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Spray drift for the assessment of exposure of aquatic organisms to plant protection products in the Netherlands

Part 1: Field crops and downward spraying

J.C. van de Zande, H.J. Holterman & J.F.M. Huijsmans

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Abstract

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As part of the Dutch authorisation procedure for pesticides an assessment of the effects on aquatic organisms in surface water adjacent to agricultural fields is required. This in turn requires an exposure assessment for these surface waters. So far, in the current Dutch authorisation procedure spray drift is the only source of exposure. For this reason a new exposure scenario was developed, which includes also input by drainage and atmospheric deposition. The endpoint of the exposure assessment is the 90th percentile of the annual maximum concentration in all field ditches alongside field crops. The spray drift model IDEFICS was used to determine the 90th percentile PEC for 66 water bodies based on wind speed, wind direction and water body geometry. This resulted in a typical water body coinciding with the weather circumstances for the reference drift curve for downward spraying of field crops (including arable crops, field vegetables, flowers, bulbs and small tree nursery crops). The state-of-the-art of the spray drift data is described and standard drift curves are defined for boom spraying in field crops. Based on the crop growth situations and the used spray techniques, different spray drift deposition curves are used to determine the exposure to surface water including the 90th percentile approach. A matrix approach was developed to assess spray drift exposure combining classes of Drift Reducing Technology (DRT; for drift reduction classes 50, 75, 90 and 95) and stepwise widths of crop-free buffer zones. The methodology of using the matrix structure is discussed for the assessment of drift deposition for downward sprayed field crops (arable). The data for spray drift deposition presented in this report are higher than the spray drift data as presently used in the Dutch authorisation procedure. This is caused by the availability of new spray drift data (which appears to show higher drift values) and by using a different water body for reference evaluation (with a subsequent change in position and dimensions of the surface water area with respect to the treated field).

Key words: spray drift, Drift Reduction Technology, surface water, crop-free zone, IDEFICS.

Preface

A few years ago the Dutch government decided to initiate an improvement of the methodology for the assessment of effects on aquatic organisms. In order to establish a comprehensive methodology, the Dutch government initiated six working groups to cover various aspects of the new methodology:

- A working group on legal aspects, dealing amongst others with the relation between the WFD and EU directive 91/414/EC (replaced by Regulation 1107/2009);
- A working group on exposure of aquatic organisms;
- A working group on effects on aquatic organisms;
- A working group on multiple stress;
- A working group on emissions from glasshouses (currently split into two working groups);
- A working group on the feedback of monitoring results to the authorisation procedure.

As part of the revision, the Dutch government charged the working group on exposure with the development of a drainpipe exposure scenario and the update of the used spray drift data. This report describes the development and parameterisation of the spray drift scenario for field crops with downward directed spray techniques. This scenario will be included in the software tool DRAINBOW, which will be described in a separate report.

This report is produced within the framework of the working group on exposure of aquatic organisms. The following persons have contributed to this working group: Paulien Adriaanse (Alterra), Jos Boesten (Alterra), Joost Delsman (Deltares), Aleid Dik (Adviesbureau Aleid Dik), Corine van Griethuysen (Ctgb), Mechteld ter Horst (Alterra), Janneke Klein (Deltares), Ton van der Linden (RIVM), Jan Linders (RIVM), Aaldrik Tiktak (PBL) and Jan van de Zande (PRI). The authors of this report acknowledge the members of this working group for discussions and suggestions for improvement.

This research has been performed within the research programme BO12-007-002/004 of the Ministry of Economic Affairs, Agriculture & Innovation.

Summary

As part of the proposed revised assessment procedure for exposure of aquatic organisms in the Netherlands an exposure scenario was developed for downward spraying in field crops. This scenario corresponds to the 90th percentile of the annual maximum concentration in all ditches that receive input from spray drift and drainpipes. The scenario is intended to be a second tier approach following a first tier consisting of one or more of the FOCUS surface water scenarios and can be succeeded by higher tiers considering refinements such as improved input parameters and drift reduction measures.

The aim of this study is to develop a new methodology for a realistic worst case scenario of exposure to drift (using a 90th percentile approach) including a methodology for the implementation of drift reducing technologies (DRTs) and other drift mitigation measures. Furthermore, the aim is to make an update of drift exposure data to establish a state-of-the-art methodology for drift evaluation.

The current authorisation procedure for plant protection products (PPPs) in the Netherlands makes a differentiation in the spray drift originating from spray applications in field crops (including arable crops, field vegetables, flowers, small fruits and small tree nursery crops), applications in fruit crops and applications in tree nursery crops. This differentiation is based on the way PPPs are applied. In field crops a boom sprayer is used where the spray is directed downward. In fruit trees and nursery trees an upward or sideward directed spray technique is used. Based on the crop growth situations and the used application techniques different spray drift deposition curves are used to determine the exposure to a standardized water surface (the 'standard ditch'). This resulted in standard drift values for the different situations known as the standard Ctgb drift table.

For the revised assessment procedure the state-of-the-art of the drift data is described for the standard drift curves for boom spraying as used in field crops. Measured spray drift curves for presently used reference situations (defining nozzle type, boom height, crop height) and drift reducing technology (DRT) are given. Furthermore, the methodology and classification of DRTs in spray drift reduction classes 50, 75, 90 and 95 is discussed.

Regarding spray drift deposits using a certain application technique, the predicted environmental concentration (PEC) in a surface water body depends on wind speed, wind direction and water body geometry. In the Netherlands, water bodies have been classified into 66 standard profiles. In a simulation study the variation in PEC levels was investigated for realistic variations in wind speed and wind direction for each of the water body profiles. The 90th percentile level of PEC values from this study is considered an adequate indicator for a realistic worst case assessment of drift deposits onto surface waters. The population and frequency distribution of water bodies was limited to those areas where both drift and outflow from drainpipes are potential sources for PPP loads. A water body profile was identified for the downward directed spray application in field crops (arable crops).

Based on the crop growth situations and the used spray techniques, different spray drift deposition curves are used to determine the exposure to surface water including the 90th percentile approach. With the obligation to develop a scenario for authorisation of PPP taking into account the measures imposed by the LOTV it was impossible to come up with a tiered approach. Not all DRTs lead to similar or stepwise decrease in spray drift exposure of the surface water, especially when they are combined with different widths of crop-free buffer zones. It was therefore decided to develop a matrix approach combining classes of DRT and stepwise widths of crop-free buffer zones. The methodology using this matrix structure is discussed for the assessment of drift deposition for downward sprayed field crops.

For downward directed spraying the spray drift data are updated for all field measurements on spray drift done up till 2005. Compared to the drift data currently used in the authorisation procedure of PPP the new drift data are higher for the downward directed spray applications. The minimal drift reducing package (50% drift reducing nozzle types, spray boom height of 0.50 m above a crop, using an end-nozzle and 1.50 m crop-free buffer zone) as used in spraying potato or flower bulb crops gave an average drift deposition of 0.88% on the water surface in the old

situation and with the updated drift data this is 1.09%. Using the new reference ditch for the 90th percentile exposure as determined in this report the spray drift deposition on surface water increases further to 1.14% as the bank width of the new ditch is smaller and the water surface is wider compared to the old standard ditch.

Generally stated, the spray drift deposition data presented in this report are higher than nowadays used in the authorisation procedure because of the use of updated drift data and a change in position and dimensions of the new reference water body for evaluation.

1. Introduction

1.1 Aim and background of the study

As part of the Dutch authorisation procedure for plant protection products (PPP), an assessment of exposure of aquatic organisms in surface waters adjacent to agricultural fields is required. Spray drift, atmospheric deposition, drainage and runoff are the most important processes involved in loading of edge-of-field surface waters with PPPs (Figure 1). In the evaluation of active substances at the EU level, the importance of all these entry routes is acknowledged (FOCUS, 2001; FOCUS, 2008). In the current Dutch authorisation procedure, however, spray drift is the only pathway for substances entering the surface water (Beltman and Adriaanse, 1999; Ctgb, 2010). Therefore, in view of EU harmonisation, the responsible Dutch ministries requested the development of a state-of-the-art methodology to calculate the input of PPPs through spray drift, atmospheric deposition and drainage (Tiktak *et al.*, 2012a). This new methodology will become part of a new exposure scenario, which is currently being developed for downward directed spray applications in field crops (Tiktak *et al.*, 2012b) and later for upward and sideward directed spray applications.

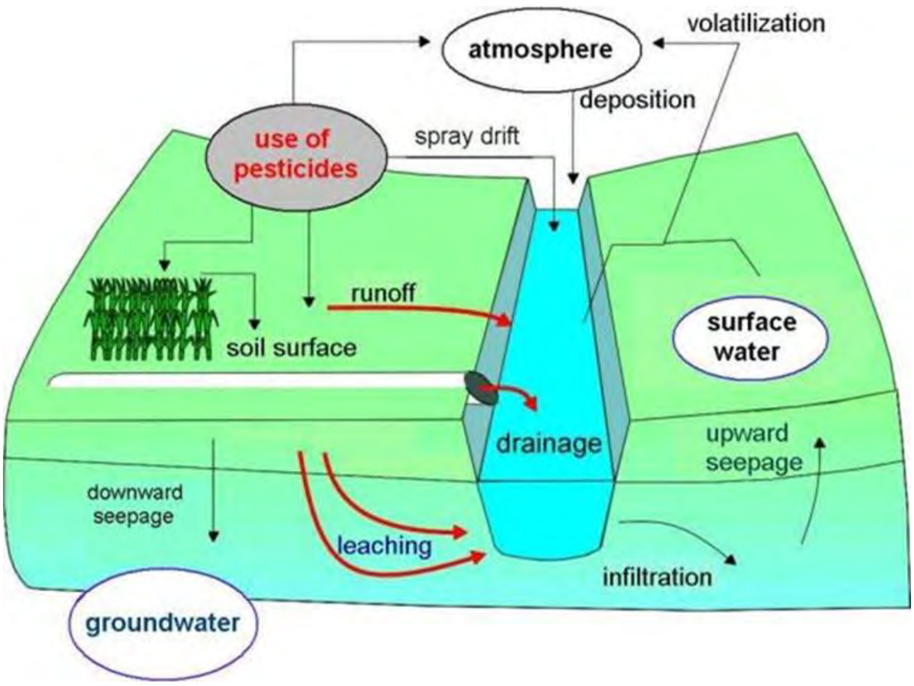

Figure 1. Main processes involved in loading of edge-of-field surface waters with plant protection products.

The aim of the study reported here is to develop a new methodology for a realistic worst case scenario of exposure to drift (using a 90th percentile approach) including a methodology for the implementation of drift reducing technologies (DRTs) and other drift mitigation measures. Furthermore the aim is to make an update of drift exposure data to establish a state of the art methodology for drift evaluation.

1.2 Structure of report

In the current authorisation procedure for PPPs in the Netherlands a differentiation is made in the spray drift originating from spray applications in field crops (including arable crops, field vegetables, flowers, bulbs, small fruits and small tree nursery crops), applications in fruit crops and applications in tree nursery crops. This differentiation is based on the way PPPs are applied. In field crops a boom sprayer is used with a downward spray direction. In fruit trees and nursery trees an upward or sideward directed spray technique is used. Based on the crop growth situations and the used spray techniques different spray drift deposition curves are used to determine the exposure to a standardized water surface (standard ditch). This resulted in standard drift values for the different situations known as the 'standard Ctgb drift table'. Chapter 2 describes in more detail the background of the current practice of estimating spray drift to surface water including the regulations by the Dutch Water Pollution Act (LOTV; VW *et al.*, 2000, 2007) and the drift data used within the authorisation of PPP by the Board for the Authorisation of Pesticides and Biocides (Ctgb) for downward directed spray applications in field crops.

In Chapter 3 the state-of-the-art of the drift data is described including standard drift curves for downward directed spray applications in field crops (boom spraying). Furthermore the methodology and classification of Drift Reducing Technologies (DRTs) is discussed.

Regarding drift deposits using a certain application technique, the predicted environmental concentration (PEC) in a surface water body depends on wind speed, wind direction and water body geometry. In the Netherlands, water bodies have been classified into 66 standard profiles (Massop *et al.*, 2006). Chapter 4 describes a simulation study where the variation in PEC levels due to realistic variations in wind speed and wind direction for each of the water body geometry profiles is investigated. The 90th percentile level of PEC values from this study is considered an adequate indicator for realistic worst case assessments of drift deposits onto surface waters. The population and frequency distribution of water bodies was limited to those areas where both drift and outflow from drainpipes are potential sources for PPP loads (see also Tiktak, *et al.*, 2012b).

In Chapter 5 for each of the subdivisions the methodology for the assessment of spray drift to surface water is described based on the combination of drift reduction technology classes and width of crop-free buffer zones including the 90th percentile approach.

In Chapter 6 discussion points are addressed and in Chapter 7 the final conclusions are given.

2. Current Dutch legislation procedures to assess spray drift

This chapter gives an overview of the use of spray drift deposition data and drift reducing technology options to mitigate spray drift in the current authorisation procedure of PPP of downward directed spray applications in field crops. The relation with the implementation of compulsory crop-free buffer zones according to the Water Pollution Act (LOTV; VW *et al.*, 2000, 2007) in the authorisation procedure is addressed. Furthermore, the way in which drift reducing technology, to be used alongside waterways following the LOTV, can be certified is addressed. Drift reduction packages as combinations of drift reducing technology and width of crop-free buffer zone used in the authorisation procedure are discussed.

2.1 Current evaluation with regard to crop differentiation for estimating drift deposition on surface water

In the authorisation procedure for PPPs in the Netherlands, a differentiation is made in the spray drift amount originating from spray applications in field crops (including arable crops, field vegetables, flowers, small fruits and small tree nursery crops), fruit crops and tree nursery crops (Figure 2). Basis for this differentiation is the way PPPs are applied.

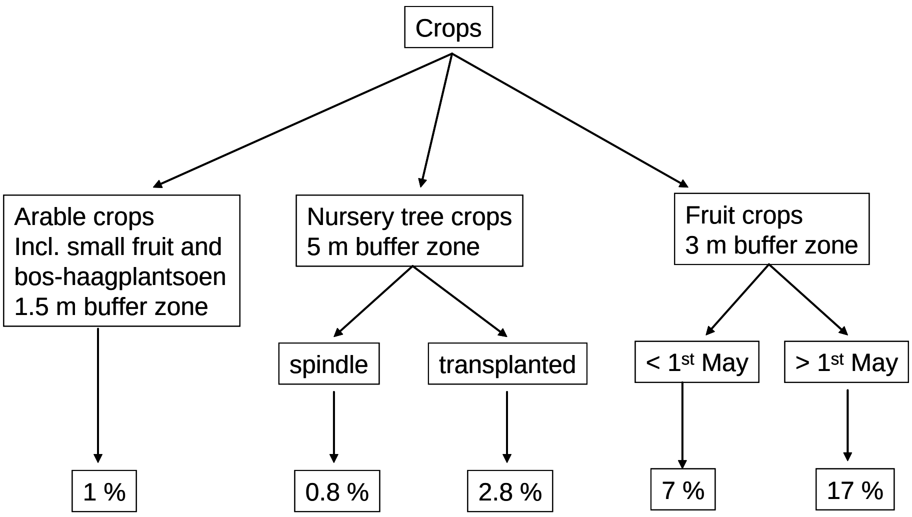

Figure 2. Differentiation in crop types and growth situations in the authorisation procedure of PPP based on spray drift and the currently used spray drift values for surface water exposure (Evaluation Manual 1.0).

In arable crops (including small nursery tree crops) a field boom sprayer is used with a downward spray direction. In fruit trees and nursery trees upward or sideward directed spray techniques are used. Based on the crop growth situations and the used spray techniques different spray drift deposition curves are used to determine the deposition on surface water, which is schematised as a standard ditch. This resulted in standard drift values for the different situations known as the standard Ctgb drift table. For downward spraying of field crops the standard drift value is 1% spray drift deposition on surface water. This is based on the situation described by the Dutch Water Pollution Act (LOTV) requiring a minimal low drift technique using spray nozzles of the drift reduction class 50, a maximal spray boom height of 0.50 m above crop canopy, the use of an end-nozzle to prevent overspray at the crop edge and a crop-free buffer zone of 1.50 m. The spray drift deposition value on surface water is 0.88% for the low drift spray technique (Zande *et al.*, 2000a), which is rounded off to 1% and used in the authorisation procedure, irrespective of the cropping situation.

For fruit crops, a differentiation is made between the situation before the first of May when trees are dormant or have little leaf development and after the first of May when trees are at full leaf stage. Used spray drift deposition values are 17% for the situation before May 1st and 7% for the situation after May 1st. The drift deposition is based on measured drift data in the full leaf stage and estimated spray drift in the dormant situation based on literature (Huijsmans *et al.*, 1997). The standard crop-free buffer zone in the fruit crop situation is 3 m. For nursery trees, a differentiation is made between spindle trees and transplanted trees having spray drift values of respectively 0.8% and 2.8%. The standard crop-free buffer zone for nursery tree crops is 5 m (LOTV).

Results of spray drift research from WUR Plant Research International (PRI, former IMAG) and Applied Plant Research (PPO) are incorporated in Dutch legislation. In the Surface Water Pollution Act and the Pesticide Act (LNV, 1998) criteria for drift deposit on surface water are used, depending on the spray technique, buffer zone and period of use during the growing season. Recently, new spray drift data have become available which will lead to an adaptation of the spray drift values for the different crop types. Moreover new legislation has entered into force on the width of crop-free buffer zones (LOTV, VW *et al.*, 2000 adapted in 2007) and commonly used drift reducing technology for the different crop types, making it necessary to differentiate more for these situations in the authorisation procedure. A further differentiation is described in the next sub-paragraph for downward directed spray applications in field crops. For upward and sideways spray techniques as used in fruit crops and tree nursery a separate scenario will be developed and will be described separately.

2.2 LOTV packages for drift reduction alongside waterways (LOTV 2000 and update 2007)

In the Water Pollution Act (LOTV; VW *et al.*, 2000, 2007) combinations of crop-free buffer zones and drift reducing measures are mentioned for fruit crop and nursery tree spraying (upward and sideward spraying) and arable crop spraying (downward - boom spraying) to reduce the emission of PPP to surface water. The measures to be taken in the field are adapted to the different crops, the other measures are of a general nature to be applied at all farms. The LOTV specifies that when spraying a crop alongside surface water with boom sprayers the outside 14 m of the field is to be sprayed using a drift reducing nozzle types, and end nozzles.

For all field crops a crop-free buffer zone of 14 m must be taken into account when a conventional boom spray application is used. The minimal drift reducing measures that are to be taken on the outer 14 m of the field adjacent to a ditch when applying PPP with a downward directed spray application (boom sprayer) are:

- Use of drift reducing spray nozzles (minimum 50% drift reduction class), and
- Use of a drift reducing end nozzle, and
- A maximum boom height of 50 cm above crop canopy.

For intensively sprayed crops, defined as crops sprayed more than 10 times per growing season or with a usage of more than 5 kg/ha PPP per growing season (LOTV; VW *et al.*, 2000), a crop-free buffer zone of 150 cm must be taken into account, for cereal crops and grassland 25 cm and for other crops 50 cm. For organically grown crops no crop-free buffer zone is defined (0 cm). A crop free zone is in the LOTV defined as the distance between the last crop row and the top of the bank of the surface water. The use of crop free and spray free zones and buffer zones differs in different countries (Huijsmans &Zande, 2011; Appendix B).

The width of the crop-free buffer zone of intensively sprayed crops can be reduced to 100 cm by using additional drift reducing measures at the outer 14 m of the field like:

- Additional air assistance on the boom sprayer
- Catch crop at the edge of the field
- Use of a shielded sprayer for bed-grown crops

If a handheld spray boom is used the crop-free buffer zone should be at least 50 cm.

Table 1 gives the crop groups and accompanying crop-free buffer zones according to LOTV (2000) for field crops sprayed with a downward spray direction (boom sprayer).

Table 1. Field crop groups sprayed with a downward spray direction (boom sprayer) and accompanying crop-free buffer zones according to LOTV (2000).

Crop sector	Crops	Crop - free zone [cm]
Arable	Potatoes (seed, consumption, starch), plant onion, seed onion	150
Flower bulbs	Flower bulbs and tubers	150
Open field vegetables	Strawberry, lettuce, carrots, salsify, leek, asparagus	150
Tree nursery	Rose bush, small conifers, Bush and hedge shrubbery, other shrubs, climbing plants, fruit trees	150
Arable	Grass seed, winter – summer wheat, winter- summer barley, rye, oats, triticale, flax	25
Livestock	Pastures and temporary grassland	25
Other crops	e.g. Cauliflower, broccoli Spinach Green peas Lucerne (alfalfa), green manure crops, colza, poppy (blue moon) seed, caraway beetroots, endive flower crops, horticultural seed production (kidney)beans, marrow pea Chicory (roots), celeriac Sugar beet, cabbage, broad bean Maize, chicory Brussels sprouts, kale Bed grown endive fallow land	50
Organic crops		0

2.3 Certification of Drift Reducing Technologies

To prevent stagnation of new developments to reduce spray drift, the LOTV (VW *et al.*, 2000, 2007) allows application techniques with equivalent drift reducing capacities to be used in practice. LOTV created a possibility to advise Waterboards to accept the use of new drift reducing techniques with reduced width of buffer zones. As it is not efficient to evaluate these new techniques separately by each individual Waterboard the Technical Committee on Technology evaluation (Technische Commissie Techniekbeoordeling - TCT) was installed to evaluate potential drift reducing technology on a national scale. TCT consists of representatives of Unie van Waterschappen (chair), Rijkswaterstaat-Waterdienst, Federatie Agrotechniek, Wageningen University – Agrarische Bedrijfs Technology (WU-ABT), Crop Protection Service (now Food Safety Authority VWA), Dutch Farmers Association (LTO) and Board for the Authorisation of Plant Protection Products and Biocides (Ctgb).

A guidance document on the evaluation of Drift Reducing Technology was developed and published 4 April 2003 by the Commission on Integral Water management (CIW) (CIW, 2003). With this guidance document water authorities can evaluate in a uniform way if an alternative application technique or (crop) measure gives at least a similar emission reduction as the prescribed drift reducing measures in the LOTV (article 3 of the LOTV).

Drift reducing nozzles and spray techniques
The TCT evaluates complete spray technique systems (measure packages in the LOTV) equipped with specific nozzle types as well as drift reduction capabilities of new drift reducing nozzle types. To quantify the drift reducing capacity of a spray technique field measurements need to be shown comparing the candidate system with a reference system or an already certified drift reducing measure under comparable field conditions (CIW, 2003) as used in field spraying of arable crops, fruit crops or tree nursery.

The reference spray technique for arable crops is a boom sprayer equipped with the standard flat fan nozzle type TeeJet XR11004 (or BCPC Fine/Medium threshold nozzle) at 3.0 bar spray pressure, operating at a speed of 6-7 km/h applying 300 l/ha.

For requests for the use of new drift reducing spray nozzles on boom sprayers research needs to be done under conditioned circumstances in the laboratory (VW & LNV, 2001, 2005). Based on drop size measurements in the laboratory a comparison is made with the reference nozzle identified by the LOTV (BCPC Fine/Medium threshold nozzle). The volume fraction of droplets smaller than 100 μm in the spray fan is a measure of the driftability. The drop size measurements are incorporated in the IDEFICS spray drift model (Holterman *et al.*, 1997) for classification of the spray nozzles in drift reduction classes (Porskamp *et al*, 1999). The various drift reduction classes are standard low drift 50%, 75, 90 and 95%, following ISO22369-2006.

Adaptation of crop free buffer zones
The grower will, for economic reasons, always chose a minimal width of the crop free buffer zone. The use of higher classes of drift reducing nozzle types will allow to apply a smaller width of the crop free buffer zone e.g. 1.0 m instead of 1.5 m. On the website www.helpdeskwater.nl the actual list of certified drift reducing techniques and nozzle types is available (TCT-CIW, 2011). The list indicates, apart from the mentioned drift reduction potential in the LOTV, also to what reduction of the crop free buffer zone it can lead to e.g. from 1.5 m to 1.0 m or 0.5 m (Table 2).

Table 2. Overview of certified downward directed spray techniques and adaptation of the standard crop free buffer zone (1.5 m) for intensively sprayed crops.

Downward directed spray techniques	Crop free buffer zone (m)	Remarks
Air assistance and spray nozzle type of spray quality Medium, Coarse or Very Coarse	1.5	Spray pressure max 3 bar
Hardi Twin Force air assistance and spray nozzle type of spray quality Medium, Coarse or Very Coarse	1.0	Max air setting, spray pressure max 3 bar
Hardi Twin Force air assistance and drift reducing nozzle type	0.5	Max air setting, spray pressure max 3 bar
Field boom sprayer equipped with spray nozzle types of the drift reduction class 90	1.0	
Lowered sprayer boom height and venturi nozzle type	1.0	Sprayer boom height at 30 cm, Lechler ID 90-015 / IS 80-02 and max spray pressure of 3 bar
Lowered sprayer boom height and venturi nozzle type and air assistance	0.5	Sprayer boom height at 30 cm, Lechler ID 90-015 / IS 80-02 and max spray pressure of 3 bar
Släpduk system	1.0	All nozzle types, spray pressure max. 3 bar

The TCT evaluates requests for use of drift reducing application techniques. The TCT evaluates whether the presented drift reducing capacity is in accordance with the requirements of the LOTV. The drift reducing technology can either be a spray nozzle or a spray system as used in the field. The TCT advises the water authorities on the documented request. The Waterboards are autonomous in their decision whether to accept the TCT advise.

