Scenarios for exposure of aquatic organisms to plant protection products in the Netherlands

Part 3: spray applications in avenue tree nurseries and downward spraying underneath fruit trees

Holterman H.J., Adriaanse P.I., ter Horst M.M.S., Tiktak A., Wipfler E.L.,van de Zande J.C.

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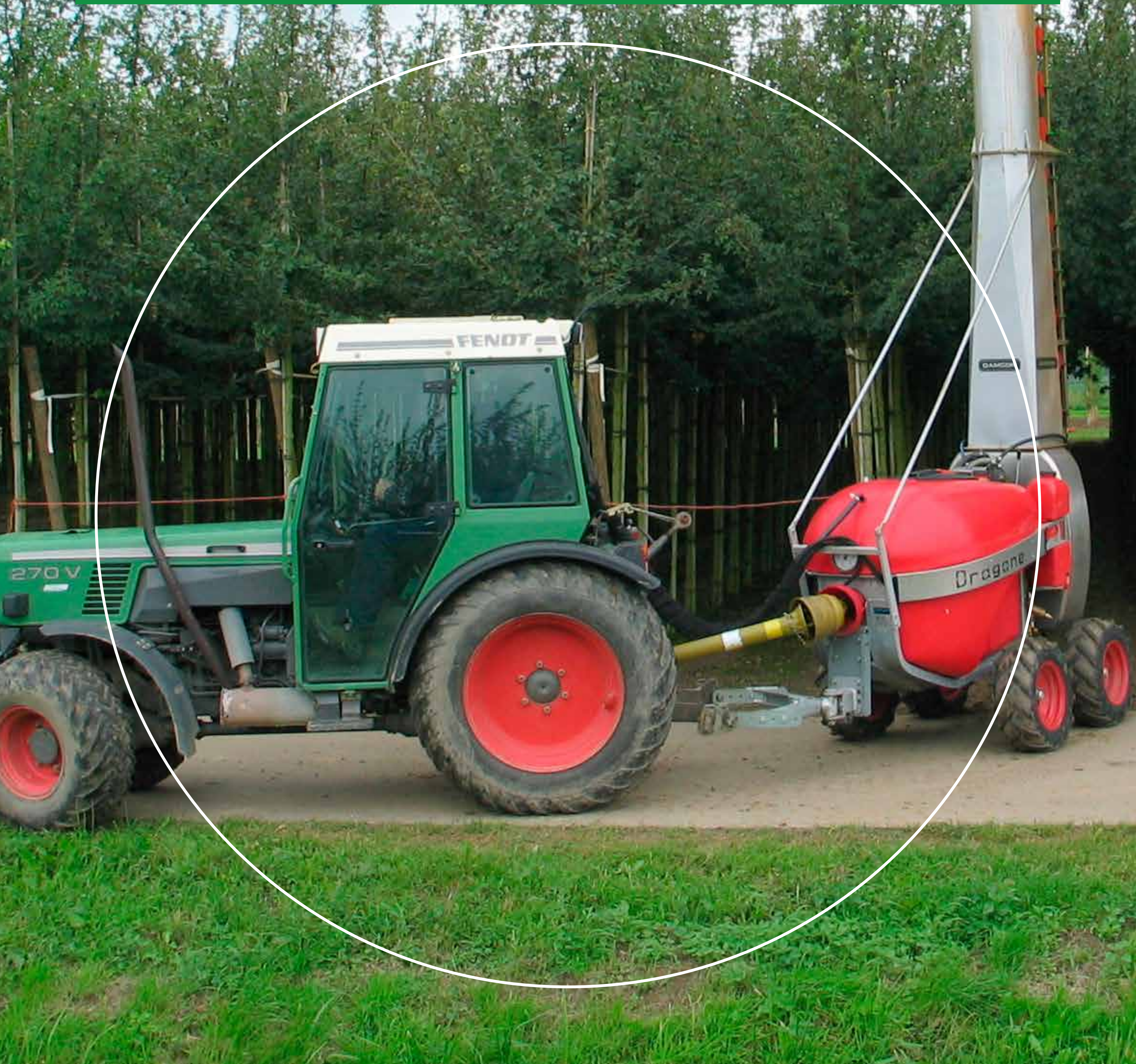

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A new exposure assessment methodology for various tree crops and application methods was developed by Wageningen UR and PBL Netherlands Environmental Assessment Agency. In addition to the scenario for upward and sideways spraying in fruit orchards, which was published in 2021, this report describes the methodology for upward and sideways spraying in avenue tree nurseries and downward spraying in such nurseries and in fruit orchards. The new procedure calculates the exposure concentration based on a statistical distribution of the exposure concentration in all relevant Dutch watercourses. The methodology results in a so-called 90th percentile exposure concentration considering all watercourses alongside fruit orchards or avenue tree nurseries. The methodology accounts for the exposure by plant protection products through spray drift, drainage and atmospheric deposition. The scenarios include drift-reducing application techniques and crop-free buffer zones. With the scenarios in this report and the report on upward and sideways applications in fruit orchards, a more realistic exposure assessment is possible for edge-of-field watercourses next to fruit orchards and avenue tree nurseries regarding both upward & sideways applications and downward applications in the Netherlands.

Keywords: pesticides, plant protection products, spray drift, drift reducing techniques, crop-free buffer zone, fruit tree orchards, avenue tree nurseries, surface water, aquatic organisms, probabilistic scenario, drainage, exposure scenarios

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Preface

This third report on scenarios for exposure of aquatic organisms to plant protection product completes a series that started many years ago. The working group on the development of such exposure scenarios delivered Part 1 in 2012, dedicated to arable crops. Part 2 has been finished recently (2021) and focusses specifically on scenario for sideways and upward spraying in Dutch fruit crops. The current Part 3 of the series deals with upward and sideways spraying scenarios for avenue tree nurseries and with downwards spraying scenarios both in avenue tree nurseries and in fruit orchards. Since Part 3 can lean on methods and results developed for Part 2, it was possible to deliver the current report only shortly after Part 2. Still, Part 3 is not a copy of Part 2; but part of the methodological approach as well as lessons learnt while working on Part 2 have been used in this third report.

The scenarios that are described in Part 2 and Part 3 (this report) were combined in one software instrument, i.e. DRAINBOW, that allows to calculate the Predicted Environmental Concentrations of plant protection product use in fruit orchards and avenue trees.

Now that Part 1 was finished many years ago, the exposure scenario for arable crops was due for an upgrade to allow for new insights, particularly in relation to the improved methodologies described in the reports of Part 2 and Part 3. Currently, an upgrade of the scenarios for arable crops is in progress.

Summary

This report describes a methodology for exposure assessment of aquatic organisms in watercourses after application of plant protection products (PPP) in Dutch pome fruit orchards and avenue tree nurseries. In fact, it combines three separate exposure assessment studies, namely for upward and sideways applications in avenue tree nurseries, downward applications in such nurseries, and downward applications in pome fruit orchards. Thus, the report is the logical successor to and complementary to a similar report on exposure assessment for upward and sideways applications in fruit orchards. Together these two reports cover the possible exposure scenarios in fruit orchards and avenue tree nurseries. The three mentioned assessment studies were dealt with separately, yet there were enough similarities to put them together in one report. Typically, upward and sideways applications involve spraying of fungicides or insecticides towards the canopy of the trees, while downward applications are herbicide treatments directly to the ground below the trees. For these applications different spray drift curves have been derived from experimental data. Spray drift curves quantify the spray deposits onto off-target ground areas downwind from the orchard or nursery, as a function of distance from the field edge (or more often, the last tree row). In particular, the spray deposits onto edge-of-field watercourses are considered. Apart from spray drift, plant protection products can enter the watercourse through drainpipes, which is an important route for exposure as well and is considered in this report. Atmospheric deposition following volatilisation of applied products after application is a third route, mainly of interest when entries of PPPs due to spray drift and drainage are very low. Surface runoff is not taken into account in these scenarios. Finally, to evaluate the exposure of aquatic organisms, the fate of PPPs in the watercourse is dealt with too.

The exposure assessment involves the exposure evaluation when either fruit orchards or avenue tree nurseries all over the Netherlands are treated. For avenue tree nurseries three subclasses are to be distinguished: spindles, transplanted trees and high avenue trees, representing different growth stages of the trees with different geometries and drift curves. Typically, downward spray applications below avenue trees are whole field treatments on bare soil to keep the ground below the trees free of weeds. For downward treatments in fruit orchards, one has to distinguish applications onto the grass strips (paths between the tree rows and surrounding the edge of the field) and applications onto the tree strips (bare soil strips on which the trees are planted). Since fruit orchards and avenue tree nurseries are spread non-uniformly over the country and are treated at different timings, there is a mixture of spatial units (the ditches) and temporal conditions (weather conditions) that lead to a wide range of spray deposits. As with upward and sideways applications in fruit orchards (Boesten et al., 2021), the method involves the determination of the 90th percentile exposure level of PPP concentrations (PEC_{90}) in the edge-of-field watercourses. One particular spatial configuration was selected, for which an exposure assessment was elaborated. For convenience and for robustness of the methods, the same spatial configuration as used for upward and sideways applications in fruit orchards was selected. For the selected configuration a temporal percentile (T_{90}) was derived, which corresponded to the countrywide PEC_{90}. Spray application schemes may involve different application techniques, one or more treatments per year and the use of an additional crop-free buffer zone. Each application scheme is characterized by a certain PEC_{90} and T_{90}.

The spray drift scenario and the drainage scenario were developed separately, each with its own temporal percentile. A robust protocol was developed to determine an appropriate temporal percentile when both drainage emission and spray drift deposition may be present. The protocol involves the determination of the dominance of either spray drift deposition or drainage emission for a number of simulated years. If one of these routes is clearly dominant, the corresponding temporal percentile is used. If both routes are equally important, the higher temporal percentile is used. A route is considered clearly dominant in the scenario if it is the dominant exposure route in more than 2/3 of the simulated years. This protocol leads to a robust and conservative exposure evaluation.

The example calculations indicate that for upward and sideways applications in avenue tree nurseries often spray drift is the dominant route for PPPs entering the watercourses, except when highly drift-reducing techniques are involved. In those cases drainage is the most important route. For downward treatments below avenue trees and fruit trees the spray drift deposits are very low and in most cases drainage is more important. For cases with low spray drift deposition, with PPPs that are immobile in the soil or when the degradation in soil is fast, drainage emission is low and atmospheric deposition following the volatilisation of deposited PPPs could become the major entry route, provided the saturated vapour pressure of the PPP is not too low. The current method appears to be sufficient and conservative for atmospheric deposition as well.

Samenvatting

Dit rapport beschrijft een methodiek voor blootstellingsbeoordeling van waterorganismen in waterlopen na toepassing van gewasbeschermingsmiddelen in fruitboomgaarden en laanboomkwekerijen. Het is een combinatie van drie afzonderlijke onderzoeken naar blootstellingsbeoordeling, namelijk voor opwaartse en zijwaartse toepassingen in laanboomkwekerijen, neerwaartse toepassingen in deze kwekerijen en neerwaartse toepassingen in fruitboomgaarden. Het rapport is daarmee de logische opvolger van en aanvulling op een vergelijkbaar rapport voor opwaartse en zijwaartse toepassingen in fruitboomgaarden. De twee rapporten samen omvatten de blootstellingsscenario's voor fruitboomgaarden en laanboomkwekerijen. De drie genoemde beoordelingen worden afzonderlijk besproken, maar er zijn genoeg overeenkomsten om ze samen te voegen in één rapport. Opwaartse en zijwaartse toepassingen behelzen de bespuiting van bomen met fungiciden of insecticiden. Neerwaartse toepassingen omvatten herbicidebespuitingen direct op de grond onder de bomen. Voor deze toepassingen zijn uit veldexperimenten verschillende driftcurves afgeleid. Driftcurves beschrijven de depositie op de grond benedenwinds van de boomgaard als een functie van de afstand tot de rand van het veld (of gewoonlijk vanaf de laatste bomenrij). In het bijzonder wordt gekeken naar de driftdepositie op sloten direct naast de boomgaard. Gewasbeschermingsmiddelen kunnen ook via drainagebuizen in de sloot terechtkomen, een andere belangrijke blootstellingsroute die in dit rapport aan de orde komt. Atmosferische depositie na vervluchtiging van spuitmiddel op de bomen of de grond onder de bomen is een derde emissieroute. Deze wordt belangrijk wanneer de bijdrage via de routes spuitdrift en drainage erg laag is. In deze scenario's wordt geen rekening gehouden met oppervlakteafspoeling (run-off). Om de blootstelling van waterorganismen te evalueren wordt ook het verder gedrag van gewasbeschermingsmiddelen in de sloot behandeld.

De beoordeling van de blootstelling veronderstelt dat ofwel de fruitboomgaarden dan wel de laanboomkwekerijen in heel Nederland worden behandeld. Voor laanboomkwekerijen worden drie groepen onderscheiden: spillen, opzetters en hoge laanbomen, die verschillende groeistadia vertegenwoordigen met hun eigen plantopzet en driftcurves. Neerwaartse bespuitingen in laanboomgaarden betreffen gewoonlijk volvelds behandelingen op de kale grond onder de bomen om deze onkruidvrij te houden. Voor neerwaartse bespuitingen in fruitboomgaarden wordt onderscheid gemaakt in toepassingen op de grasstroken (de paden tussen de bomenrijen en de randstrook rondom de boomgaard) en toepassingen op de boomstroken (kale grondstroken waarop de bomen zijn geplant). Fruitboomgaarden en laanboomkwekerijen zijn niet gelijkmatig over Nederland verdeeld en worden op een of meer tijdstippen in het jaar behandeld. Dit leidt tot een groot aantal mogelijk combinaties van sloten en weersomstandigheden, waarvoor de emissieroutes berekend moeten worden. Net als bij opwaartse en zijwaartse toepassingen in fruitboomgaarden (Boesten et al., 2021), wordt het 90-percentiel blootstellingsniveau van concentraties (PEC_{90}) van gewasbeschermingsmiddelen in de randsloten bepaald. Eén ruimtelijke configuratie wordt geselecteerd om het landelijke blootstellingsrisico te beschrijven. Er is gekozen om dezelfde ruimtelijke configuratie te gebruiken als voor opwaartse en zijwaartse toepassingen in fruitboomgaarden. Voor deze geselecteerde configuratie is een temporeel percentiel (T_{90}) afgeleid, waarvoor de concentratie in de selectiesloot gelijk is aan de landelijke PEC_{90}. Er is rekening gehouden met verschillende toedieningstechnieken, één of meerdere behandelingen per jaar en gewasvrije bufferzones. Voor elk toepassingsschema zijn de bijbehorende PEC_{90} en T_{90} bepaald.

Voor driftdepositie en drainage zijn afzonderlijke scenario's ontwikkeld, elk met een eigen temporeel percentiel. Er is een robuust protocol ontwikkeld om een geschikt temporeel percentiel te bepalen wanneer zowel drainage-emissie als driftdepositie een rol spelen. In dit protocol wordt bepaald welk van beide routes dominant is gedurende een aantal gesimuleerde jaren. Wanneer een route duidelijk dominant is, wordt het bijbehorende temporele percentiel gebruikt. Als beide routes even belangrijk zijn, wordt het hoogste van beide temporele percentielen gebruikt. Een emissieroute wordt als duidelijk dominant beschouwd als deze in ten minste 2/3 van de gesimuleerde jaren de belangrijkste blootstellingsroute is. Dit protocol geeft een robuuste en conservatieve evaluatie van blootstelling.

De rekenvoorbeelden laten zien dat voor opwaartse en zijwaartse toepassingen in laanboomkwekerijen driftdepositie meestal de dominante route is voor de emissie naar randsloten, behalve wanneer het gaat om toedieningstechnieken met een hoge driftreductie. In die gevallen is drainage de belangrijkste route. Bij neerwaartse bespuitingen onder laanbomen en fruitbomen is re zeer weinig driftdepositie en dus is drainage dan meestal belangrijker. Wanneer de driftdepositie laag is en de gewasbeschermingsmiddelen betrekkelijk immobiel zijn in de bodem, of wanneer de afbraak van gewasbeschermingsmiddelen in de bodem erg snel is, is ook de emissie via drainage laag en kan atmosferische depositie de belangrijkste emissieroute worden, mits de verzadigde dampdruk van het middel niet te laag is. De huidige methodiek blijkt ook voor atmosferische depositie te gebruiken en conservatief te zijn.

1 Introduction

1.1 Background

In 2007 the Dutch government established a working group to update the Dutch exposure assessment of aquatic organisms to plant protection products (PPPs). The current Dutch exposure assessment is based on PPP entries via spray drift only and this was considered inappropriate after the development of the FOCUS surface water scenarios at EU level (FOCUS, 2001; EFSA, 2020) which clearly indicated the importance of the input from drainpipes, considering also that 40% of the Dutch arable fields have drainpipes (Tiktak et al., 2012a). Between 2007 and 2012 an exposure assessment procedure for downward spraying in field crops was developed which resulted in a series of reports that include the drainpipes as exposure route as well as atmospheric deposition (Tiktak et al., 2012a, 2012b; Van de Zande et al., 2012). Between 2013 and 2021, an exposure assessment procedure for upward and sideways spraying in fruit crops was developed (Boesten et al. 2021), as well as scenarios for avenue trees and scenarios for downward spraying below fruit crops and avenue trees.

This report adds to the exposure scenarios described in Boesten et al. (2021) and describes the approach and details for the scenarios:

1. Avenue-US: upward and sideways spraying of PPPs in avenue tree nurseries, distinguishing three growth stages: spindle trees, transplanted trees and high trees,
2. Avenue-DWN: downward spraying to the soil in avenue tree nurseries,
3. Fruit-DWN: downward spraying to the soil in fruit orchards.

Note that regarding tree nurseries, this report is limited to avenue tree nurseries, where the spray application is directed upward and sideways towards the trees. For other nursery crops, that are treated by downward spraying, the arable crop scenario is applicable, which is outside the scope of this report.

1.2 Exposure assessment goal

As described by EFSA (2010), regulatory exposure assessments for plant protection products have to be based on well-defined exposure assessment goals, that include seven elements (Boesten, 2017). The exposure assessment goal definition used is the same for all scenarios as described in Boesten et al. (2021) and in this report. The definition of the exposure assessment goal is described in detail in Section 1.2 of Boesten et al. (2021) and can be summarized as:

The 90th percentile from the spatio-temporal (statistical) population of annual maximum concentrations in the Netherlands, whereby:

- The type of concentration is (e.g. Ecotoxicologically Relevant type of Concentration, ERC) is the concentration of freely dissolved chemical in the water,
- The spatial unit considered is the edge-of-field ditch next to a treated field. This ditch is a permanent ditch, which does not fall dry in summer,
- Concentrations are averaged over 100 m of ditch length.

The exposure risk for aquatic organisms can be acute or chronic. The current model considers acute exposure as the major driver for the risk assessment, in line with the guidance document on aquatic ecotoxicology (EFSA, 2013). This means that the level of exposure is governed by the maximum PPP concentration occurring at some day in a year. We refer to the annual maximum concentration as the Maximum Predicted Environmental Concentration, PEC_{max}.

1.3 Exposure routes

Three exposure routes for PPPs (also called pesticides in this report) to enter the edge-of-field watercourses were accounted for: spray drift deposition, drainpipe emission and atmospheric deposition. Historically, scenarios were first developed for the spray drift route. Although this seems reasonable for upward and sideways applications in fruit orchards regarding the relatively high spray drift deposits, for the scenarios in this report it appeared that drainage or even atmospheric deposition could be the dominant entry route in several situations, particularly when spray drift is mitigated considerably.

A considerable part of fields where avenue tree nurseries and fruit orchards are located involves field that are drained (Section 2.4 and 3.3). Therefore including drainpipe emission in the scenarios is important.

For upward and sideways applications in fruit orchards, a protocol was developed to deal with situations where both spray drift and drainage are important (Boesten et al., 2021). This protocol has been slightly adapted to use it for avenue tree nurseries (Section 4.4).

Some example runs (Section 8.4) indicated that atmospheric deposition could become the major entry route when both spray drift and drainpipe emissions were low. Spray drift often is low with downward spray applications, or when highly drift-reducing techniques are used. Drainpipe emissions can be low for immobile or fast degrading PPPs.

1.4 Scenarios

Different definitions exist of the term 'scenario' as used in the exposure assessment context. In this study we use the term scenario for PPP applications in different crop classes while defining the method of applying the PPPs. In this way, fruit orchards and avenue tree nurseries involve different scenarios. Similarly, upward and sideways applied sprays and downward applied sprays represent different scenarios as well. The rationale behind this is that the computational methods for spray application scenarios in fruit orchards and avenue tree nurseries involve a different approach. Additionally, with downward directed spray applications in fruit orchards and avenue tree nurseries, the weeds on the ground below the trees (bare soil or partly covered by grass) are the target rather than the trees in that orchard. Figure 1 gives an overview of the scenarios for fruit orchards and avenue tree nurseries. The five blue boxes are defined as 'scenarios' in this study. Fruit US refers to pome and stone fruit orchards, already described by Boesten et al. (2021). For small fruit, hop and vines no specific scenarios have been developed; the scenario for fruit orchards is used with some adaptations or boundary conditions. For Fruit DWN a distinction is made between applications on tree strips (in the tree rows) and on grass strips (between the tree rows). Further details of the scenario approach are elaborated in Chapter 4.

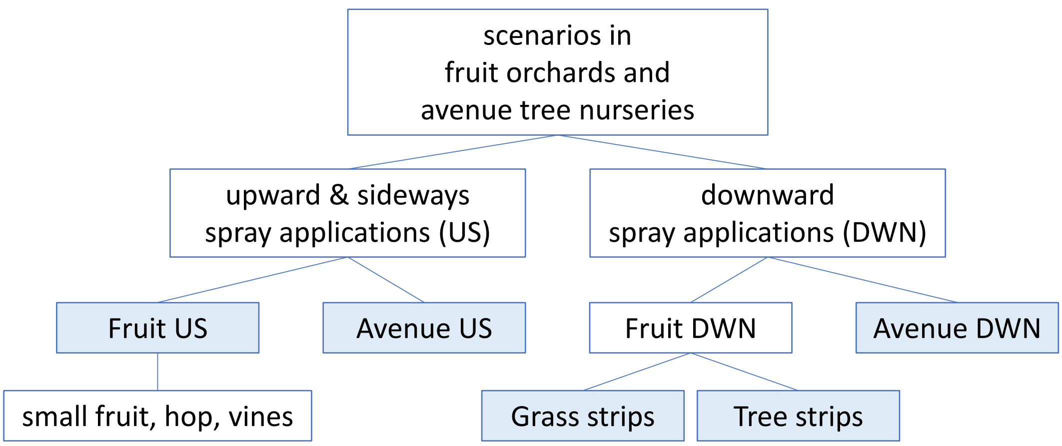

Figure 1 *Schematic layout of scenarios for spray applications in fruit orchards and avenue tree nurseries. The coloured blocks refer to the defined scenarios in this study.*

1.5 Structure of the report

Chapter 2 deals with the common cultivation practices of avenue trees in nurseries. Fungicide and insecticide spray applications towards the canopy of the trees (upward and sideways) and herbicide treatments (downward) onto the ground below the trees are described. Both conventional and drift-reducing application techniques are described as used in practice. The importance of drainage and irrigation is mentioned as well.

Similarly, Chapter 3 deals with the cultivation of pome fruit trees in orchards. This summarizes the most important aspects as given in Van de Zande et al. (2019). Regarding the goals of this report, the focus is on downward applications on grass strips and tree strips below the trees.

Chapter 4 deals with several aspects of the scenario development concepts. The basic structure is explained regarding the use of local spray drift models for countrywide exposure scenarios, which then were linked to scenarios for a selected spatial configuration. The incorporation of drainage as a complementary entry route next to spray drift is given also.

With Chapter 5 the details behind the spray drift computations are explained, including the description of countrywide scenarios, local scenarios for the selected watercourse and parameterisation of the xSPEXUS spray drift model, for the Avenue-US, Avenue-DWN and Fruit-DWN scenarios. The derivation and use of temporal percentiles are described.

In Chapter 6 the details of the drainage route are described. This requires dealing with aspects like interception by the crop and the use of spray dosage adjustment factors to compute drainage adequately.

Chapter 7 deals with the parameterisation of the fate model TOXSWA, specifically for the scenarios in this report.

Various example runs are elaborated extensively and discussed in Chapter 8.

The discussion follows in Chapter 9. Finally, conclusion and recommendations follow in Chapter 10.

2 Avenue tree nurseries

2.1 Cultivation

Tree cultivation in the Netherlands
The Netherlands has held a leading position in the world market for tree nursery products for years. Approximately 65% of the production is exported to more than 65 countries (Laanboompact, 2021). Characteristic of the tree cultivation are the wide range of products in concentrated locations of avenue tree nurseries (Figure 2). In the Boskoop area, the emphasis is on ornamental shrubs and conifers. Zundert has been the heart of the Dutch cultivation of woodland and hedge plants for years. Limburg (Lottum) and the northeast of Groningen are mainly known for roses and rose rootstocks. In North Brabant (Haaren, Zundert, Oudenbosch) and around Opheusden, mainly avenue, forest and park trees are grown (TCO, 2020). In Haaren, Oudenbosch and Zundert the nurseries are on sandy soils, while in the Opheusden area it concerns river clay soil (Maas & Van Reuler, 2008).

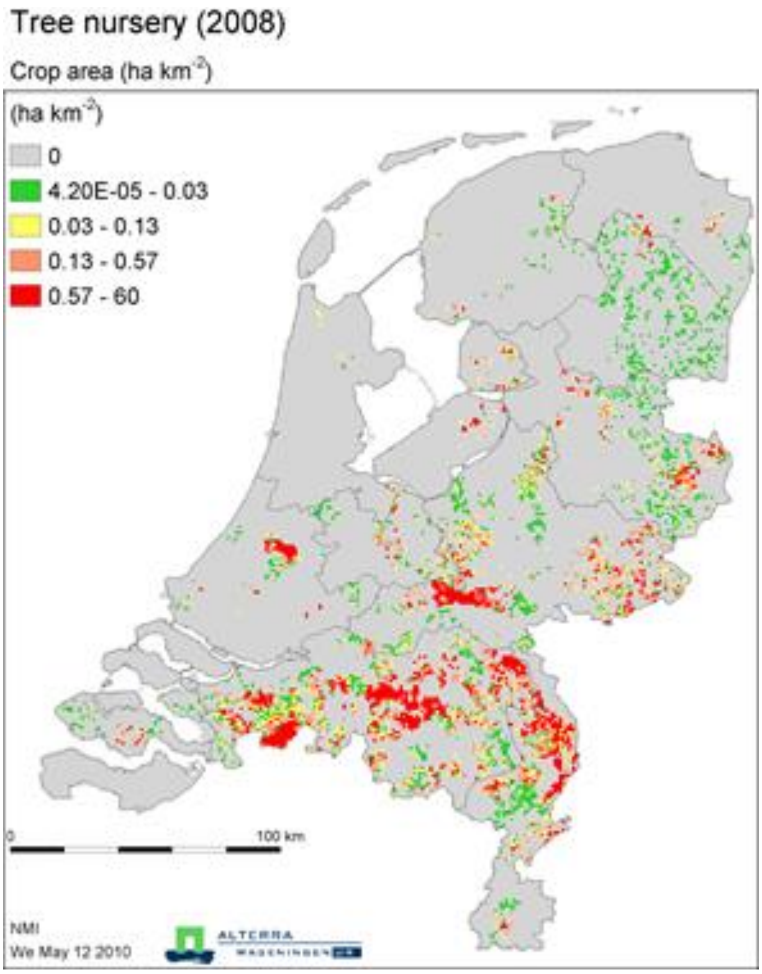

Figure 2 *Distribution of tree nurseries in the Netherlands (from: Kruijne et al., 2012).*

Avenue tree cultivation
There are about 150 avenue tree cultivation companies in the '*Rivierenland*' region, covering an area of about 1650 ha. The total area of avenue tree nurseries in the Netherlands is approximately 4750 ha, so approximately 35% of this area is located in the *Rivierenland* region (CBS, 2021; reference year 2020). The

size per company varies widely. In addition to many small companies (5-7 ha), a limited number of medium-sized (15 ha) to large companies (30-70 ha) occur.

Avenue trees are grown in three stages: spindle trees, transplanted trees and high trees (Figure 3). The cultivation of spindle trees is intensive and often takes place at specialized companies. With spindle trees, the lower trunk still has side branches. With transplanted avenue trees these lower branches are removed, leaving a crown on the tree. The transplanted avenue trees grow and become high avenue trees. In comparison to other tree nursery crops, the cultivation of transplanted and high avenue trees is relatively extensive.

The trees are planted in rows with a distance of approximately 1 m between the trees in a row. The distance between the rows of trees is about 1.5 m for spindle trees and 2.0 m for transplanted and high avenue trees. These paths allow access to the trees. The cultivation of avenue trees is usually carried out on bare ground. The soil is kept free from weeds by applying herbicides or mechanical weed control. Outside the last tree row, a crop-free zone with width of at least the interrow distance is present (i.e. the minimal agronomic crop-free zone, Table 5). At the headland more space is needed for turning the agricultural machinery; typically, a 5 m crop-free zone is present at the headland.

Figure 3 *Avenue trees in three stages, from left to right: spindle trees, transplanted trees (pruned lower branches and developing crown) and high trees (>5 m).*

In order to reduce the herbicide use, recently in few tree nurseries grass strips were sown similar to fruit tree cultivation (see Section 3.1). However, tree growth reduction was observed due to competition for water and nutrients (Sluis, 2014). Still, the use of grass strips in avenue tree nurseries is uncommon and not accounted for in the present scenarios.

Phenological development
For avenue trees, spring and summer bloomers can be distinguished (Goudzwaard, 2013). Spring flowering takes place in February-May and summer flowering in June-July. For many spring bloomers, seeds are produced in the period May-July, while for most summer bloomers this is in September-October. Hiemstra (2012) and Exterkate & de Beer (2010) mention that for avenue trees a distinction can be made between spring bloomers that blossom in the period March-May and summer bloomers that blossom in the period June-July. Some spring bloomers blossom before leaf development occurs (February-March or March-April). Some summer bloomers blossom until very late (July-September).

The '*Natuurkalender*' (nature's calender; www.naturetoday.com) gives the most complete picture of the phenological development of trees by making a distinction between leaf development, flowering, period of fruit ripening, full autumn colour and end of leaf fall. The data in the *Natuurkalender* were provided by volunteers who noted the development stages of the trees at several times during the year and reported their findings on the *Natuurkalender* website for various years. For a few of the most important nursery tree species, i.e. the tree species beech (Fagus), birch (Betula), oak (Quercus), alder (Alnus) and horse chestnut (Aesculus), an inventory has been made of the data mentioned for the various development stages from 2012 to 2016. The period of leaf development of these tree species is between March 3 and May 27 and the period of leaf fall is from September 15 to December 20. The flowering periods stated in the *Natuurkalender* correspond to those mentioned in Goudzwaard (2013), Hiemstra (2012) and Exterkate & de Beer (2010). The period that the trees are in leaf is broadly similar to that of fruit trees. Combining the information of the above-mentioned sources, Table 1 was compiled showing growth stage periods and the associated BBCH ranges for avenue trees.

Table 1 *Typical developments stages and corresponding BBCH codes and period of year for avenue trees.*

Development stage	**BBCH code**	**Period of year**
Leaf development	10 – 19	April, May
Flowering period	60 – 69	March - May
Fruits ripe / seed drop	81 – 89	September
Full autumn colour	91 – 96	October
End of leaf fall	97	November

2.2 Upward and sideways spray applications

Insecticide and fungicide spray applications in avenue trees are applied only when the trees are in full leaf, since trees are most vulnerable to attacks by insects and fungi during the growing season. A distinction is made between the three growth stages (spindles, transplanted and high avenue trees), where slightly different application equipment is used (Figure 4).

Figure 4 *Conventional spraying techniques in spindle and transplanted avenue trees (left & centre) and high avenue trees (right) (Van de Zande et al., 2019).*

The conventional application technique in spindles and transplanted trees involves an axial fan sprayer equipped with hollow cone nozzles (Albuz ATR yellow, 12 bar spray pressure). For spindle trees the applied spray volume is 400 – 550 L ha^{-1}; for transplanted trees this is 300 – 400 l ha^{-1}. Typical driving speed is 2.5 – 4.5 km h^{-1}. With high avenue nursery trees, the axial fan sprayer is equipped with different nozzles: hollow cone nozzles (TeeJet TXB8003, 8 bar spray pressure). The applied spray volume is 410 – 460 l ha^{-1} with a driving speed of 4.0 – 4.3 km h^{-1}. Spray drift experiments were carried out between 1996 and 2008 which involved the conventional application technique and several drift reducing techniques. Average downwind deposits of spray drift for the three growth stages are shown in Figure 5. Average environmental conditions for these experiments were a wind speed of about 2.5 m s^{-1}, wind direction perpendicular to the field edge and air temperature about 19ºC. Further details on these experiments and their results are given in Van de Zande et al. (2019).

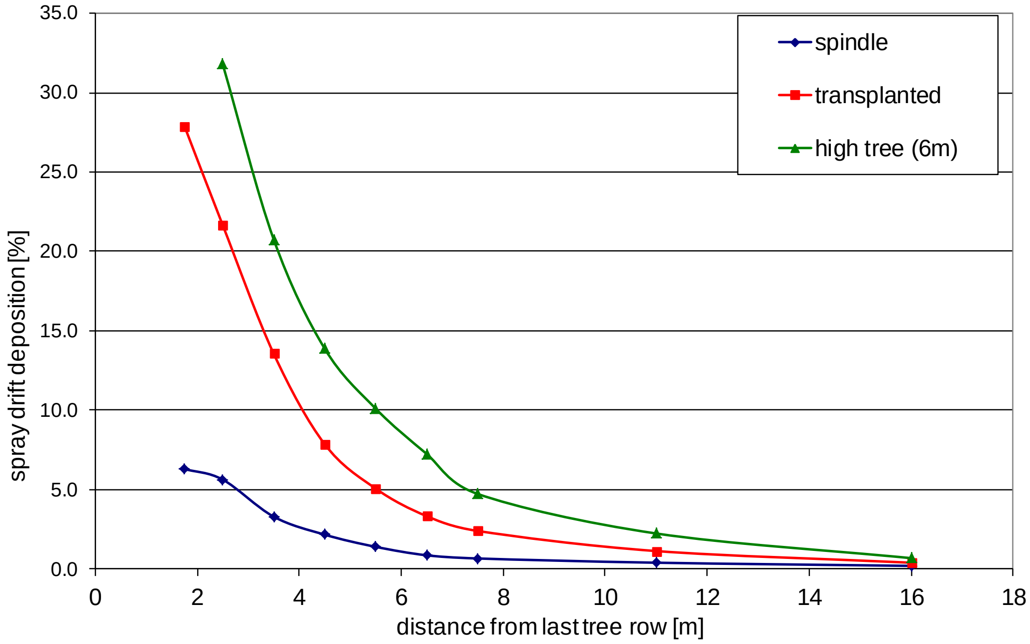

Figure 5 *Mean spray drift deposits (% of applied dose) as a function of distance downwind from last tree row, for conventional application techniques in spindles, transplanted and high avenue trees (Van de Zande et al., 2019).*

Several drift reduction techniques were evaluated. Table 2 lists the techniques and settings that were selected for classification DRT50, DRT75, DRT90 and DRT95. Note that not all classes are available for each tree type. While the application techniques for spindles and transplanted trees are similar, the corresponding downwind deposits of spray drift are not. This results in different drift reductions (see Section 5.1.1). Table 3 gives an overview of the available application techniques for spindles, transplanted and high avenue trees. Since January 2018 the Environmental Activities Decree (EAD; MinI&W, 2021) requires the use of at least a DRT75 application technique for all PPP applications in outdoor crops. However, for avenue tree nurseries there was a transitional period until January 2021 in which this requirement was not yet obligatory.

Table 2 *Selected application techniques for upward/sideways spraying in avenue tree nurseries; representatives for drift reduction classes 50%, 75%, 90% and 95% in the Netherlands (Van de Zande et al., 2019).*

Drift reduction class	**Spray drift reduction technology in drift reduction class [1]**	
	Spindles and transplanted trees	High trees
50% [2]	conventional sprayer with 50% drift reducing nozzles	mast sprayer with 90% drift reducing nozzles
75%	n/a	mast sprayer with standard nozzles, with gap-detection sensor
90%	conventional sprayer with 95% drift reducing nozzles	n/a
95%	n/a	mast sprayer with 90% drift reducing nozzles, with gap-detection sensor

[1] n/a = not available

[2] Environmental Activities Decree requires at least a DRT75 technique so DRT50 is not allowed since 2021.

Table 3 *Available classes of spray application techniques for upward and sideways applications in avenue tree nurseries[1].*

Orchard type	conventional	DRT75	DRT90	DRT95
High avenue trees	X	X		X
Transplanted trees	X		X	
Spindle trees	X		X	

[1] cells for technique classes that currently are not available are left empty.

Overview of current labels of authorised plant protection products
Avenue trees are only sprayed when they are in leaf and spraying is carried out after an infection has been observed or preventively. For fungicides and insecticides that are authorised for use in avenue trees, an inventory has been made of the growth stage in which these products can be used, the application time, the number of applications per cycle and the minimum interval in days between successive applications based on the pesticide label; see Table 4. Only products are considered that are approved as crop treatment, which means for upward and sideways applications.

Table 4 *Typical range of parameters regarding spray applications in avenue tree nurseries as can be found on pesticide labels.*

Description	Fungicides	Insecticides
Mentioned growth stages of application (BBCH code [1])	11 – 91	10 – 90
Time of application (months)	Jan – Dec	Jan – Dec
Number of uses (applications per year)	1 – 9	1 – 8
Minimum interval (days between applications)	5 – 21	7 – 21

[1] BBCH code is interpreted by the working group based on the phenological stage indicated on pesticide label.

Note that the application times do not always correspond to those of the stated BBCH ranges. This can be partly because the crop subgroup 'avenue trees' is embedded in the much larger group of tree nursery crops (in which both deciduous and evergreen crops can be present), which often are not indicated separately on the label. Therefore, care should be taken to draw conclusions on the period of the year as indicated on the label in relation to BBCH ranges for specifically the group avenue trees. For instance, some products can be used all year round (January – December) while also specific development stages are mentioned (e.g. BBCH 31-89; captan). So far, no relationship between DOY and BBCH was found for avenue trees in the literature.

Crop-free zones
According to the Environmental Activities Decree, since 1998 for all avenue tree nurseries the minimal crop-free zone is 5.0 m when an edge-of-field watercourse is present (measured from the centre of the last tree row to the slope of the adjacent watercourse). The minimal agronomic crop-free zones depend on tree type, see Table 5 for these distances.

Table 5 *Minimal agronomic crop-free zone (CFZ) for upward and sideways spray applications in avenue trees. EAD refers to Environmental Activities Decree.*

Orchard type	Min Agron CFZ [m]	Min CFZ, EAD requirement [m]
Spindle trees	1.5	5.0
Transplanted trees	2.0	5.0
High avenue trees	2.0	5.0

2.3 Downward spray applications

Spray drift experiments were carried out in 2010 and 2011 which involved the conventional application technique and several drift reducing techniques.

For downward spray applications in avenue tree nurseries, the standard application technique involves the use of a spray boom fitting just between the tree rows (Figure 6, left-hand side). Typically, the sprayer boom is 30 cm above the ground and the distance between the nozzles is 30 cm as well. The standard sprayer is supplied with Teejet XR11004 nozzles and a liquid pressure of 2.0 bar is used. Drift reducing techniques are available for DRT classes DRT50, DRT75 and DRT90 (Table 7). These drift reducing techniques involve the use of 50% and 90% drift reducing nozzles or shielding the sprayer boom (Figure 6, right), see Table 6 (Stallinga et al., 2012a, 2012b).

The downwind drift deposits are not affected significantly by the tree size. Therefore, the same drift curves and drift reduction curves can be used for spindles, transplanted trees and high trees. Also, for downward applications in fruit orchards the same application techniques are used.

Table 6 *Selected application techniques for downward spraying to the ground below avenue tree nurseries; representatives for drift reduction classes 50%, 75% and 90% in the Netherlands (Stallinga et al., 2012a, 2012b).*

Drift reduction class	Spray drift reduction technology in drift reduction class
	All avenue trees:
50% [1]	conventional sprayer with 50% drift reducing nozzles
75%	shielded weed sprayer, conventional nozzles
90%	conventional sprayer with 90% drift reducing nozzles

[1] since 2021 application techniques must be at least 75% drift reducing (EAD).

Figure 6 *Herbicidal spray application onto the ground below high avenue trees. Left: conventional application; right: shielded sprayer (DRT75).*

Table 7 *Available classes of spray application techniques for downward spray applications in fruit orchards and avenue tree nurseries [1].*

Orchard type	conventional	DRT75	DRT90	DRT95
Fruit orchards and all avenue tree nurseries	X	X	X	

[1] cells for technique classes that currently are not available are left empty.

The minimal agronomic crop-free zone is 1.5 m (spindles) or 2.0 m (transplanted and high avenue trees), yet according to the EAD at least a crop-free zone of 5.0 m must be used (Table 5, Section 2.2).

Additionally, a 0.5 m spray-free zone is accounted for in downward applications (Figure 7). In that case the last nozzle must be an end nozzle.

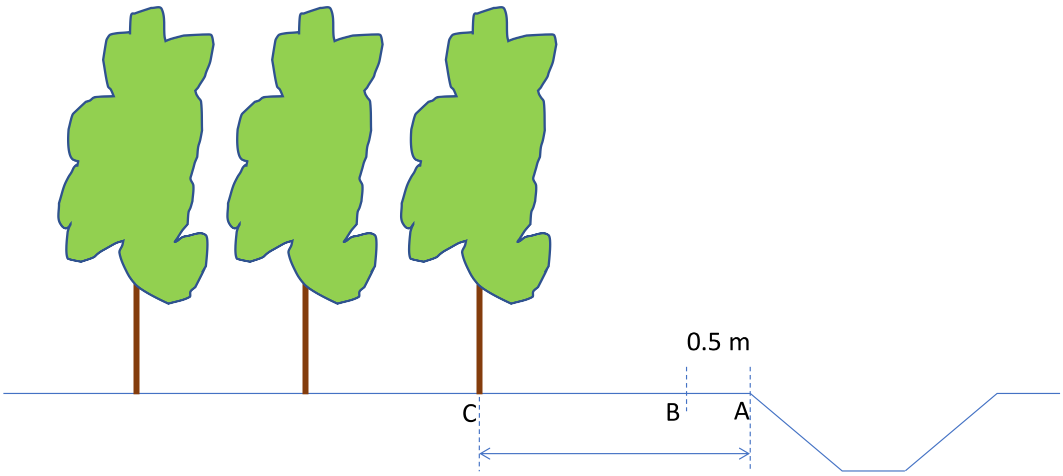

Figure 7 *Schematic layout of an avenue tree nursery; relevant positions for downward applications. According to EAD the crop-free zone (CA) must be at least 5.0 m. The outer 0.5 m edge (BA) is a spray-free zone in downward spraying.*

With upward and sideways spray applications, the use of crop-free buffer zones can be used as a mitigation measure. With downward spraying underneath avenue trees, a crop-free zone is irrelevant as the sprayed ground area remains the whole nursery except for a 0.5 m strip at the outer edge. However, instead a spray-free zone might be applicable. In such a case the spray edge (location B in Figure 7) shifts upwind and drift deposits on the waterbody's surface will decrease. Usually drift deposits on the waterbody's surface are very low with downward spray applications compared to those with upward and sideways spray applications. Therefore, an additional spray-free zone is not necessary with these downward spray applications.

Overview of current labels of authorised plant protection products

Herbicide treatments below avenue trees and fruit trees are carried out both preventively and curatively, i.e. after emergence of the weeds. For herbicides that are authorised for use below avenue trees and pome fruit trees, an inventory has been made of the growth stage in which these products can be used, the application time, the number of applications per cycle and the minimum interval in days between successive applications; see Table 8. Only products were considered that are approved at grass strips or tree strips in downward spraying.

Table 8 *Typical range of parameters regarding downward spray applications below fruit trees and avenue trees as can be found on pesticide labels.*

Description	Herbicides
Mentioned growth stages of application (BBCH code)	0 – 99
Time of application (months)	Jan – Dec
Number of uses (applications per year)	1 – 2
Minimum interval (days between applications)	5 – 28

While some PPPs could be used between January and December, other PPPs were only allowed in winter, spring or summer. Most PPPs are allowed only once per year.

Crop-free zones

According to the Environmental Activities Decree (EAD), spray treatments on grass strips or bare soil require a minimal crop-free zone of 0.5 m. Since in these cases no clear 'centre of last crop row' is defined, the crop-free zone is replaced by a spray-free zone of 0.5 m, measured between the edge of the sprayed area (defined as ½ nozzle distance outside the outmost spray nozzle) and the slope of the adjacent watercourse.

2.4 Drainage and irrigation

The growing of avenue trees in the Netherlands is capital-intensive and the growing occurs on one field (no rotation of crops). Therefore, installing a good drainage system is a useful investment for growers of avenue trees. It is estimated that around 30-50% of the avenue tree nurseries in the '*Rivierenland*' region are drained with drainpipes (Massop & Schuiling, 2016; CBS, 2014). These drainpipes are mostly located between 0.75 - 0.90 m below the soil surface. The distance between drainpipes is unknown (for fruit trees a distance of 10 m between drainpipes is common practice).

Irrigation of tree nursery via drip irrigation occurs once or twice in June/July and August for sandy soils. The total volume per irrigation event is 25 mm. In clayey soils the trees are irrigated once or twice in July and September with an average volume of 35 mm. This differs from fruit orchards for which the trees are sprinkled in March/April to prevent frost damage of the flower buds.

3 Fruit orchards

3.1 Cultivation

The cultivation and growing areas for fruit trees in The Netherlands is described in Van de Zande et al. (2019). A summary will be given in this section.

Fruit crops are grown in specific areas in the Netherlands (Figure 8). Total fruit crop area in the Netherlands is about 19900 ha with the main fruit crops apple and pear having a cropped area of 6200 ha and 10000 ha, respectively, in 2020 (CBS, 2021). Fruit crop growing is especially concentrated in the Betuwe, Zeeland, West-Friesland, South-Limburg and in the new polder areas Flevoland and Noordoostpolder.

Typically, for fruit orchards in the Netherlands the interrow distance is 3 m; within a row the spacing between the trees is 1 m. The trees strips are 1 m wide and the grass strips between the tree rows are 2 m wide (Figure 9). Outside the last tree row, a crop-free zone with width of at least the interrow distance is present (i.e. the minimal agronomic crop-free zone, 3 m). At the headland more space is needed for turning the agricultural machinery; typically, a 6 m crop-free zone is present at the headland of fruit orchards.

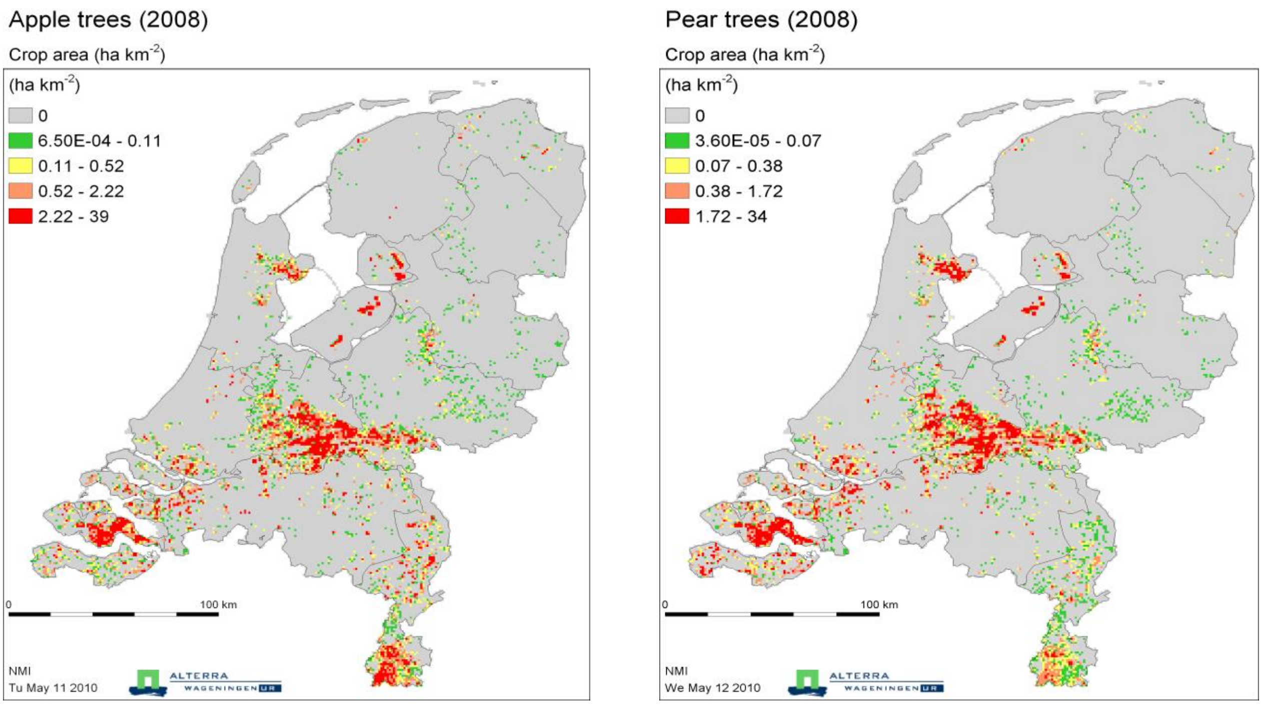

Figure 8 *Distribution of fruit crop area (apple, pear, 2008) in the Netherlands (from: Kruijne et al., 2012).*

Although the fruit crop area is relatively small in the Netherlands, locally the exposure of surface water to PPPs can be high as many spray treatments take place in apple and pear orchards. Typical application schemes for apple and pear in the Netherlands show that most PPPs are applied once per year, only a few PPPs are applied 2-3 times. However, the fungicide captan is applied 14-15 times per season from spring to autumn (Van de Zande et al., 2019).

3.2 Downward spray applications

No specific spray deposition experiments for herbicide treatments in fruit orchards have been carried out. In fact, downward spray applications below fruit trees and the resulting downwind drift deposits are very similar to applications below avenue trees. Therefore, the same drift curves and drift reduction curves can be used as with downward applications in avenue tree nurseries (Section 2.3). However, the presence of grass strips in between the tree rows is a clear difference, both for the applications and for the seepage processes. Therefore, for downward spray applications below fruit trees two cases are to be distinguished. The spray treatment can be applied to either the tree strips (bare soil strips underneath the trees) or the grass strips (strips between the rows, including the grass edges around the orchard). PPPs applied to the grass strip are partly intercepted by the grass, the generally used interception percentage is 90%; this agrees with EFSA (2014) that mentions the same interception percentage for permanent grass.

Figure 9 *Typical pome fruit orchard, showing rows of trees planted on bare soil (the tree strips) with grass strips in between.*

Figure 10 indicates how grass strips and tree strips are laid out in the orchard. The grass strips, represented by the green horizontal lines, cover the outer edge of the field and the strips in between the tree rows. The trees strips are located below the tree rows. For downward treatments a spray-free zone of 0.5 m must be taken into account at the outer edge of the field when an edge-of-field watercourse is present (zone A to B). For pome and stone fruit orchards, the minimal agronomic crop-free zone is 3.0 m.

For downward spray applications to the ground, this crop-free zone essentially is irrelevant, as the above-mentioned spray-free zone is to be dealt with. Still, the crop-free zone is relevant for the location of the tree strips relative to the field edge. This affects the downwind spray deposits slightly when tree strips are sprayed, and even less when the grass strips are sprayed; see also section 5.1.3.The drift curves and drift reduction curves are the same as those used for downward applications in avenue tree nurseries (see Section 2.3, Table 7). The EAD requires the use of at least a DRT75 application technique for all PPP applications in outdoor crops. Additionally, for fruit orchards the crop-free zone must be at least 4.5 m. However, when a DRT90 technique is used, the crop-free zone can be reduced to 3.0 m (EAD; MinI&W, 2021).

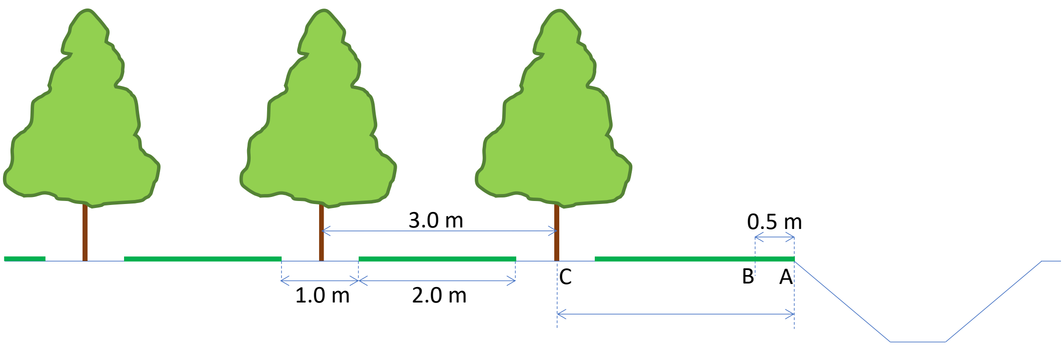

Figure 10 *Schematic layout of fruit tree orchards with tree strips and grass strips. Green horizontal lines at the bottom indicate the grass strips; the areas in between represent the tree strips. Zone AC is the crop-free zone. Typically, downward directed sprays are applied either on the tree strips or on the grass strips; zone AB is the spray-free zone with width 0.5 m.*

Overview of current labels of authorised plant protection products
Herbicide treatments below fruit trees are very alike the treatments below avenue trees. Often the same pesticides can be used, however some pesticides are intended for grass strips only while others are intended for the tree strips only. Therefore, in the inventory of authorised products, no distinction was made between products typically for use in pome fruit orchards and those used in avenue tree nurseries. The ranges given in Table 8 (Section 2.3) are valid for herbicide treatments in fruit orchards as well.

3.3 Drainage and irrigation

Drainage and irrigation were described before by Boesten et al. (2021). For convenience and clarity parts are repeated and summarized here.

Fruit orchards require a controlled groundwater level. Most of the fruit orchards in the Netherlands are therefore drained while using tube drainage, whereby the drainpipes are laid 0.8 – 1.2 m below the soil surface. Drained orchards can be found specifically in the Flevoland and the Noordoostpolder areas. The Betuwe area has less fruit orchards with drained fields. Calculations based on the spatially distributed fate model GeoPEARL show that around 78 percent of the Dutch fruit orchards are drained (Boesten et al., 2021).

For optimal yield of apples and pears Dutch farmers supply additional water by drip irrigation to avoid moisture stress. About 75% of Dutch fruit growers have irrigation systems in place for drip irrigation. Bal and Verhage (2011) indicated that the annual water need is between 36 – 147 mm (based on the total surface area of the orchard). In an average year the annual irrigation is typically 110 mm (personal communication M.P. van der Maas, 2019) which is added to the annual precipitation which is around 790 mm in the Netherlands. The irrigation is applied only to the tree strip which receives an annual irrigation of 330 mm whereas the grass strip between the tree rows is not irrigated. In addition to drip irrigation, water is supplied by sprinkler irrigation in case of night frost during the blooming period. According to Van der Maas (personal communication, 2020) this happens in 50% of the years with an average of three irrigations in the years that night frost occurs. About 20 mm is supplied per night.

4 Scenario concepts

4.1 General approach

The general approach to develop the scenarios presented in this report is similar to the approach carried out for upward and sideways (US) applications in fruit orchards (Boesten et al., 2021). Starting with a local model for downwind spray drift deposits, a countrywide exposure model was developed for drift deposits onto edge-of-field waterbodies. One of the local situations was selected and the predicted pesticide concentration in the selected ditch was compared to the countrywide predicted concentrations. For the local ditch a temporal percentile was derived that corresponded to the countrywide 90th percentile exposure level of pesticide concentrations in all edge-of-field watercourses. The drainage entry route was accounted for afterwards, similarly for atmospheric deposition. The following sections deal with each of these steps more thoroughly, covering the scenarios Avenue-US, Avenue-DWN and Fruit-DWN.

4.2 Spray drift

4.2.1 Local spray drift models

While for Fruit-US a sophisticated spray drift model (SPEXUS; Holterman et al., 2017) was developed, for upward and sideways applications in avenue tree nurseries no such model could be developed due to the limited amount of available data from drift experiments. Instead, curves were fitted to the average spray drift deposits and described by a mathematical function of downwind distance from the last tree row. Similarly, drift-reducing application techniques were described by fitted curves as well. Also, for downward spray applications in fruit orchards and tree nurseries the drift curves and drift reduction curves were established experimentally. These spray drift and drift-reduction curves are described in detail in Section 5.1.

Among the experiments, the environmental conditions varied only moderately. Therefore, the fitted curves can merely describe averaged spray drift deposits under common environmental conditions. The only environmental parameter that can be varied in the drift model is wind direction, which effectively leads to an increase of traveling distance of the drifting spray cloud when the wind direction deviates from a cross wind (see section 5.2.3). This causes spray drift deposits to decrease, even down to zero when the wind is blowing towards the crop (away from the ditch). Therefore, the wind direction is the most important environmental condition that drives spray drift deposition.

4.2.2 Countrywide spray drift simulations

Let us define a spraying scenario by a unique combination of the crop situation (fruit orchards; one of the three stages of avenue trees), spray application technique and crop-free zone. For each spraying scenario the spray drift simulations were carried out for many years and for all spatial configurations countrywide. This resulted in unique cumulative probability density functions (cpdf) of pesticide concentrations (PEC) in the edge-of-field watercourses. The 90th percentile (PEC_{90}) concentration was derived from these cpdfs. They correspond to the expectation values of the 90th percentile exposure level for each spraying scenario.

4.2.3 Selection of local configuration

In order to be able to evaluate the countrywide exposure concentration, a local configuration must be selected such that it can be used for the countrywide evaluation instead. The main area of the avenue tree nurseries in the Netherlands is found in the '*Rivierenland*' area (Annex 1), like fruit orchards. Therefore, it was decided to use for the avenue tree scenarios the same parameterisation of the hydrology of the scenario ditch as used for the fruit scenario. For Fruit-US this selection was carried out and resulted in the following configuration: a watercourse in the hydrological district *Rivierenland* (meteorological district *Herwijnen*), waterbody type *Betuwe stroomruggrond* (secondary waterbody, code 601002), at winter water level (0.30 m depth), with water surface width 2.34 m (Boesten et al., 2021); see Figure 11. For convenience and for robustness of the methods, the same local spatial configuration was selected for the Avenue-US, Avenue-DWN and Fruit-DWN scenarios.

