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The BROWSE model for predicting exposures of residents and bystanders to agricultural use of plant protection products: an overview

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Abstract

New models have been developed, with the aim of improving the estimate of exposure of residents and bystanders to agricultural pesticides for regulatory purposes. These are part of a larger suite of models also covering operators and workers. The population that is modelled for residents and bystanders relates to people (both adults and children) who have no association with the application (i.e. not occupational exposure) but are adjacent to the treated area during and/or after the application process. The scenarios that the models aim to describe are based on consideration of both best practice and of real practice, as shown in surveys and from expert knowledge obtained in stakeholder consultations.

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

An overview of the models is given, and a description of model input values and proposed defaults. The main causes of uncertainty in the models are also discussed. There are a number of benefits of the BROWSE model over current models of bystander and resident exposure, which includes the incorporation of mitigation measures for reducing exposure and the use of probabilistic modelling to avoid an over-conservative approach.

It is expected that the levels of exposure that the BROWSE model predicts will, in some cases, be higher than those predicted by the current UK regulatory model, this is largely because the modelled scenarios have been updated to account for current practice and current scientific knowledge.

Keywords: spray drift; vapour drift; boom sprayer; orchard sprayer

Abbreviations

a.s.	Active substance

BREAM	Bystander and Resident Exposure Assessment Model
BROWSE	Bystanders, Residents, Operators and WorkerS Exposure models for plant protection products
EFSA	European Food Safety Authority
OPS	Operational Atmospheric Transport Model for Priority Substances
PEARL	Pesticide Emission Assessment at Regional and Local scales
PPP	Plant protection product

Nomenclature

G	Quantity of active substance on the ground (mg a.s. m^{-2}) deposited as spray drift
H	Duration of exposure (h)
Kom	Coefficient of sorption on organic matter (m^3 kg^{-1})
Q	Dermal exposure (mg a.s.) per person
TC	Transfer coefficient (m^2 h^{-1})
TTR	Turf transferable residue, defined as the fraction of G which can be transferred to the body

1. 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. The report recommended a new model should be developed, which was subsequently addressed in the BREAM (Bystander and Resident Exposure Assessment Model) project (Anon, 2011). This 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. The review (Hamey et al., 2009), fed into a scientific opinion on the preparation of a guidance document on Pesticide Exposure Assessment for Workers, Operators, Bystanders and Residents, which was then published, (EFSA Panel on Plant Protection Products and their Residues (PPR), 2010), subsequently revised and a guidance document has now been published (EFSA, 2014).

The BROWSE project (Bystanders, Residents, Operators and WorkerS Exposure models for plant protection products) was therefore set up to allow improvements in the science and the available data relevant to human exposure to pesticides to be incorporated into regulatory assessments.

At the start of the 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 it was concluded that it would be possible to build on the BREAM project to produce an improved model applicable to all EU member states; based on data and expert knowledge on spray drift from orchard air-blast (i.e. air-assisted) sprayers that will allow a new semi-empirical model to be developed and that significant effort should be expended on developing a new model for vapour exposure after the application of plant protection products.

The work undertaken in the BROWSE project has therefore focused on three causes of exposure identified as having potential for improvement: emission during application due to drift using boom sprayers or orchard sprayers and emission of vapour from crop or soil after application.

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

- 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 and to allow for a selection of representative scenarios.

The BROWSE software is publicly available at https://secure.fera.defra.gov.uk/browse/software/.

This paper describes the structure of the model, the underlying science, and the rationale for the default values and the available range for input parameters. Example model outputs are given, but a fuller description of the exposures predicted by this model, how these compare with existing regulatory models, a sensitivity analysis for some of the input variables and the extent to which the BROWSE model can be validated is given in the companion paper Butler Ellis et al (2016)

2. Model structure

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 three models (boom sprayer, orchard sprayer and vapour drift) have the same structure, each with three main components:

- A source (i.e. the quantity and characteristics of the active substance emitted into the air)
- Dispersion downwind
- Interaction with a bystander or resident to determine exposure.

The three models for emission of pesticides are different for orchard sprayers, boom sprayers and vapour drift, since the mechanisms for releasing the pesticide into the air in each case are different. The dispersion downwind could, in principle, be modelled in the same way, but in practice this was not the case, because of the different source modelling approaches. Interaction with a bystander or resident is, however, the same for all three models.

A generic conceptual model is shown in Fig. 1. Ground deposit, airborne concentrations, and potential dermal exposures are intermediate model outputs. Ingested, inhaled and dermal exposures are the final model outputs.