2.4 Authorisation of PPPs and LOTV

In the authorisation procedure of PPPs further restrictions (on top of the LOTV restrictions) can be prescribed to the use of PPPs. For a number of PPPs it is mandatory to use spray nozzles from the 75% and/or 90% drift reduction class when spraying the PPP or additional crop-free buffer zones. Based on these requirements the farmer has to equip his sprayer with the appropriate drift-reducing nozzles when spraying that PPP.

It is important to know that apart from the regulations of the LOTV also requirements on the use of the correct drift reducing nozzles are set based on the Plant Protection Products and Biocides Act (LNV *et al.*, 2007). The application of a specific PPP requires a crop free buffer zone to be implemented at the edge of the field alongside waterways as described on regulation based on the Plant Protection Act. Some of these crop free buffer zones can be reduced when using specific drift reducing nozzle types. The Ctgb uses a list of classes of drift reducing nozzle types, based on the LOTV drift reducing nozzle list (VW & LNV, 2005). Following the amendments of LOTV (VW *et al.*, 2007) the publication of the drift reducing nozzle list is no longer in the State Gazette. The TCT is now responsible for updating the drift reducing nozzle list (www.helpdeskwater.nl). The TCT and Ctgb agreed to have one and the same list of drift reducing nozzles and technique classes to be used, set up by the TCT (TCT-CIW, 2011).

The TCT certified spray techniques and classified nozzle types (Table 2) are also used in the authorisation procedure of a PPP. The PPP authorisation prescribes the minimum requirements with regard to the combination of drift reducing technique class and width of crop free buffer zone. These requirements are also mentioned in the user authorisation and on the label of the PPP.

3. Spray drift data and Drift reducing Technology

After an introduction on how spray drift is measured in the field this chapter deals with a historic overview on how drift data used in the authorisation procedure changed over time due to changes in reference situations. Measured spray drift curves for nowadays defined reference situations (nozzle type, boom height, crop height) and drift reducing technology are given for downward directed (boom) spraying in field crops (arable and vegetable crops). Furthermore the differentiation of spray techniques in drift reducing technology classes is discussed.

3.1 Field experiments

Spray drift experiments in the field were carried out according to the ISO standard 22866 (ISO22866, 2006) adapted for the situation in the Netherlands (ground deposits, ditch, surface water alongside the sprayed field) following the Dutch protocol (CIW, 2003). Drift deposition was measured on ground surface at the downwind edge of an experimental field with a crop. Average canopy height of the crop was measured. The swath width of the crop sprayed was 24 m. The length of the sprayed track was at least 75 m. The distance of the last downwind nozzle to the edge of the field (the last crop leaves) was determined. The measurements were spread regularly over the growing season to obtain an average crop season (crop height and canopy density) result. Spray drift measurements were carried out adding the fluorescent dye Brilliant Sulpho Flavine (BSF; 3.0 g/L) and a surfactant (Agral; 0.1%) added to the spray agent. Ground deposits were measured on collection surfaces placed horizontally at ground level in a double row downwind of the sprayed swath. The collectors were placed at distances 0.5-1.0, 1-1.5, 1.5-2, 2-3, 3-4, 4-5, 5-6, 7.5-8.5, 10-11, 15-16 m from the last downwind nozzle. Collectors used were synthetic cloths (Technofil TF-290) with dimensions of 0.50x0.10 m and 1.00x0.10 m.

Meteorological conditions during the spray drift experiments were recorded. Wind speed and temperature were recorded at 5 s intervals at 0.5 and 2.0 m height, using cup anemometers and Pt100 sensors, respectively. Relative humidity was measured at 0.5 m height and wind direction at 2.0 m height.

Spray drift experiments for a standard sprayer and a drift reducing technology (DRT) or mitigation measure were carried out in at least 8 replicates per sprayer or mitigation measure.

Spray deposits were calculated and presented as percentage deposit of the applied volume rate per unit surface-area on the different distances of the collectors. Spray depositions are calculated and presented as percentage of the applied rate per unit surface area on the different distances of the collectors. Especially important is the distance of 1.50 – 5.50 m from the last crop row, being the place where ditches (surface water) are commonly situated (Figure 3, Huijsmans *et al.*, 1997). Drift deposition on the middle of the ditch (2.25 –3.25 m from the last crop row), i.e. the water surface, is taken into account for the authorisation of PPP.

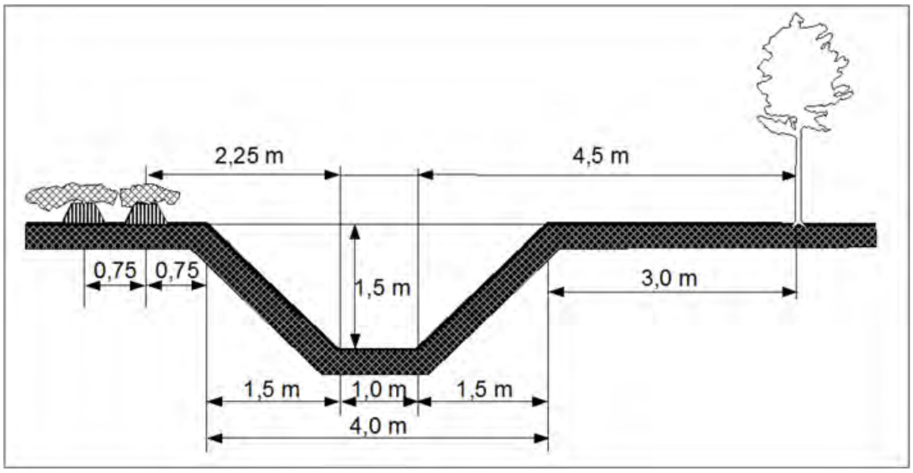

Figure 3. *Schematic presentation of the standard ditch and its dimensions in the Netherlands (after Huijsmans et al., 1997).*

In case of a comparison between technologies or mitigation measures with the reference situation spray drift reduction was calculated for the zones 0.5-4.5 m, 1-5 m, 1.5-5.5 m and 2-3 m, 2.5-3.5 m, 3-4 m from the last nozzle being the zones where in the Netherlands most often a ditch (4 m wide) with surface water (1 m wide) is located (Huijsmans *et al.*, 1997). Differences were analysed with a standard statistical package (GENSTAT, analysis of variance; Payne *et al.*, 2006 or IRREML; Keen & Engel, 1998) at a 95% confidence level.

3.2 Spray drift data

During the period 1988-1995, field measurements of spray drift with boom sprayers in potatoes (one of the LOTV intensively sprayed crops) resulted in spray drift deposition of 5.4% on surface water (LNV/VROM, 1998) for a reference situation of Dutch downward spraying (Huijsmans *et al.*, 1997). The reference situation was at that time defined as spraying a (potato) crop with a spray boom height of 0.70 m above canopy, using Fine spray quality nozzles (Southcombe *et al.*, 1997) and a crop free buffer zone of 0.75 m. Results from field drift measurements during the period 1995-2000 were used to determine new spray drift deposition values for the reference spray technique (taking into account a boom height of 0.50 m) and the standard low drift technique to be used alongside ditches based on the LOTV regulation. For the LOTV standard low drift technique, the spray drift deposition value was 1%, taking into account a compulsory crop-free buffer zone of 1.5 m, a boom height of 0.5 m above canopy, a 50% drift reducing nozzle type and using an end nozzle. In the period 2000-2005, additional spray drift measurements were performed with the reference spray technique and the standard low drift spray technique resulting in a larger database of spray drift values for potato.

From these data drift curves are generated for the reference spray technique and the standard low drift technique, generally referred to as the standard drift curves when spraying a crop. Also drift measurements have been performed with both techniques for the bare soil situation. The drift curves can be described with a double exponential equation.

The drift of low drift spray techniques can be presented as relative to the reference spray technique. Comparative field measurements were always done in parallel with the reference spray technique, in the same crop and under the same weather circumstances. Therefore, a large set of drift curves of spray drift reducing techniques can be presented for similar weather conditions. The total number of measurements and the average weather conditions during drift measurements are presented in Table 3 for the reference technique and the standard low drift technique, for both potato and bare soil spraying.

Table 3. Weather conditions during spray drift experiments (average and (standard deviation)) of reference spray technique and standard low drift technique in a potato crop and on a bare soil surface.

Crop	Spray technique	No measurements	Temperature at 2 m height [°C]	Average wind angle# [°]	Average wind speed at 2 m height [m/s]
Potato	Reference	126	20.2 (2.8)	4.3 (25)	3.4 (1.0)
	Low drift	78	20.5 (3.1)	-3.9 (24)	3.4 (0.9)
Bare soil	Reference	24	17.1 (2.4)	2.8 (19)	3.2 (1.0)
	Low drift	22	17.8 (2.9)	-5.1 (15)	3.2 (1.4)

perpendicular is 0°.

Based on field measurements, in which a drift reducing technique is always measured alongside/in parallel with the reference drift situation, drift reduction was determined for the following spray techniques:

- Air assistance on a boom sprayer (Porskamp *et al*, 1995; Michielsen *et al.*, 1999);
- Nozzle types of the classes 50%, 75% and 90% reduction (Michielsen *et al.*, 1998,1999, 2001);
- Low boom height with two nozzle types (De Jong *et al.*, 2000; Stallinga *et al.*, 2004);
- Low boom height with two nozzle types and additional air assistance (De Jong *et al.*, 2000; Stallinga *et al.*, 2004);
- Släpduk system with two nozzle types (Zande *et al.*, 2005b);
- Air assistance system (Hardi Twin Force) with two nozzle types (Zande *et al.*, 2006a);
- Tunnel sprayer for bed grown crops (Porskamp *et al.*, 1997) when spraying an arable crop, a flower bulb crop or an flower, ornamental or small fruit crop.

For the bare soil surface situation drift reduction measurements were performed with a band sprayer (Zande *et al.*, 2000b), air assistance (Stallinga *et al.*, 1999), and a Hardi Twin Force air assistance with two nozzle types (Zande *et al.*, 2006a).

Appendix A gives an overview of the separate experiments on drift reducing technologies and mitigation measures for boom spraying.

3.3 Generating standard spray drift curves for boom spraying

Currently used drift curves

Measurements of downwind spray deposits in the period 1995-2000 for a conventional boom sprayer were combined to determine a reference spray drift curve. These measurements were characterized by the use of XR11004 nozzles at a pressure of 3 bar (medium spray quality; Southcombe *et al.*, 1997) and a boom height of 0.5 m above a potato crop during the relevant period for fungicide treatments (half June – half September). Similarly, measurements using standard low-drift nozzles were combined to give a drift curve for a standard drift-reducing technique. These measurements involved the use of pre-orifice nozzles DG11004 at 3 bar with an UB8504 end nozzle, resulting in a drift reduction of 50% (Porskamp *et al.*, 1999). This nozzle arrangement is certified by the TCT-CIW (2009) as drift reducing and specified as a reference low-drift nozzle by the LOTV.

For various drift reducing spray techniques, drift reduction with respect to the reference spray technique was determined at a distance of 2-3 m from the last nozzle in the certification process. However, for many crop situations the actual location of the water surface differs from this range. Therefore the computed drift reduction at 2-3 m used for nozzle certification is in fact not representative of the field situation but a good estimate of the general drift reduction potential.

New reference drift curves
Based on a large number of drift measurements in the period 1995-2005 (see Section 3.1) a new reference drift curve was established. Based on this new reference curve, for various drift-reducing techniques the drift reduction was determined at a distance of 2-3 m. After that, these techniques were grouped into drift reduction classes as shown in Table 4.

Table 4. Downward directed spray drift reducing technologies and the drift reduction classes.

Drift reduction classes	Spray drift reducing technology in drift reduction class
50%	50% drift reducing nozzle types * Air-assisted boom sprayer + nozzles drift reduction class 0 Low-boom height (30 cm) conventional boom sprayer + nozzles drift reduction class 0
75%	75% drift reducing nozzle types * Band sprayer in maize + nozzles drift reduction class 0 Släpduk sprayer + nozzles drift reduction class 0 Hardi Twin Force air-assisted sprayer + nozzles drift reduction class 0
90%	90% drift reducing nozzle types Band sprayer in sugar beet + nozzles drift reduction class 0 Low-boom height (30 cm) conventional boom sprayer + nozzles drift reduction class 50 Air-assisted boom sprayer + nozzles drift reduction class 50 *
95%	95% drift reducing nozzle types Low-boom height (30 cm) air-assisted boom sprayer + nozzles drift reduction class 0 Low-boom height (30 cm) air-assisted boom sprayer + nozzles drift reduction class 50 Hardi Twin Force air-assisted sprayer + nozzles drift reduction class 50 Släpduk sprayer + nozzles drift reduction class 50 Tunnel sprayer for bed-grown crops + nozzles drift reduction class 0 Air-assisted boom sprayer + nozzles drift reduction class 90 *

* *Representative curve for class.*

For each drift reduction class an appropriate technique was selected (marked with * in Table 4) to calculate a drift deposition curve as a representative curve for that class. As this curve expresses a minimal drift reduction for that class it can be used as representative for all techniques in that class. To minimize uncertainties due to day-by-day variations, it proved useful to first compute drift reductions as a function of distance for each measurement. Averaging these reduction curves for a certain technique and combining the outcome with the new reference curve yielded representative drift curves for the various drift reduction classes. The curves obtained that way, as well as the reference curve, were fitted using the following empirical expression:

$$f(x) = \frac{A_0\, e^{xA_1} + B_0\, e^{xB_1}}{1 + C_0 e^{xB_1}} \qquad (1)$$

where f(x) is downwind spray deposit [% of applied dosage] at distance x [m] from the last nozzle; A_0, A_1, B_0, B_1, C_0 are regression constants. Constants A_1 and B_1 have the unit m^{-1}, the others are dimensionless). These constants depend on crop type (cropped or bare soil) and application technique. Parameters A_0 through C_0 were determined iteratively.

The typical curves obtained for the different Drift Reduction Technology classes when spraying a field crop are given in Figure 4 for the cropped situation and in Figure 5 for the bare soil or small crop situation. At the field edge (0-2 m) drift reduction is limited as overspray occurs of the last nozzle which depends much on the top angle of the outside nozzle. Therefore drift deposition curves can cross in this area. The shape of the drift deposition curves exist clearly of two parts. A steep declining part close to the crop edge and a constant decreasing part further away.

The reference techniques of the drift reduction classes are based on the evaluation in the cropped situation (spraying a potato field). This means that the spray deposition curves in the bare soil / short crop situation can have other drift reduction steps (Fig. 4). The choice for a bare soil/short crop or a cropped spray drift situation is based on crop height at application time. When crop height is below 20 cm the bare soil surface drift curves (Fig. 4) are used. Grassland follows therefore the bare soil / short crop spray drift approach.

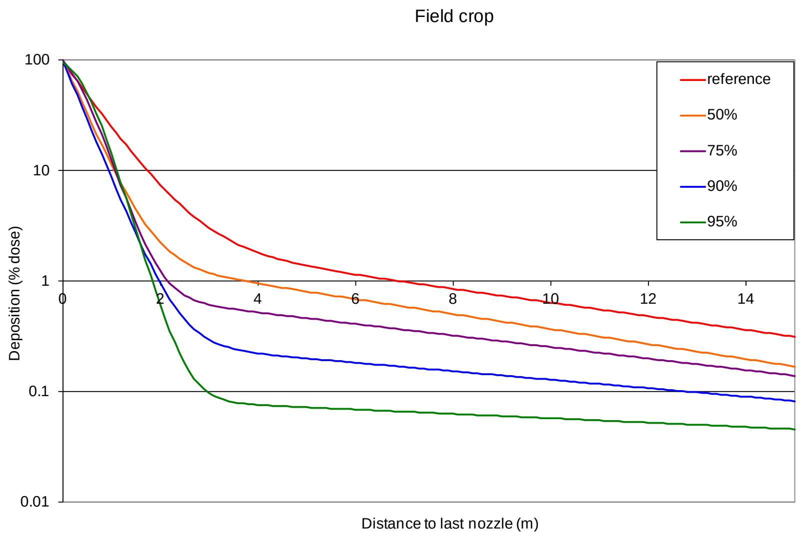

Figure 4. *Spray drift deposition curves of the standard and 50%, 75%, 90% and 95% drift reducing technology spray techniques for downward directed spray applications (boom sprayer) in a crop situation.*

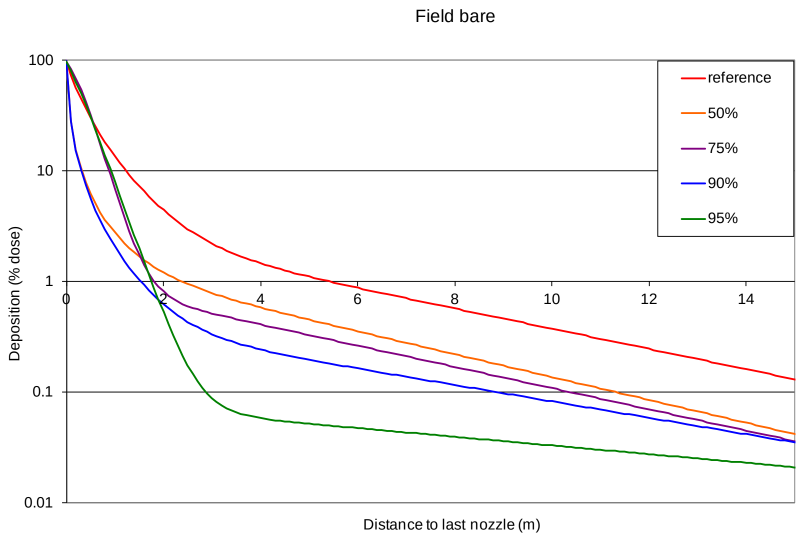

Figure 5. *Spray drift deposition curves of the standard and 50%, 75%, 90% and 95% drift reducing technology spray techniques for downward directed spray applications (boom sprayer) in a bare soil – short crop situation.*

4. Variation in PEC levels in Dutch water bodies due to spray drift

4.1 Introduction

This chapter deals with the computation of the variation in PEC values in Dutch water bodies due to the deposition of drift of PPPs onto surface waters. The method accounts for natural variation in average wind speed, wind direction and the variety and occurrence of Dutch water bodies. From these computations a realistic estimate of the 90th percentile of PEC values is derived for a fixed spray drift curve.

Drift deposits of PPPs onto surface waters are computed using the IDEFICS spray drift model (Holterman, *et al.*, 1997). These simulations are carried out for a cross wind (i.e. perpendicular to the field edge), with average wind speed ranging from 0 to 5 $m{\cdot}s^{-1}$. At higher wind speeds the application of spray is no common practice because of the high risk of drift hazards. A standard set-up is chosen to simulate the application of spray in a potato field crop, using conventional low-drift nozzles (DG11004 at pressure 300 kPa and spray volume rate 300 $l{\cdot}ha^{-1}$). A crop-free buffer zone of 1.5 m is assumed. PEC values are derived easily from drift deposits (Appendix D).

Although wind direction in the Netherlands is not completely randomly distributed, in the simulations wind direction is assumed random, as fields do not normally have preference of orientation. If the wind direction is defined zero for a cross wind at the downwind field edge, only wind directions between -90 and 90° need to be considered. For other directions the selected field edge is on an upwind side and spray drift is zero by definition.

Wind speed follows a certain frequency distribution which may vary for different locations. For convenience wind speed data from the meteorological station 'Haarweg' in Wageningen is used to establish a frequency distribution.

All Dutch water bodies (up to 6 m width) have been categorized into 66 standard profiles (Massop *et al.*, 2006). Each standard profile has its own geometry; its total length occurring in the Netherlands has been estimated. These data are required for calculating PECs from drift deposits and as weight factors in the distribution of PEC values.

The methods used in this chapter result in a set of standard profiles that can be used as reference profiles for PEC monitoring. These methods are based on simulations of drift for field spraying.

4.2 Methods

Basically, the three major variables causing PEC variations are average wind speed, average wind direction and water body profile. For each of the 66 standard profiles, PEC values are estimated for 20 values of average wind speed (0.25 – 5.00 $m{\cdot}s^{-1}$ in steps of 0.25 $m{\cdot}s^{-1}$) and 35 wind directions (-85° - 85° in steps of 5°) towards the water body. This yields a total number of 46200 different situations. Each situation has its own probability of occurrence, based on the frequency distribution of wind speeds and the weight factor (by total length) of the standard profiles. As wind direction is assumed to be randomly distributed, its weight factor is equal in each situation.

Drift simulations with IDEFICS depend only on average wind speed (assuming cross winds only), so 20 simulations must be carried out. The effect of wind direction on drift deposits is computed using a method described below. Although standard profiles can be very different, these do not affect the drift process itself, yet from their geometry the location and width of the water surface is derived to compute drift deposits on that surface. PEC values are computed from drift deposits, using the geometry of the standard profiles. The next paragraphs will clarify the methods involved.

4.2.1 Computation of drift deposits

Downwind spray deposits as a function of distance ('drift curves') are established using IDEFICS for 20 average wind speeds. Each drift curve is fitted with an empirical function consisting of the sum of two exponentials:

$$f(x) = A_0\, e^{xA_1} + B_0\, e^{xB_1} \qquad (1)$$

where y is the amount of drift at downwind distance x. This equation is a simplification of the one presented in Section 3.1.3, by setting factor C_0 to 0 (as the denominator only affects drift immediately next to the crop, typically x<1m, which is not relevant here). These fits yield 20 sets of values for the parameters A_0, A_1, B_0 and B_1, one set for every wind speed. Subsequently, for each parameter the set of obtained values is fitted as an empirical function of wind speed. Using these functional descriptions of the four parameters, the double-exponential fit of the drift curve describes drift deposits as a combined function of downwind distance and wind speed.

The following settings are chosen in the simulations with IDEFICS:

- Spray nozzle DG11004 at 300 kPa and dose rate 300 $l \cdot ha^{-1}$; the concentration of the active ingredients in the spray liquid was adjusted corresponding to a dose of 1 kg per ha;
- Average wind speed ranging from 0.25 to 5.00 $m \cdot s^{-1}$, in 0.25 $m \cdot s^{-1}$ intervals; wind speed represent the values at 2 m height above a field of cut grass;
- Crop height 0.50 m;
- Sprayer boom height 0.50 m above the crop;
- Outer nozzle located 0.50 m inward from crop edge;
- Crop-free zone 1.50 m (in potato crop: distance from outer ridge to onset of the bank of the ditch);
- Weather conditions: temperature 15°C, relative humidity 60%, neutrally stable atmosphere.

Figure 6 shows an example of downwind drift deposits and a fitted drift curve. Symbols indicate results from IDEFICS, the curve indicates the fitted double-exponential function. The fitted curve represents model results well, except for a few deposits very close to the field edge. These latter positions, however, are irrelevant for computations on the water surface of the standard profiles, which never are located that close to the field edge. Figure 7 gives an example of downwind deposits on the standard ditch (2.375-3.375 m downwind, Fig. 5) and at 10 m downwind, for wind speeds ranging from 0 to 5 $m \cdot s^{-1}$.

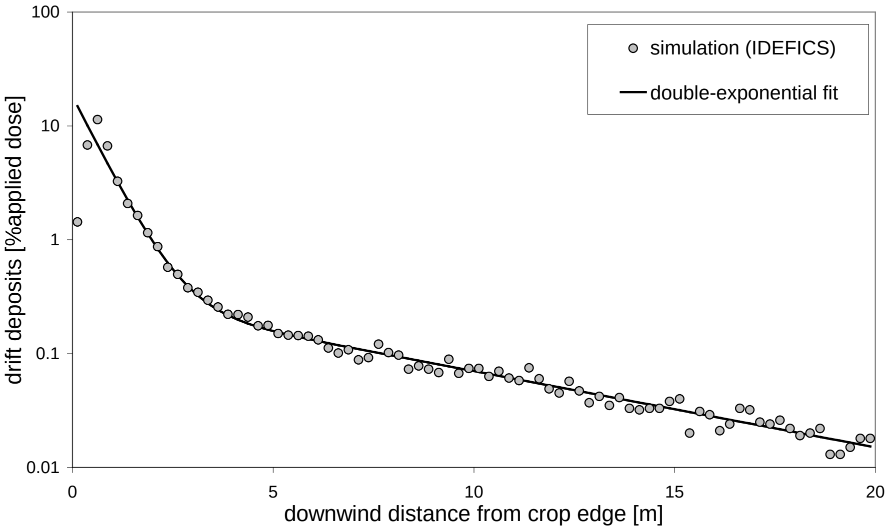

Figure 6. Downwind deposits of spray drift for an application in a potato crop using DG11004 nozzle in a cross wind with an average speed of 3.0 $m \cdot s^{-1}$.

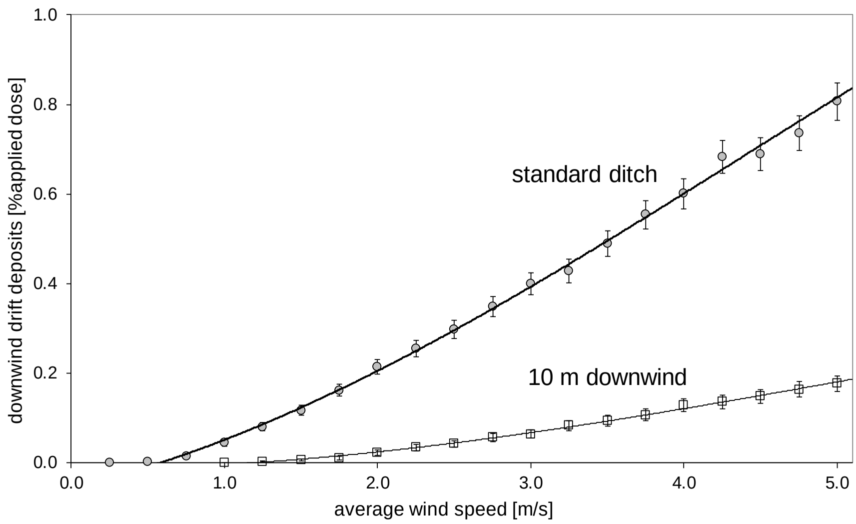

Figure 7. *Downwind deposits of spray drift as a function of wind speed for standard ditch (2.375-3.375 m) and 10 m downwind. Based on simulations with a potato crop using DG11004 nozzles in a cross wind. Bars indicate estimated standard deviations.*

4.2.2 Computation of PEC

PEC values are computed from drift deposits as follows (see Appendix D):

$$PEC = \frac{B\,D\,w}{A}$$

Where D is the applied dose [kg·m^{-2}]; B is the average drift deposit on the water surface, relative to D [-]; w is the width of the water surface [m]; A is the vertical cross-section of the standard profile [m^2].