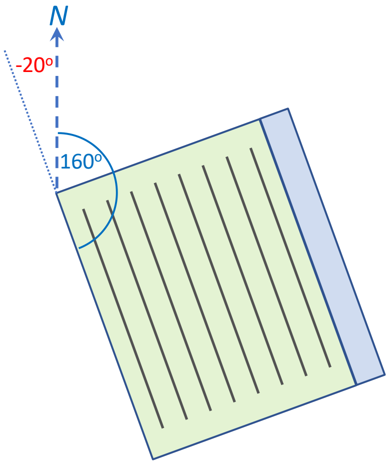

Figure 11 *Local configuration of selected waterbody (blue strip) at east side of an orchard (green field) which has tree rows oriented from approximate NNW to SSE (20º counter clockwise from north-south). This is the same configuration as used in fruit upward and sideways scenarios.*

4.2.4 Local spray drift simulations

Similar to the countrywide spray drift simulations, simulations were carried out for many years for the selected spatial configuration only (the 'local' situation). The resulting cpdfs of the local situation differ from the corresponding countrywide cpdfs. The countrywide PEC_{90}s were looked up in the local cpdfs, leading to a temporal percentile T_{90} for each spraying scenario. Thus, the other way round, if the local situation is studied with a certain spraying scenario for many years and the years are ranked according to increasing exposure level, the temporal percentile of the local situation corresponds to the same percentile of ranked years. Then the exposure level (PEC_{max}) of that year indicates the countrywide PEC_{90} without having to carry out countrywide simulations.

Details of the countrywide exposure model are given in Section 5.2. and more specifically for the Avenue-US, Avenue-DWN and Fruit-DWN in Sections 5.3, 5.4 and 5.5, respectively.

The method was developed for Fruit-US (Boesten et al, 2021) and applied in this study as well. However, it can only be used when the countrywide PEC_{90} concentration does occur in the local watercourse. In fact, the above-mentioned local watercourse (Figure 11) was selected just that way. Unfortunately, for Avenue-US and the downward scenarios the range of pesticide concentrations in the local watercourse did not always cover the corresponding countrywide PEC_{90}. The latter was often higher than the maximum concentration in the local watercourse. To be able to use the same selected watercourse, the local drift values were increased by a factor such that the temporal percentile of the (enhanced) local situation corresponded to the countrywide PEC_{90}. This method is described in section 5.2.5. For a justification of the method see Discussion (Chapter 9).

4.3 Drainage

4.3.1 Upward and sideways applications in fruit orchards, a review

Tiktak et al. (2012a) and Boesten et al. (2021) described a procedure for selecting a drainage scenario for arable soils and fruit orchards, respectively, based on data from the Andelst field site (Scorza Júnior et al., 2004). At this site sufficient data is available to parameterise and test the PEARL model including the effect on pesticide leaching of macropores. The advantage of taking a real site is that full benefit can be taken from the experimental data, so that a consistent and credible exposure scenario can be build.

The Andelst field site dataset and the corresponding parameterised PEARL model was derived for an arable crop. Crop specific properties in the model including irrigation and interception had to be changed to reflect fruit orchards instead of arable crops. Moreover, a grass strip and the fruit strip were parameterised to reflect heterogeneity of management practices in fruit orchards (see also Section 3.2). This fruit orchard specific drainpipe scenario was run for a 15-years period which resulted in a temporal frequency distribution consisting of 15 annual maximum concentrations for a range of model substances. From this frequency distribution, one annual maximum concentration was selected to be the endpoint of the drainage exposure assessment. The selection was done based on a comparison with outcomes of the spatially distributed model GeoPEARL. The selected year was the 63rd percentile year (Tiktak et al., 2012a).

In Dutch fruit orchards, apple trees are commonly grown in rows at a distance of 3 m between the rows (Section 3.1). Tree strips are 1 m wide and grass strips are 2 m wide (Figure 10). Thus, the tree strips cover 1/3 of the fruit orchard area and the grass strips cover 2/3 of that area. The pesticide emission via drainpipes was simulated for tree strips and the grass strips separately. The dosage specified on the pesticide label is however valid for the whole orchard (both tree strips and grass strips are included). To account for the pesticide mass deposited on the tree strip (1/3 of the area) and the grass strip (2/3 of the area) specific dosage adjustment factors and crop interception fractions were determined.

For calculating the exposure via drainage two types of contributions are computed, one assuming that the whole area is covered with trees and the second assuming that the whole area is covered with grass. Afterwards, the drain water flow and solute fluxes in drain water of both contributions are combined while weighting according to the actual areal factors for tree strips (1/3) and grass strips (2/3).

4.3.2 Upward and sideways applications in avenue tree nurseries

The parameterisation of the drainpipe emission for fruit orchards (Section 4.3.1) was also used for avenue tree nurseries. The reason was pragmatic, i.e. to prevent having to carry out another model parameterisation. Only the crop interception factors were changed. The approach taken was that the drainpipe scenario should be protective for avenue trees, and hence it was accepted that the exact percentile remained unknown as long as it is larger than or equal to the PEC_{90}. The rationale is described in Section 6.1.

Avenue trees are commonly grown in rows at a distance of 1.5 or 2 m and all soil below and between avenue trees remains generally bare (Section 2.1). To be able to use the fruit orchard parameterisation for the calculation of emission from drainpipes for avenue tree nurseries, it is necessary to calculate the exposure contribution for both the full tree strip soil area and the full grass strip soil area. Since there is no grass below avenue trees, in fact the second case with the full grass strip area is a special case of full tree strip (bare soil) area. This requires an appropriate adjustment of dosage and interception such that the correct deposition on the soil is simulated. This was elaborated in Section 6.2.

4.3.3 Downward applications

For downward applications in avenue tree nurseries, the same procedure as given above was followed. Clearly, dosages and interceptions are to be adjusted accordingly. See Section 6.3 for details.

For downward applications in fruit orchards, the original approach of Fruit-US was applied (see above), with separate calculations for tree strips and grass strips. The appropriate dosage adjustment factors and interception factors are described in Section 6.4.

4.4 Combination of spray drift and drainpipe emission

For both entry routes, spray drift deposition and drainpipe emission, a methodology to derive PEC_{90} was developed, while using the same selected spatial unit. However, the spray drift scenario did not explicitly consider the contribution of the drainage and vice versa, i.e. in determining the temporal percentiles for drift deposition only drift was considered as entry route and for the temporal percentiles of drainage only the drainage was considered. The separate spray drift and drainage scenarios have different temporal percentiles. For Fruit-US a protocol was developed to select a temporal percentile when both spray drift and drainage are considered as entry routes; this protocol is described in detail in Boesten et al., 2021. The concepts of that protocol are used here as well. The protocol results in a temporal percentile that considers both drift and drainage and their relative importance as exposure routes. The result yields a protective and moderately conservative PEC_{90}.

The protocol offers a simple and practical solution. Basically, if spray drift is the major entry route in the simulation, the temporal percentile for drift is used. If drainage is the major entry route, the temporal percentile for drainage is to be used. If both contributions may play a role, the maximum of both temporal percentiles is taken (as a conservative approach). To decide which route is dominant, in a multi-year (N years) scenario simulation the annual PEC_{max} values are estimated together with the major entry route leading to those PEC_{max} values. While spray drift occurs within the hour of spray application, a drainage events can last for several hours. Therefore, the protocol considers a 24-hour average for drainage on the date at which the PEC_{max} occurs. If the contributions of both routes to PEC_{max} is almost the same (their ratio is between ½ and 2), then the dominant route for that year is undecided. Next, the number of years for which spray drift is dominant (N_{sd}) and for which drainage (N_{dn}) is dominant are counted separately. If $N_{sd} \geq 2/3$ N, then the T_{90} that belongs to the drift scenario is selected; if $N_{dn} \geq 2/3$ N, then the T_{90} that belongs to the drainage scenario is selected (N.B. this always is 63%; Section 4.3.1); in all other situations no clear dominance of one route can be established and the maximum T_{90} of both routes is selected.

In case of just one spray application per year, in a significant number of years the wind direction is such that the spray drift contribution is zero anyway, so it can be expected that the number of drainage dominant years is relatively large. In that case the above criterion for N_{dn} appears not statistically justified. Changing the drainage criterion to $N_{dn} \geq 2/3 N + 1$ (i.e. adding 1) appears sufficient for common values of N (between 10 and 30).

See also Boesten et al. (2021) for further details on the protocol.

4.5 Atmospheric deposition

Atmospheric deposition may be relevant for volatile substances. As a first estimate, and hence first tier, the approach as used by Tiktak et al. (2012a) and FOCUS (2008) will be applied in the same way as proposed by Boesten et al. (2021). The contribution of atmospheric deposition is considered as additional to the spray drift deposition and the drainpipe emission and will be added for each spray application independent of the weather conditions and timing.

The proposed atmospheric deposits as percentage of the applied dose are given in Table 9. For substances with a very high vapour pressure, i.e. larger than 10^{-2} Pa, it is recommended to use expert knowledge. The atmospheric deposition is considered to take place within 24 hours after a spray application. The FOCUS-Air deposition values for arable crops are used that are considered to deposit at a distance of 1 m from a wind tunnel. For upward and sideways spraying in fruit orchards and tree nurseries, the values for application to the plant are multiplied by a factor 2 to account for the difference between atmospheric deposition from fruit orchards or avenue tree nurseries with respect to arable crops. This is in line with recommendations in FOCUS (2008). For downward spraying onto grass strips (fruit orchards) the data for 'plant' are used, while for spraying onto bare soil (below avenue trees or tree strips below fruit trees) the last column of Table 9 is used.

Table 9 *Percentage of the dose that is considered to deposit on the ditch water surface in 24 hours after application. Values are based on the recommended values as provided in FOCUS (2008) and Tiktak et al. 2012a (for the last row).*

Range of vapour pressure	Application to the plant [1] (arable crop)	Application to bare soil
VP < 10^{-5} Pa	0	0
10^{-5} Pa < VP < 10^{-4} Pa	0.09	0
10^{-4} Pa < VP < 5 10^{-3} Pa	0.22	0.22
5 10^{-3} Pa < VP < 10^{-2} Pa	1.56	1.56
10^{-2} Pa <VP	Expert judgement	Expert judgement

[1] for upward and sideways applications in fruit orchards and avenue tree nurseries these values are multiplied by 2

4.6 Fate in the watercourse

For the avenue tree scenarios the same type of watercourse was selected as for the fruit orchard scenario, i.e. a secondary edge-of-field ditch of the hydrotype '*Betuwe stroomruggronden*' (see Section 4.2.3). So the same parameterisation could be used for the hydrology of the selected watercourse. More details on the hydrology of the selected watercourse are provided in Section 7.1.

Simulations of hydrology and fate and behaviour of the pesticide in the ditch are done over a ditch length of 300 m. However, the 100 m part in the centre of this 300 m long ditch is considered in the exposure assessment. This 100 m of ditch is affected by pesticides used in a field of 1.4 ha. The endpoint of the exposure assessment is the calculated PEC averaged over the so-called target stretch, i.e. the centre 100 m part of the 300 m long ditch.

5 Spray drift

This chapter deals with the details of the spray drift simulations. The local spray drift curves and drift-reduction curves are described in Section 5.1. The basics of the implementation of the spray drift model in the countrywide scenarios is described in Section 5.2. Specific implementations for avenue upward and sideways applications and for the downward applications with avenue trees and fruit trees are dealt with in subsequent sections (5.3, 5.4 and 5.5).

5.1 Local spray drift models

5.1.1 Spray drift curves for upward and sideways applications

Previously, for upward and sideways (US) spray applications in fruit orchards, the SPEXUS model has been developed based on an extensive database of experimental data (Holterman et al., 2017, 2018). For upward and sideways spray applications in avenue tree nurseries, the amount of available experimental data on downwind drift deposits was much less. Consequently, the spray drift model as developed for avenue tree nurseries is less complicated and is based on a set of 'drift curves' describing downwind deposits of spray drift as a function of distance from the last tree row. These drift curves are mathematical descriptions of best fitting curves for the experimental data. There are separate drift curves for spindle trees, transplanted trees and high avenue trees, for conventional spray applications and various drift reducing techniques. Table 3 in Section 2.2 shows the current set of application techniques for which spray drift curves are available.

Spray drift measurements in these three stages resulted in different downwind deposits of spray drift, with lowest deposits in the spindles stage and highest deposits in the third stage. Although for the different tree types in US scenarios different drift curves were determined, all drift curves follow the same mathematical expression for conventional application techniques (Holterman & van de Zande, 2021):

$$y = (A_0\, e^{-A_1 x} + B_0\, e^{-B_1 x})/(1 + C_0\, e^{-B_1 x}) \qquad (1)$$

where y are the deposits (usually given as percentage of the applied dose) and x is the distance downwind from the centre of the last tree row. A_0 through C_0 are constants depending on tree type. These constants are given in Annex 7 for the reference application techniques in avenue tree nurseries. Figure 12 shows the spray drift results from measurements (dots) together with fitted curved (lines), based on Eq.(1).

The drift curves for drift reducing application techniques were obtained by multiplying the drift deposits from the conventional application by a drift reduction factor. The drift reduction factor R is a function of downwind distance as well. The following equation was fitted to the experimental drift reduction factors, leading to drift reduction curves with distance (Holterman & van de Zande, 2021):

$$R = P_0\, e^{-P_1 x} + Q_0\, e^{-Q_1 x} + S_0 \qquad (2)$$

where R is the relative drift reduction, a value between 0 (no reduction) and 1 (complete reduction; zero drift deposits). The constants P_0 through S_0 depend on tree type and application technique. Their values are given in Annex 7. Mathematically, depending on the value of the constants, R might take values outside the range 0 through 1 for certain distances. In those cases, R is assumed to take the corresponding boundary value (0 for $R<0$ and 1 for $R>1$). Effectively, this means that drift reductions should be physically realistic ($R\leq1$) and drift reducing techniques are assumed to never enhance drift deposits compared to the conventional application technique ($R\geq0$). In the scenarios in this report, the situation with $R>1$ never occurred, while $R<0$ only occurred occasionally for very short distances (irrelevant for deposits onto edge-of-field watercourses) and in a few cases with wind directions almost parallel to the field edge. The latter cases correspond with relatively low spray deposits which do not affect the determination of PEC_{90}.

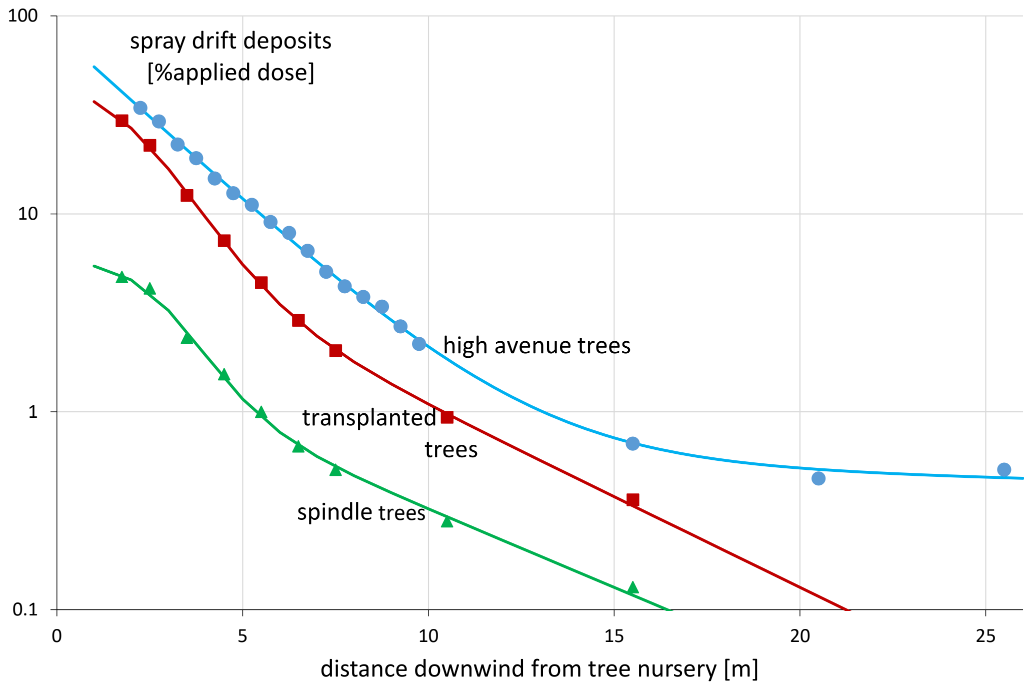

Figure 12 *Downwind deposits of spray drift next to avenue tree nurseries as a function of distance from the centre of the last tree row, for the reference application technique. Dots: measured deposits; solid lines: fitted curves based on Eq.(1).*

For each group of avenue tree nurseries several drift reducing techniques have been evaluated, Table 3 in Section 2.2. Measured drift reductions and fitted curves, using Eq.(2), are shown in Figure 13, Figure 14 and Figure 15 for high avenue trees, transplanted trees and spindles, respectively. The measurements are represented by the dots and connected by dotted lines, showing that these are slightly erratic, mainly due to the limited number of experiments available. The bars indicate the standard errors of means for each dot in the graphs. These standard errors considered in estimating the best fitting curves (measured deposits with a smaller error were fitted more closely that those with a larger error). The given reduction curves represent actual drift reductions sufficiently well. Figure 13 shows that for high avenue trees the drift reduction curve of DRT75 crosses the DRT50 curve at about 7.5 m from the last tree row. This is directly linked to the actual application techniques selected for these DRT classes (see Table 2 in Section 2.2).

The drift curves for conventional applications (Figure 12) can be combined with the reduction curves (Figure 13, Figure 14, Figure 15) to yield the actual drift curves for all application techniques. These are shown in Figure 16, Figure 17 and Figure 18 for high avenue trees, transplanted trees and spindle trees, respectively. In these graphs the dotted lines indicate the measured spray deposits, while the smooth fitted lines were computed by multiplying Eq.(1) by 1-R (where R is given by Eq.(2)).

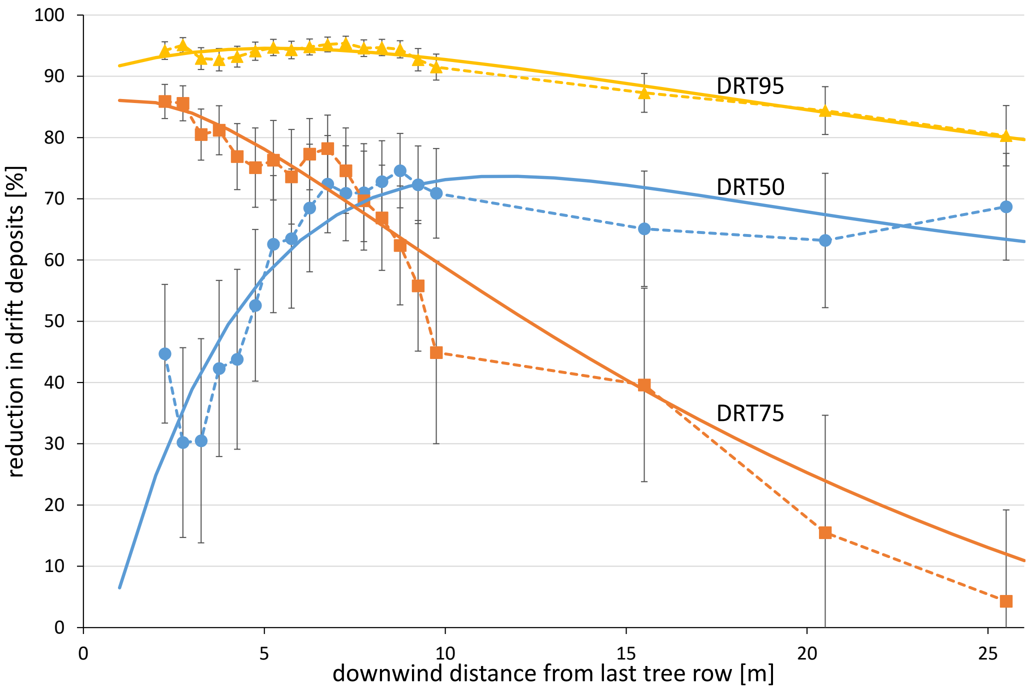

Figure 13 *Spray drift reduction curves as a function of downwind distance from last row of high avenue trees; measured reductions (dots) and fitted curves (solid lines; Eq.(2)); for drift reducing techniques DRT50, DRT75 and DRT95. Bars indicate the standard error of means in the experimental data.*

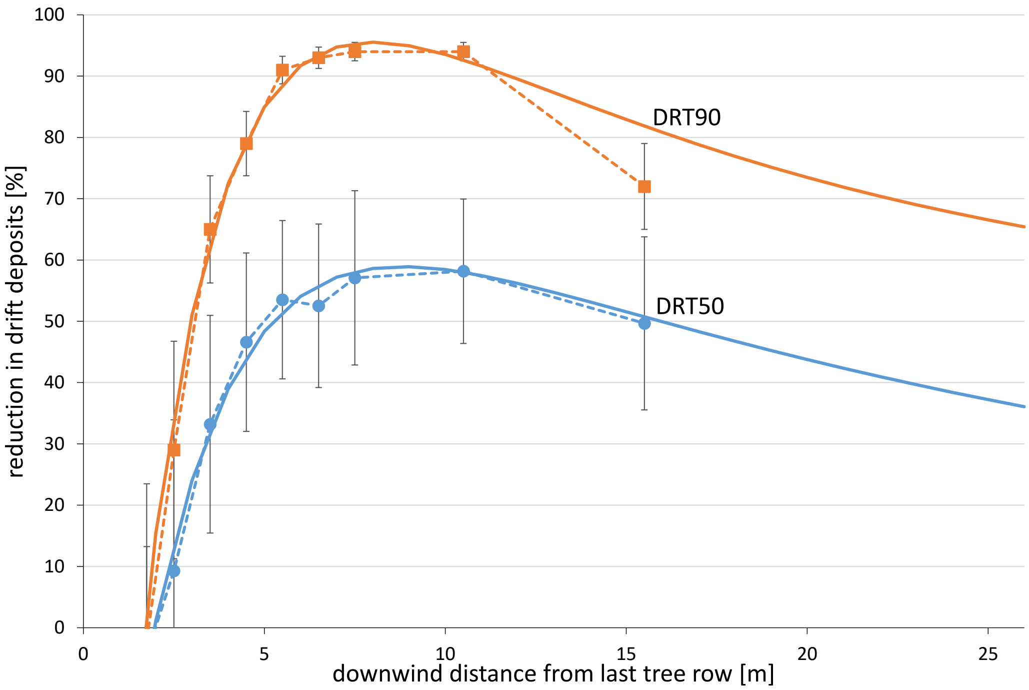

Figure 14 *Spray drift reduction curves as a function of downwind distance from last row of transplanted avenue trees; measured reductions (dots) and fitted curves (solid lines; Eq.(2)); for drift reducing techniques DRT50 and DRT90. Bars indicate the standard error of means in the experimental data.*

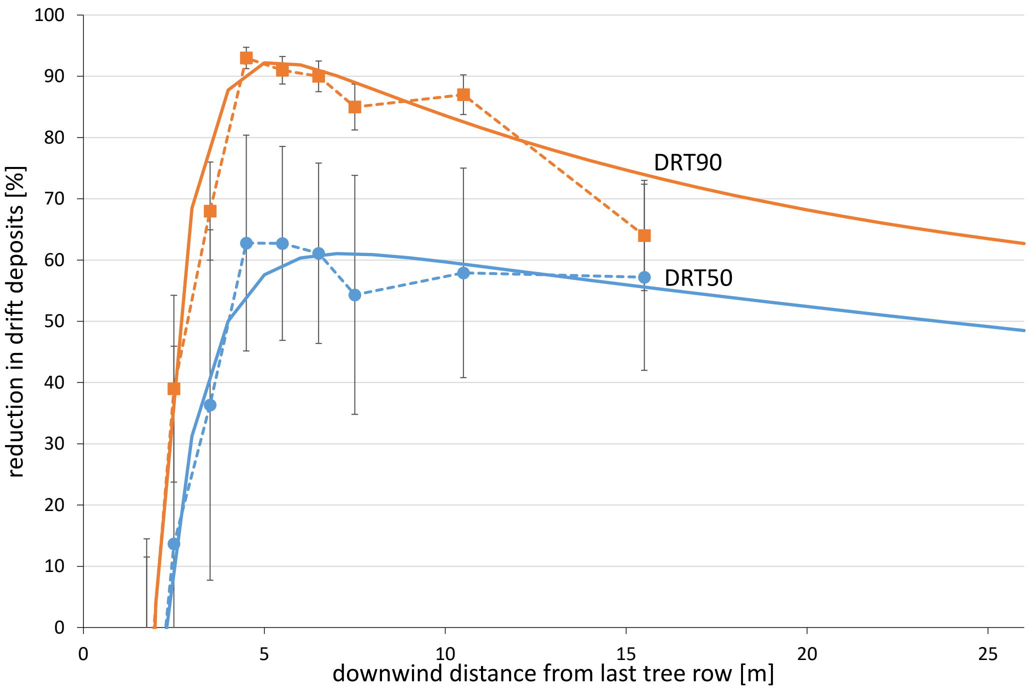

Figure 15 *Spray drift reduction curves as a function of downwind distance from last row of spindle avenue trees; measured reductions (dots) and fitted curves (solid lines; Eq.(2)); for drift reducing techniques DRT50 and DRT90. Bars indicate the standard error of means in the experimental data.*

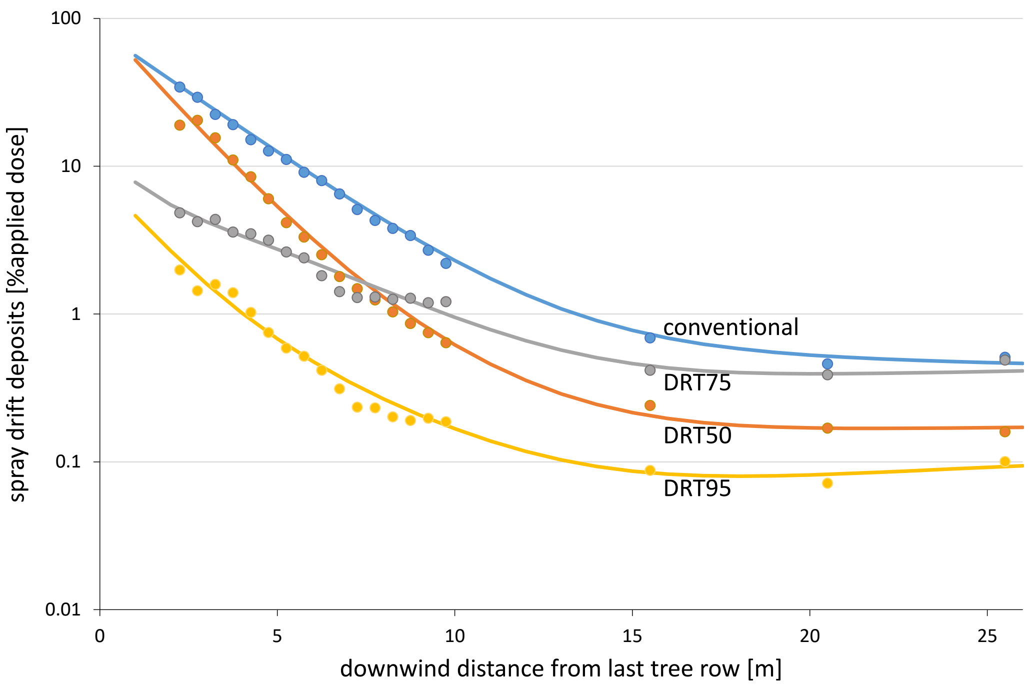

Figure 16 *Downwind deposits of spray drift for high avenue trees, upward and sideways spray applications, as a function of distance from the last tree row. For conventional and drift reducing application techniques. Dots: measured deposits. Solid lines: for conventional application: curve fitted using Eq.(1); for drift reducing techniques: combining the conventional drift curve and the drift reduction curves of Figure 13.*

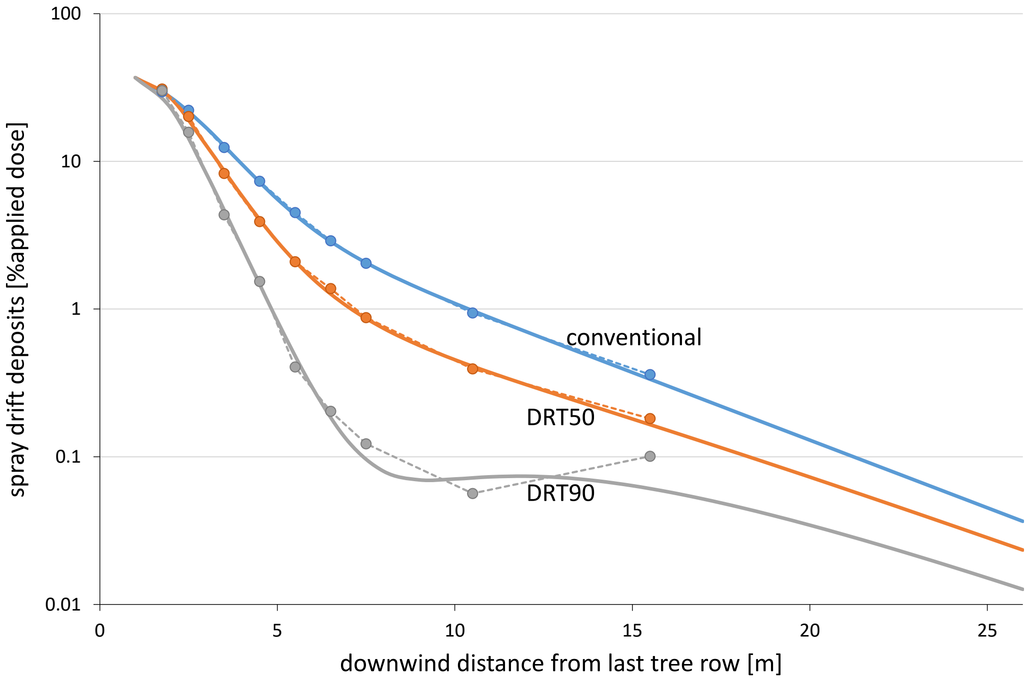

Figure 17 *Downwind deposits of spray drift for transplanted avenue trees, upward and sideways spray applications, as a function of distance from the last tree row. For conventional and drift reducing application techniques. Dots: measured deposits. Solid lines: for conventional application: curve fitted using Eq.(1); for drift reducing techniques: combining the conventional drift curve and the drift reduction curves of Figure 14.*

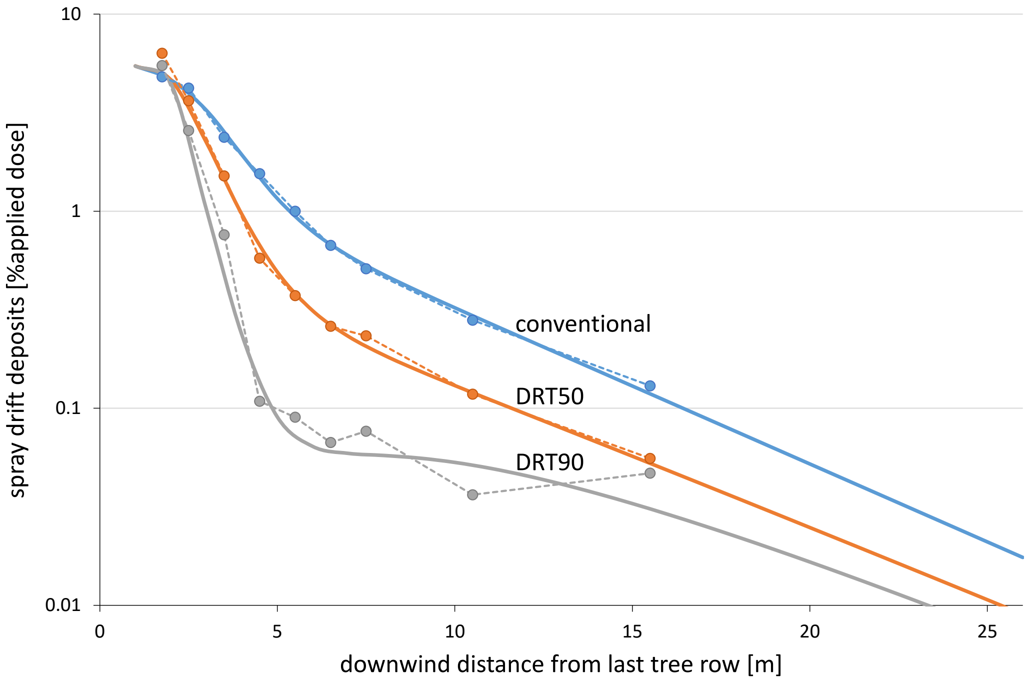

Figure 18 *Downwind deposits of spray drift for spindle trees, upward and sideways spray applications, as a function of distance from the last tree row. For conventional and drift reducing application techniques. Dots: measured deposits. Solid lines: for conventional application: curve fitted using Eq.(1); for drift reducing techniques: combining the conventional drift curve and the drift reduction curves of Figure 15.*

The fitted drift curves and drift reduction curves were obtained from experimental drift measurements. Therefore the fitted curves describe the situation with average environmental conditions as occurred during the experiments, which were representative from a wind speed of about 3 m s^{-1} and a wind direction within

±30° from perpendicular to the field edge. This implies that the given fitted drift curves cannot be used to investigate the effect of environmental variables (such as wind speed, temperature, humidity). However, the effect of wind direction on downwind drift deposits is implemented relatively easily. Any wind direction θ deviating from perpendicular to the edge of the field will lead to a longer distance the droplets have to travel through air before reaching the edge-of-field watercourse. In can be shown that the effective distance travelled is increased by a factor 1/cos θ, so any distance x in Eqs.(1), (2) and in the next section Eq.(3) must be multiplied by this factor. This is described in detail in Section 5.2.3.

Since the drift curves were derived from a collection of spray drift experiments with the wind direction arbitrary within the range -30 to +30°, the averaged drift deposits were slightly lower than when the wind direction would have been exactly perpendicular to the field edge. It was estimated that drift deposits for an exactly perpendicular wind direction were about 10% higher than the experimentally averages (Holterman et al., 2021). Therefore in the spray drift model an adjustment factor 1.1 was used on for all computed drift deposits.

5.1.2 Spray drift curves for downward applications

For downward spray applications underneath fruit trees or avenue trees, a similar procedure was followed. From the available experimental data a set of drift curves was derived. In fact, the process of spray drift with these downward applications was not affected significantly by the presence of the trees in the orchard or nursery. This means that for fruit orchards and the three avenue tree nursery types the same set of drift curves could be used. Additionally, the available drift reducing techniques resulted in different drift reduction curves, yet again irrespective of the tree type (fruit trees or all avenue tree types). Table 7 in Section 2.3 shows the current set of application techniques for which spray drift curves were determined. The drift curve for conventional spray application is given by:

$$y = A_0\,(x + C_0)^{A_1} + B_0\,(x + C_0)^{B_1} \qquad (3)$$

where y are the downwind spray deposits (as percentage of the applied dose) and x is the distance downwind from the edge of the sprayed ground area (typically 0.5 m inside the field boundary, Figure 7). A_0 through C_0 are constants which are independent of the tree crop. So there is just one set of constants for all avenue tree types and for fruit trees as well. Note that this equation differs from Eq.(1) for upward and sideways applications, since Eq.(3) gave a better fit of the experimental drift data. The constants are given in Annex 7 for the reference application technique.

For the drift reduction curves in downward spray applications, Eq.(2) was used, as with upward and sideways applications. Clearly, different constants should be used, see Annex 7. Figure 19 shows the drift reduction curves of DRT50, DRT75 and DRT90 for downward spray applications in avenue tree nurseries. Figure 20 shows the downwind deposits of spray drift for downward applications below avenue trees. The drift curve on top represents the conventional application (Eq.(3)), while the other curves represent the drift-reducing techniques; these are computed as the product of the conventional drift deposition curve (i.e. the top curve) and the drift reduction curves of Figure 19 (or actually using 100% minus the drift reduction).

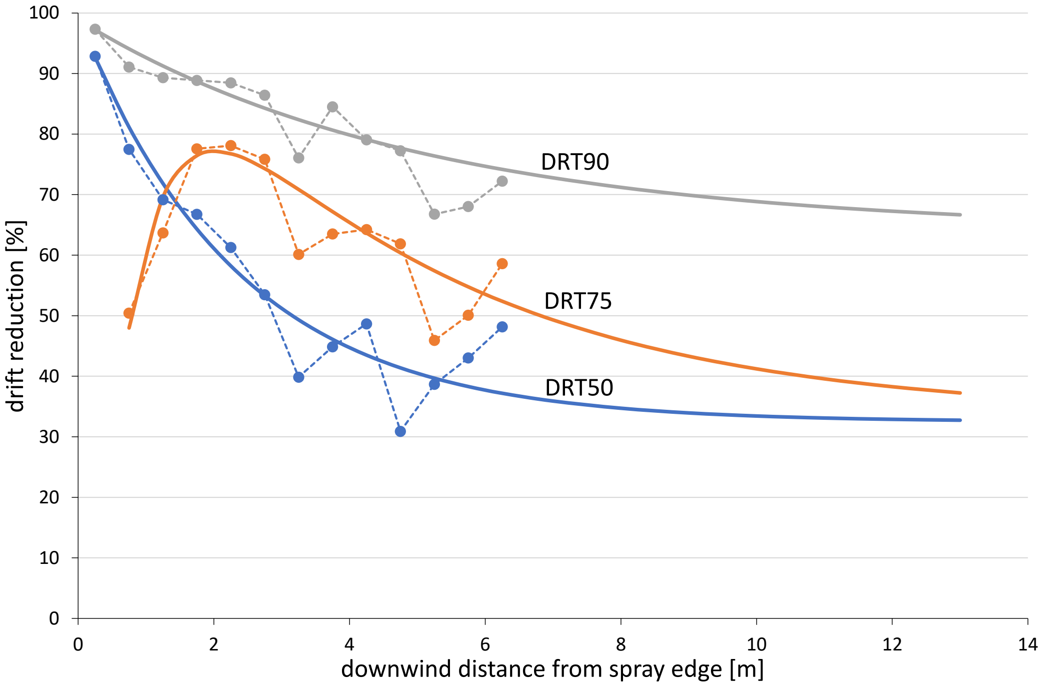

Figure 19 *Drift reduction curves for downward applications in avenue tree nurseries, as a function of distance from the edge of the treated ground area. Note that the field edge is located 0.5 m downwind from the treated area. Dots: measured drift reductions. Solid lines: fitted drift reduction curves obtained using Eq.(2).*

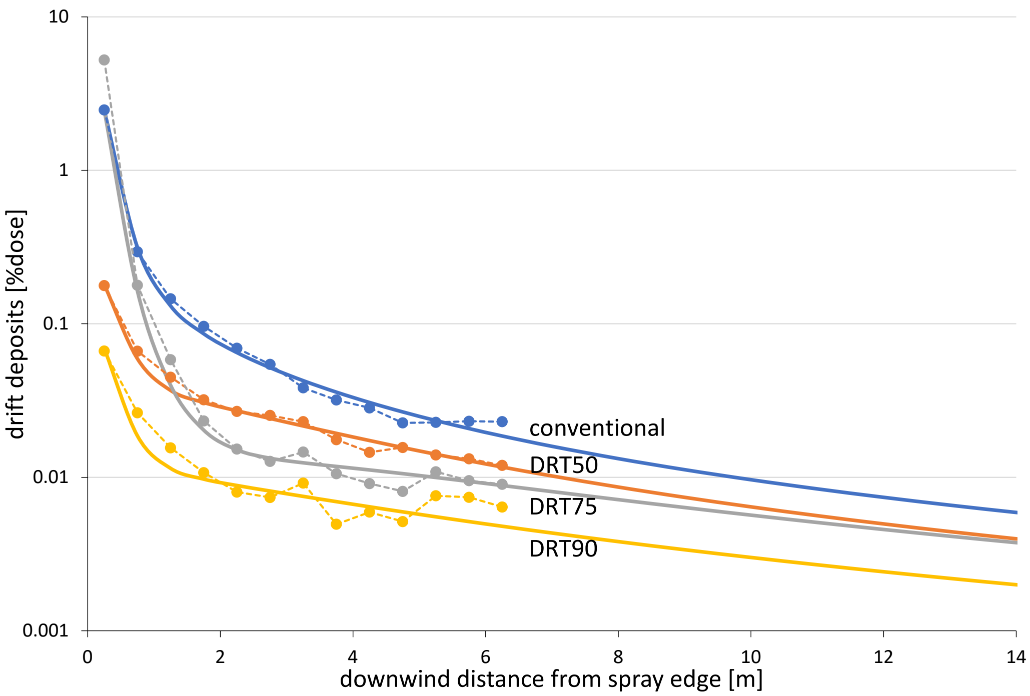

Figure 20 *Downwind deposits of spray drift for downward directed spray applications below avenue trees in a nursery, as a function of distance from the edge of the treated ground area. For conventional and drift reducing application techniques. Dots: measured deposits. Solid lines: for conventional application: curve fitted using Eq.(3); for drift reducing techniques: product of conventional drift curve and the drift reduction curves of Figure 19.*

5.1.3 Tree strips and grass strips in fruit tree orchards

For spray drift calculations when spraying tree strips or grass strips below fruit trees, the same drift curves apply as with downward spraying underneath avenue trees (Section 5.1.2, Figure 19, Figure 20). However, since not the whole ground area is treated, the net spray drift will be lower than with a full ground treatment. The effective spray drift can be calculated by assuming a full ground treatment and subtracting the spray drift from the unsprayed strips. The method is explained in the following paragraphs.

Figure 21 indicates how grass strips and tree strips are laid out in the orchard. The grass strips (green lines) are located from A (the field edge) to x_1, x_2 to x_3, x_4 to x_5 and so on. The tree strips are the areas in between: x_1 to x_2, x_3 to x_4 and so on. Zone A-B is the spray-free zone of 0.5 m at the field edge. The edge strip A-C represents the minimal agronomic crop-free zone. Note that x_1-C is half the width of a tree strip, which usually is 0.5 m (the typical tree strip width is 1.0 m, see Section 3.2). The first grass strip where spray is applied ranges from B to x_1, having a width that is 2x0.5 m narrower than the crop-free zone A-C.

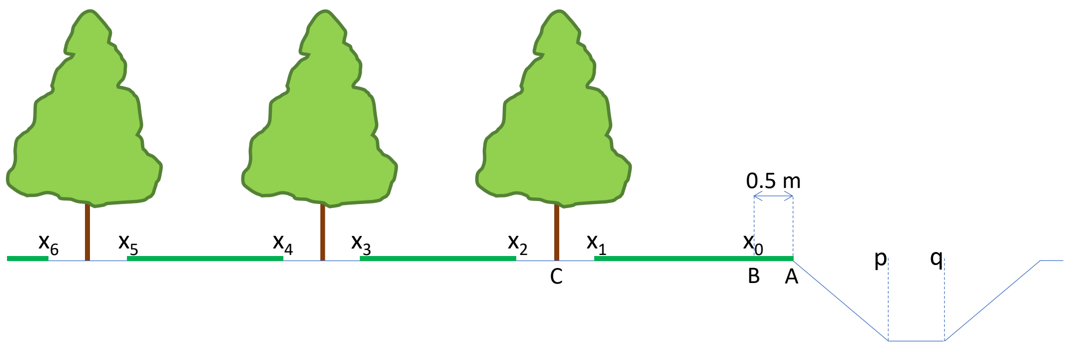

Figure 21 *Schematic layout of fruit tree orchards with tree strips and grass strips; relevant positions for computations. Green horizontal lines at the bottom indicate the grass strips; the areas in between represent the tree strips.*

When the wind direction is perpendicular to the tree rows, the spray drift deposits onto an edge-of-field waterbody is the sum of contributions of the consecutive strips that are treated (Figure 22, left-hand side). For instance, with a treatment on the grass strips, the contributions to spray drift originating from the edge strip and consecutive interrow grass strips must be added. At the edge strip, the strip A-B is the spray-free zone which is not treated.

On the other hand, when the wind direction is parallel to the tree rows (Figure 22, right part), the spray drift deposits onto an edge-of-field waterbody consists of the contributions of the headland treatment and an area-weighted contribution of the strips that are treated in the orchard. For grass strips, the weighting factor typically is 2/3 (the areal fraction covered by grass). Consequently, when treating the tree strips, the areal weight fraction is 1/3. Clearly, in the case of tree strips treatment, the headland (grass) is untreated and does not contribute to spray drift.

A detailed mathematical description of the method is given in Annex 6. Since many tree strips or grass strips may contribute significantly to the downwind drift deposits, usually many strips (typically at least 20) have to be considered. This may affect the computation time considerably. Annex 6 describes an empirical approximation method that gives accurate results, while only two grass strips and one tree strip are considered in the computations.

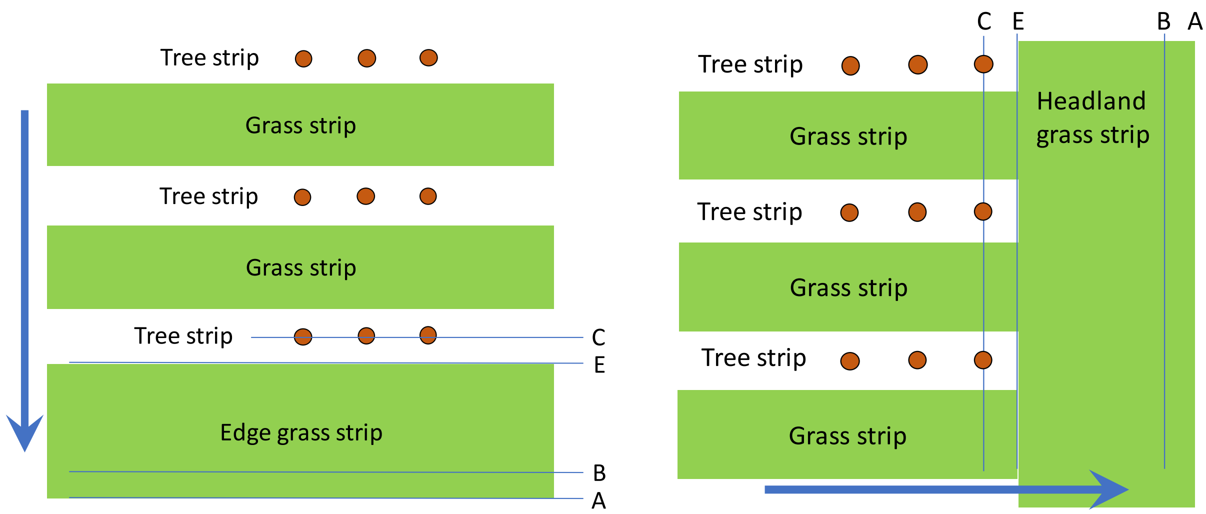

Figure 22 *Schematic layout of fruit tree orchards with tree strips and grass strips (view from above); A is field edge, B is spray edge, C is row of last trees, E is edge of first tree strip; arrow indicates direction of spray drift (i.e. wind direction); left: wind direction perpendicular to tree rows, spray drift is computed from series of contributions of subsequent strips; right: wind direction is parallel to tree rows, spray drift is computed as weighted areal contribution (see text for explanation).*

With downward applications in avenue tree nurseries the whole ground area is treated, except for the small outer edge (B-A). The position of the trees does not affect the downwind drift deposits, and therefore introducing an additional crop-free buffer zone (by increasing the width of zone A-C) does not affect downwind drift deposits either. However, for grass strip or tree strip applications in fruit orchards only a part of the ground area is treated. For instance, with grass strip spraying, the tree strips are left untreated and do not contribute to downwind drift deposits. Since the exact location of these tree strips depends on the width of the crop-free zone (i.e. whether or not a crop-free buffer zone is added), the downwind spray deposits must be affected by the width of the crop-free zone. For grass strip applications, the effect is limited. The wider the crop-free zone, the further away are the untreated tree strips from the field edge. Consequently, the edge grass strip is slightly wider and the grass strip treatment is approximating the treatment of the whole ground area. This means that a wider crop-free zone will lead to slightly higher downwind deposits of spray drift in this case.

A tree strip application is the complement of a grass strip application, considering that together they represent a treatment of the whole ground area. So, when for a grass strip application the spray drift deposits increase with increasing crop-free zone width, for a tree strip application the spray drift deposits must decrease with an equal amount. Yet, the downwind spray drift deposits with tree strip applications are much less than those for grass strip applications. So in a relative sense the spray drift with tree strip applications is affected stronger by changing the width of the crop-free zone than the drift deposits with grass strip applications.

Figure 23 illustrates these effects, showing drift deposition curves as a function of downwind distance for various crop-free buffer zones (0, 1, .. 6 m). The drift curves at the top are for a grass strip treatment; these curves almost coincide, even though the crop-free buffer zone (cfbz) increases up to 6 m. There is only a very small increase in drift deposits with increasing cfbz. For tree strip treatments, however, there is a clear effect of increasing cfbz leading to decreasing drift deposits. The graph also shows that drift deposits for tree strip applications are roughly one order of magnitude below the drift deposits for grass strip applications.

This example shows that it is meaningful to account for a varying crop-free zone in scenario studies, particularly for tree strip applications in fruit orchards. Note that with tree strip spraying the use of a crop-free buffer zone is similar to using a spray-free zone, since in both cases the outer edge of the sprayed area moves away from the edge-of-field watercourse. For grass strip spraying the spray-free zone remains 0.5 m for each crop-free zone.

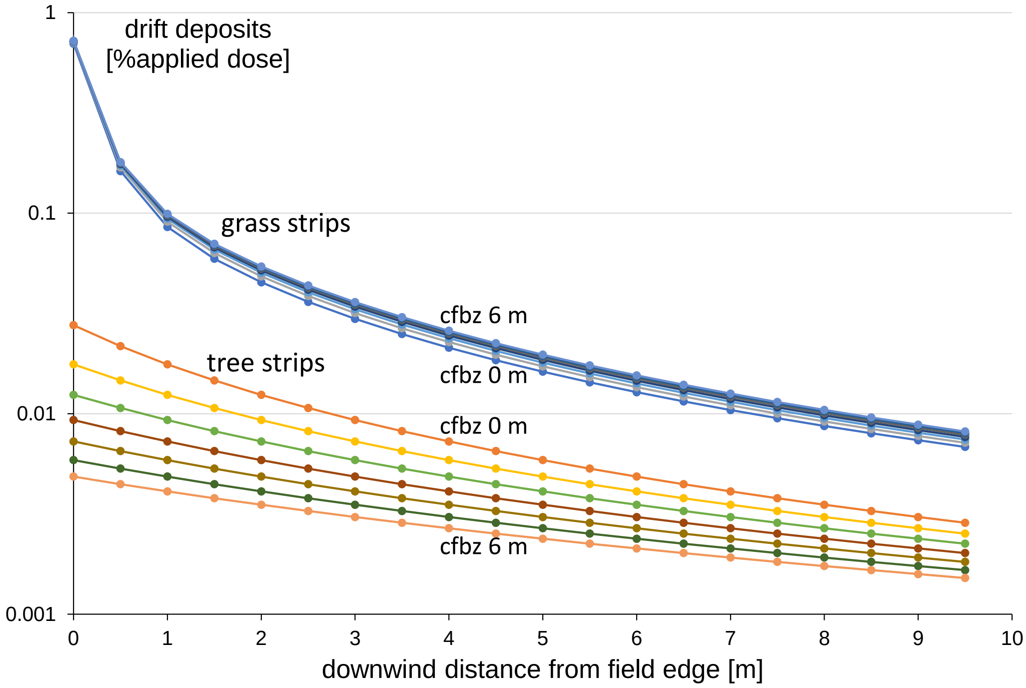

Figure 23 *Spray drift deposits as a function of downwind distance, for grass strip and tree strip applications in a fruit orchard, for crop-free buffer zones (cfbz) 0 - 6 m. Wind direction is perpendicular to the tree rows, minimal agronomic crop-free zone is 3.0 m. Note that drift from grass strips increases with crop-free buffer zone, while drift from tree strips decreases with increasing crop-free buffer zone.*

5.2 Countrywide drift exposure model

In the previous Section, local spray drift models were dealt with. For the countrywide probabilistic exposure assessment, these local models must be applied to all possible relevant situations in The Netherlands for the scenario to be studied. The statement 'all relevant situations' implies both spatial configurations and temporal configurations. In principle, spatial variables are those that do not change over time and are geographically bound to a region or country. Temporal variables are those that may differ for different days or periods during the year or over several years. The spatial and temporal variables differ depending on the scenario: for upward and sideways applications or downward applications in fruit orchards or avenue tree nurseries, different sets of spatial and temporal variables are involved. These are discussed in the next section.

Both the different spray drift curves and the different procedures in the exposure model lead to different countrywide and local probability functions. For each scenario these are derived, together with corresponding temporal percentiles for the selected spatial configuration. In the countrywide and local scenarios simulations an applied dose of 1 kg·ha^{-1} per spraying event was assumed. Since the dose rate is just a factor that affects all exposure routes in the same way, this choice is arbitrary. In the parameterised models and example runs, appropriate dose rates were used that correspond to the pesticides used.

5.2.1 Spatial and temporal variables

The scenario modelling for upward and sideways spraying in avenue tree nurseries is less complicated than that for upward and sideways application in fruit orchards. This also holds for downward applications in both fruit orchards and avenue tree nurseries. Table 10 shows the spatial and temporal variables involved in modelling the different spray application scenarios in fruit and avenue tree crops. For comparison, the case of upward and sideways treatments in pome fruit orchards ('Fruit US') is added; this case is described by the SPEXUS model and is dealt with by Boesten et al. (2021) and regarding spray drift deposition, more specifically by Holterman et al. (2021). In the other three cases of Table 10, currently there is no such sophisticated model to compute spray drift deposits onto edge-of-field waterbodies. Experimentally obtained and mathematically fitted deposition curves are used instead. As a result, the only temporal variable is wind direction with respect to the orientation of the orchard or nursery. Considering spray drift deposits, the effective wind direction must be determined; this is defined as the wind direction with respect to the direction of a cross wind at the field edge (i.e. perpendicular to the field edge).

Table 10 *Spatial and temporal variables in scenario models for fruit tree orchards and avenue tree nurseries.*

	Fruit US [1]	Avenue US	Avenue DWN [1]	Fruit DWN
Spatial variables				
Districts	X			X
Waterbody types	X	X [2]	X [2]	X
Water level	X	X	X	X
Orchard orientation	X			X
Side of orchard where waterbody is located	X	X		X
Temporal variables				
BBCH (DOY)	X			
Wind speed	X			
Wind direction	X	X	X	X
Temperature	X			

1 US = scenarios with upward and sideways applied sprays; DWN = scenarios with downward applied sprays (herbicide treatments underneath the trees).

2 There are four important districts with avenue tree nurseries; it is assumed that each of these districts has the same distribution of waterbody types.

In the case of avenue tree nurseries, there is only limited information on the districts where these nurseries are located and which edge-of-field waterbodies are present. An inventory of Van de Zande and Massop (see Annex 1) showed that only 3 districts are relevant comprising 12 waterbody types (defined by Massop et al., 2006). It was assumed further that the frequency distribution of these 12 edge-of-field waterbodies was the same for the 3 districts. Thus, the district parameter turned out to be a redundant spatial variable, not adding relevantly to the spatial configuration. This implied that districts and waterbody types could be combined into one spatial variable. Unlike fruit orchards, there is no preferred orientation of the tree rows in avenue tree nurseries. As a result of these assumptions and conditions, the number of spatial variables is limited. For upward and sideways application in avenue tree nurseries (‘Avenue US’), the side of the nursery where the waterbody is located is relevant, as the crop-free zone alongside the tree rows usually is narrower than that at the headland.

In winter the water level usually is fixed (MinI&W, 2022), while in summer the Water Boards may set the water height to appropriate levels. For exposure scenarios with upward and sideways spraying in fruit orchards, an inventory was made of summer water levels and their frequencies of occurrence for all meteorological districts (Holterman et al., 2021). That information was used for the case of avenue tree nurseries as well. For simplicity, weighted averages of the summer level frequencies were determined for primary and secondary watercourses; see Annex 2 for details. Since the water Boards can adjust the summer water level depending on environmental conditions, the summer water level has temporal aspects as well. In the current model this temporal aspect of water levels is not included; for instance, water levels are not linked to weather conditions or forecasts.

Considering the difference in crop-free zone width of the headland side and the side along the tree rows, two field edge types had to be accounted for in the scenarios with avenue tree nurseries. With fruit orchards, due to the unequal distribution of orchard orientations, the effective wind direction with respect to the edge of the field is distributed unequally too. Therefore all four field sides have to be considered in the scenario simulations.

For downward spraying to the soil below avenue trees (‘Avenue DWN’) the position of the trees is irrelevant as it does not affect the deposition of spray drift. This limits the spatial variables even more: now the side of the tree nursery where the waterbody is located is not relevant either.

For downward spraying in fruit orchards ('Fruit DWN') the same spatial configurations apply as with upward and sideways treatments in fruit orchards. The limitation in this case is only due to low number of temporal variables involved, as mentioned above.

5.2.2 Temporal percentile for local configuration

The modelling procedure is as follows and is similar to the procedure for pome fruit orchards with upward and sideways applications (Boesten et al., 2021). First, a countrywide scenario is carried out, where the spray deposits onto all edge-of-field waterbodies are computed for a large number of years with random weather conditions. This leads to a cumulative probability density function (cpdf) of PECs describing the level of exposure for all waterbodies next to the fruit orchard or tree nursery. From this cpdf the 90th percentile value (PEC_{90}) is derived.

A second simulation involves the same application scenario for the selected spatial configuration only. For the local situation a different cpdf is obtained. In this case, the variation in computed PECs is only caused by variation in wind direction, the only temporal variable. Ideally, the concentration PEC_{90} derived from the countrywide cpdf would occur in the selected waterbody also, yet at a different temporal probability, identified as T_{90}. As an example, Figure 24 illustrates the procedure: start at the 0.9 probability on the y axis and find point A on the countrywide (blue) cpdf. Then on the x axis the PEC_{90} value can be found. Point B on the local (orange) cpdf corresponds to the same PEC value; then from B go left to the y axis to find the local T_{90} belonging to the countrywide PEC_{90}. Note that for the countrywide curve approaches the top (probability 1) almost asymptotically, while the local (orange) cpdf turns up steeply at its top to a certain clear PEC value. Different scenarios (that is, with different application techniques, possibly crop-free buffer zones, number of spray applications) lead to different cpdfs and consequently to different PEC_{90}s and T_{90}s.

