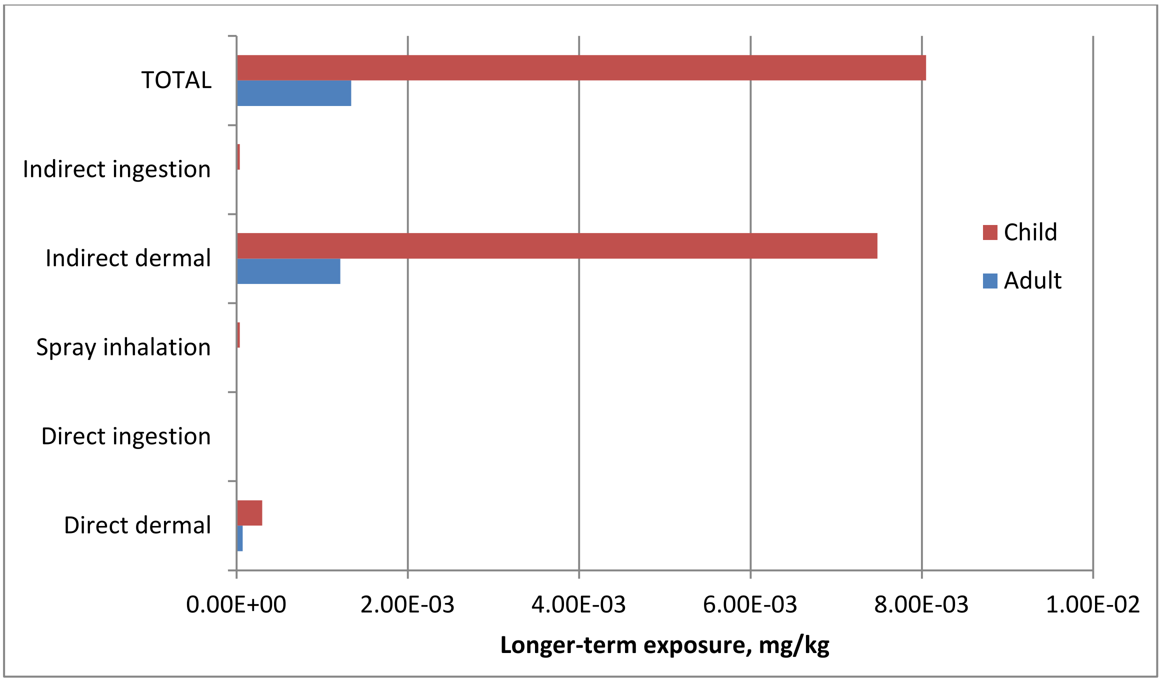


Figure 6. Relative importance of exposure routes to spray from orchard applications for adult and child exposure for the example scenario given in section 11.2. Acute exposure is based on the 95th percentile, longer term exposure on 75th percentile, from BROWSE v4.4