4.2.3 Frequency distribution of wind speeds

Hourly averaged wind speeds at 2 m height were taken from 10 years (1998-2007) of meteorological data from the weather station 'Haarweg' in Wageningen. From these data a frequency distribution of occurring wind speeds was derived, see Figure 8. The figure shows a clear difference between frequency distributions of a natural day of 24 hours and for daylight hours only. A table of sunrise and sunset times for the year 2008 (KNMI) was used to determine daylight hours for each day of the year. Taking data on an hourly basis, sunrise and sunset times could be fitted with a simple sine function. The bold curve in Figure 8 shows the polynomial for daylight hours and is used to calculate the weight factor for occurring wind speeds. The dashed curve shows the distribution for 24 hours, clearly indicating that on average wind speeds are much lower during nightly hours. Both polynomials are fitted to values up to wind speed of 6 m·s^{-1}, to prevent anomalies near the intended upper boundary of 5 m·s^{-1}.

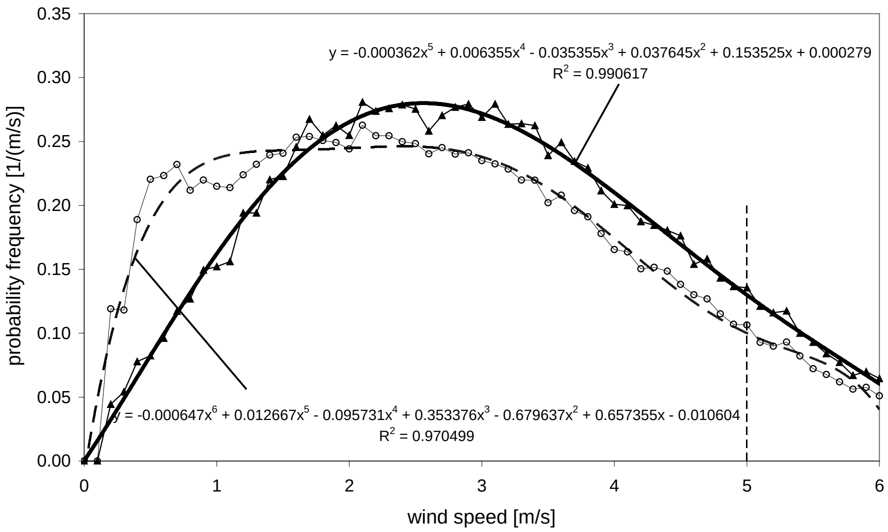

Figure 8. *Frequency distribution of hourly averaged wind speeds at 2 m height; 10 year averages for meteorological station 'Haarweg', Wageningen. Circles: distribution for natural day (24 h); triangles: distribution for daylight hours only. Dashed curve: polynomial fit for 24 h distribution; bold curve: polynomial fit for daylight distribution.*

4.2.4 Wind direction

If wind direction is not perpendicular to the field edge a simple correction can be made so that the cross-wind drift curves can be used throughout. In fact, accounting for wind direction affects the distances from field edge to water body surface and its effective surface width. See Figure 9 to illustrate this. Assume the water surface is located at a distance ranging from x_1 to x_2 [m], relative to the field edge. If wind direction is θ, the spray cloud travels a slightly longer path (s_1 [m]) to the water surface, and the effective surface width ranges from s_1 to s_2 [m]. The distance the spray drops have to travel from crop edge to water body is:

$$s_1 = \frac{x_1}{\cos\theta}$$

And the effective surface width the spray cloud experiences is:

$$s_2 - s_1 = \frac{x_2 - x_1}{\cos\theta}$$

In this case, the average drift deposits are computed as the integral of the drift curve (the same curve as with a cross wind) from s_1 to s_2, divided by width $s_2 - s_1$.

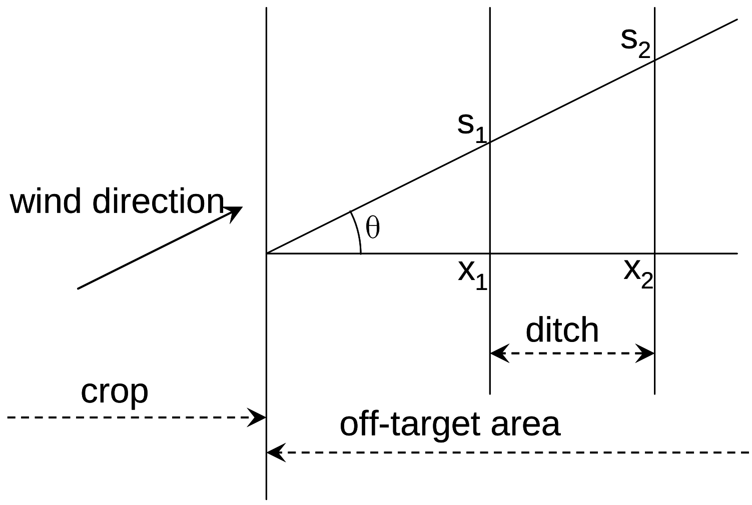

Figure 9. *Graph to illustrate that non-perpendicular wind direction implies an increase in distance to water body surface and effective surface width for drift deposits.*

Drift deposits onto water body surface are highest in a cross wind and decrease gradually when wind direction deviates from perpendicular to the field edge, see Figure 10. The solid line in this graph results from the method described above. Simulations using IDEFICS (v3.4) with various wind directions are represented by the square symbols in the graph. Estimated standard errors (bars in Figure 10) originate from the stochastic character of IDEFICS and can be reduced by taking more droplets in the simulations. The figure shows small differences between simulations and theoretical curve; see Appendix C for clarifications.

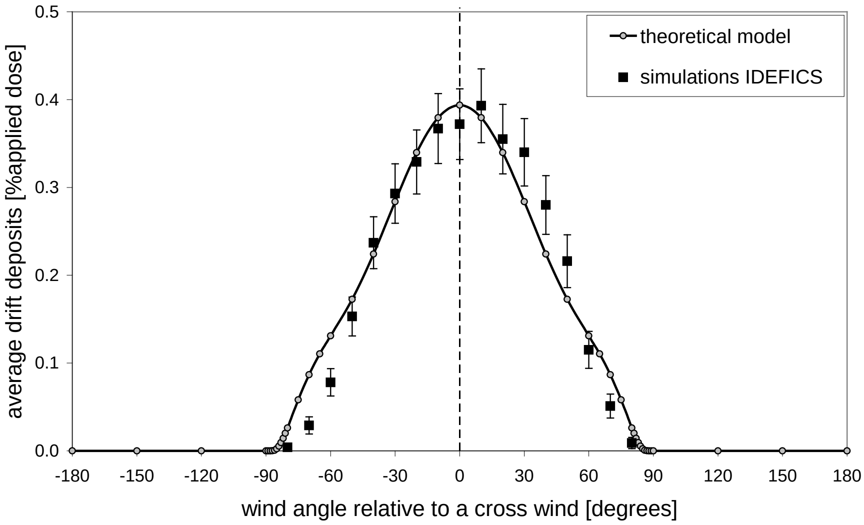

Figure 10. *Example showing average drift load onto a water body as a function of wind direction. Wind direction zero represents a cross wind. Symbols: results from simulations with IDEFICS; bars: estimates of standard deviation; solid line: computation using the theoretical approach (1/cosθ correction) applied to the double-exponential curve for the cross-wind case.*

In this study 35 discrete wind directions are selected, ranging from -85° to 85° with respect to the cross-wind direction, in steps of 5°. The solid curve of Figure 10 indicates that 5° increments offer sufficient resolution. Angles of -90° and 90° represent wind direction parallel to the crop edge, which in fact cannot produce off-target deposits off that edge. Therefore these angles (and all angles beyond these values) are omitted from the computations.

4.3 PEC distributions

Table 5 shows a summary of results from PEC computations. *N* is the total number of situations involved; *PEC_nn* is the *nn*-th percentile of PEC values for the given selection of situations; *PECspan* is defined by (PEC_90 – PEC_10) / PEC_50. PECspan is a measure of relative variation of PEC values in the given selection. Selection A represents all possible cases (N=46200). The other selections (B through F) are subsets. Selection B represents all cases where wind direction is perpendicular to the field edge (N=1320: 66 water bodies times 20 wind speeds). Clearly, the median PEC value is higher than in selection A, since all cases with non-perpendicular wind directions, which tend to give relatively low PEC values, are excluded from selection B. Similarly, selection C is limited to cases with wind speed of 2.75 m/s, which is about the daytime average wind speed. Selections D, E and F are subsets representing the three water body classes (each containing 22 standard profiles of primary, secondary and tertiary water bodies, respectively). The results show that ditches, which are relatively close to the sprayed field, yield relatively high PEC values. The class of water bodies with widths of 3-6 m display relatively low PEC values, due to the fact that these water bodies often are located relatively far from the field edge and their large width effectively dilutes spray deposits more than in case of the other water bodies. Varying depths of the water bodies can have an additional effect. Note that for all subsets PECspan is less than for the full set of situations (A).

Table 5. Summary of results from PEC computations.

Code	Selection	N	PEC_10	PEC_50	PEC_90	PECspan
			[mg/m^3]	[mg/m^3]	[mg/m^3]	[-]
A	All situations	46200	0.0164	0.700	3.74	5.3
B	Cross-wind cases only	1320	0.213	1.84	7.54	4.0
C	Cases with wind speed 2.75 m/s	2310	0.110	0.839	3.54	4.1
D	Cases with tertiary water bodies	15400	0.0488	1.49	7.14	4.8
E	Cases with secondary water bodies (<3m width)	15400	0.0126	0.565	2.19	3.8
F	Cases with primary water bodies (3-6m width)	15400	0.00329	0.230	0.845	3.7

Figure 11 shows the distributions for selections A, B and C. Selecting B, the cross-wind cases, clearly shows relatively high PEC values as explained above. Selection C, fixed wind speed cases, has a distribution curve which is slightly steeper than that of selection A: selection C lacks cases with very low and very high PEC values, i.e. when wind speed is low and high, respectively.

Figure 12 shows the global distribution (selection A) and the three cases with water bodies in one class only (selections D, E and F). Clearly, the distribution for tertiary water bodies (selection D) yields the highest PEC values, while the distribution for wide water bodies (selection F) yields the lowest PEC values. Variations in water body width have a major effect on PEC values; water depths can have an additional effect, as indicated by Figure 13. This figure shows that ditches are relatively shallow, while wide water bodies are relatively deep; this correlates inversely with (e.g.) 90th percentile PEC values.

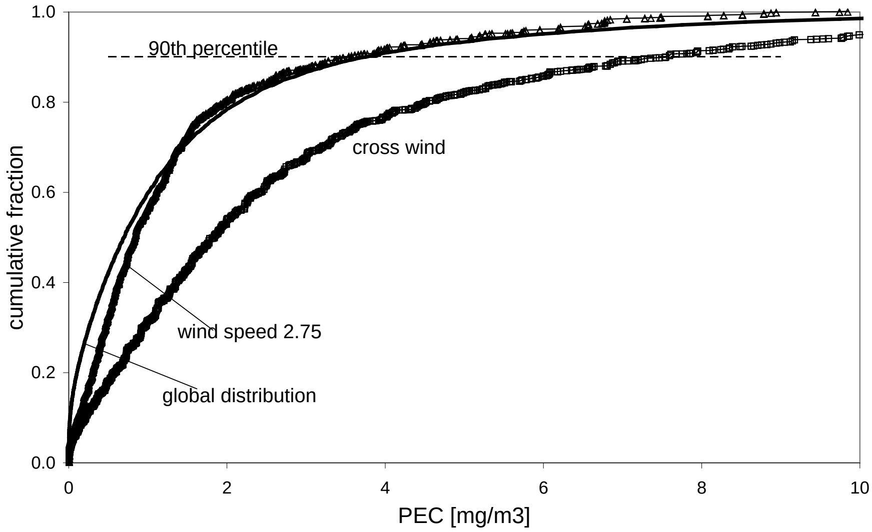

Figure 11. *Cumulative frequency distributions of PEC values: global distribution (selection A) and subsets with fixed wind speed (selection C) and cross-wind cases (selection B).*

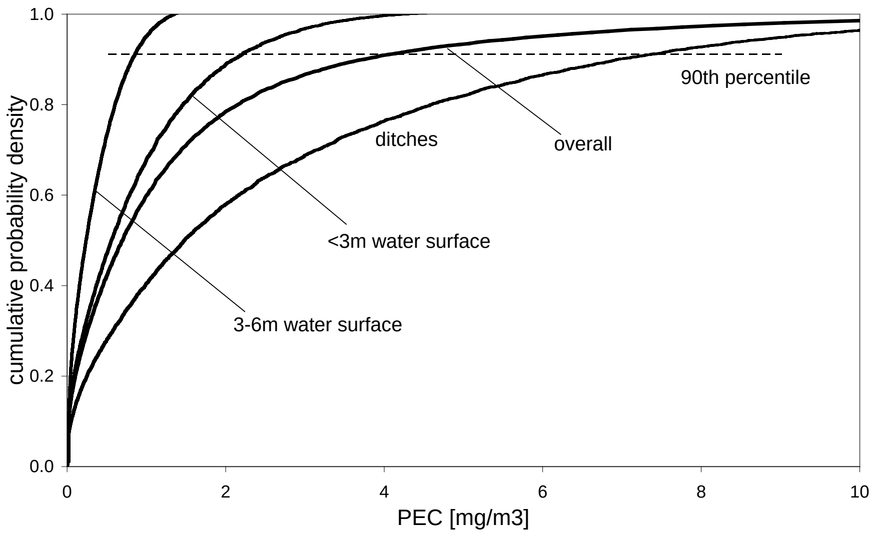

Figure 12. *Cumulative frequency distributions of PEC values: global distribution (selection A) and subsets per water body class (selections D, E, F).*

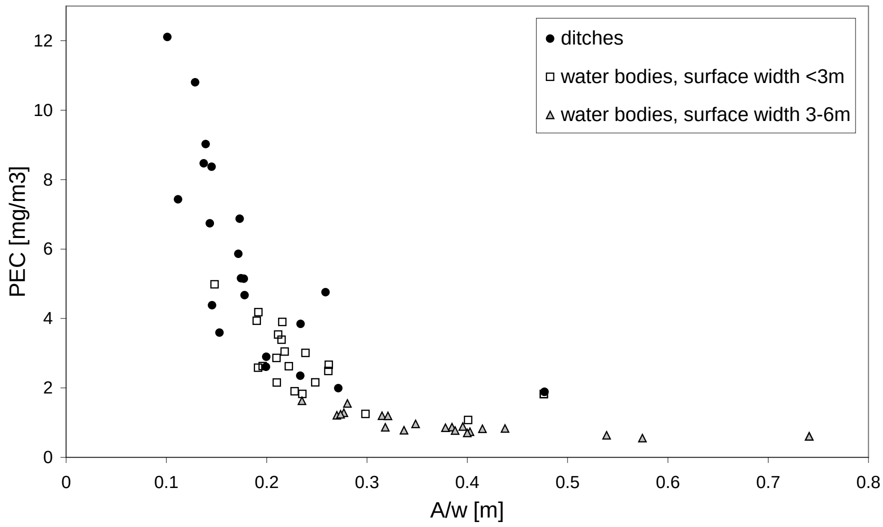

Figure 13. Relation between 90th percentile PEC and effective water depth (A/w) for all standard profiles. Different symbols indicate different water body classes.

4.4 Selection of suitable standard profiles

Now that the PECs for many situations have been established, can we select a situation that is suitable to be used as a reference for risk assessment? More specifically: is it possible to select a standard profile to be monitored in practice as an indication of risk of PPP exposure in all Dutch water bodies? This section deals with this problem. A stepwise procedure is described which is applied to two cases, considering (a) all areas with water bodies and (b) its subset containing drained areas only.

4.4.1 Stepwise selection procedure

The procedure to select representative standard profiles for monitoring consists of 4 steps, described below.

Step 1: sorting situations per standard profile
For each standard profile, the PEC value for 700 situations of wind speed (20 cases) and wind direction (35 cases) has been determined. This range of PEC values is sorted in ascending order for each standard profile separately. This yields 66 sorted distributions. The sorting orders of these distributions look very similar: e.g. situations with low wind speed and large wind angle give low PEC values and these situations will end up at the beginning of the distributions. However, there appeared to be minor differences between the various sorting orders.

Step 2: sorting standard profiles
For each of the distributions of step 1 the median PEC value is determined. This yields a median value (indicated as PEC50) for each standard profile. In step 2 all standard profiles are sorted with respect to increasing PEC50 values. Typically, wide and deep water bodies generally have low PEC values and their PEC50 will be relatively low as well; these water bodies will end up at the beginning of the sorted list of standard profiles. Each standard profile was assigned a weight factor proportional to the total length of that profile in the Netherlands.

Step 3: combining steps 1 and 2 in one plot
Taking the midpoints of each standard profile in a cumulative weighted order as values on the x-axis in a 3D graph, and the midpoints of wind speed/direction cases in their cumulative weighted orders (per standard profile) as values on the y-axis, and selecting corresponding PEC values at the z-axis, a 3D plot of PECs vs. standard profile and wind

speed/direction is obtained. In a corresponding 2D plot lines of constant PEC values ('iso-PEC' lines) can be drawn, e.g. see Figure 14 in the next section. This graph will be named 'PEC plot' in the following text.

Step 4: selection of suitable situations as reference cases in risk assessment
In risk assessment, situations where the computed PEC values are near the 90th percentile of the global distribution are considered to be representative and potentially suitable as monitoring objects. A large number of situations (i.e. combinations of standard profile, wind speed and wind direction) appear to come near the line of 90th percentiles. The following limitations are posed to narrow down the potential situations:

1. for field crops: allow only wind speeds of 3.25 and 3.50 m·s^{-1} and wind directions ranging from -10° to 10°; see below for reasoning;
2. define 'near' 90th percentile as a deviation within 1, 2 or 3% from 90;
3. the standard profiles in the selection should be relatively abundant in the Netherlands.

The limitation for field crops represents the range of wind conditions for trials performed for field crops in the past. Measured drift deposits for these cases are available to compare with results from simulations. This limits the number of potential situations to 10 per standard profile (2 wind speeds times 5 wind directions). This limits the number of situations to 15 per standard profile (3 wind speeds, 5 wind directions). Limitation 3 not really is a limitation; it just defines the term 'near 90th' in practical form.

4.4.2 Application to all areas

First, the stepwise procedure is applied to all areas with water bodies. Figure 14 shows the PEC plot (after step 3). Considering the limitations for field crops (as given in step 4), Figure 15 shows the PEC plot with only three lines of constant percentiles: 87, 90 and 93%. Small crosses indicate all situations within limitation 1. Vertical sets of 10 crosses belong to the same standard profile. Varying horizontal distance between such sets reflect the variation in weights for the standard profiles. Only the crosses between the 87th and 93rd percentiles are valid with respect to limitation 3 (setting the allowed deviation to 3%).

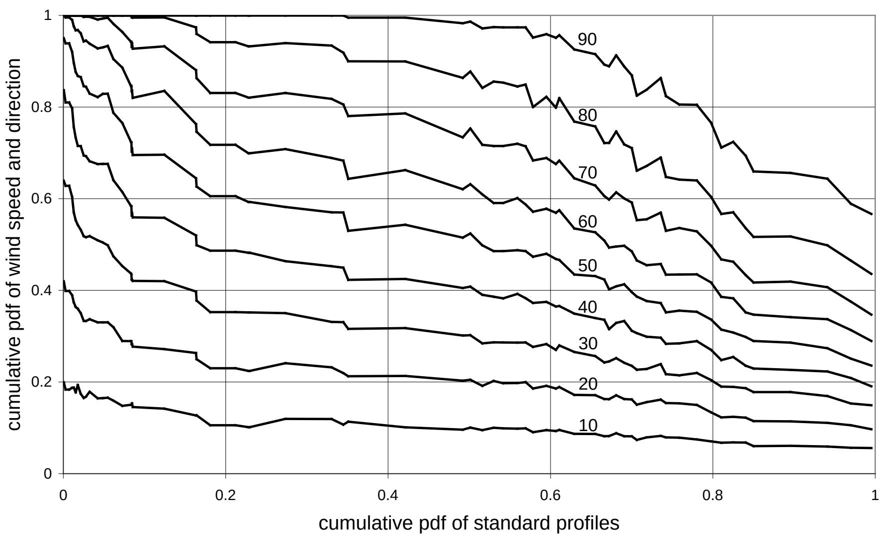

Figure 14. Lines of constant PEC values based on percentiles of the global distribution, as a function of weighted order of standard profiles (horizontal axis) and wind speed/direction cases (vertical axis). Numbers indicate the percentiles (%).

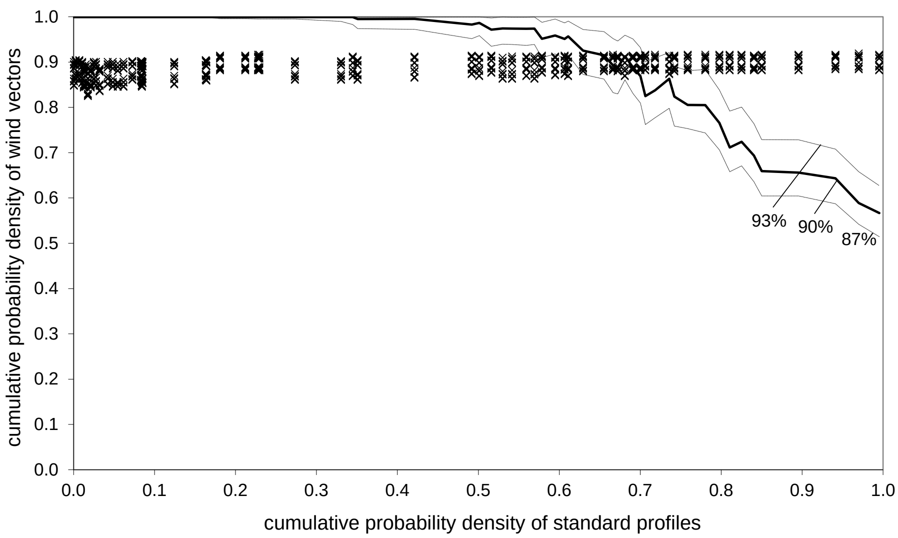

Figure 15. *'PEC plot' showing all cases within limitation 1 (small crosses), as well as the lines of percentiles 87, 90 en 93%.*

Figure 16 zooms in at the cases within the 87th and 93rd percentiles. Large dots are within 89 and 91%, small dots within 88 and 92% and crosses within 87 and 93%. Dots and crosses are located on a more or less horizontal band, while the percentile lines roughly follow downward slopes in the graph. Consequently, standard profiles with most situations within the percentile limits are located in the centre of the graph, while standard profiles with only a few valid situations are located to the left or right in the graph.

Table 6 gives an overview of the same results per standard profile. It shows that for several standard profiles all 10 wind speed/direction situations are within the 3% margins around the 90th percentile (see column 'prcmarge 3%'). If all 66 standard profiles were equally likely to occur, their weight factor would have been 1/66 (~0.015). Column 'WFrel' gives the ratio of actual weight factor and this averaged weight factor of ~0.015. For instance, WFrel>1 implies that the corresponding standard profile is more abundant than average. Therefore, a suitable standard profile for reference should have a WFrel value near or preferably above 1 (in fact quantifying the criterion for abundance in Section 4.4.1).

Suitable standard profiles are more likely to be found in the central regions of Figure 16, or near the central rows in Table 6.