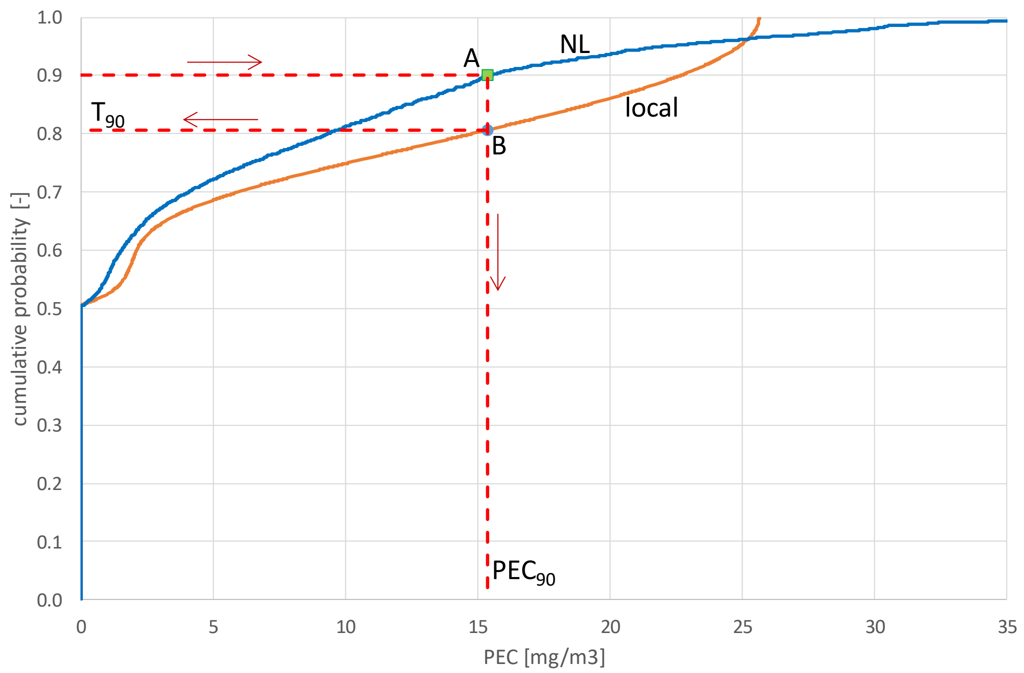

Figure 24 *Procedure to find the T_{90} for the local situation, representing the countrywide PEC_{90}. See text for detailed description. Blue curve: countrywide cpdf; orange curve: local cpdf (scenario: high avenue trees US, 1 conventional application/year, crop-free zone 5.0 m).*

5.2.3 Implementing wind direction

Effective wind direction (θ) with respect to a cross wind (perpendicular to the field edge) is incorporated as a factor that increases the distance from the field edge to the edges of the watercourse (Figure 25). All downwind distances involved are enhanced by a factor 1/cos θ for directions between -90° and 90°. For other effective wind directions the wind is not blowing towards the adjacent watercourse (the field edge is not a downwind edge) and the distance enhancement factor has no meaning.

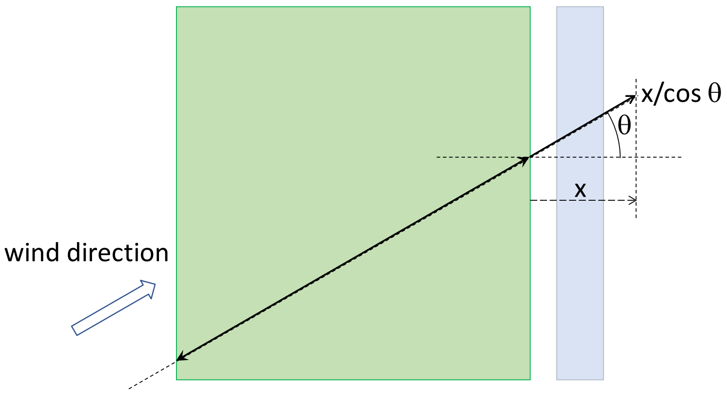

Figure 25 *Illustration showing how effective wind direction affects the downwind distance of the drifting spray cloud.*

Unlike fruit orchards, avenue tree nurseries do not have a preferred orientation of the tree rows. Consequently, although the actual (meteorological) wind direction does have preferred directions (e.g. often blowing from the south-west in The Netherlands), each effective wind direction is equally likely to occur. For the countrywide scenarios this has a clear and fortunate advantage that the temporal variation does not need to be stochastic but can be deterministic, as explained next. In principle, the temporal variation is a year-by-year variation of all temporal variables. In case of avenue tree nurseries, with only one variable that is homogeneously distributed, the whole range of wind directions (360°) can be uniformly divided by the number of years in the scenario, such that each year is represented by a (different) wind direction. In this way a very large number of years is not required (to suppress the stochastic variance) and the number of years can be limited. Clearly, as in this method the number of years equals the number of wind directions, the results will be more accurate when the number of wind directions is not too small. Trials with different numbers of wind directions showed that using 180 directions (i.e. 180 years) gives sufficiently accurate results.

For multiple spray applications per year, each application is related to a random wind direction. Usually, the wind direction closest to perpendicular to the field edge will lead to the highest drift deposits and consequently the PEC_{max} for that year. The probability that this worst-case wind direction is close to perpendicular increases with the number of applications in one year. It can be shown that the probability that PEC_{max} occurs at effective wind direction θ is given by the following equation:

$$P(\theta) = \frac{m}{360}\,(1 - |\theta|/180)^{m-1} \qquad (4)$$

Where m is the number of spray applications per year; the unit of P is deg^{-1}. Figure 26 shows a plot of the probability distributions for different values of m. As mentioned above, with only one annual spray application, each wind direction was equally likely to occur. In other words, the annual PEC_{max} could occur for any wind direction equally likely. With multiple spray applications, the annual PEC_{max} is more likely to occur for small values of the effective wind direction (close to perpendicular to the field edge). Thus, the same method using the year - wind direction analogy can be used in deterministic scenario computations, while using Eq.(4) as the weighting factor for the wind direction to account for multiple spray applications. Note that the method can only be applied to the avenue tree scenarios. For fruit orchards the orientation of tree rows is not random and so the effective wind direction is not random either.

NB the above method implicitly assumes that drift deposits decrease with increasing wind direction, or equivalently, drift deposits must decrease with increasing distance. Unfortunately, this is not always the case, as can be seen in Figure 16 and Figure 17 where in some cases the drift deposits tend to increase at some distances. However, these graphs show that such effects are relatively small, while only occurring at distances where drift deposits are relatively low. This means that it is unlikely that PEC_{90} values are affected.

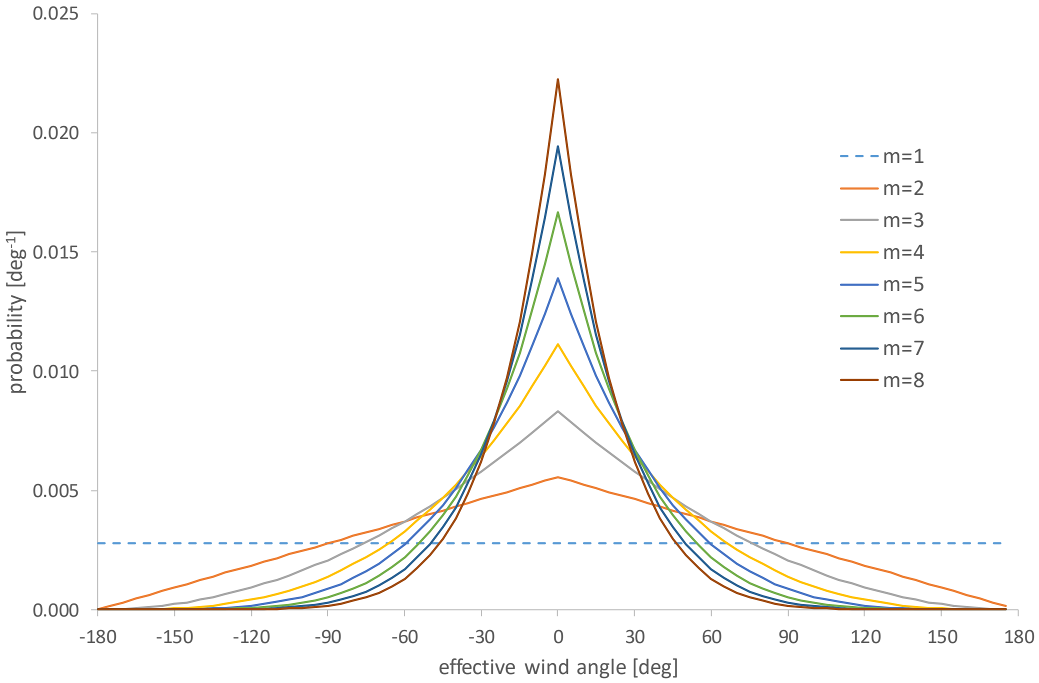

Figure 26 *Probability that PECmax occurs at effective wind direction θ for different numbers (m) of applications per year. For avenue tree nurseries.*

5.2.4 Smart headland approach

The scenarios for upward and sideways applications in fruit orchards involved the optional use of an additional crop-free buffer zone to extend the minimal agronomic crop-free zone (Boesten et al, 2021). At the headland, the minimal crop-free zone was 6 m rather than 3 m as at the sides along the tree rows, to allow for the spraying equipment to take its turn. In the scenarios, the additional crop-free buffer zone was applied to both headland and alongside equally. However, this is not a reasonable procedure in practice. It makes more sense that the crop-free zone at the headland will not be widened as long as it is still wider that the crop-free zone alongside the three rows. As an example, say, a 1 m buffer zone is applied. Then alongside the crop-free zone increases from 3 m to 4 m. The headland width is 6 m which is still wide enough (wider than 4 m alongside), so the farmer has no reason to apply the 1 m buffer zone to the headland as well. When the applied buffer zone would be more than 3 m wide, a widening of the headland would be appropriate, to obtain a width equal to the extended crop-free zone alongside; see Figure 27.

Compared to the approach when the additional crop-free buffer zone would have been applied to all orchard sides, the smart headland approach will lead to a slightly higher PEC_{90} countrywide. The selected local situation is not affected, as the selected waterbody is alongside the tree rows, not at the headland. Consequently, resulting the smart headland approach leads to higher T_{90}s and a situation as shown in Figure 28 is reached more often. See Annex 5 for further details.

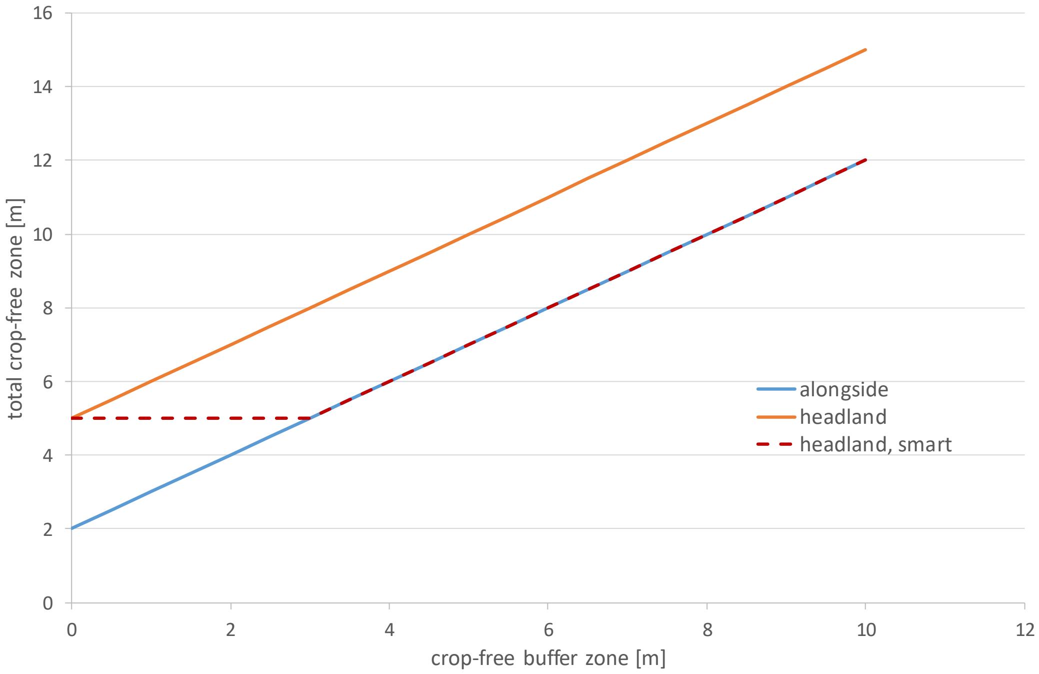

Figure 27 *Crop-free zone around an avenue tree nursery, as a function of an additional crop-free buffer zone alongside the tree rows (blue line) and at the headland (orange line). The dashed line indicates the 'smart' headland approach, where headland is not widened until the total crop-free zone alongside is the same as the headland width.*

5.2.5 Local adjustment procedure

As noted in Section 5.2.2, typically the local cpdf bends up steeply at its higher end when approaching cumulative probability 1. This effect can be relatively strong in several cases where the variation in computed PECs for the local configuration becomes relatively small. The steeply rising higher end of the local cpdf can take up a relatively large part of the curve. As a consequence, the countrywide PEC_{90} may not always occur in the local situation, when even the highest possible local PEC (worst case) does not reach the countrywide PEC_{90}. Figure 28 gives an example, where point A represents the countrywide PEC_{90} while the local (orange) cpdf always takes lower PEC values. In fact, the T_{90} would equal 1 in this case, which has no meaning since all PEC_{90}s larger than the one at point B would have a T_{90} of 1. Different solution routes to this 'matching problem' were discussed in the working group (Annex 11), yet only one practical solution appeared satisfactory and was implemented, as described below.

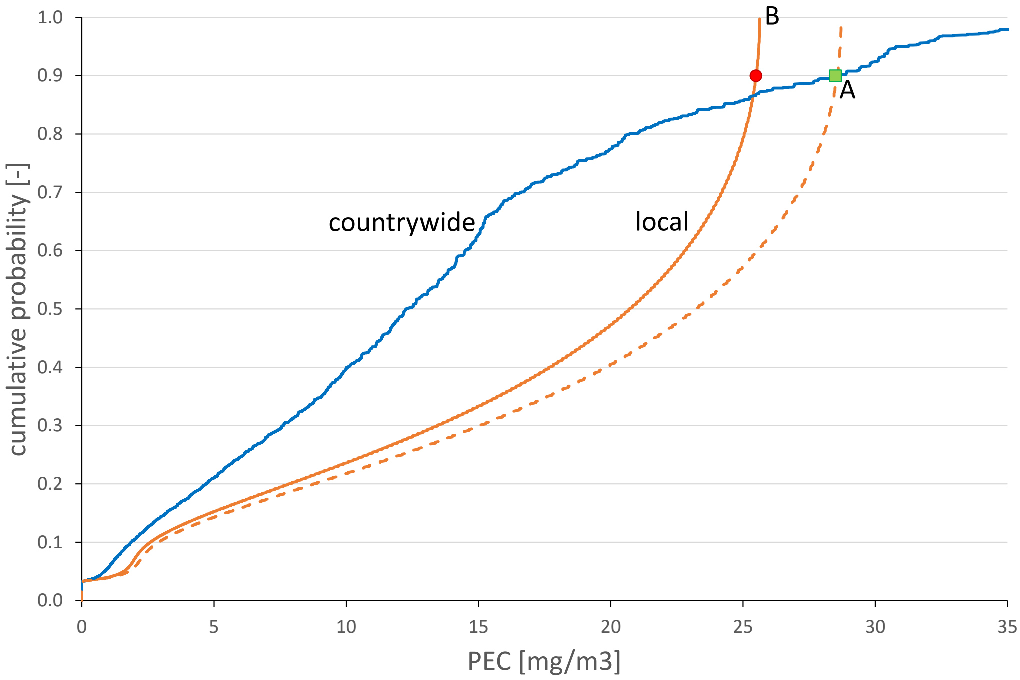

Figure 28 *Example of countrywide cpdf (blue curve) and local cpdf (orange curve) where the countrywide PEC_{90} is not resolved by the local T_{90}. Green square (A): indication of PEC90 at countrywide curve; red dot: 90^{th} percentile PEC on local curve, used in the solution described in the text; point B: highest PEC in local situation. Orange dashed curve: local curve with zeta correction, passing through the green square (A) (Scenario: high avenue trees US, 5 conventional applications/year; crop-free zone 5.0 m).*

The chosen solution uses an appropriate scaling of drift deposits (and consequently PEC values) in the local situation, in such a way that the local cpdf always covers the countrywide PEC_{90}. Figure 28 indicates the essence of the problem, but also the implemented solution. In this scenario, the worst (= highest) PEC in the local configuration is about 25.5 mg/m^3 (point B) where the orange curve reaches its highest point (with cumulative probability 1). Clearly this point corresponds to a PEC that is lower than the countrywide PEC_{90} of about 28.0 mg/m^3 (point A), so the local maximum is not high enough to describe the countrywide PEC_{90}. Therefore the following workaround was developed. The local 90^{th} percentile PEC was determined (red dot at orange curve in Figure 28). This PEC_{loc90} value is less than PEC_{90}. Define their ratio ζ by:

$$\zeta = PEC_{90}/PEC_{loc90} \qquad (5)$$

Now in this case, $\zeta > 1$. If all local PEC values would be increased by a factor ζ, then the orange curve would be slightly stretched along the x axis, giving the dashed orange curve. The factor ζ is defined such that the (shifted) red dot and green square would coincide. Clearly, this does not represent the actually occurring PECs in the local waterbody, but it is equivalent to the situation where the applied pesticide dosage is increased by the same factor ζ. By applying this factor the new local 90^{th} percentile PEC equals the countrywide PEC_{90}. For the avenue-US scenario the range of possible values of ζ appears to be between 1 and 1.24, depending on tree type, spray application technique, width of crop-free zone and number of treatments per year (see Section 5.3.2). For downward applications in fruit orchards and avenue tree nurseries, the maximum ζ appears to be slightly less. The scaling method is applied to all scenarios where the actual T_{90} tends to become larger than 90%. Then an appropriate scaling by factor ζ assures that a new local T_{90} equals 90%. When the actual T_{90} is less than 90%, then $PEC_{loc90} > PEC_{90}$ and $\zeta < 1$. In fact, no ζ scaling factor is required in this case, as the actual T_{90} suffices. In Sections 5.3, 5.4 and 5.5 the PEC_{90}s, T_{90}s and scaling factors ζ are quantified for the various scenarios.

5.2.6 Dealing with low number of years in the parameterised model

The lists of PEC_{90}s, T_{90}s and ζ values as described above were determined from cpdfs that were built form a huge number of individual cases (many spatial units, many random years). Therefore, these cpdfs were highly accurate and approach the 'true' cpdfs (i.e. for infinite number of years) closely. The TOXSWA model was parameterised to run for 20 actual years (1986-2006) of which the first 5 are warming-up years and the last 15 are used as assessment years for the calculation of the exposure endpoint. TOXSWA requires spray drift deposition values as input for these 20 years. Drift deposits are computed by the xSPEXUS model using the actual weather data on the days of application throughout these 20 years. However, statistically the number of 15 years (for the assessment) is too small to obtain a sample distribution that is representative of the true cpdf. Therefore, drift deposits in the parameterised scenario were selected from the true cpdf instead. This method has been developed and used before for Fruit-US scenarios (Boesten et al., 2021). It was applied to the scenarios in this report as well.

Figure 29 shows an example how using actual weather data leads to PEC_{max} values (blue diamonds) that differ from the true multi-year distribution (orange cpdf curve). The projected PEC_{max} values (red dots) are used in the exposure assessment. Since each year is independent of all other years, the results for all years are equally likely. Therefore the cumulative probabilities on the y axis are evenly distributed. The procedure gives a robust method of providing realistic spray drift data while not being affected by extreme weather conditions. A detailed description of the method is given by Boesten et al. (2021; their Section 3.6).

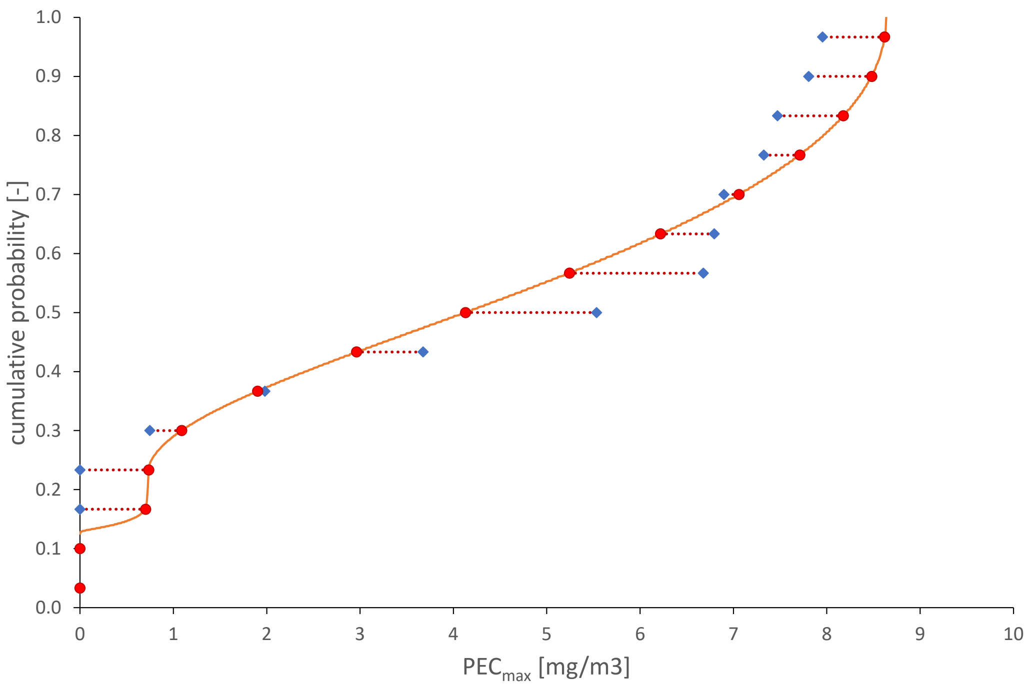

Figure 29 *Example of PEC_{max} values based on actual weather data (blue diamonds) and projections using the 'true' cpdf (red dots on orange cpdf). High avenue trees, upward and sideways applications, 3 DRT50 applications per year, total crop-free zone 5 m, 15 assessment years.*

5.3 Avenue tree nurseries – upward and sideways applications

5.3.1 Exposure model

Compared to the countrywide scenarios for fruit orchards, for avenue tree nurseries there is only limited information available on the possible spatial configurations and their distribution throughout the Netherlands. Annex 1 indicates that 12 waterbody types in 3 meteorological districts can represent the countrywide spatial distribution of avenue tree nurseries with adjacent waterbodies. It was assumed that the frequency distribution of the 12 waterbody types was the same in the 3 districts of interest. Figure 30 shows the relative frequency of occurrence of the 12 waterbody types in the 3 districts; see also Table 11. Two field edge types were accounted for in the scenarios: the side parallel to the tree rows and the side at the headland. Thus, the spatial configuration involves 12 waterbody types, 9 water levels and 2 field sides. These combine to 216 different spatial situations.

With avenue tree nurseries, three planting systems are distinguished: spindles, transplanted trees and high trees (Section 2.1). With upward and sideways application in these three systems different spray drift deposition curves are available from field experiments (Section 5.1.1). In fact, the three planting systems can be considered as three independent crop systems.

On the temporal part of the scenarios, only wind direction with respect to the orientation of the field edge has to be accounted for. Drift and PEC computations are carried out for a number of years for each spatial configuration. In Section 5.2.3 it is shown that, since effective wind direction is arbitrary for avenue tree nurseries, each year can represent a different wind direction, while these wind directions are uniformly distributed over 360°. This 'year – wind direction' analogy is applicable to scenarios with more than one spray application per year as well, provided an appropriate weight factor is used for each wind direction (represented by Eq.(4)).

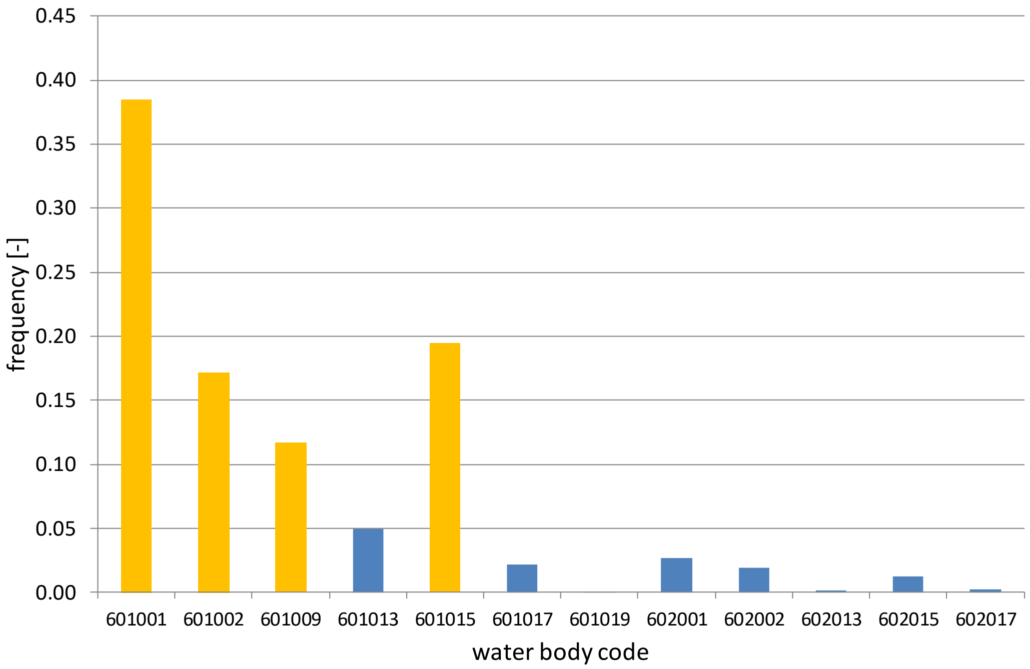

Figure 30 *Relative frequency distribution of 12 waterbody types as edge-of-field watercourses next to avenue tree nurseries. Orange bars indicate the waterbody types that occur more than average (average is 1/12 = 0.083). Waterbody types are indicated with a code. The corresponding hydrotype and class are given in Table 11.*

Table 11 *Relevant waterbody types next to avenue tree nurseries in the selected regions. The column Fraction gives their relative importance (frequency of occurrence).*

Class	Hydrotype	Waterbody code	Fraction [-]
Secondary	Betuwe-komgronden	601001	0.385
	Betuwe-stroomruggronden	601002 *	0.171
	Nuenengroep profiel	601009	0.117
	Singraven-beekdalen	601013	0.049
	Tegelen/Kedichem profiel	601015	0.194
	Westland-DH-profiel	601017	0.021
	Westland-D-profiel	601019	0.001
Primary	Betuwe-komgronden	602001	0.027
	Betuwe-stroomruggronden	602002	0.019
	Nuenengroep profiel	602009	0.000
	Singraven-beekdalen	602013	0.001
	Tegelen/Kedichem profiel	602015	0.013
	Westland-DH-profiel	602017	0.002
	Westland-D-profiel	602019	0.000
	Total		1.000

* waterbody type selected for the local scenarios (see Section 4.2.3)

Figure 31 gives a schematic view of the countrywide scenario simulation model. The left-hand side shows various loops of the spatial variables, involving 216 spatial configurations (=12x9x2). Each spatial configuration has its own spatial probability corresponding to its statistical weight. The dashed rectangle represents the loops with temporal variables. Drift and corresponding PEC value is computed for each combination of spatial and temporal settings. The dashed rectangle is shown in detail on the right-hand side of the scheme. It includes the possibility of multiple spray events during the year. On the temporal part, 180 years (i.e. 180 wind directions, with interval of 2°) are selected. Thus, 216x180 = 38880 PECs are computed in a countrywide scenario, or a multiple of this number if multiple applications per year are simulated.

The block on the right-hand side identified as 'compute drift' is representing the spray drift model that computes deposits from one tree nursery onto an edge-of-field watercourse. This drift model involves the averaged drift curves for spindles, transplanted and high avenue trees as described in Section 5.1.1. The availability of drift reduction curves depends on tree growth stage: for spindles and transplanted trees, the application techniques for DRT50 and DRT90 are available, for high avenue trees this is DRT50, DRT75 and DRT95 (Section 5.1.1). Thus, there are 10 different combinations of tree growth stage and application techniques.

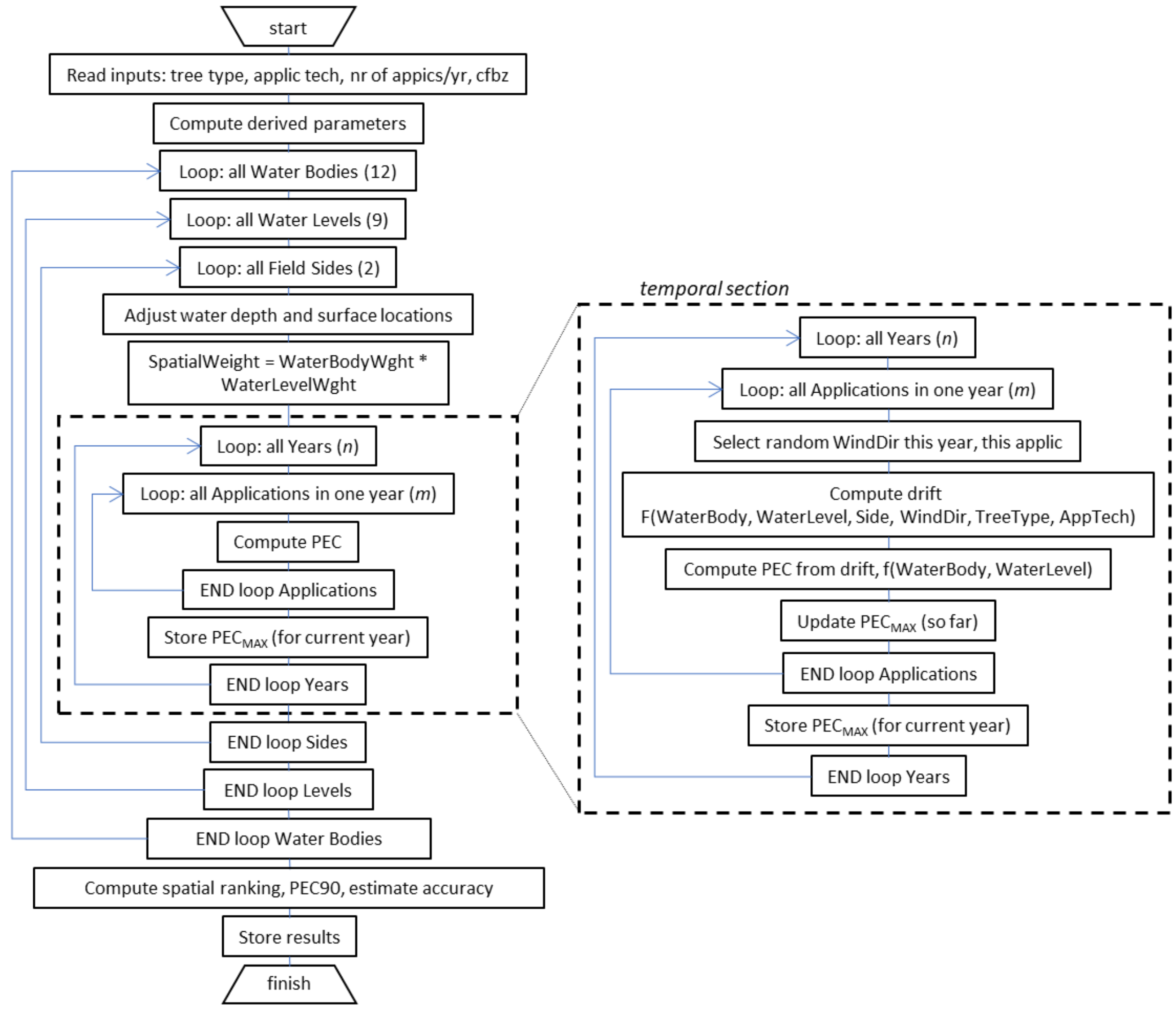

Figure 31 *Flow chart for countrywide scenario simulations, avenue tree nurseries with upward and sideways applications.*

Countrywide scenarios simulations were carried out for these 10 cases, each combined with 10 crop-free buffer zones (0 - 9 m) that were added to the minimal agronomic crop-free zone. The minimal crop-free zone at the headland was 5 m; the smart headland approach was followed throughout (Section 5.2.4). For spindles, where the minimal agronomic crop-free zone is 1.5 m, the additional buffer zones were selected such that the total crop-free zone was a whole-numbered distance (in m), see Table 12. Finally, these simulations were carried out for 1 to 10 applications per year. This led to 1000 countrywide simulation runs (the product of 10 crop/technique cases, 10 crop-free buffer zones and 10 sets of application numbers).

Table 12 *Range of total crop-free zones in the scenario simulations for upward and sideways spray applications in avenue tree nurseries.*

Crop stage	Min Agron CFZ [m]	Total crop-free zone [m]
high avenue	2.0	2.0, 3.0, .. 11.0
transplanted	2.0	2.0, 3.0, .. 11.0
spindles	1.5	1.5, 2.0, 3.0, ..10.0

Figure 32 shows PEC_{90} values for high avenue trees with the countrywide simulations. On the left-hand side PEC_{90} values are shown as a function of the number of spray applications per year, for different crop-free buffer zones with a conventional application technique. As expected, PEC_{90} increases with increasing number of applications, since it becomes increasingly likely that the annual PEC_{max} values are associated with a wind direction close to a cross wind. On the right-hand side PEC_{90} is shown as a function of the crop-free buffer zone (added to the minimal agronomic crop-free zone), for one spray application per year and different application techniques. PEC_{90} decreases with increasing crop-free zone, although the rate of decrease depends on the application technique. Note that for DRT75 the rate of decrease is low and the curve crosses the one for DRT50 at a crop-free buffer zone of about 3 m. The minimal agronomic crop-free zone for high avenue trees is 2 m and the centre of a secondary edge-of-field watercourse is roughly 2 m outside the field edge. Then, with a crop-free buffer zone of 3 m, the centre of the watercourse is about 7 m from the last tree row. This agrees with Figure 16, where the drift curves for DRT50 and DRT75 cross at about 7.5 m from the last tree row.

Figure 33 and Figure 34 show in a similar way some results for transplanted trees and spindle trees, respectively. Note that PEC_{90} values for transplanted trees are much lower than those for high avenue trees, while for spindle trees the PEC_{90}s are lowest. This agrees with the drift curves and drift reduction curves of Section 5.1.1. PEC_{90} values for all simulations are listed Table 48 in Annex 10.

Following the countrywide scenario simulations, the same simulations were carried out for the selected local situation. In this case the temporal part involved 1000 years, with the same number of wind directions equally distributed over 360°. Since no random temporal variables are involved, the choice of 1000 years is large enough to obtain sufficiently accurate results. These simulations resulted in tables of T_{90} and ζ values. These are discussed in the next section, together with their implementation in the parameterised drift model.

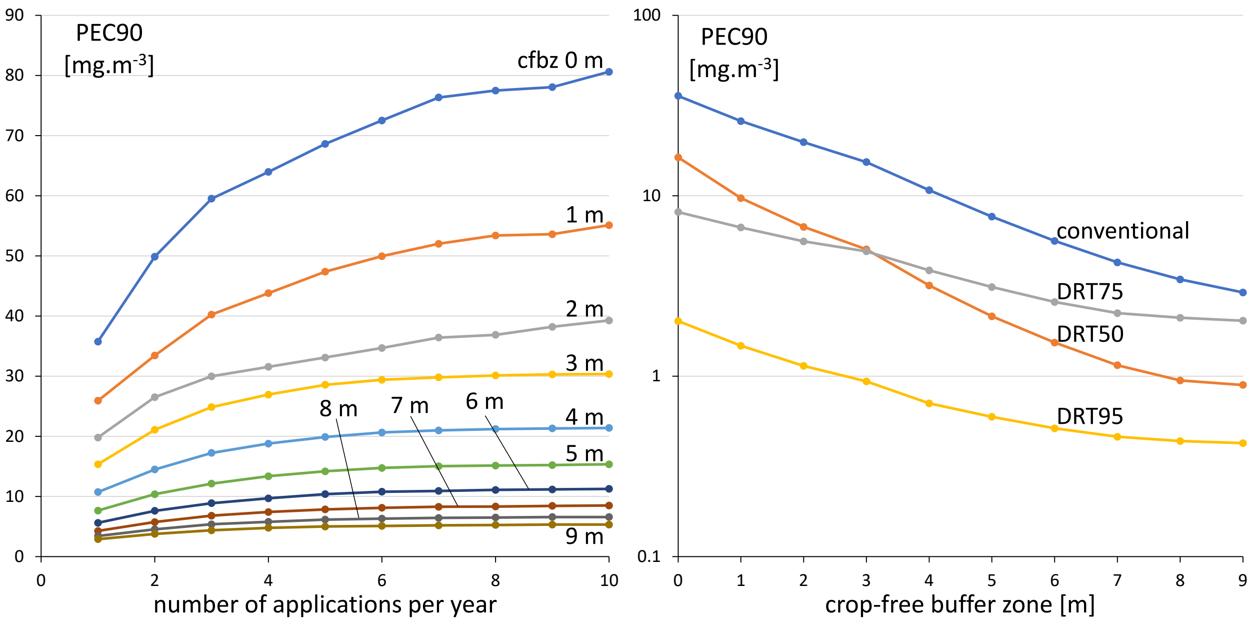

Figure 32 *Results of countrywide simulations for* *<u>high avenue trees</u>*, *upward and sideways spray applications; left: PEC_{90} vs number of applications per year, for different crop-free buffer zones (cfbz), conventional application technique; right: PEC_{90} vs crop-free buffer zone for different application techniques, one application per year. Dose rate 1 kg·ha^{-1}.*

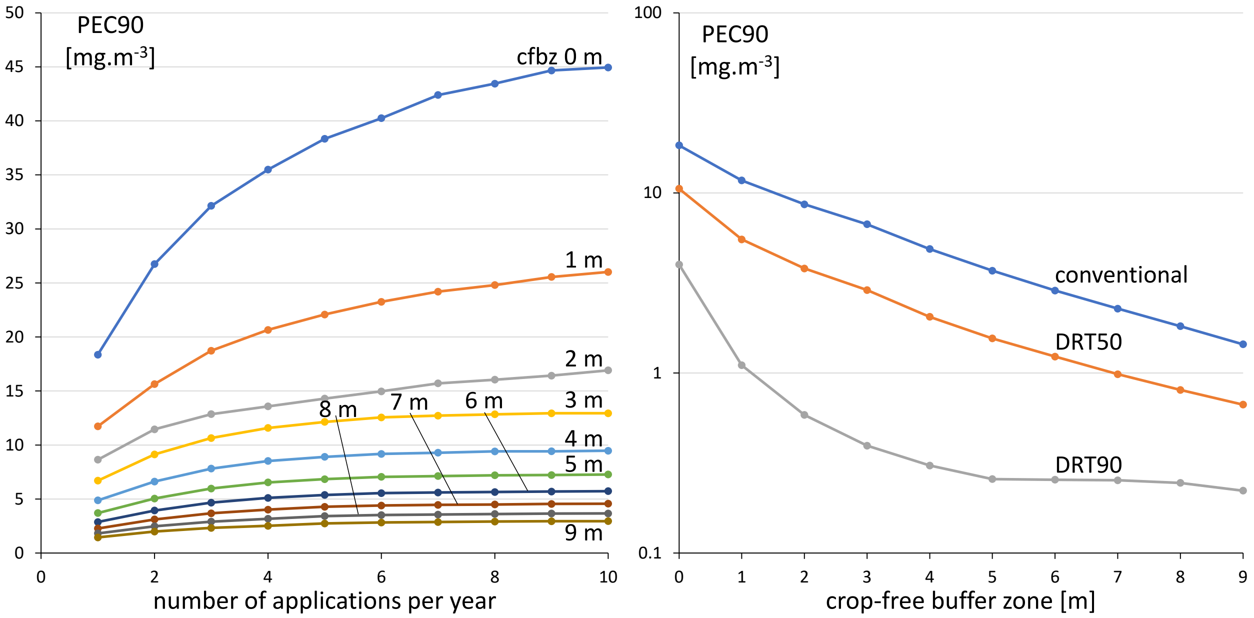

Figure 33 *Results of countrywide simulations for <u>transplanted avenue trees</u>, upward and sideways spray applications; left: PEC$_{90}$ vs number of applications per year, for different crop-free buffer zones (cfbz), conventional application technique; right: PEC$_{90}$ vs crop-free buffer zone for different application techniques, one application per year.*

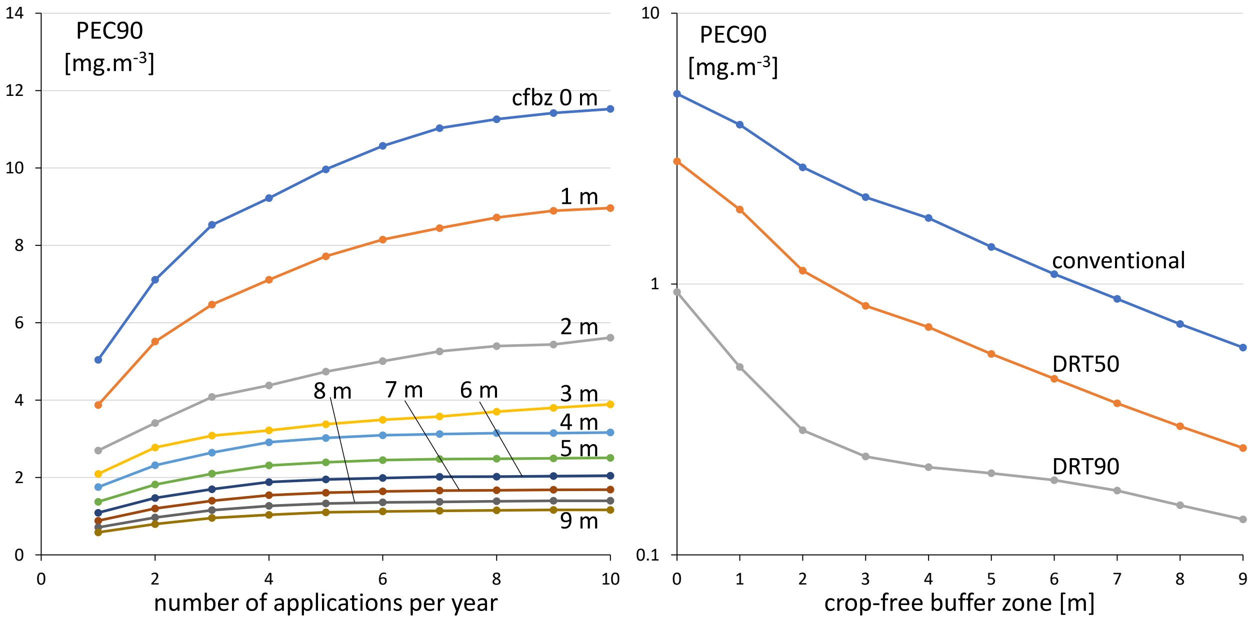

Figure 34 *Results of countrywide simulations for <u>spindle avenue trees</u>, upward and sideways spray applications; left: PEC$_{90}$ vs number of applications per year, for different crop-free buffer zones (cfbz), conventional application technique; right: PEC$_{90}$ vs crop-free buffer zone for different application techniques, one application per year.*

5.3.2 Parameterisation

For each countrywide scenario the resulting PEC$_{max}$ values (38880) were sorted increasingly, thus forming a cumulative probability density function (cpdf) of the countrywide situation. The 90th percentile of the cpdf gave the PEC$_{90}$ value for that scenario. Similarly, for the local simulation the 1000 PEC$_{max}$ values were sorted also leading to a cpdf for the local situation. The corresponding PEC$_{90}$ of the countrywide scenario was looked up on the x-axis of the local cpdf, giving the required temporal percentile T_{90} at the y-axis (see also Section 5.2.2).

Figure 35 shows the T_{90}s for all simulated scenarios, as a function of the number of applications per year. The graph shows that it is not easy to distinguish a clear pattern in T_{90} values. Expressing the T_{90}s as a function of crop-free buffer zone gives a different picture which is also hard to interpret. Note that for many cases the T_{90} equals 1, when the countrywide PEC_{90} is higher than the maximum PEC that can occur in the local scenario. Such cases are dealt with in Section 5.2.5 where a local adjustment procedure is proposed. This procedure involves the use of a spray drift enhancement factor ζ; this factor is determined in such way that the adjusted T_{90} is reduced to 0.9. The computed values of ζ are shown in Figure 36, for all simulated scenarios, as a function of the number of applications per year. In many cases ζ is less than 1; in these cases no adjustment is required as T_{90} is less than 0.9. The graph shows that ζ increases with increasing number of applications, but it approximates an upper limit of about 1.24.

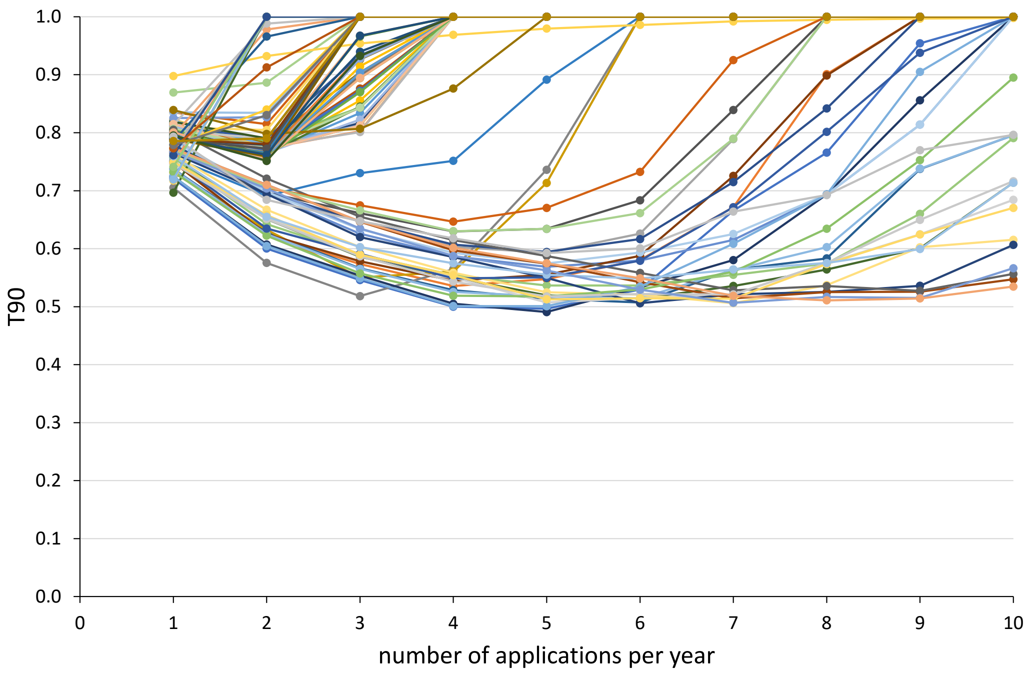

Figure 35 *Avenue trees US, T_{90}s vs number of spray applications per year, for all tree types, application techniques and crop-free buffer zones in the simulation set.*

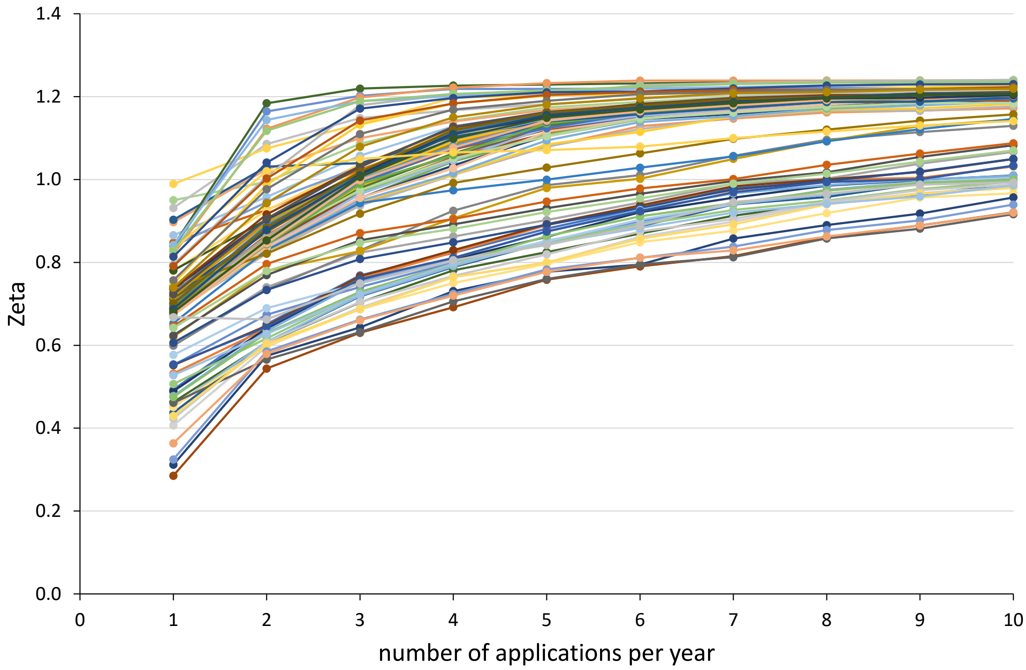

Figure 36 *Avenue trees US, spray drift enhancement factor ζ vs number of spray applications per year, for all tree types, application techniques and crop-free buffer zones in the simulation set.*

Since the values of T_{90} and ζ appeared hard to model mathematically in terms of avenue tree growth stage, spray application technique, number of applications and crop-free buffer zone, it was decided to use their values in a tabular form in the parameterised drift model xSPEXUS (see

and Table 50 in Annex 10 for full tables). For an arbitrary crop-free buffer zone within the limits of Table 12 linear interpolation was used to appropriately estimate T_{90} and ζ. A crop-free buffer zone outside these limits was not allowed in xSPEXUS (an error message was returned).

In case of multiple applications in one year, each application may have its own application technique (within the range of available techniques of course). Then for each occurring application technique the T_{90} is determined, for the avenue tree growth stage and number of applications per year. This T_{90} belongs to a scenario where all applications are assumed to be carried out with the same technique, i.e. the same DRT class. Then, selecting the maximum T_{90} for the occurring application techniques is a conservative approach. If this maximum is above 0.9, then it is reduced to 0.9 and the adjustment factor ζ is determined as well. The flowchart of this procedure is shown in Figure 37. In the parameterised drift model xSPEXUS the use of more than 10 applications per year is not supported, which is conform applications in practice, see Table 4 in Section 2.2.

In a scenario of *n* assessment years with *m* spray applications per year, xSPEXUS must produce a *n*×*m* table of drift deposits to be used in TOXSWA. The projection method described in Section 5.2.6 is shown in the flowchart of Figure 38, but now extended for multiple applications. The actual PEC values are only used for ranking of the projected PEC_{max} values (named $TRUE_{max}$ in the flowchart to distinguish them from the actual PEC_{max} values) and to provide ratios for the other drift deposits (not responsible for the annual maximum). In this way, the robust PEC_{max} values from the true cpdf can be ranked in a realistic way.

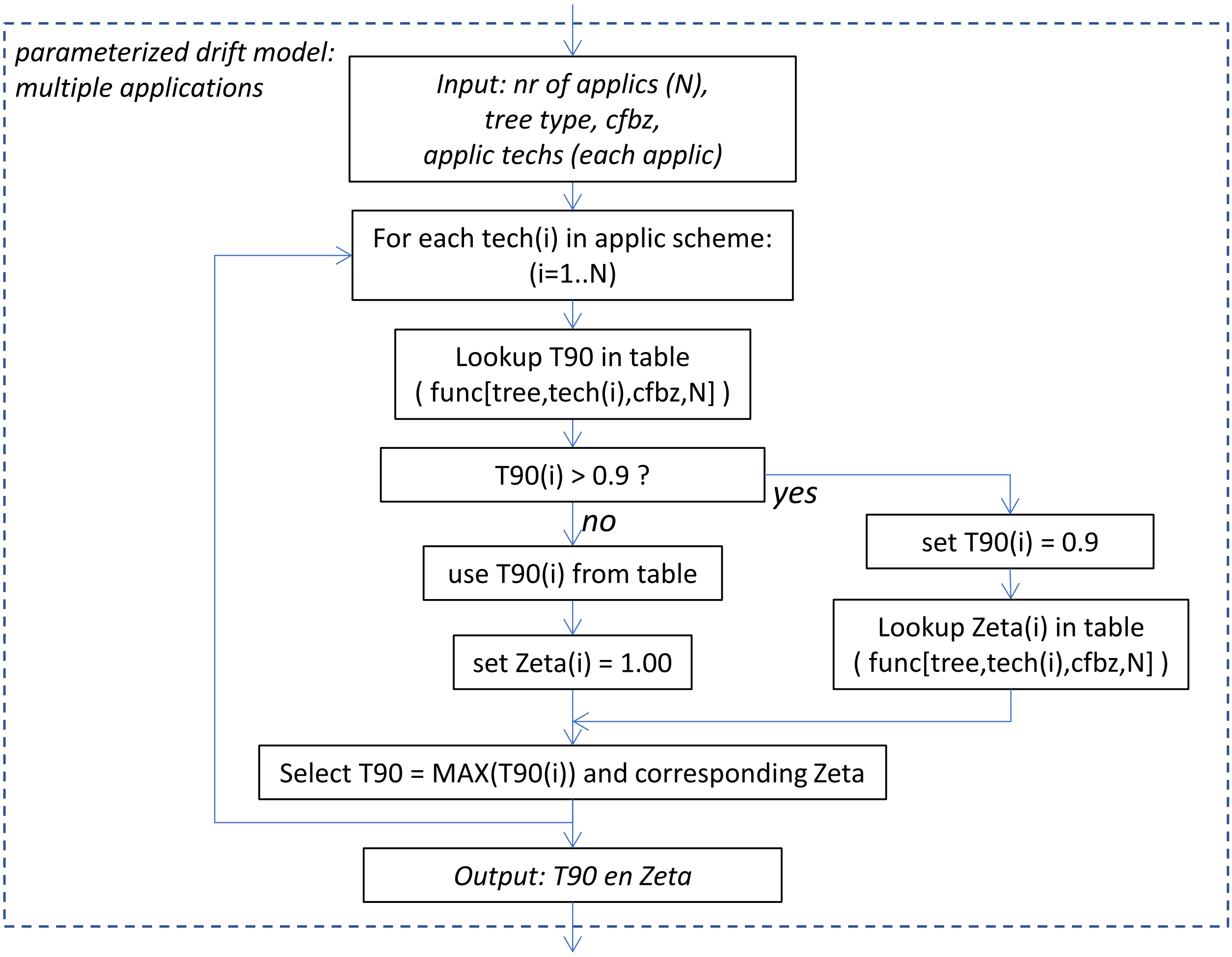

Figure 37 *Decision table to select an appropriate (conservative) T_{90} value in case of multiple spray application in one year, upward and sideways applications in avenue tree nurseries. Cfbz= crop-free buffer zone; tree = avenue tree growth stage (tree type); tech = application technique.*

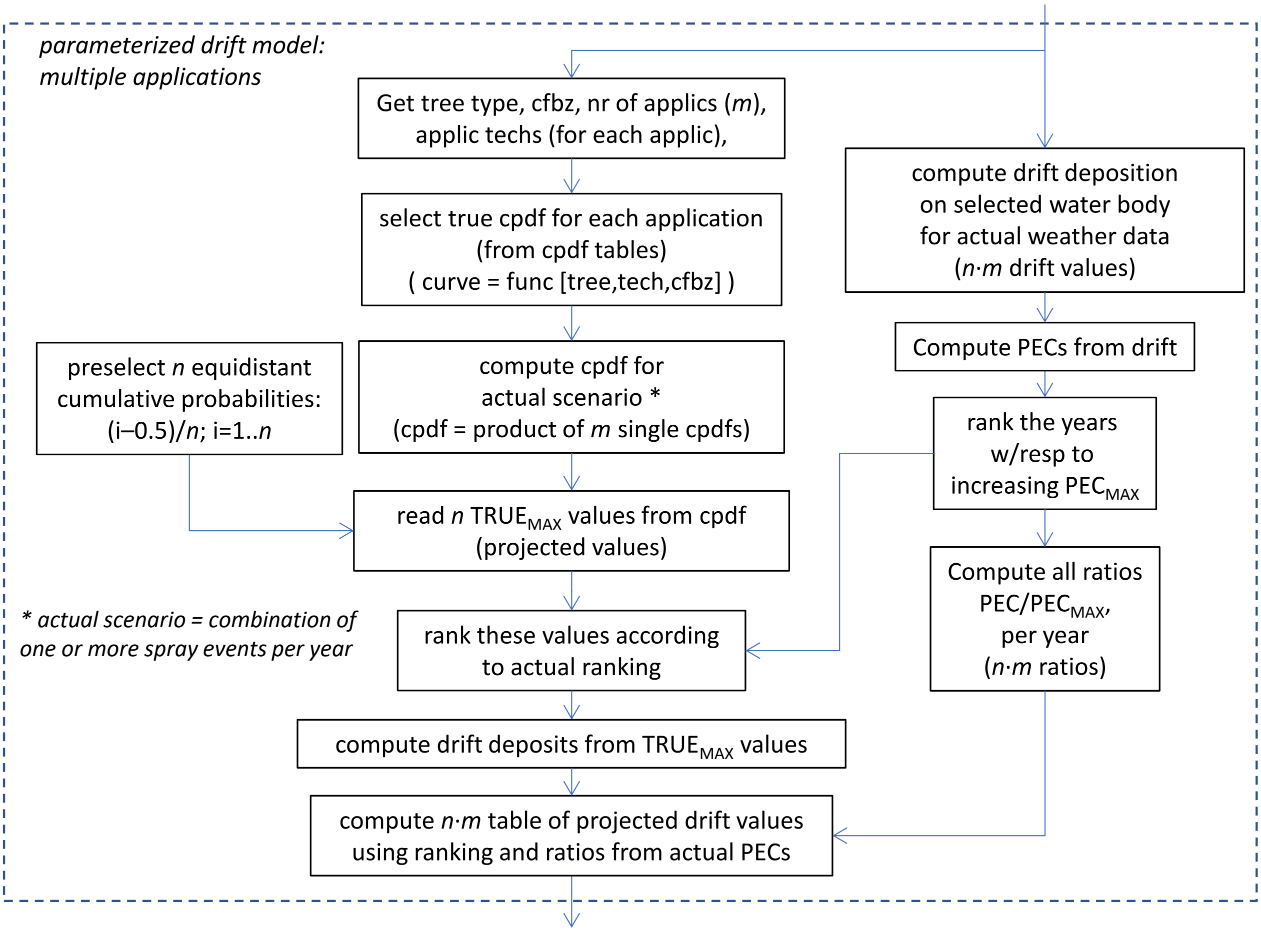

Figure 38 *Flowchart to compute drift table in xSPEXUS; upward and sideways applications in avenue tree nurseries. Cfbz= crop-free buffer zone; tree = avenue tree growth stage (tree type); tech = application technique; n: number of years in the scenario, m: number of applications per year.* $TRUE_{MAX}$ *is the* PEC_{MAX} *from the true cpdf (name only used to distinguish it from* PEC_{MAX} *for actual weather data in this chart).*

5.4 Avenue tree nurseries – downward applications

5.4.1 Exposure model

The countrywide scenarios for downward spray applications in avenue tree nurseries are very similar to those for upward and sideways applications. A clear difference is that no distinction between the side along the tree rows and at the headland has to be made (see Table 10). Therefore the number of spatial units is reduced to 108 (compared to 216 for Avenue-US scenarios). The flowchart of Figure 31 is applicable, except for the loop for two field sides which can be omitted now. Using 180 years with wind directions evenly distributed around a circle (the earlier mentioned 'year – wind direction' analogy), the total number of PEC computations is 19440 (or a multiple if more than one spray applications per year is involved).