2.1. *Boom sprayer model*

The source and dispersion of spray from a boom sprayer application was described by a mechanistic spray drift model, sometimes referred to as the Silsoe model (Butler Ellis and Miller, 2010). This was used to determine airborne concentrations at the required heights and distances downwind, as well as ground deposits. Due to the computational time required to run the model, it was not appropriate to include it directly into software that was intended to run probabilistically, i.e. with a large number of repeat runs, sampling inputs from distributions. 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 simulations over a range of input values to determine a distribution of outputs. This approach is described in Kennedy et al. (2012) and Kennedy and Butler Ellis (2016).

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 (e.g. Miller, 1993, Nuyttens, 2006a, 2006b, Arvidsson, 2011), namely: sprayer boom height; spray quality; boom width and number of upwind passes; distance downwind; wind speed and angle; crop height; and forward speed. Spray drift reduction is taken into account simply as a percentage reduction in spray drift. There is an empirical estimate of the effect of humidity in three categories of low, medium and high, based on results from Parkin et al. (2003)

2.2. *Orchard sprayer*

There is currently no model available that can be used to predict airborne spray drift and ground deposition downwind of an orchard air-blast sprayer in a regulatory context. There is, however, a significant quantity of experimental data from the Netherlands and UK (Cross et al*.* 2001a, 2001b, 2003, and van de Zande et al. (2014)) which can be used and therefore an empirical approach has been taken. The data are insufficient to separate out 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 as separate user inputs in the spray component of the model are sprayer type (cross-flow or axial-fan), growth stage (dormant, transition, full leaf), distance downwind and spray drift reduction.

The combined field measurements of spray drift from the Netherlands and the UK were used to determine a potential distribution of airborne spray (at a single distance) and ground deposits (at a range of distances) due to spray drift for a given sprayer type and growth stage. Empirical data (Michielsen et al., 2007) were used to translate airborne spray to different distances, and both airborne and ground deposits to different levels of spray drift reduction. Further details relating to the methodology for this are given in van de Zande et al. (2014).

There are clearly very significant differences in both the structure of the crops sprayed with air-blast sprayers, and the climatic conditions, across different EU member states. These will influence the levels of drift, and therefore the model would benefit very much from the inclusion of a much wider range of data. However, this model sets out a possible framework for an improved exposure model and is a first step towards making the necessary improvements to the existing regulatory models, which are based on very much narrower data. If it is shown that the current formulation of the BROWSE *orchard sprayer* model is inadequate for some situations, it will be possible in the future to include further data should any become available.

2.3. *Vapour Drift*

The emission of vapour from a treated field crop (the source) is described by the PEARL (Pesticide Emission Assessment at Regional and Local scales) model ((Van den Berg & Leistra, 2004). This model has been used since 2001 in the EU registration process for the leaching of pesticides to groundwater. The version of PEARL used for BROWSE is described in more detail by van den Berg et al (2016). The PEARL model has been tested in volatilisation studies against experimental data (Leistra et al., 2005, Leistra and Van den Berg, 2007, Leistra et al., 2008), so it is considered a suitable model for volatilisation exposure assessments under field conditions. The PEARL model has been coupled to the atmospheric dispersion model OPS (Operational Atmospheric Transport Model for Priority Substances) that predicts atmospheric concentration and dry deposition of pollutants. OPS simulates the atmospheric process sequence of dispersion, transport, chemical conversion and finally deposition (Van Jaarsveld, 2004). The high-resolution version of OPS used for the BROWSE scenarios, designated OPS-St, allows hour-to-hour variations in emissions to be included (Van Pul et al., 2008) 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 air temperature across the growing season) within each EU regulatory zone. The methodology for identifying these locations is described in more detail in van den Berg et al. (2016.).

3. Interaction with bystander and resident

In order to model the behaviour of bystanders and residents in the context of pesticide exposure, it is necessary to define what population we are aiming to address. EFSA (European Food Safety Authority) (2014) proposed that the definitions of residents and bystanders should be related to the duration of exposure, i.e. bystanders have acute exposure, and residents, longer-term exposure. However, this definition caused difficulties amongst BROWSE project stakeholders (Brennan et al., 2013) and therefore for the purposes of the BROWSE model, residents and bystanders are considered as a single population of 'persons who could be located within or directly adjacent to the area where plant protection product (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', irrespective of whether they live there or are visiting on a temporary basis.

Any differences between the BROWSE resident and bystander definitions and those of EFSA are only in the wording and are not substantive. However, there are, potentially, differences in the way the definitions are translated into a modelling scenario. For modelling purposes, 'adjacent' requires definition (since distance is a variable and this can have a significant impact on exposure). The range of distances chosen was 2 - 20 m. Acute exposure over a period of up to 24 h is considered for people who are between 2 and 20 m and downwind of the treated area. Longer term exposure is considered for people who are in locations surrounded by fields on all sides at a distance of between 2 and 20 m, and remain there for 365 days a year.