Table 6. *Overview of standard profiles with PEC values around the 90th percentile for downward directed spraying of field crops, with wind speeds ranging from 3.25 to 3.50 m·s-1 and wind direction between -10° and 10°. Profiles are sorted for increasing PEC50 values (i.e. according to their x axis location in the PEC plot).*

WLcode[5]	HydroRegio	HydroType	WB class[1]	[2]						WFprof[3]	CWprof[4]	WFrel[5]
				Prcmarge 1%		Prcmarge 2%		Prcmarge 3%				
				#	CWwind	#	CWwind	#	CWwind			
601006	Zandgebied	Keileemprofiel	B					3	0.912	0.01674	0.579	1.10
601015	Zandgebied	Tegelen/Kedichem profiel	B					3	0.912	0.00733	0.607	0.48
601003	Zandgebied	Dekzand profiel	B	3	0.912	5	0.910	10	0.897	0.03567	0.629	2.35
601009	Zandgebied	Nuenengroep profiel	B	5	0.911	8	0.902	10	0.898	0.01591	0.655	1.05
600002	Rivierkleigebied	Betuwe-stroomruggronden	A	7	0.892	10	0.898	10	0.898	0.00647	0.666	0.43
601011	Zandgebied	Open profiel	B	7	0.891	10	0.898	10	0.898	0.00513	0.672	0.34
600019	Zeekleigebied	Westland_DH-profiel	A	5	0.906	8	0.897	10	0.892	0.01253	0.681	0.83
601004	Duinstrook	Duinstrook	B	7	0.892	10	0.898	10	0.898	0.00723	0.691	0.48
601005	Zandgebied	Eem en/of keileemprofiel	B	5	0.885	9	0.896	10	0.898	0.01141	0.700	0.75
600008	Zandgebied	Loss profiel	A					5	0.888	0.00079	0.706	0.05
600013	Beekdalen	Singraven-beekdalen	A			2	0.882	7	0.892	0.02333	0.718	1.54
600012	Zandgebied	Peelo profiel	A	2	0.874	7	0.886	10	0.894	0.01174	0.736	0.77
601008	Zandgebied	Loss profiel	B					5	0.884	0.00085	0.742	0.06
600001	Rivierkleigebied	Betuwe-komgronden	A					2	0.882	0.01106	0.780	0.73
		Profiles:	Number:	8		9		14				
		Situations:	Number:	41		69		105				

1 *WB class: water body class: A: tertiary water body; B: water body with surface width < 3 m; C: water body with surface width 3-6 m.*

2 *Prcmarge: acceptable margin around the 90th percentile of the global cumulative distribution of PEC values; #: number of situations within the give margins (note that the max number is 10: 2 wind speeds times 5 wind angles); CWwind: position at the cumulative distribution of wind speed/direction combinations, averaged over the situations within the given margins (i.e. averaged position at y axis in PEC plot).*

3 *WFprof: weight factor of the standard profile (cumulative length of current profile divided by cumulative lengths of all profiles).*

4 *CWprof: position of standard profile in the cumulative distribution of standard profiles (based on their PEC50): i.e. position at x axis in PEC plot; the standard profiles in this table are listed with ascending values of CWprof.*

5 *Weight factor per profile relative to a global average of 1/66 per profile.*

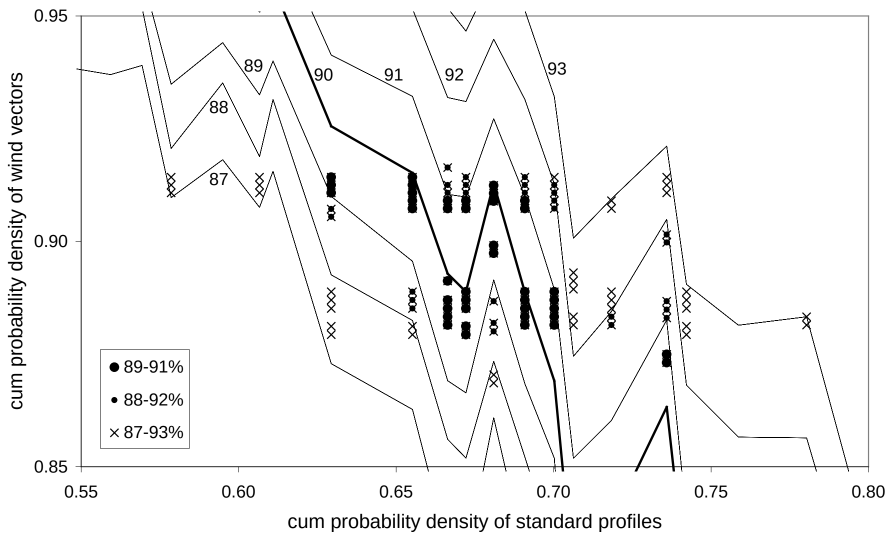

Figure 16. Similar to Figure 15, zoomed in at the situations within percentiles 87 and 93, and neglecting all cases outside these lines.

4.4.3 Application to drained areas

In the previous section the stepwise selection procedure for suitable standard profiles was applied to all areas containing water bodies. In this section the same procedure is applied to the subset with drained areas only. In fact this directly affects the weights of standard profiles, and as such will change the PEC plot. Consequently, the list of suitable standard profiles may differ from the results of the previous section.

In step 1, the weight factor for each standard profile was determined as the ratio of the total length of that profile along drained parcels and the total length along drained areas of all standard profiles. It appeared that 10 standard profiles were not present in drained areas; in fact these disappeared from the set of profiles. For mathematical reasons, their weight factor was set to 10^{-10}, small enough to cause no problems in the selection of suitable profiles.

The sorting order of standard profiles (step 2) is based on their PEC50 values (i.e. the median value from wind speed/direction variations) and is not affected by the weight factor of step 1. Thus, the order is identical to the one in Section 4.4.2. Clearly, as some profiles technically disappear from the list, while weight factors of others can be significantly different from before, the position of standard profiles along the x axis of the PEC plot differs as well.

The new PEC plot for drained areas is shown in Figure 17. This graph differs slightly from Figure 14. Particularly, some vertical jumps have appeared, e.g. for x≈0.11 and x≈0.27. Such positions indicate the 'disappeared' profiles with weights effectively zero (i.e zero local width at x-axis).

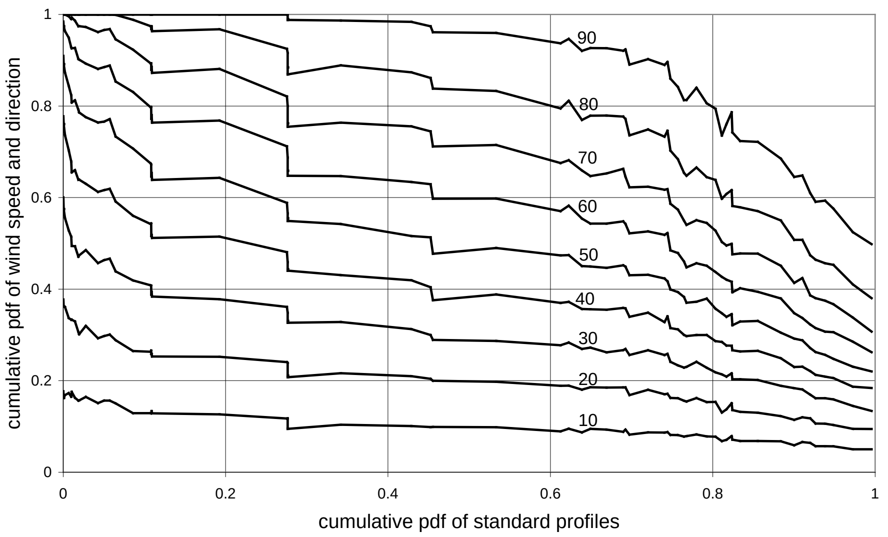

Figure 17. *Lines of constant PEC values based on percentiles of the global distribution for drained areas, as a function of weighted order of standard profiles (horizontal axis) and wind speed/direction cases (vertical axis). Numbers indicate the percentiles (%).*

In the selection of suitable standard profiles for risk assessment in drained areas, again, the criteria (limitations) given in Section 4.4.1 are applied. Figure 18 shows the resulting PEC plot for drained areas, with only three lines of constant percentiles: 87, 90 and 93%. Small crosses indicate all situations within the limitations for field crops. Only the crosses between the 87th and 93rd percentiles are valid in the 'near 90th' limitation.

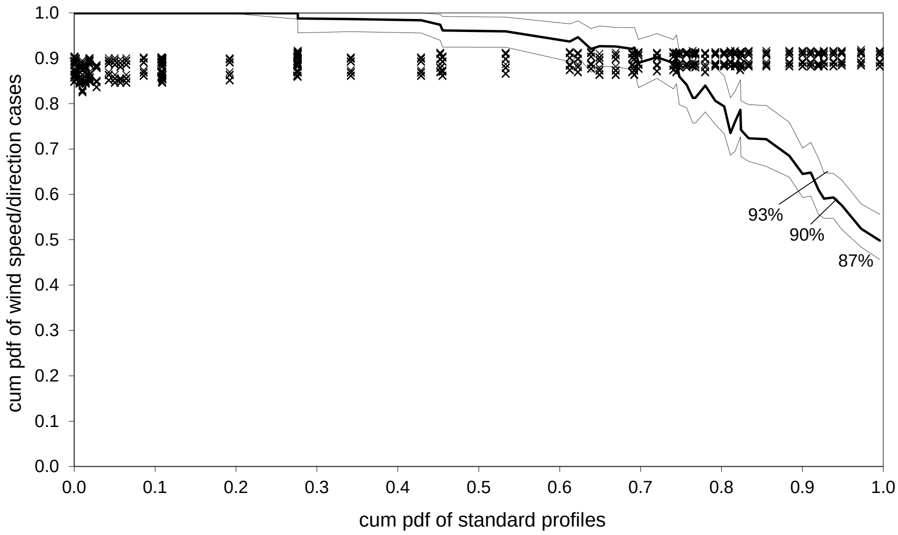

Figure 18. *PEC plot for drained areas, showing all cases within the limitations for field crops (small crosses), together with the lines of percentiles 87, 90 en 93%.*

Figure 19 zooms in at the cases within the 87th and 93rd percentiles. Large dots are within 89 and 91%, small dots within 88 and 92% and crosses within 87 and 93%. Dots and crosses are located on a more or less horizontal band, while the percentile lines roughly follow downward slopes in the graph. Consequently, standard profiles with most situations within the percentile limits are located in the centre of the graph, while standard profiles with only a few valid situations are located to the left or right in the graph.

Table 7 gives an overview of the same results per standard profile. It shows that for several standard profiles all 10 wind speed/direction situations are within the 3% margins around the 90th percentile (see column 'prcmarge 3%'). Column 'WFrel' gives the ratio of actual weight factor and averaged weight factor (~0.015) if all profiles were equally abundant.

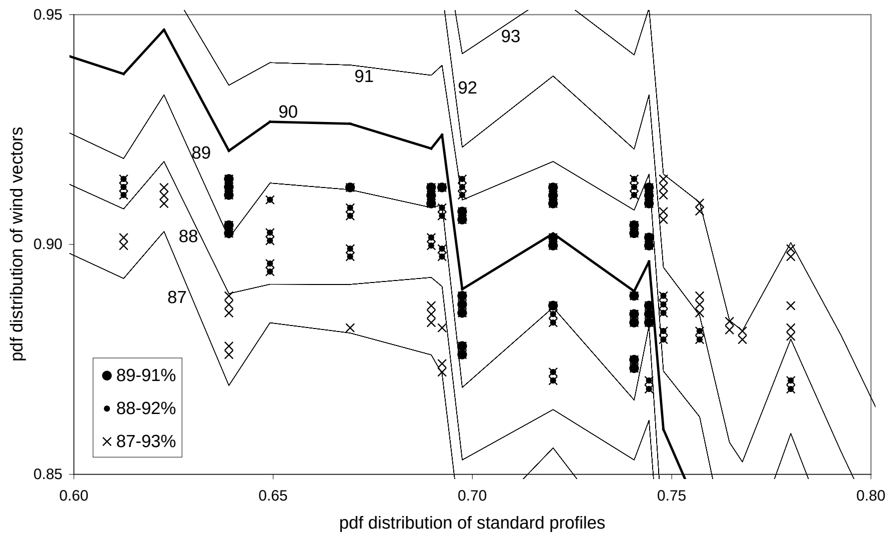

Figure 19. *Part of Figure 18 zoomed in at the situations within percentiles 87 and 93, and neglecting all cases outside these lines. Only the cases limited for field crops are shown.*

The last column in Table 7 shows that many standard profiles in this table show up in Table 6 as well, i.e. these profiles are potentially suitable for reference whether or not drainage is considered.

Table 7. Overview of standard profiles with PEC values around the 90th percentile for downward directed spraying of field crops, with wind speeds ranging from 3.25 to 3.50 m·s⁻¹ and wind direction between -10° and 10°. Profiles are sorted for increasing PEC50 values (i.e. according to their x axis location in the PEC plot). For drained areas only.

WLcode	HydroRegio	HydroType	WB class[1]	[2]						WFprof[3]	CWprof[4]	WFrel[5]	Present in Table 6[6]
				prcmarge 1%		prcmarge 2%		prcmarge 3%					
				#	CWwind	#	CWwind	#	CWwind				
601002	Rivierkleigebied	Betuwe-stroomruggronden	B			3	0.912	5	0.908	0.00360	0.612	0.24	
600020	Zeekleigebied	Westland-DHC-profiel	A					3	0.911	0.01666	0.623	1.10	
601007	Zandgebied	Keileem-Peelo profiel	B	5	0.909	5	0.909	10	0.896	0.01589	0.639	1.05	
601010	Zandgebied	Oost NL profiel	B			5	0.901	5	0.901	0.00474	0.649	0.31	
600017	Zeekleigebied	Westland-D-profiel	A	1	0.912	5	0.905	6	0.901	0.03546	0.669	2.34	
601013	Beekdalen	Singraven-beekdalen	B	3	0.911	5	0.907	8	0.898	0.00523	0.690	0.35	
601014	Zandgebied	Stuwwallen	B	1	0.912	5	0.905	8	0.894	0.00022	0.692	0.01	
601006	Zandgebied	Keileemprofiel	B	7	0.890	10	0.896	10	0.896	0.00991	0.697	0.65	X
601001	Rivierkleigebied	Betuwe-komgronden	B	6	0.903	10	0.893	10	0.893	0.03568	0.720	2.35	
601015	Zandgebied	Tegelen/Kedichem profiel	B	7	0.887	10	0.895	10	0.895	0.00501	0.741	0.33	X
600016	Zeekleigebied	Westland-C-profiel	A	8	0.898	10	0.893	10	0.893	0.00243	0.744	0.16	
601003	Zandgebied	Dekzand profiel	B			5	0.884	10	0.897	0.00477	0.748	0.31	X
601009	Zandgebied	Nuenengroep profiel	B			2	0.880	7	0.891	0.01342	0.757	0.89	X
600002	Rivierkleigebied	Betuwe-stroomruggronden	A					2	0.882	0.00157	0.765	0.10	X
601011	Zandgebied	Open profiel	B					2	0.880	0.00491	0.768	0.32	X
600019	Zeekleigebied	Westland_DH-profiel	A			2	0.869	7	0.883	0.01939	0.780	1.28	X
		Profiles:	Number:	8		13		16					
		Situations:	Number:	38		77		113					

1 *WB class: water body class: A: ditch; B: water body with surface width < 3 m; C: water body with surface width 3-6 m.*

2 *Prcmarge: acceptable margin around the 90th percentile of the global cumulative distribution of PEC values; #: number of situations within the give margins (note that the max number is 10: 2 wind speeds. times 5 wind angles); CWwind: position at the cumulative distribution of wind speed/direction combinations, averaged over the situations within the given margins (i.e. averaged position at y axis in PEC plot)*

3 *WFprof: weight factor of the standard profile (cumulative length of current profile divided by cumulative lengths of all profiles).*

4 *CWprof: position of standard profile in the cumulative distribution of standard profiles (based on their PEC50): i.e. position at x axis in PEC plot; the standard profiles in this table are listed with ascending values of CWprof.*

5 *Weight factor per profile relative to a global average of 1/66 per profile.*

6 *Standard profiles that occur in Table 6 as well.*

4.5 Scenario selection for drained areas

The final selection is based on expert judgment, taking into account the 90th percentile criterion for PEC exposure, the ditch profile being apparent in all three margin levels (1%, 2%, and 3%) and by selecting the profile which has the highest fraction of ditch profile length relative to total ditch length (column WFprof). With respect to the ditch for downward directed spray techniques, preference was given to a ditch that is typical for the region where the drainpipe scenario is located, as this would yield a coherent scenario. Table 8 and Figure 20 give the most important characteristics of the selected ditch.

Table 8. Characteristics of the selected ditches.

	Downward directed spray technique ditch
Code	601001
Hydroregion	River clay area
Hydrotype	Betuwe backland
Ditch type	Secondary ditch
Width top ditch (m)	4.20
Width bottom ditch (m)	2.16
Width water (m)	2.62
Height water (m)	0.23
Lineic volume (m^3 m^{-1})	0.550
Slope (horizontal:vertical)	1

4.6 Conclusions

For drained areas a systematic procedure was followed in order to select a ditch covering realistic worst case conditions with respect to exposure from drift deposition. The selection resulted in a number of possibilities. Application of additional plausibility criteria reduced the number of ditches chosen to a ditch for downward directed spray techniques in field crops. The selected ditch is a secondary water course typical of river clay areas with a water width of 2.6 m, a water depth of 0.23 m, and a lineic volume of 0.550 m^3 m^{-1} (code 601001).

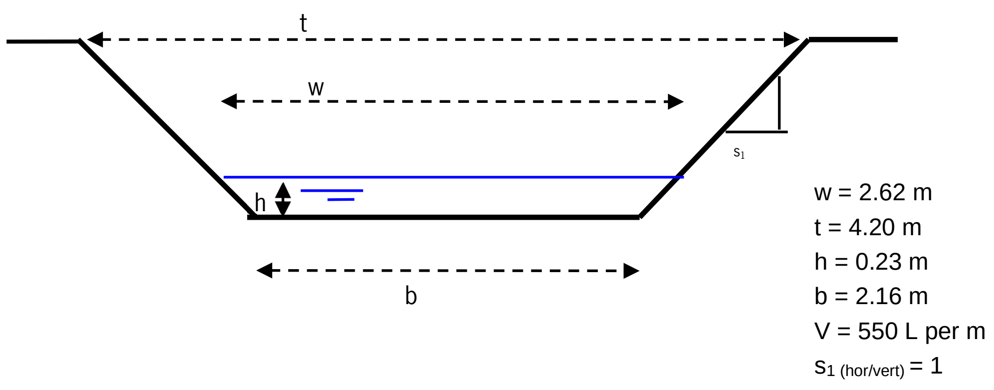

Figure 20. Dimensions of the ditch for downward directed spray techniques in field crops – 601001, where w is the width of the water surface, h is the water depth, b is the width of the bottom of the ditch, t is the width of the top of the ditch, s1 is the side slope (horizontal/vertical), and V is the lineic volume of the water in the ditch.

5. Proposed exposure assessment for crop groups using a matrix approach for drift reducing techniques

In the authorisation procedure for PPPs in the Netherlands, different spray drift deposition curves are used (Chapter 3) to determine the exposure to surface based on the crop growth situations and the used spray techniques. With the obligation to develop a scenario for authorisation of PPPs taking into account the taken measures with the LOTV it was impossible to come up with a tiered-approach. All drift reducing technologies do not lead to similar or stepwise decreasing spray drift exposure of the surface water, especially not when they are combined with different widths of crop-free zones. It was therefore decided to develop a matrix approach combining classes of Drift Reducing Technology and stepwise widths of crop-free buffer zones. In this chapter the methodology is discussed of a matrix structure for the assessment of drift deposition combining classes of DRT and width of crop-free buffer zones for downward sprayed crops.

The standard crop types for downward directed spraying can be distinguished in crops having a minimum agronomic crop-free zone of 0.25 m, 0.50 m and 0.75 m. (coinciding with the crop groups cereals, other crops and intensively sprayed crops of the LOTV) (Figure 21).

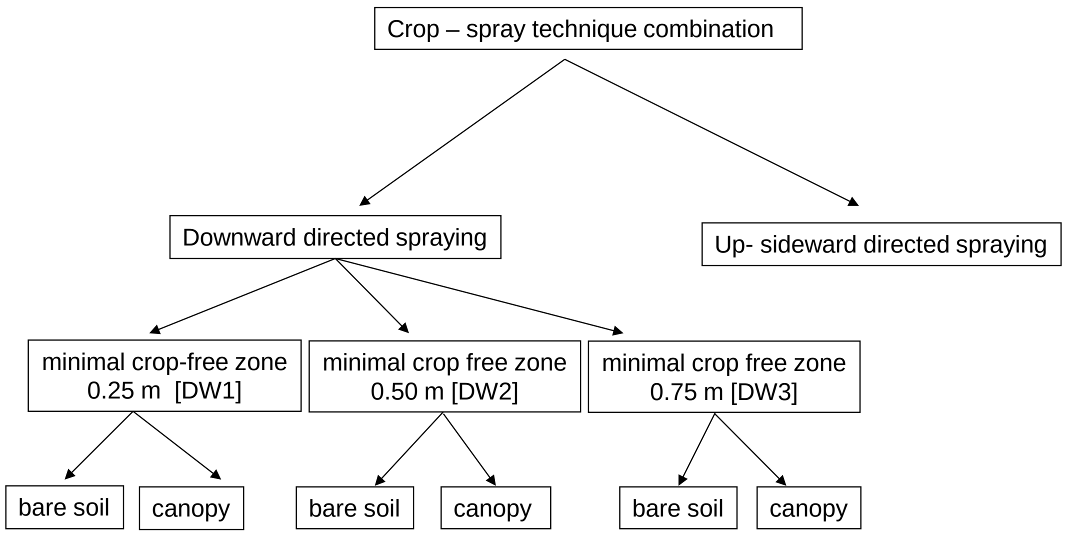

Figure 21. Differentiation of the assessment of spray drift to crop type groups and growth situations for crops (minimum agronomic crop-free zone) sprayed with downward directed application techniques.2 years

5.1 Crop type group DW1 (LOTV cereals)

The downward sprayed crop type group DW1, cereals in LOTV (wheat, barley, rye, oats, triticale, grass seed, flax, teff, spelt, etc) must at least have a standard crop free buffer zone of 0.25 m. A crop-free zone is defined as the width between the last plant row (or edge of plant bed for bulbs and onions) and the top of the ditch bank (Huijsmans & van de Zande, 2011). As these crops are not sprayed following the crop rows the last nozzle position is defined to be at 0.25 m to the inside of the outside crop row (0.5 m from the top of the bank) (Figure 22).

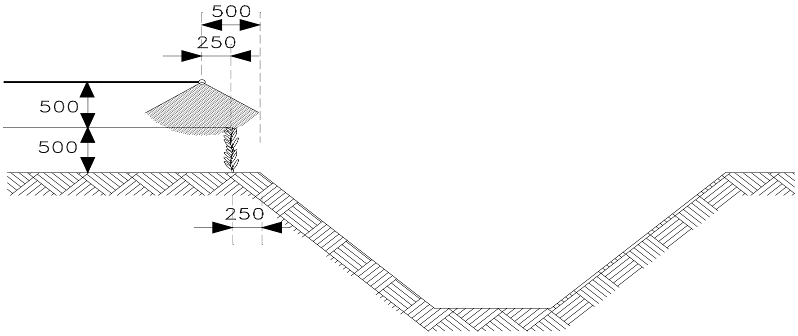

Figure 22. *Schematic presentation of the situation when spraying cereals. The minimal agronomic crop-free zone has a width of 0.25 m. Distance to the edge of the ditch from the last nozzle is 0.5 m and to the surface water 2.0 m. Boom height is 0.5 m above a crop, which is 0.5 m tall. The distances in the figure are in mm. (Adapted from Huijsmans et al., 1999).*

5.2 Crop type group DW2 (LOTV other crops)

The downward sprayed crop type group DW2, other crops in LOTV (i.e. sugar beet, maize, oil rape seed, legumes, vegetables, cabbages, small fruits, ornamentals, flowers, etc.) must at least have a standard crop free buffer zone of 0.50 m (Figure 23). Based on the row spacing of the crop the last nozzle position is fixed at either 12.5 cm outside the last crop row, on top of the last crop row or 25 cm or 50 cm inside of the last crop row. These specific situations mean that based on the same drift curve spray drift deposition on surface water may differ between crops in this group.

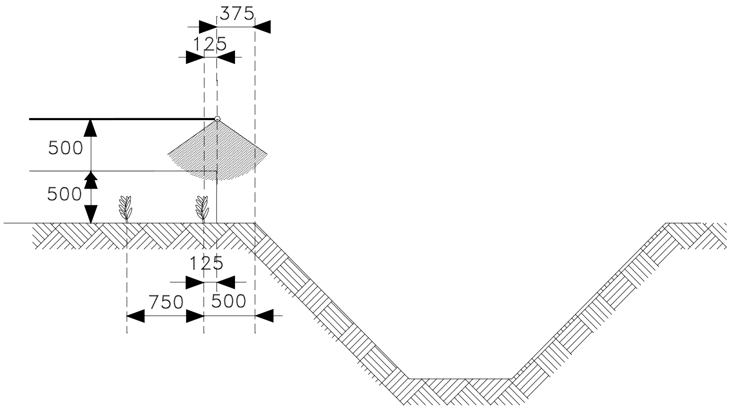

Figure 23. *Schematic presentation of the situation when spraying a maize crop. Minimal agronomic crop-free zone is 0.5 m, last nozzle distance to the edge of the ditch is 0.375 m, sprayer boom height is 0.5 m above a crop of 0.5 m height. The distances in the figure are in mm. (Adapted from Huijsmans et al., 1999).*

5.3 Crop type group DW3 (LOTV intensively sprayed crops)

The downward sprayed crop type group DW3, intensively sprayed crops as defined by LOTV (VW *et al.*, 2000) as crops sprayed more than 10 times or with a usage of more than 10 kg PPP per growing season (i.e. potato, flower bulbs, strawberry, roses, small nursery trees, ornamentals, carrots, leek, asparagus, onions, lettuce, salsify, etc.) have a minimum crop-free zone of 0.75 m. Nowadays the LOTV standard crop free buffer zone for these crops is 1.50 m. The width of 0.75 m was based on the minimum required width in agricultural practice (harvest, mechanisation, tyre width). Based on the row spacing of the crop the last nozzle position is fixed at either 12.5 cm outside the last crop row (Figure 24), on top of the last crop row or 25 cm or 50 cm inside of the last crop row. These specific situations mean that based on the same drift curve spray drift deposition on surface water may differ between the distinguished crops.