The number of different scenarios can be reduced significantly. Spray drift in downward applications is independent of the growth stage of the trees. So there is no need for separate scenario runs for high trees, transplanted trees and spindles. This implies that a possible crop-free buffer zone is not relevant either. Typically, an herbicide treatment is done on the whole ground area except for a spray-free zone of 0.5 m at the field edge. In principle, a wider spray-free zone could be applied which affects the spray drift deposits onto an edge-of-field waterbody. However, in current practice no additional spray-free zone is applied, and therefore it was not accounted for in the simulation scenarios. So the only variables involved in the application scenarios were the number of spray applications per year (1 - 10) and the application technique (conventional, DRT50, DRT75, DRT90). Thus 40 scenarios simulations were carried out.

Figure 39 shows the PEC_{90} values as a function of the number of spray applications per year, for the various application techniques. All PEC_{90} values are also tabulated in Fout! Verwijzingsbron niet gevonden. in Annex 10. As before, the PEC90 values increase with increasing number of applications. However, from about 6 applications onwards the PEC_{90} stabilizes. Note that the concentrations are very low, compared to those obtained for upward and sideways applications.

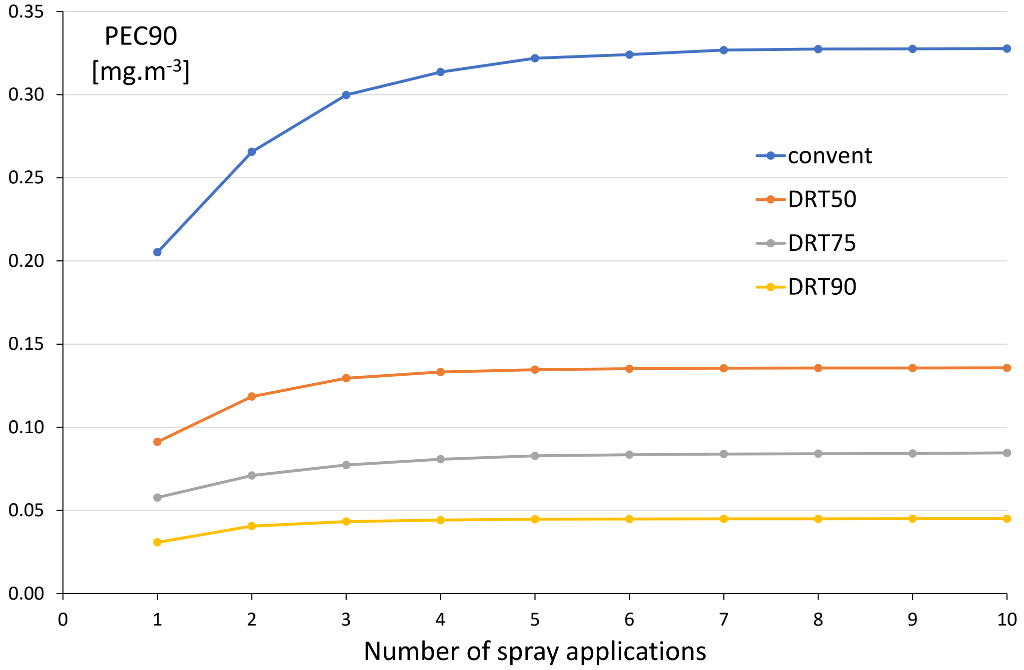

Figure 39 *Results of countrywide simulations for downward spray applications below avenue trees; PEC_{90} vs number of applications per year for different application techniques.*

5.4.2 Parameterisation

The set of simulations for the countrywide situation was also carried out for the selected local situation. In this case the temporal part involved 1000 years, with the same number of wind directions evenly distributed over 360°. These simulations resulted in tables of T_{90} and ζ values.

Figure 40 shows the corresponding T_{90} and ζ values. Only for a single spray application per year the T_{90}s are below 0.9 (and consequently ζ is less than 1). In case of 2 spray applications per year, only for the conventional technique the T_{90} is below 0.9. in all other cases T_{90} is >0.9 and the drift enhancement procedure using the ζ factor is used. The factor ζ stabilizes from about 6 applications and beyond, with an absolute maximum of 1.22, which is about the same as with upward and sideways applications in avenue tree nurseries.

The parameterisation of the spray drift model is very similar to that for upward and sideways applications in avenue tree nurseries (Section 5.3.2), but significantly simpler as only 40 different situations are involved. The T_{90} and ζ values as shown in Figure 40 are tabulated (Fout! Verwijzingsbron niet gevonden. in Annex 10) and used as such in the xSPEXUS model. The parameterised process follows the flowcharts of Figure 37 and Figure 38 and is equal to the procedure described for upward and sideways applications in avenue trees (Section 5.3.2).

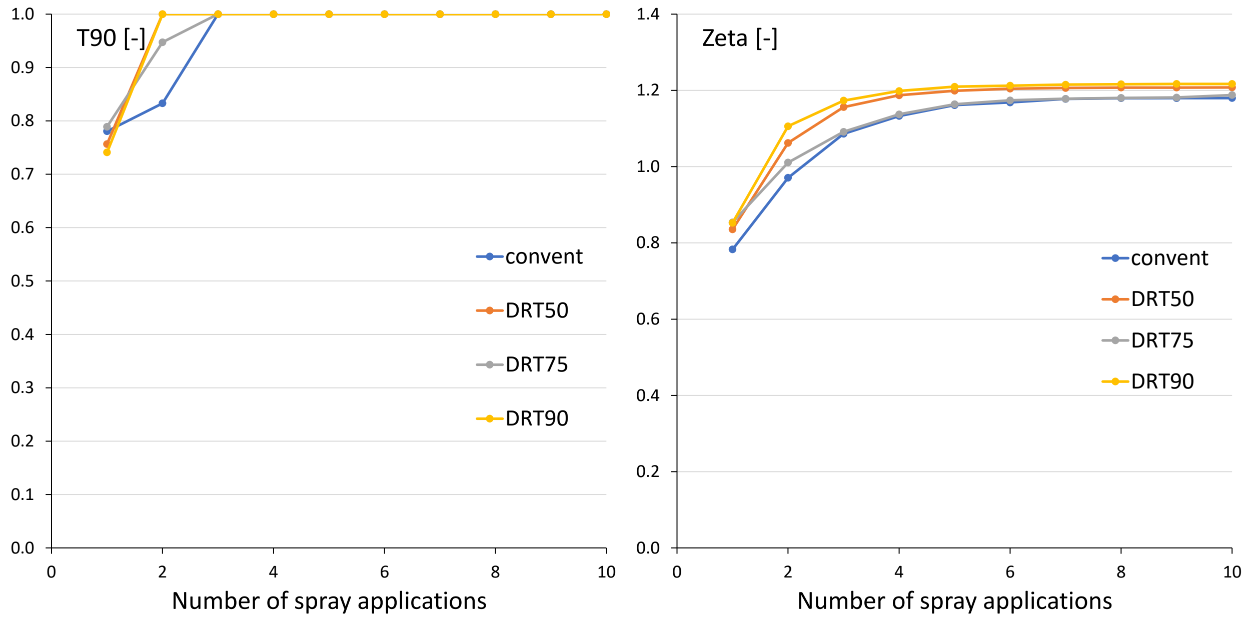

Figure 40 *Results of countrywide simulations for downward spray applications below avenue trees; left: T_{90} vs number of applications per year for different application techniques; right: corresponding adjustment factor ζ vs number of applications per year for different application techniques.*

5.5 Fruit tree orchards – downward applications

5.5.1 Exposure model

The exposure model for downward spray applications in fruit orchards is a kind of mixture of fruit-US and avenue-DWN modelling. According to Table 10 in Section 5.2.1 the same spatial variables are used as with fruit-US, while regarding the temporal variables only wind direction is accounted for, like with avenue-DWN. Additionally, the drift curves and drift reduction curves for avenue-DWN are applicable to fruit-DWN as well. However, since tree strips or grass strips are treated separately rather than the whole ground area, downwind drift deposits must be computed as a series of contributions for the treated strips. This is explained in Section 5.1.3. The minimal crop-free zone at the headland was 6 m; the smart headland approach was followed throughout (Section 5.2.4).

For a detailed description of the spatial variables and how these are implemented in the exposure model, see Boesten et al. (2021) and Holterman et al. (2021). The number of unique spatial settings is about 74,000. Since the orientation of the tree rows in fruit orchards is not random, the effective wind direction (with respect to the orientation of the tree rows) is not random either. Therefore, the 'year – wind direction' analogy as used in scenarios for avenue tree nurseries is not applicable here. This means that the number of years in the exposure scenario must be large enough to obtain sufficiently accurate results. For the countrywide scenarios 100 years were chosen, giving 7,4 million PEC values. Figure 41 gives the flowchart of the countrywide scenario simulations. In the local scenario simulations (clearly with only 1 spatial unit) the number of random years was 100,000.

The width of the crop-free zone determines where the tree strips and grass strips are located, thus it affects the downwind spray deposits. Although the absolute effects are limited, see also Figure 23 in Section 5.1.3, particularly for the spray treatment of tree strips the relative effects are significant. Therefore the possibility of using a crop-free buffer zone was implemented in the scenarios. So scenario simulations were run for 4 application techniques (conventional, DRT50, DRT75, DRT90), 1 – 10 applications per year and an additional crop-free buffer zone 0 – 9 m (added to the minimum agronomic crop-free zone of 3 m). Thus, the total crop-free zone in the scenario simulations covered the range 3, 4, .. 12 m. This led to 400 scenario simulation to be carried out.

Figure 42 shows PEC_{90} as a function of number of spray applications per year, for the available application techniques. On the left-hand side the results for grass strip treatments and on the right-hand side for tree strip treatments. The resulting PEC_{90} values are even lower than with downward treatments below avenue trees, which agrees with the fact that with strip-wise treatments only 2/3 and 1/3 of the ground area are sprayed, for grass strips and tree strips, respectively. As expected, more spray applications per year lead to a higher PEC_{90}. Note the different scales of the y axes: PEC_{90}s for tree strip treatments are much lower than for grass strip treatments, as already indicated in Section 5.1.3. In Figure 43 the effect of crop-free buffer zone on PEC_{90} is shown for spray applications on grass strips (left-hand side) and tree strips (right-hand side). While for tree strips the PEC_{90} values decrease with increasing crop-free buffer zone, for grass strips it is the other way round (although the effect is small). A wider crop-free zone corresponds with a wider first grass strip (outside the tree rows), which leads to slightly higher spray drift deposits and therefore slightly larger PEC_{90}. Again, note that the y axes have different scales. A complete list of resulting PEC_{90} values is given in Table 52 and Table 55 for spraying grass strips and trees strips, respectively (Annex 10).

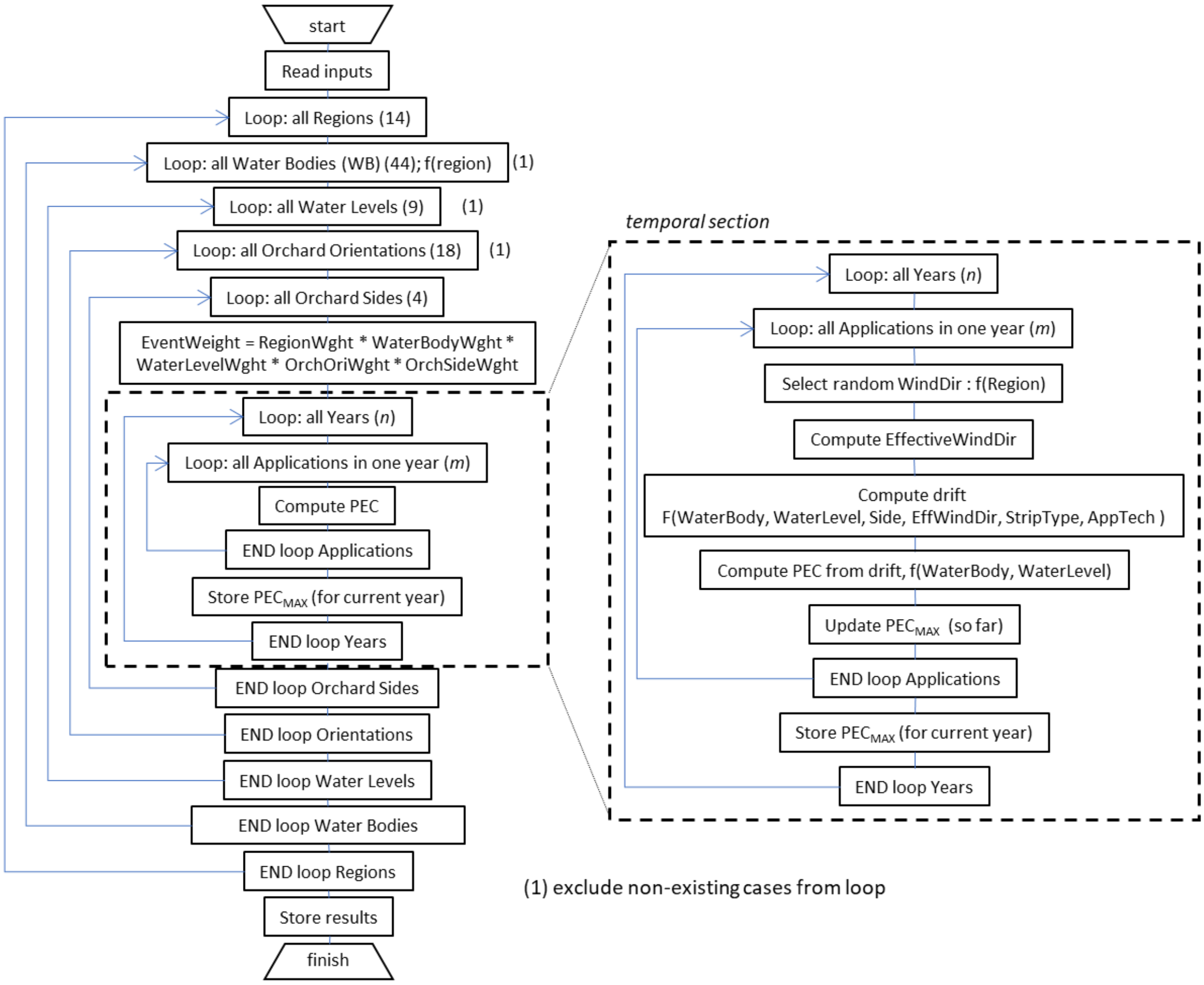

Figure 41 *Flow chart for countrywide scenario simulations, downward applications in fruit orchards.*

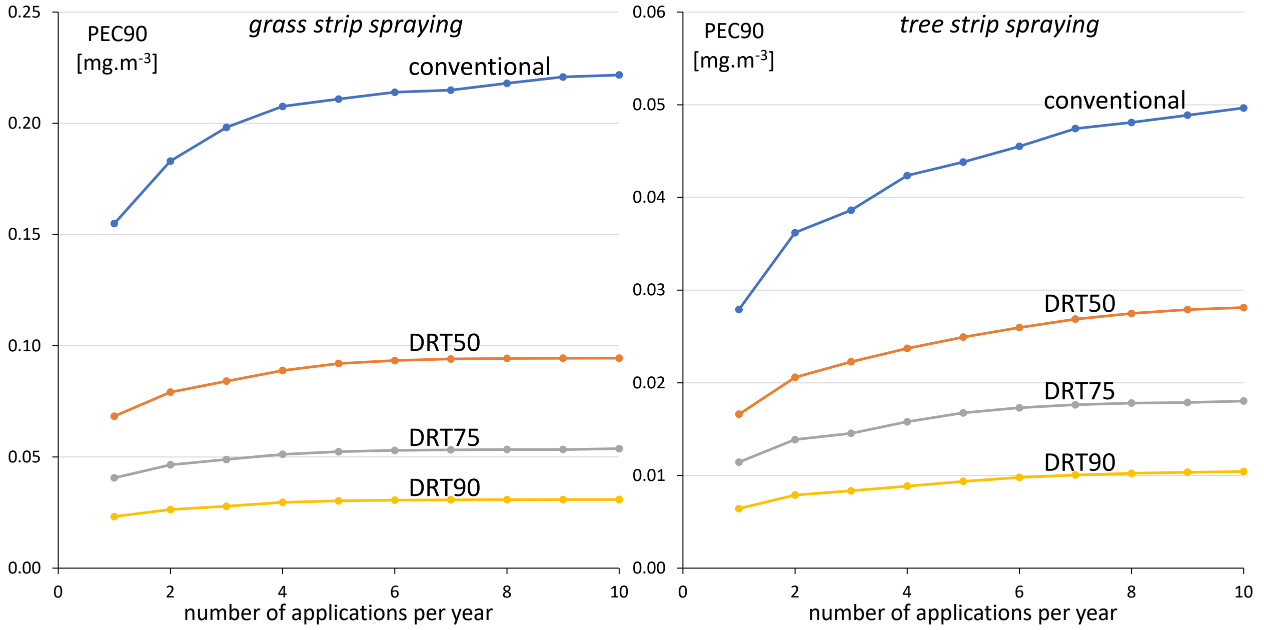

Figure 42 *PEC*$_{90}$ *as a function of number of spray applications per year, downward applications in fruit orchards; various application techniques; crop-free buffer zone 0 m. Left: spraying grass strips; right: spraying tree strips. Note the different ranges of the y axes.*

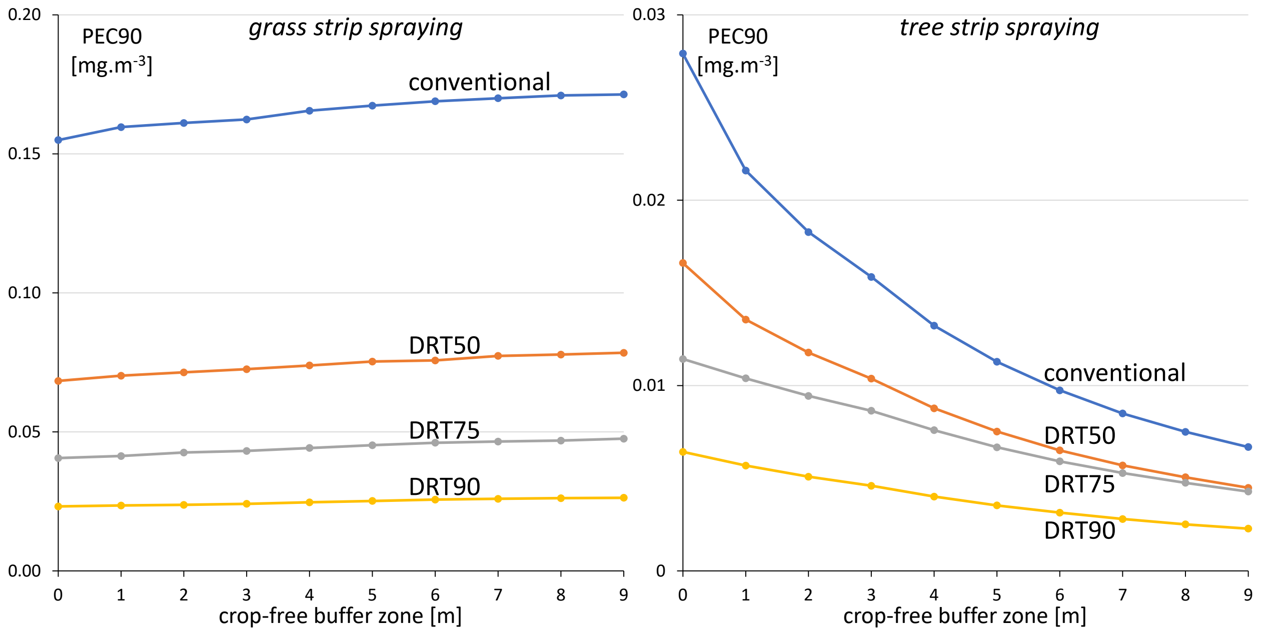

Figure 43 *PEC*$_{90}$ *as a function of crop-free buffer zone, downward applications in fruit orchards; various application techniques; 1 spray application per year. Left: spraying grass strips; right: spraying tree strips. Note the different ranges of the y axes.*

5.5.2 Parameterisation

The set of simulations for the countrywide situation was also carried out for the selected local situation. In this case the temporal part involved simulations over 100,000 random years. Combining the countrywide and local simulations resulted in tables of T_{90} and ζ values. Figure 44 shows the T_{90} and ζ values for grass strip treatments as a function of the number of spray applications per year. Each curve represents a certain combination of application technique and crop-free buffer zone. The graph of T_{90} shows that it is not easy to distinguish a clear pattern of T_{90} (i.e. to describe it by a mathematical function of the involved variables). The curves of ζ appear to be structured much better. As seen with avenue tree nurseries, ζ increases with increasing number of applications per year. In several cases ζ is above 1 and its use is required. The upper limit is about 1.16, which is lower than for downward spraying in avenue tree nurseries. For tree strip treatments, the graphs of T_{90} and ζ are shown in Figure 45. The factor ζ shows the familiar increase with increasing number of applications. However, the curves for T_{90} have a rather peculiar shape. Remarkably, for 9 or 10 applications per year, in some cases T_{90} is >0.9 and the adjustment procedure comes into effect, while in few other cases T_{90} is very low (<0.1). The latter occurs with conventional application technique and absence of a crop-free buffer zone. Comparable to cases of large T_{90} (>0.9), for cases with small T_{90} (<0.1) an adjustment procedure could have been developed. However, it involves only two cases and T_{90} is not far below 0.1 (0.093 and 0.084 for 9 and 10 applications per year, respectively). Therefore it was decided not to adjust these cases of low T_{90}. A complete list of tabulated values of T_{90} are given in Table 53 and Table 56 for spraying grass strips and trees strips, respectively (Annex 10). Corresponding tables of ζ are given in Table 54 and Table 57 for spraying grass strips and trees strips, respectively (Annex 10).

In the parameterisation for the xSPEXUS model it appeared convenient to use these tabulated values of T_{90} and ζ, as with the scenarios for avenue tree nurseries. In fact, the parameterisation is very similar to that for upward and sideways applications in avenue tree nurseries (Section 5.3.2). The flowchart of Figure 37 for the adjustment procedure for large T_{90} is applicable, with the exception that no tree type has to be given for fruit orchards. In case of multiple applications per year, different application techniques are allowed. Then a conservative T_{90} is determined, as described in Section 5.3.2. For an arbitrary crop-free buffer zone within the limits of those used in the countrywide sand local scenarios (0 – 9 m; see previous section), linear interpolation was used to estimate T_{90} and ζ. A crop-free buffer zone outside these limits was not allowed in xSPEXUS (an error message was returned). Similarly, the flowchart of Figure 38 for computing the table of drift deposits (applying the projection method of Section 5.2.6) can be used for fruit-DWN as well, with the same exception regarding tree type.

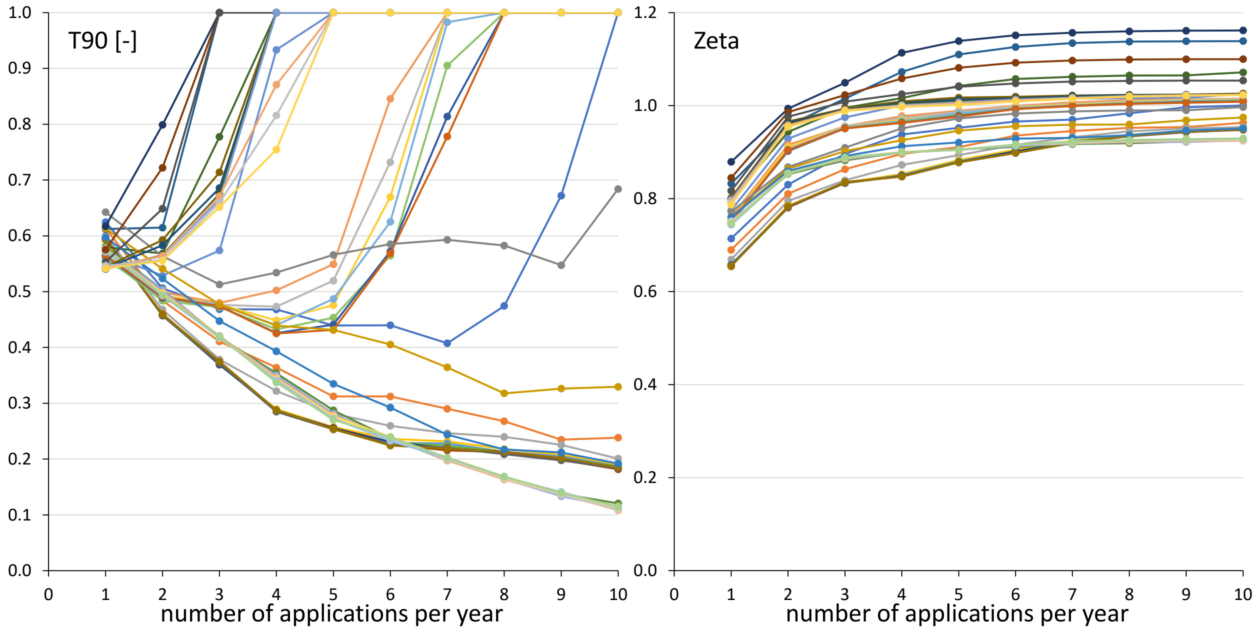

Figure 44 *Temporal percentiles (T_{90}) and drift adjustment factors (ζ) for grass strip treatments below fruit trees, as a function of the number of spray applications per year. Each curve represents a different combination of application technique and crop-free buffer zone.*

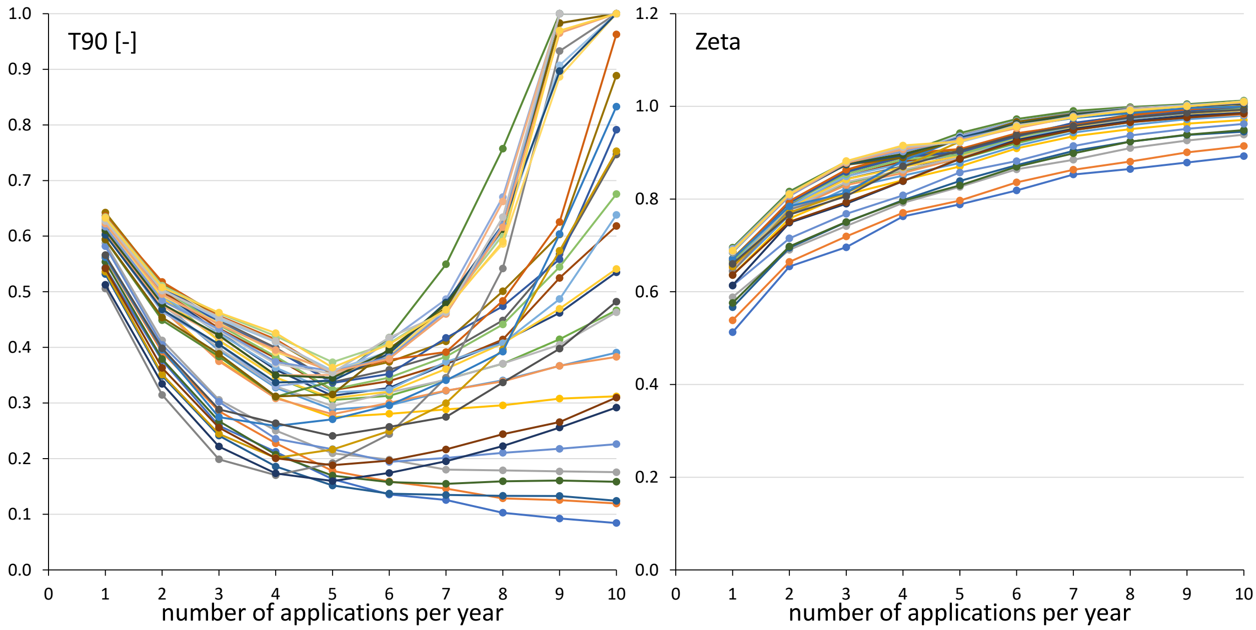

Figure 45 *Temporal percentiles (T_{90}) and drift adjustment factors (ζ) for <u>tree strip</u> treatments below fruit trees, as a function of the number of spray applications per year. Each curve represents a different combination of application technique and crop-free buffer zone.*

6 Drainage

6.1 Is the fruit orchard scenario protective for avenue tree nurseries?

We assessed whether the drainpipe scenario for fruit trees is protective for avenue tree nurseries, i.e. whether the exposure assessment based on the fruit orchard scenario will predict equal or higher pesticide concentrations than expected for avenue tree nurseries.

As the *Rivierenland* region covers 35 percent of the total area in The Netherlands used for avenue tree nurseries, while this region has clayey soils that are probably drained, we use this region to assess the protectiveness of the fruit crop scenario. The rationale behind taking a drained clayey soil to represent avenue tree nursery conditions is that sandy soils will have less drain emission and hence will be less vulnerable to pesticide emission via drainpipes. So, if the fruit orchard drainage situation is protective for drained clayey soils, it will also be protective for sandy soils.

6.1.1 Drain water volumes

The main driving factor for pesticide emission from drainpipes to surface water is the leaching of excess precipitation or irrigation water to the drainpipes. Excess water leaches to the drainpipes via macropore flow but also via the soil matrix. Evaporation and transpiration are both factors that decrease the excess water volume and hence the total volume of water flowing through the drainpipes to surface water. The main differences in growing practices between fruit orchards and avenue tree nurseries are the row distances, irrigation practices and differences in evapotranspiration. To assess the impact of these differences we compared the daily volume of water that was emitted via the drainpipes to the surface water for fruit orchards and avenue tree nurseries.

6.1.1.1 Parameterisation of the hydrological model (SWAP)

The soil hydrology is modelled with the hydrological model SWAP, that is part of the PEARL model. The fruit orchard scenario was taken from Boesten et al. (2021). The avenue tree scenario was derived from the fruit orchard scenario and crop specific properties and crop specific agronomical practices were changed. The soil type considered is a clayey soil with around 30-35% of clay and around 50% of silt. No tillage is considered. The formation of macropores is considered in the model. Weather data of the Herwijnen weather station was used. The bottom boundary condition was calibrated for the arable crop situation in Andelst and reused. The rooting depth of fruit trees and avenue trees is 80 cm below soil surface. The drainpipes are situated at 82 cm below soil surface.

As compared to the fruit orchard parameterisation the following specific aspects for avenue tree nurseries were changed in the model:

- Drip irrigation used in avenue tree nurseries comprises 1 or 2 irrigations in July and 1 or 2 irrigations in September, all with a dose of about 35 mm. This is similar to fruit orchards in which on average 140 mm irrigation is given annually. Also, for fruit orchards sprinkling irrigation is used to prevent frost damage of the flower buds in spring. This type of irrigation is not used for avenue trees. In the model 35 mm irrigation occurs four times a year, i.e. July 1st; July 21st; September 1st and September 21st. More detailed information on irrigation is provided in Annex 3.
- The trees are planted in rows with a distance of approximately 1 m between the trees in a row. The distance between the rows of trees is about 1.5 m for spindle trees and 2.0 m for transplanted and high avenue trees (Section 2.1). For fruit trees the distance between rows is 3 m of which 2 m grass strip (Section 3.1). In contrast to the fruit orchard parameterisation, for the avenue tree nursery model no differentiation was made between the tree strip and the paths in between the tree rows, as both are bare soil.

- The Leaf Area Index (LAI) and Penman-Monteith crop factor used in the parameterisation is considered to be crop stage dependent. Both values are lower than for fruit trees. Table 13 shows the values used in the parameterisation, the dates associated with specific development stages are considered to be the same as for fruit trees. Simulations with SWAP are done with LAI and crop factors based on the geometry of a nursery of spindle trees. The estimation of the LAI and crop factors is described in Annex 3.

Table 13 *Leaf Area Index (LAI) and Penman-Monteith crop factor as function of the day in the year for the crop nursery trees in the Netherlands as used in the scenario for avenue tree nurseries. The model interpolates linearly between the dates. The LAI and Crop factor used for fruit tree orchards is given in brackets for reference.*

Date	**LAI [1]**	**Crop factor [1]**	**Description [2]**
01/Jan	0	1	No leaves
01/Apr	0	1	Start growth of leaves
30/Jun	4.7 (6.9)	1.23 (1.66)	Maximum development of leaves
31/Oct	4.7 (6.9)	1.23 (1.66)	Start of defoliation
31/Dec	0	1	End of defoliation

[1] Values for fruit trees is given in brackets.

[2] This description only roughly indicates the phenological state; therefore it slightly deviates from the stages and periods mentioned in Table 1 (Section 2.1).

6.1.1.2 Comparison of water balances

Annual water balances

This section compares water balances in fruit orchard and avenue tree nurseries. Additional information is provided in Annex 3. Precipitation is the same for both fruit orchards and avenue tree nurseries. Irrigation is almost similar for both scenarios. The (upward) flow over the bottom boundary of the model (at 1 m soil depth) is 38 mm higher for avenue tree nurseries than for fruit orchards in the simulation. Actual evapotranspiration plus evaporation from intercepted water for fruit trees was 540 mm and 586 mm for avenue trees; a difference of 46 mm. There is a small difference of 9 mm in drainage. The latter implies that the expected annual drain flow to the surface water is, according to this model comparison, almost equal for fruit trees and avenue trees.

Transpiration is one of the outputs of the model simulation. Van der Maas & Op 't Hof (2006) report that a full-grown apple tree well supplied with water transpires about 700 L per year. If we assume that about the same is valid for avenue trees, then 700 L per tree per year corresponds to a potential transpiration of 467 mm per year (considering 6667 trees per ha). The simulated potential transpiration for avenue trees is 448 mm, which corresponds fairly well with the 700 L per year transpiration.

Table 14 *Average annual water balance (in mm per year) simulated using the Andelst parameterisation for fruit and for avenue trees for the period 1991 -2005. P is precipitation, I is irrigation, Q_{bot} is the bottom boundary flux (positive downward and at 3.2 m depth), E_{int} is evaporation of intercepted water, E_{sol} is soil evaporation, E_{trp} is transpiration, Dr is drainage; act. = actual and pot. = potential.*

Water balance terms (mm/yr)	**P**	**I**	**Q_{bot}**	**E_{int}**	**E_{sol}**		**E_{trp}**		**Dr**
					act.	**pot.**	**act.**	**pot.**	
Fruit tree orchards	785	141	-72	79	147	183	314	382	458
Avenue tree nurseries	785	140	-110	71	164	198	351	448	449

Hourly volumes

The hourly volume fluxes of drainage water (in $m^3\ m^{-2}\ h^{-1}$) as function of time are plotted in Figure 46. Although the pattern for avenue trees and fruit trees is very alike, some differences seem to occur.

Figure 47 Hourly drainage fluxes for the fruit orchard and avenue tree nursery are plotted against each other. Dots deviating from the 1:1 line (black line in Figure 47) indicate that on the same time the hourly drainage fluxes of the two systems differ. As dots are found on both sides of the 1:1 line drainage fluxes for the avenue tree nursery are not systematically lower or higher than for the fruit orchard. Figure 48 shows that for about 82% of the time drainage fluxes of both scenarios differ less than 10% (in 73% of the time there is no difference).

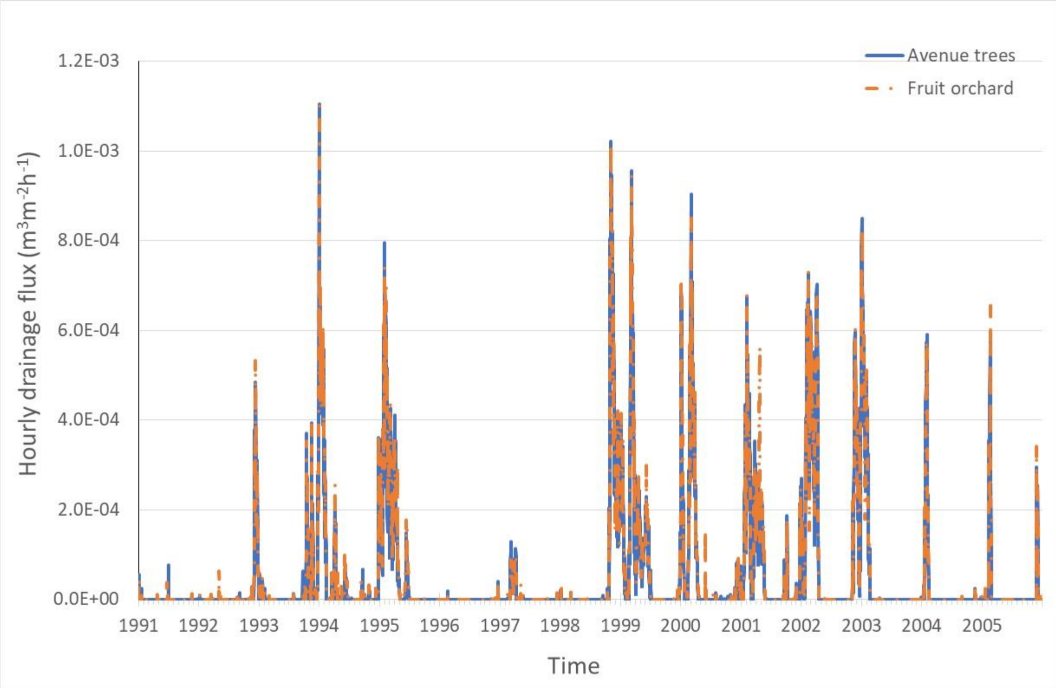

Figure 46 *Hourly volume fluxes of drainage water (in $m^3\ m^{-2}h^{-1}$) as function of time for fruit orchard and avenue tree nursery.*

Conclusion

Comparison of the water balances (Table 14) shows that the average total annual drainage for the fruit orchard scenario is slightly higher than for the avenue tree nursery scenario. From Figure 46 it can be concluded that the number of drainage events of the two different scenarios are comparable and that almost all events occur at the same time.

Figure 47 shows that generally the hourly drainage fluxes of the two scenarios are comparable. Where deviations occur (about 27% of the time in the period 1991 -2005), drainage fluxes for the avenue trees are not systematically lower or higher than for the fruit orchard.

Therefore we concluded that the drainage scenario for the fruit orchards is protective for avenue tree nurseries considering the water volumes discharged to surface water. Therefore the drainage scenario for fruit orchards can be used for calculating the lateral water fluxes from avenue tree nurseries into the scenario ditch.

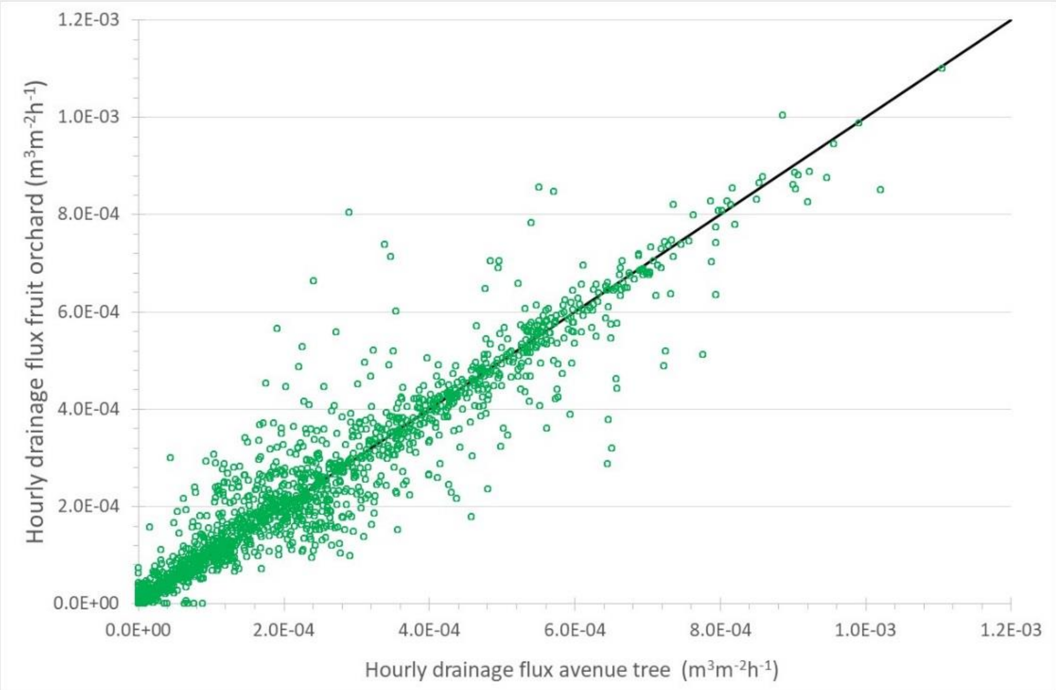

Figure 47 *Comparison of hourly volume fluxes of drainage water (in $m^3\,m^{-2}h^{-1}$) for fruit orchards and avenue tree nurseries.*

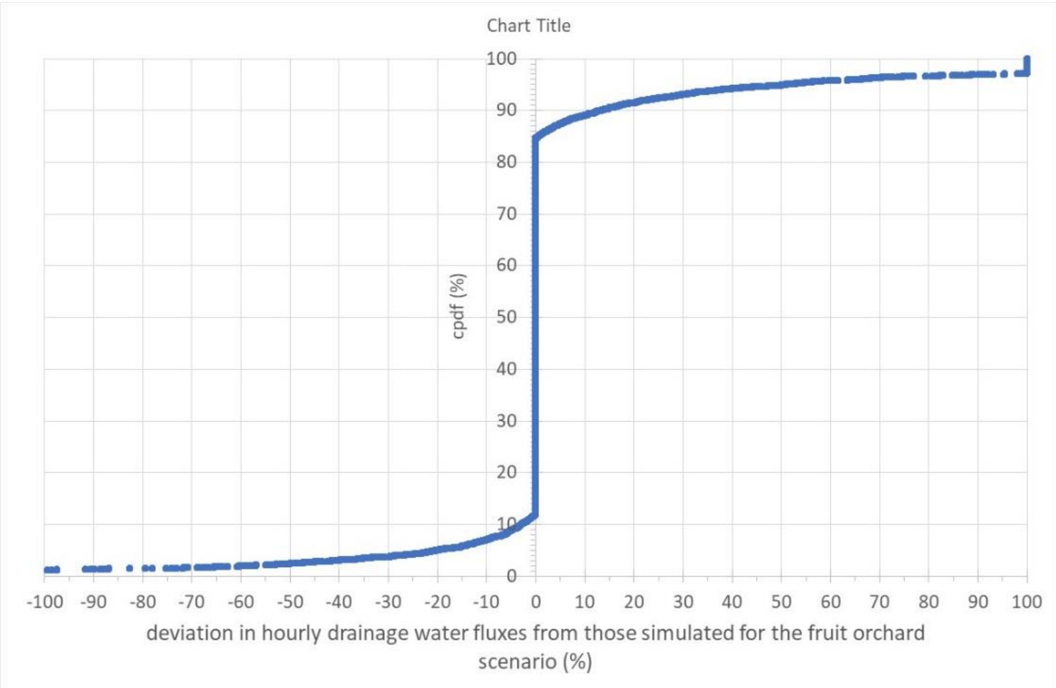

Figure 48 *Cumulative probability density function of the percentage of deviation of the hourly drainage flux of the scenario for avenue tree nurseries from the hourly drainage flux of the fruit orchard scenario[1] (based on simulation results for the period 1991-2005).*

[1] The percentage of deviation is calculated from $100\%\cdot(q_{drain,orchard} - q_{drain,avenuetree})/q_{drain,orchard}$ where $q_{drain,orchard}$ is the hourly volume flux of drainage water in $m^3\,m^{-2}h^{-1}$ calculated using the SWAP parameterisation for the fruit orchard and $q_{drain,avenuetree}$ is the hourly volume flux of drainage water in $m^3\,m^{-2}h^{-1}$ calculated using the SWAP parameterisation for avenue trees.

6.1.2 Adsorption

For pesticides with a high sorption coefficient, adsorption of pesticide to organic matter and clay plays a large role as it may decrease the total emitted mass via the drainpipes. Avenue trees are grown in soils with a higher level of organic matter than fruit trees. This decreases the emitted mass, hence, regarding adsorption the fruit orchard scenario will be protective for avenue tree nurseries. Note that for the sandy soils in the Brabant region (Section 2.1) the emission via drainpipes is probably of little relevance.

6.2 Avenue tree nurseries – upward and sideways spray applications

6.2.1 Introduction

Section 6.1 and Annex 3 show that it is justified to use the parameterisation of the drainage scenario for fruit orchards for avenue tree nurseries as well. As explained in Section 4.3.1 for the simulation of the drainage fluxes with the PEARL model, the dosage needs to be adjusted, which is different from the adjustment developed for the fruit orchard. Modified adjustment factors are required since:

- The geometry of avenue tree nurseries is different: the tree rows are 2 m apart whereas in fruit orchards they are 3 m apart; below and between the avenue trees all soil is bare whereas in the fruit orchard the 1 m tree strips (bare soil) are separated by 2 m strips covered with grass
- Distribution of spray deposits on trees and soil below for avenue trees differs from that for fruit trees

Below the dosage adjustment factors and interception fraction for the drainage scenario for avenue tree nurseries are elaborated.

6.2.2 Methodology

Van de Zande et al. (2019, Table 20) state that 65% interception occurs by the trees of the tree nursery and 35% is deposited on the bare soil below the trees. This applies to all three types of avenue tree growing systems (spindle trees, transplanted trees and high avenue trees). Crop interception is defined here as the fraction of all sprayed liquid that is deposited on the trees.

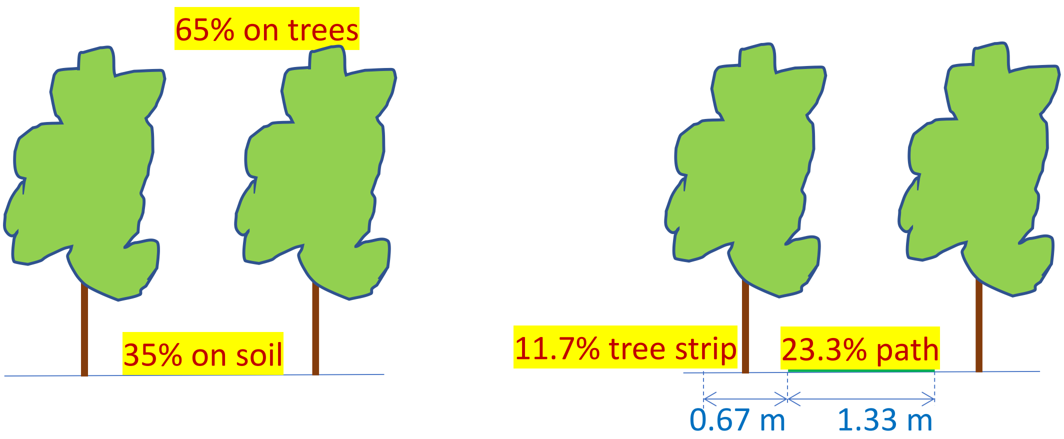

Figure 49 *Left: interception by the trees and deposition on the soil in avenue tree nurseries according to Van de Zande et al. (2019). Right: the 35% that is deposited on the soil in avenue tree nurseries is distributed over tree strip and path, following the strip approach for fruit orchards (see explanation in the text).*

Following the approach developed for fruit orchards, the total deposition on the soil has to be distributed over the tree strip and the grass strip (both of which are bare soil in avenue tree nurseries). If we assume tree strips relate to 1/3 of the ground area in the avenue tree nursery, then 1/3 * 35% = 11.7% deposits on the bare soil underneath the trees on this strip. The imaginary 'grass strips' are the bare soil paths in between the tree rows, which relate to 2/3 of the ground area, where deposits are 2/3 *35% = 23.3% (Figure 49, right-hand side). Hereafter we refer to the 'grass strip' as the path strip (since there is no grass on these paths). This means that the total amount of spray applied to the 'tree strip' is 65% (deposited on the trees) + 11.7% (deposited on the soil under the trees) = 76.7%; on the paths between the tree strips 23.3% is deposited, expressed as percentage of all sprayed liquid.

Because the procedure of determining the drainpipe emission involves two whole-field simulations, first for one ha of tree strip and next for one ha of path strip, the dosages derived above (76.7% of the applied mass on the tree strip and 23.3% on the paths in between) should be multiplied by the inverse of their respective areal coverage factors. So, for a full-field treatment the dosage as mentioned on the pesticide label for an imaginary tree nursery of only 'tree strips' needs to be multiplied by a factor of 2.30 (i.e. 76.7% * 3/1= 230% of the intended dosage) and the dosage for an imaginary avenue tree nursery of only 'paths' by a factor 0.35 (i.e. 23.3% * 3/2 = 35% of the intended dosage). The dosage adjustment factors of 2.30 for the tree strip and 0.35 for the path strip are applied irrespective of the spraying technique.

Crop interception (expressed as percentage of the volume of sprayed liquid applied to the tree strips) on the tree strip is then 65/76.7 = 84.8%. Crop interception on the paths in between is 0% (by definition; there is no crop there).

Table 15 summarizes the dosage adjustment factors and crop interception factors for the tree strip and path strip of the tree nursery assuming that the PEARL parameterization of the tree strip of the orchard is used for the tree strip of the tree nursery and that the parameterization of the grass strip of the orchard is used for the path strip of the tree nursery.

A soundness check of the approach described above is given in Annex 9.

Table 15 *Dosage adjustment factors and crop interception factors of the tree strip and the path strip of the tree nursery assuming a spatial distribution of 1/3 tree strip and 2/3 path strip in the tree nursery, for upward and sideways spraying.*

Fruit orchards	**Avenue tree nurseries**		
Type of strip	**Type of strip**	**Dosage adjustment factor**	**Crop interception factor**
Tree strip - 1/3 of area	Tree strip - 1/3 of area	2.30	0.848
Grass strip – 2/3 of area	Path strip (in between tree strips) – 2/3 of area	0.35	0.0

6.3 Avenue tree nurseries – downward spray applications

The parameterisation of the drainage scenario for upward and sideways spraying in fruit orchards is also used for downward spray applications in avenue trees. Two PEARL simulations are done: one assuming the whole area is tree strip and the second assuming the whole area is grass strip, or actually the paths in between the tree strips for avenue tree nurseries. Afterwards, the results (drain water flow and solute fluxes in drain water) for both simulations are combined while weighting according to the actual spatial factors for tree strips (1/3) and paths (2/3).

In case of downward spraying, the dosage adjustment factors to be used for both PEARL simulations are set to 1. Using the same procedure as given in Section 6.2, this can be derived as follows. For both strips the entire ground area receives spray deposits (100% deposition on both strips). Note that the full dose is directed to and received by the ground area; the interception by the trees is 0%. Suppose this deposition on the soil of both the tree strips and the paths in between corresponds to a treatment of 100 L ha^{-1}. If only the tree strips would have been sprayed, which cover 1/3 of the nursery's ground area, the averaged dose in the nursery would be 33.3 L ha^{-1}. Then, applying the inverse of the relative areal coverage, the full dose for a field of only tree strips would be 3/1 * 33.3 = 100 L ha^{-1}. This is equal to the original full dose, therefore the adjustment factor is 1.

Similarly, when spraying only the path strips, covering 2/3 of the area, then the average dose would be 66.7 L ha^{-1}. Again, applying the inverse of the relative areal coverage, the full dose for a field of only path strips would be 3/2 * 66.7 = 100 L ha^{-1}. Since this is equal to the original full dose, the required adjustment factor is 1.

Dosage adjustment factors and crop interception factors used for the PEARL simulations for downwards spraying of the total ground area of the avenue tree nursery are summarized in Table 16.

Table 16 *Dosage adjustment factors and crop interception factors of the tree strip and the path strip of the tree nursery assuming a spatial distribution of 1/3 tree strip and 2/3 path strip in the tree nursery.*

Treatment on the pesticide label	**Dosage adjustment factor for tree strip**	**Dosage adjustment factor for path strip**	**Interception on tree strip (1)**	**Interception on path strip (2)**
Downward spraying, total ground area of the avenue tree nursery (outside and in between rows treatment)	1.00	1.00	0	0

(1) downwards spraying, so the trees are not treated, hence the crop interception is zero.
(2) the path strip concerns bare soil, hence the crop interception is zero.

6.4 Fruit tree orchards – downward spray applications

For downwards spraying in fruit orchards the dosage adjustment factors to be used for the PEARL simulations for the grass strip and the tree strip are both set to 1. In fact, the derivation is equal to that given in Section 6.3 for downward applications in avenue tree nurseries. However, downward applications in fruit orchards involve either a tree strip treatment or a grass strip treatment. These two treatments imply a different set of adjustment and interception factors. This is explained below.

With a tree strip application, the grass strips are not treated and the applied dose on the grass strips is zero. The dosage adjustment factor for the tree strip is 1 (see Section 6.3). Crop interception is zero because the trees are not treated. The grass strips are not treated either in this case, hence a dosage adjustment factor of 0 is assumed for the grass strip (in fact any factor would do, since the applied dose is zero).

With a grass strip application, the tree strips are left untreated and the dose on these strips is zero. The dosage adjustment factor for the grass strip is 1 (see Section 6.3). On the grass strip, the crop intercepting the applied spray is grass, having an interception factor of 0.9. The tree strips are not treated in this case, hence a dosage adjustment factor of 0 is assumed for the tree strips (again, this factor is irrelevant since the dosage is zero on the tree strips).

Unlike the PEARL simulations for fruit-US, with downward applications in fruit orchards the dosage adjustment factors for both strips are 1. This is caused by the fact that with downward applications the actual dosages on tree strip and grass strip are the same (i.e. 100 L ha^{-1} as assumed), while with upward and sideways applications most of the spray is directed to (and received by) the tree strip whereas the grass strip receives only a small part of the applied spray.

Dosage adjustment factors and crop interception factors used for the PEARL simulations for downwards spraying of either the tree strip or the grass strip are summarized in Table 17.

Table 17 *Dosage adjustment factors and crop interception factors of the tree strip and the grass strip for downward spray applications in the fruit orchards.*

Treatment	**Dosage adjustment factor for tree strip**	**Dosage adjustment factor for grass strip**	**Interception on tree strip (1)**	**Interception on grass strip**
Downwards spraying of the tree strips in a fruit orchard	1.00	0	0	0.9 (n.a)
Downwards spraying of the grass strips in a fruit orchard	0	1.00	0 (n.a)	0.9

n.a. = not applicable; because with a dosage adjustment factor of zero, the crop interception is not relevant

(1) downwards spraying, so the trees are not treated, hence the crop interception is zero

7 Parameterisation of TOXSWA

7.1 Hydrology

Similar to the fruit orchard scenario a secondary edge-of-field ditch of the hydrotype '*Betuwe stroomruggronden*' was selected for the avenue tree nursery scenarios (Section 4.2.3,). Also in view of having the main area of the avenue tree nurseries in the '*Rivierenland*' area, it was decided to use for the avenue tree nursery scenarios the same parameterisation of the hydrology of the selected ditch as used in the fruit orchard scenario.

The corresponding mean ditch geometry of the selected ditch is described by Massop et al. (2006), as listed in Table 18 and depicted in Figure 50.

Table 18 *Dimensions of the selected ditch for all scenarios.*

Symbol	Description	Ditch properties
	Hydrotype	Betuwe stroomruggronden
	Ditch type	secondary ditch
t	Width top ditch (m)	3.90
b	Width bottom ditch (m)	1.74
w	Width water (m)	2.34
h	Water depth (m)	0.30
A	Lineic volume (m^3 m^{-1})	0.612
s_1	Slope (horizontal:vertical)	1

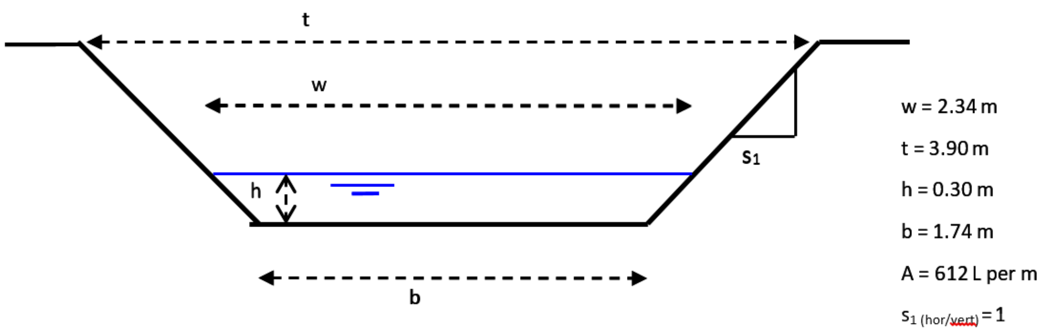

Figure 50 *Dimensions of the ditch for the selected scenario, where w is the width of the water surface, h is the water depth, b is the width of the bottom of the ditch, t is the width of the top of the ditch, s1 is the side slope (horizontal/vertical), and A is the lineic volume of the water in the ditch.*

The selected ditch is assumed to be positioned in a polder type of landscape of similar ditches running parallel towards a larger watercourse for inlet/outlet (Figure 51). Based on a GIS analysis applied in the *Rivierenland* area, the distance between the ditches was estimated to be 140 m (Wipfler et al., 2018). Simulations (hydrology and fate and behaviour of the pesticide in the ditch) were done over a length of 300 m. Of this 300 m, the middle part of 100 m was assumed to be treated with pesticide.