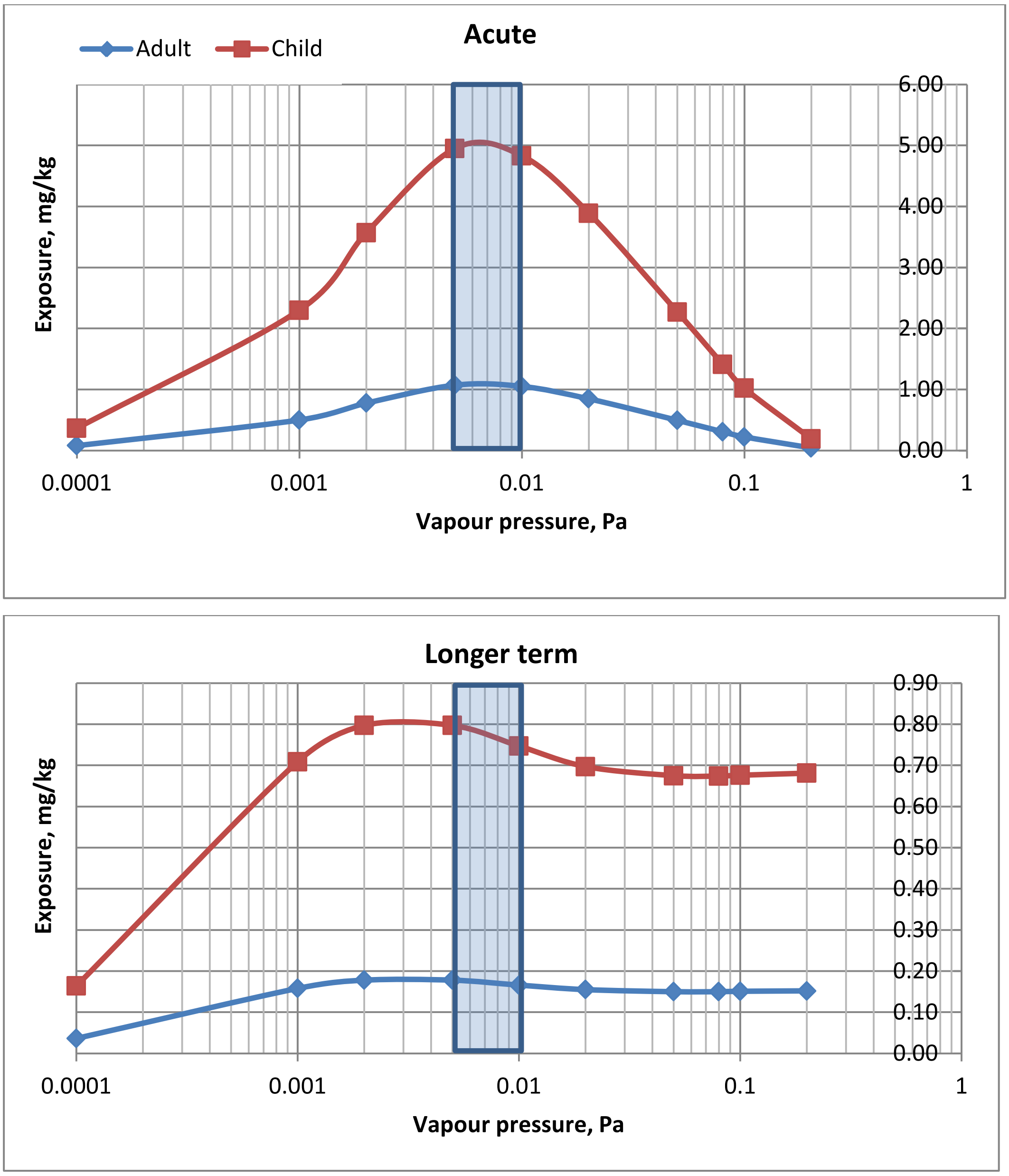
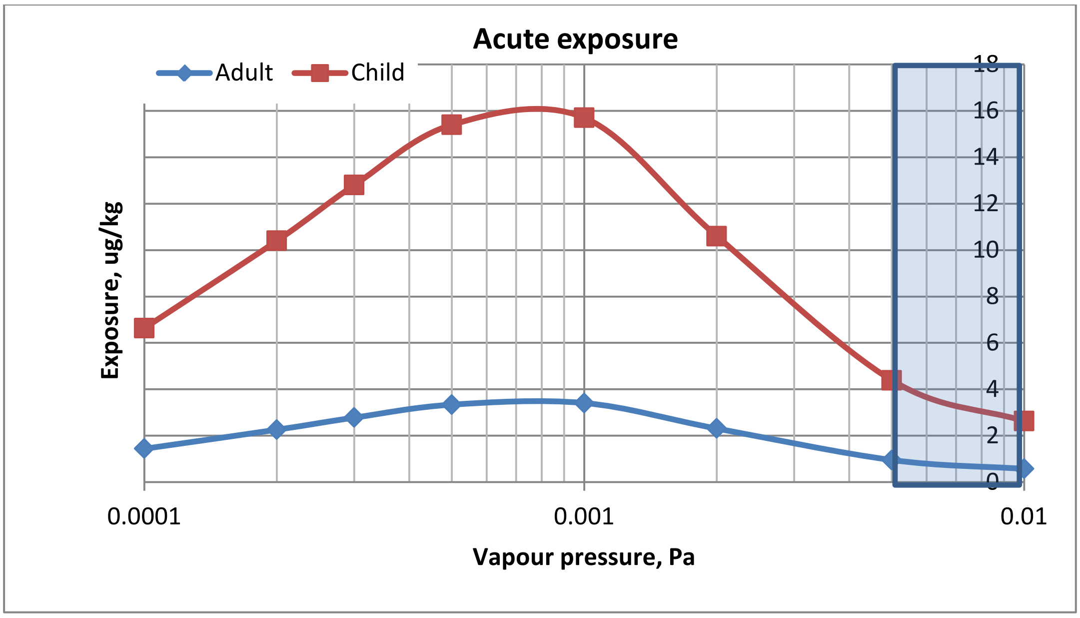


Figure 7. Acute and longer-term exposures for a range of vapour pressures for a default scenario in the Northern zone. The blue area relates to the exposures for an active substance which has a vapour pressure denoted as ‘moderately volatile’ in Efsa guidance (EFSA Panel on Plant Protection Products and their Residues (PPR), 2010).