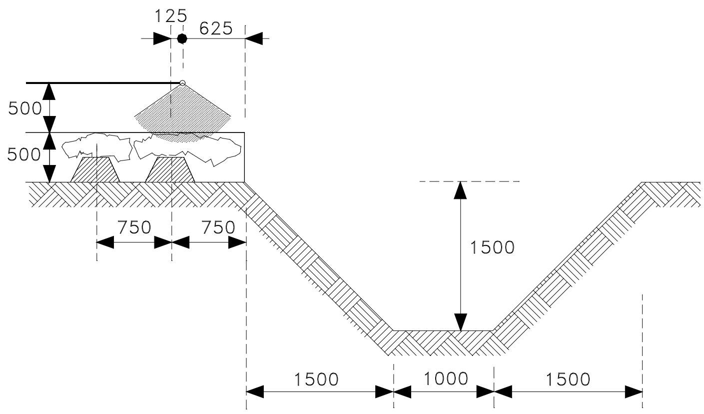

Figure 24. Schematic presentation of the situation when spraying potatoes. Minimal agronomic crop-free zone width is 0.75 m. Distance to the edge of the ditch from the last nozzle is 0.625 m. Boom height is 0.5 m above the crop, which is 0.5 m tall. The distances in the figure are in mm. (Adapted from Huijsmans et al., 1999).

5.4 Treatments with downward directed applications

Crops sprayed with downward directed spray techniques (boom sprayers) are identified in the 'Definitielijst Toepassingsgebieden Gewasbeschermingsmiddelen' (DTG) (Zande & Ter Horst, 2012), comprising all relevant crops which can be used for the authorisation of PPPs in the Netherlands, and can be further distinguished in crops from the crop type groups DW1, DW2 or DW3. These crop type groups are determined based on the minimal required crop-free zone needed for agricultural practices (harvest, mechanization, tyre width). The minimal crop-free zones are 0.25 m, 0.50 m and 0.75 m respectively for the crop types groups DW1, DW2 and DW3. (Figure 21,Table 10).

The different treatments are evaluated in the boxes of Figure 21 and are presented in Table 9.

Table 9. Different crops from the DTG list classified over crop type groups DW1, DW2, and DW3 specifying minimal agronomic crop-free zone of 0.25 m, 0.50 m, and 0.75 m for downward directed spray applications.

DW1	DW2	DW3
Cereals (1.3)[+])	Beetroot (1.2)	Potatoes (1.1)
Grass seed crops (1.6)	Maize (1.4)	Strawberries (3.2.1)
Hops (1.11.1.4) only for weed control	Pulses (1.5)	
Fruit crops (3) except strawberries (3.2.1) and cranberry (3.2.2.4) only for weed control	Oil bearing seeds (1.7)	Lettuce (4.1.1)
Small fruits (3.2) herbicide treatments for first two years after planting	Fibre crops (1.8)	Endive (4.1.2)
Caraway (5.5.1.1)	Green fertiliser crops (1.9)	carrots (4.5.2.1)
Poppy seed (5.5.1.2)	Fodder crops (1.10)	Hamburg root parsley (4.5.2.3)
Avenue trees (7.3.1.1) for weed control	Other arable crops (1.11) except Hops (1.11.1.4)	Parsnips (4.5.2.4)
	Small fruits (3.2) fungicide and insecticide treatments for first two years after planting	
	Cranberry (3.2.2.4)	Jerusalem artichoke (4.5.3.3)
	Vegetable crops (4) except Lettuce (4.1.1), Endive (4.1.2) and Vegetable sprouts (4.2.5)	Onion (4.6)
	Fruiting vegetables (4.3) except Solanaceae (4.3.3)	Asparagus (4.7.1.1)
	Cabbages (4.4)	Leek (4.7.1.6)
	Root vegetables (4.5) except carrots (4.5.2.1), Hamburg root parsley (4.5.2.3) Parsnips (4.5.2.4), Jerusalem artichoke (4.5.3.3)	Ornamental crops (7) except Forced shrubs (7.2.1.3), Cut green (7.2.1.4), Avenue trees (7.3.1.1) for weed control, Flower seed crops (7.5), Marsh and water plants (7.6) and Breeding crops and basic seed production (7.7)*)
	Stalk vegetables (4.7) except Asparagus (4.7.1.1) and Leek (4.7.1.6)	
	Other vegetable crops (4.8)	
	Herb crops (5) except Caraway (5.5.1.1) and Poppy seed (5.5.1.2)	
	Forced shrubs (7.2.1.3)	
	Cut green (7.2.1.4)	
	Flower seed crops (7.5)	

**) To be treated as crop itself.*

[+]) Number refers to DTG list entry in Zande & Ter Horst, 2012).

5.5 Crop differentiation in authorisation procedure

Crop groups and use of spray drift curves

For each of the crop type groups a differentiation can be made in the place of the last nozzle on the spray boom in relation to the last crop row. This position of the last nozzle defines the starting point of the drift curve for this specific crop (Figure 25). Last nozzle to row distances for the different crop types are typically: 12.5 cm outside of the last crop row, on top of the last crop row, 25 cm inside of the last crop row and 50 cm inside the last crop row/outside edge of the crop (Table 10). This means that the spray drift calculations for the different crops (about 300 from the DTG list) can be limited to 9 specific situations (now known) of crop type groups, as indicated in Table 10.

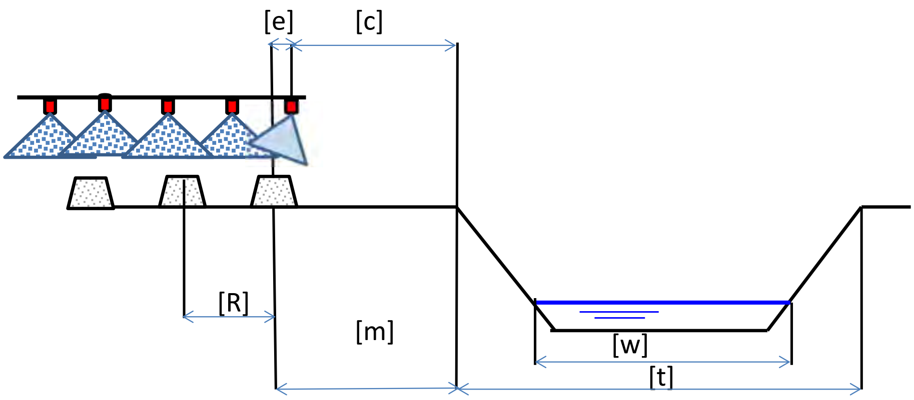

Figure 25. Definitions of the distances used in the determination of the spray drift deposition on surface water for field (boom) sprayers. [m] is the distance between the top of the ditch bank and the centre of the last plant row (i.e. the minimal agronomic crop-free zone), [e] is the distance between the last nozzle position and the centre of the last crop row, [c] is the distance between the last nozzle and the top of the ditch bank (=m+e), [R] is the distance between the crop rows, [w] is the width of the water surface, and [t] is the width of the ditch (i.e. the distance between the top of the banks).

Table 10. Specific crop type groups defined by crop-free buffer zone and last nozzle position for downward directed sprayed crops.

Crop type group	Crop-free buffer zone [m] [m]	Distance nozzle to row [m][1]) [e]	Distance nozzle to edge of the ditch [m] [c=m+e]
DW1	0.25	0.25	0.50
	0.25	0.50	0.75
DW2	0.50	-0.125	0.375
	0.50	0	0.50
	0.50	0.25	0.75
	0.50	0.50	1.00
DW3	0.75	-0.125	0.675
	0.75	0	0.75
	0.75	0.25	1.00

[1] *A positive value of [e] means that the last nozzle is positioned inside the last plant row; a negative value means that the last nozzle is positioned outside the last plant row.*

Standard ditch downward directed sprayed crops
In Chapter 4 a statistical model is described to compute probability levels of PECs due to spray drift deposits onto surface waters for 66 water bodies in the Netherlands and a 10-year averaged probability distribution of wind velocity and the downwind spray deposits. A probabilistic frequency distribution of PEC values was derived from the results. For the typical average wind speed and wind direction situation of the downward directed crop spray drift experiments a 90th percentile of PEC value can be used to identify a typical water body profile, the 'open field ditch'. The 601001 profile was defined as the 90th-percentile PEC value water body profile and will be used in the further analysis of spray drift deposition on surface water for downward directed spray techniques. The effect of the standard drift situation for crops sprayed with downward directed spray techniques and of drift reducing measures will be shown based on this '601001 – open field ditch' (Figure 26).

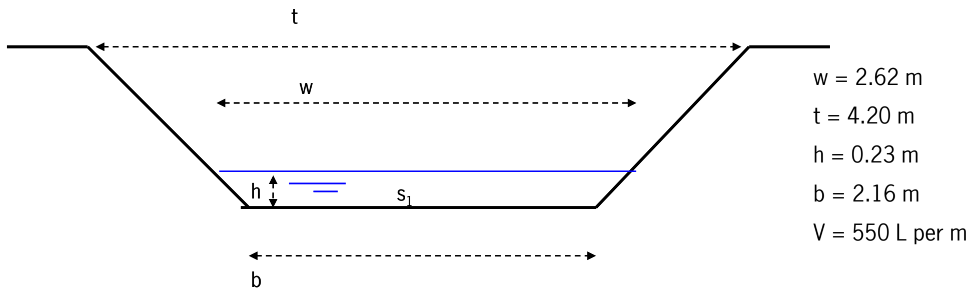

Figure 26. Schematic presentation of the 601001 open field ditch used for the drift evaluation of downward directed spray applications.

Crop height and spray drift
Crop height is important as spray drift from spraying a developed crop canopy is higher than from spraying a bare soil surface/small crop situation. This distinction is made based on plant height. When plant height is lower than 20 cm it is defined that the bare soil drift curve is to be used, else the developed crop canopy drift curve is to be used. Depending on the phenological development of the crop this distinction between bare soil surface/short crop or developed crop canopy situation is specified by a BBCH code for crop growth stage (BBCH, 2001). This BBCH crop growth stage is used to make the distinction between short crop or developed crop canopy and may differ depending on the crop type. E.g. for cereals the distinction is made at BBCH 31 (first node at least 1 cm above tillering node, in the stem elongation stage), and for maize at BBCH 15 (5 leaves unfolded). For potatoes the distinction is made at BBCH 19/21 (9 or more leaves visible /1st basal side shoot visible (>5 cm)). The BBCH codes for distinction between bare soil surface/short crop and developed crop situations is, for the DTG crops, given in Zande & Ter Horst (2012).

The spray drift deposition values are based on the spray drift curves for the canopy and the bare soil surface/small crop situation (Chapter 3). For the original 1.5 m crop-free buffer zone and ditch dimensions (Figure 3) the spray drift deposition values become for the standard low drift situation 1.09% for the canopy situation and 0.71% for the bare soil/small crop situation instead of the nowadays used 0.88% (rounded 1.0% in the authorisation) for the canopy situation (new drift data and standard ditch, Figure 26). These drift deposition values are changed into 1.14% and 0.72% for the canopy and bare soil/small crop situation, respectively, for the 601001 open field ditch dimensions (new ditch effect).

Figures 4 and 5 show that drift deposition declines with increasing distance to the crop sprayed. This means that by enlarging the crop free buffer zone the drift exposure on surface water is reduced for all sprayers (Standard and DRT sprayers). This means that the estimation of spray drift deposition at surface water can be evaluated in a matrix approach. The spray drift deposition can be estimated for the standard spray technique, secondly for drift reducing techniques and measures; thirdly for all spray techniques with step-wise wider crop-free buffer zones (Figure 27).

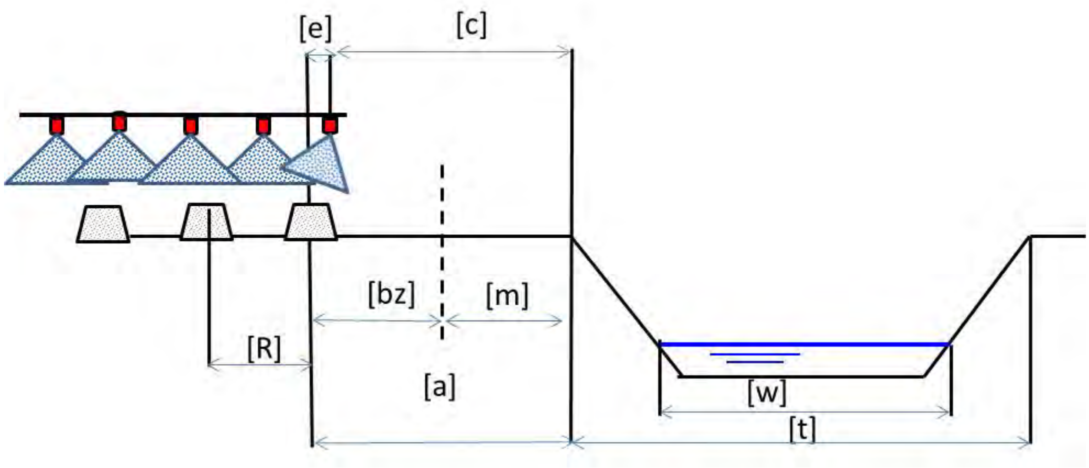

Figure 27. Definitions of the distances of the minimal agronomic crop-free zone [m], the crop-free buffer zone [bz] used in the determination of the spray drift deposition on surface water for field (boom) sprayers. [a] is the distance between the top of the ditch bank and the centre of the last plant row (i.e. the total crop-free zone = [b] + [m]).

This matrix approach counts for all differentiated crop type groups: DW1, DW2 and DW3 (cereals, other crops and intensively sprayed crops), having minimal agronomic crop-free zones ([m] in Figure 28) of respectively 0.25 m, 0.50 m and 0.75 m.

Technique/Crop-free buffer zone (m)	0	0.25	0.50	0.75	1.00	1.25	1.50	→
Standard	→	→						
DRT50	↓							
DRT75	↓							
DRT90								
DRT95								

Figure 28. Matrix structure for the calculation of spray drift deposition on surface water for downward directed spray techniques in open field crops.

If for an agrochemical the spray drift deposition level leads to a predicted environmental concentration (PEC) that is higher than the Regulatory Acceptable Concentration (RAC) in the standard situation a next cell situation in the matrix is evaluated. The evaluation route is from top left of the matrix (standard spray technique and smallest crop-free buffer zone) to right under (drift reduction technology 95 spray technique and broadest acceptable crop-free buffer zone).

For each of the drift reduction classes standard, 50%, 75%, 90%, and 95% in combination with a 0.25 m minimal agronomic crop-free zone the spray drift deposition can be calculated at the '601001 – open field ditch'. Drift values can be compared to the required threshold level of the plant protection product. This will result in a table of crop-free buffer zones and total crop-free zones required for the standard spray technique and the spray techniques certified in the drift reduction classes 50%, 75%, 90% and 95% (Figure 29). For these typical spray drift deposition curves and width of the crop-free buffer zone and the total crop-free zone (sum of minimal crop-free zone and crop-free buffer zone) the drift deposition on surface water area is calculated for the different 0.25 m distance steps, as defined by Dutch policy up to a maximum width of 20 m. Results of spray drift deposition for the standard ditch dimensions (601001; ditch width (bank to bank distance) 4.2 m, water surface width 2.62 m) with a nominal water table level in spring of 23 cm and average wind conditions during measurements is presented for some crop-free distances in Table 11 for the crop situation and in Table 12 for the bare soil surface situation.

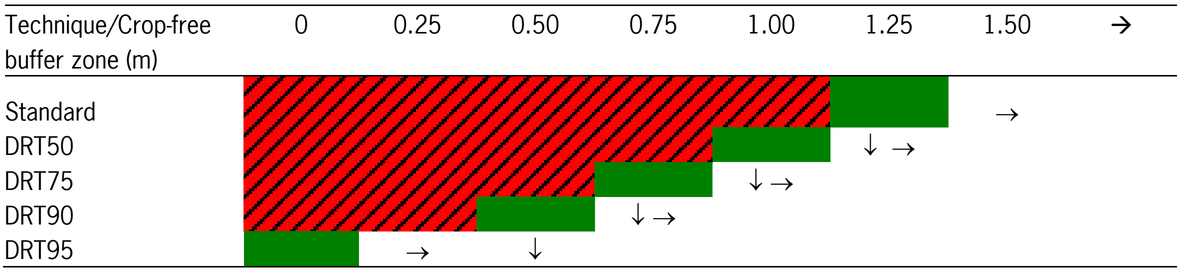

Figure 29. *Evaluation matrix of combinations of drift reducing technology classes and width of crop-free buffer zones. Red means no authorisation possible because the resulting PEC exceeds the RAC. Green means authorisation possible because the resulting PEC is below the RAC. Arrows show the direction of the evaluation.*

Table 11. *Spray drift deposition (% of applied dose) as a function of class of spray drift reducing technologies, nozzle position and width of crop-free buffer zone and total crop-free zone in the DW1 crop situation (minimal agronomic crop-free zone 0.25 m). The values were calculated for ditch 601001 using a fixed water depth of 0.23 m.*

Nozzle position [e in Table 10]	Spray technique							
	Total crop-free zone (m)	0.50	1.00	2.00	3.00	4.00	5.00	6.00
	Crop free buffer zone width (m)	0.25	0.75	1.75	2.75	3.75	4.75	5.75
-0.125	Standard	6.604	4.068	2.078	1.454	1.178	1.002	0.864
-0.125	DRT50	2.320	1.466	0.991	0.822	0.700	0.599	0.512
-0.125	DRT75	1.564	0.798	0.536	0.468	0.415	0.368	0.326
-0.125	DRT90	1.120	0.491	0.241	0.203	0.185	0.169	0.155
-0.125	DRT95	1.083	0.269	0.082	0.073	0.069	0.066	0.063
0	Standard	5.800	3.660	1.961	1.409	1.153	0.983	0.849
0	DRT50	2.017	1.357	0.963	0.805	0.687	0.587	0.502
0	DRT75	1.261	0.724	0.526	0.461	0.408	0.362	0.321
0	DRT90	0.885	0.422	0.233	0.201	0.183	0.167	0.153
0	DRT95	0.745	0.203	0.080	0.072	0.069	0.066	0.063
0.25	Standard	4.551	3.019	1.769	1.331	1.105	0.947	0.819
0.25	DRT50	1.605	1.200	0.916	0.773	0.660	0.565	0.483
0.25	DRT75	0.902	0.632	0.507	0.447	0.396	0.352	0.312
0.25	DRT90	0.585	0.331	0.221	0.196	0.178	0.163	0.150
0.25	DRT95	0.368	0.132	0.077	0.071	0.068	0.065	0.062

Table 12. Spray drift deposition (% of applied dose) as a function of class of spray drift reducing technologies, nozzle position and width of crop-free buffer zone and total crop-free zone in the DW1 bare soil/low crop situation (minimal agronomic crop-free zone 0.25 m). The values were calculated for ditch 601001 using a fixed water depth of 0.23 m.

Nozzle position [e in Table 10]	Spray technique	Crop free buffer zone width (m)						
	Total crop-free zone (m)	0.50	1.00	2.00	3.00	4.00	5.00	6.00
	Crop free buffer zone width (m)	0.25	0.75	1.75	2.75	3.75	4.75	5.75
-0.125	Standard	3.99	2.69	1.60	1.16	0.90	0.72	0.58
-0.125	DRT50	1.11	0.86	0.61	0.47	0.37	0.29	0.23
-0.125	DRT75	0.95	0.59	0.42	0.34	0.27	0.22	0.17
-0.125	DRT90	0.58	0.40	0.26	0.20	0.17	0.14	0.12
-0.125	DRT95	0.56	0.22	0.07	0.05	0.05	0.04	0.04
0	Standard	3.58	2.48	1.52	1.12	0.88	0.70	0.57
0	DRT50	1.03	0.82	0.59	0.45	0.35	0.28	0.22
0	DRT75	0.81	0.55	0.41	0.33	0.26	0.21	0.17
0	DRT90	0.52	0.37	0.25	0.20	0.16	0.14	0.12
0	DRT95	0.53	0.17	0.06	0.05	0.05	0.04	0.04
0.25	Standard	2.94	2.14	1.39	1.05	0.83	0.67	0.54
0.25	DRT50	0.91	0.75	0.55	0.43	0.33	0.26	0.21
0.25	DRT75	0.63	0.50	0.39	0.31	0.25	0.20	0.16
0.25	DRT90	0.43	0.33	0.23	0.19	0.16	0.13	0.11
0.25	DRT95	0.29	0.12	0.06	0.05	0.05	0.04	0.04

As the water table is now fixed in the scenario the PEC from spray drift deposition is the same for all application dates. If the water table height would vary in time the spray drift deposition would change as presented in Figure 30.

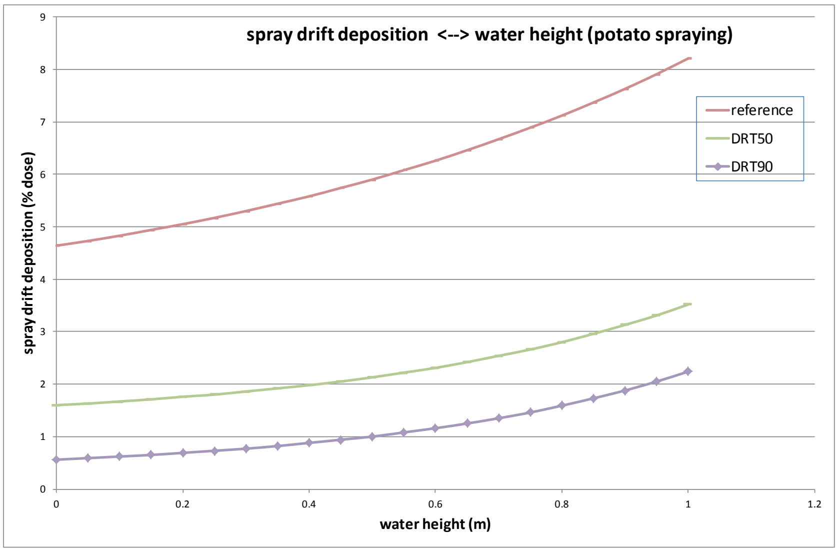

Figure 30. Change in spray drift deposition on surface water as a consequence of changing water table heights in the 601001 open field ditch when spraying a potato crop with reference, DRT50 and DRT90 spray techniques.

As an effect of the widening of the width of the water surface and the depth of the water the water volume in the ditch increases with increasing water table height. Due to the increasing water table height the PEC varies because of the increasing spray drift deposition and the increasing water volume (dilution). The effect of both is shown in Figure 31 when spraying a potato crop with different spray techniques.

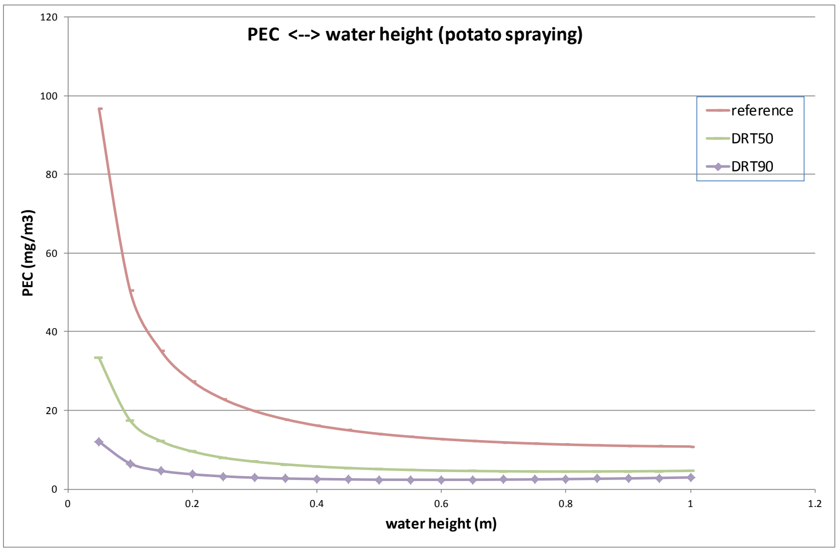

Figure 31. *Change in PEC in the water as a consequence of changing water table heights in the 601001 open field ditch when spraying a potato crop.*

A variation in water table height of 5 cm from an average value of 25 cm results in a 30% change in PEC between the 20 cm and 30 cm water table height for the standard, DRT50 and DRT90 application techniques spraying a potato crop.

In the evaluation procedure (Tiktak *et al.*, 2012b) the spray drift deposition is calculated for the evaluation point 5 m downstream of the start of the evaluation ditch. The concentration in surface water from spray drift deposition is for this 5 m point spray deposition taken and averaged for a 100 m length open field ditch. With a base flow the water table height is 19 cm; with a variation in height of 3 cm there is little change in water volume (PEC see Figure 31). This is reason to assume that variation in water table height does not need to be taken into account for variation in spray drift deposition.

6. Discussion

There appears to be a difference between drift deposits as computed with IDEFICS and deposits derived from field studies (and presently used by the Ctgb): the simulations seem to underestimate drift deposits. A relatively large variation in some parameters in field studies is likely to be a major cause for this discrepancy. For instance height of the sprayer boom is fixed in the simulations, while in field studies this height varies constantly during the trial. Variation in spray drift deposition and PEC can therefor differ. Another parameter of importance is wind speed and direction: variation in practice is much higher than the stochastic variation in IDEFICS. These considerations may result in lower PEC values from simulations than from field studies. However, since the drift model is based on the physics of particle transport through air, it is reasonable to assume that proportionality between model results and results from field conditions met in practice is maintained. For this study (chapter 4) the determination is about relative variations in PEC values, and there for the model results for statistical ranking is valid.