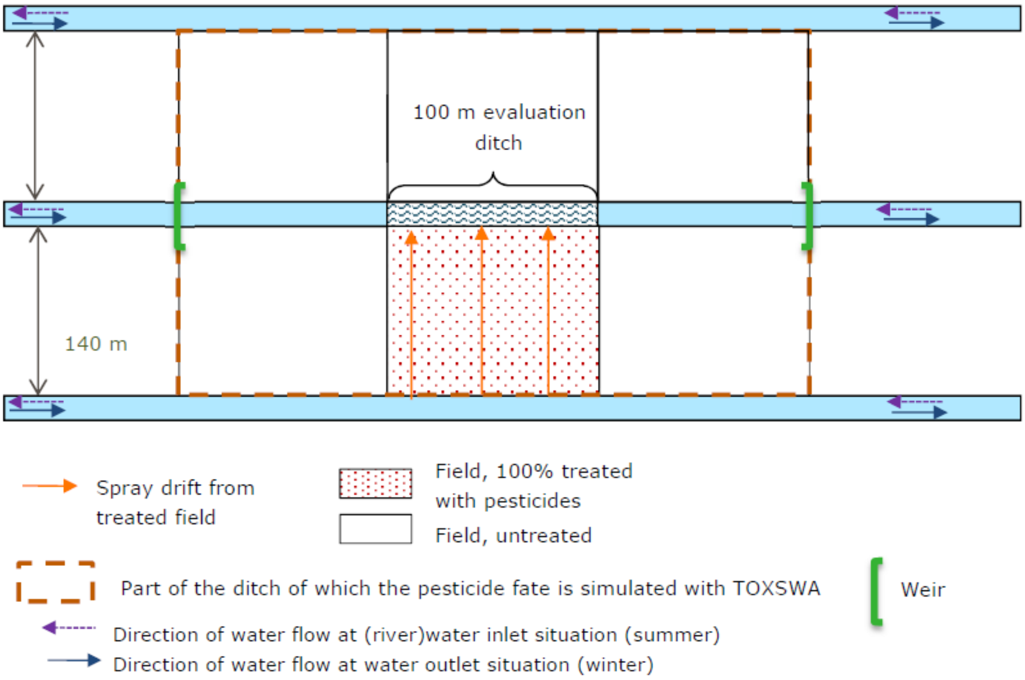

Figure 51 *Schematic representation of the position of the evaluation ditch in the landscape.*

The SWQN model (Smit et al., 2009) was used to describe water flow rates and water depths in the ditch as a function of time (Wipfler et al. 2018), using calibrated flow rates as boundary conditions and drainage water fluxes from the SWAP/PEARL model parameterised for the fruit orchard (see Section 4.3). As mentioned before, for the fruit orchard and avenue tree nursery scenarios the same ditch hydrology is used. This means that SWQN was not calibrated for avenue tree nurseries using drainage water fluxes from a SWAP/PEARL simulation with a specific parameterisation for avenue tree nurseries. This was considered defensible as the drainage scenario for fruit trees was considered to be protective for avenue tree nurseries (Section 6.1). The derivation of the water flow rates used as boundary conditions is described in detail in Wipfler et al. (2018) and summarized in Boesten et al. (2021).

7.2 Other TOXSWA scenario input parameters

7.2.1 Introduction

Not only the selected ditch was similar for the fruit orchard scenario and avenue tree nursery scenario, but also all other TOXSWA scenario input parameters were similar for both scenarios. These TOXSWA scenario input parameters are described in detail by Ter Horst et al. (2020) and summarized for the fruit-US scenario by Boesten et al. (2021). For completeness a very short summary of the TOXSWA scenario input parameters, other than related to hydrology, is provided in the following sections.

7.2.2 Water temperature

Water temperatures are simulated on an hourly basis using hourly meteorological data from the KNMI meteorological station Herwijnen as input. The concept for simulating water temperatures used by TOXSWA is described by Beltman et al. (2017) and is based on taking in to account all relevant terms of the energy budget of the water system, including the external source of incoming drainage water. Temperatures of drainage water are simulated by the SWAP/PEARL model and provided to TOXSWA. Furthermore, a well-mixed water layer and sediment temperatures equal to water temperatures are assumed. Details of the parameterization are provided by Ter Horst et al. (2020).

7.2.3 Sediment properties

Sediment properties for the fruit orchard and avenue tree scenarios were taken from measurements from one out of four locations relevant for Dutch fruit crops. At the location selected, Willemstad, the lowest organic matter content was measured. This location was selected because the properties of the selected location gave the highest PEC_{90} in the water layer of the scenario ditch (Boesten et al. 2021). Sediment properties of the selected location are provided in Table 19.

Table 19 *Properties of the sediment from the selected location: Willemstad.*

Layer	Organic matter content (%)	Dry bulk density (kg L^{-1})	Porosity (m^3 m^{-3})	Tortuosity (-)
0-1 cm	12	0.32	0.83	0.73
1-10 cm	10	0.49	0.78	0.67

7.2.4 Discretization of the sediment

The vertical discretization of the sediment as recommended by Beltman et al. (2018) was used (see Annex 8 for details). This discretization is in line with the sediment discretization used for the FOCUS Surface Water scenarios. Using this default sediment discretization might not result in convergence of the numerical solution of the balance equation of the sediment for substances with a higher sorption coefficient. Analogous to FOCUS Surface Water, the software tool DRAINBOW therefore offers the option to use the refined sediment discretization for substances with a $Koc_{sediment}$ value equal or larger than 30 000 L kg^{-1}. This refined sediment discretization is provided in Annex 8.

In case of a TOXSWA simulation for a parent with metabolite(s) where the substances have very different sorption values, the use of the refined sediment discretization might result in numerical instability. In such a case it is advised to use the default discretization. Using the default discretization for the substance with the $Koc_{sediment}$ equal or larger than 30 000 L kg^{-1} will lead to an overestimation of the PEC in the water layer which is however conservative from a registration point of view.

8 Example runs

8.1 Objectives of the example calculations

Calculations with the newly developed scenario are done for two substances and their corresponding application patterns which are commonly used in Dutch tree nurseries. These calculations are performed to demonstrate the calculation procedure and the main pathway (drift deposition or drainpipe emission) of the annual PEC_{max}.

The processes for drainage and ditch in the scenario for avenue tree nurseries are similar to those for fruit orchards. However, for avenue tree nurseries the spray drift deposits and corresponding temporal percentiles are different from the ones calculated for fruit orchards. Calculations are done with the sediment properties of location Willemstad (Adriaanse et al., 2015).

Regarding these similarities of drainage and ditch the working group considered it unnecessary to make an in-depth analysis for the scenarios in this report of the effect of certain scenario characteristics (e.g. hydrology, entry route), substance properties or the application scheme on the annual PEC_{max}. More insight on this was already provided for the fruit-US scenarios (Boesten et al., 2021).

The example calculations discussed here focus on the methodology and the contribution of the exposure routes drift deposition and drainpipe emission, and to a limited extend, atmospheric deposition.

8.2 Summary of the scenario calculation procedure

For the calculation of the PEC_{90}, being the 90^{th} percentile of the countrywide scenario, TOXSWA receives input from both the drainpipe emission and spray drift deposition. The input from the drainpipe emission is provided by the PEARL model, which calculates the fate in the soil-vegetation compartment based on substance properties and dose. Spray drift deposits are calculated by the local spray drift model xSPEXUS.

Next, TOXSWA calculates the concentration in the water phase over 15 year after a so-called warming-up period of 5 years. The simulation period is confined by the use of the extended Andelst data set. The original Andelst dataset (Scorza Júnior et al., 2004) could be extended to only 15 years (1991 - 2005) due to the limited availability of data needed for the lower boundary condition in SWAP-PEARL (see section 5.2 in Tiktak et al., 2012b). The percentile year for the exposure assessment is selected via a procedure described in Boesten et al. (2021), which is summarized in Section 4.4. Calculations were done with the following model versions: xSPEXUS version 1.41, SWAP version 3237, PEARL version 3.2.17.7 and TOXSWA model version: 3.3.7-A (Feb 22, 2021).

Three sets of example calculations were done for:

- upward and sideways spraying of two substances (I_b and F) in spindles and high avenue trees
- downward spraying of two substances (H_d and H_p) in high avenue trees
- downwards spraying of one substance (H_{py}) in fruit orchards

The substances were selected by the working group in consultation with the Ctgb. The substances are loosely based on active ingredients that are currently authorised for the use in avenue tree nurseries and fruit cultivation. EFSA agreed end-points of the substance properties were used. The dosage and application pattern selected for each substance is considered to be representative for the Dutch agricultural practice in tree nurseries and fruit orchards. The most relevant substance properties and the application scheme for each substance are given in Table 20, Table 21 and Table 22. The full list of substance properties is provided in Annex 4. Results of the example calculations are given in Sections 8.3, 8.4 and 8.4. In each of these sections the following graphs for the target stretch of the scenario ditch are presented:

- The average water concentration of dissolved substance as a function of time for the 15 evaluation years (1991 – 2005);
- The annual maximum water concentration of dissolved substance (PEC_{max}) per year for the 15 evaluation years;
- The average water concentration of substance dissolved as function of time for the selected target year only;
- Cumulative monthly mass balance terms for the 15 evaluation years.

Note that average concentrations of dissolved substance in the water layer of the target stretch of the scenario ditch are reported (so the concentrations do not include the mass of substance sorbed to suspended solids) and they have been averaged over the 100 m target stretch.

If considered necessary, additional graphs are included to support explanations of certain aspects of the results.

8.2.1 Upward and sideways spraying in avenue tree nurseries

The calculations for upward and sideways spraying of substance I_b and F in avenue tree nurseries were done with a total crop-free zone of 5 m (the requirement by the Environmental Activities Decree, EAD; MinI&W, 2021). The EAD also requires at least a DRT75 application technique. For spindle trees no DRT75 technique is available, therefore the next higher technique, DRT90, was used instead. For high avenue trees the DRT75 application was used. A conventional spray application with spindle trees leads to lower drift deposits than with high avenue trees. Combining the former with the higher drift reducing DRT90 technique and the latter with the lower drift reducing DRT75 technique, the differences in downwind spray deposits for spindles and high avenue trees become even larger. Thus, these combinations of tree type and mitigation measures cover the lower and upper range of spray drift deposition (as percentage of the applied dose) for avenue tree nurseries. Details are shown in Table 20.

Table 20 *Substance, dosages and application patterns used for the example calculations for upward and sideways spraying in avenue tree nurseries.*

Substance	**I_b**	**F**
Substance type	insecticide	Fungicide
Substance group	butenolide	Phthalimide
Crop	Spindle trees (DRT90) High avenue trees (DRT75)	Spindle trees (DRT90) High avenue trees (DRT75)
Applied dosage	0.15 kg/ha	1.2 kg/ha
Number of applications	4 (at 7 days interval)	5 (at 10 days interval)
Date of 1st application	Day 113 (23 April)	Day 120 (30 April)
$DegT_{50,soil}$ (d)	94.8	3.82
$DegT_{50,water}$ (d)	228	1 (pH 7, 25°C)
$DegT_{50,sediment}$ (d)	1000	1000
Kom_{soil} (L/kg)	57.0	56.3

8.2.2 Downwards spraying in avenue tree nurseries

The calculations for downwards spraying of herbicides H_d and H_p in high avenue trees were done for a DRT90 technique and a spray-free zone of 0.5 m, following the EAD (MinI&W, 2021). As herbicide treatments usually are done in either spring or autumn, separate simulations were done for a spring application and an autumn application for herbicide H_d. For herbicide H_p two spring simulations were done, the first simulation with two treatments in April and the second with two treatments in May. Details are shown in Table 21. All calculations were done using a DRT90 application technique, combined with a spray-free zone of 0.5 m (as prescribed by the EAD).

Table 21 *Substance, dosages and application patterns used for the example calculations for downwards spraying in avenue tree nurseries.*

Substance	**H_d**	**H_p**
Substance type	herbicide	Herbicide
Substance group	dinitroaniline	Pyridine
Crop	High avenue trees (DRT90, spray free zone 0.5 m)	High avenue trees (DRT90, spray free zone 0.5 m)
Applied dosage	1.0 kg a.i./ha	0.05 kg a.i./ha
Number of applications	1	2 (at 7 days interval)
Date of 1st application	Spring treatment: day 111 (21 April) Autumn treatment: day 312 (8 November)	April treatment: day 104 (14 April) May treatment: day 135 (14 May)
$DegT_{50,soil}$ (d)	182.28	7.05
$DegT_{50,water}$ (d)	1000 (pH 7, 20ºC)	1000 (pH 7, 20ºC)
$DegT_{50,sediment}$ (d)	31.08 (pH 7, 20ºC)	1000 (pH 7, 20ºC)
Kom_{soil} (L/kg)	8000	0.818
P_{sat} (Pa)	3.0 10-4 at 20°C	1.36x10-3 at 20°C

8.2.3 Downwards spraying in fruit orchards

The calculations for downward spraying in fruit orchards were done with herbicide H_{py} and its leaching-sensitive metabolite H_{py_Met1}. Herbicide treatments in fruit orchards can be done either in-row (i.e. spraying of the bare soil strip under the fruit trees) or at the outside edge and the paths between the tree rows (i.e. spraying of the grass strips). Each of these treatments can take place in spring or in autumn, thus leading to the following four simulations carried out:

- In-row treatment (tree strip) in spring
- Outside edge and path treatment (grass strip) in spring
- In-row treatment (tree strip) in autumn
- Outside edge and path treatment (grass strip) in autumn

All calculations were done using a DRT90 application technique. For the grass strip treatments a spray-free zone of 0.5 m was taken into account (see Section 3.2). The total crop-free zone (tcfz) was 3.0 m. However, Figure 23 (Section 5.1.3) shows that downwind spray drift deposits for grass strip treatments are highly insensitive to the width of the crop-free zone. For the tree strip treatments the tcfz was 4.5 m. Further details are shown in Table 22.

Table 22 *Substance, dosages and application patterns used for the example calculations for downwards spraying in fruit orchards.*

Substance	**H_{py}**	**H_{py_Met1}**
Substance type	herbicide	metabolite of H_{py}
Substance group	pyrazole	
Crop	Fruit orchard (apple) (DRT90)	
Applied dosage	0.0.21 kg a.i./ha	
Number of applications	2 (at 21 days interval)	
Date of 1st application	Spring treatment: day 111 (21 April) Autumn treatment: day 310 (6 November)	
$DegT_{50,soil}$ (d)	0.32	16.5
$DegT_{50,water}$ (d)	0.08	81.7 (pH 7, 20ºC)
$DegT_{50,sediment}$ (d)	1000	1000
Kom_{soil} (L/kg)	1130.5	73.09
Formation fraction	N.A.	Soil: 0.949 Water and sediment: 1.0

8.3 Results of calculations for upward and sideways spraying in avenue tree nurseries

8.3.1 Substance I_b

Substance I_b is a butenolide which is applied four times in spindle trees and high avenue trees with a dose of 0.15 kg ha^{-1} in the period April-May. Figure 56 shows the average concentration (dissolved) of substance I_b in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for spindle trees (with DRT90 application) and high avenue trees (with DRT75 application). Concentrations patterns of the simulations for spindle trees and high avenue trees were very similar, although spray drift deposits for high avenue trees were more than one order of magnitude higher than those for spindle trees due to differences in tree shape and application techniques used (see Section 5.1.1). For both crops the concentrations were driven by drainage events. I_b is a relatively mobile and persistent substance. Part of the substance applied is transported quickly to the drains via the macropores, relative shortly after application. However, another part will reside during summer in the soil matrix and then leach to the drainpipes in the autumn of the year of application and/or in spring the following year (see for instance the timings of the annual PEC_{max} values in Figure 54 and Figure 55).

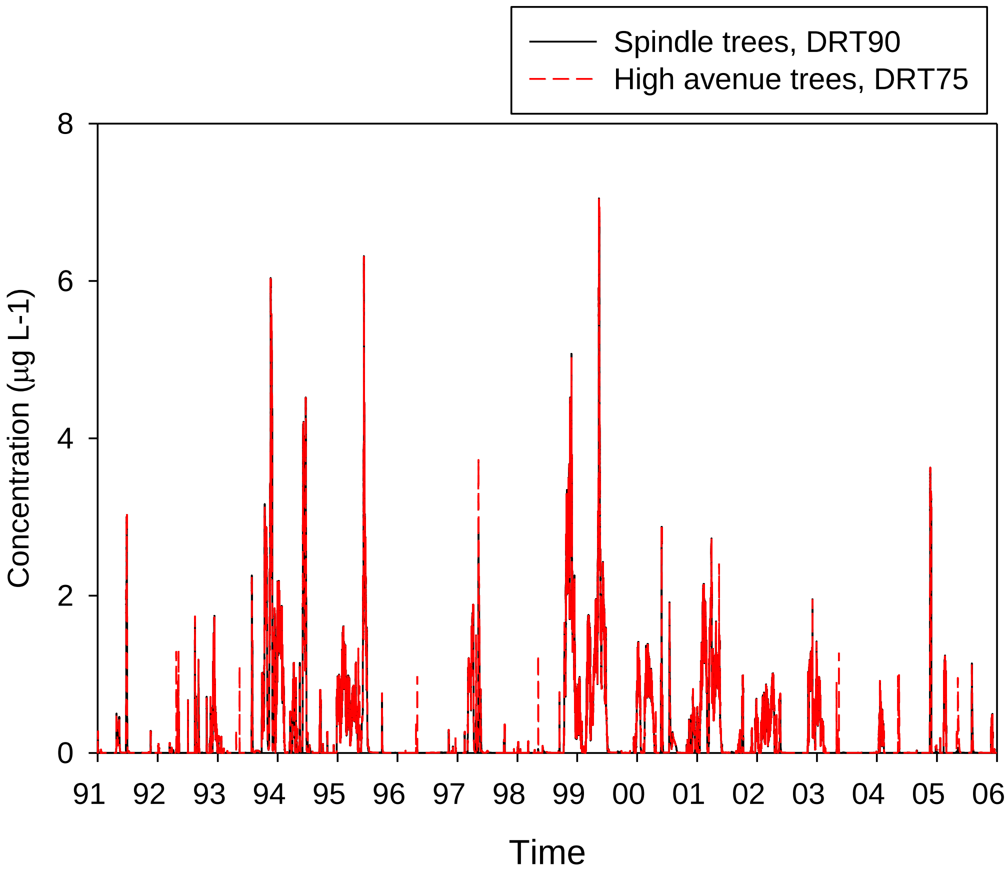

Figure 52 *Average concentration (dissolved) of substance I_b in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for two tree nursery crops, for four applications in spring. For spindle trees with DRT90 and high avenue trees with DRT75.*

Figure 53 shows the annual maximum concentration (dissolved) of substance I_b in the water of the 100 m target stretch for spindle trees using DRT90 applications and high avenue trees using DRT75 applications. The blue arrows indicate the annual PEC_{max} value of the corresponding target temporal percentile, which was for both crops the 63rd percentile from drainage. For spindle trees, the 63rd percentile is found in 2004 and for high avenue trees the 63rd percentile is found in 1997.

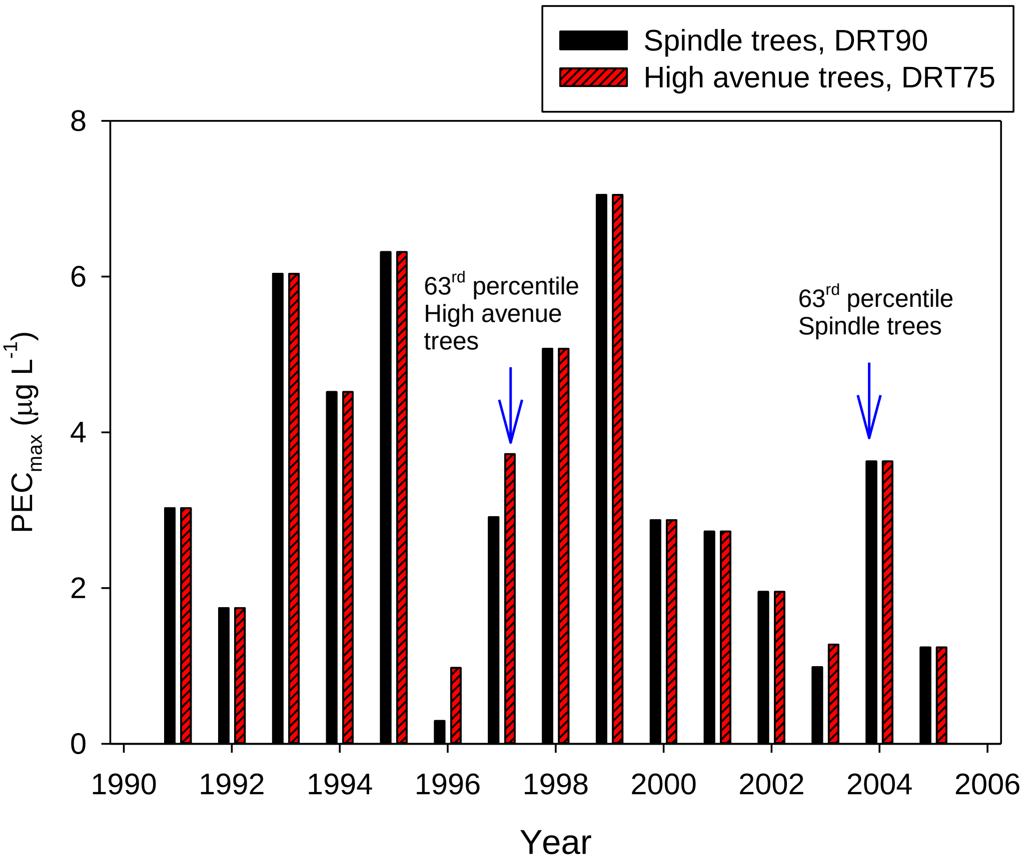

Figure 53 *Annual maximum concentration (dissolved) of substance I_b in the water of the 100 m target stretch for four spray applications in spring in two tree nursery crops: spindle trees with DRT90 and high avenue trees with DRT75. The arrows indicate the 63rd percentile annual maximum concentration for spindle trees and high avenue trees.*

In Figure 54 the annual PEC_{max} values and corresponding dates from the TOXSWA summary output file are given for the simulation with spindle trees (DRT90). Applying the protocol for selecting the temporal percentile when both drift and drainage occur (Section 4.4), it was determined whether the PEC_{max} was predominantly caused by drainage or by spray drift. In this case 14 PEC_{max} values were predominantly caused by drainage while one was caused by spray drift. According to the protocol of Section 4.4 the T_{90} of the drainage route must be selected if 10 or more annual peak concentrations are caused by drainage. This was clearly the case in this simulation and therefore the T_{90} of the drainage route was selected, 63%.

Similarly, Figure 55 shows the output of the simulation with high avenue trees (DRT75). In this case 12 PEC_{max} values were predominantly caused by drainage and three were caused by spray drift. Applying the above-mentioned protocol, the T_{90} of the drainage route was selected, 63%.

```
* Percentile summary for substance Ib
* -------------------------------------------------------
* Rank  Percent    Yearly max.     Date of maximum
                   Concentration
                   dissolved
*  (-)      (%)     (µg.L-1)
* -------------------------------------------------------
   1     3.33      0.2926          08-Nov-1996-00h00   drain
   2    10.00      0.9834          02-Jan-2003-01h00   drain
   3    16.67       1.237          19-Feb-2005-01h00   drain
   4    23.33       1.743          11-Dec-1992-03h00   drain
   5    30.00       1.952          04-Dec-2002-03h00   drain
   6    36.67       2.726          29-Mar-2001-01h00   drain
   7    43.33       2.871          29-May-2000-23h00   drain
   8    50.00       2.910          07-May-1997-23h00   drift
   9    56.67       3.026          27-Jun-1991-23h00   drain
  10    63.33       3.629          20-Nov-2004-23h00   drain
  11    70.00       4.519          21-Jun-1994-07h00   drain
  12    76.67       5.076          27-Nov-1998-05h00   drain
  13    83.33       6.038          20-Nov-1993-01h00   drain
  14    90.00       6.317          10-Jun-1995-11h00   drain
  15    96.67       7.050          13-May-1999-13h00   drain
* The peak concentration dissolved in the water layer of Ib
* selected to represent the 63rd percentile is 3.629 ug/L and is found on 2004-11-20
* End of TOXSWA REPORT: Exposure concentration in water layer
* ------------------------------------------------------------------------
```

Figure 54 *Information on the annual PEC_{max} concentrations in the target stretch of the ditch extracted from the *.sum output file of TOXSWA; simulation with substance I_b for spindle trees and DRT90. The last column is added manually and indicates the dominant source for the annual PEC_{max}.*

```
* Percentile summary for substance Ib
* --------------------------------------------------------------
* Rank  Percent    Yearly max.     Date of maximum
                   Concentration
                   dissolved
*  (-)      (%)     (µg.L-1)
* --------------------------------------------------------------
   1     3.33      0.9758          30-Apr-1996-09h00    drift
   2    10.00       1.237          19-Feb-2005-01h00    drain
   3    16.67       1.274          14-May-2003-09h00    drift
   4    23.33       1.743          11-Dec-1992-03h00    drain
   5    30.00       1.952          04-Dec-2002-03h00    drain
   6    36.67       2.726          29-Mar-2001-01h00    drain
   7    43.33       2.871          29-May-2000-23h00    drain
   8    50.00       3.026          27-Jun-1991-23h00    drain
   9    56.67       3.629          20-Nov-2004-23h00    drain
  10    63.33       3.723          07-May-1997-23h00    drift
  11    70.00       4.519          21-Jun-1994-07h00    drain
  12    76.67       5.076          27-Nov-1998-05h00    drain
  13    83.33       6.038          20-Nov-1993-01h00    drain
  14    90.00       6.317          10-Jun-1995-11h00    drain
  15    96.67       7.050          13-May-1999-13h00    drain
* The peak concentration dissolved in the water layer of Ib
* selected to represent the 63rd percentile is 3.723 ug/L and is found on 1997-05-07
* End of TOXSWA REPORT: Exposure concentration in water layer
* ------------------------------------------------------------------------
```

Figure 55 *Information on the annual PEC_{max} concentrations in the target stretch of the ditch extracted from the *.sum output file of TOXSWA; simulation with substance I_b for high avenue trees and DRT75. The last column is added manually and indicates the dominant source for the annual PEC_{max}.*

Figure 56 shows the concentration patterns for spindle trees and high avenue trees in the year of the temporal percentile derived above (2004 for spindle trees, 1997 for high avenue trees). The PEC_{max} of spindle trees is found on 21 November and is caused by drainage. In May 2004 two small concentration peaks caused by spray drift (7 May, 14 May) are visible. However, these are much smaller than the concentration peaks in November.

For high avenue trees the PEC_{max} is found on 7 May 1997. In 1997, all four applications lead to a drift event (23 April, 30 April, 7 May, 14 May). Drainage events that play a role are found on 22 April and 6 and 7 May. The concentration pattern visible for high avenue trees in the period April-May is caused by a combination of spray drift and drainage, however on 7 May the contribution of spray drift to the PEC_{max} is larger than the contribution of drainage to the PEC_{max}. It seems contradictory that the PEC_{max} of a situation where drainage events are dominant is caused by spray drift in the selected year. However, this is irrelevant as the temporal percentile is based on PEC_{max} values for all simulation years and is only to be used to select a representative year.

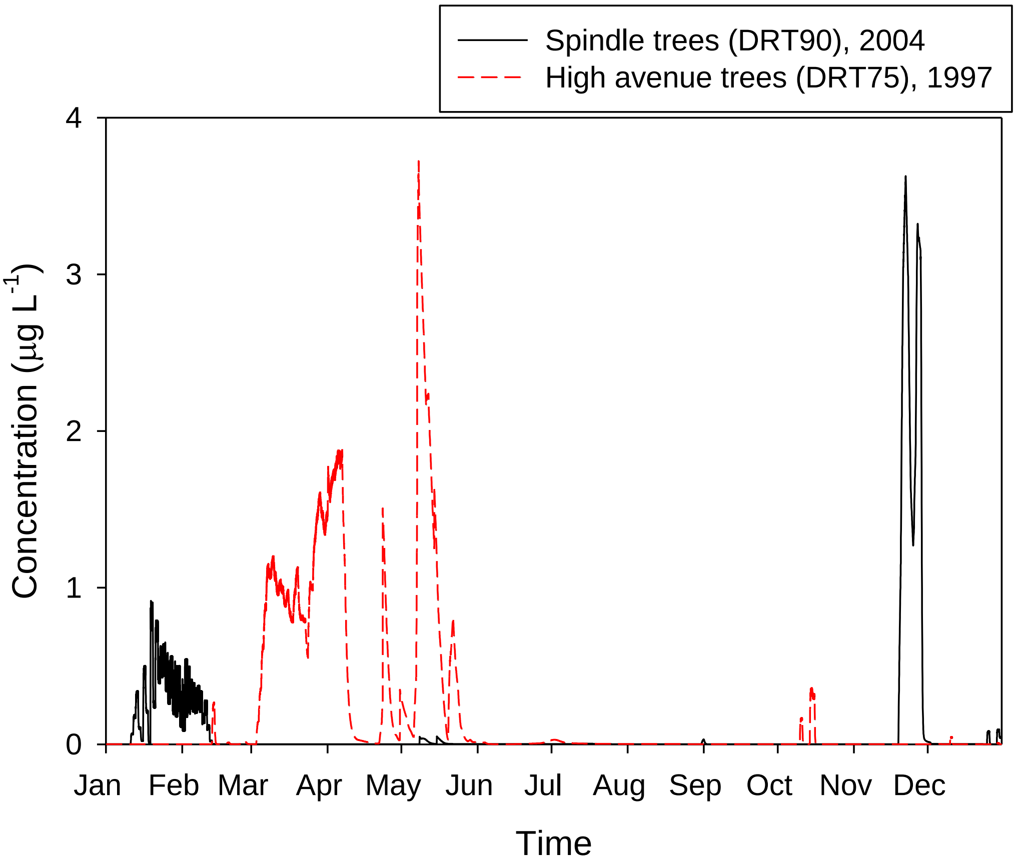

Figure 56 *Average concentration (dissolved) of substance I_b in the water of the 100 m target stretch as function of time for the year in which the target percentile is found (for both the 63rd percentile year: 2004 and 1997 for spindle trees (DRT90) and high avenue trees (DRT75)).*

Figure 57 shows that during the 15 years evaluation period, the largest part of the mass of substance I_b entered the ditch by drainage and not by spray drift. For high avenue trees only three of the annual PEC_{max} values were the result of spray drift and not of drainage. In these years concentrations in the drainage water were not high compared to the peak concentration in the ditch caused by spray drift. The volume of drainage water entering the ditch was often large causing the total mass of I_b entering the ditch by drainage to be much larger than the mass entering the ditch by spray drift.

Figure 57 also shows that, for the 100m as well as 200m boundary of the target stretch, the inflow/outflow lines are negative and thus in both cases the outflow of mass dominated the inflow of mass. Moreover, the outflow at x = 200m was significantly larger than the outflow at x = 100m, thus water flowed mainly from x = 100m to x = 200m.

Differences in the mass balances of spindle trees and high avenue trees were found in spray drift. For high avenue trees the mass entering the ditch via spray drift was larger than for spindle trees, although this is difficult to notice from Figure 57. Note further that the emission from the drains was erratic and in some of the simulated years the inflow via drain flow was almost zero, as can be seen from the nearly horizontal lines during 1996-1999.

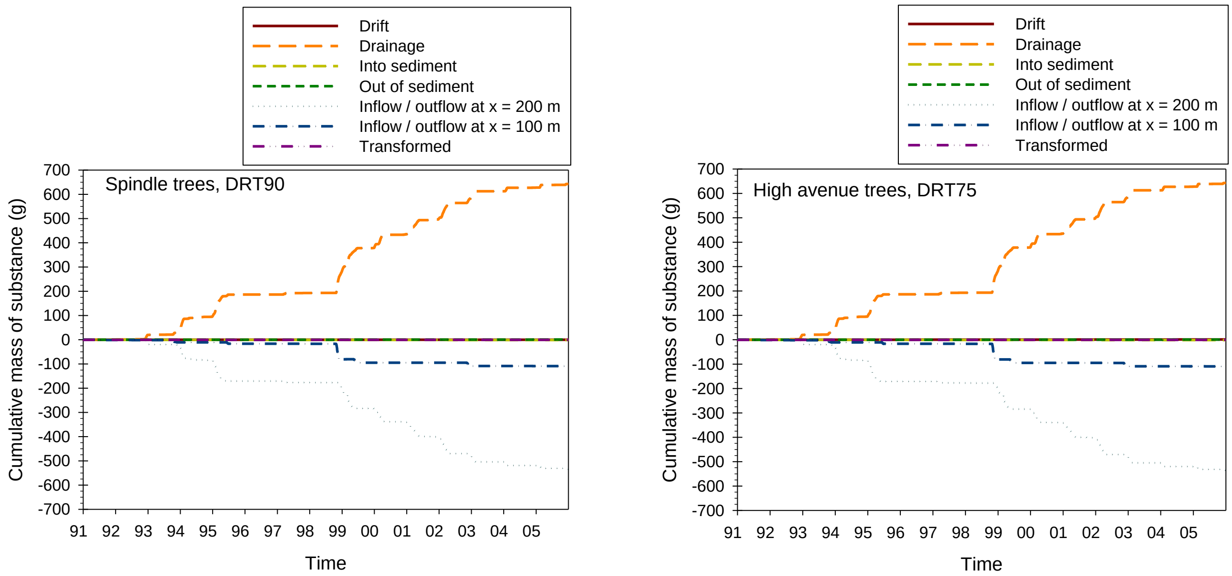

Figure 57 *Cumulative mass balances of substance I_b in the target stretch of the watercourse for spindle trees with DRT90 (left-hand side) and high avenue trees with DRT75 (right-hand side) as a function of year. Negative values indicate a sink and positive values a source. Note, that due to varying flow directions substance may both enter the target stretch (inflow) or leave the target stretch (outflow) via the boundaries of the target stretch (x = 100m and x = 200m).*

Substance I_b mainly left the ditch via outflow of water (Figure 57). The degradation half-life in water was set to 228 d and the degradation half-life in sediment was set to 1000 d, so the role of degradation was limited. The sorption coefficient for sediment ($K_{om,sed}$) was assumed to be the same as the $K_{om,soil}$, namely 57 L kg^{-1}. This is a value that is associated with slight mobility (e.g. see Mensink et al., 1995). Therefore I_b mass transports into and out of the sediment were minor parts of the mass balance. Volatilisation and atmospheric deposition were essentially zero (saturated vapour pressure of 9.1 10^{-7} Pa) and were not plotted in Figure 57.

A regular emission of the substance into the ditch via drainage was observed in autumn and winter, as many annual peak values of PEC occurred in the period November – February (see Figure 54 and Figure 55). These emissions in combination with a limited degradation caused a constant presence of substance I_b in the ditch in these periods. Outside periods with regular drainage supply the substance concentration appeared to be low since the substance quickly flowed out of the ditch.

8.3.2 Substance F

A fungicide F is applied 5 times with a dose of 1.2 kg ha^{-1} in spindle trees and high avenue trees, from 30 April onwards and with intervals of 10 days. Figure 58 shows the average concentration (dissolved) of substance F in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for spindle trees (DRT90) and high avenue trees (DRT75). For each year a set of peak concentrations was observed in the period May-June. These peak concentrations were higher for high avenue trees (DRT75) than for spindle trees (DRT90), because the spray drift deposition of substance F was generally about a factor 10-25 higher for avenue trees and DRT75 than for spindle trees and DRT90. Such a difference is understandable because of the differences in tree height and drift reducing technique used (see Section 5.1.1).

In periods of coinciding concentration patterns, concentrations of substance F for both spindle trees and high avenue trees were driven by drainage events, which do not depend on the tree type or the application technique (e.g. end of 1993, 1999 and 2000).

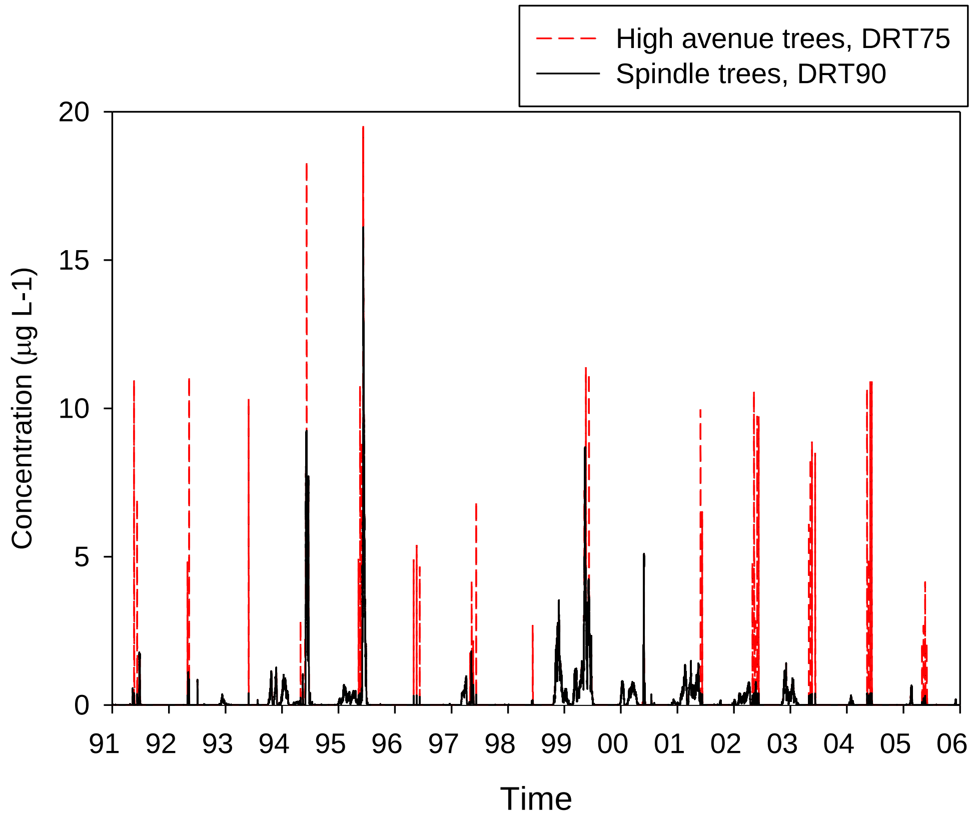

Figure 58 *Average concentration (dissolved) of substance F in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for two tree nursery crops using for each a different class Drift Reducing Technology (DRT).*

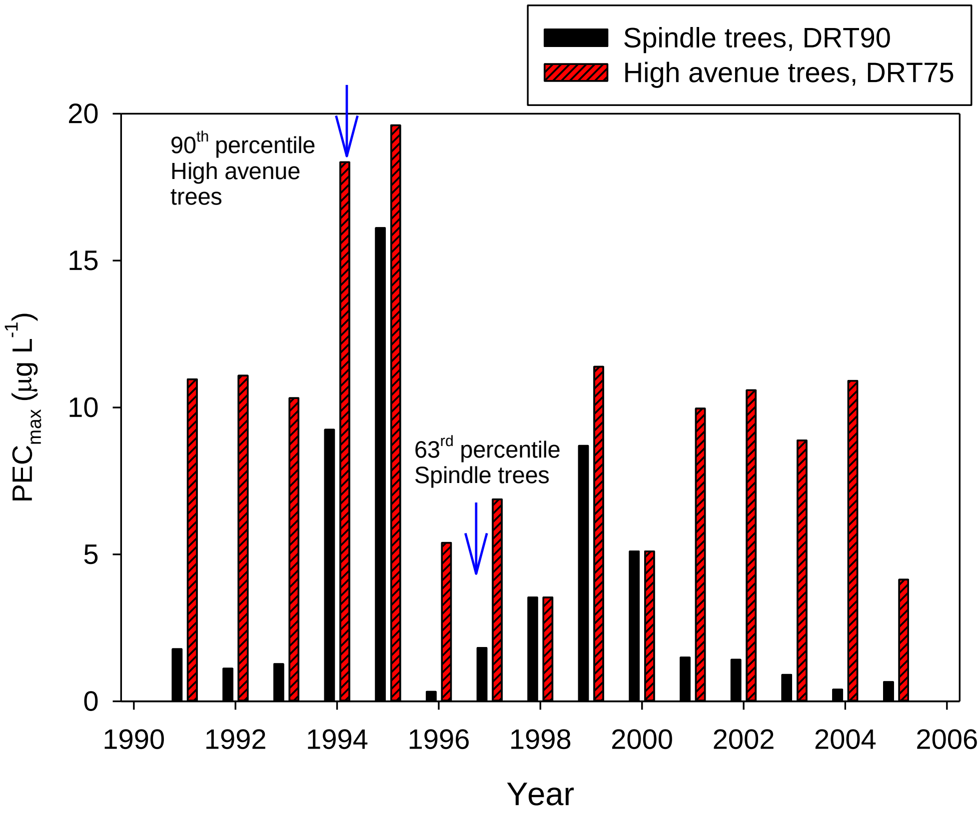

Figure 59 *Annual maximum concentration (dissolved) of substance F in the water of the 100 m target stretch for two tree nursery crops using for each a different class Drift Reducing Technology (DRT). The arrows indicate i) the 63rd percentile annual maximum concentration for the spindle tree simulation and ii) the 90th percentile annual maximum concentration for high avenue tree simulation.*

Annual maximum concentrations (dissolved) of substance F in the water of the 100 m target stretch (PEC_{max}) for spindle trees (DRT90) and high avenue trees (DRT75) are presented in Figure 59. The blue arrows in Figure 59 indicate the annual PEC_{max} of the selected T_{90}. For spindle trees, the selected T_{90} is the 63rd percentile from the drainage entry route. For high avenue trees, the selected T_{90} is the 90th percentile from the spray drift entry route.

Figure 60 and Figure 61 provide the percentile summary output of the TOXSWA model, for high avenue trees and spindles, respectively. Annual PEC_{max} values and corresponding dates were ranked by PEC_{max} value. For each PEC_{max} value it was indicated whether the PEC_{max} was caused predominantly by spray drift or drainage. Applying the protocol of Section 4.4 indicated that for high avenue trees the T_{90} of drift was applicable, while for spindles the T_{90} of drainage was to be used. Figure 62 shows the concentration patterns for spindle trees (DRT90) and high avenue trees (DRT75) in the year of the selected T_{90}.

For spindle trees (DRT90) the 63rd percentile of the 15 annual PEC_{max} values was found in the year 1997 (7 May); for high avenue trees (DRT75) the 90th percentile (i.e. T_{90} for drift in this case) of the 15 annual PEC_{max} values was found in the year 1994 (9 June).

Inspection of the drainage output file of PEARL showed that the PEC_{max} for spindle trees (DRT90) was found on a day (7 May) with drainage events on the proceeding two days (6 and 7 May). The concentration pattern in Figure 62 shows a very small peak due to spray drift on 30 April followed by a quick decline to a very small background concentration on 3 May (0.0007 $\mu g\ L^{-1}$). From 6 May to 8 May the concentration increased again due to drainage. Apparently, the PEC_{max} on May 7th 1997 was caused by drainage, as confirmed by applying the protocol for selecting the T_{90}. This has been indicated in Figure 61.

For high avenue trees (with DRT75), the PEC_{max} in the year of the selected T_{90} was found on a day of an application. This points towards a peak concentration predominantly caused by spray drift. However, this does not necessarily mean that the annual PEC_{max} was exclusively the result of spray drift; drainage entries may have contributed to the peak concentration. Applying the protocol for selecting the T_{90} year resulted in drift as the main contributor to the PEC_{max}.

```
* Percentile summary for substance F
* ---------------------------------------------------------------
* Rank  Percent    Yearly max.     Date of maximum
                   Concentration
                   dissolved
*  (-)      (%)     (µg.L-1)
* ---------------------------------------------------------------
   1     3.33       3.536          27-Nov-1998-05h00   drain
   2    10.00       4.142          20-May-2005-09h00   drift
   3    16.67       5.098          29-May-2000-23h00   drain
   4    23.33       5.389          20-May-1996-09h00   drift
   5    30.00       6.872          09-Jun-1997-09h00   drift
   6    36.67       8.885          20-May-2003-09h00   drift
   7    43.33       9.971          30-May-2001-09h00   drift
   8    50.00       10.32          30-May-1993-09h00   drift
   9    56.67       10.59          10-May-2002-09h00   drift
  10    63.33       10.91          09-Jun-2004-09h00   drift
  11    70.00       10.96          20-May-1991-09h00   drift
  12    76.67       11.09          10-May-1992-09h00   drift
  13    83.33       11.39          20-May-1999-09h00   drift
  14    90.00       18.35          09-Jun-1994-09h00   drift
  15    96.67       19.61          10-Jun-1995-09h00   drain

* The peak concentration (dissolved) in the water layer of F
* selected to represent the 90th percentile is 18.35 ug/L and is found on 1994-06-09
* End of TOXSWA REPORT: Exposure concentration in water layer
* -------------------------------------------------------------------------
```

Figure 60 *Information on the annual PEC_{max} concentrations in the target stretch of the ditch extracted from the *.sum output file of TOXSWA; simulation with substance F, high avenue trees and DRT75. The last column is added manually and indicates the dominant source for the PEC_{max}.*

```
* Percentile summary for substance F
* ---------------------------------------------------------------
* Rank  Percent    Yearly max.     Date of maximum
                   Concentration
                   dissolved
*  (-)      (%)     (µg.L-1)
* ---------------------------------------------------------------
    3.33      0.3215          20-May-1996-09h00   drift
   10.00      0.3999          30-May-2004-09h00   drift
   16.67      0.6541          21-Feb-2005-23h00   drain
   23.33      0.9018          13-Jan-2003-19h00   drain
   30.00       1.114          04-May-1992-23h00   drain
   36.67       1.263          24-Nov-1993-23h00   drain
   43.33       1.417          04-Dec-2002-03h00   drain
   50.00       1.486          29-Mar-2001-01h00   drain
   56.67       1.773          23-Jun-1991-23h00   drain
   63.33       1.816          07-May-1997-23h00   drain
   70.00       3.536          27-Nov-1998-05h00   drain
   76.67       5.098          29-May-2000-23h00   drain
   83.33       8.702          15-May-1999-11h00   drain
   90.00       9.246          09-Jun-1994-09h00   drift
   96.67       16.11          10-Jun-1995-09h00   drain
* The peak concentration (dissolved) in the water layer of F
* selected to represent the 63th percentile is 1.816 ug/L and is found on 1997-05-07
* End of TOXSWA REPORT: Exposure concentration in water layer
* -------------------------------------------------------------------------
```

Figure 61 *Information on the annual PEC_{max} concentrations in the target stretch of the ditch extracted from the *.sum output file of TOXSWA; simulation with substance F, spindle trees and DRT90. The last column is added manually and indicates the dominant source for the PEC_{max}.*

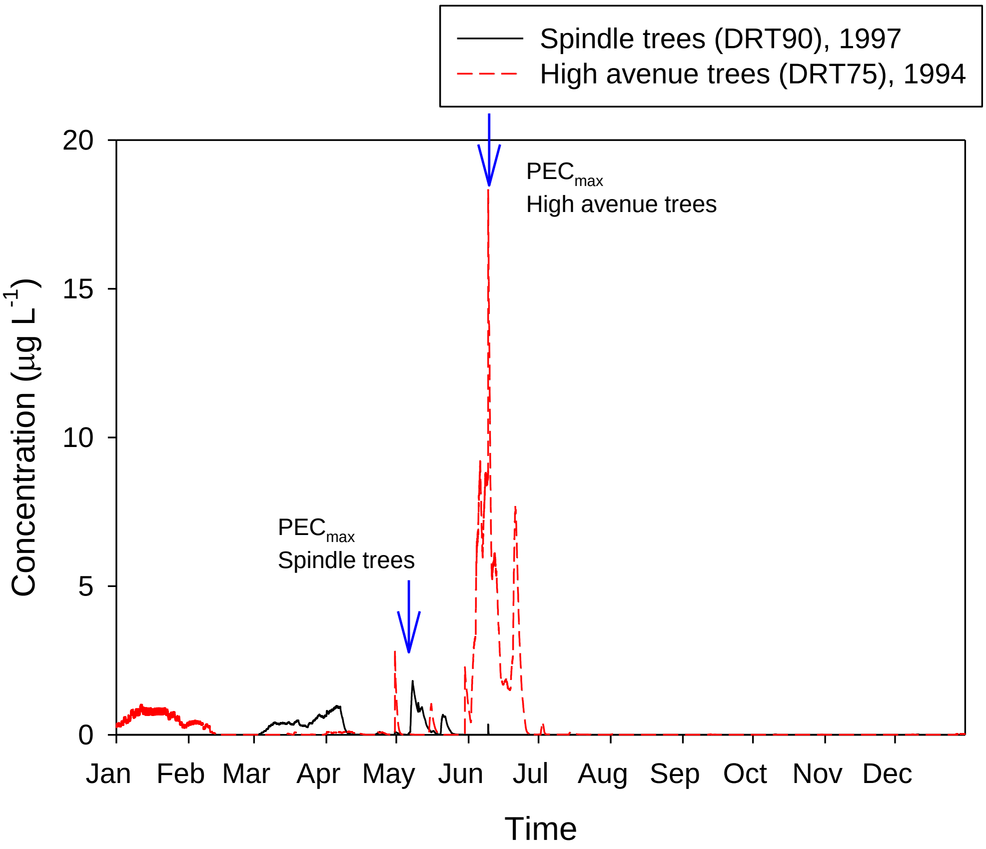

Figure 62 *Average concentration (dissolved) of substance F in the water of the 100 m target stretch as function of time for the year in which the target percentile is found (1997 for spindle trees and DRT90 and 1994 for avenue trees and DRT75).*

Note that for spindle trees and DRT90 most annual PEC$_{max}$ values are caused by drainage (12 times), whereas for high avenue trees and DRT75 most annual PEC$_{max}$ values are caused by drift (also 12 times).

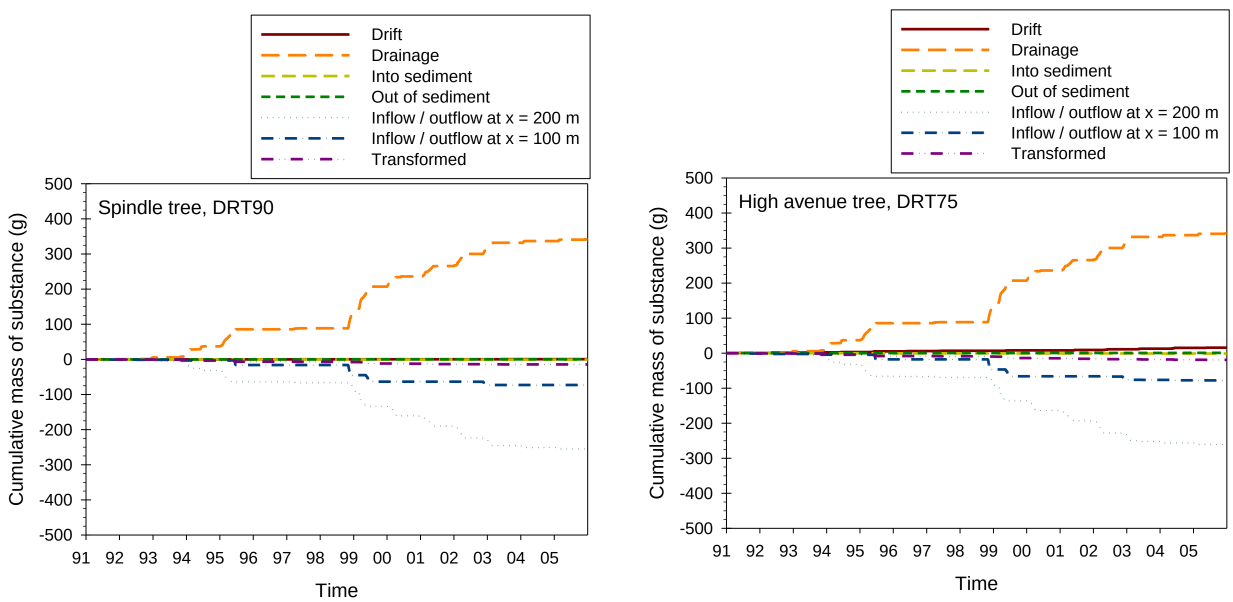

Figure 63 *Cumulative monthly mass balances of substance F for spindle trees and DRT90 (left-hand side) and high avenue trees and DRT75 (right-hand side). Negative values indicate mass transport out of the water layer. Note, that due to varying flow directions substance may both enter the target stretch (inflow) or leave the target stretch (outflow) via the boundaries of the target stretch (x = 100m and x = 200m).*

Similar to the example of substance I_b, the largest part of the mass of substance F entered the ditch by drainage and not by spray drift (Figure 63). The amount of drainage water entering the ditch is often large leading to a much higher total mass of F entering the ditch by drainage than by spray drift. Note however that the cumulative mass of F via drainage after 15 years (about 400 g) was smaller than the total mass of I_b after 15 years (about 640 g) despite the fact that F was applied 5 times a year with a dose of 1.2 kg ha^{-1} and I_b only 4 times a year with a dose of 0.15 kg ha^{-1}. Based on the application data a higher cumulative mass of F via drainage than of I_b would have been expected. $K_{om,soil}$ values of both substances were comparable. However, the half-life in soil is much lower for F (3.82 days) than for I_b (94.8 days), which means that F has a much lower potential for leaching to the drains than I_b because it degrades more quickly in soil.

Outflow of water was largely responsible for the disappearance of substance F from the water layer of the target stretch of the scenario ditch. Moreover, the outflow at x = 200m was significantly larger than the outflow at x = 100m. Contrary to substance I_b, a transformation of substance F in the water clearly contributed to the disappearance of the substance from the water layer (due to a degradation half-life in water of 0.2 d). Transport in and out of the sediment of substance F were minor parts of the mass balance. This is explained by the low value of the sorption coefficient for sediment ($K_{om,sed}$) which was assumed to be the same as the $K_{om,soil}$, namely 56.3 L kg^{-1}.

Volatilisation was zero (saturated vapour pressure of 7 10^{-7} Pa) and was not plotted in Figure 63. Substance F has a lower leaching potential than substance I_b, mainly due to the much faster degradation in soil ($DegT_{50,soil}$ of 3.82 d for F and $DegT_{50,soil}$ of 94.8 d for I_b) as the sorption coefficients of both substances do not differ much ($Kom_{,soil}$ of 76.8 L kg^{-1} for F and $Kom_{,soil}$ of 57.0 L kg^{-1} for I_b). Whereas for substance I_b, in most years drainage predominantly contributed to the annual PEC_{max}, for substance F and high avenue trees, spray drift was most often the dominant contributor to the annual PEC_{max}. However, unlike for high avenue trees, for spindle trees drainage contributed more often to the PEC_{max} predominantly, despite the relatively low leaching potential of substance F. This was caused by the much lower spray drift deposits with spindle trees compared to high avenue trees.

8.4 Results of calculations for downward spraying in avenue tree nurseries

8.4.1 Substance H_d

Substance H_d is a rather persistent and slightly mobile herbicide which is applied once in high avenue trees with a dose of 1.0 kg a.i. ha^{-1} either on 21 April or on 8 November. The substance has a saturated vapour pressure of 3.0 10^{-4} Pa at 20°C.

Figure 64 shows the average concentration (dissolved) of substance H_d in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for the two different application timings. The highest peaks were found in spring (when application was on 21 April) or autumn (when application was on 8 November). These peaks are needle-shaped. Further analysis should point out which sources are causing the annual PEC_{max} values.

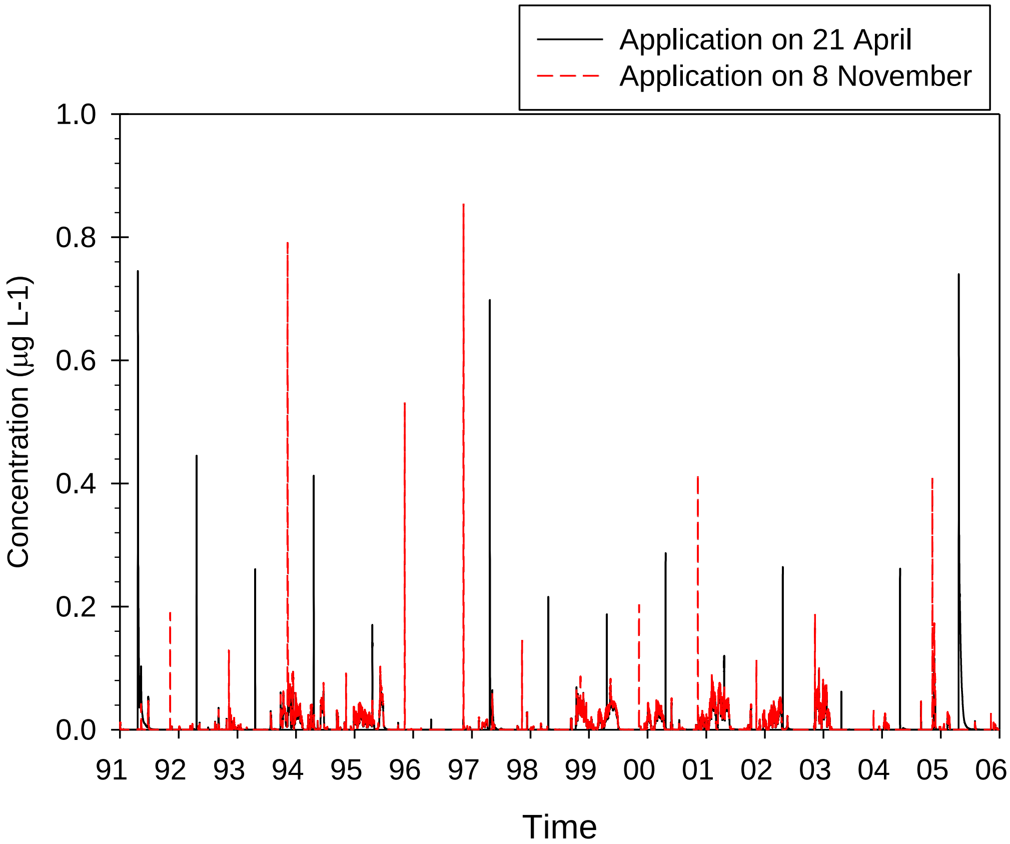

Figure 64 *Average concentration (dissolved) of substance H_d in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for two different timings of applications (21 April and 8 November).*

Figure 65 shows the annual maximum concentration (dissolved) of substance H_d in the water of the 100 m target stretch for two different timing of applications (21 April and 8 November). The arrows indicate the annual PEC_{max} value of the corresponding target temporal percentile, which was for both simulations the 63^{rd} percentile. These 63^{rd} percentile PEC_{max} values were found in 2000 and 1999 for the applications on 21 April and 8 November, respectively.