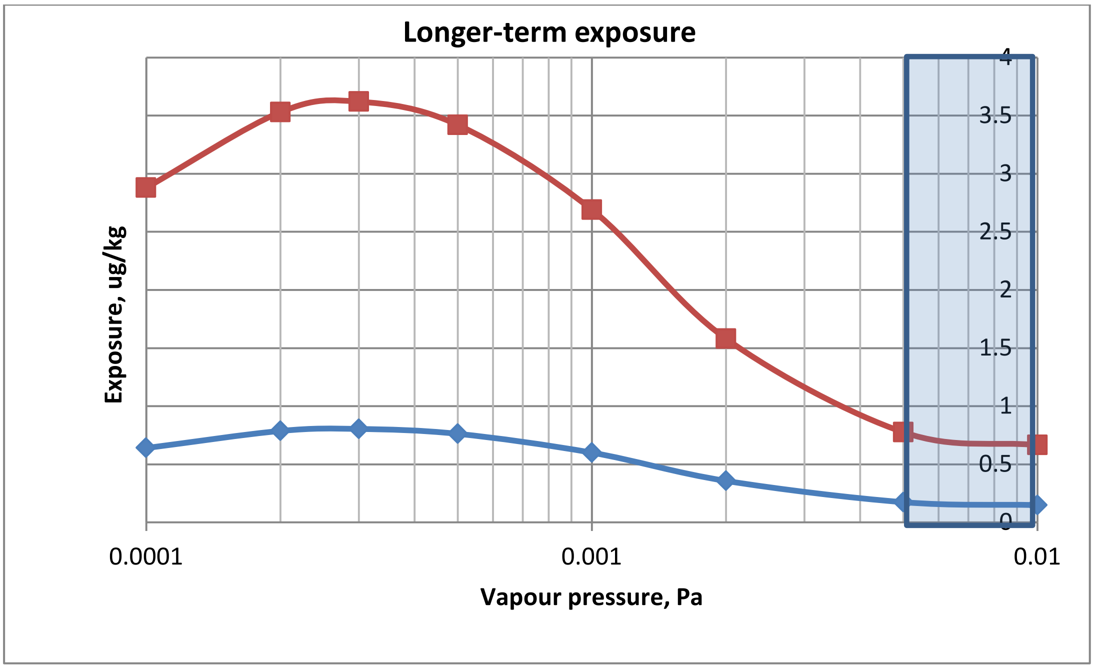
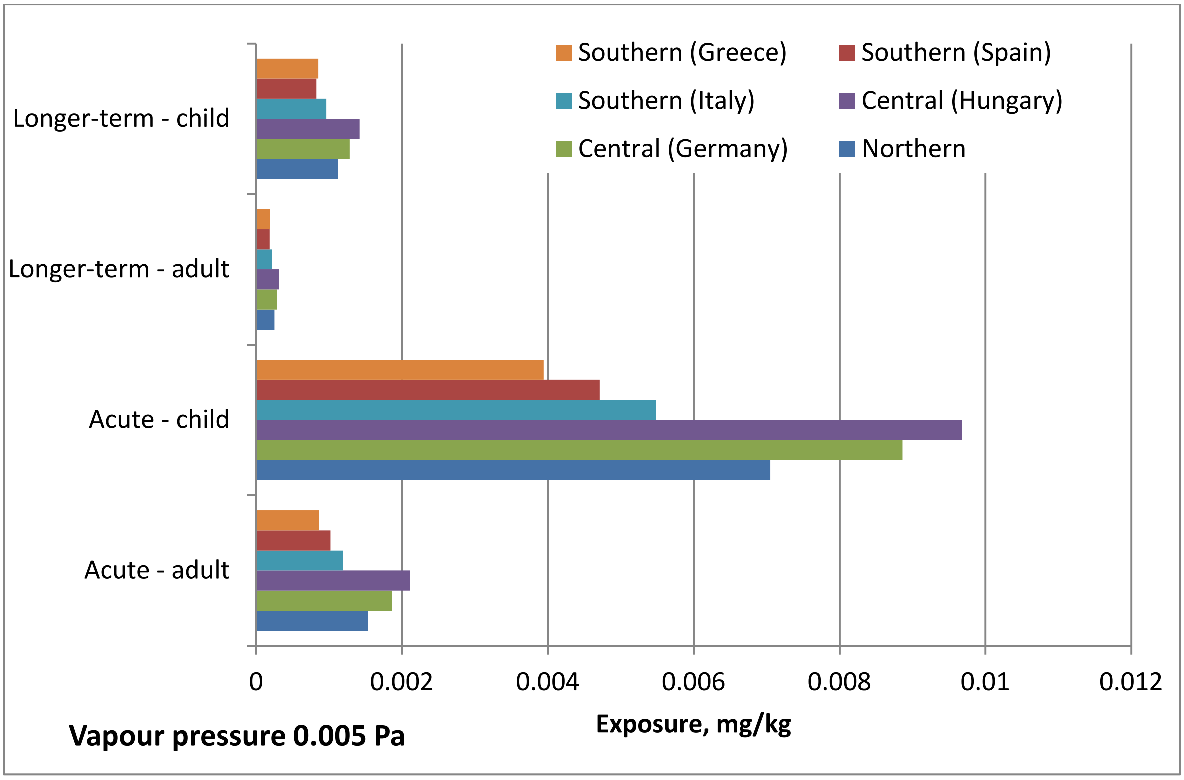


Figure 8. Acute and longer-term exposures for a range of vapour pressures for a default scenario in the Southern zone (Spain). The blue area relates to the exposures for an active substance which has a vapour pressure denoted as 'moderately volatile' in Efsa guidance (EFSA Panel on Plant Protection Products and their Residues (PPR), 2010).