The application of a PPP is now fixed to a date in the growing season of a crop. The weather conditions on that day are not taken into account, irrespective of rain fall during the day of spray application or the trafficability of the soil surface. This is not a realistic situation and should be further developed. The development of a scenario with an application timer based on maximum wind speed during the day, and actual and historic rainfall at the day of application is therefore suggested. This requires however also a new procedure for the scenario selection.

The scenario 'ditch' does not take into account variation in the height of the water table in that ditch during the spraying season. Variation in the height of the water table results in variation of the width of the drift evaluation zone which subsequently results in variation of the drift deposition on surface water (see Paragraph 5.1.4). Because the variation in water level is estimated to be low (based on TOXSWA parameterisation; Tiktak *et al.*, 2012b), this is considered acceptable.

Spray drift reducing technology not only affects spray drift but also the spray deposition pattern in crop canopy and the amount of the spray deposition on soil underneath (Zande *et al.*, 2003; Zande *et al.*, 2005a). A DRT 50 spray technique increased spray deposit on soil surface in all crop stages of a potato crop with 5% to 10%. Depending on the growth stages of the different crop types these differences in spray deposition patterns over crop canopy (interception) and soil underneath crop canopy will change during the growing season. For some drift reducing techniques and crop types a differentiation can be made depending on the BBCH code and the period of growth in the year. In the application for the authorisation of use of a PPP always a period of application or a specific growth stage is mentioned. It is recommended to consider the effect of the drift reducing technology on the spray deposition on soil surface and thus the effect on potential leaching and drainage on concentrations in surface water for PPP. So far, no easy-to-use relationships are available for the effect of drift reducing techniques on crop interception and development of such relationships is recommended.

For the downward directed standard spray techniques and the 50% drift reducing technique the results of 126 experiments for the standard technique and 78 experiments for the 50% drift reducing technique are available. This large number secures the robustness of the used spray drift deposition curves for use in the authorisation procedure. For the drift reducing techniques (nozzles) 75% and 90% the spray drift curves are based on only 10 comparative experiments between the drift reducing technique (nozzle) and the reference. Furthermore, these measurements were also carried out with drift reducing nozzle types commercially available at that time (1997-1999). Since that time new spray nozzles were developed in the drift reduction classes 75, 90 and 95. Classification of these nozzles is based on drop size measurements in the laboratory and spray drift model (IDEFICS) calculations. They were never measured under field conditions. Therefore, it is advised to assess spray drift for new representative nozzle types of the 75%, 90%, and 95% drift reduction classes to get more robust spray drift deposition curves for these drift reduction classes.

Spray drift deposition at surface water is now based on the calculated deposition of a single spray drift curve. This one value spray drift deposition is in the authorisation procedure of PPP distributed over a 100 m length field ditch, as if the spray drift deposition is evenly distributed along the field edge. Due to variation in sprayer boom movement, variation in driving speed and therefore spray pressure (and spray dose of the PPP) a large variation of the spray drift deposition may occur over the length of the ditch (Figure 32). In a typical potato field situation average spray drift deposition in this situation was 6.7% for the conventional flat fan nozzle, 1.5% for the pre-orifice flat fan nozzle (DRT50) and 0.89% and 0.44% for both nozzle types in combination with air assistance. The coefficient of variation of the drift deposition at 2 m distance was quantified as 41% and 38% for respectively the flat fan and the pre-orifice flat fan nozzle type and 75% and 47% for respectively both nozzle types in combination with air assistance. In the potato situation both spray drift deposition as variation in spray drift were a two-fold higher than in the bare soil surface situation although weather conditions were similar (wind speed 2.7-2.9 m/s). Furthermore, stopping and starting effects of the sprayer and differences in sprayer movement in headlands (due to turning) will cause variation in the actual spray drift exposure.

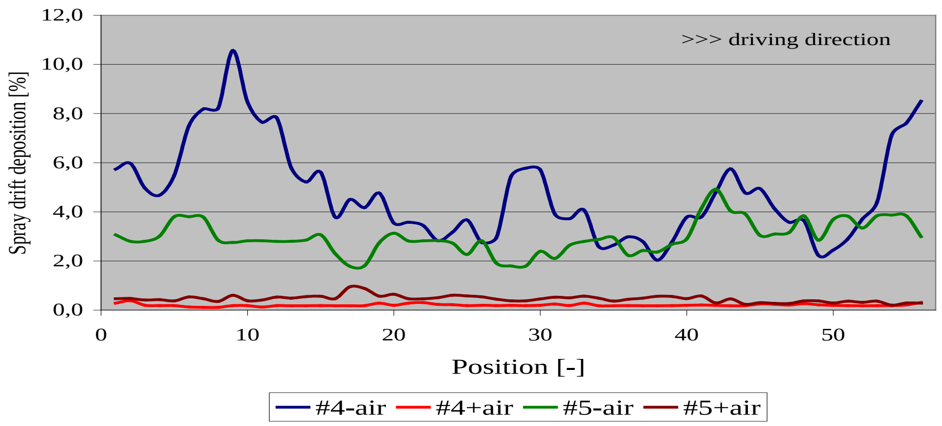

Figure 32. *Example of variation in spray drift deposition (2 repetitions) alongside the crop edge (60 x 0.25 m collectors is15 m length) at 2 m distance spraying a bare soil surface with a standard flat fan nozzle (XR11004; 300 l/ha) with and without air assistance (Zande et al., 2006b).*

Spray drift measurements in the field alongside the field edge over long distances and the headlands (Zande *et al.*, 2006b) and preliminary simulations with IDEFICS indicate that sprayer boom movement, variation in wind speed and direction during spraying, and stop and start effects of the sprayer have a non-linear effect on drift deposits. The variation in spray drift deposition alongside the field is covered with the variation in the individual measurements of spray drift following the standard procedure and is in line with the average value of spray drift used in this study. The separate factors start and stop of the spraying, and spraying headlands may give rise to higher PEC values. To come to a more realistic exposure of surface water at the field edge it is suggested to take these parameters into account and to develop a variation function for spray drift for field practice based on the spray drift deposition curves and develop IDEFICS further to take account of these effects.

The used spray drift curves in this study are generated from a large database of spray drift measurements under the restrictions of a maximum wind speed of 5 m/s (measured at 2 m height) and a maximum temperature of 25 °C. Spray drift data originate from field measurements which are done under worst case spray drift situations with respect to wind direction: e.g. wind direction is within 30° from perpendicular to the field edge. This means that no measurements were done when the wind speed was less than approximately 1.5 m/s as the wind direction below this wind speed is too variable. Consequently, the dataset is biased to higher wind speeds and unfavourable wind directions. Therefore, spray drift measured in the field experiments is expected to be higher than for the average spray conditions in practice as the most often used 'good periods for spraying' (early in the morning and late at night when the wind has fallen) are not represented in the average spray drift curves used in this study. However, the scenario selection procedure described in Section 4 ensures that the proposed exposure assessment will deliver the desired 90th percentile PEC.

For downward directed spraying, spray drift data are used which are updated for all spray drift field measurements done up till 2005 in the Netherlands. Compared to the spray drift data now used in the authorisation procedure of PPPs the spray drift deposition of these updated spray drift curves on the currently used standard ditch is higher for the downward directed spray applications. The minimal drift reducing package (50% drift reducing nozzle types, spray boom height of 0.50 m above a crop, using an end-nozzle and 1.50 m total crop-free zone) for spraying e.g. potato and flower bulb crops was 0.88% in the old situation and is based on the updated spray drift data 1.09%. Using the 90th percentile exposure ditch (601001) as determined in this report for downward directed spraying the spray drift deposition on surface water increases further to 1.14% as the bank width of the ditch is smaller and the water surface is wider compared to the old standard ditch.

Spray drift data for downward spraying (boom sprayers) used in this study are based on field experiments spraying an area of one working width wide (18-24 m) at the downwind edge of the field. With higher DRT (75, 90, 95) class techniques used on the outside swath (14 – 24 m) only and spraying the rest of the field with conventional techniques (DRT 0) there is a potential contribution from next swath spraying over the outside swath to deposit in surface water. Indicative measurements (Zande *et al.*, 2010) show that this may be in the order of 5-20% additional spray drift deposition on surface water area. Further quantification of the out of field drift component next to outside swath spraying is needed before these effects can be introduced in the authorisation procedure as an additional spray drift component for different DRT classes.

The Cascade Drift Model shows that not only edge-of-field water bodies are affected, but also water bodies farther downwind (Holterman & Van de Zande, 2010; see also Appendix E), though deposits on these latter water bodies are relatively low. With respect to the upwind water bodies, it was hypothesised that these are downwind water bodies to the next parcel upwind, so all water bodies should be considered as drift receiving. Appendix E shows that evaluating the fraction of affected edge-of-field water bodies is slightly more complicated and has both spatial and temporal aspects not considered so far. That is, this fraction may range from roughly 25% up to about 100% depending on the regional situation of treated fields and the time scales involved (primarily water flow rates and number of parcel treated within a certain time interval). For intensely sprayed fields and regions the upper limit of 100% is a safe (i.e. worst case) choice. Simulations with realistic systems are necessary to get more clarity on the influence of spraying and spray drift deposit on upward water bodies at the landscape level.

So far, only the effects of a single spray application on spray deposits onto water bodies are considered. In practice, spray applications may be repeated several times at more or less constant time intervals during the growing season. Two extreme cases can be distinguished: case A: PEC levels remain constant between two successive applications; case B: PEC levels reduce to zero before the next application takes place. Slowly flowing water bodies with low decay rates of PPP belong to case A, while fast flowing water bodies or high decay rates of PPP in the water body are representative of case B. In case A repeated treatments lead to accumulation of PPP in the water body and the highest PEC level will occur at the end of the spraying season, i.e. after the last spray application. In case B a highest PEC level will result from one of the applications (typically when average wind speed is high and wind direction is roughly perpendicular to the field edge towards the water body). Up to now, it was not known how repeated treatments would affect the reasoning of Chapter 4 and if this would change the selection of the monitoring profiles. In a first attempt the ranking order of water body profiles with respect to PEC levels is investigated when considering a single application or multiple applications (Appendix F). It indicates that the ranking order does not change much when considering a single or multiple applications. However, these findings do not show how the frequency distribution of occurring PEC levels is affected, i.e. if and how the 90th percentile is changed due to multiple applications. A further study involves statistical simulations for both case A and case B (Appendix G). This study indicates that in case A the cumulative pdf for PEC values is only slightly affected. Particularly near the 80th – 90th percentile region the curve changes only little. In case A, scenarios based on a single application therefore may be close to multiple applications as well and in fact appear to be slightly more conservative. However, in case B the cumulative pdf is significantly affected and the 90th percentile PEC value is increased by a factor of about 2.5 for 10 applications. This increase in PEC values strongly depends on the number of applications considered. Therefore, scenarios based on a single application probably are insufficiently protective for case B.

The above results differ from those of the FOCUS study on Surface Water Scenarios considerably (FOCUS, 2001). In the FOCUS study, the pdf used for drift is represented by a normal distribution. Besides, no spatial variation is considered; only three standardized water bodies are considered separately. These aspects are the main reasons why multiple spray applications lead to the use of lower percentiles on the single-application curve. Clearly, the cumulative pdf in our study is not a normal distribution, a result of both the temporal and spatial variations accounted for. This is the main reason why the 90th percentile PEC level does not change much for multiple applications in case A. Unfortunately, the FOCUS study considers case A only, whereas case B seems more representative in several typical scenarios. For example, a pyrethroid insecticide in lilies applied 20 times at a 7-day interval clearly shows an almost complete decay between successive applications (Tiktak *et al.*, 2012b; section 10.2, Figure 47). A similar concentration profile with time is observed for a phenyl-pyridinamine fungicide applied 15 times to a potato crop at a 7-day interval (Tiktak *et al.*, 2012b; section 10.3, Figure 52). Apparently, case B seems more appropriate in many situations than case A, although in practice it will often be a mixture of both.

7. Conclusions

For the evaluation of spray drift deposition the reference spray technique for field crops is a boom sprayer equipped with standard Medium spray quality flat fan nozzles, a nozzle spacing on the boom of 0.50 m, operating at a boom height of 0.50 m at a speed of 6 km/h applying a spray volume of 300 l/ha.

A Drift Reduction Technology (DRT) classification method is developed to facilitate the implementation of presently available and new spraying techniques into a system of generic drift reduction classes. For each DRT class, a representative drift curve is established to compute drift deposits as a function of downwind distance. Spray drift reduction is evaluated against spray drift deposition of a reference spray technique at a given distance.

A matrix approach, consisting of combinations of Standard sprayer, DRT classes and crop free buffer zones, is developed to describe the effects of drift reducing measures and techniques and width of buffer zones on spray drift deposition onto surface water. This matrix approach includes state of the art knowledge of drift deposition for different application techniques and crop-free buffer zones.

Exposure assessment is based on 90th percentile PEC levels determined for Dutch water bodies under realistically varying weather conditions. A water body profile was selected as reference for exposure assessment in surface water adjacent to field crops. A typical dimension for the 90th percentile water body is a top of bank to top of bank width (ditch width) of 4.20 m for the field crop water body. Surface water width is 2.62 m, whereas the nowadays used standard ditch in the evaluation of PPP has a ditch width of 4.00 m and a surface water width of 1.00 m.

For the reference water body, drift deposits onto the water surface can be computed using the drift curves for the DRT classes, implying a range of crop-free buffer zones. This drift exposure matrix shows for each drift reducing technique the required crop-free buffer zone for a safe application of PPPs sprays.

The spray drift deposition data presented in this report are higher than the nowadays used spray drift data in the Dutch authorisation procedure because of updated higher spray drift values in the spray drift database and because of a change in position and dimensions of the surface water area of the evaluation ditch.

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Appendix A.
Overview of the separate drift researches on drift reducing technologies and mitigation measures for boom spraying

MYCPP reference situation
The reference situation for the MYCPP for field crop spraying was a conventional boom sprayer spraying a potato crop during the growing season with an average wind speed of 3 m/s. Crop height was on average 0.5m above soil-surface and sprayer boom-height was 0.7m above crop height. Spray volume was 300 l/ha, spraying was done with a flat fan nozzle-type (BCPC-class Medium). From field experiments performed in the period 1991-1993 (34 repetitions) it was found that the spray-drift deposition at the soil at 2.25-3.25 m downwind of the last potato-row was 5.4% of the application rate per surface area (Porskamp *et al.*, 1995).

Effect of spray volume and air assistance
To quantify the effect of spray volume and air assistance on spray drift, a number of drift measurements were executed in the period 1992-1994 (Porskamp *et al.*, 1995). Spray volumes compared were 150 l/ha and 300 l/ha, resp. a Fine and a Medium spray quality (Southcombe *et al.*, 1997). Sprayer boom height was set to 0.7m above the canopy of the potato crop. Within this volume range the spray quality (resp. 52 and 34 repetitions) did not significantly affect the drift deposition in the experiments. Spray drift deposition on the distance 2.25-3.25 m from the last potato-row was on average 5.3% for both nozzle types sprayed conventionally.
Compared to the conventional spraying (86 rep.), a field boom sprayer with air assistance (70 rep.) achieved a 50% reduction in spray drift on the soil surface at the same downwind distance.

Effect of crop free buffer zone
Increasing the distance from the crop boundary, and therefore the last nozzle to the surface water zone, by means of a non-cropped spray-free zone of 2.25m (3 potato ridges) reduced the deposition by 70% on the surface water zone (Porskamp *et al.*, 1995).

Effect of crop height
In a wheat crop the effect of crop height on drift was measured. It was found that there is no difference between the drift for 40 cm high summer wheat and 80 cm high winter wheat. For both crop heights, however, the drift was higher than for spraying on bare soil. In all cases spraying with an air-assisted sprayer resulted in a lower drift (Stallinga *et al.* 1999).

Effect of shielding and air assistance
In a series of experiments in a flower-bulb crop (1993-1996) the drift deposition on the soil next to the sprayed field was measured (33 rep.) for an air-assisted and a shielded field-sprayer and a prototype tunnel sprayer for bed-grown crops (Porskamp *et al.*, 1997). Sprayers were equipped with flat fan nozzles, either a XR11003 or a XR11004 sprayed at 3 bar pressure. Sprayer boom height was set to 0.5m above a crop canopy of on average 0.3m. The field experiments were performed in tulips, lilies or a flower-bulb look-alike crop, cut mustard. No effect of these crop types was found on spray drift data. Also no effect was found of the used nozzle types on spray drift. A shielded sprayer boom and air assistance reduced spray drift deposition at 2-3m distance from the last nozzle with 50%. A tunnel sprayer for bed-grown crops reduced spray drift with 90%.

'Low drift' nozzles and air assistance in potatoes
Drift data are available for standard flat-fan or low-drift nozzles from field research spraying potatoes (Michielsen *et al.*, 1998, 1999, 2001). In these experiments the sprayer was equipped with nozzles representative for the spray drift reduction classes 0, 50, 75 and 90 to establish the reference fallout values against which other application

techniques can be judged (Porskamp *et al.*, 1999). Spray quality definitions follow the BCPC scheme (Southcombe *et al.*, 1997). All nozzle types were used at a spray pressure of 3 bar to thereby apply 150 l/ha or 300 l/ha at a sprayer speed of 6 km/h. Boom height was 0.5m above a potato crop, which, itself, had a 0.5m tall canopy. Average wind speed during the experiments was 4.0 m/s at a height of 2m; mean wind direction was 15° from perpendicular to the driving direction.

Field tests were performed on spray drift in 1997, 1998 and 1999 to quantify the effect of two spray volumes using 'low-drift' nozzle types and air assistance (Zande *et al.*, 2000c). Spray drift was quantified for a series of low-drift nozzle types all applying a spray volume of 150 l/ha and 300 l/ha. With identical travelling speed, sprayer boom height (0.5 m above crop canopy) and liquid pressure (3 bar) the nozzle types standard flat fan (XR), drift guard (DG), anvil flat fan (TT) and two types of injection nozzles (ID and XLTD) were evaluated in the field. All nozzles were used in a conventional way and with the use of air assistance (Hardi Twin, full capacity - nozzles kept vertical). The height of the potato crop canopy was 0.5 m. Results show that the terminology 'low drift nozzle' needs further specification. From the experiments it became clear that within the group of low drift nozzles a ranking by level of drift reduction is preferable. The comparison with a standard sprayer-nozzle configuration is of value, also for comparison of the results with other drift experiments. Although a spray volume of either 150 l/ha or 300 l/ha was used with all nozzles, the difference in the range of droplet sizes resulted in drift reductions up to more than 85% when compared to a XR11004 nozzle (Zande *et al.*, 2000c).

Low boom height

In a series of field experiments performed in 1999 the effect of lowering the sprayer boom height was quantified for sprayer boom heights of 30, 50 and 70 cm above crop canopy. Conventional spraying was compared with air-assisted spraying at the three heights above an arable crop. At a distance of 2–3 m from the last nozzle perpendicular to the driving direction, spray drift was reduced by 54% for conventional spraying when the boom height was decreased from 70 cm to 50 cm above crop canopy. When the boom was lowered from 50 cm to 30 cm drift reduced by 56%. Lowering sprayer boom height from 70 cm to 30 cm resulted in 80% drift reduction. The use of air assistance reduced drift on average by 86% at surface water distance, irrespective of boom height (De Jong *et al.* 2000).

Drift data are also available from experiments comparing a reduced sprayer boom height in combination with two types of drift-reducing nozzles and air assistance with a standard sprayer using a reference nozzle (XR11004) (Stallinga *et al.*, 2004). In these experiments a sprayer was used capable of reducing boom height to 0.30m above crop canopy. Nozzle spacing on the sprayer boom was 0.25m. In the last nozzle body an end nozzle (IS8002) was fitted. Drift experiments were performed spraying a potato crop. Average wind speed during the experiments was 2.6 m/s at a height of 2m; mean wind direction was 11° from perpendicular to the driving direction. Based on the results on the zones 1-5 and 1.5-6 m from the last nozzle the conclusion was drawn that lower boom heights at 0.30 m above crop canopy can in combination with pre-orifice flat fan (DG80015) nozzle types or venturi flat fan (ID90015) nozzle types sprayed at 3 bar (or lower), at a nozzle spacing of 0.25 m, reduce spray drift more than 50% or even more than 90% respectively compared to the reference system (300 litres ha-1 - XR11004). With the additional use of air assistance (Rau AirPlus) used with an airflow vertically downward and nozzles in a 35o backwards direction these combinations reach drift reduction classes of 90 for the DG80015 nozzle and 95 for the ID90015 nozzle type.

Släpduk

Drift data are available from Släpduk spraying system experiments (Zande *et al.*, 2005b). The Släpduk system used a shield to float over crop canopy that maintains nozzle height over crop canopy. Average nozzle height was therefore around 0.20 m. Nozzle spacing on the sprayer boom was 0.33m. Drift experiments were performed comparing the Släpduk spraying system with a standard spray application using a reference nozzle (XR11004) spraying a potato crop. Average wind speed during the experiments was 3.4 m/s at a height of 2m; mean wind direction was 13° from perpendicular to the driving direction. The Släpduk with its lowered heights of spray boom gave a significant spray drift reduction (more than 75% when used with a flat fan nozzle (XR110015) and up to 99% when used in combination with a venturi flat fan nozzle (AI110015)) despite the increased number of nozzles and the lower flow rates.

End nozzle
Overspray of plant protection products when spraying the edge of the field can be reduced by the use of an end-nozzle. An end nozzle produces a cut-off spray fan like from an off-center (OC) or UB nozzle type. Depending on the placement of the last nozzle towards the crop-edge the nozzle is placed in the last nozzle connector or 0.2m more to the outside (potatoes). An end nozzle (UB8504), in combination with a low drift nozzle (DG11004), reduced spray drift with 20% (60% with air assistance) on 2-3m distance from the last nozzle (Michielsen *et al.*, 1999). On 1-2 m distance this effect was 50% (80% with air assistance).

Band sprayer
Band sprayer data were taken from the spray drift field experiments of band spraying in an early growth stage of maize (Zande *et al.*, 2000b). The chemical was applied in a 0.2m band, a nozzle height above surface of 0.1m with either one (02E80) or two nozzles (015E80) per row. In the band application experiments even spray nozzles were used, spraying at 3 bar pressure, producing a Fine spray quality (Southcombe *et al.*, 1997). Row spacing in maize was 0.75m. The spray drift deposit for the band sprayer was measured up to 16 m distance from the last crop row. Drift experiments were performed comparing the band spraying system with a standard spray application using a reference nozzle (XR11004) spraying a maize crop. The spray drift curve was based on ten replicates (double sampling rows). Average wind speed at 2 m height during the tests was 4 m/s. Spray volume for the band sprayer was 130 l/ha and 200 l/ha for resp. the maize and the sugar beet crop, defined by the difference in row width of both crops (resp. 0.75 m and 0.50 m). Crop height of the sugar beet (4–8 leaves) and of the maize (3–5 leaves) was 10–15 cm. Drift reduction due to the use of the band sprayer was 90% compared with a field sprayer (300 l/ha, medium nozzle type). The drift reduction was achieved both with a single-nozzle and a dual-nozzle version per crop row.

Appendix B.
Crop-free buffer zones – spray free buffer zones in EU

From: Huijsmans & van de Zande, 2011. Workshop harmonisation spray drift.

What are the definitions of the following descriptions:
Do you apply crop-free buffer zones or spray free buffer zones or a combination of both elements ? What is the distance to last nozzle, to centre sprayer, to edge of field, to edge of surface water or last crop row?
Crop-free buffer zones, specified as areas around the field where no crop or not the same crop is grown are (compulsory) applied in general in the Netherlands and France alongside watercourses. Width of these crop-free buffer zones varies between 0.25-1.50 m (resp. cereals – intensively sprayed crops like potato) and 3 m (orchards) for the Netherlands and is in general 5.0 m in France.

All other countries apply spray free buffer zones, meaning the same crop as the sprayed crop is not sprayed for a certain width at the outside boundary of the field alongside watercourses. These spray free buffer zones have a minimum width of 5 m for the UK, 1 m for arable crops and 3 m for fruit crops in Belgium, and 6 m for Sweden. In Sweden the width of the spray free buffer zone is dependent on the wind direction and being maximum in the wind direction, wind speed, temperature, dose and spray technology. Spray free buffer zones can be widened depending on the toxicity evaluation of the PPP and can be up to 50 m wide. These maximum widths of spray free buffer zones can be lessened by using drift reducing technology and/or dose reduction. In Germany and Belgium the width of the spray free buffer zone depends on the combined use of drift reduction techniques and can be up to 20 m maximum.

In the Netherlands only crop free buffer zones are applied; the width of this zone can be enlarged due to a toxicity evaluation of a PPP or be lessened by using drift reducing technology till the minimum compulsory width is met.

What is the position of the sprayer and nozzles related to the sprayed crops
Only the Netherlands specifies for boom sprayers the position of the last nozzle relative to the last crop row. This originates from the experience in measuring spray drift in a crop situation where the nozzle position above the last crop row is fixed and edge of field (crop canopy) varies. Other countries measure spray drift in short cereals, on cut grass or bare soil surface, where the edge of field is defined as half a nozzle spacing distance from the last nozzle.

For orchard sprayers the Netherlands defines the starting position of the drift curve as the last tree row. Other countries specify it as half a row distance from the last tree row.