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

i. Being present, adjacent to, and downwind of, an area (field or orchard) being treated with PPP. 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).

ii. Being present, adjacent to, and downwind of, an area that has recently been treated with PPP. 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).

iii. Dermal exposure on the hands may result in ingestion exposure through hand-to-mouth contact, particularly for children, following exposure through either route 1 or route 2. Short-term and longer-term exposure are calculated simultaneously in the BROWSE model.

The relationship between predicted airborne spray and the quantity of spray deposited on a human body is entirely empirical and based on previously obtained data, (Kennedy et al., 2012). This relates only to boom sprayers, and so is used in the BROWSE boom sprayer exposure model. There is limited similar data relating to orchard sprayers (Butler Ellis et al., 2014), which is insufficient to define the relationship for the orchard model, so the combined orchard and boom data is used.

4. Model Inputs

The minimum inputs required to run the model are listed in Table 1, with defaults available for the large number of additional inputs required. Thus the model can be run very simply, or with a greater degree of complexity depending on the knowledge of the user and the information provided relating to the product. In addition, the BROWSE interface allows the user to calculate exposures for drift only or vapour only, in which case the redundant parameters are not required.

4.1. *Default input parameters*

The intention is that users can select model inputs that are appropriate to the particular active ingredient, crop, application equipment and location under consideration, and therefore a single set of default parameters would not necessarily be appropriate. However, for convenience, default values are provided in the software. For the parameters in Table 1 where there are no defaults, initial values are still provided but it is expected that the user will change these for the specific active substance being evaluated.

The rationale for the choice of defaults is to achieve a reasonable worst case exposure assessment. Therefore, the defaults are not themselves worst cases but, whenever possible, will reflect either the real distribution of values or a single value from that distribution between the mean and the maximum. The variable ranges are aimed at providing as wide a choice of options as possible, whilst being consistent with good and typical practice, and within the envelope that we expect the model to be reasonably accurate.

These defaults were established through a combination of expert judgement and survey data, and other available information. A number of surveys have been conducted that have informed this process: in the UK (Garthwaite, 2004); across European member states (Glass et al., 2012); and as part of the BROWSE project (Remoundou et al., 2015). The BROWSE survey was the only one to consider residents and bystanders, whereas the others have focussed solely on operator behaviour.

Tables 2 - 5 show the model input parameters, their defaults and permitted range, and notes on the rationales for these suggestions, including the sources of information used. For boom height above the crop and wind speed, these values represent the expected average values. The BROWSE model simulates the random variation around these mean values, as explained in Kennedy et al. (2012) and Kennedy and Butler Ellis (2016).

5. Example model outputs

Examples of model outputs, based on current default values and BROWSE version 5.2, are given in Figs. 2-4. The actual values of the outputs will depend on the number of iterations for obtaining the distribution. The current default is 17,500 iterations, but this still gives some variability in output values. This could be reduced by increasing the number of iterations, but this will also increase the run time of the model.

It is expected that the levels of exposure that the BROWSE model predicts will be, in many cases, higher than those predicted by the current UK regulatory model. This is because of a number of reasons:

- Current practice in boom spraying has changed, and the BROWSE model defaults reflect this;
- The main variables influencing vapour exposure have been taken into account;
- The variability of exposures is predicted, allowing higher percentiles to be chosen to represent the worst case;
- There are some aspects of the model where there is insufficient data available for model inputs, and this is reflected in a higher level of conservatism.

A comparison between BROWSE exposures and those of other regulatory models is given in Butler Ellis et al (2016)

6. Major uncertainties in models and model inputs

Components of the models have been tested against available data wherever possible, and a description of this testing is contained in a separate paper (Butler Ellis et al., 2016). However, there are elements of the model where there are significant uncertainties either in the modelling approach, or in the input data. Those considered to be the most important are discussed below.

6.1. *Vapour pressure*

The vapour pressure is an important driver of vapour exposure, so the reliability of values to be used should be checked. Sometimes strongly divergent values are reported for a certain plant protection product in literature (Leistra, 2005). Data available relating to vapour pressure of the active ingredient that is available in published literature generally relates to measurements made under laboratory conditions (e.g. Guth et al., 2004). There is evidence that the product co-formulants and other components of the sprayed tank mix will influence volatility, as well as the surface onto which it is applied. Butler Ellis, Lane et al. (2010) showed that volatilisation can occur at levels very different from the published vapour pressure of the active ingredients would suggest.