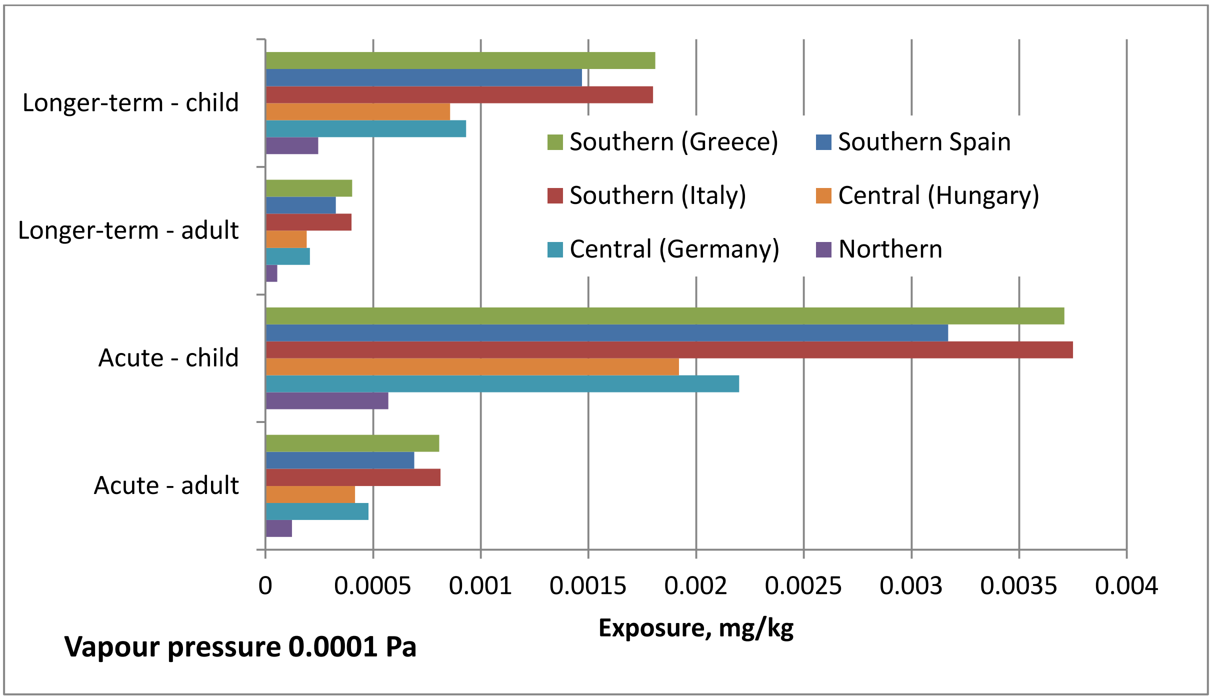
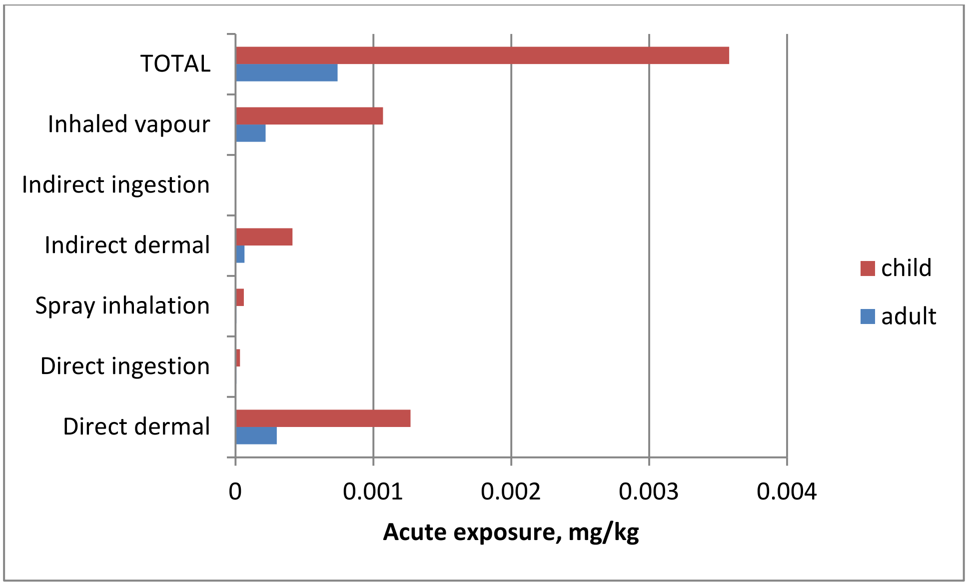


Figure 9. Predicted exposures for active substances with two different vapour pressures for the six sets of meteorological data currently available



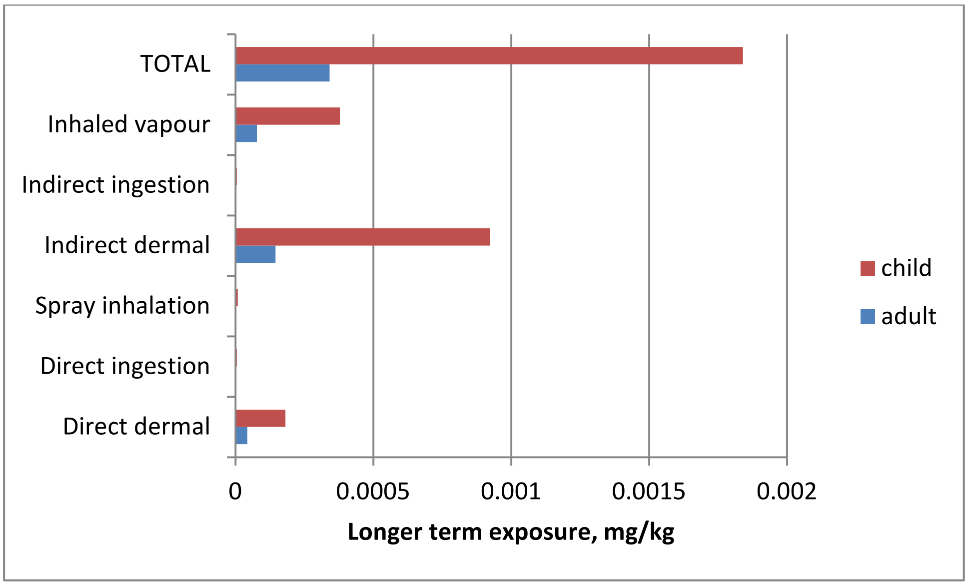


Figure 10. Contribution of all exposure routes for a boom application – low volatility pesticide in the central zone.