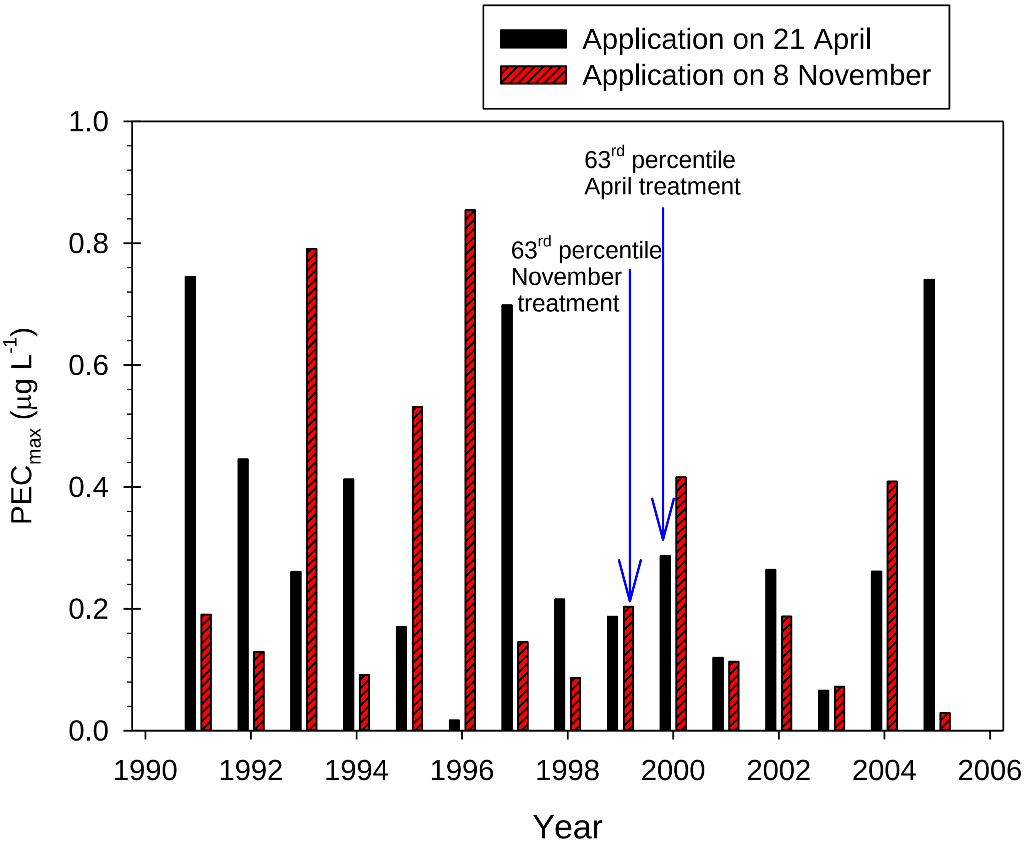

Figure 65 *Annual maximum concentration (dissolved) of substance H_d in the water of the 100 m target stretch for two different timings of applications (21 April and 8 November). The arrows indicate the annual maximum concentration of the target percentile year selected.*

Table 23 provides information on the annual PEC_{max} values and corresponding dates of all 15 evaluation years for the application on 21 April and 8 November. Applying the protocol for selecting the temporal percentile (Section 4.4) when both drift and drainage occur resulted for both simulations in PEC_{max} values that were all caused by drainage. A closer inspection of the time for which the PEC_{max} was found, revealed that many PEC_{max} values were found exactly 24 hours after application. This implies that the PEC_{max} was probably caused by atmospheric deposition and not by one of the other routes. Deposition of substances on edge-of-field surface waters due to volatilisation is considered to be relevant for substances with a vapour pressure higher than 10^{-4} Pa when applied to the soil (FOCUS, 2008). The vapour pressure of H_d is 3.0 10^{-4} Pa at 20°C which is slightly above the mentioned threshold. Atmospheric deposition is expressed in the TOXSWA model as the cumulative fraction of the dosage deposited during the first 24 h after application of the substance. Then the maximum concentration is achieved after 24 hr, which makes it plausible that the contribution of the atmospheric deposition is dominant above drift and drain emission.

For atmospheric deposition, the mass that is deposited on the water surface is considered to be equal to the 90^{th} overall percentile of the total area of use during the year. It is independent of the application timing and for each year the same. The difference in PEC_{max} between the years is due to differences in the water depth and the water velocity of the receiving water course. Therefore, for situations in which atmospheric deposition is the dominant entry route, the most appropriate temporal percentile would be the 50^{th} percentile year. When atmospheric deposition is the dominant route, then the peak value occurs on the day after the spray application, as explained above. Then, the protocol as presented in Section 4.4 (which distinguishes only spray drift and drainage) would point to drainage as the dominant route (since on the day of the peak value drift deposits are zero). Consequently, the selected temporal percentile would be that of the drainage route, i.e. 63% which is slightly above the presumed 50% mentioned above. This is considered acceptable as it is a conservative approach from a PPP registration perspective.

Table 23 *Detailed information on the annual PEC_{max} of H_d in the target stretch of the ditch of for treatment type in-row i.e. treatment of bare soil and two different timings of applications (spring, autumn). Highlighted texts indicate occasions where atmospheric deposition appeared to be dominant.*

Percentile (%)	Application on 21 April			Application on 8 November		
	Annual PEC_{max} dissolved ($\mu g\ L^{-1}$)	Time of PEC_{max}	dominant source PEC_{max}*	Annual PEC_{max} dissolved ($\mu g\ L^{-1}$)	Time of PEC_{max}	dominant source PEC_{max}*
3.33	0.01709	08-11-96 00:00	drain	0.02886	12-02-05 03:00	drain
10	0.06598	18-01-03 23:00	drain	0.07222	18-01-03 23:00	drain
16.67	0.1197	22-04-01 03:00	drain	0.08655	09-11-98 01:00	drain
23.33	0.17	22-04-95 09:00	drain	0.09129	09-11-94 00:00	drain
30	0.1872	22-04-99 09:00	drain	0.1133	09-11-01 09:00	drain
36.67	0.2156	22-04-98 02:00	drain	0.1294	09-11-92 09:00	drain
43.33	0.2607	22-04-93 09:00	drain	0.1456	09-11-97 09:00	drain
50	0.2614	22-04-04 01:00	drain	0.1875	09-11-02 09:00	drain
56.67	0.2641	22-04-02 09:00	drain	0.1907	09-11-91 09:00	drain
63.33	0.2867	22-04-00 09:00	drain	0.2037	09-11-99 09:00	drain
70	0.4124	22-04-94 02:00	drain	0.4089	09-11-04 09:00	drain
76.67	0.4452	22-04-92 09:00	drain	0.4158	09-11-00 09:00	drain
83.33	0.6983	22-04-97 09:00	drain	0.5315	09-11-95 09:00	drain
90	0.7403	22-04-05 09:00	drain	0.7911	09-11-93 09:00	drain
96.67	0.7452	22-04-91 09:00	drain	0.8546	09-11-96 09:00	drain

* Dominant source according the protocol for selecting the temporal percentile when both drift and drainage occur (Section 4.4).

The annual PEC_{max} of H_d highlighted in Table 23 are those for which atmospheric deposition was the main entry route. In the model calculations, atmospheric deposition was constant (no annual variation; in these simulations 0.22 mg m^{-2}; see Table 9, Section 4.5), so an explanation is needed for the rather large variation in annual PEC_{max} predominantly caused by atmospheric deposition. For this analysis we focus on the simulation with the autumn application (8 November). For the years 1994, 1998, 2003 and 2005 it was unlikely that the PEC_{max} would have been caused by atmospheric deposition (since the date and time that the peak occurred was not exactly 24 h after spray application), so we focus on the remainder of the years. Of the remaining years, only 2000 and 2002 have drainage events (incl. substance in the drain water) on the day that the PEC_{max} is found. Therefore drainage does not explain the difference between annual PEC_{max} values in e.g. 1996 and 2001. Next the relation between the annual PEC_{max} and the water depth at the time of the PEC_{max} was analysed (Figure 66). There was only little variation in water depth at the time of the PEC_{max} for the years highlighted in Table 23 (between 0.26 and 0.273 cm). However a clear relation between the PEC_{max} and the water depth was visible; i.e. larger PEC_{max} values were found for smaller water depths. Therefore it was concluded that the variation in annual PEC_{max} values that were predominantly caused by atmospheric deposition was explained by the difference in water depth at the time the annual PEC_{max} was found.

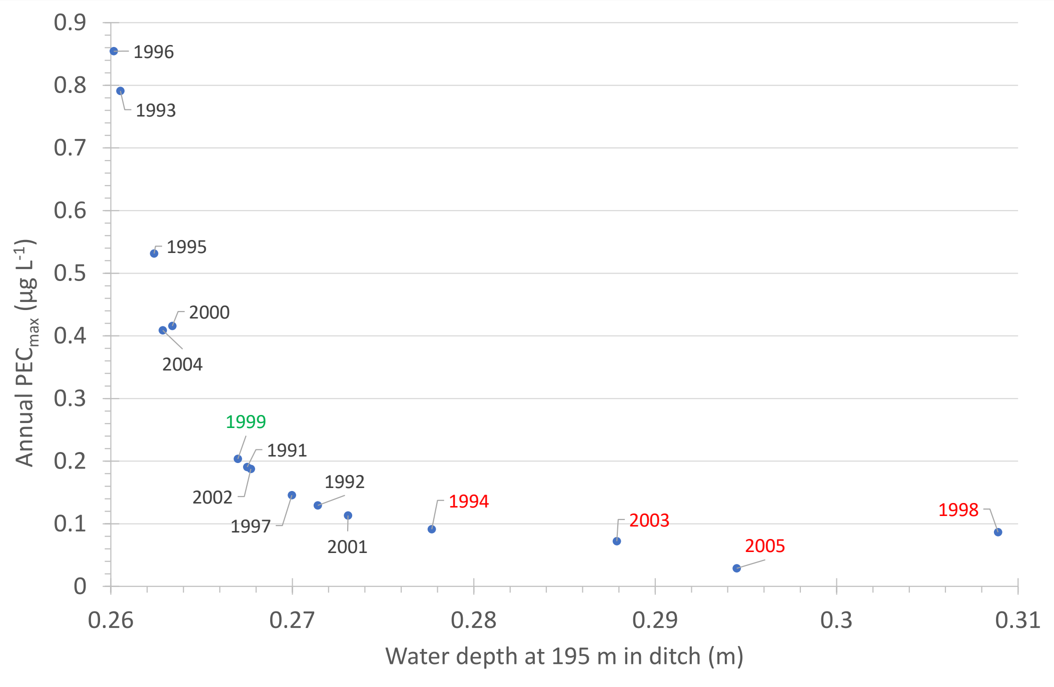

Figure 66 *Annual PEC_{max} of H_d in the target stretch of the ditch for the autumn treatment (annual application on 8 November) as function of the water depth in the ditch at the time the annual PEC_{max} was found. The year in which the annual PEC_{max} was found is indicated by a label. 1999 is the 63rd percentile year. For the years 1994, 1998, 2003 and 2005 the PEC_{max} probably was not caused by atmospheric deposition; these years are indicated by labels in a red colour.*

Figure 67 shows the concentration patterns of substance H_d in the selected year for the two different timing of applications (21 April and 8 November). Both the April and November application show needle-shaped peak concentrations around the day of application. The contribution of the drainage route is also clearly visible by periods of non-zero concentrations in the ditch. These concentrations due to drainage were lower than the peak concentrations caused by atmospheric deposition.

For the simulation with the April application we further analysed the contribution of spray drift, atmospheric deposition and drainage around the date of the PEC_{max} occurrence (22 April 2000). The spray drift deposition on to the ditch was 0.007 mg m^{-2} (i.e. 0.007% of 1 kg ha^{-1}) on 21 April 9:00 and the cumulative fraction of the dosage deposited during the first 24 h after application on to the ditch by volatilisation was 0.22 mg m^{-2} (i.e. 0.22% of 1 kg ha^{-1}; see Section 4.5). There were no drainage events on 21 and 22 April 2000 (determined via inspection of the *.e2t output file of PEARL). The same analysis was done for the simulation with the November application. The spray drift deposition on to the ditch was 0.003 mg m^{-2} (i.e. 0.003% of 1 kg ha^{-1}) on 8 November 9:00 and the cumulative fraction of the dosage deposited during the first 24 h after application on to the ditch by volatilisation was 0.22 mg m^{-2}. There were no drainage events on 8 and 9 November 1999 (determined via inspection of the *.e2t output file of PEARL). This analysis confirmed that for the 63rd percentile PEC_{max} the contribution of atmospheric deposition exceeded those of spray drift and drainage.

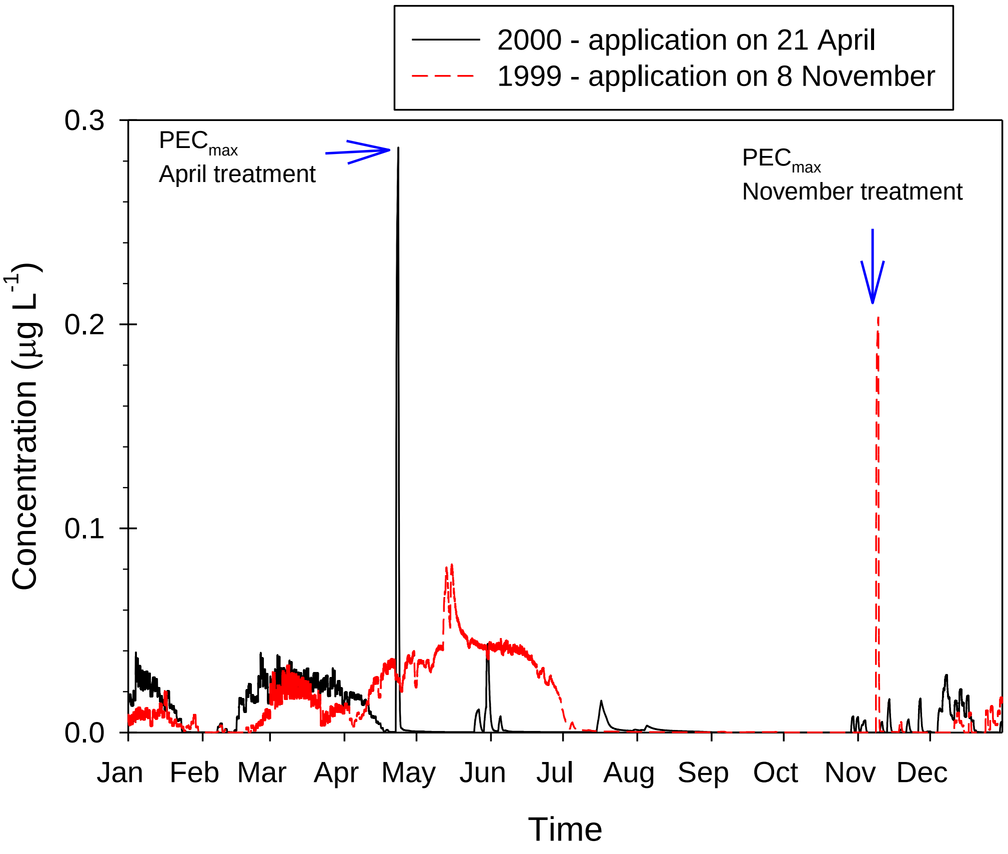

Figure 67 *Average concentration (dissolved) of substance H_{py} in the water of the 100 m target stretch as function of time for the year in which the target percentile is found for two different timings of applications (21 April and 8 November).*

Figure 68 shows that during the 15 years evaluation period, the largest part of the mass of substance H_d entered the ditch by drainage and not by spray drift or atmospheric deposition. The volume of drainage water entering the ditch was often large causing the total mass of H_d entering the ditch by drainage to be much larger than the mass entering the ditch by spray drift and atmospheric deposition. The simulation with the 8 November application resulted in a slightly larger cumulative mass entering the ditch than the simulation with the 21 April application. Note further that the emission from the drains was erratic and in some of the simulated years the inflow via drain flow was almost zero, as can be seen from the nearly horizontal lines during 1996-1999.

Although difficult to notice in Figure 68 (but confirmed by analysing the data), the cumulative mass of substance entering the ditch via atmospheric deposition (i.e. 0.78 g for the simulation with the April treatment) was larger than that entering via spray drift (i.e. 0.12 g for the simulation with the April treatment).

Mass transported from the water to the sediment and vice versa is not shown in Figure 68. For the simulation with the 21 April application cumulative mass transported to the sediment was 0.18 g and the cumulative mass transported from sediment back to the water layer was 0.09 g (period 1991 – 2005).

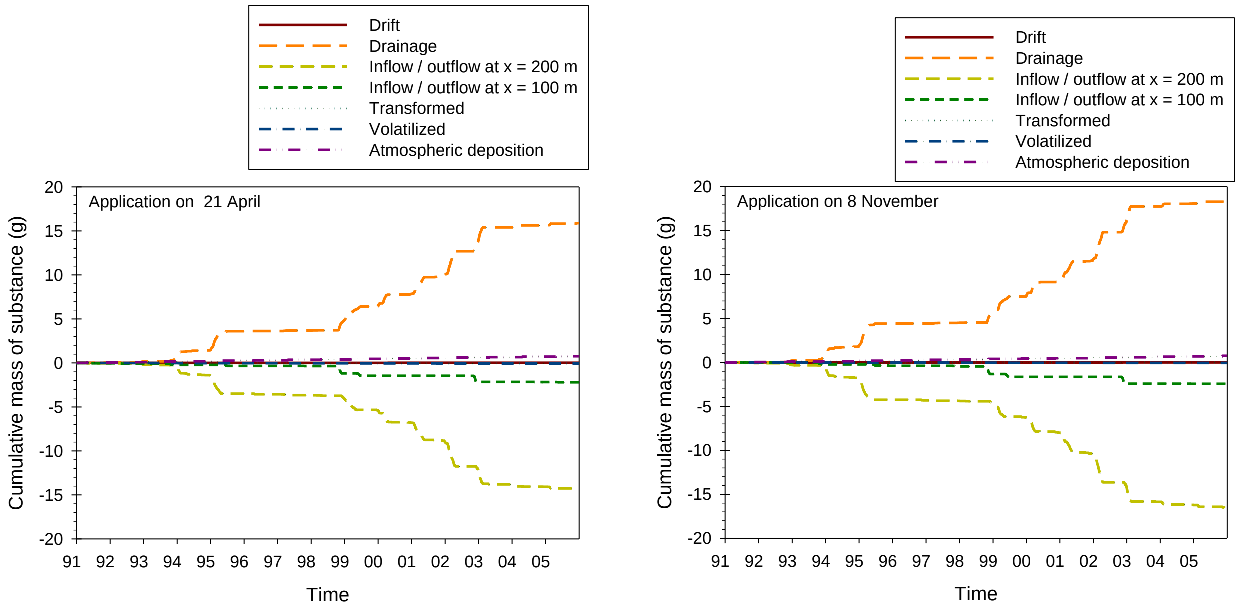

Figure 68 *Cumulative mass balances of substance H_d for the application on 21 April (left-hand side) and for the application on 8 November (right-hand side); all as a function of year. Negative values indicate a sink and positive values a source. Note, that due to varying flow directions the substance may both enter the target stretch (inflow) or leave the target stretch (outflow) via the boundaries of the target stretch (x = 100m and x = 200m).*

For this particular substance with its low leaching potential and reduced spray drift deposition the atmospheric deposition delivered a larger contribution to the PEC_{max} than drainage or spray drift. Atmospheric deposition was calculated according FOCUS (2008) i.e. a first-tier approach in which it was assumed that the wind blowed perpendicular to the direction of the ditch which was a worst-case assumption.

8.4.2 Substance H_p

Substance H_p is a highly mobile, but readily degradable herbicide which is applied two times in high avenue tree nurseries with a dose of 0.02 kg a.i. ha^{-1} on either 14 April and 21 April or on 14 May and 21 May. Figure 69 shows the average concentration (dissolved) of substance H_p in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for the two different application timings. Figure 69 shows both concentrations due to drainage (i.e. there are concentrations in autumn/winter) and spray drift (somewhat regular pattern of needle-shaped peaks in spring). Further analysis should point out which sources are causing the annual PEC_{max} values.

Figure 70 shows the annual maximum concentration (dissolved) of substance H_p in the water of the 100 m target stretch for two different timing of applications (April, May). The arrows indicate the annual PEC_{max} value of the corresponding target temporal percentile, which turned out to be the 63rd percentile for both simulations after applying the protocol for selecting a temporal percentile when both drift and drainage occur (Section 4.4). For the treatment in April, the 63rd percentile PEC_{max} was found in 1998 and for the treatment in May the 63rd percentile PEC_{max} was found in 1991.

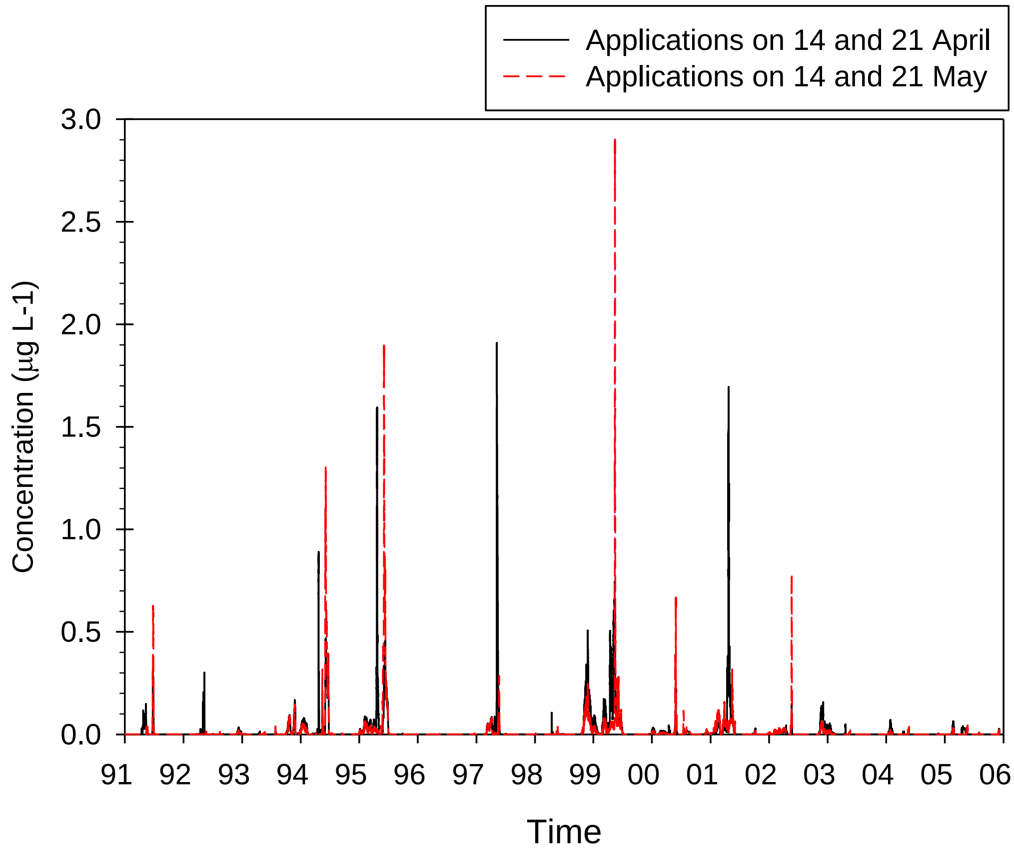

Figure 69 *Average concentration (dissolved) of substance H_{py1} in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for two different timings of applications (April, May).*

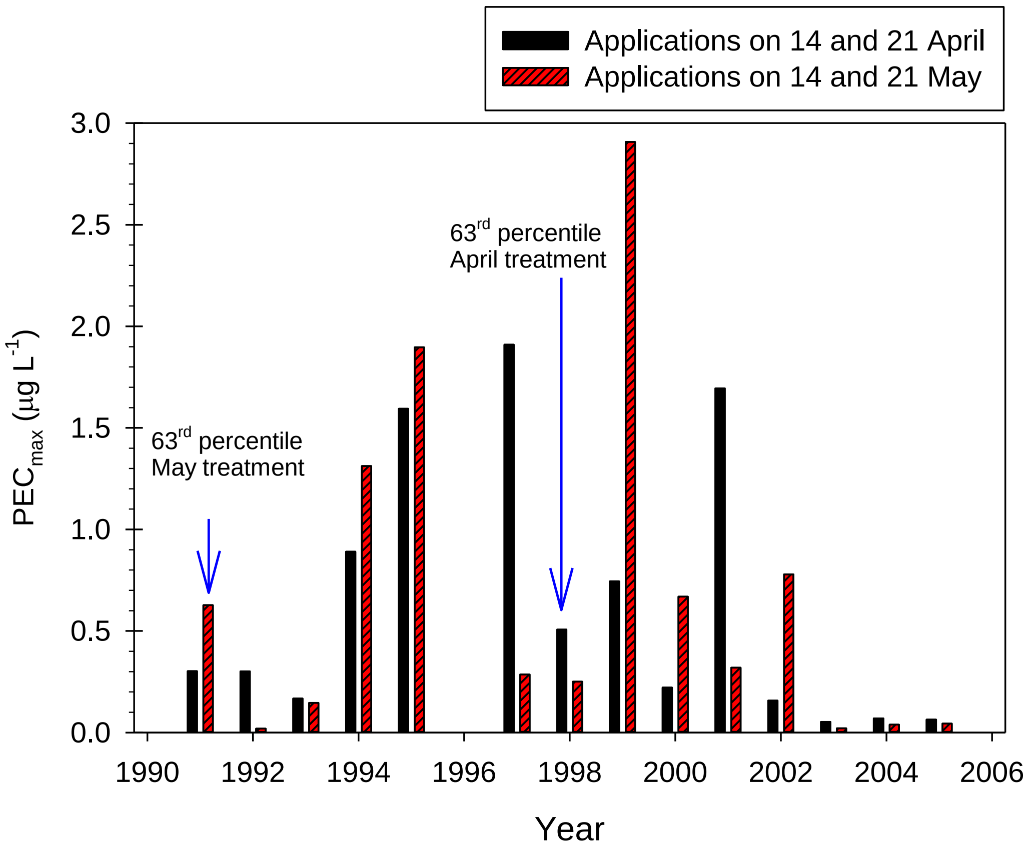

Figure 70 *Annual maximum concentration (dissolved) of substance H_{py} in the water of the 100 m target stretch for two different timings of applications (April, May). The arrows indicate the annual maximum concentration of the target percentile year selected.*

Table 24 provides information on the annual PEC_{max} values and corresponding dates of all 15 evaluation years for the April treatment and the May treatment. Substance H_p is rather volatile (saturated vapour pressure of 1.36 10^{-3} Pa), which means that atmospheric deposition could be an important entry route. For these particular cases, the cumulative fraction of the dosage deposited during the first 24 h after each application on to the ditch by volatilisation was 0.011 mg m^{-2} (i.e. 0.22% of 0.05 kg ha^{-1}).

The times on which the annual PEC_{max} was found provided an indication on whether the PEC_{max} was caused by atmospheric deposition (i.e. exactly 24 hours after application).

Table 24 shows for the April treatment no PEC_{max} values that could be caused by atmospheric deposition and for the May treatment only three (in 2001, 2004 and 2005; highlighted in the table). Applying the protocol of Section 4.4 to these simulations pointed to drainage as the dominant route and the 63rd percentile was selected. Indeed this is justified because the majority of the annual PEC_{max} is caused by drainage even when considering atmospheric deposition as an entry route also.

Table 24 *Detailed information on the annual PEC_{max} of H_p in the target stretch of the ditch of for treatment type in-row i.e. treatment of bare soil and two different timings of applications (April, May). Highlighted texts indicate occasions where atmospheric deposition appeared to be dominant.*

	Applications on 14 and 21 April			Application on 14 and 21 May		
percentile (%)	**Annual PEC_{max} dissolved (µg L^{-1})**	**Time of PEC_{max}**	**dominant source PEC_{max}***	**Annual PEC_{max} dissolved (µg L^{-1})**	**Time of PEC_{max}**	**dominant source PEC_{max}***
3.33	0.003864	19-12-96 23:00	drain	0.003626	19-12-96 23:00	drain
10	0.05256	13-01-03 23:00	drain	0.01971	10-12-92 23:00	drain
16.67	0.06392	21-02-05 23:00	drain	0.02119	13-01-03 23:00	drain
23.33	0.0696	27-01-04 23:00	drain	0.03896	15-05-04 09:00	drain
30	0.1577	04-12-02 03:00	drain	0.04407	22-05-05 09:00	drain
36.67	0.1672	24-11-93 23:00	drain	0.1465	24-11-93 23:00	drain
43.33	0.222	29-05-00 23:00	drain	0.2505	27-11-98 05:00	drain
50	0.3016	10-05-92 23:00	drain	0.2857	22-05-97 00:00	drain
56.67	0.3022	23-06-91 23:00	drain	0.3192	15-05-01 09:00	drain
63.33	0.5066	27-11-98 05:00	drain	0.6274	26-06-91 01:00	drain
70	0.7444	13-05-99 11:00	drain	0.6691	29-05-00 11:00	drain
76.67	0.8899	22-04-94 23:00	drain	0.7786	21-05-02 23:00	drain
83.33	1.595	22-04-95 23:00	drain	1.312	05-06-94 23:00	drain
90	1.695	23-04-01 23:00	drain	1.897	04-06-95 19:00	drain
96.67	1.91	08-05-97 00:00	drain	2.908	15-05-99 21:00	drain

* Dominant source according the protocol for selecting the temporal percentile when both drift and drainage occur (Section 4.4)

Figure 71 shows the concentration patterns of substance H_p in the selected temporal percentile year for two different timings of applications (April, May). H_p is readily degradable ($DegT_{50,soil}$ of 7.05 d), so annual PEC_{max} can only be caused by drainage events within a few weeks after application. This was true for roughly a quarter of the 15 annual PEC_{max} values for the April treatment and for roughly half of the 15 annual PEC_{max} values for the May treatment. This is for instance visible in Figure 71 for the simulation of the May treatment where the 63rd percentile PEC_{max} was found on 26 June 1991, so a few weeks after the two applications in May (both resulting in spray drift deposition on the ditch). After the applications on 15 and 21 May, the first drainage event was found on 21 June.

There were also PEC_{max} values found in autumn or winter. Further analysis showed that these occurred in years for which spray drift deposits were zero or for which there were no or only very small drainage events in the few weeks after application. This is illustrated in Figure 71 for the case of the April treatment. After the two very small concentrations peaks in April mainly due to spray drift, substantial drainage events did not occur in 1998 until half of October (confirmed by inspecting the drainage data in the relevant PEARL output file). Apparently, due to these drainage events in autumn the remaining substance in the soil dissolved and reached the water in the ditch. This means that in this year not all of the H_p applied to the soil did degrade during summer. This can be explained as follows. In the days/weeks after the applications on 15 and 21 April there was no flow via the bypass domain[2] of the macropores to the drains. However, water and substance was transported via the internal catchment domain[3] of the macropores to the soil matrix at different depths in the soil, where part of H_p degraded (but slower than in the top 30 cm). The remaining part was transported to the drains in autumn when precipitation events were abundant and large enough to trigger drainage events.

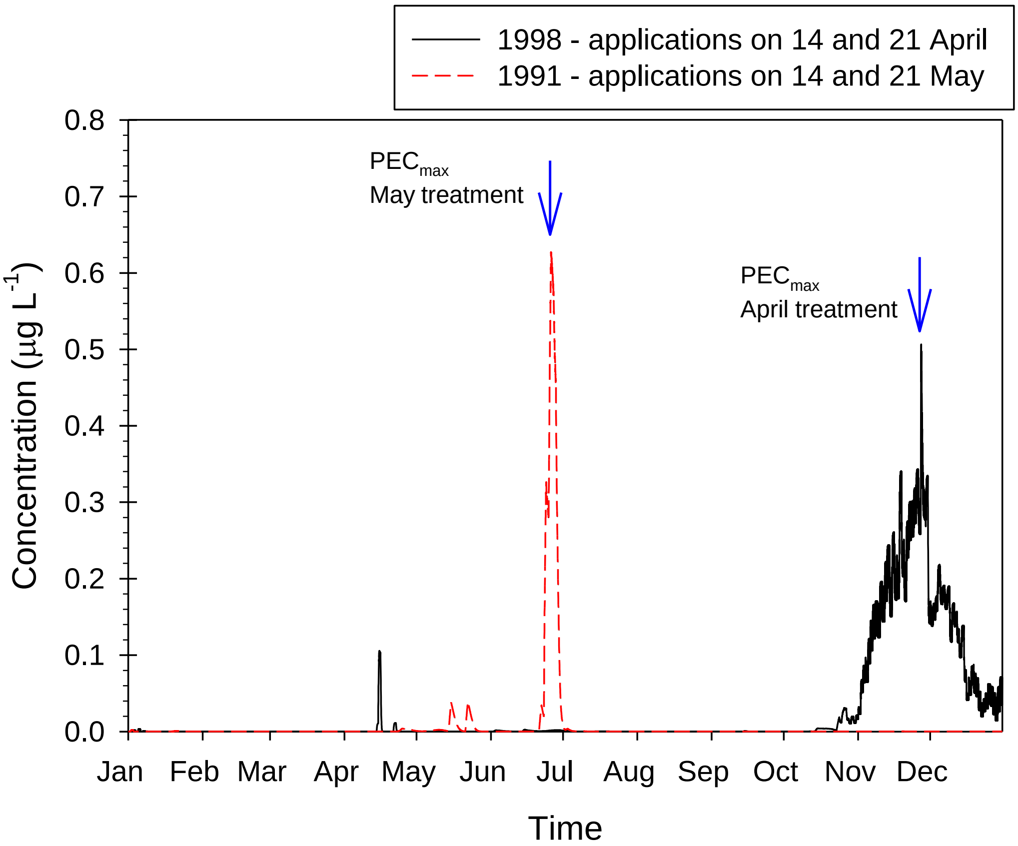

Figure 71 *Average concentration (dissolved) of substance H_p in the water of the 100 m target stretch as function of time for the year in which the target percentile is found for two different timings of applications (April, May).*

Figure 72 shows the cumulative mass balance terms for the water layer of the target stretch of the evaluation ditch. Main components of the mass balance were an input via drainage and an output via outflow. Note that the cumulative mass in the drainage water was larger for the April treatment than for the May treatment. However, the annual PEC_{max} values of the April treatment were generally slightly lower than the annual PEC_{max} values of the May treatment.[4] As visible in Table 24, for the April treatment 7 of the PEC_{max} values occurred in autumn and winter, all related to drain events. This delayed leaching to the drains can be explained as follows. The substance was transported through the macropores to the matrix at greater depth, where only little degradation occurred until precipitation in autumn caused the leaching of the remaining substance to the drains. For the May treatment more PEC_{max} values (also related to drain events) are found in the few weeks after application. Leaching to the drains is much quicker than for the April treatment.

[2] In the bypass domain water is transported fast and deep in to the soil, bypassing the soil matrix; see Tiktak et al., 2012b for the conceptual model of macropore flow.

[3] In the internal catchment domain macropores end at different depths in the soil profile and water is captured at the bottom of the individual macropores, resulting into forced infiltration of macropore water into the soil matrix (Tiktak et al., 2012b)

[4] Note that this finding is in line with the results of the analysis of the sensitivity of the drain emission scenario to the application date which was reported in chapter 6.7 in Boesten et al. (2021).

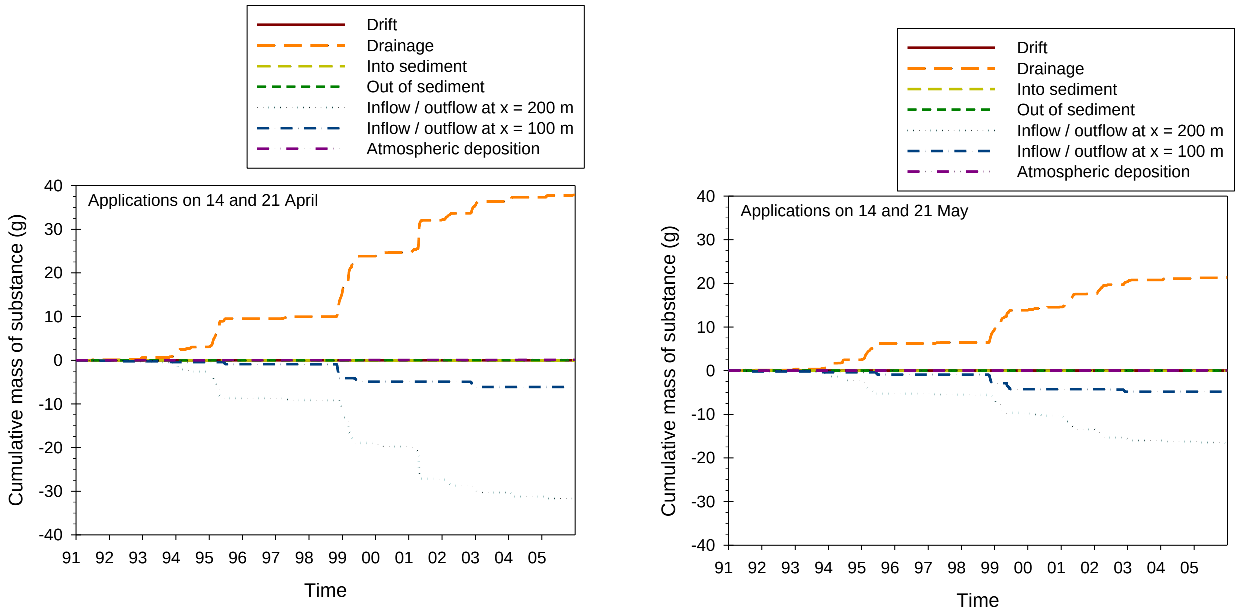

Figure 72 *Cumulative mass balances of substance H_{py} for the April treatment (left-hand side) and the May treatment (right-hand side) with downward spraying in an avenue tree nursery; all as a function of year. Negative values indicate a sink and positive values a source. Note, that due to varying flow directions the substance may both enter the target stretch (inflow) or leave the target stretch (outflow) via the boundaries of the target stretch (x = 100m and x = 200m). The process of transformation is not plotted because it is negligible due to the large half-lives in water and sediment.*

Note that despite the substance H_p degrades rapidly in soil, in most years the drainage route was the dominant source for the PEC_{max}. This is first of all due to limited contribution of spray drift but secondly due to macropore flow which leads to increased and delayed leaching to the drains. It seems that the mobility of substances in soil has a larger impact on the PEC_{max} than persistence in soil.

In contrast, for substance H_d, which is rather persistent and immobile, atmospheric deposition was found to be the dominant source (Section 8.4.1). The example calculations with substances H_d and H_p suggest that, when spray drift deposition is highly reduced, atmospheric deposition is not a relevant entry route for slightly to very mobile substances (estimated order of magnitude: $K_{om,soil}$ <1 – 100 L kg^{-1}; more research is however needed to fine tune this criterion).

8.5 Results of calculations for downward spraying in fruit orchards

8.5.1 Substance H_{py} (parent)

Substance H_{py} is an herbicide which is applied two times in fruit orchards with a dose of 0.021 kg a.i. ha^{-1} on either 21 April and 12 May or on 6 November and 27 November and on either the tree strips or on the grass strips. Figure 73 shows the average concentration (dissolved) of substance H_{py} in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for the four different combinations of application timing and treatment type (A: treatment of the tree strips and B: treatment of the grass strips).

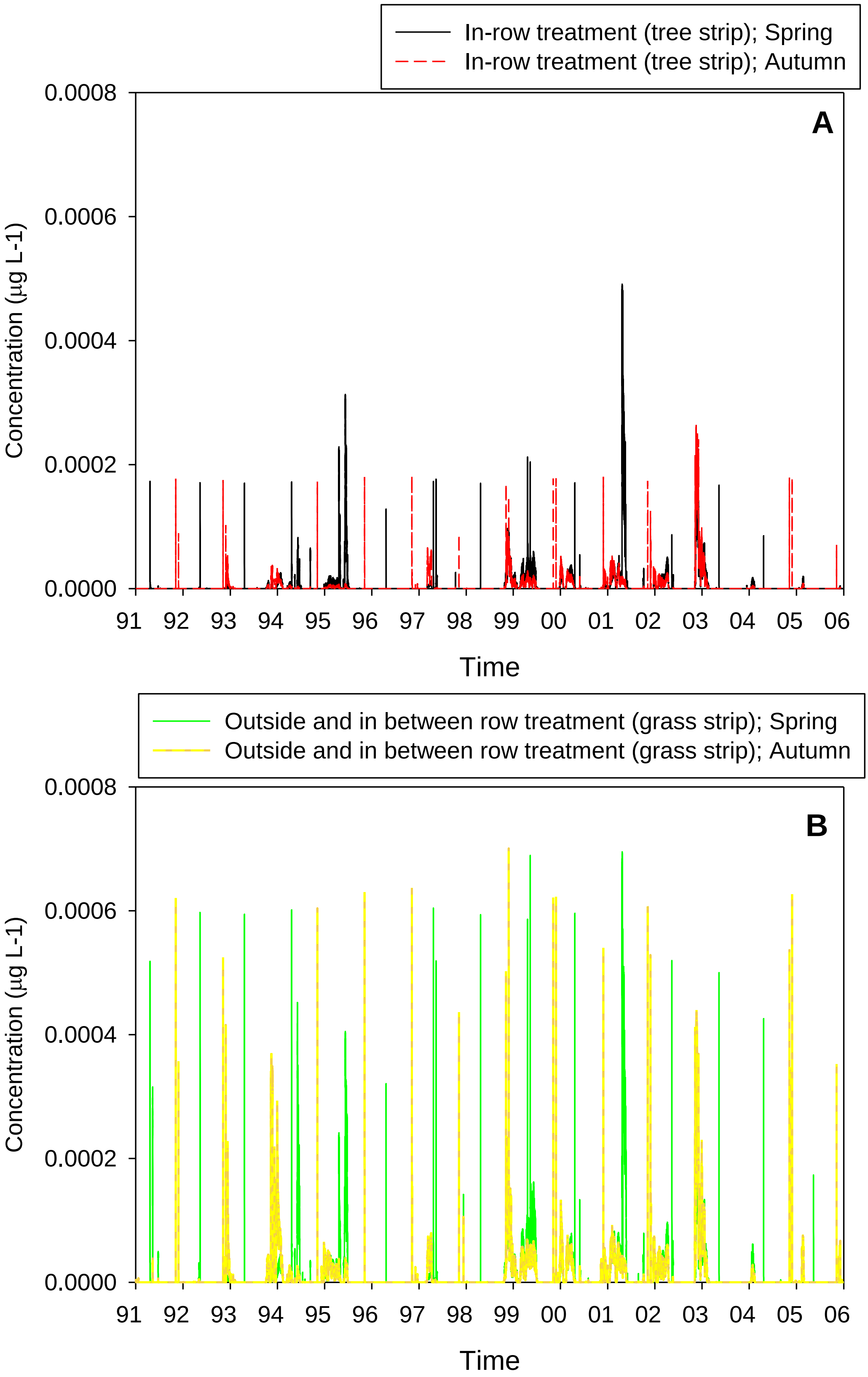

Figure 73 *Average concentration (dissolved) of substance H_{py} in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for two different timings of applications (spring, autumn) and two different treatment types (**A**: treatment of tree strips; **B**: treatment of grass strips).*

Figure 73 shows that, when comparing graph A with graph B, although the concentration patterns were very similar, higher concentrations were found for treatment of the grass strips than for treatment of the tree strips. First of all, spray drift deposits are much lower for a tree strip treatment than for a grass strip treatment, as explained in Section 5.1.3 and shown in Figure 23. Secondly, the contribution of drainage to the concentration in the ditch is generally also higher for treatment of the grass strip than for treatment of the tree strip. This is for instance visible in Figure 73 in years with a large input via the drain e.g. 1994, 1995, 2001 and 2003. The grass strip covers 2/3 of the orchard and the tree strip 1/3. Drainage water from both strips assembles in the drainage tubes i.e. the fluxes on an hourly basis are summed up, whereby the weight of the tree strip was 1/3 and that of the grass strip was 2/3. If only the tree strip is treated, only 1/3 of the total drainage from the orchard is polluted. If only the grass strip is treated, a larger part, namely 2/3 of the total drainage from the orchard is polluted.

Table 25 provides an overview of the annual PEC_{max} of H_{py} in the target stretch of the ditch of the selected percentile year for the four combinations of application timing and treatment type. Using the protocol of Section 4.4 to select the temporal percentile when both drift and drainage occur, it was determined that in all four simulations at least eleven annual PEC_{max} values were caused by spray drift as the dominant route and thus the T_{90} for spray drift was selected. Although spray drift deposits are relatively low with downward treatments, the substance H_{py} degrades rapidly in the soil ($DegT50_{soil}$ = 0.32 d) and its contribution to drainage is practically zero. Therefore spray drift turned out to be the major entry route. For the tree strip treatments, both in spring and autumn, the T_{90} was 38.2% for the spray drift route. For the grass strip treatment, both in spring and autumn, the T_{90} was 80.0% in this case. Note the large differences in T_{90} values for grass and tree strip treatments, as was already shown in Section 5.5.2.

Table 25 *The annual PEC_{max} of H_{py} in the target stretch of the ditch of the selected percentile year for two different timings of applications (spring, autumn) and two different treatment types (in-row i.e. treatment of tree strip and outside and in between row i.e. treatment of the grass strip).*

	Selected temporal percentile	**Annual PEC_{max} dissolved (μg L^{-1})**	**Time of PEC_{max}**	**dominant source PEC_{max}**
In-row treatment (tree strip); Spring	38.2	1.70E-04	21-04-1998 09:00	drift
In-row treatment (tree strip); Autumn	38.2	1.73E-04	06-11-1994 09:00	drift
Outside and in between treatment (grass strip); Spring	80.0	6.04E-04	21-04-1997 09:00	drift
Outside and in between treatment (grass strip); Autumn	80.0	6.30E-04	06-11-1995 09:00	drift

Figure 74 shows the annual maximum concentration (dissolved) of substance H_{py} in the water of the 100 m target stretch for two different timing of applications (spring, autumn) and two different treatment types (in-row i.e. treatment of tree strip and outside and in between row i.e. treatment of the grass strip). The arrows indicate the annual PEC_{max} value of the corresponding target temporal percentile, which was the 38.2nd percentile for treatment of the tree strip (in-row) and the 80.0th percentile for treatment of the grass strip (outside and in between rows). For the treatment of the tree strip, the 38.2nd percentile PEC_{max} is found in 1998 and 1994 for respectively for the applications in spring and autumn. For the treatment of the grass strip, the 80.0th percentile PEC_{max} is found in 1997 and 1995 for respectively the applications in spring and autumn.

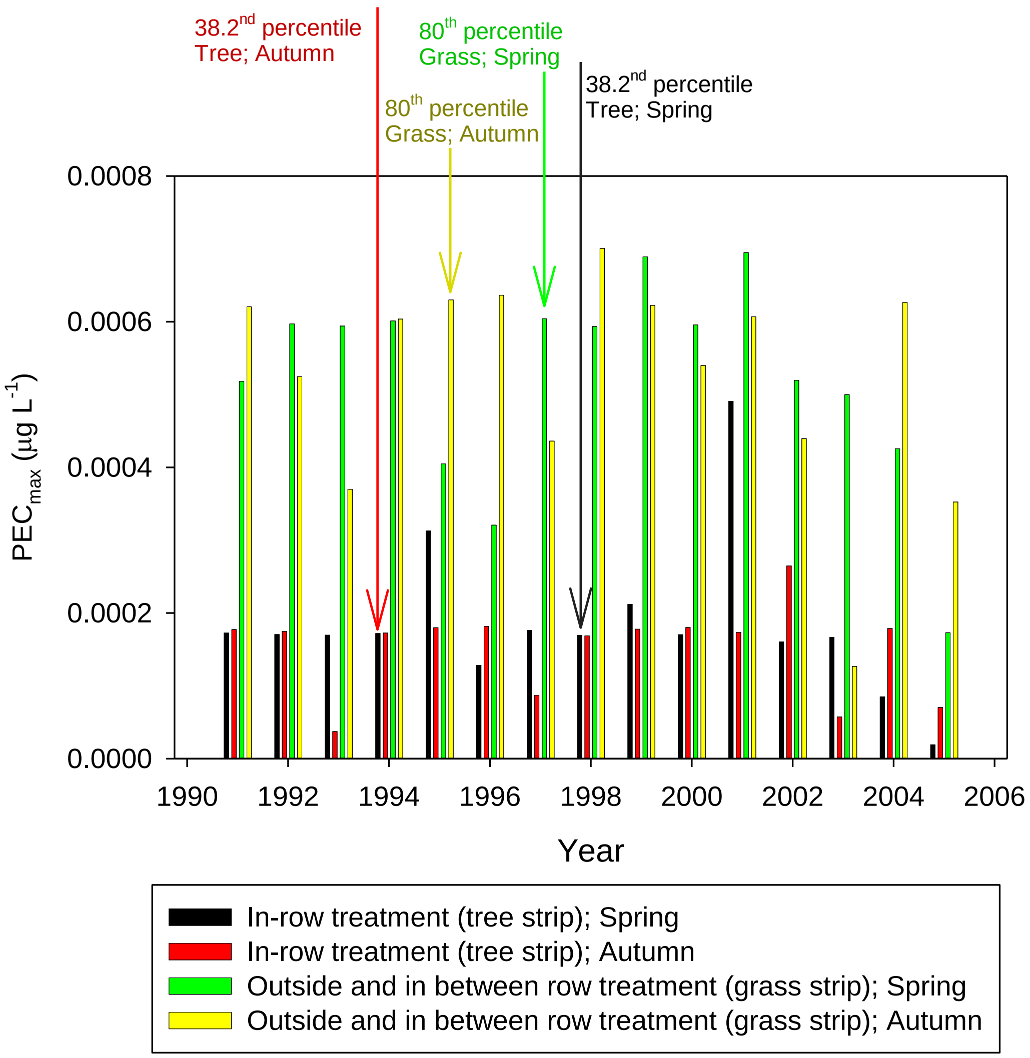

Figure 74 *Annual maximum concentration (dissolved) of substance H_{py} in the water of the 100 m target stretch for two different timings of applications (spring, autumn) and two different treatment types (tree strip treatment and grass strip treatment). The arrows indicate the annual maximum concentration of the target percentile year selected.*

Table 26 and Table 27 provide information on the annual PEC_{max} values and corresponding dates of all 15 evaluation years for the tree strip treatment and the grass strip treatment, respectively.

Figure 75 shows the concentration patterns of substance H_{py} in the selected temporal percentile year for two different timing of applications (spring, autumn) and two different treatment types (graph **A**: tree strip treatment and graph **B**: grass strip treatment). Graph A shows for both the spring and autumn application needle shaped patterns on a day of application and reaching a maximum in the selected year. This confirms that for these two simulations spray drift is the source of the annual PEC_{max} in the selected temporal percentile year.

Graph B shows that the needle shape of the peak of the PEC_{max} of the spring application on the grass strip of the fruit orchard is less pronounced. PEC_{max} values of both the spring and autumn application on the grass strip of the fruit orchard are found on the time of an application (Table 27) indicating that the PEC_{max} is caused by spray drift. The drift event on 21 April 1997 is followed by a small drainage event on 22 April. Around 6 November 1995 there are no drainage events (determined by inspecting the relevant PEARL output file) hence the PEC_{max} shows a more pronounced needle shape.