Country specific information:

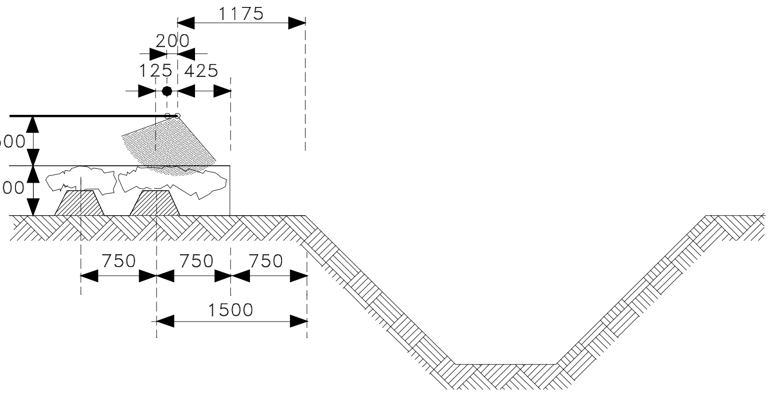
NL

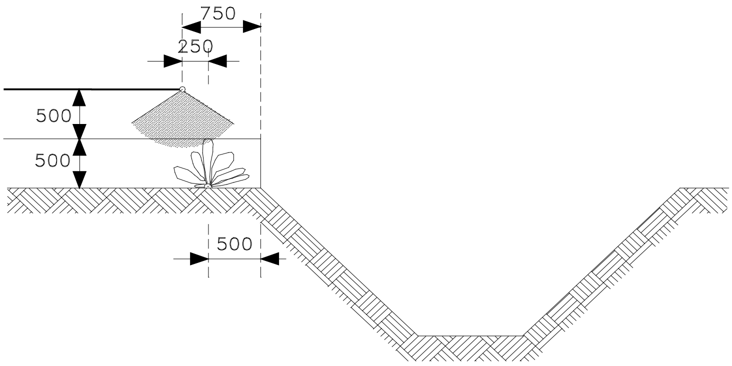
Crop-free buffer zones are applied for all crops.

- A crop-free buffer zone is defined as the area between the last crop row and the top of the ditch bank at the outside of a field.
- On the crop-free buffer zone no or no similar crop is grown as on the rest of the field.
- The crop-free buffer zone is not sprayed.

In tree nursery a spray free zone is defined.

- The spray free zone is defined as the area between the tree row and the top of the bank of the ditch.
- On the spray free buffer zone another tree variety is grown than on the rest of the field.
- The spray free buffer zone is not sprayed.
- Only a limited number of tree varieties are listed to be grown on this area.





Crop-free buffer zones (distance between top of bank and centre of crop row) for a potatoes (top) and a sugar beet crop (bottom).

Germany

Germany only applies spray free buffer zones. A spray free zone is defined as the distance between the end of the sprayer boom and the edge of the field.

The distance between the last nozzle and the edge of field is ½ nozzle distance. Drift reducing sprayers are listed in reduction classes and are alone or in combination with no spray zones (5 m, 10 m, 15 m, 20 m kept from surface waters) used to reduce drift.

UK

Spray free.
Plant protection products specify spray free buffer zones.

For ground boom applications the spray free zone is defined not by reference to the equipment but as a zone which direct spray must not be allowed to fall into.

For ground crops the spray boom will be above the sprayed crops, and it may or may not extend over the buffer zone. Obviously if it does extend over the buffer zone the nozzles potentially spraying directly into the buffer zone must be switched off.

For broadcast air assisted sprayers spraying tree or bush crops, the ‘outermost row’ is the crop row nearest to the buffer zone, and the sprayer may be operated on the buffer zone side of this row with the spray directed only towards this row.

The edge of the water body is variable, particular as water levels change, and the buffer zone also applies to dry ditches, so the reference point for the origin position of the buffer zone is take as the top of the bank.

Figure 1 – Buffer zone and watercourse widths

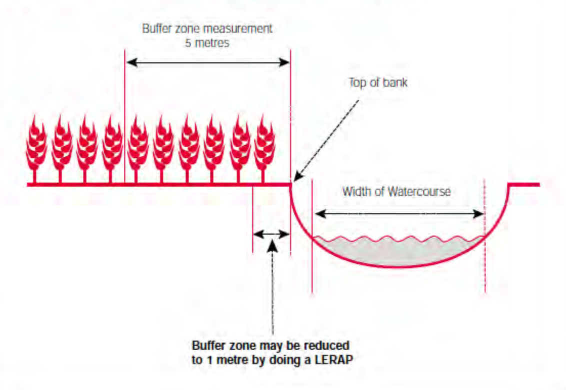
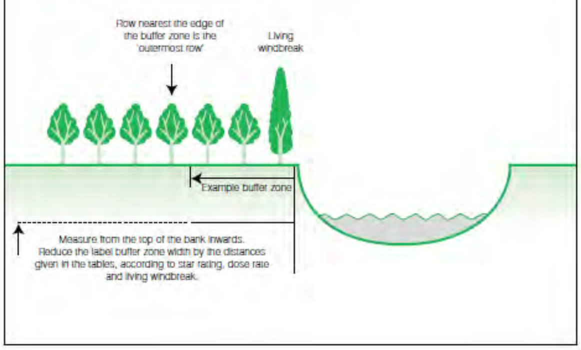


Figure 1 – Buffer zone measurement

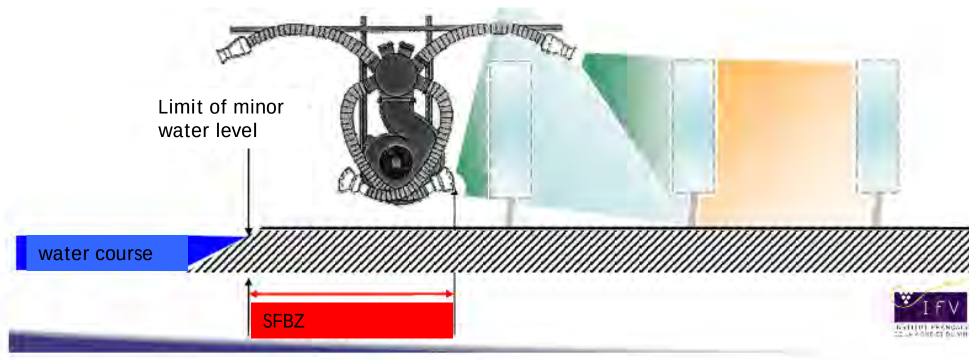


Spray free buffer zones as used in the UK for boom sprayers (arable crops) and air-assisted sprayers (orchards) measured between top of bank and no spray deposit area or outermost tree row sprayed doing a LERAP (Local Environmental Risk Assessment Procedure).

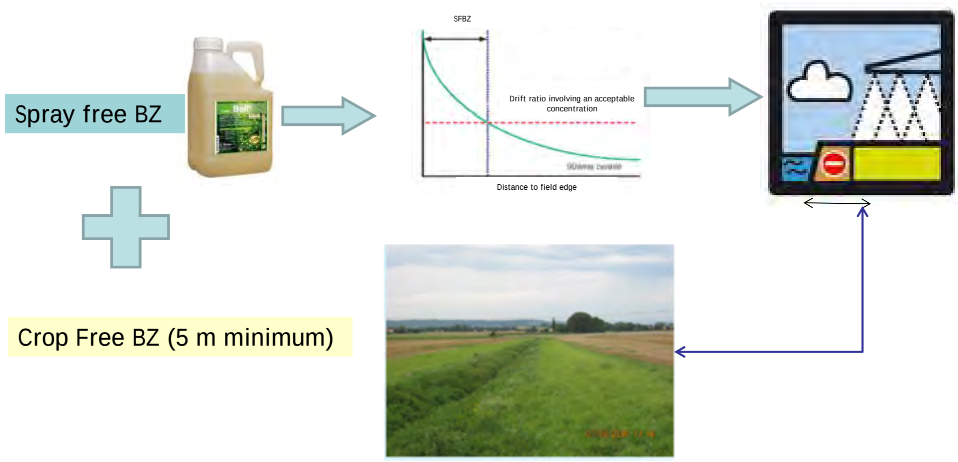
France

Both crop free buffer zones (green/vegetation strips of at least 5 meters) and/or spray free buffer zones (from 5 to 100 meters) are applied in France along water courses. The minimum spraying distance is then 5 meters between the last nozzle to the edge of surface water. Vegetation strips shall be composed of grass or a hedge in case of low adjacent crops or hedge or trees in case of orchards or relatively high crops.

Water course boundary is defined as the minor water bed level (excluding flood conditions). By the law, BZ must consist of at least 5 m width green stripe with vegetation along water courses (visible on a 1/25 000th map as continuous or discontinuous blue lines) as defined by IGN (French National Institute of Geography).
SFBZ are based on an authorization decision for each label.



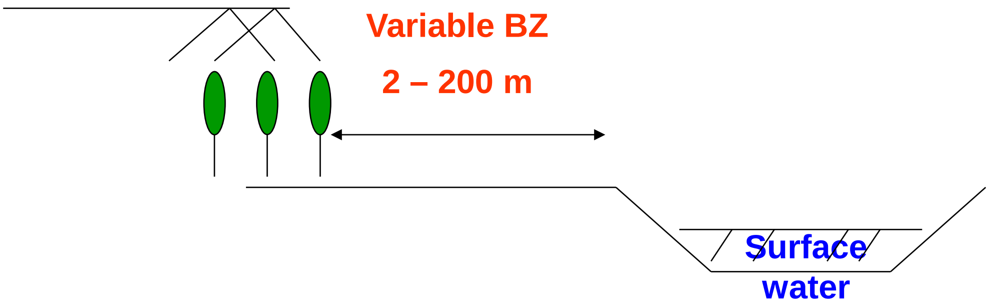
Spray free buffer zone measured from point of the highest water table level in the ditch to the nozzle position in the field.



Spray free buffer zone takes into account the compulsory 5 m crop free buffer zone (grass strip) alongside waterways

Belgium

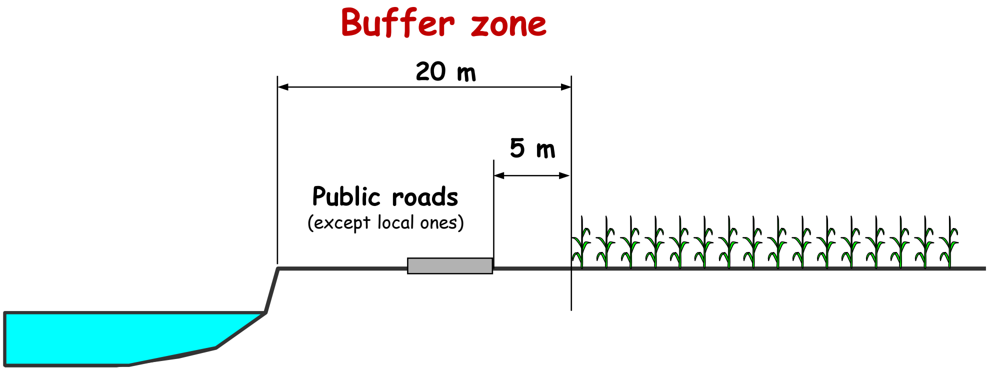
The necessity to define a spray free buffer zone is defined for each plant protection product. Belgian buffer zones are defined as non-sprayed zones near the surface water. The width of the spray free buffer zone is defined after surface water risk assessment and is defined as the distance between the last treated row of the crop (the row which is the nearest to the surface water) and the top of the bank of the surface water. In all circumstances, a spray free buffer zone of 1 meter in arable crops and 3 meter in orchards is to be respected against the non-target surfaces.



Buffer zone definition, distance between last treated row and top of the bank of the surface water

Poland

We use spray free buffer zones. In some circumstances those zones are the same as crop-free buffer zones (especially when we need to protect non-target terrestrial arthropods or plants). The buffer zone width is measured from the last active nozzle to the top of the water body bank. We also consider the width from the edge of the field to the top of the water body bank.



Use of crop-free buffer zone in Poland 5m to public road and 20 m to surface water

Sweden

Wind based buffer zones are based on distance in wind direction from boom end or center of orchard sprayer to the object to protect. When wind direction has changed it is OK to spray the area.
Ground based buffer zone is regarding surface run-off and leakage. 6 m to high-water level in open water courses. To water the distance could never be closer than 6m.
To other objects in wind direction shortest distance according to policy is 2 m.

Austria

Austria applies spray free buffer zones – the distance is calculated from the treated area to the edge of the surface water – for arable crops the minimal distance (without any mitigation measures) is 1 m and for orchards and vines 3 m.

Denmark

The current mitigation of PPPs is based on no spray buffer zones combined with a 2 m crop-free buffer zone along surface water bodies. Political discussions are ongoing to have crop and spray free vegetation zones higher that 2 m along all surface water bodies.

A 2 m crop free zone exists along all surface water bodies. No specific requirements are stated regarding stray technique, sprayer boom height, field situation climatic conditions.

Only use of no spray buffer zones are applied as means of mitigation. No spray buffer zone distances of 2, 10 and 20 m are used. A maximum applicable no spray buffers is given, depending on the crop type: 20 m for field crops, 30 m for vegetable, ornamentals and fruit bushes, and 50 m for orchards. Spray free buffer zones are based on specific authorization decisions and included on the label.

Appendix C. Effect of wind direction on drift deposits

Figure C.1 shows the relation between wind direction and drift deposits onto a water body surface for a sprays application using DG11004 low-drift nozzles with a wind speed of 3 m·s^{-1}. Deposits are highest in a cross wind and are decreasing for wind angles increasingly deviating from perpendicular. The solid line indicates the theoretical curve as computed using the method described in the main text (i.e. using the 1/cosθ correction on effective distances). Results from simulations using IDEFICS version 3.4 are shown as small squares; the bars indicate estimated standard errors. These errors results from the stochastic character of the simulations and can be reduced by taking more droplets in the simulations.

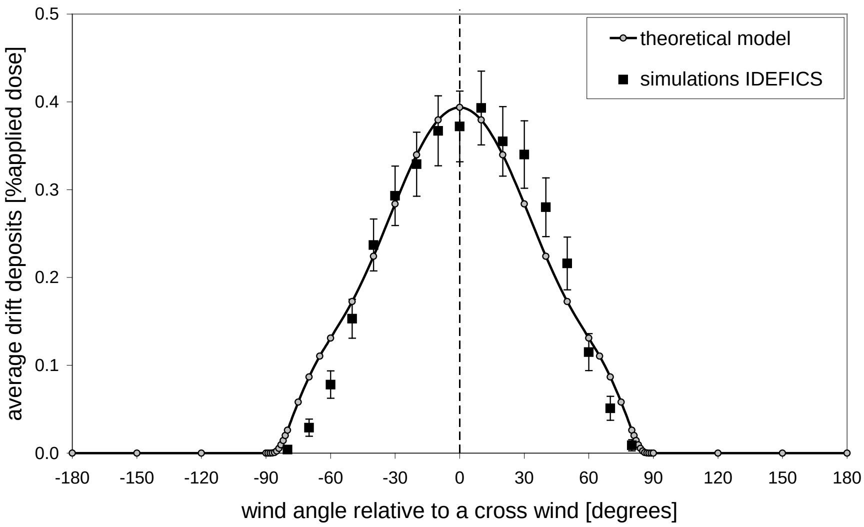


Figure C.1. Example showing average drift load onto a water body as a function of wind direction. Wind direction zero represents a cross wind. Symbols: results from simulations with IDEFICS; bars: estimates of standard deviation; solid line: computation using the theoretical approach (1/cosθ correction) applied to the double-exponential curve for the cross-wind case.

Results from simulations agree well with the theoretical curve, though there are minor differences. Firstly, the simulations appear to be slightly asymmetric around wind angle 0: drift deposits at a certain positive angle appear to be higher than those at the same negative angle. This is caused by the driving direction in the simulations: for positive wind angles the sprayer experiences a sloping head wind, while for negative wind angles wind comes sloping from behind. Combined with the head wind induced by the driving speed, effectively wind speed is higher for positive wind angles than for negative wind angles. Therefore it might be expected to find higher drift values in the former case than in the latter case.

Secondly, at angles above 60° and below -60° simulation results appear to be less than the theoretical curve would suggest. In fact the theoretical approach is idealized in the sense that implicitly it is assumed that there is no lateral diffusion (i.e. in a direction perpendicular to wind direction). Simulations with IDEFICS, however, do take lateral diffusion into account. For wind angles nearly parallel to the field edge, such lateral diffusion may cause droplets to turn back to the crop and deposit there. Clearly, this will lead to lower downwind drift deposits.

Appendix D.
Computation of PEC from drift deposits

Assume a generalized water body with surface width w, bottom width b and water depth h; see Figure D.1.

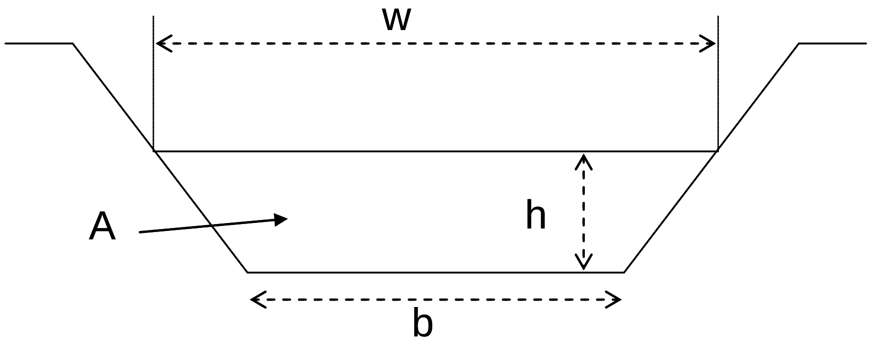


Figure D.1. Schematic cross-section of a water body; w: water surface width; b: width at bottom; h: height of water; A: area of the 'wet' cross-section.

If the water body has length L, the total surface area equals:

$S = w \cdot L$ [m^2]

The cross-section has a 'wet' area given by the product of water depth and averaged width:

$A = h \cdot (w+b)/2$ [m^2]

Thus, the volume of water in the water body equals:

$V = L \cdot A = L \cdot h \cdot (w+b)/2$ [m^3]

Assume that width averaged drift deposits are given by B [$mg \cdot m^{-2}$], then absolute drift loads onto the water surface are B·S [mg]. Dividing this amount by volume V gives PEC:

$PEC = B \cdot S/V$ [$mg \cdot m^{-3}$]

Or:

$PEC = B \cdot w/A$ [$mg \cdot m^{-3}$]

The ratio A/w has the dimension of length and represents the effective water depth below a surface with width w.

Appendix E.
Percentage of edge-of-field water bodies affected by spray drift

Using the Cascade Drift Model (Holterman & Zande, 2010), the effect of parcel selection and wind direction on the drift load onto water bodies can be investigated. Fig.E.1 gives an example of 10 arbitrarily selected parcels in the pilot region (~10km^2) in South-East Drenthe. Coloured clouds indicate downwind deposits, darker colours indicate higher deposits than lighter colours. Due to the low resolution of coloured squares, it seems that some upwind edge-of-field ditches are affected; this is not really the case. The picture shows that not only the (downwind) edge-of-field water bodies are affected, but also water bodies farther downwind, though deposits there are much lower. Comparing Fig.E.1 and Fig.E.2 indicates that the selection of treated parcels, combined with the wind direction during the application, determine which (and how many) water bodies are potentially affected.

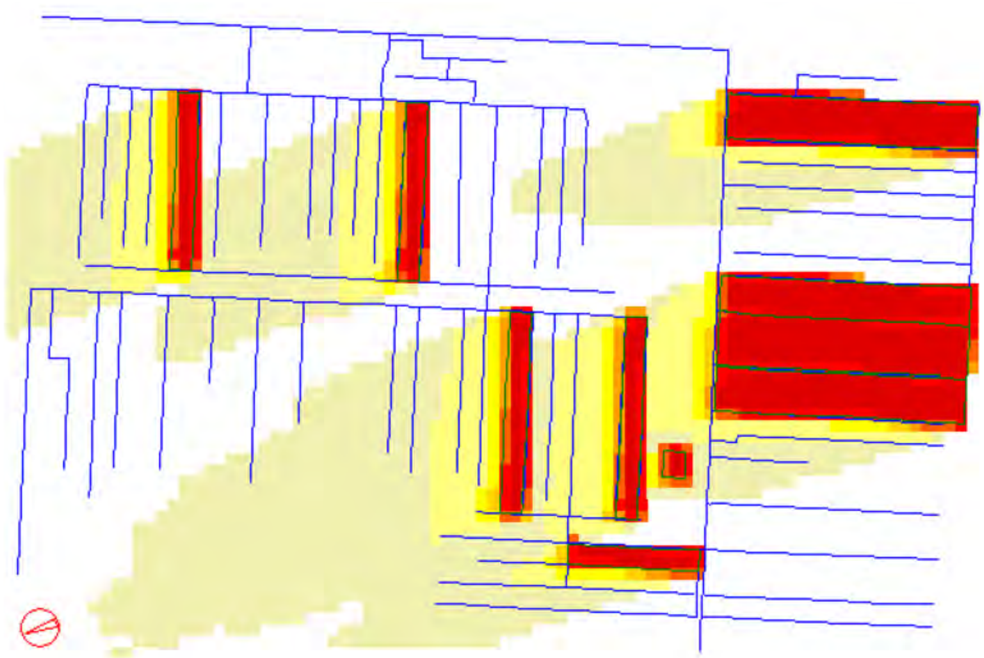


Figure E.1. Wind from angle 70° (ENE). Dark red areas have near 100% deposition (in fact the sprayed fields). From orange to light yellow the relative deposition decreases rapidly. Blue lines indicate the network of water bodies.

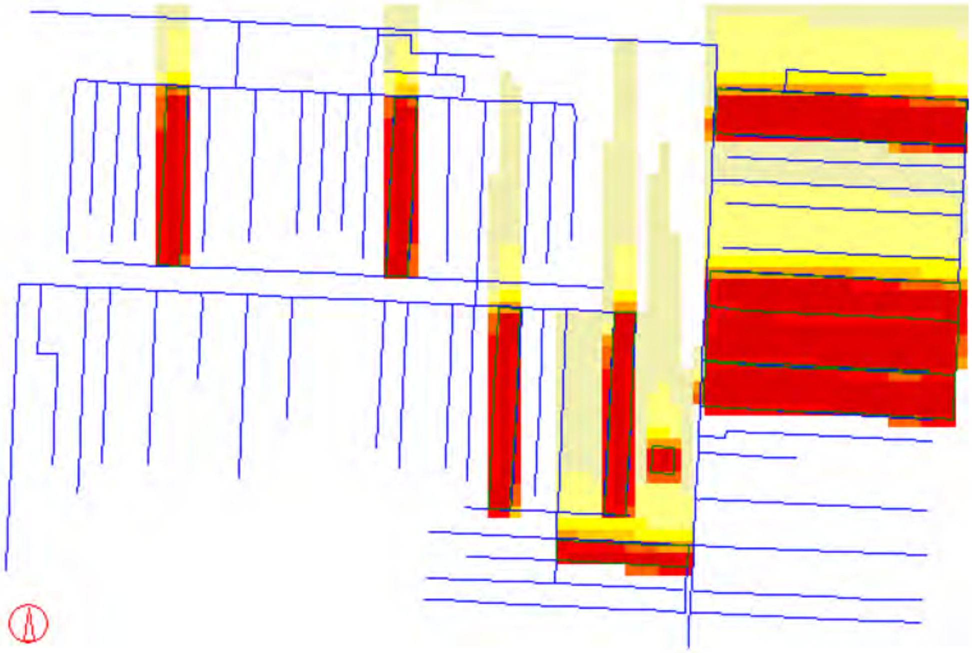


Figure E.2. Wind direction from South (180°). Dark red areas have near 100% deposition (in fact the sprayed fields). From orange to light yellow the relative deposition decreases rapidly.

Percentage of affected edge-of-field water bodies

Consider a square parcel surrounded by edge-of-field water bodies at all sides. If wind direction is parallel to one pair of sides, then only one side is at the downwind edge and one side is at the upwind edge. So in fact only at one side a water body is affected by drift. This gives a 25% fraction of water bodies affected by drift. If wind direction is not parallel to any of the parcel edges, two edges will be at the upwind side, and the other two will be at the downwind side. This gives a 50% factor for affected water bodies. However, as wind direction is not perpendicular to the field edges, the drift loads will be less than in the case of a perpendicular wind direction. If this effect would be accounted for in the percentage of affected water bodies, the 50% would be considerably lower. Anyway, a factor between 25% and 50% seems reasonable, with 50% as a worst-case extreme. If parcels are not square but rectangular, the same factor arises, since it can be assumed that parcels are oriented at random with respect to wind directions occurring. If the network of water bodies is less dense, i.e. individual parcels are not surrounded by 4 water bodies, then the fraction of affected water bodies decreases.

How about other water bodies in the same region?

By definition, water bodies not directly adjacent to the sprayed field are not considered edge-of-field for that particular field. So these water bodies are not accounted for in the fraction of affected water bodies.

What if several parcels are sprayed at the same time?

If parcels are not adjacent to each other, each parcel has its own set of 4 edge-of-field water bodies, and the above mentioned situation continues. Assume two parcels touch each other at one side, like in Fig.E.3. In that case the parcels together are surrounded by 7 water bodies. If wind direction is given by the arrow in Fig.E.3., 3 water bodies are upwind and 4 water bodies are downwind. So the fraction of affected edge-of-field water bodies is 4/7 or 57%, which is >50% obviously. This effect of an increased fraction of affected water bodies is only present if one or more water bodies are at the same time on an upwind and downwind side for different parcels. Clearly this not only depends on the location of the parcels, but also on the wind direction with respect to the location of parcels.