This means that although vapour pressure for a given PPP is appropriate as a model input, it does not have a well-defined value, and there is significant uncertainty surrounding it. There is clearly a correlation between laboratory measures of vapour pressure and volatilisation when measured under controlled conditions, but these are generally measured for single products, rather than the more complex tank mixes that occur in practice.

Further work is therefore needed to better understand the range of vapour pressures that can occur in practice, and to determine how to treat this in an exposure assessment model.

6.2. *Airborne spray drift from orchard applications*

The data used to develop the airborne spray component of the orchard model, while they are the best that are currently available, do not give sufficient confidence in (a) our prediction of spray drift in different meteorological conditions from the limited range covered by the available data, or (b) our predictions of the effect of distance on exposure. Further experimental data are needed to expand the data on which the model is based, to support the extrapolation from a single distance to a wider range of distances that was used in the model, to better describe the relationship between airborne spray and bystander exposure, and to provide data for model validation.

6.3. *Indirect exposure model: Transfer coefficients & Turf Transferable Residues*

The model of exposure to turf contaminated with spray drift is essentially unchanged from previous regulatory models, and is given in Eq. (1):

$$Q = G \times TTR \times TC \times H \qquad (1)$$

where:

Q is the dermal exposure (mg active substance, a.s.) per person;

G is the quantity of active substance on the ground (mg a.s. m^{-2}) deposited as spray drift, determined from the spray drift model emulator;

TTR is the turf transferable residue, defined as the fraction of G which can be transferred to the body;

H is the duration of exposure (h);

TC is the transfer coefficient [m^2 h^{-1}], and is defined by Eq. (1), i.e. experimental measurements are made of Q and TTR, where G and H are known, and these are used to determine TC.

This is a very simplistic model, based on very limited data. Values for TTR, TC and H, used as input to this model have been reviewed. New data for TC and TTR are part of the revised resident exposure assessment in the USA (U S Environmental Protection Agency (EPA), 2012) but the experimental procedures used to obtain these data have not been published. It is therefore open to debate whether these data should be used in the BROWSE model, which aims to be transparent. The data were included, despite the drawbacks relating to transparency, because we believe it is the most comprehensive and reliable dataset available, particularly when compared with the previously used data.

The purpose behind the US data was the assessment of exposure to turf treated directly with a pesticide application (i.e. at full dose) rather than to turf contaminated by the lower values found in spray drift. Applications to turf are often at much higher water volumes than those used in agricultural applications, and it is likely that these experiments were undertaken at high volumes, which could result in a significant fraction of the applied pesticide being absorbed into the ground and unavailable for transfer. By contrast, a drifting spray plume will be of low volume and fine droplets, and would settle only on the top of the sward, thereby being much more available for transfer. The TTR, expressed as a fraction of the quantity of pesticide per unit area, could therefore be significantly higher than the 0.05 mean value indicated by the US data.

The TTR has to be considered alongside a transfer coefficient, measured in the same experiment, since TC is defined by Eq. (1). Therefore, it is difficult to justify increasing the TTR to account for the uncertainty outlined above without consideration of TC, and some data to support it. There is the possibility of using alternative TTR and TC data in the BROWSE model should any become available.

EFSA (2010 and 2014) proposed alternative values of transfer coefficients but did not indicate the source. Values of 0.73 $m^2 h^{-1}$ and 0.26 $m^2 h^{-1}$ were suggested for adults and children respectively in 2010, and higher values, 1.45 and 0.52 $m^2 h^{-1}$ in 2014. US mean values are higher still (18.0 and 4.9 $m^2 h^{-1}$). The value in the current exposure model used by the UK Chemicals Regulation Directorate is 0.52 $m^2 h^{-1}$ for children, again without citing the source. A previous US exposure assessment (Residential Exposure Assessment Work Group, 1997) suggested 4.3 and 0.87 $m^2 h^{-1}$, and indicated that their value for a child was derived by scaling the adult value according to the relative body surface areas. There is therefore a wide range of values that could be used in a regulatory model.

Indirect dermal exposure, as defined in Eq. (1) is linearly proportional to the values of TTR and TC and if distributions given by the US data are used as model inputs, this can dominate total exposure, particularly for boom sprayers, as shown in Fig. 2. It is important that further work is done, and relevant data obtained, to support this part of the resident and bystander exposure model.

The assertion that the transfer coefficient is proportional to the body surface area (Residential Exposure Assessment Work Group, 1997) is not supported by any data, and in more recent US models (U.S. Environmental Protection Agency (EPA), 2012), the method for translating TC from adult to child is not clear. The transfer coefficient is defined in Eq. (1) as the area of ground contacted by the body per unit time, not the body surface area contacted by the ground per unit time. It is likely that there is a correlation between the two, but they are not identical. For example, a child and adult walking barefoot will have different body surface areas in contact with the ground, defined by the ratio of their footprint areas, but the child is likely to take more steps than the adult, and therefore the ground surface area contacted will not have the same ratio between adult and child as the footprint area.