Table 26 *Detailed information on the annual PEC_{max} of H_{py} in the target stretch of the ditch of for tree strip treatment type and two different timings of applications (spring, autumn).*

	In-row treatment (tree strip); Spring			In-row treatment (tree strip); Autumn		
percentile (%)	**Annual PEC_{max} dissolved (μg L^{-1})**	**Time of PEC_{max}**	**dominant source PEC_{max}**	**Annual PEC_{max} dissolved (μg L^{-1})**	**Time of PEC_{max}**	**dominant source PEC_{max}**
3.33	0.1928E-04	2005-02-21-23h00	drain	0.3730E-04	1993-11-23-09h00	drain
10	0.8520E-04	2004-04-21-09h00	drift	0.5745E-04	2003-01-13-17h00	drain
16.67	0.1283E-03	1996-04-21-09h00	drift	0.7051E-04	2005-11-06-09h00	drift
23.33	0.1606E-03	2002-11-24-23h00	drain	0.8730E-04	1997-11-06-09h00	drift
30	0.1667E-03	2003-05-12-09h00	drift	0.1688E-03	1998-11-06-09h00	drift
36.67	0.1696E-03	1998-04-21-09h00	drift	0.1726E-03	1994-11-06-09h00	drift
43.33	0.1698E-03	1993-04-21-09h00	drift	0.1735E-03	2001-11-06-09h00	drift
50	0.1703E-03	2000-04-21-09h00	drift	0.1750E-03	1992-11-06-09h00	drift
56.67	0.1707E-03	1992-05-12-09h00	drift	0.1774E-03	1991-11-06-09h00	drift
63.33	0.1719E-03	1994-04-21-09h00	drift	0.1779E-03	1999-11-27-09h00	drift
70	0.1728E-03	1991-04-21-09h00	drift	0.1789E-03	2004-11-06-09h00	drift
76.67	0.1763E-03	1997-05-12-09h00	drift	0.1801E-03	1995-11-06-09h00	drift
83.33	0.2120E-03	1999-04-21-09h00	drift	0.1802E-03	2000-11-27-09h00	drift
90	0.3130E-03	1995-06-10-07h00	drain	0.1819E-03	1996-11-06-09h00	drift
96.67	0.4910E-03	2001-04-22-05h00	drain	0.2649E-03	2002-11-16-07h00	drain

Table 27 *Detailed information on the annual PEC_{max} of H_{py} in the target stretch of the ditch of for grass strip treatment and two different timings of applications (spring, autumn).*

percentile (%)	**Outside and in between row treatment (grass strip); Spring**			**Outside and in between row treatment (grass strip); Autumn**		
	Annual PEC_{max} dissolved (μg L^{-1})	**Time of PEC_{max}**	**dominant source PEC_{max}**	**Annual PEC_{max} dissolved (μg L^{-1})**	**Time of PEC_{max}**	**dominant source PEC_{max}**
3.33	0.1731E-03	2005-05-12-09h00	drift	0.1268E-03	2003-01-13-17h00	drain
10	0.3208E-03	1996-04-21-09h00	drift	0.3525E-03	2005-11-06-09h00	drift
16.67	0.4051E-03	1995-06-10-07h00	drain	0.3702E-03	1993-11-14-23h00	drain
23.33	0.4260E-03	2004-04-21-09h00	drift	0.4365E-03	1997-11-06-09h00	drift
30	0.5002E-03	2003-05-12-09h00	drift	0.4398E-03	2002-11-19-01h00	drain
36.67	0.5185E-03	1991-04-21-09h00	drift	0.5249E-03	1992-11-06-09h00	drift
43.33	0.5198E-03	2002-05-12-09h00	drift	0.5403E-03	2000-11-27-09h00	drift
50	0.5937E-03	1998-04-21-09h00	drift	0.6040E-03	1994-11-06-09h00	drift
56.67	0.5944E-03	1993-04-21-09h00	drift	0.6073E-03	2001-11-06-09h00	drift
63.33	0.5961E-03	2000-04-21-09h00	drift	0.6208E-03	1991-11-06-09h00	drift
70	0.5973E-03	1992-05-12-09h00	drift	0.6228E-03	1999-11-27-09h00	drift
76.67	0.6015E-03	1994-04-21-09h00	drift	0.6268E-03	2004-11-27-09h00	drift
83.33	0.6044E-03	1997-04-21-09h00	drift	0.6302E-03	1995-11-06-09h00	drift
90	0.6894E-03	1999-05-12-09h00	drift	0.6368E-03	1996-11-06-09h00	drift
96.67	0.6952E-03	2001-04-22-05h00	drain	0.7008E-03	1998-11-27-09h00	drift

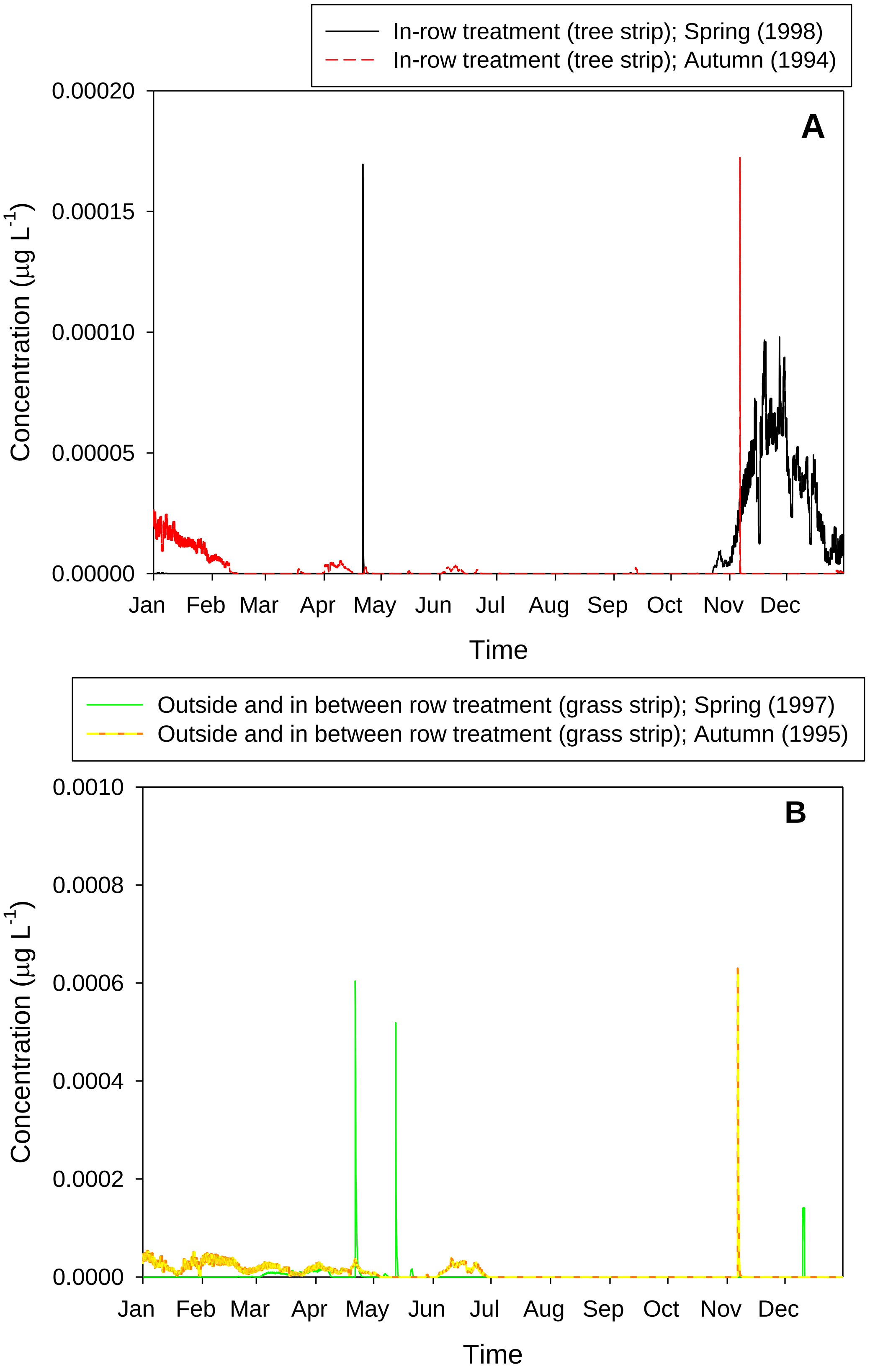

Figure 75 *Average concentration (dissolved) of substance H_{py} in the water of the 100 m target stretch as function of time for the year in which the target percentile is found for two different timings of applications (spring, autumn) and two different treatment types (**A**: tree strip treatment; spring application: 1998, autumn application 1994 and **B**: grass strip treatment; spring application: 1997, autumn application: 1995).*

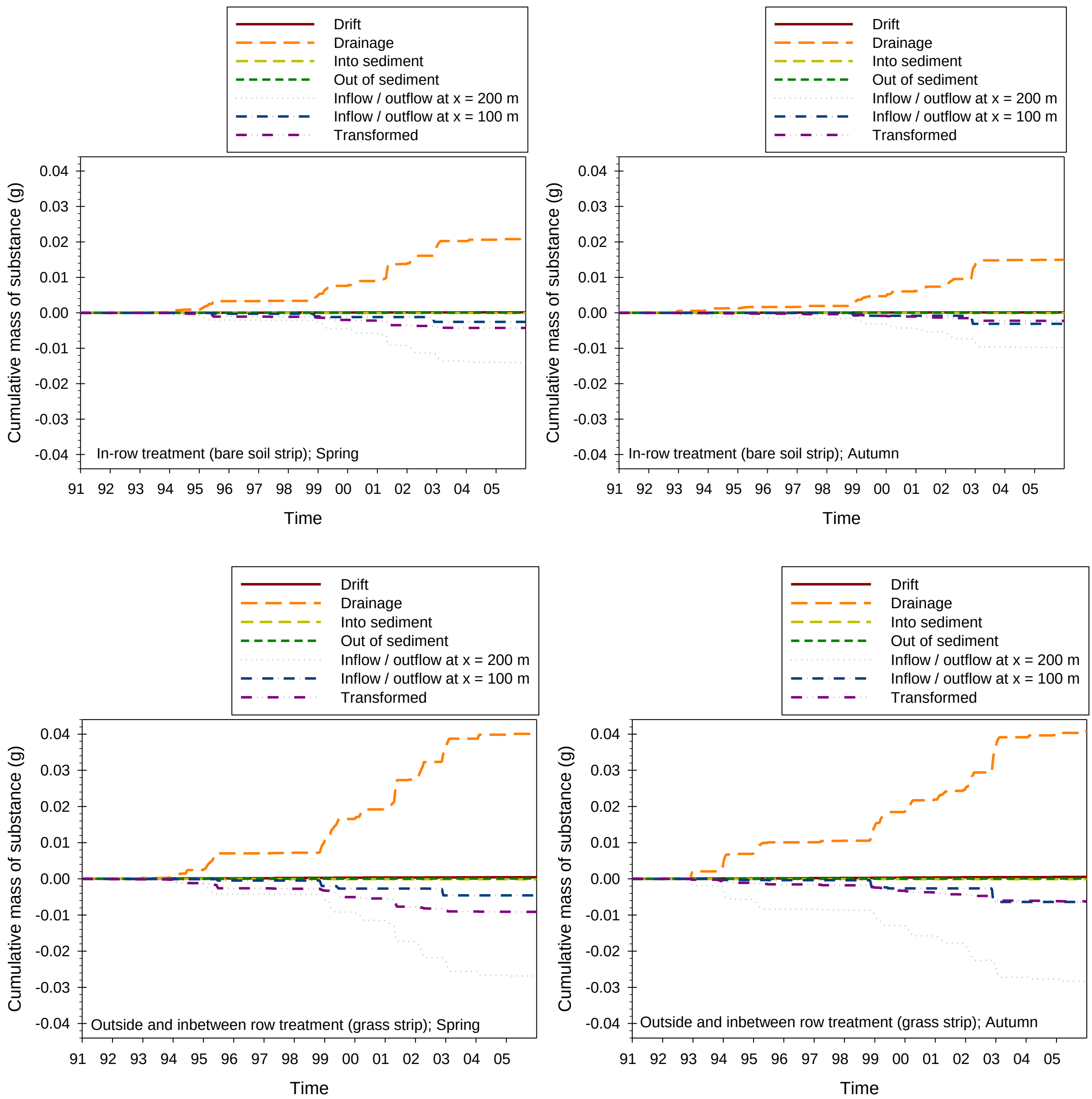

Figure 76 *Cumulative mass balances of substance H_{py} in the target stretch of the watercourse for the tree strip treatment in spring (upper left-hand side), the tree strip treatment in autumn (upper right-hand side), the grass strip treatment in spring (lower left-hand side) and the grass strip treatment in autumn (lower right-hand side); all as a function of year. Negative values indicate a sink and positive values a source. Note, that due to varying flow directions the substance may both enter the target stretch (inflow) or leave the target stretch (outflow) via the boundaries of the target stretch (x = 100m and x = 200m).*

Figure 76 shows that during the 15 years evaluation period, the largest part of the mass of substance H_{py} entered the ditch by drainage and not by spray drift. The volume of drainage water entering the ditch was often large leading to a large total mass of H_{py} entering the ditch by drainage compared to the mass entering the ditch by spray drift. Note further that emission from drains was erratic, in some of the simulated years the inflow via drain flow was almost zero, as can be seen from the nearly horizontal lines during 1996-1999.

Figure 76 also shows that, as well for the 100m as 200m boundary of the target stretch, the inflow/outflow lines are negative and thus in both cases the outflow of mass dominated the inflow of mass. Moreover, the outflow at x = 200m was significantly larger than the outflow at x = 100m, thus water flowed mostly from x = 100m to x = 200m

Simulations were done using a $DegT50_{water}$ of 0.08 d hence the contribution of transformation to the mass balance was considerable.

Next the mass balances of the four simulations were compared. Pesticide input via drainage was about twice as large for the treatment of the grass strip (outside and in between row) than for the treatment of the tree strip (in-row treatment). This was due to the larger area of the grass strips (2/3 of the orchard, 90% crop interception) compared to the tree strips (1/3 of the orchard, no crop interception). This ratio 1/3 : 2/3 (=1:2) was also seen when comparing the cumulative masses of drainage over 15 years (i.e. about 0.02 g for treatment of the tree strip and about 0.04 for treatment of the grass strip). This implies that the cumulative mass fluxes, i.e. the total mass emitted per m^2, of the two treatment types (tree strips vs grass strips) were roughly equal (Table 28). This is somewhat puzzling as the interception fraction of the grass strip is 0.9 and of the tree strip 0. A larger cumulative mass flux of the tree strip would be expected.

To clarify this, we calculated the cumulative H_{py} mass fluxes (1991-2005) of the two PEARL simulations for the grass strip using an interception fraction of 0 instead of 0.9 (Table 28). For the simulation with the spring treatment the total mass flux in the drain water was 4.6 μg m^{-2}, whereas 4.3 μg m^{-2} was found when using an interception fraction of 0.9; i.e. only factor 1.06 higher for the simulation with the interception fraction of 0. An explanation of the lower importance of interception in spring could be that the substance was quickly washed-off the crop after the applications, then reached the soil where the largest part transforms into metabolite H_{py_Met1} and the remainder part of the substance leached quickly to the drains.

For the simulation with the autumn treatment and an interception fraction of 0, the total mass flux in the drain water was 3.5 μg m^{-2}, whereas 4.4 μg μg m^{-2} was found when using an interception fraction of 0.9. It seems strange that zero interception led to lower mass fluxes in the drain water. However, the half-life of the H_{py} in soil is 0.32 d, so if all pesticide would reach the soil immediately after the application, the substance would be transformed quickly to the metabolite H_{py_Met1}. In case of interception by the crop, H_{py} resides on the crop where transformation is much slower (half-life of 10 days). If in the days after application several precipitation events lead to drainage events, this would mean a sort of retarded supply of H_{py} to the drain. This theory is illustrated in Figure 77 by the case of an increase in the concentration H_{py} in the ditch water caused by drainage in the period 18-21 November 2004 for the simulation with 90% crop interception and treatment of the grass strip in Autumn. This increase in the concentration H_{py} in the ditch water was not visible if crop interception would have been 0%. Figure 78 shows the concentration H_{py} in the drain water for both simulations. The 90% crop interception simulation showed a much larger peak concentration in the drain water than the 0% crop interception simulation.

Table 28 *Cumulative mass fluxes of H_{py} for the period 1-Jan-1991/ 31-12-2005.*

	Mass flux from soil matrix (μg m^{-2})	**Mass flux from macropores (μg m^{-2})**	**Total mass flux in drain water (μg m^{-2})**
Tree strip treatment in Spring; results of PEARL simulation	0.5	4.0	4.5
Grass strip treatment in Spring; results of PEARL simulation	0.5	3.8	4.3 (4.6 zero interception)
Tree strip treatment in Autumn; results of PEARL simulation	0.2	3.0	3.2
Grass strip treatment in Autumn; results of PEARL simulation	0.4	4.0	4.4 (3.5 zero interception)

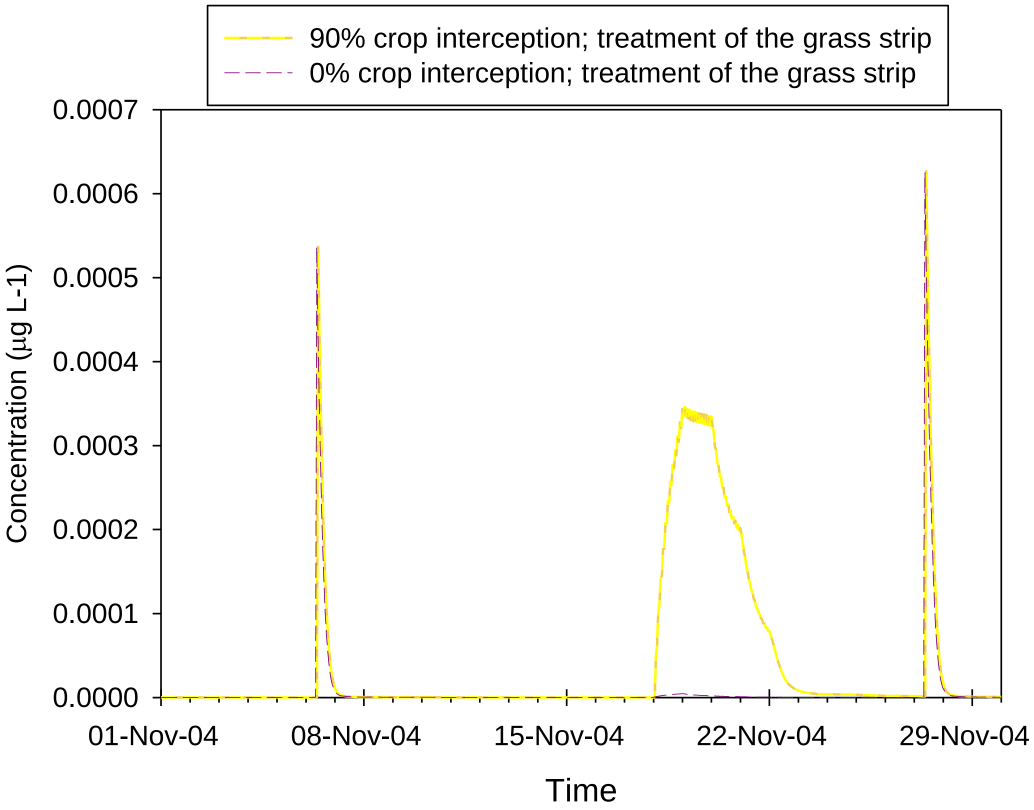

Figure 77 *Average concentration (dissolved) of substance H_{py} in the water of the 100 m target stretch as function of time for the period 1 November – 31 December 2004 for the simulation with grass strip treatment in the autumn and 90% crop interception. Note that the substance is applied on 6 and 27 November and that on these dates peak concentrations as result of spray drift are found.*

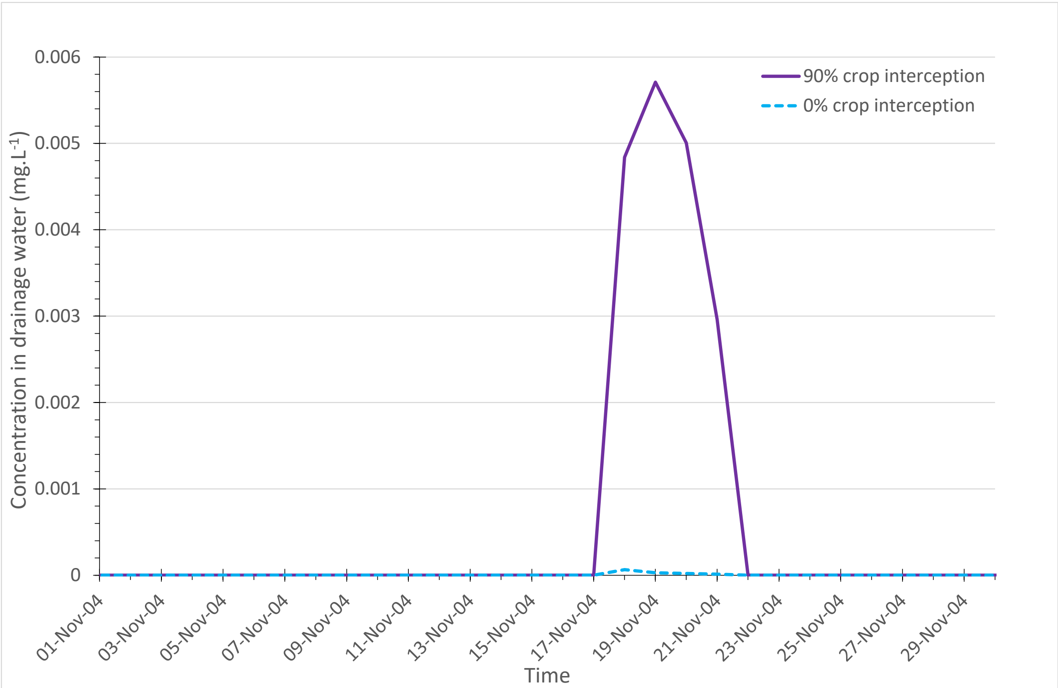

Figure 78 *Concentration in the drainage water as function of time for the grass strip treatment in Autumn for i) 90% crop interception and ii) 0% crop interception.*

As a first step, the origin of the drainage event causing the peak concentration in water in the period 18-21 November 2004 visible in Figure 77 is traced. Precipitation leading to the concentration in water in the period 18-21 November 2004 starts on 16 November that year with 0.75 mm (Table 29).

Table 29 *Precipitation in the period 1 -30 November 2004.*

Date	Precipitation (mm)	Date	Precipitation (mm)	Date	Precipitation (mm)
01-Nov-04	0.00	11-Nov-04	0.00	21-Nov-04	2.04
02-Nov-04	1.13	12-Nov-04	1.54	22-Nov-04	0.96
03-Nov-04	1.92	13-Nov-04	0.54	23-Nov-04	0.33
04-Nov-04	0.29	14-Nov-04	0.00	24-Nov-04	0.00
05-Nov-04	0.00	15-Nov-04	0.00	25-Nov-04	0.00
06-Nov-04	0.75	16-Nov-04	0.75	26-Nov-04	1.04
07-Nov-04	0.00	17-Nov-04	3.50	27-Nov-04	0.00
08-Nov-04	0.00	18-Nov-04	8.17	28-Nov-04	3.00
09-Nov-04	0.00	19-Nov-04	4.71	29-Nov-04	0.00
10-Nov-04	3.63	20-Nov-04	3.29	30-Nov-04	0.00

Next, the different water fluxes in and out of the two macropore domains (bypass and internal catchment) were analysed to trace the source of the drain water entering the ditch. Figure 79 shows that i) water entered the macropores via both direct infiltration and infiltration by runoff and ii) water was exchanged between the macropores and the matrix with a net flux towards the matrix (largest net flux from the internal catchment domain to the matrix). Thus, water entering the macropores did not directly reach the drains but went to the matrix. Note, that the water fluxes in Figure 79 were similar for both the 0% and 90% crop interception simulations.

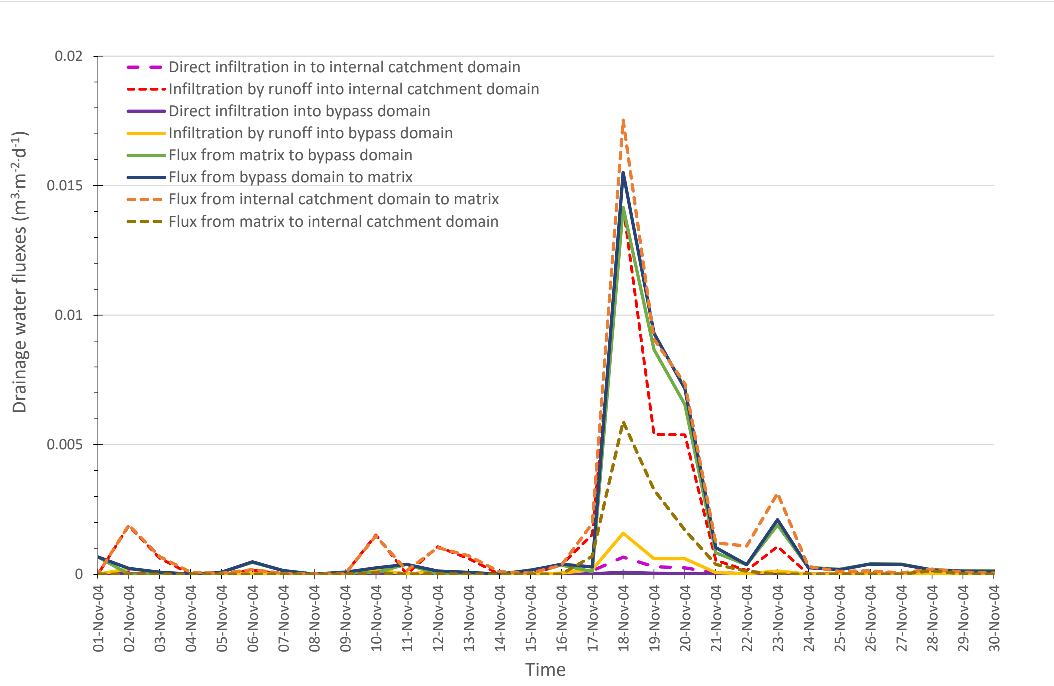

Figure 79 *Water fluxes in and out of the two macropore domains (bypass and internal catchment).*

Figure 80 shows that the mass of substance H_{py} entered the drain via the matrix. However, this mass was much larger for the 90% crop interception simulation than for the 0% crop interception simulation.

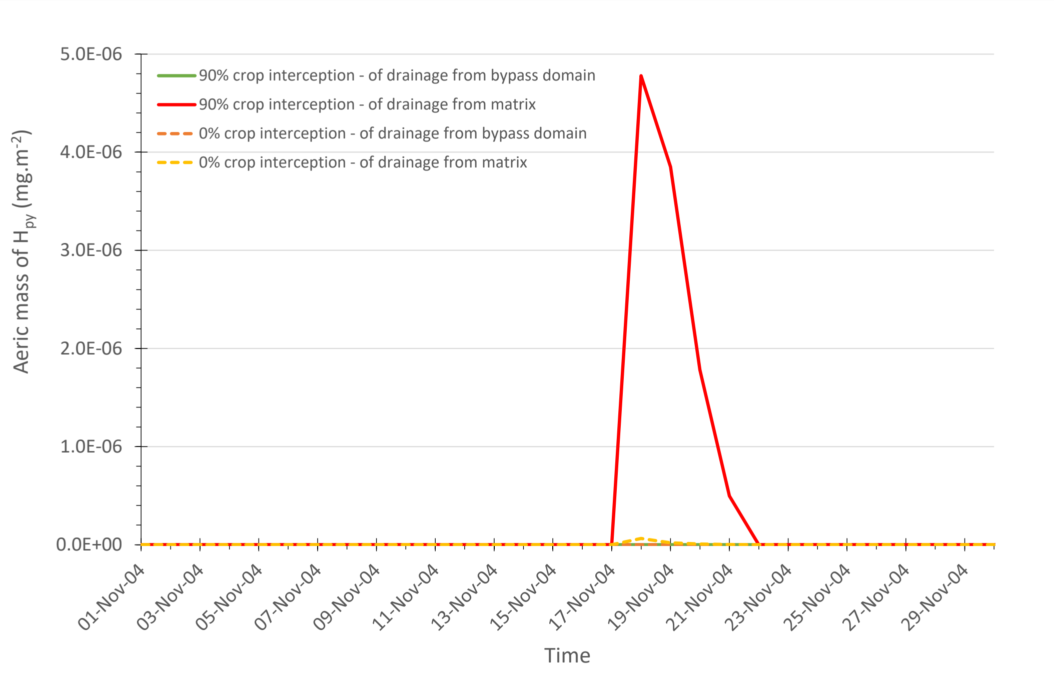

Figure 80 *Aeric mass of H_{py} in drainage from the bypass domain (macropores) and in drainage from the micropores (soil matrix) as function of time for the grass strip treatment in Autumn for i) 90% crop interception and ii) 0% crop interception.*

Next question is why more substance mass was reaching the drains (via the matrix) for the simulation with 90% crop interception than for the 0% crop interception simulation. To answer this, the masses H_{py} at the canopy, washed-off from the canopy, applied to the soil surface and in the soil matrix were analysed for i) 90% crop interception and ii) 0% crop interception (Figure 81). The aeric mass applied to the soil surface as result of the applications on 6 and 27 November was of course larger for the 0% interception simulation because 100% of the applied spray reached the soil surface. Figure 81 shows that for the 0% interception simulation the aeric mass in soil decreased according to a first order reaction. The 90% interception simulation shows a more irregular and somewhat retarded decline of both the aeric mass at the canopy and the aeric mass in soil. At some days the decline of the aeric mass at the canopy was faster due to wash-off. At these days the aeric mass in soil increased slightly, as can be seen around 10 and 17/18 November. Around 18 November, the mass H_{py} in soil was nearly zero for the 0% crop interception simulation. However, for the 90% crop interception simulation the mass H_{py} in soil increased again due to wash-off from the canopy. As seen in Figure 79 and Figure 80, around 18 November water and substance were transported via the macropores to the matrix and subsequently reached the drain.

This case illustrates that in case the half-life of substance on the crop is one or more orders of magnitudes larger than the half-life of substance in soil, crop interception might cause a retarded supply of substance to the drain.

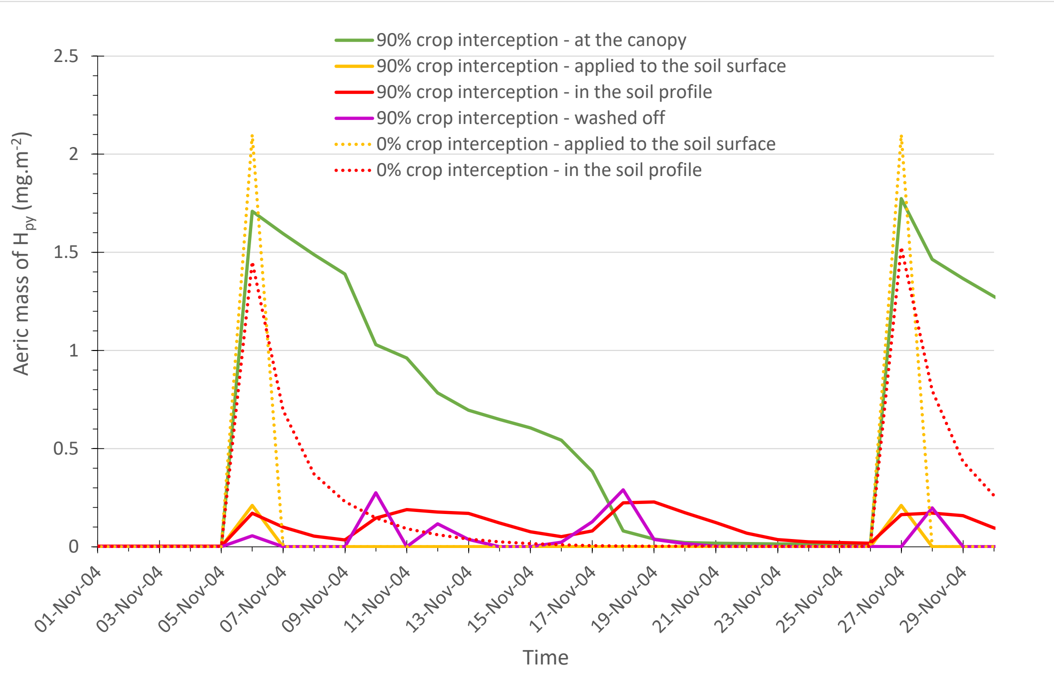

Figure 81 *Aeric mass of H_{py} at the canopy (grass), applied to the soil surface and in the matrix of the soil as function of time for the grass strip treatment in Autumn for i) 90% crop interception and ii) 0% crop interception. Note that for the 0% crop interception simulation the aeric mass at the canopy is not plotted because all values are zero.*

8.5.2 H_{py_Met1} (metabolite)

Substance H_{py_Met1} is a relevant metabolite of herbicide H_{py} which was applied two times in fruit orchards with a dose of 0.021 kg a.i. ha^{-1} on either 21 April and 12 May or on 6 November and 27 November and on either the tree strip (in-row treatment) or on the grass strip (outside and in between row treatment). H_{py} was almost fully transformed into H_{py_Met1} in all compartments (formation fraction 0.94 in soil and formation fraction 1 in water and sediment)

Figure 82 shows the average concentration (dissolved) of substance H_{py_Met1} in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for the four different combinations of application timing and treatment type (A: tree strip treatment and B: grass strip treatment). Concentration of H_{py_Met1} can be the result of i) transformation of parent H_{py} in the ditch after spray drift deposition and/or ii) transformation of parent H_{py} in the ditch after a drainage event with drain water containing H_{py} entering the ditch or ii) drain water containing H_{py_Met1} entering the ditch (i.e. after transformation of H_{py} to H_{py_Met1} in soil and leaching of H_{py_Met1} to the drains).

Figure 82 shows that, when comparing graph A with graph B, the concentration patterns were very similar and slightly higher concentrations were found for treatment of the grass strips than for treatment of the tree strips. This difference in concentration level between the two treatment types was not as large as for the parent substance H_{py} (Figure 73). Whereas the concentration pattern of parent substance H_{py} showed a regular pattern of needle shaped peaks, which points towards concentration peaks caused by spray drift, the concentration patterns of the metabolite H_{py_Met1} showed a more irregular pattern which suggests dominance of the drainage route.

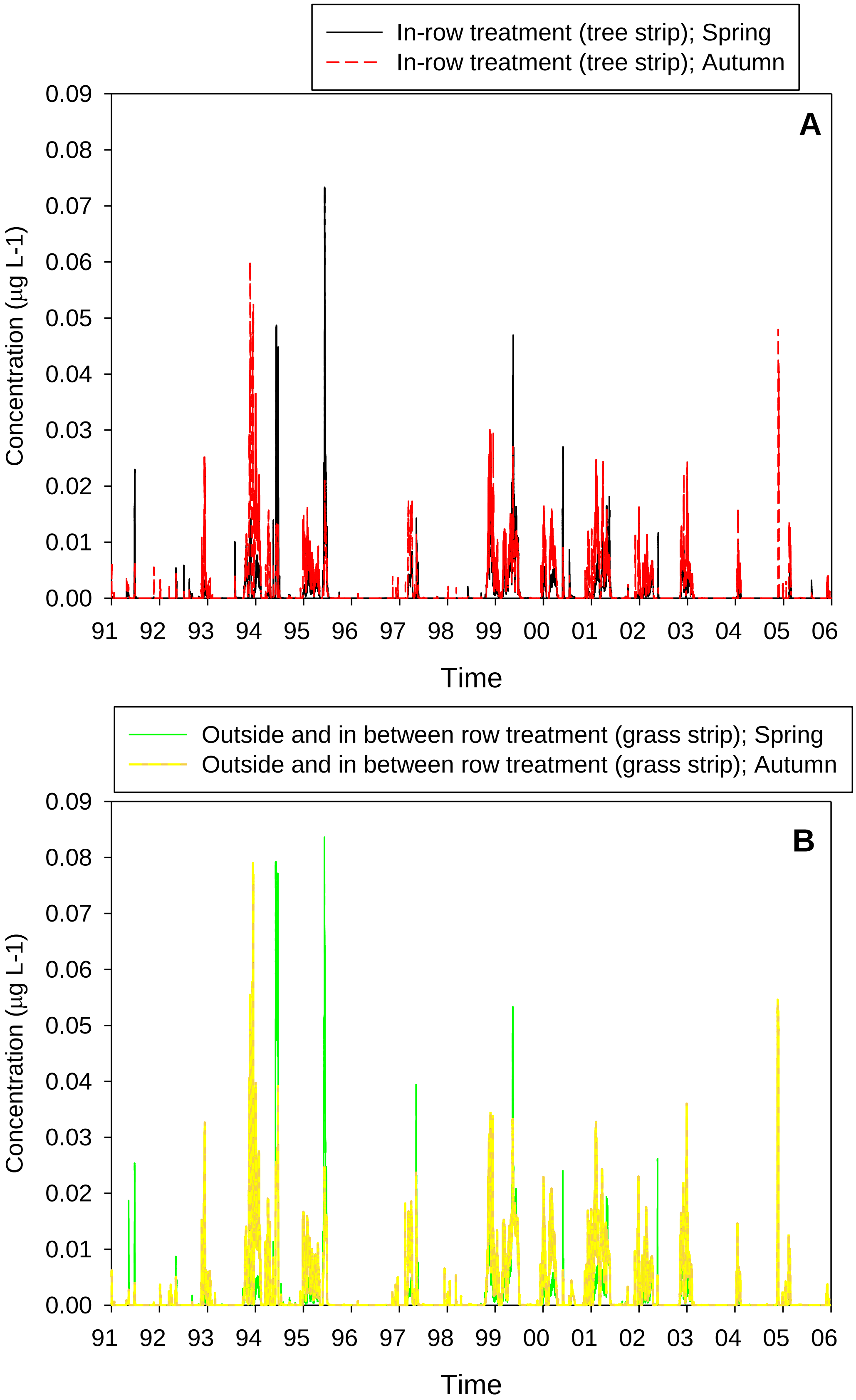

Figure 82 *Average concentration (dissolved) of substance H_{py_Met1} in the water of the 100 m target stretch as function of time for the evaluation period 1991 – 2005 for two different timings of applications (spring, autumn) and two different treatment types (**A**: tree strip treatment; **B**: grass strip treatment).*

Figure 83 shows the annual maximum concentration (dissolved) of substance H_{py_Met1} in the water of the 100 m target stretch for two different timing of applications (spring, autumn) and two different treatment types (tree strip treatment and grass strip treatment). Boesten et al. (2021) argued to use the 63rd percentile of the drainage route for metabolites that were formed in soil. This approach was followed here. The arrows in Figure 83 indicate the annual PEC_{max} value of the 63rd percentile of the drainage route for all four simulations.

For the treatment of the tree strips, the 63rd percentile PEC_{max} was found in 1998 and 1992 for the applications in spring and autumn, respectively. For the treatment of the grass strips, the 63rd percentile PEC_{max} was found in 1991 and 1999 for the applications in spring and autumn, respectively.

Table 30 provides an overview of the selected PEC_{max} of H_{py_Met1} in the target stretch of the ditch for the selected percentile year for the four combinations of application timing and treatment type.

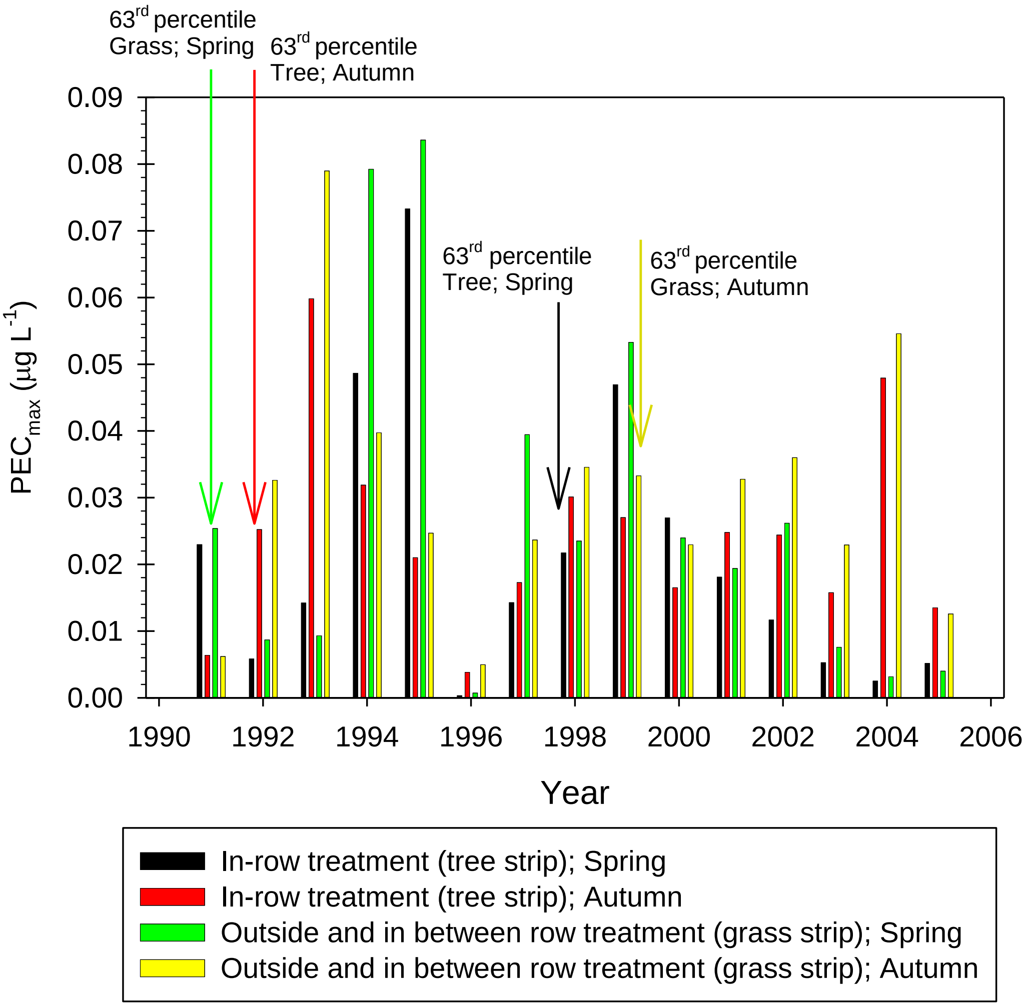

Figure 83 *Annual maximum concentration (dissolved) of substance H_{py_Met} in the water of the 100 m target stretch for two different timings of applications (spring, autumn) and two different treatment types (tree strip treatment and grass strip treatment). The arrows indicate the annual maximum concentration of the target percentile year selected.*

Table 30 *The annual PEC_{max} of H_{py_Met1} in the target stretch of the ditch of the selected percentile year for two different timings of applications (spring, autumn) and two different treatment types (tree strip treatment and grass strip treatment).*

	Selected temporal percentile	Annual PEC_{max} dissolved (µg L^{-1})	Time of PEC_{max}
In-row treatment (tree strip); Spring	63	0.2174E-01	1998-11-27-05h00
In-row treatment (tree strip); Autumn	63	0.2524E-01	1992-12-07-23h00
Outside and in between treatment (grass strip); Spring	63	0.2540E-01	1991-06-25-23h00
Outside and in between treatment (grass strip); Autumn	63	0.3329E-01	1999-05-13-13h00

Figure 84 shows the concentration patterns of substance H_{py_Met1} in the selected temporal percentile year for two different timings of applications (spring, autumn) and two different treatment types (graph **A**: treatment of the tree strips and graph **B**: treatment of the grass strips). Three out of 4 simulations show concentrations patterns that were typical for a drainage dominated system (i.e. a very irregular concentration pattern in either spring or autumn, depending on the timing of the application). The simulation for the treatment of the grass strip in spring (solid, green line in graph B) showed two almost needle shaped peaks around half of May and end of June (note drift deposition of the parent on 21 April and 12 May 1991). The first peak around half of May could be the result of transformation of the parent of the drift event on 12 May 1991. However, detailed inspection of the data showed that the peak was found on 11 May 1991, so one day before the drift event. Inspection of the drainage data in the PEARL output file of the metabolite showed that on 11 May 1991 a drainage event occurred. Therefore, the peak around half May was the result of a drainage event and not of a drift event. The second peak around end of June 1991 coincided with a drainage event lasting for several days and therefore this peak was the result of drainage as well (of both the parent and the metabolite).

Even though metabolite H_{py_Met1} is formed in both soil as the water-sediment system, analysis of the concentration patterns showed that the metabolite concentration in the ditch was mainly caused by drainage and therefore it is justified to select the 63rd temporal percentile.

Figure 85 shows the cumulative mass balance terms for the water layer of the target stretch of the evaluation ditch. Main components of the mass balance were an input via drainage and an output via outflow. The mass of metabolite entering the ditch via drainage and leaving the ditch via outflow was much larger for the metabolite than for the parent (compare Figure 85 and Figure 76). This was due to the short half-life in soil of the parent (0.32 d), causing the parent substance to be transformed very quickly into the metabolite and only a small part of the parent substance could leach to the drains.

Furthermore, the mass of metabolite entering the ditch via drainage (and leaving the ditch via outflow) was for both treatment types roughly a factor 2.5 higher in autumn than in spring, whereas the difference in mass of metabolite entering the ditch via drainage between the two treatment types did not differ much. This was different for the parent, which showed a factor 2 difference in substance mass in drain water between the two treatment types and hardly a difference in substance mass in drain water between the seasons in which the application occurs.

First it can be questioned why there is barely any difference in metabolite mass in the drain water between the tree strip treatment and the grass strip treatment. Afterall, 2/3 of the orchard was covered with grass, hence more metabolite mass in the water drained from the entire orchard could be expected for the grass strip treatment.

Note that if the cumulative metabolite mass in the drain water for the entire orchard would be roughly the same for the two treatment types, whereas the ratio grass strip: tree strip in the orchard is 2, then the mass fluxes of H_{py_Met1} in drainage water would not be equal for the separate strips. In fact, the mass fluxes of H_{py_Met1} in drainage water for the tree strip treatment should be two times as high compared to those for the grass strip treatment. This was indeed the case as shown in Table 31.

Table 31 *Cumulative mass fluxes of H_{py_Met1} for the period 1-Jan-1991/ 31-12-2005*

	Mass flux from soil matrix (μg m^{-2})	**Mass flux from macropores (μg m^{-2})**	**Total mass flux in drain water (μg m^{-2})**
In-row treatment in Spring; results of PEARL simulation for the tree strip (tree strip)	69.4	419.5	488.9
Outside and in between row treatment in Spring; results of PEARL simulation for the grass strip	35.4	234.5	269.9 (412.7 zero interception)
In-row treatment in Autumn; results of PEARL simulation for the tree strip (tree strip)	171.0	988.3	1159.3
Outside and in between row treatment in Autumn; results of PEARL simulation for the grass strip	113.8	618.4	732.2 (1219.9 zero interception)

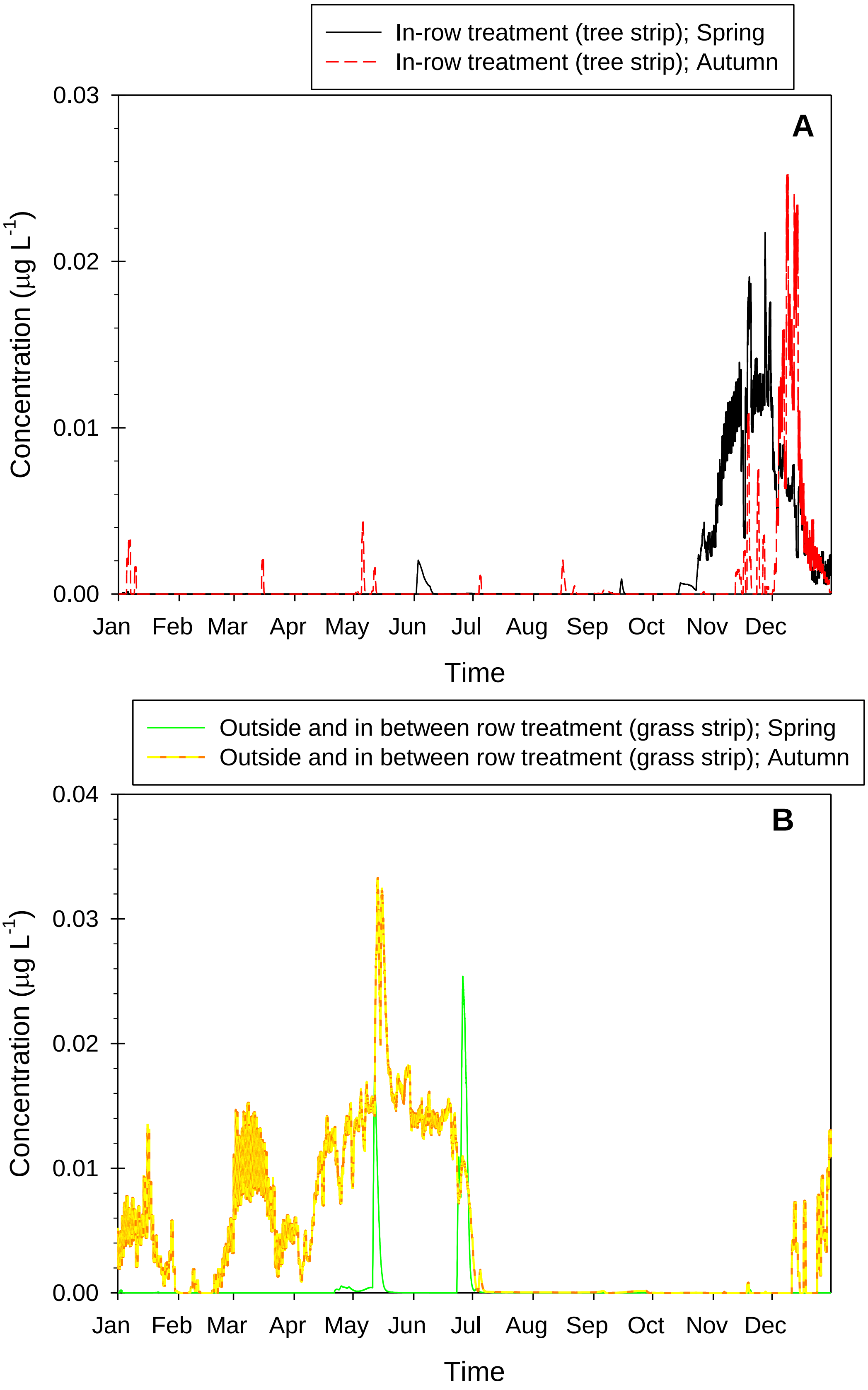

Figure 84 *Average concentration (dissolved) of substance H_{py_Met1} in the water of the 100 m target stretch as function of time for the year in which the target percentile is found for two different timings of applications (spring, autumn) and two different treatment types (**A**: tree strip treatment, spring application 1998, autumn application 1992 and **B**: grass strip treatment, spring application 1991, autumn application 1999).*

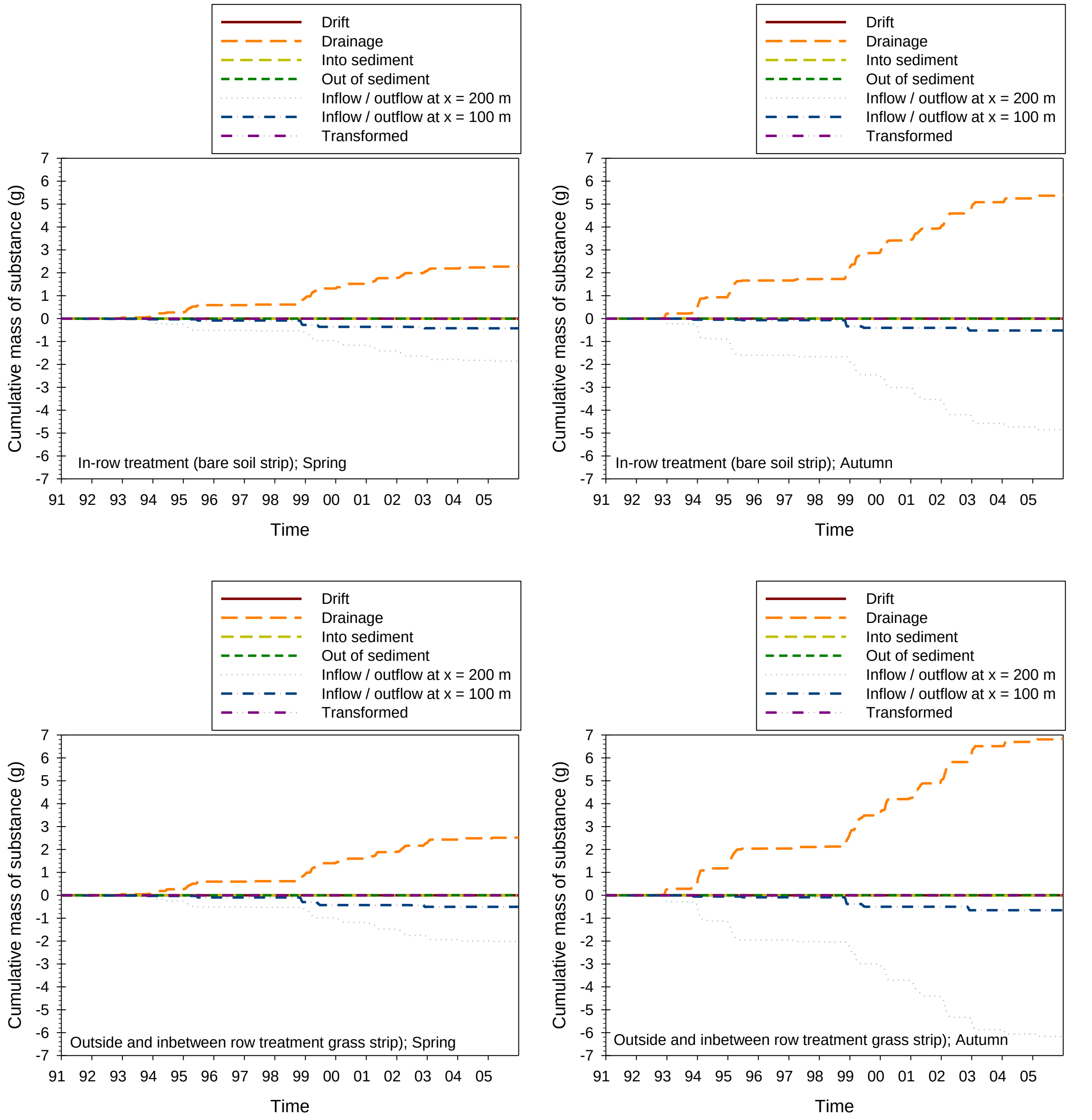

Figure 85 *Cumulative mass balances of substance H_{py_Met1} in the water of the target stretch, for the tree strip treatment in spring (upper left-hand side), the tree strip treatment in autumn (upper right-hand side), the grass strip treatment in spring (lower left-hand side) and the grass strip treatment in autumn (lower right-hand side); all as a function of year. Negative values indicate a sink and positive values a source. Note, that due to varying flow directions the substance may both enter the target stretch (inflow) or leave the target stretch (outflow) via the boundaries of the target stretch (x = 100m and x = 200m).*

Why were cumulative mass fluxes of H_{py_Met1} in drainage water twice as high for the tree strips compared to the grass strips? This can be explained by the difference in interception. As described in the section concerning the parent, we ran the PEARL simulation for both the spring and autumn treatment of the grass strip with zero interception. The cumulative drainage mass fluxes of H_{py_Met1} for the period 1991-2005 of the 0% crop interception simulations were compared to the results of 90% crop interception simulations. For the simulation with the spring treatment the total mass flux of H_{py_Met1} in the drain water was 412.7 μg m^{-2}, whereas 269.9 μg m^{-2} (about a factor 2 lower) was found when using 90% crop interception. The former cumulative mass flux of H_{py_Met1} for the spring treatment of the grass strip using 0% crop interception was rather close to the 488.9 μg m^{-2} cumulative mass flux of H_{py_Met1} for the spring treatment of the tree strip (also zero interception). From this it may be concluded that for the spring treatment interception largely explains the difference of a factor 2 in cumulative mass flux of H_{py_Met1} between the tree strip and the grass strip.

The autumn treatment showed the same pattern. For the simulation with the autumn treatment the total mass flux of H_{py_Met1} in the drain water was 1219.9 μg m^{-2}, whereas 732.2 μg m^{-2} (roughly a factor 2 lower) was found when using 90% crop interception. The first cumulative mass flux of H_{py_Met1} for the spring treatment of the grass strip using zero interception is very similar to the 1159.3 μg m^{-2} cumulative mass flux of H_{py_Met1} for the spring treatment of the tree strip (also zero interception). This means that for the autumn treatment also interception largely explains the difference of a factor 2 in cumulative mass flux of H_{py_Met1} between the tree strip and the grass strip.

As can be seen in Table 27, the mass H_{py_Met1} was for both treatments roughly a factor 2.5 lower in spring than in autumn (i.e. 488.9 versus 1159.3 for the tree strip and 269.9 versus 732.2 for the grass strip). This is explained as follows. For the parent, H_{py}, the cumulative mass entering the ditch via the drain was about equal for the spring and autumn treatments. This also means that the amount of mass available for transformation to the metabolite H_{py_Met1} was about equal for the spring and autumn treatments. However, compared to the autumn treatment apparently a smaller part of it leached to the drain as result of the spring treatment. This might be due to the period with relatively few drainage events following the spring applications. I.e. H_{py_Met1} formed as result of the spring applications was transported to deeper soil layers where part of it degraded and the remaining part leached to the drains in autumn where precipitation events were large enough to trigger drainage events[5].

The theory described above was illustrated for the spring treatment of the tree strip) for the period 1 April – 31 December 1998; i.e. the year in which the PEC_{max} was found for this specific simulation (see also Figure 84A). This case was selected because in 1998 some minor concentration peaks in the ditch water showed up in spring and continuous concentration in the ditch water showed up in November and December. First of all, Figure 86 shows the concentration H_{py_Met1} in soil at different depths as function of time. During the simulation the concentration in soil was building up as result of applications on 21 April and 11 May. Thereafter, at 30 cm depth the concentration was slowly declining. At deeper depths e.g. 80 cm, until June the concentration increased as result of the treatment. Subsequently, the concentration showed a slightly irregular pattern around 0.08 μg L^{-1} in June followed by a slow decline. Around mid-September the concentration at 80 cm depth exceeded those at 50 and 60 cm depth. Thus in autumn the concentrations of H_{py_Met1} in soil were largest just above the drainpipes (at 82 cm below soil surface).

Figure 87 shows the aeric mass H_{py_Met1} as function of time of different processes involving the macropores. In spring major processes were runoff into the internal catchment domain and the bypass domain and transport from the matrix into the internal catchment domain and bypass domain. I.e. in the upper layer of the soil H_{py} degraded quickly to $H_{py\_Met1.}$ Next, as result of precipitation, runoff caused water (containing H_{py_Met1}) to disappear into the macropores. A small part of the water was transported to the drain (Figure 88) and the remaining part was transported from the macropores to the matrix. This explains why in Figure 86 at deeper depths (50, 60 and 80 cm) an irregular pattern of increasing and decreasing concentration in soil is visible.

In autumn the main process visible in Figure 87 was the transport of H_{py_Met1} from the matrix to the bypass domain. This exchange was triggered by a groundwater table rising above the level of the drains (82 cm below soil surface) (Figure 89). This resulted in drainage fluxes into the ditch (Figure 88) and hence increased concentrations in the ditch water (Figure 84A).

[5] Note that degradation is modelled in PEARL as a temperature dependent process (Arrhenius equation), degradation of Hpy_Met1 in soil is faster in spring/summer than in autumn due to the higher temperatures in spring/summer.

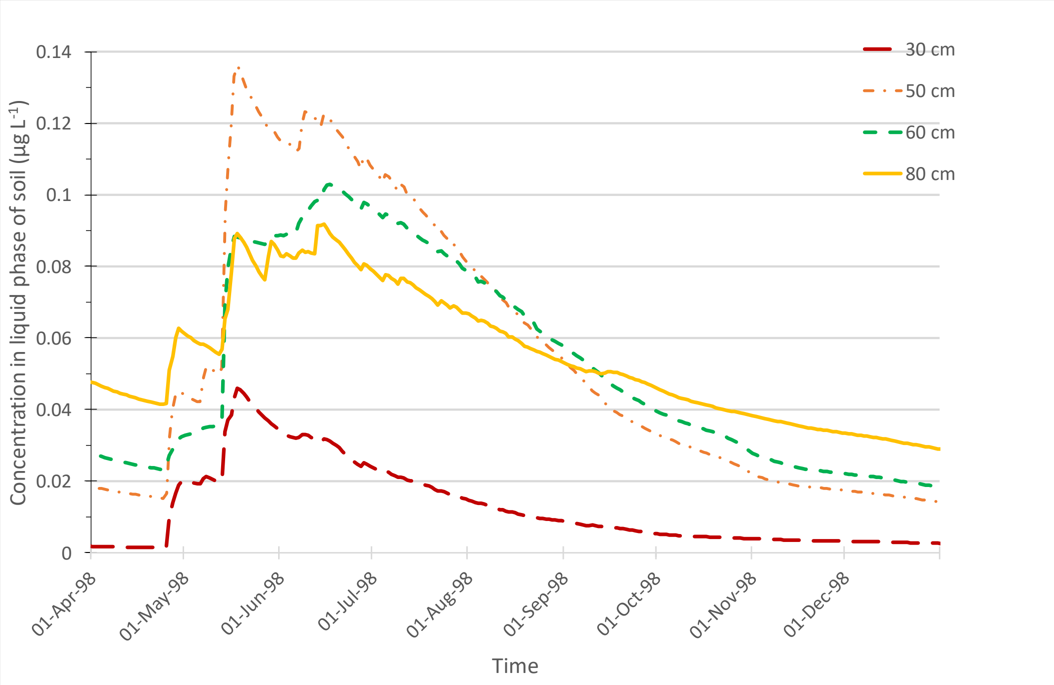

Figure 86 *Concentration H_{py_Met1} in the liquid phase of the soil as function of time and at different depths in soil.*

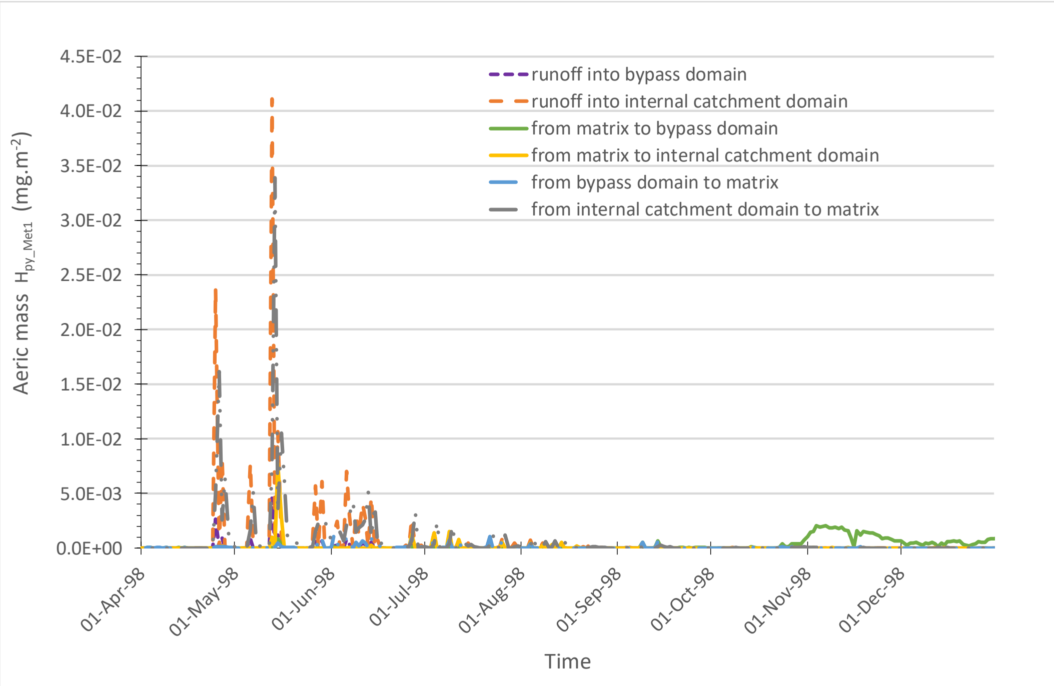

Figure 87 *Aeric mass H_{py_Met1} as function of time of different process involving the macropores*

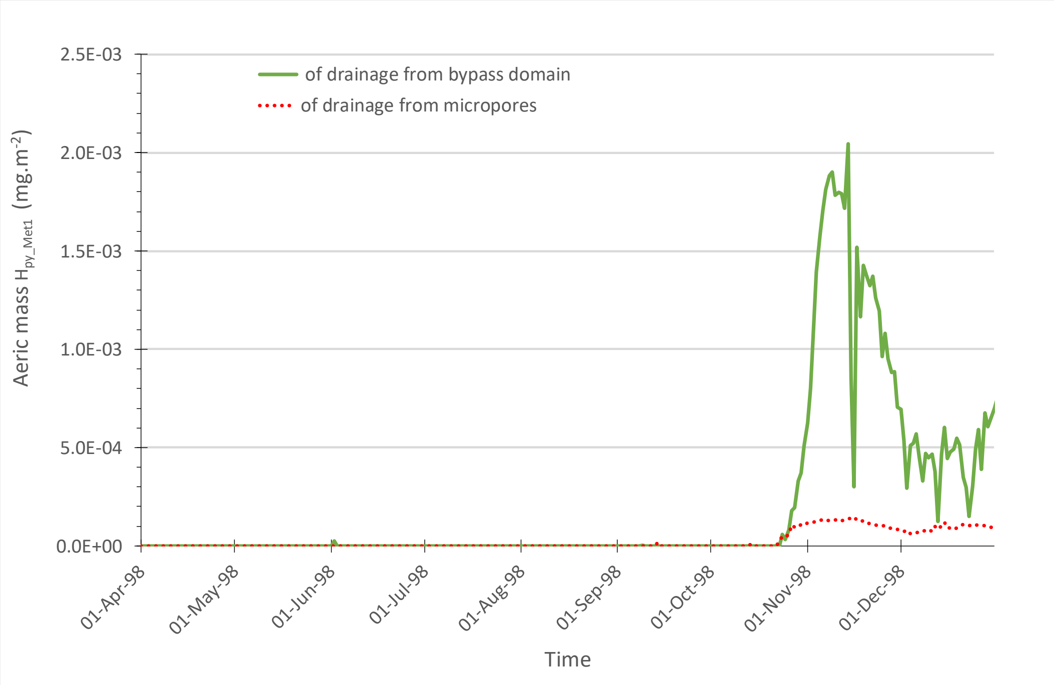

Figure 88 *Aeric mass H_{py_Met1} of i) drainage from the bypass domain (macropores) and of ii) drainage from the micropores (soil matrix) as function of time.*

Figure 89 *Groundwater level of the tree strip of the fruit orchard as function of time. The red dotted line indicates the level of the drains at 82 cm below soil surface.*

9 Discussion

In Chapter 4 to 7 of this report we have described a proposed methodology for exposure assessment of aquatic organisms in watercourses after application of plant protection products in Dutch pome fruit orchards and avenue tree nurseries, which was applied in a number of example situations in Chapter 8. For pragmatic reasons or lack of underpinning information we made a number of assumptions on developed workarounds or adjustment approaches. We discuss the possible consequence of some of them below.