Appendix 1. Development and use of emulators

[see separate document]

Appendix 2. Further details about the Pearl model

Erik van den Berg

A diagram of the conceptual model for the vapour exposure component, which describes the source and dispersion, is shown in Fig. A2.3.

The saturated vapour concentration of the pesticide in the air at the deposit surface on the leaves is calculated from the vapour pressure by using the Gas Law as described by:

$$c_{g,ps} = \frac{M \cdot p_s}{R \cdot T} \qquad \text{[A2-1]}$$

where:

$c_{g,ps}$ = concentration in the air at the plant surface (kg m^{-3})

M = molecular mass (kg mol^{-1})

p_s = saturated vapour pressure of the pesticide (Pa)

R = universal gas constant (J K^{-1} mol^{-1})

T = temperature (K)

The potential rate of volatilisation of pesticide from the deposit/leaf surface is calculated by:

$$J_{v,pot} = \frac{\left(c_{g,ps} - c_{air}\right)}{r} \qquad \text{[A2-2]}$$

with:

$J_{v,pot}$ = potential flux of volatilisation from the surface, kg m^{-2} d^{-1}

c_{air} = concentration in the turbulent air just outside the laminar air layer
= (kg m^{-3} ;set at zero)
r = resistance to transport from plant surface to atmosphere (d m^{-1})

All the areic quantities, such as fluxes, are expressed per m^2 field surface (not plant surface).

The actual rate of pesticide volatilisation is described by taking into account the mass of pesticide on the plants:

$$J_{v,act} = f_{mas} J_{v,pot} \qquad [A2\text{-}3]$$

with:

$J_{v,act}$ = actual rate of pesticide volatilization (kg m^{-2} d^{-1})
f_{mas} = factor for the effect of pesticide mass on the plants (-)

The pesticide is assumed to be deposited on the leaves in spots of variable thickness. The thinner the deposit at a certain place, the sooner that place will be depleted by volatilisation. The concept is that the volatilising surface decreases in proportion to the decrease in mass of pesticide in the deposit. So:

$$f_{mas} = \frac{A_p}{A_{p,ref}} \qquad [A2\text{-}4]$$

with:

A_p = areic mass of pesticide on the plants (kg m^{-2})
$A_{p,ref}$ = reference areic mass of pesticide on the plants, 1.0 10^{-4} kg m^{-2} (= 1 kg ha^{-1}).

The equation for the conservation of mass of pesticide on the plant surface reads:

$$\frac{dA_p}{dt} = -J_{vol,act} - R_{pen} - R_w - R_{ph} \qquad [A2\text{-}5]$$

with:

t = time (d)

All areic quantities in this equation are expressed on the basis of m2 field surface. In the current approach for the first tier in BROWSE, the dissipation terms R_{pen}, R_w and R_{ph} representing penetration into the plant tissue, wash-off and photo-transformation are not considered.

A description of the coupled Pearl-OPS models is given in Appendix 5.

Appendix 3. Selection of locations for vapour exposure model

(see separate document)

Appendix 4. Summary of mean temperature and wind speeds for selected locations for meteorological data driving vapour exposure models

Appendix 5. Post processing of PEARL-OPS output data

Erik van den Berg, Cor Jacobs

Acute exposure

Description of application scenario:

- Repeated applications on a weekly basis in the period 1 April – 30 September, first application date starting on 15 April.
- Simulation period is 5 years, so total number of applications is 5 x 24=120.
- Starting time of application: 9.00 h.
- Just before the next application the mass of product remaining on the plant surface is set to zero.

The target output is the maximum average 24-h concentration in air at 10 m distance for each application.

The calculation procedure is as follows:

- For each application a series of 24-h average concentrations is calculated. Each average is based on 24 hourly values; each hourly value is the highest concentration at 10 m prevailing at that hour.
- The first 24-h average is calculated from the hourly output value for 10:00 h on the day of application and the next 23 hourly values. The second 24-h average starts is calculated from the hourly output value for 11:00 h on the day of application and the next 23 hourly values. This procedure is repeated until a full 7- day period is covered. From this series, the maximum 24-h value is selected for that application.

This results in 120 values of the maximum 24-h average concentration for which a frequency distribution is prepared. From this distribution, a specific percentile is selected to be presented in the assessment report.

Longer term exposure

The application scenario is the same as for acute exposure.

The target output is the 7-d, 14-d, 1-month and 3-months average concentration in air at 2 m distance.

First the 7-day average concentration is calculated for each application. The starting value for this average is the hourly output for 10:00 h on the day of application. The next hourly values are selected to cover the full 7 d period. Each hourly value is the highest concentration at 10 m prevailing at that hour. This gives a total of 7 x 24= 168 hourly values from which the 7-day average is calculated.

This procedure is repeated for each application, so in total 120 values are obtained for the 7-d average concentration.

The 7-day average concentration is divided by 2 to calculate the 14-d average, divided by 4 to calculate the monthly average and divided by 12 to calculate the 3-monthly average.

So for the 7-d , 14-d, 1 month and 3 months exposure period a series of 120 values is calculated. This gives 4 frequency distributions for which the specific percentiles are calculated.

For multiple applications, the single application longer-term exposure is calculated as above, and then multiplied by the maximum number of applications in the assessment period.