In the BROWSE model, the same distribution of values of TC from the US data is used for both adult and child, on the grounds that it is likely that the data derives from a range of sizes of volunteers (although probably not children). The distribution is likely to represent a worst case for children.

Similarly, Eq. (1) suggests that exposure increases with duration. There is no data to support this, and while it is a useful conservative first approximation, it is probable that saturation occurs, either because the pesticide on the ground becomes depleted or because there is a maximum dermal loading.

The estimation of this component of the total exposure is possibly the weakest, and would benefit considerably from obtaining relevant experimental data to refine the model and the input parameters.

7. 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:

- The model is sufficiently flexible to allow the wide range of application practices and crops around the EU to be addressed, including all outdoor field crops sprayed with a conventional boom, and fruit crops sprayed with an air-blast sprayer;
- 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;
- The model is appropriate for a wide range of agricultural crops,

- It is possible to use the current BROWSE models 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 be default values. At higher tiers, the user can enter alternative input data that may be more appropriate to the specific proposed use;
- Mitigation measures to reduce exposure (such as spray drift reduction technology) can be taken into account if required.

8. Conclusions

A new model has been developed, with the aim of improving our estimate of exposure of residents and bystanders to pesticides used in a wide range of agricultural applications. The population that is modelled relates to people (both adults and children) who have no association with the application (i.e. not occupational exposure) but are adjacent to the treated area during and after the application process.

The probabilistic approach taken has allowed a distribution of exposures to be determined, and also ensures that the worst case exposures, obtained by consideration of the higher percentiles, are not unrealistic.

The scenario that the model aims to describe is based on consideration of both best practice, and of real practice as shown in surveys and from expert knowledge obtained in stakeholder consultations. It is recognised that many improvements are possible in the model which can be made as more data becomes available.

It is expected that the levels of exposure that the BROWSE model predicts will be, in many cases, higher than those predicted by the current UK regulatory model.

Possible increases in exposure predictions within the framework of pesticide approvals are likely to lead to greater pressure for drift reduction. While mitigation measures for reducing resident and bystander exposure are not currently accepted as part of a product approval, the use of engineering and other controls for spray drift reduction could become increasingly important in enabling plant protection products to remain available to European growers.

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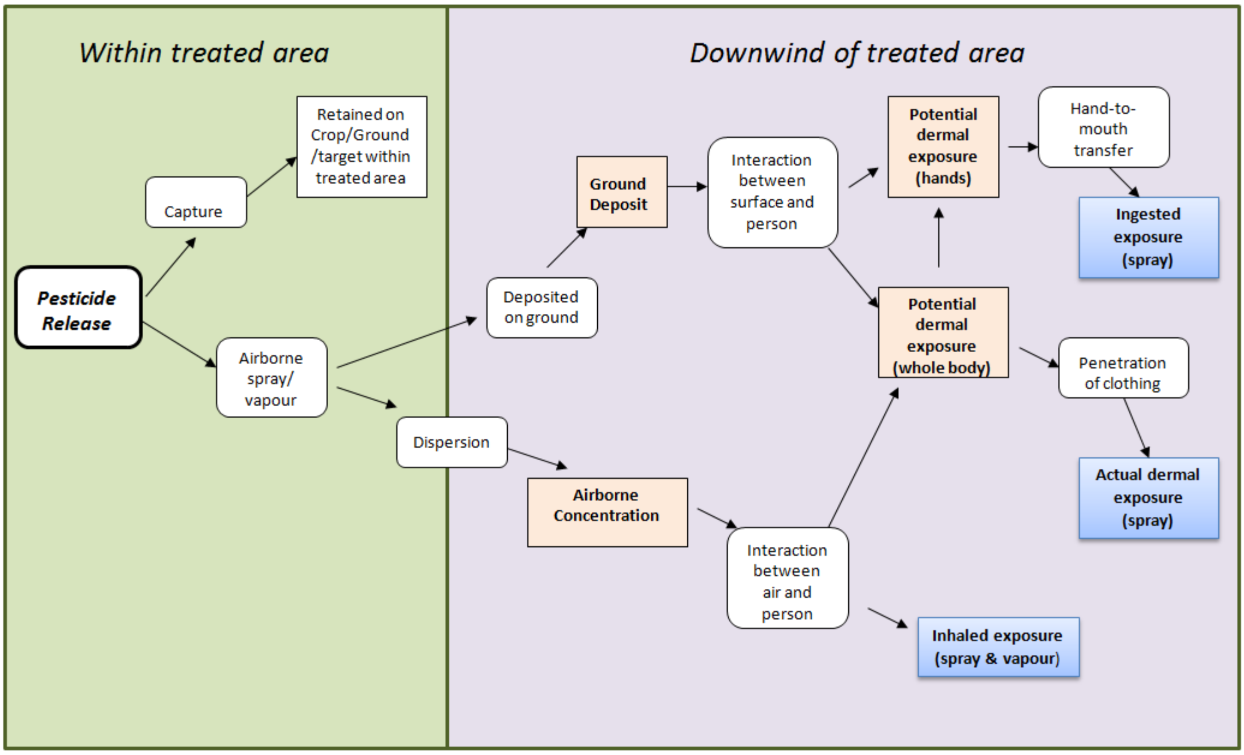