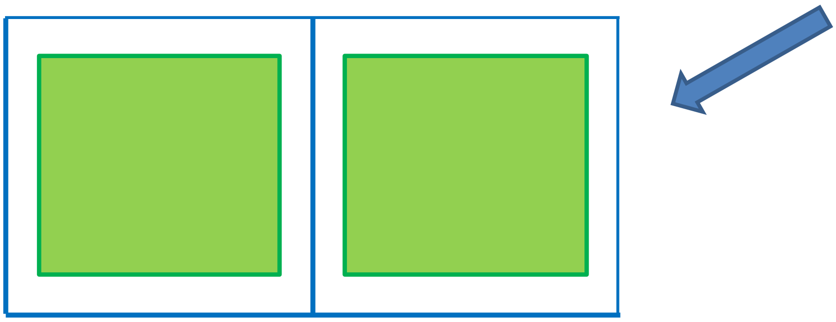


Figure E.3. Two square parcels treated with wind direction from NE. Thin blue lines: upwind (unaffected) water bodies; thick blue lines: downwind water bodies receiving drift deposits.

From this example it is clear that the fraction of affected edge-of-field water bodies can increase well above 50%, depending on the number of parcels treated and their 'areal density' in the local region. Assume a hypothetical region of *m* by *n* equally sized square parcels, all surrounded by edge-of-field water bodies. In that case the $m{\cdot}n$ parcels together have $N = 2m{\cdot}n + m + n$ edge-of-field water bodies. If the wind is directed non-parallel (e.g. similar to that in Fig.3.), then all water bodies are receiving drift deposits, except *m* water bodies at the top and *n* water bodies at the right edge of the region. So the fraction of affected water bodies in this case is:

$$\alpha = \frac{2mn}{2mn + m + n}$$

Example: m=n=10: α=200/220 = 91%. This is a rather extreme situation but it shows that the theoretical upper limit actually is 100% for very large regions with many parcels all treated together.

What is considered a treatment 'at the same time'?
It seems reasonable to identify treatments 'at the same time' on a time scale of water flow in the water bodies (or rather the water body segments with lengths equal to the parcel side lengths). If the flow rate in the water bodies is low, say one refreshment per day, then all treatments on a single day can be considered 'at the same time'.

What about affected water bodies farther downwind?
Water bodies farther downwind are not edge-of-field, and by definition are not accounted for. However, as Fig.E.1 and Fig.E.2. show, these water bodies may receive some drift deposits. On the other hand, typical drift curves decrease rapidly with downwind distance, so the drift loads on water bodies farther downwind is in most cases much lower than those on edge-of-field water bodies. So not accounting for such water bodies seems reasonable. However, if the monitoring would not be on the edge-of-field water bodies but e.g. at the outflow points of the local network of water bodies, the contribution of deposits on all water bodies eventually add up and may be significant.

Appendix F.
Effect of repeated applications on scenario selection for spray drift - simulations

How do repeated applications affect the scenario selection for spray drift?

Two extreme cases can be distinguished:

A. The concentration in the surface water remains constant between subsequent applications; PECs caused by subsequent applications therefore add up.
B. The concentration in the surface water decreases to zero between subsequent applications; the maximum PEC occurring is taken as the determining value.

The current risk analysis was based on a single application. PECs were computed for 35 wind directions (-85 to +85 deg, in steps of 5 deg), 20 wind speeds (0.25 to 5.00 m/s in steps of 0.25 m/s) and 66 standard profiles of water bodies. Plotting the 66 standard profiles (sorted and weighted) against the 700 combinations of wind direction and speed (also sorted and weighted) showed plot of constant percentiles. A subset, based on wind speeds and directions corresponding to actual measurements in field crops and fruit crops, was determined. Only the cases that gave PECs near the 90th percentile were considered. From these cases a reference water body for field crops and fruit crops was selected.

For repeated treatments, the next question arises: *do the percentile curves in the given plot change with respect to those for a single treatment*? A full percentile plot covering all possible situations for repeated treatments is not feasible, since even for a few repetitions the number of situations is much too large to carry out computations for within a reasonable time. The only alternative would be to compute only a limited subset of situations and to derive a percentile plot from these computations. However, it is not clear how to create a cumulative pdf from such a limited set when we do not know where all the cases not computed would end up in this cpdf. Therefore the question may be rephrased as follows, acknowledging that in the percentile plot the water bodies are sorted according to increasing median PEC: *does the order of sorted water bodies change if repeated applications are considered with respect to the order for a single application*? This question is much easier to deal with and can be answered by simulating a fixed number of repetitions. In order to have a comparable set of repeated applications, this set must be equal for each water body. The following procedure is carried out:

1. From the 700 wind direction/speed cases, a random set of 10 cases is selected (representing 10 repetitions). The probability of each wind direction/speed situation was accounted for. Such a set of 10 cases represents one event, statistically.
2. The PECs for these 10 cases are recorded for each of the 66 standard profiles, relative to the overall PEC90 from the study for a single application.
3. Regarding case A: the average of relative PECs is recorded (i.e. the sum of PECs divided by the number of applications per event); regarding case B: the maximum PEC per event is recorded.
4. Since in fact a set of 10 applications represents only one event statistically, this process must be repeated to give statistically satisfactory results. The number of events was chosen to be 100.

Repeated treatments, case A

Rather than taking the PEC values themselves, relative values with respect to the overall PEC90 are used. Furthermore, these relative PECs are summed and divided by the number of applications within the event, giving the average PEC relative to the overall PEC90. Fig.F.1 shows the distributions of the averaged (relative) PEC for 100 events of 10 applications each, for water bodies 600001 and 601001. Clearly, 100 events is hardly enough to get a clear distribution, but it gives a first impression. Fig.F.2 shows the average PEC as a function of the median PEC from the single-application study, for each standard profile. The results show an almost linear relationship, for both a single event of 10 applications and averaging over 100 of such events. These linear relationships indicate that summing PECs for multiple applications does not change the results from the single-application study considerably, as far as the sorting order of standard profiles is concerned. This is supported by Fig.F.3 showing the arrangement of standard profiles based on average PEC with respect to the arrangement of profiles for the single-application (based on median PECs). There are only minor differences in the two arrangements.

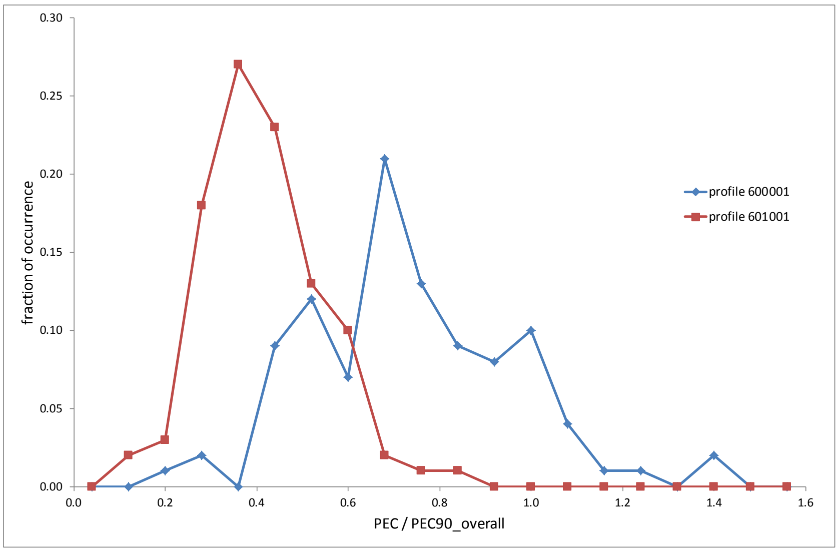


Figure F.1. *Frequency distribution of average PEC relative to the overall PEC90, for 100 events of 10 applications each. For the two standard profiles selected as references in the single-application study.*

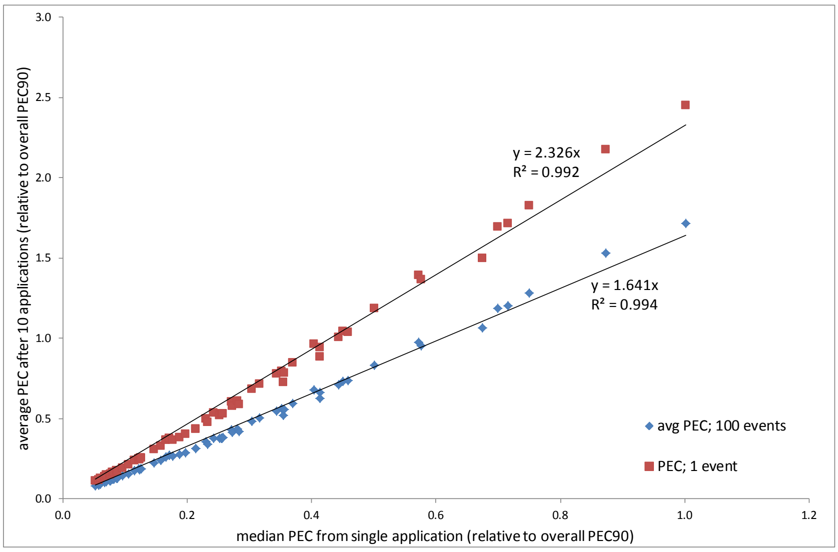


Figure F.2. *Average PEC of 10 applications as a function of the median PEC for each standard profile from the single-application study. Red square symbols: results for one particular event; blue diamond symbols: averaged results for 100 events. All PECs are relative to the overall PEC90 of the single-application study.*

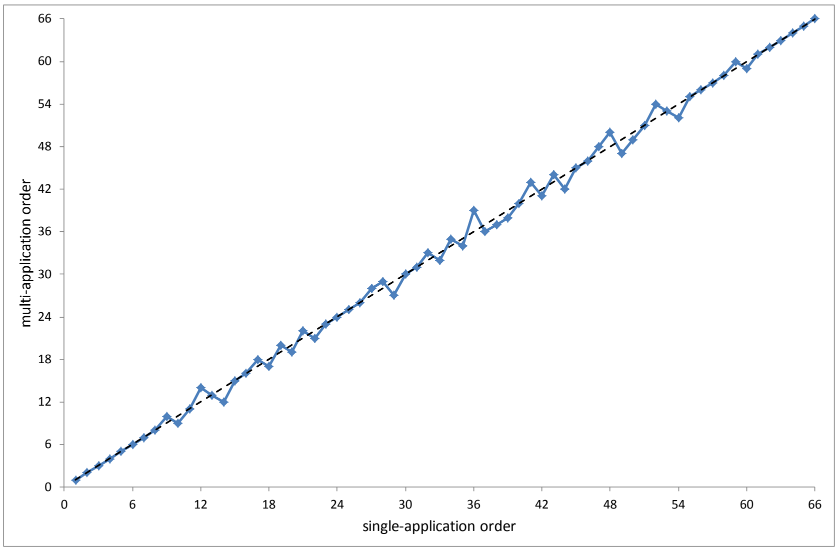


Figure F.3. *Indexed arrangement of standard profiles for increasing averaged PECs as a function of the arrangement based on median PECs for a single-application. Results represent average of 100 events of 10 applications each.*

Repeated treatments, case B

In Case B the maximum PEC after 10 applications is recorded. Clearly, this will tend to yield higher PEC values than the averages as obtained in Case A. Indeed the distributions of maximum (relative) PECs for 100 events given in Fig. F.4 show larger value on the x-axis than in Fig. F.1. The same 100 events as in Case A are used, so a fair comparison is possible between the two cases. Similar to Fig. F.2, Fig. F.5 shows the maximum PEC per event as a function of the median PEC from the single-application study, for each standard profile. Again, the results show an almost linear relationship, for both a single event and averaging over 100 events. Similar to Fig. F.3, Fig. F.6 compares the arrangement of standard profiles for increasing maximum PEC per event (y-axis) and the arrangement based on median PEC form the single-application study (x-axis). Both Fig. F.5 and Fig. F.6 indicate that taking the maximum PEC of 10 applications does not alter the conclusions of the single-application study considerably as far as the sorting order of standard profiles is concerned.

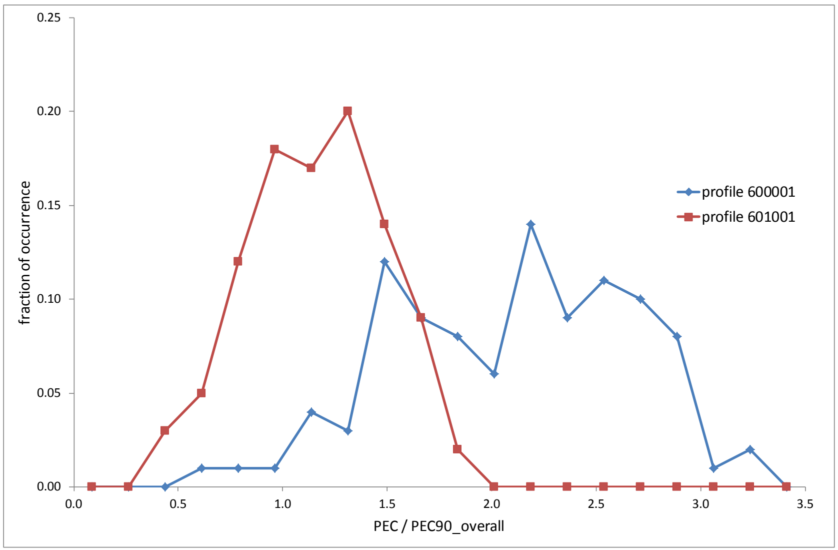


Figure F.4. *Frequency distribution of maximum PEC relative to the overall PEC90, for 100 events of 10 applications each. For the two standard profiles selected as references in the single-application study.*

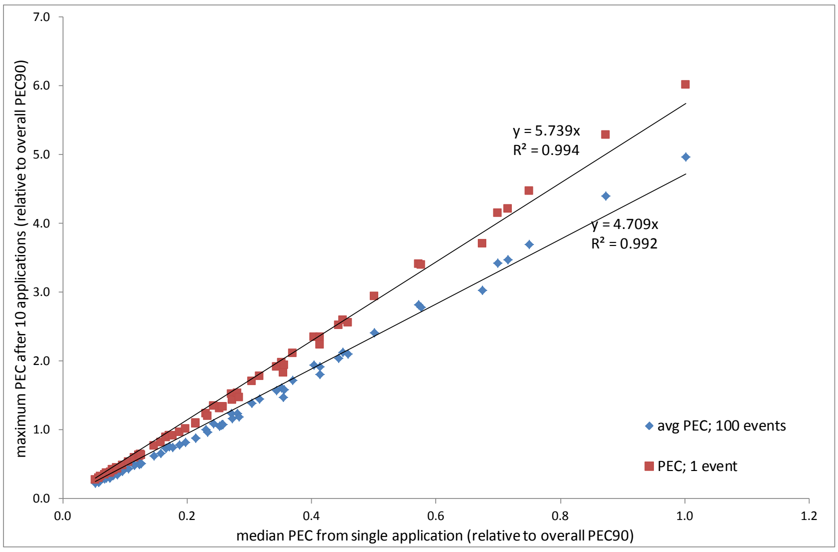


Figure F.5. *Maximum PEC of 10 applications as a function of the median PEC for each standard profile from the single-application study. Red square symbols: results for one particular event; blue diamond symbols: averaged results for 100 events. All PECs are relative to the overall PEC90 of the single-application study. All events are equal to those used in Case A (Fig. F.2).*

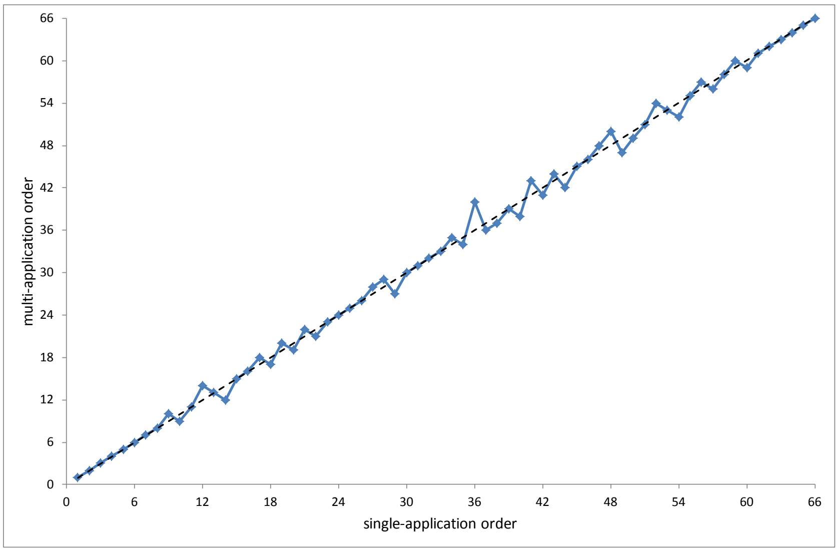


Figure F.6. *Indexed arrangement of standard profiles for increasing maximum PECs as a function of the arrangement based on median PECs for a single-application. Results represent average of 100 events of 10 applications each.*

Conclusion

The results for both Case A and Case B show that the arrangements of standard profiles for increasing PECs is hardly different from the arrangement for the single-application situation. Moreover, the sum of PECs (or its corresponding average) and the maximum PEC for an event of 10 applications are almost linearly related to the median PEC from the single-application case. This implies that so far there is no reason to assume that conclusions regarding the selection of reference standard profiles form the PEC-percentiles plot will be different when multiple applications are involved. However, although sorting order and linearity support the assumption that the selection of standard profiles for reference may not depend on the number of applications, there still is no hard evidence that this assumption really is true. Additional study is required to confirm (or reject) the assumption.

So far 10 applications per event were assumed. Regarding the results from this study, having another number of applications per event is not likely to alter the conclusions with respect to arrangements of standard profiles or the linear relationships observed.

Appendix G.
Statistics of repeated spray applications and distributions of PEC levels

So far the study of effect of spray drift on PEC levels was focused on a single spray application. In practice several treatments during the growing season are more common. How this may affect PEC levels and risk assessment is the topic of this study. Two extreme cases can be distinguished:

A. The concentration in the surface water remains constant between subsequent applications within a growing season; PECs caused by subsequent applications within a growing season therefore add up.
B. The concentration in the surface water decreases to zero between subsequent applications; the maximum PEC occurring is taken as the determining value.

Reality will be somewhere in between. It may be near to case A for frequent applications and low decay of PPP in the ditch, while it may be near case B for less frequent applications or fast decay of PPP in between applications.

Case A: summing of PECs
Suppose a given parcel is sprayed several times during the growing season. Obviously, parcel and adjacent water body do not change, however weather conditions will be different for each application. Applications under favourable conditions (giving low PEC) may be partly compensated by applications under less favourable conditions (with relatively high PEC). For comparison with a single treatment it is convenient to look at the averaged PEC for a treatment (i.e. sum of PECs divided by the number of applications). Due to the compensating effect of repeated applications, the probability of very low or very high average PECs is less than for a single application. The probability density function (pdf) for repeated applications therefore is narrower than that for a single application. Consequently, it is hypothesized that the corresponding 90^{th} percentile PEC value is lower than that for a single application.

Case B: maximum of PECs
Again, due to varying weather conditions PEC values of individual applications will vary as well. The probability of having a relatively high PEC value in one of the applications increases when the number of applications increases. This means that the pdf for repeated applications in case B is biased towards larger PEC values. Therefore, it is hypothesized that the 90^{th} percentile PEC level is larger than that for a single application.

Statistical analysis
Clearly, the above analysis is purely qualitatively. To get a better understanding, cases A and B are investigated by statistical simulations. Assume the number of applications n equals 10. After n applications, the order of magnitude of summed PEC in case A is about n times the values observed for a single treatment. Therefore, for comparison it is convenient to look at the average PEC rather than the sum of PECs. The treatments differ in weather conditions only (wind speed and wind direction towards the water body). In the simulations, wind speed and direction are selected from their weighted frequency distributions. Clearly, there is a practically infinite number of ways to select 10 weather conditions. A set of n treatments is called an 'event'. So each different set of 10 weather conditions gives a different event with different average and maximum PEC. For statistical reasons it is therefore necessary to carry out a large number of different events and process the subsequent results statistically. In this study 500 events are carried out, each of 10 treatments on each of the 66 standard profiles. This gives 33000 results (events and standard profiles combined), for both average and maximum PEC per event. These results are sorted small to large, their probability given by weight (frequency probability) of the standard profile and weight (probability) of the wind speed/direction combination. Fig.G.1 shows the cumulative pdf of 33000 values for average PEC (avgPEC) and maximum PEC (maxPEC) as a function of PEC value, relative to the 90^{th} percentile PEC of a single treatment ($PEC_{90single}$). For comparison the cumulative pdf for a single application is added.

The larger vertical dashed line represents the PEC value equal to $PEC_{90single}$. The horizontal dashed line indicates the locations of the 90th percentile PEC values for each curve. The blue curve (avgPEC) has lower cumulative probabilities for low PEC values, while it has higher cumulative probabilities for large PEC values (i.e. the curve is closer to cum-pdf=1 there). Indeed this shows that the cumulative pdf from avgPEC is steeper than for a single application (i.e. the pdf is narrower), as was hypothesized above. Similarly, the purple curve (maxPEC) is shifted to the right with respect to the single-application curve. Careful inspection of the curve for maxPEC would reveal that this distribution too is narrower than that for a single application (i.e. the coefficient of variation of occurring PEC values is lower than that for a single application).

At the 90th percentile level, the curve for avgPEC stays close to the single-application curve: the point S representing the new PEC_{90} has shifted only slightly to a lower PEC value. This suggests that decisions based on PEC_{90} for a single treatment are valid for multiple treatments as well, as far as case A is concerned. In fact such a decision system is conservative for multiple treatments, as the corresponding percentile at $PEC=PEC_{90single}$ is at a slightly higher level (~92%, point P).

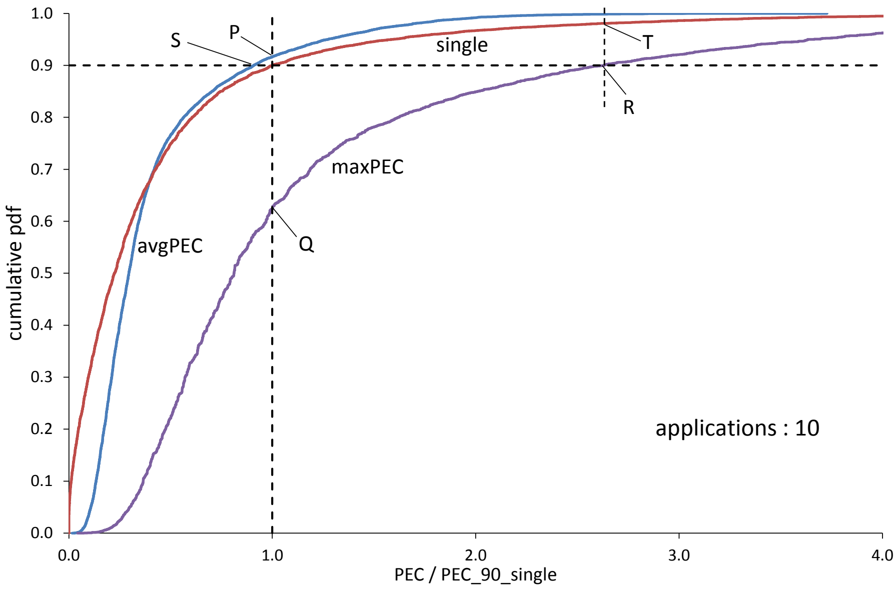


Figure G.1. Cumulative pdf showing PEC values (relative to PEC90 of single application) for multiple spray applications (n =10). Red curve: cum-pdf for single application; blue curve: for average PEC after n applications; purple curve: for maximum PEC after n applications. Points P, Q, R, S, T: see text.

On the other hand, for maxPEC the new PEC_{90} is indicated by point R which has shifted to a much larger PEC value. Point Q, indicating the percentile at $PEC=PEC_{90single}$ is at a level of about 60% which is well below 90%. Therefore, for case B the single-application decision system does not give sufficient safety for water bodies. In that case it would be better to have a decision system looking at situations that have PEC values near point R, although for a single treatment such a system would be very protective (point T; ~98%).

For a single application in field spraying, the standard profile 601001 was selected as a reference profile since it has PEC values near $PEC_{90single}$ for wind speeds about 3.25 m/s and wind directions roughly perpendicular to the field edge. In fact, these situations show up on the red single-application curve at the intersection point of that curve and the horizontal dashed line. If drift computations for such a reference application are repeated *n* times, clearly in all occasions the same PEC would be found. Thus, on the blue curve for avgPEC, these computations would show up at point P which is slightly more protective than for a single application, as stated above. For case B (maxPEC), however, one would end up in point Q after repeated computations with the same drift curve for the reference profile and the given wind speed and direction. Results of such computations appear not to give a 90th percentile protection. To be protective at the 90th percentile level, one might (a) use another (more conservative) drift curve, or (b) select another reference water body. As stated above, this would give a decision system that is very protective for a single application and even more for multiple applications of type 'case A'.

The examples in this study are carried out for $n = 10$. It can be shown that the curve for case A (avgPEC) is rather insensitive to changes in n (at least up to $n = 20$), particularly near the 90th percentile. The curve for case B (maxPEC), however, gets worse when n increases. Point R moves to the right when n increases. Therefore, the development of a decision system for case B requires additional investigation in itself.

The above findings are quite different from those described in the FOCUS report on Surface Water Scenario (FOCUS, 2001), for three reasons. Firstly, FOCUS assumed a normal distribution of drift values, which is clearly not the case in the current study. This is the main reason that the 90th percentile PEC level does not change much in case A. Secondly, in FOCUS no spatial component was considered, only a few standardized water bodies separately. Thirdly, in FOCUS only case A was considered implicitly; case B, which is less conservative, is not considered.