Appendix 6. BROWSE_ PEARL-OPS Parameterisation for the BROWSE Exposure Scenarios for Residents and Bystanders

[see separate document]

Appendix 7. Probabilistic model descriptions for orchard sprayers

[see separate document]

Appendix 8. Comparison of PEARL-OPS predictions with field measurements of vapour concentration.

[see separate document]

Appendix 9. Stakeholder comments and responses from October 2013 Workshops. WP3

Clare Butler Ellis, Christine O'Sullivan

Comment	Response
Verbal comments from Stakeholder workshop	
Need clarification on rationale for bystander – some believed 24 hours was too long an exposure time for bystander.	Agreed that clarification needed. This point addressed in more detail below, under responses to written comments.
Need clarity over how formulation is taken into account in models.	Formulation can influence absorption parameters, which are input directly into the model, spray quality, which can be directly input into the model and phys-chem properties. Generally, phys-chem properties only available for active, so cannot take account of formulation (also true of current exposure assessment methods). This is discussed in technical documentation. In short, user will have to have some knowledge about the effect of formulation on input parameters to be able to explore this.
Is it over-conservative to add a high percentile of drift exposure to a high percentile of dermal contact, if both are rare events? Or to sum 95%iles of different routes for same event? Explain this well.	The probabilistic nature of the model ensures that this type of over-conservatism doesn't occur except where it cannot be avoided. This will be explained in technical documentation
Explain why on results page individual values don't sum to totals (also WP1-2?)	This relates to the point above – because we don't sum the percentiles of the individual components, but instead determine a distribution of totals, the percentile of the total is not the same as the total of the percentiles.
Check reasons why child exposure is so much higher than adult (BW, height, other?)	Some checks done – it is largely down to bodyweight and breathing rate – differences in vapour concentration are only small; differences in spray drift contamination can be larger, but usually adult is still greater than child. There have been bugs in the software which may have contributed to this but we hope all are now removed.
Question the assumption that direct spray exposure is negligible contribution to longer term exposure.	This has now been changed so that it is included, even if negligible.
What happens when same person is resident and bystander at another location on same day?	We have always recognised that a resident can be a bystander too, but this was not sufficiently clear.

	The issue of the consequences for a high acute exposure in addition to a lower longer-term exposure is outside the scope of this project, but the models could be used to address this in the future.
Is 2-20m final choice for distance? Could limits be open to user change? How are values in range sampled (between or within persons, between and within days?) Need to consider what happens when UBZ is used (unsprayed buffer zone)	It would be possible to include a wider range of distances in future developments of the BROWSE model but there is a danger that it becomes an unrealistic worst case. Further discussion of this below, relating to the written comments. Need a rationale for the 'right' distance range to be included. Sampling for distance (and all variables) is for a combination of people and days.
Can take account of drift reduction nozzles etc? Buffer zones.	Drift reduction can be included. Buffer zones can be included for exposure to spray, by changing the distance range (e.g. instead of 2 – 20 m, it could be 10 – 20 m). There are no buffer zones for human exposure in existing regulations.
Comment that models are too UK based	The models are able to take into account a wide range of practices, representative of all (we hope) member states, and locations for meteorological data do not include any in the UK, so we disagree that the model is UK based. However, many of the defaults are currently based on UK practice, because that is where the information is available, and the presentations have possibly had a UK bias. We will in future aim to present the bystander/resident scenario from a wider European perspective. If other member states have data that shows inputs should be different from the defaults, these can be used.
Explain scenarios more fully, e.g. that acute scenarios include only one direct exposure to an application event.	We have improved these descriptions in the documentation
Either remove one set of met data from central/southern zone options, or provide guidance for which one should be used in which circumstances	There was some disagreement in the project over this. There is no rationale for using one set of data in the zone over another, and therefore it is logical to remove all but one for each zone. This has not been done, however, to date.
Unclear what things can reflect regional variation (built in or possibility for user to enter themselves). Each WP to have a section on this in their	This has been included in the documentation

documentation (which parameters vary regionally in ways that impact exposure significantly and what does model include (or have options for) to address this,	
Written comments following the workshop	
Administration enquiries	
Missing document? Deliverable 5.1 DRAFT work package 3: Models of exposure to agricultural pesticides for bystanders and residents Appendix 1 Development and use of emulators – Separate document was missing.	Appendix 1 was sent out as far as we are aware – final documentation will contain all appendices.
Assumptions regarding residents exposure:	
Components included in bystander risk assessment but not for residents: (why?) - Spray inhalation, direct dermal and ingestion are included in the bystander model but should also be included in residents model. - Software shows resident exposures as proportion of AOEL but bystander exposure is proportion of AAOEL? - Recommendations for acute and long term exposure are proposed by EFSA 2010. This is still a draft document and the information cannot be relied upon. Hence acute exposure for residents has been overlooked.(The ACP's BRAWG report states that **acute exposure assessments** are required for **both bystanders and residents**, and that for residents longer term assessments are also needed) - Residents receive both acute exposure (repeated) and ongoing chronic exposures	Stakeholder workshop in Oct 2013 showed that there was serious confusion over the definitions of bystander and resident, and acute and longer term exposure, and therefore a different approach is needed. The agreed approach now is to define 'residents and bystanders' as the population we are addressing, and consider acute and longer term exposure for both. This is because residents can (and are likely to be) bystanders too, and they are not therefore separate populations. The model presented at the stakeholder workshop did include only indirect spray exposure for the longer-term exposure assessment. The final version now includes direct spray exposure as a result of stakeholder feedback.
- 7 day default interval used between spray events but commonly more frequently eg 'strip a day approach'	Very dependent on product and crop. More frequent is possible, and for a pesticide that could be used in this way, a daily application can be simulated.
- Systemic oral exposure only proposed for children residents - no equivalent for adult residents.	Not true – it is included for both, and there is an assumption that the adult behaves in the same way as a child.