Within treated area
Downwind of treated area
Pesticide Release
Capture
Retained on Crop/Ground /target within treated area
Airborne spray/ vapour
Deposited on ground
Dispersion
Ground Deposit
Interaction between surface and person
Potential dermal exposure (hands)
Hand-to-mouth transfer
Ingested exposure (spray)
Potential dermal exposure (whole body)
Penetration of clothing
Actual dermal exposure (spray)
Airborne Concentration
Interaction between air and person
Inhaled exposure (spray & vapour)

Fig. 1

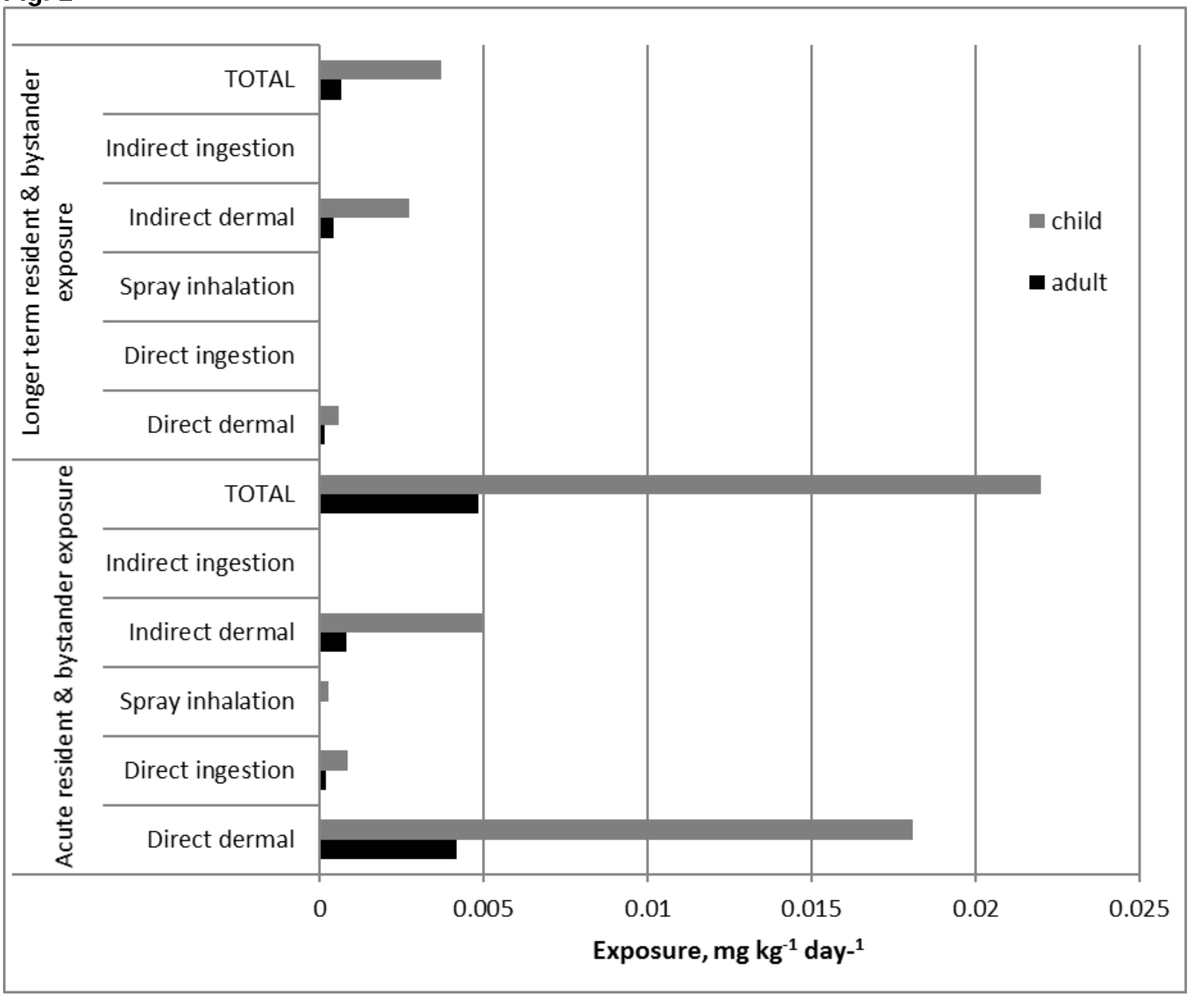
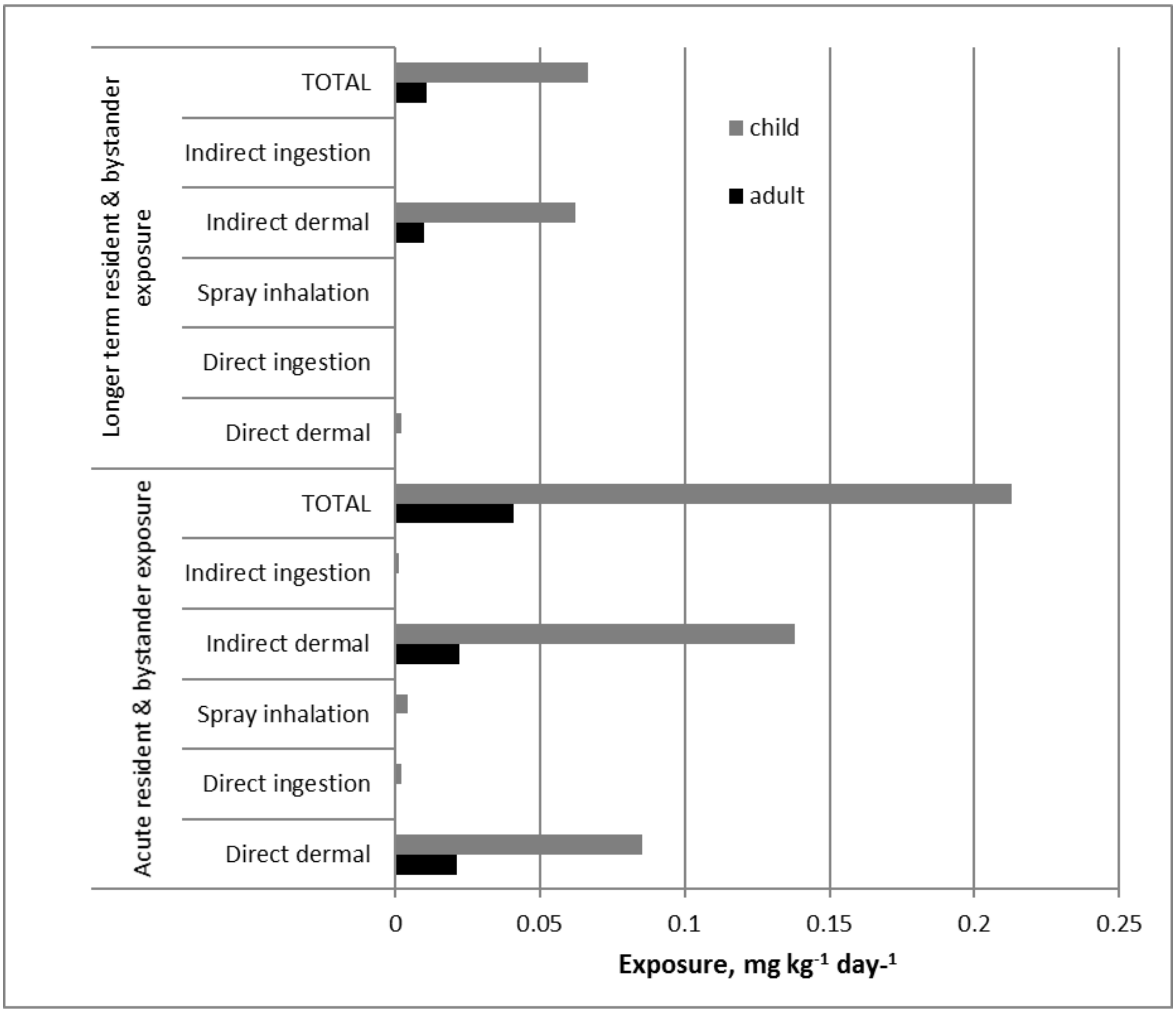
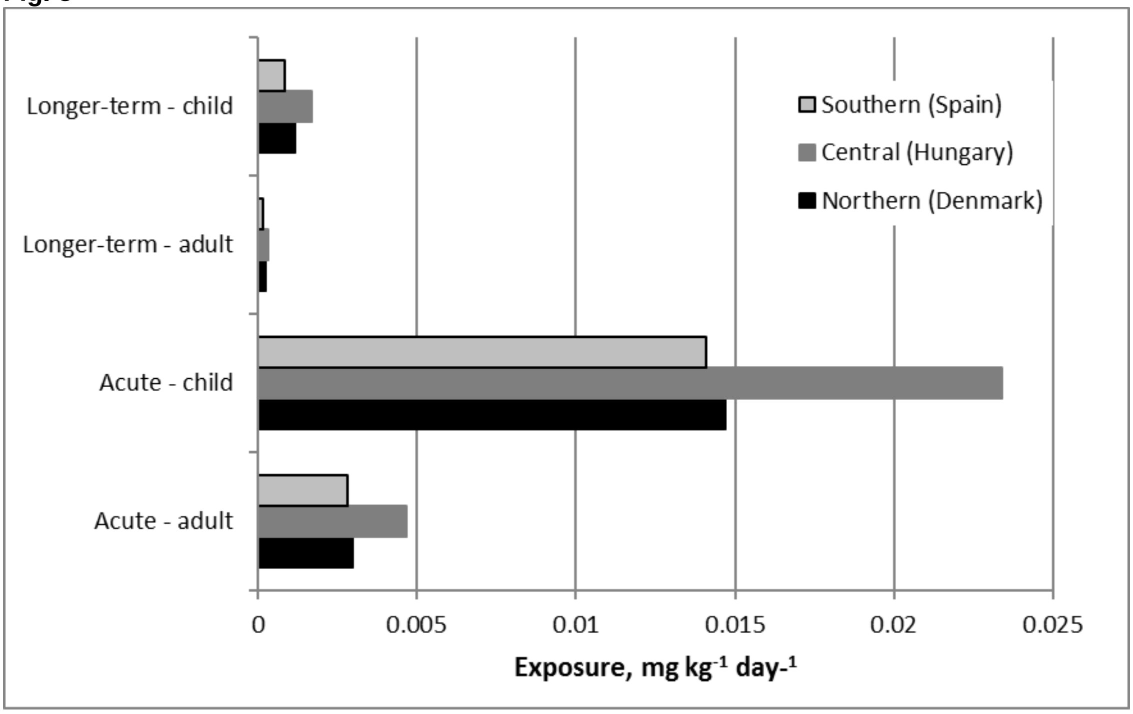