Assumption that if operators and workers are protected then residents and bystanders will is erroneous	We have not made such an assumption. The model focuses on resident and bystander behaviour and is entirely separate from operator and worker models.
Real risk of a person being directly exposed to the same chemical many times during the application period	Insufficient data is available to show what the probability is of repeat exposures for modelling purposes, but the model has been changed to include this.
Workers include direct contamination by air inhalation Excluded from residents but should be included	This is included (vapour inhalation)
Definition of resident In EU law, a resident is defined as someone who lives and works or attends school or other institution in the locality of the treated area. Why does BROWSE define this differently? They must reside at a location for 365 days/year…surrounded by fields on at least 2 sides. Etc,	Definition is not different, just more specific in order to develop the model. We have taken a 'worst case' resident – i.e. if our hypothetical resident is protected, then everyone is protected, even if they live further away
Why is the mass of product on the plant, set to zero just before the next applications? – Studies show it can accumulate on the soil or plant surface as water evaporates.	Accumulation on plant was intended to be taken into account for multiple applications, but there were insufficient resources to make this part of the model work correctly (it is quite complicated trying to work out all the possible combinations of application dates, and also ensure the model runs quickly). However, the pesticide will only accumulate on the plant if it does not volatilise or degrade, and therefore the situations where there is accumulation are also situations where the vapour exposure is low. Multiple applications usually occur because the pesticide does not remain on the plant for very long and needs to be replenished.
Vapour exposure assessment is over 24 hours for residents? – When exposure can be for days weeks or months.	Acute exposure is 24 hours; longer term exposure can be weeks or months
Proposed that residents to be at a 10m distance, inconsistent with 2m spray drift recommendation. The original code has output at distances 1-20m so why was it changed to 2m?	Residents can be anywhere between 2 and 20 m. For vapour exposure, this is fixed at an average of 10 m as explained in documentation. The 'change' from 1 to 2 m is a result of the emulation process. The emulator is an approximation of the 'original code', but the original code is only run down to 1m so that when we approximate it at 2m with the emulator we

	avoid additional approximation errors due to being at the edge of its input range.
2 m is too great, and 20 m is too short.	Direct exposure at less than 2 m has been thought to be unrealistic because of the dangers of being hit by the spray boom. It is anticipated that either the sprayer would stop, or the bystander/resident would move away. However, indirect exposure at shorter distances could be possible and we could consider including this in future developments. It is likely to have only a small effect on model results, however. Including people at a distance of greater than 20 m could be possible but: (a) this would reduce the predicted exposure by including more people in the distribution with low exposures, and (b) the models become increasingly unreliable as distance increases, and if we were to attempt to include residents and bystanders who are 'miles away' we would need another approach.
Exposure to volatilization from soil does not seem to be included – but should be?	Has now been implemented
The UK Code of Practice is for guidance only therefore the farmer or operator do not have to comply:	Other EU countries have different 'best practices' & guidelines, therefore model is designed to deal with a wide range of situations, including outside of the UK code of practice. Default values are guided by best practice, but not restricted by this.
Is wind speed considered at anything lower or higher than 2m above ground?	When you define a wind speed, you need to say what height above ground it is measured at – otherwise it is meaningless. Weather forecasts are usually given at 10 m height, but on-farm measurements would normally be at 2 m height. The model works out the wind speed at all other heights.
What happens if wind speed is outside of the range stated?	Wind speed is addressed in different ways, depending on the model. For exposure from orchard sprayers, it is captured in the data used to develop the model, which was obtained over a range of wind speeds, but generally at the higher end, including outside of 'best practice'. For vapour exposure, real meteorological data is used over a 5-year period, capturing all possible met conditions apart from perhaps some very extreme events. For exposure from boom sprayers, wind

	speed is a variable that is input by the user. Spray applications would not occur outside the range available as the maximum user-input wind speed available in the model is roughly Force 7. The recommended default wind speed is based on an analysis of real data and is explained in the technical report.
What happens if the actual forward speed is outside of the range stated?	Forward speed would not be above the maximum stated (25 km/h) and there is no evidence that an increase in exposure would be a direct result of higher speeds.
Treated area: The defined sizes of area are too small as does not represent the miles of surrounding agricultural land and multiple events a resident can be exposed to.	We acknowledge that there is no good rationale for selecting areas. The maximum treated area currently available (for vapour exposure) is 2 km x 2 km. This is intended to represent multiple fields. Comments on this were invited at the stakeholder workshop and some stakeholders felt that 2 km x2 km was too large. No alternative approach has been proposed. Future work could address this, based on an analysis of land use in different member states.
Long term exposure. Duration of long term exposure should include hrs, days, weeks post application 3 months exposure is insufficient	Exposure over less than 1 day is covered by acute exposure. In principle, any duration of exposure from one day upwards could be included in the longer term exposure, but in practice, risk assessors work to set timescales. This does not define the time over which the bystander or resident is exposed, but the averaging period. Highest resident/bystander exposures result from shortest averaging periods, therefore this is a conservative approach.
Deliverable 5.1 DRAFT WP3: Models of exposure to agricultural pesticides for bystanders and residents	
Skin to mouth transfer and surface area: Who assumed the figures : - 43% skin to mouth transfer - 0.07 proportion of hand area with mouth (default 0.002m^2) What happens to figures outside of the stated ranges?	Based on published literature, consistent with approach taken by WP1, and are explained in the technical reports. For resident and bystander exposures, the oral exposure route is relatively small and therefore changes in these figures will have a negligible effect on total exposure
at 6.1 ‘Assessment tabs: general inputs – used in all WP’s: Why has inhalation not been included in this	‘inhalation’ is not a general model input

table? Also there is not exposure listed for exposure via eyes.?	Exposure via eyes is not considered as separate from dermal exposure.
Total exposure P31:Why has indirect inhalation been excluded from list of factors included in the bystander and resident exposure?	Need to define what you mean by indirect inhalation – there is inhalation of spray and inhalation of vapour included already
P50 "The design of the coupling is shown in Figure 6.3-1 - could not find this unless it is figure A2.1?	Final documentation will address any mistakes
Omissions + general comments	
Exposure to pesticides - To include pollen, dust and soil	Exposure from pollen, dust and soil cannot currently be modelled as there is no data available to quantify the source. It would be expected to be much lower than exposure from direct spray/vapour, but we agree that some data to justify this assumption should be sought.
- 60kg body mass excludes lower body weights including babies	Body weight can be user-selected; a distribution of body weights is the recommended default, which includes lower weights. Potentially, babies are not the most highly exposed group in children as they are not mobile and have a lower breathing rate:bodyweight ratio. Data for toddlers are used to represent all children, as they have the highest breathing rate: bodyweight ratio, and are also mobile.
- Vulnerable groups not represented e.g. pregnant women, elderly, ill or disabled.	All groups are represented in terms of bodyweight, breathing rate and behaviour, which are the main factors determining exposure.
Orchard spraying "…This model has yet to be implemented in the BROWSE model" – at what point will stakeholders be able to comment on this?	The orchard model has been implemented in the final version.
Use of the terms Bystander and Residents Several occasions in various documents where only 'Bystander' has been used whereas both 'Bystander and Resident' should be edited in.	Terminology has now changed.
UK Pesticide Campaign evidence ignored UK Pesticide Campaign's published evidence and data has not been referred to in any of the reference sections so effectively ignored.	The documentation cites all the original data that has been used in the development of Work Package 3, some of which has been brought to our attention by stakeholders, for which we are very grateful. Peer-reviewed publications are our preferred source of information. ' Grey' literature and qualitative information have been taken into

	account where ‘expert judgement’ has been required, and this includes input from project partners, advisory panel and stakeholders, who are not cited individually. Verbal stakeholder interactions have operated under ‘Chatham House Rules’ and therefore are not cited. We can confirm that the material provided by the UK Pesticide Campaign has been considered at all stages in the project, as well as those of other stakeholders, where appropriate.
Contradiction in statements (by MCBE) Residents predominantly exposed to spray drift (droplets) during application----**originally stated, but now stating**…. Residents are mainly exposed after application and largely to vapour	There has been confusion over the term ‘resident’ and we agree that this needed to change.
Model Improvements? Ensure realistic worst case exposure scenarios for all exposure groups - ie include all exposure routes (residents exposed to direct spray)	This is the stated aim, and the exposure of residents to direct spray is included.
Impact of model on risk management? If a proper assessment was made by the model, then NO pesticide would be approved for use near residents homes, playgrounds etc.	It is possible that this could be the case, based on the new model, if the results suggest that the exposures are much higher than the current exposure models. However, it would be necessary to have new data to validate the model, since the validation to date has been limited, and based only on existing data on which the current exposure models are based.
How well has the BROWSE project taken account of its stakeholders views? Very poorly – for reasons already noted, also, - No representation of residents on advisory panel - Consultation with Stakeholders constrained despite being considered important. E.g. Would have liked to have contributed to the surveys of residents Not clear; haven’t been informed of developments since last stakeholder workshop	We recognise that some stakeholders would have preferred more/different mechanisms of input into the project, but the project was constrained both by the resources available and by what was agreed with the commission.
Lack of clarity between vapour emission and volatilisation	There is little difference between the two: volatilisation is the process by which vapour is emitted from the crop. We will check final

	documentation to ensure it is as clear as possible.
Soil fumigants not included Are likely to cause resident exposure	Agreed, and could have been within the scope of the project, but was not highlighted as a priority scenario, so resources did not allow it to be addressed. Again, an area for future development.
Percentiles How do we interpret the percentiles – does a 95 percentile mean that 1 in 20 people has higher exposure, or that all people have higher exposure on 5% of occasions?	This is addressed in the final documentation – but it is a difficult question to answer satisfactorily. Our best judgement is that it means that 1 in 20 events (being both people and spray occasions) will result in higher exposure – but an individual could have a higher probability of exceeding this if, for example, they regularly behave in a way that leads to high exposure levels.
How were these percentiles chosen by Efsa?	Efsa would need to answer this question
Validation Resident model not compared to any actual data. Hope that data will be available for comparison soon	Agree, although further funding would be needed to do the comparison. We hope that this becomes available.
Conservatism How does this work?	This is addressed in the final documentation, but it is difficult to quantify the overall level of conservatism without more data for validation. For some models, it is possible for the user to influence the level of conservatism by selecting inputs.