Longer term resident & bystander exposure
Acute resident & bystander exposure
TOTAL
Indirect ingestion
Indirect dermal
Spray inhalation
Direct ingestion
Direct dermal
child
adult
0
0.005
0.01
0.015
0.02
0.025
Exposure, mg kg-1 day-1

Fig. 2



Longer term resident & bystander exposure
Acute resident & bystander exposure
TOTAL
Indirect ingestion
Indirect dermal
Spray inhalation
Direct ingestion
Direct dermal
child
adult
0
0.05
0.1
0.15
0.2
0.25
Exposure, mg kg-1 day-1

Fig. 3



Longer-term - child
Longer-term - adult
Acute - child
Acute - adult
Southern (Spain)
Central (Hungary)
Northern (Denmark)
0
0.005
0.01
0.015
0.02
0.025
Exposure, mg kg-1 day-1

Fig. 4

Fig. 1 - Conceptual model for the determination of exposure of residents and bystanders to agricultural use of pesticides.

Fig. 2 - Acute and longer term exposures to spray drift predicted by the BROWSE boom model. Acute exposure based on 95th percentile, and longer term exposure based on 75th percentile of the distribution of model outputs. Direct exposure derives from the airborne spray plume; indirect exposure from contact with a lawn contaminated with spray drift. Model input values for this simulation were BROWSE default values, with an applied active substance dose of 500 g/ha and a dermal absorption of 10%.

Fig. 3 - Acute and longer term exposures to spray drift predicted by the BROWSE orchard model. Acute exposure based on 95th percentile, and longer term exposure based on 75th percentile of the distribution of model outputs. Direct exposure derives from the airborne spray plume; indirect exposure from contact with a lawn contaminated with spray drift. Model input values for this simulation were BROWSE default values, with an applied active substance dose of 500 g ha^{-1} and a dermal absorption of 10%.

Fig. 4 - Acute and longer term exposures to vapour predicted by the BROWSE boom and orchard models. Acute exposure based on 95th percentile, and longer term exposure based on 75th percentile of the distribution of model outputs. Model input values for this simulation were BROWSE default values, with an applied active substance dose of 500 g ha^{-1} and a vapour pressure of 0.005 Pa at 20^{o}C.