Appropriateness of the selected local scenario
In several cases the local scenario could not represent the countrywide PEC_{90} well, considering spray drift deposits. In fact, in such cases the countrywide PEC_{90} appeared to be higher than could be obtained in the local situation even under worst conditions. The workaround involved the introduction of an enhancement factor for spray drift deposits in the local situation. Using this factor is equivalent to increasing the applied dosage in the local situation. Since the processes of spray drift deposition are not affected by the dosage, the spray drift deposits are simply proportional to that dosage. Therefore it is justified to use a dosage enhancement for the local situation, such that an adequate temporal percentile could be obtained in all cases. Additionally, the required enhancement factor does not exceed a value of 1.24, so it does not lead to excessively high or unrealistic dosages. Since drainage emission and atmospheric deposition are in principle derived processes (i.e. their strength depending on the applied spray dosage), the enhancement method affects all routes, directly or indirectly.

Applying the grass strip / tree strip distinction developed for fruit orchards to avenue trees
In fruit orchards the ground below the trees is partly bare, partly covered by grass, in particular the tree rows are on bare soil strips, while the paths in between the rows are grass strips. Drainage from tree strips and grass strips is computed independently. Finally, their results are combined using the areal coverage fractions of tree strips and grass strips as weighting factors. This method has been developed earlier for upward and sideways applications in fruit orchards and it is used again for the scenarios in this report. The method requires the use of dosage adjustment factors and crop interception factors, to be determined separately for the two strips. This seems strange in case of avenue tree nurseries, where no tree strips and grass strips can be identified in practice (the paths between the tree rows are bare soil too). The method may seem a little odd or complicated, yet it assures that even in case of non-linear drainage processes the final results are appropriate. However, particularly for upward and sideways applications the method relies on knowing the actual distribution of the applied amount of spray on the tree canopy, soil below the trees and on the paths in between the rows. The sensitivity of this distribution to the final drainage results has not been investigated.

Combining the drift deposition and the drainage emission scenarios
Ideally, a single scenario development study would have been carried out which involves both spray drift deposition and drainage emission. However, with current knowledge it was not possible to develop such a scenario within the given timeframe. Therefore, and as before with upward and sideways application in fruit orchards, the entry routes of spray drift deposition and drainage emission were studied separately, combining the results afterwards in the local situation. Still, the method to combine spray drift and drainage as described in Section 4.4 appears to be robust and moderately conservative and therefore is considered adequate.

Are the countrywide scenarios for avenue tree nurseries realistic?
Regarding the countrywide scenarios for avenue tree nurseries, only four important regions in The Netherlands have been considered. Additionally, due to lacking data, several assumptions had to be made regarding the watercourse types in those regions. Also limited data is available for spray drift deposition. The current approach provides a reasonable exposure assessment when spraying avenue tree nurseries, making the best use of the available information.

Crop-free zone and spray-free zone with downward treatments in fruit orchards and avenue tree nurseries

With downward applications below the trees in fruit orchards or avenue tree nurseries, the placement and size of the trees is relatively unimportant. With avenue tree nurseries, spray drift deposits are not affected by the position of the trees. With fruit orchards, the width of the crop-free zone affects downwind spray drift deposits only slightly. Actually, using a spray-free zone (i.e. leaving a part of the field edge untreated) could be more interesting. However, developing scenarios extended for spray-free zones as well would become much more complicated, whereas absolute deposits of spray drift already are very low with the minimal spray-free zone of 0.5 m. Therefore developing scenarios with additional spray-free buffer zones are left to possible future investigation.

Atmospheric deposition

Example calculations showed that atmospheric deposition could become important when the contribution of both spray drift and drainage would become very low. This would be the case when highly drift-reducing techniques would be used, particularly in downward spray applications. Additionally, the PPP should be immobile in soil or degrade rapidly in soil, while its saturated vapour pressure should be at least moderate. It was not possible to develop a scenario for atmospheric deposition in a similar way as was done for spray drift deposition and drainage emission. Therefore, although atmospheric deposition was considered in TOXSWA, it was not part of the determination of the required temporal percentile for the local situation. However, the examples showed that the methodology for spray drift and drainage was conservative for atmospheric deposition as well. So no additional methods have to be derived to account for atmospheric depositions.

Small fruit, hop and vines

No specific scenarios have been developed for downward spraying in small fruit, hop and vines. We propose to use the scenario for downward spraying in fruit orchards (large fruit). For upward and sideways spray applications a similar choice was made (Boesten et al., 2021): the scenarios for small fruit, hop and vines were derived from that for large fruit, with small adjustments.

10 Conclusion and recommendations

10.1 Conclusions

This report describes a methodology for exposure assessment of aquatic organisms in watercourses after application of plant protection products (PPPs) in Dutch pome fruit orchards and avenue tree nurseries. In fact, it describes three separate exposure assessment studies, namely for upward and sideways applications in avenue tree nurseries, downward applications in such nurseries, and downward applications in pome fruit orchards. The report is the successor to a similar report on exposure assessment for upward and sideways applications in fruit orchards. The three mentioned assessments were dealt with separately, yet there were enough similarities to put them together in one report. Typically, upward and sideways applications involve spraying of fungicides or insecticides towards the leaf canopies of the trees, while downward applications are herbicide treatments directly to the ground below the trees.

The method described in this report involves the determination of a 90th percentile exposure concentration (PEC_{90}) in edge-of-field watercourses. The three main routes for PPPs to enter the watercourse are spray drift deposition, drainpipe emission and atmospheric deposition. Atmospheric deposition is mainly of interest when spray drift and drainage are very low. To evaluate the exposure concentration for aquatic organisms, the fate of PPPs in the watercourse is important, particularly when multiple spray applications are considered during a period of the year.

For avenue tree nurseries, three subclasses are to be distinguished: spindles, transplanted trees and high avenue trees. These subclasses represent different growth stages of the trees with different geometries and drift curves. Downward treatments in avenue tree nurseries are generally applied to the whole field. With those treatments the type of avenue trees appeared to be irrelevant for the spray drift deposition. For downward treatments in fruit orchards, one has to distinguish applications onto the grass strips (the paths between the tree rows and at the edges of the field) and applications onto the tree strips (the bare soil strips on which the trees are planted). Not only spray drift deposition differed for these two cases, but also the emissions due to drainage.

Scenario simulations were carried out for combinations of conventional and drift-reducing application techniques and different crop-free zones. A selected spatial configuration (a local ditch) was used to evaluate the countrywide exposure concentrations in edge-of-field watercourses. This requires the determination of a temporal percentile for the local ditch that corresponds to the countrywide PEC_{90}. For convenience and for robustness of the methods, the same configuration was selected as was used for upward and sideways applications in fruit orchards (Boesten et al., 2021). However, under several conditions the local configuration could not represent the countrywide PEC_{90} adequately. Therefore a protocol was developed to adjust (enhance) local spray drift deposits by a constant factor, whenever needed for a certain scenario. The required enhancement factor was determined in such a way, that the local exposure assessment could represent the countrywide PEC_{90}. Fortunately, this factor appeared to be limited to at most 1.24. Although the method seems artificial, it is equivalent to increasing the spray dose in the local scenario, which is certainly an acceptable way of doing. With this local adjustment procedure, the methods in this report form a robust and conservative way of evaluating exposure concentrations in edge-of-field watercourses next to avenue tree nurseries and fruit orchards.

Regarding drainage emissions, the method used was equivalent to the method developed for upward and sideways applications in fruit orchards (Boesten et al., 2021). This method involved the separate computation of the drainage contributions of PPP deposits on the tree strips and on the grass strips, which were combined afterwards using the areal covering fractions of tree strips and grass strips. This approach was applicable to all scenarios. The drain emission method is based on real data from the experimental site in Andelst (the Netherlands).

A procedure for the selection of an appropriate temporal percentile for the local ditch when both spray drift and drainage were significant contributors to the PPP concentration in the ditch has been developed earlier for upward and sideways applications in fruit orchards (Boesten et al., 2021). The same procedure could also be applied to the scenarios in this report. The procedure involves the determination of the dominant entry route of PPPs into the edge-of-field watercourse. If either spray drift or drainage is clearly dominant, then the temporal percentile corresponding to that route is selected. In case both entry routes are equally important, then the higher of the two temporal percentiles is used. In this way a robust and moderately conservative assessment is obtained.

The example calculations indicate that for upward and sideways applications in avenue tree nurseries often spray drift is the dominant route for PPPs entering the watercourses, except when highly drift-reducing techniques are involved. In those cases drainage is the most important route. For downward treatments below avenue trees and fruit trees the spray drift deposits are very low and in most cases drainage is more important. For PPPs that are immobile in the soil or when the degradation in soil is fast, drainage emission will be low and atmospheric deposition following the volatilisation of deposited PPPs could become the major entry route, provided the saturated vapour pressure of the PPP is not too low. Obviously this is limited to cases where spray drift deposition is low too. Although the methodology for selecting the temporal percentile does not consider situations in which atmospheric deposition is dominant, the current method appears to be sufficient and conservative for atmospheric deposition as well.

10.2 Recommendations

As part of the methodology discussed in this report is the same as applied for upward and sideways applications in fruit orchards (Boesten et al., 2021), similar recommendations apply. These and additional recommendations are listed below:

TWA
The scenario selection procedure is based on the annual maximum concentration whereas the exposure assessment will also apply to e.g. annual or seasonal maxima of the 7-day time-weighted average (TWA) concentration. It is uncertain whether a selection procedure based on a TWA concentration would have given the same result. As long as drift deposition is the dominant entry route, it can be expected that there is a close relationship between a TWA peak concentration and an instantaneous peak concentration. For the drainage route the situation is less clear. Scenario selection on the basis of instantaneous peak concentrations is general practice, also for example in EFSA (2020). It may be worthwhile to check the level of protection for situations in which the drain emission is dominant.

Sensitivity to application date
For situations with low drift deposition the PEC_{90} is found to be sensitive to the application date. This is undesirable as the outcome of the assessment will not be robust and may lead to ambiguity in the calculation of the PEC_{90}, which is used in the risk assessment. In dialogue with the risk managers it was decided, as a first step, to define application schemes in the software (i.e. DRAINBOW) using BBCH crop stages, thus limiting the possibility to directly select a favorable date. It is recommended to evaluate this approach and explore options to include the level of protectiveness of the selected dates in DRAINBOW.

Atmospheric depositio
In addition to spray drift and drainage, atmospheric deposition has been included to guarantee protectiveness of the exposure scenario. For pragmatic reasons, the simple and conservative approach for arable crops is used, which is in line with current EU practices. In principle a higher tier could be developed since more national data is available. Such a methodology can build further on previous (national) work on the exposure of residence and bystanders.

Metabolites
Metabolites can be formed in the soil, in the surface water and in the sediment. For metabolites formed in soil, the drainage emission will be the main emission route and hence the corresponding temporal percentile year should be selected, which is the 63rd percentile year. We propose to use the following approach in the exposure assessment of metabolites:

For metabolites formed only in water or sediment, use the temporal percentile year as selected for the parent. For metabolites formed only in soil, use the 63rd percentile year. In case metabolites are formed both in soil and in water/sediment, the higher temporal percentile year (of drift and drainpipe) should be selected.

The developed scenario will become part of the software instrument DRAINBOW. This instrument supports the execution of exposure assessments for all types of combinations of substance properties and application schemes. Also, the formation of metabolites is simulated by DRAINBOW. The instrument provides maximum concentrations of the metabolites formed for all simulated years and standardly the metabolites concentration is selected in the final summary for the selected year based on the parent situation.

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Abbreviations

BBCH-scales	Phenological development stages of crops. BBCH stand for the stakeholders involved: Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie
cfbz	Crop-free buffer zone; optional zone to add to the minimal agronomic crop-free zone to decrease spray drift deposits on the edge-of-field ditch
cpdf	Cumulative probability density function
DRT	Drift-reducing technique
DWN	Downward (spray application)
EAD	Environmental Activities Decree (MinI&W, 2021)
ERC	Ecotoxicologically Relevant type of Concentration
PEC	Predicted Environmental Concentration
PEC_{90}	90^{th} percentile exposure concentration, concentration that corresponds to the overall 90^{th} percentile of exposure concentrations
PEC_{max}	Annual maximum PEC
PPP	Plant protection product
SPEXUS	Spray drift exposure model for upward and sideways applications in fruit orchards (for one orchard, one ditch)
tcfz	Total crop-free zone. The total crop-free zone is considered to be the sum of *the minimal agronomic crop-free zone* and *the crop-free buffer zone*.
T_{90}	Local temporal percentile that corresponds to the 90^{th} overall percentile of exposure concentrations
US	Upward and sideways (spray application)
xSPEXUS	Extended SPEXUS model; specifically adapted for use in DRAINBOW, for upward and sideways applications in fruit orchards; currently extended to avenue-US, fruit-DWN, and avenue-DWN scenarios as well

Annex 1 Avenue tree nurseries in The Netherlands

The location of tree nurseries in the Netherlands was determined by using the Dutch land use maps (LGN7, map of 2012). LGN-Code 61 represented tree nurseries: "all tree cultivation regardless of the size of the crop". Avenue trees are part of the area given by code 61. In LGN7 the area of tree nurseries is 23195 ha (371126 grid cells of size 625 m^2). The total area of avenue tree nurseries in the Netherlands is 3300 ha (Section 2.1), which is about 14% of all tree nurseries. Four avenue tree concentration areas were indicated by the Avenue Tree Pact (Laanboompact, 2021). An overlay was made with municipal boundaries (Municipality boundaries 2002 – 2006, Bridgis.nl). The four municipalities of interest were Kesteren (Opheusden), Haaren, Haldenberge (Oudenbosch) and Zundert (Figure 90). The areas covered by tree nurseries within these municipalities was determined. The areas were 858 ha, 611 ha, 295 ha and 2160 ha for the municipalities of Kesteren, Haaren Haldenberge and Zundert, respectively, giving a total area of 3925 ha.

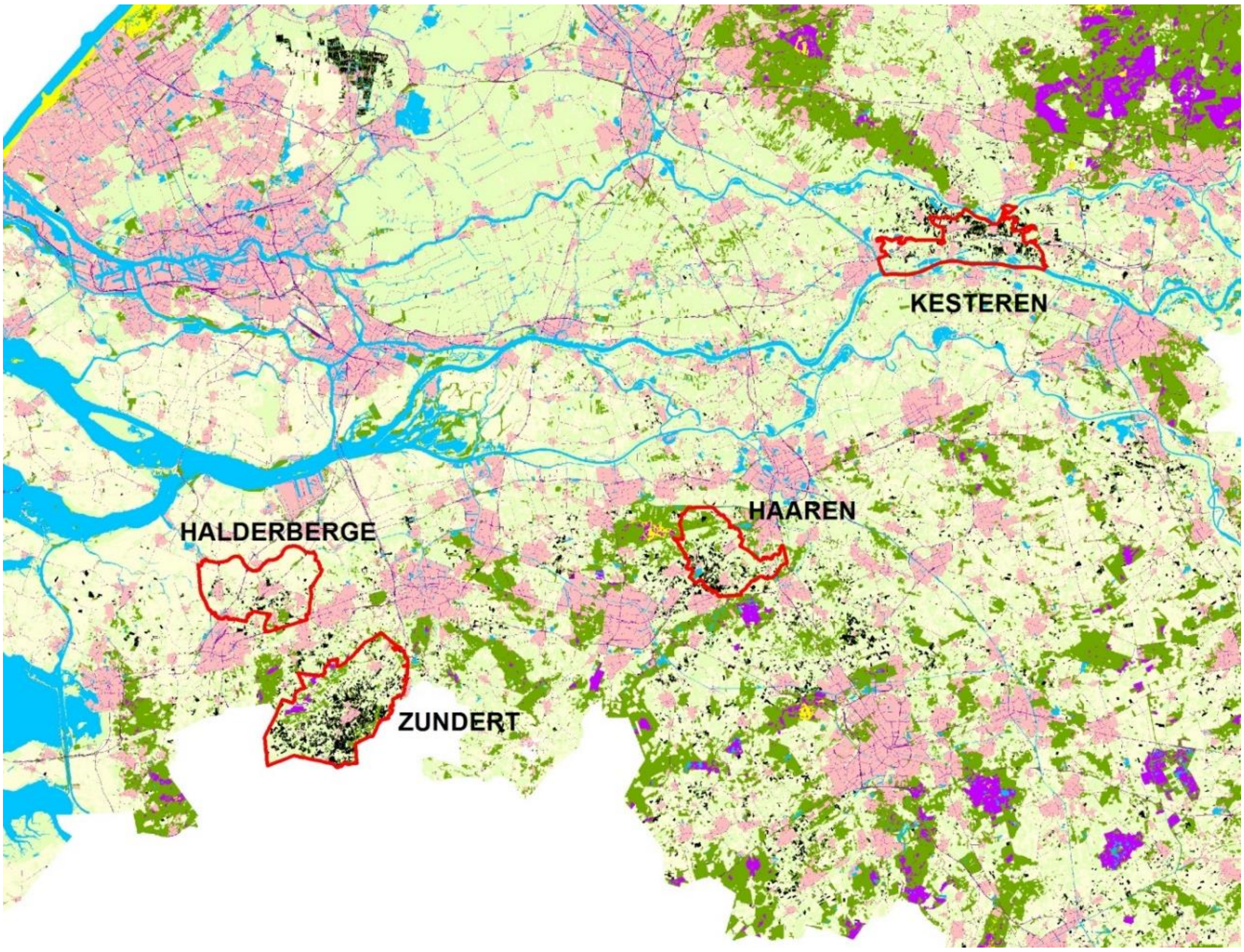

Figure 90 *Concentration areas of avenue tree nurseries in four municipalities. Black dots: avenue tree nurseries; red lines indicate the boundaries of the municipalities.*

Compared to the total of 3300 ha for avenue tree nurseries in the Netherlands, the four municipalities appear to cover 625 ha more than the national target. To downsize the sum of areal sizes of the four municipalities to get it closer to 3300 ha, the municipality of Zundert was selected to correct using the division in (4 digits) postal code areas (Figure 91). The areal size of the postal code region in Zundert are given in Table 32.

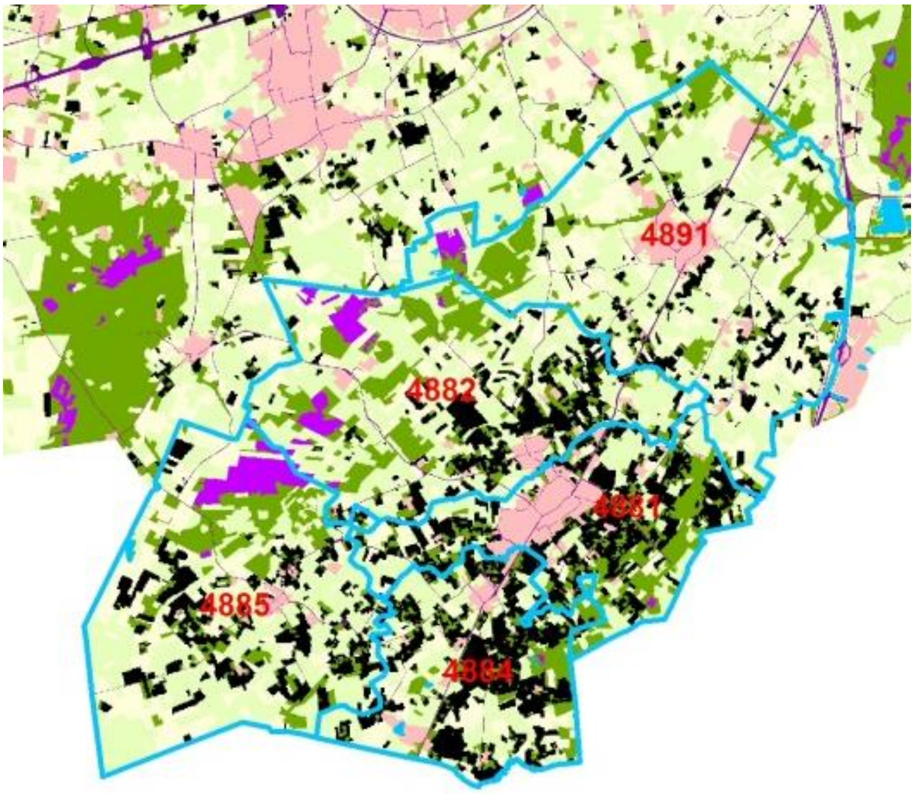

Figure 91 *Zundert municipality and its five postal code areas.*

By leaving out the two smallest postal code regions (4891 and 4882), a reduction is total size for tree nurseries of 673 ha is accomplished, resulting in a total tree nursery area of 3252 ha for the four municipalities, which is close to the 3300 ha to represent the Netherlands as a whole.

Table 32 *Postal code regions in Zundert and their areal size with tree nurseries.*

Postal code region	Area [ha]
4881	505
4882	383
4884	538
4885	442
4891	290
Total	2159

Within the selected municipalities and postal code regions, the total length of waterbodies adjacent to avenue tree nurseries was determined, distinguishing different hydrotypes and waterbody width classes. The results are given in Table 33. The tertiary ditches are excluded from the scenarios because most of them do not carry water permanently throughout the year. So only the primary and secondary ditches are considered. Table 34 gives a summary of primary and secondary waterbodies and their (relative) lengths next to avenue tree nurseries in the selected four municipalities. Note that there is no distinction made for the different regions. Clearly secondary waterbodies are much more important than primary waterbodies; approximately 94% of all edge-of-field waterbodies belongs to the secondary class. Waterbody type 601001 is by far the most important waterbody top consider for avenue tree nurseries (38.5% of all edge-of-field waterbodies next to avenue tree nurseries). Note that the selected waterbody type (601002; see Section 4.1) for local scenarios is frequently occurring as well next to avenue tree nurseries (17.1%).

Table 33 *Total length of various waterbody types adjacent to avenue tree nurseries in the selected four municipalities and postal code regions (year 2011).*

Hydrotype	Tertiary ditches [m]	Secondary width < 3 m [m]	Primary width 3 – 6 m [m]	Total [m]
Betuwe-komgronden	18238	82692	5719	106650
Betuwe-stroomruggronden	6554	36801	4099	47454
Nuenengroep profiel	62880	25168	0	88048
Singraven-beekdalen	39322	10544	245	50111
Tegelen/Kedichem profiel	239018	41707	2704	283428
Westland-DH-profiel	190	4580	418	5188
Westland-D-profiel	16	201	0	218
Total	366219	201694	13185	581098

Table 34 *Relevant waterbody types next to avenue tree nurseries in the selected regions. Fraction gives their relative importance (length-based).*

Class	Hydrotype	Waterbody code	Length [m]	Fraction [-]
Secondary	Betuwe-komgronden	601001	82692	0.385
	Betuwe-stroomruggronden	601002 *	36801	0.171
	Nuenengroep profiel	601009	25168	0.117
	Singraven-beekdalen	601013	10544	0.049
	Tegelen/Kedichem profiel	601015	41707	0.194
	Westland-DH-profiel	601017	4580	0.021
	Westland-D-profiel	601019	201	0.001
Primary	Betuwe-komgronden	602001	5719	0.027
	Betuwe-stroomruggronden	602002	4099	0.019
	Nuenengroep profiel	602009	0	0.000
	Singraven-beekdalen	602013	245	0.001
	Tegelen/Kedichem profiel	602015	2704	0.013
	Westland-DH-profiel	602017	418	0.002
	Westland-D-profiel	602019	0	0.000
	Total		214878	1.000

* waterbody type selected for monitoring in local scenarios

Table 34 shows that about 60% of all waterbodies next to avenue tree nurseries is on river clay soils (‘Betuwe komgronden’ and ‘Betuwe stroomruggronden’). Approximately 35% of the edge-of-field waterbodies is on sandy soils (‘Nuenengroep profiel’, ‘Singraven-beekdalen’, ‘Tegelen/Kedichem profiel’). Only 2.4% of the watercourses is on marine clay soils (mainly ‘Westland-DH profiel’).

The four municipalities belong to three meteorological districts. Table 35 shows the relative distribution of edge-of-field watercourses over these districts. Note that about 60% belongs to the district ‘Rivierenland’ (10), which is also the most important district for fruit orchards (Holterman et al., 2021).

Table 35 *Relative distribution of watercourses in the four municipalities belonging to different meteorological districts. Column ‘Total’ represents weighted average for primary and secondary waterbodies.*

Meteorological district	District code	Secondary [%]	Primary [%]	Total [%]
Rivierenland	10	59.2	74.5	60.2
West Brabant	12	25.3	25.5	25.3
Oost Brabant	13	15.5	0.0	14.5
All		100.0	100.0	100.0

Annex 2 Drift scenarios for upward and sideways applications in avenue tree nurseries

For spray drift with upward and sideways spraying in avenue tree nurseries, only relatively simple drift curves and drift reduction curves are available (see Section 5.1.1). As a consequence, only limited information is available on effect of various spatial and temporal parameters. In Annex 1 it is shown that 12 waterbody types in 3 meteorological districts can be used for representative countrywide drift scenarios in avenue tree nurseries. Due to lack of information, it is assumed that these 12 waterbody types occur in all 3 districts in the same relative proportion, so their frequency distribution is used for all districts; see Table 34 in Annex 1.

Additionally, it is assumed that the same frequencies of summer water levels are applicable as with upward/sideways scenarios in fruit orchards. This involves the frequencies of summer water levels (or actually the level differences with respect to the constant winter water level) per meteorological district. Table 36 shows the frequencies (%) of summer level differences in districts 10, 12 and 13, as described in Holterman et al. (2021). The two bottom rows show the averaged frequencies for all three districts together, using their weights as given in Table 35 in Annex 1 for primary and secondary watercourses.

Finally, to account for the headland approach as mentioned in Section 5.2.4, a distinction between headland side and the side along the tree rows has to be made. This implies 2 sides to account for in the scenarios. Each side type has the same probability (50%) to occur.

Thus, the spatial configuration involves 12 waterbody types, 9 water levels (or differences) and 2 nursery sides. These combine to 216 spatial situations.

Table 36 *Frequency distribution [%] of water level differences in summer vs winter, per district. Two bottom rows indicate weighted averages for secondary and primary watercourses for the whole country, using the districts' weight factors of Table 35 in Annex 1.*

District	**Difference in summer and winter water level [cm]**								
	-20	**-10**	**0**	**10**	**20**	**30**	**40**	**50**	**60**
10	0.02	5.30	17.37	24.49	39.00	7.88	5.22	0.50	0.14
12	0.09	0.34	22.65	14.52	30.03	21.27	9.58	1.06	0.46
13	0.64	1.79	77.46	6.01	11.90	1.90	0.30	0.00	0.00
Avg Sec	0.14	3.50	28.02	19.10	32.53	10.34	5.56	0.56	0.20
Avg Prim	0.04	4.04	18.71	21.95	36.71	11.29	6.33	0.64	0.22

Annex 3 Additional information on the parameterisation of the SWAP model for avenue trees

To complement section 6.1.1, this Annex provides more detailed information on the parameterisation of the SWAP model for avenue trees for the aspect irrigation and the estimation of crop factors and LAI. Furthermore, this annex provides a more elaborated analysis of the comparison of the results of the irrigated apple/grass system with the results obtained for the parameterisation of avenue trees described in section 6.1.1.1.

Irrigation

According Jan van de Zande (Wageningen Plant Research) irrigation in tree nurseries on clay soils takes place once or twice in July and September, applying about 35 mm per irrigation event.

The irrigation routine used for fruit is replaced by the most worst-case irrigation scheme of 4 irrigation events per growing season:

- Schedule irrigation, fixed irrigation depth, fixed irrigation depth of 35 mm
  - 1 July (development stage; 50% of final shoot length; BBCH34),
  - 21 July (development stage; 70% of final shoot length; BBCH37),
  - 1 September (development stage; fruits ripe; BBCH81),
  - 21 September (development stage; leaf colouring, start leaf fall; BBCH91)

For fruit, additional irrigation to prevent frost damage is applied. This type or irrigation is not applied in tree nurseries. In the SWAP parameterisation for fruit this irrigation was added to the precipitation in the meteorological file. For the tree nursery scenario the original precipitation values are used.

Crop factors and Leaf Area Index (LAI)

Geometry of a Dutch tree nursery

Avenue trees are commonly grown in rows at a distance of 1.5 m (spindles) or 2 m (transplanted and high avenue trees) with 1 m distance between the trees in a row (this gives 6667 or 5000 trees per ha, respectively). Below the trees there is a strip of about 0.67 m that is kept bare and the remaining 1.33 m between the rows is also bare (Figure 92).

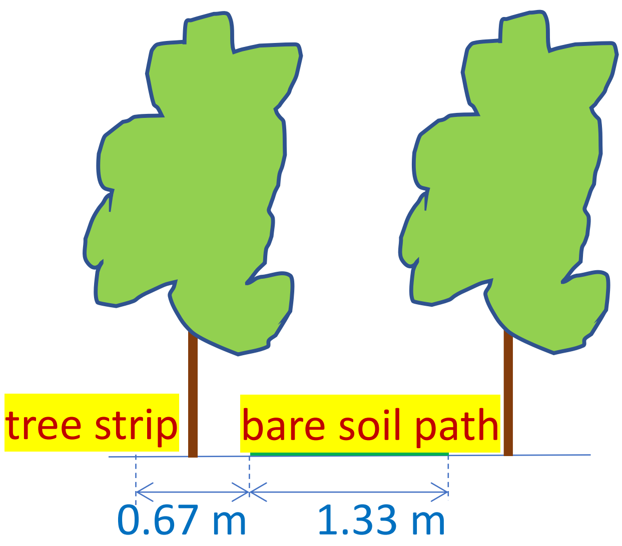

Figure 92 *Avenue tree rows on bare soil, with row distance of 2 m. Applying the areal ratio of tree strips and grass strips (1/3 and 2/3 respectively), these imaginary strips are 0.67m and 1.33 m wide.*

Estimation of LAI and crop factors
Maas & Op 't Hof (2006) reported that Dutch apple trees transpire 0.28 L per m^2 of leaf and per mm of Makkink reference evaporation. They assume 7 m^2 of leaf for a full-grown tree. We will assume that this information also applies to avenue trees.

Assuming 6667 (spindle) trees per ha gives 7 × 6667 = 46669 m^2 of leaves per ha (so an LAI of 4.7) and a potential transpiration of 0.28 × 46669 = 6533 L/ha = 1.31 mm per mm of Makkink reference evaporation (calculated back to the total surface area). This corresponds with a crop factor of 1.31 for Makkink (which gives a P-M crop factor of 1.31/1.23 = 1.07 for the period July-August[6]; Feddes, 1987).

These numbers include only transpiration, so we still have to add the contribution of the potential evaporation from the bare soil. SWAP assumes that the potential soil evaporation is a fraction equal to exp(-*f* LAI) of the potential evapotranspiration with *f* = 0.39. This is based on measurements of extinction of radiation in canopies by Ritchie et al. (1972). Assuming that the extinction of radiation is caused by the leaves spread over the 1 ha of tree nursery, an LAI of 4.7 is used in this equation.

Applying the assumption of Maas & Op 't Hof (2006) an LAI of 4.7 is calculated for avenue trees. For an LAI of 4.7 the fraction exp(-0.39 LAI) becomes 0.16 (so 16%). If we require that the contribution of the evaporation to the overall crop factor is 16%, subsequently the contribution of the transpiration to the overall crop factor is 84%, which means that the P-M crop factor of 1.07 is 84% of the total. Consequently, we obtain an overall crop factor of 1.07/0.84 = 1.27, which gives a contribution of evaporation from the bare soil to the overall crop factor of 0.16 × 1.27= 0.20. However, FOCUS (2009) uses a P-M 'crop factor' for bare soil of 1.0. So, SWAP should calculate a contribution of the bare soil to the crop factor of 0.16 × 1 = 0.16 and not of 0.20. To overcome this problem, we used a crop factor for trees in full leaf of 1.07 + 0.16 = 1.23 and modified the *f* value such that 1.23 exp(-*f* × 4.7) equals 0.16, so *f* = 0.43. In autumn and winter, the tree nursery is more or less a bare-soil system, so its P-M crop factor is estimated at 1.0 (see Table 37).

Table 37 *Leaf Area Index (LAI) and Penman-Monteith crop factor as function of the day in the year for the crop nursery trees in the Netherlands as used in the SWAP simulation for avenue trees. SWAP interpolates linearly between the dates.*

Date	Time (relative)	LAI	Crop factor	Description
01/Jan	0.0	0	1	No leaves
01/Apr	0.249	0	1	Start growth of leaves
30/Jun	0.496	4.7	1.23	Maximum development of leaves
31/Oct	0.833	4.7	1.23	Start of defoliation
31/Dec	1.0	0	1	End of defoliation

Elaborated comparison with water balance of the irrigated apple/grass system (see Ter Horst et al., 2020)
We compared the results of the irrigated apple/grass system (run 1-3) with the results obtained for the parameterisation of avenue trees described in section 6.1.1.1 (Table **38**).

First we focussed on the comparison between run 1 (fruit – tree strip) and run 4 (avenue trees), because parameterisation of avenue trees was based on the parameterisation of the tree strip for fruit.

Actual evapotranspiration plus evaporation from intercepted water in run 1 was 792 mm compared with 586 mm in run 4; a difference of 206 mm. Precipitation was equal for both runs and drainage was more or less comparable (457 for run 1 and 449 for run 4; a difference of 8 mm). This means that the difference in actual evapotranspiration plus evaporation from intercepted water is mostly explained by the difference in

[6] Analogous to the theory in Feddes, 1987, the P-M crop factor $f_{P\text{-}M}$ can be derived from the Makkink crop factor, f_M according:

$$f_{P\text{-}M}\, ET_{P\text{-}M} = f_M\, ET_M$$

$ET_{P\text{-}M}$ is evapotranspiration according to Penman_Monteith and ET_M is evapotranspiration according to Makkink
The multiplication factor $ET_{P\text{-}M}$ / ET_M is given by Feddes (1987) for 10-day period averages. For the period July-August the average multiplication factor $ET_{P\text{-}M}$ / ET_M is 1.23, resulting in a $f_{P\text{-}M}$ of 1.07.

irrigation and upward seepage. For run 1 irrigation is 228 mm higher than for run 4. As for run 1 the sum of actual evapotranspiration and evaporation from intercepted water is 206 mm higher than for run 4, about 14 mm (228 mm – 206 mm – 8 mm of drainage) of additional water is needed for run 4 from another source. This source is the upward seepage which was with 110 mm for run 4 13 mm higher than the upward seepage in run 1.

Next, a comparison was made between run 3 (the weighted average of run 1 and run 2 – representing the entire fruit orchard: tree strip + grass strip) and run 4 (avenue trees).

Actual evapotranspiration plus evaporation from intercepted water in run 3 was 540 mm compared with 586 mm in run 4; a difference of 46 mm. There is a small difference of 9 mm in drainage (458 for run 3 and 449 for run 4). Irrigation was almost similar for both runs, meaning that somewhat more upward seepage (about 40 mm) was needed in run 4 to fulfil the water demand of the crop.

Table 38[7] *Average annual water layers (mm) simulated the Andelst parameterisation for fruit (apples – tree strip only!) and the Andelst parameterisation for avenue trees (proposal this document) for the period 1991 -2005. P is precipitation, I is irrigation, Q_{bot} is the bottom boundary flux (positive downward and at 1 m depth), E_{int} is evaporation of intercepted water, E_{sol} is soil evaporation, E_{trp} is transpiration, Df is downward flow (P+I-E_{int} - $E_{sol,act}$ - $E_{trp,act}$), Dr_m is drainage from the soil matrix, Dr_b is drainage from the bypass domain (i.e. the macropores) and Dr_{tot} is the sum of the two drainages; act. = actual and pot. = potential.*

Nr	Parameterization	P	I	Q_{bot}	E_{int}	E_{sol}		E_{trp}		Df	Dr_m	Dr_b	Dr_{tot}
						act.	pot.	act.	pot.				
1	tree strip spr.+drip irrigated	785	368	-97	93	124	144	575	665	360	64	393	457
2	grass strip sprinkler irrigated	785	28	-60	72	159	203	184	240	399	67	392	459
3	weighted average of run 1 and 2	785	141	-72	79	147	183	314	382	386	66	392	458
4	Avenue trees according proposal this document	785	140	-110	71	164	198	351	448	339	64	385	449

7 Note that the SWAP/PEARL simulations are done with newer model versions than the versions used by Ter Horst et al. (2020). Consequence is that for the simulations described here different (correct) values of the macropore shrinkage paramaters are used. The results of runs 1, 2 and 3 deviate are therefore somewhat different than the ones reported by Ter Horst et al. (2020).

Annex 4 Substance parameters for the example calculations

The most important substance parameters were assumed to be substance dependent. All other parameters were assumed to be substance independent, and their values have been taken from the literature. The substance independent data are listed first.

Parameters that were assumed to be substance independent

- E_a for degradation in soil: 65.4 kJ mol^{-1} (EFSA, 2007)
- Factor *B* describing moisture dependency of degradation in soil: 0.7 (FOCUS 2000)
- E_a for transformation in surface water: 65.4 kJ mol^{-1} (EFSA, 2007)
- Wash-off factor: 100 m^{-1} conservative value based on EFSA (2017)
- Depth dependency of degradation in soil as proposed by FOCUS (2000)[8]
- Uptake factor for plants: 0.0 (FOCUS 2000)[9]
- Molar enthalpy of vaporisation: 95 kJ mol^{-1} (FOCUS 2000)
- Molar enthalpy of dissolution: 27 kJ mol^{-1} (FOCUS 2000)
- Molar enthalpy of sorption: 0 kJ/mol (FOCUS 2000)
- Reference diffusion coefficient in water: 0.43 ×10^{-4} m^2 d^{-1} (FOCUS 2000)
- Reference diffusion coefficient in air: 0.43 m^2 d^{-1} (FOCUS 2000)
- Reference temperatures for diffusion, vapour pressure, water solubility, sorption, transformation rates in soil and water: 20^{o}C
- Reference moisture content for degradation: pF 2
- K_{om} for sorption in the sediment and for sorption to suspended solids: we assumed the same value as for soil as listed in the table below
- Freundlich exponent for sediment: we assumed the same value as for soil
- Half-life for degradation on plant surfaces: 10 d (EFSA 2017).

Substance specific input parameters are loosely based on the EFSA conclusion/agreed endpoints for a selection of actual active substances and are shown in the table below.

---

8 i.e. in the PEARL *.prl file the following is done

*table **interpolate***
FacZTra (-) Factor for the effect of depth [0|1]
hor lp
0.00 1.00
0.30 1.00
0.31 0.50
0.60 0.50
0.61 0.30
1.00 0.30
1.01 0.00
3.20 0.00
end_table

9 The example substances used are non-systemic, hence an uptake factor of 0.0 as recommended by FOCUS (2000) is used.

Table 39 *Substance specific input parameters.*

Substance property	**F**	$\mathbf{I_b}$	$\mathbf{H_d}$	$\mathbf{H_p}$	$\mathbf{Hp_y}$	$\mathbf{H_{py\_Met1}}$
Molar mass (g mol^{-1})	300.59	288.68	281.3	191.96	413.18	385.1
DegT50 in water at pH 7, 20°C (d)	1	228	1000	1000	0.08	81.7
DegT50 in sediment at pH 7, 20°C (d)	1000	1000	31.8	1000	1000	1000
Kom for soil (L kg^{-1})	76.8	57.0	8000	0.818	1130.5	73.09
Freundlich exponent (-)	0.9	0.8657	0.954	0.836	1.0	0.94
DegT50 at 20°C, pF = 2 in topsoil (d)	3.82	94.8	182.28	7.05	0.32	16.5
Water solubility at 20°C, pH 7 (mg L^{-1})	5.2	3200	0.330	143 000	0.082	83.1
Saturated vapour pressure at 20°C (mPa)	0.0042	9.1 x 10-4	0.3	1.36	4.3 10-6	4.3 10-6
pK_a	no pH dependent sorption	no pH dependent sorption	no pH dependent sorption	no pH dependent sorption	no pH dependent sorption	no pH dependent sorption
Formation fractions metabolite	NA	NA	NA	NA	NA	Soil: 0.949 Water/sediment: 1

Table 40 *Application scheme for example calculations.*

Substance	**Crop**	**Application scheme incl. mitigation measures**
F	Spindle trees and high avenue trees	5 x 1.2 kg a.i. ha^{-1}, start (day 120 – 30 April) - 10 days interval DRT90 + 5 m total crop-free zone for spindle trees DRT75 + 5 m total crop-free zone for high avenue trees
$\mathbf{I_b}$	Spindle trees and high avenue trees	4 x 0.15 kg a.i. ha^{-1}, start d 113 - 23 April – 10 days interval DRT90 + 5 m total crop-free zone for spindle trees DRT75 + 5 m total crop-free zone for high avenue trees
$\mathbf{H_d}$	High avenue trees	1.0 kg a.i. ha^{-1} Run 1: 1 application on 21 April (111) Run 2: 1 application on 8 November (312) DRT90 + 50 cm spray free zone
$\mathbf{H_p}$	High avenue trees	0.05 kg a.i. ha^{-1} per application Run 1: 2 applications on 14 April (104), 21 April (111) Run 2: 2 applications on 14 May (135), 21 May (142) DRT90 + 50 cm spray free zone
$\mathbf{Hp_y}$ ($\mathbf{H_{py\_Met1}}$)	Large fruit – apple[10]	0.212 kg a.i. ha^{-1} per application Run 1: 2 applications on 21 April (111) and 12 May (132) Run 2: 2 applications on 6 Nov. (310) and 27 Nov. (331) In-row treatment (tree strip): DRT90 + 4.5 m total crop-free zone Outside and in between row treatment (grass strip): DRT90 + 0.5 m spray free zone

[10] Note that the choice of any 'large fruit' in the DTG list will result in the same PEC_{max} value.

Annex 5 Smart headland

In the 'smart headland' approach the use of an additional crop-free buffer zone is limited to the sides along the tree rows, as long as the minimal agronomic headland width is larger than the crop-free zone alongside. For high avenue trees, the minimal agronomic crop-free zone along the tree rows is 2.0 m and the headland width is 5.0 m. So only after adding a 3.0 m buffer zone the crop-free zone alongside reached 5.0 m width. A further increase of the crop-free zone should affect the headland width as well, to keep up with the width alongside. This was graphically shown in Figure 27 in Section 5.2.4.

The smart headland approach differs from the 'standard' approach where the buffer zone would be applied to the headland throughout, even when the headland would still be wider than the crop-free zone alongside. In this annex the effect of using the smart headland approach on exposure assessment is evaluated compared to the standard approach.

Clearly, when the buffer zone is 0 m, the situation in the standard and smart headland approach are the same. When the additional buffer zone is small, the crop-free zone alongside still is narrower than the headland width. Thus, the higher PECs will be obtained alongside, while at the headland side the PECs must be lower. When the crop-free buffer zone increases, the difference between standard headland width and smart headland width increases as well, up to the situation where all sides of the nursery have the same width of the crop-free zone. For avenue trees this occurs at a buffer zone width of 3.0m. For larger buffer zones, the relative differences between standard and smart headland widths becomes less. Consequently, the relative effect on PEC_{90} decreases as well.

Figure 93 gives an example of de cpdfs for high avenue trees with standard and smart headland width, for a crop-free buffer zone of 1.0 m (left) and 3.0 m (right). The difference in PEC_{90} is significant in the second case, but limited (in this case, in the standard approach PEC_{90} is about 28% lower than in the smart approach). Generally, the smart headland approach may give significantly higher PEC_{90} values compared to the standard approach, particularly when the crop-free buffer zone is close to the difference crop-free zone widths for the headland and the side along the tree rows. The smart headland approach was applied throughout in the scenarios for avenue tree nurseries.

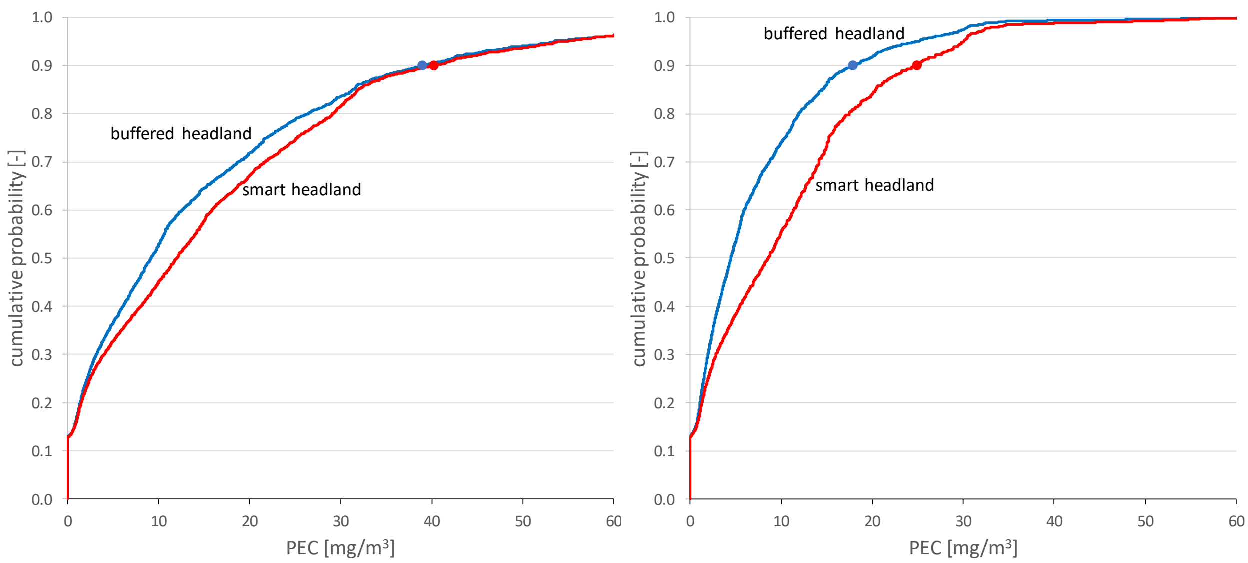

Figure 93 *Smart headland vs standard (buffered) headland; effect on PEC_{90} (red and blue dots). Scenario: avenue trees US, 3 conventional applications/year; left: crop-free buffer zone 1 m; right: crop-free buffer zone 3 m.*

For downward spray applications in avenue tree nurseries, typically, a spray-free zone of 0.5 m is applicable, irrespective of the width of crop-free zones. Therefore, for these scenarios the smart headland approach has no significance.

However, for downward spray applications in fruit orchards, there is a minor significance of the smart headland approach. Since the crop-free zones around the orchard determine where the trees are located with respect to the field edge, the location of the tree strips depends on the width of the crop-free zone. Consequently, particularly with the treatment of the tree strips, the width of the crop-free zone affects the downwind deposits of spray drift and thus the standard and smart headland approach are expected to give slightly different results.

For fruit orchards with US spray applications the usefulness of the smart headland approach was not recognized in time. It was estimated afterwards how using the smart headlands would affect the PEC_{90}s (Holterman et al., 2021; their Annex 10). The estimation showed that with a smart headland in fruit orchards the PEC_{90} would at most increase by about 15%, which is much less than the relative differences observed for avenue tree nurseries. This is probably caused by the much larger number of spatial and temporal variables involved with fruit US scenarios, which tends to suppress the changes in the cumulative frequency distributions due to varying only a single parameter.

Annex 6 Method for computing spray drift from strip application

The computation of spray drift deposits onto an edge-of-field waterbody is becoming more complicated when the treated area is not a full field but merely a series of strips. This is the case with grass strips treatments and tree strips treatments in downward spraying in fruit orchards. Figure 94 indicates how grass strips and tree strips are laid out in the orchard. The grass strips (green horizontal lines) are located from A (the field edge) to x_1, from x_2 to x_3, x_4 to x_5 and so on. The tree strips are the areas in between: from x_1 to x_2, x_3 to x_4 and so on. Usually, zone A to B is a spray-free zone with 0.5 m width at the field edge. The zone A to C represents the minimal agronomic crop-free zone. For fruit orchards, the tree strip is 1 m wide (e.g. x_1 to x_2) while the interrow grass strip is 2 m wide (e.g. x_2 to x_3). Note that x_1-C is half the width of a tree strip, so this is 0.5 m. The first grass strip where spray is applied ranges from x_0 (B) to x_1, having a width that is 2x0.5 m narrower than the crop-free zone A-C.

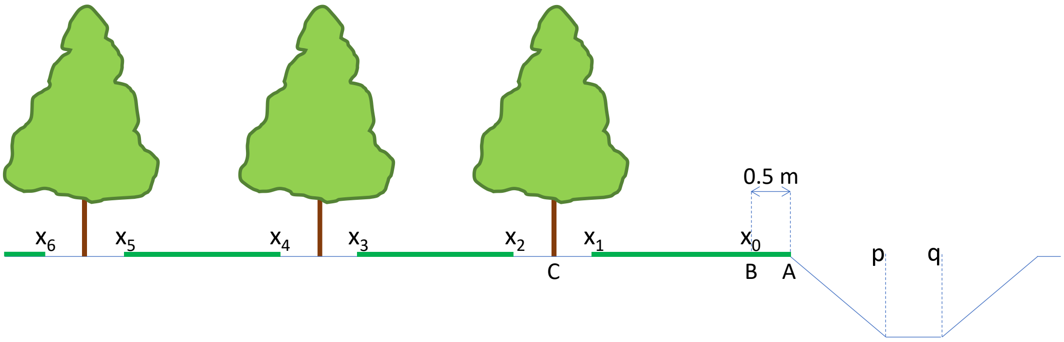

Figure 94 *Schematic layout of fruit tree orchards with tree strips and grass strips; relevant positions for computations. Green horizontal lines at the bottom indicate the grass strips; the areas in between represent the tree strips.*

The drift curve Eq.(3) given in Section 5.1.2 compute the deposits f(x) in a single point at a distance x from the edge of the sprayed area, assuming the whole area upwind from that edge is treated. In this annex, the field edge A is taken as the origin of the x axis. Then the spray deposits in some point at distance x downwind from A is given by $f(x\text{-}x_0)$ assuming the whole ground area upwind from B (x_0) would have been sprayed (NB x_0, x_1 etc are upwind from A so represent negative distances).

Assume the water surface of the edge-of-field waterbody has boundary locations p and q, then the average deposits on the water surface equals the integral of f(x) for x ranging from p to q. When spraying the whole ground area, define U_k as the average drift deposits onto the edge-of-field waterbody while allowing a spray-free zone up to x_k (k=0,1,2,..):

$$U_k = \frac{1}{p-q} . \int_p^q f(x - x_k). dx \qquad (6)$$

So U_0 represents the spray drift deposits when spraying all ground area left from x_0, U_1 the same while spraying everything left from x_1, and so on. Then the contribution of spraying the edge grass strip only (from x_0 to x_1) is given by:

$$D_{g,0} = U_0 - U_1 \qquad (7)$$

Similarly, the spray drift caused by treating the first tree strip is given by:

$$D_{t,1} = U_1 - U_2 \qquad (8)$$

The suffix g refers to a grass strip, the suffix t to a tree strip. Similar expressions define spray drift deposits from subsequent grass and tree strips. Note that the grass edge strip has been given index 0, while in-field strips are indexed 1, 2 etc.

Then, for a treatment of all grass strips, the total drift load $D_{g,tot}$ is the sum of all grass strip contributions:

$$D_{g,tot} = D_{g,0} + D_{g,1} + D_{g,2} + \cdots \tag{9}$$

where $D_{g,0}$ is the contribution from the grass edge strip, $D_{g,1}$, $D_{g,2}$ and so on from the subsequent interrow grass strips. For spray application on tree strips, the edge strip (grass) is not treated and the summation would yield:

$$D_{t,tot} = D_{t,1} + D_{t,2} + \cdots \tag{10}$$

Often, the contributions to spray drift deposits decrease only slowly, so spray drift from many strips must be computed to obtain a sufficiently accurate result. Computation time increases proportional to the number of strips in computations like Eq.(9) and (10), so procedures that allow a reduction of the number of required strip computations are very useful. The following procedure describes how the number of required strip computations can be reduced. This procedure combines a 'direct' and 'indirect' summation. If the whole ground area would have been treated, the total drift deposits on the edge-of-field waterbody would be the sum of all strip-wise contributions (ordered as consecutive strips):

$$D_{whole} = D_{g0} + D_{t1} + D_{g1} + D_{t2} + D_{g2} + \cdots \tag{11}$$

Note that D_{whole} equals U_0, which is the defined as the drift deposits occurring when the whole ground area left of x_0 is treated. The sum of grass strip contributions can be computed 'directly' using Eq.(9), but also 'indirectly' by subtracting its complement (i.e. the sum of tree strip contributions) from D_{whole}:

$$D_{g,tot} = D_{whole} - (D_{t1} + D_{t2} + \cdots) \tag{12}$$

Similarly, the direct sum of tree strip contribution must equal the difference between D_{whole} and the sum of grass strip contributions:

$$D_{t,tot} = D_{whole} - \left(D_{g1} + D_{g2} + \cdots\right) \tag{13}$$

If the contribution of only few strips is computed, the direct sum is too low (for both grass strips and tree strips), but the indirect sums (Eq.(12) and (13)) are too high. It can be expected that their average is a much better estimate of the infinite sum of strips, which is supported by Figure 95 and Figure 96 as examples for treatment of grass strips and tree strips, respectively. The x axis in these figures represents the distance covered by the grass and tree strips used in the summation. At short distances only a few strips are used and the direct and indirect summations are far from accurate. However, their average is accurate for much less trips in the summations.

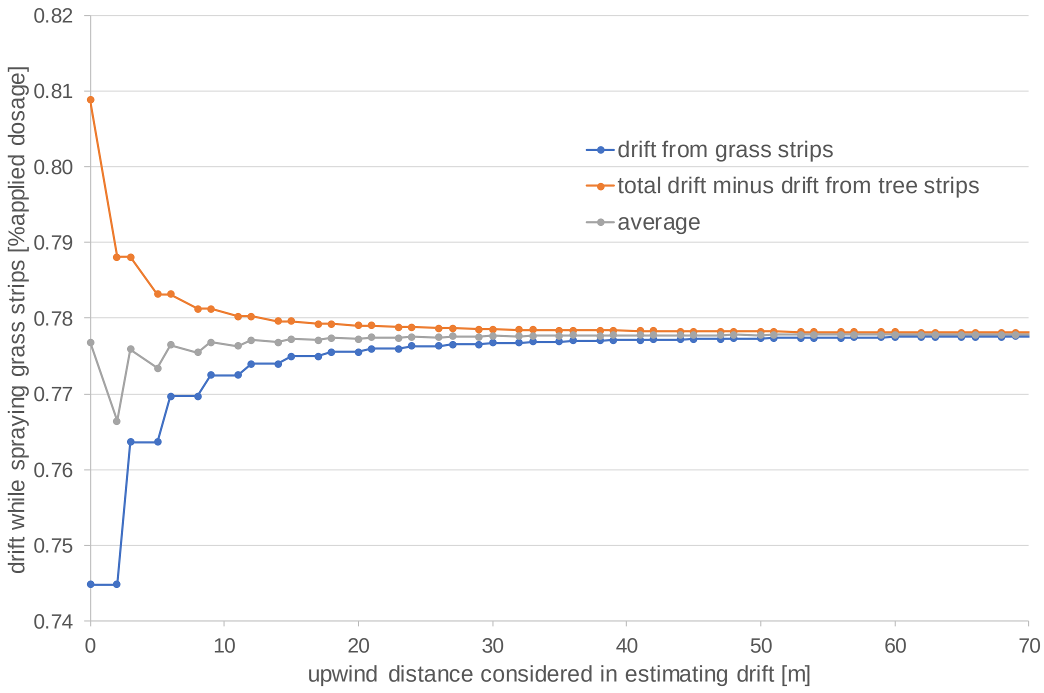

Figure 95 *Treatment of grass strips in a fruit orchard: spray drift deposits exactly at field edge (position A in Figure 94) as a function of the upwind distance of treated ground area. Direct (blue) and indirect (orange) summation of strip contribution and their average (grey).*

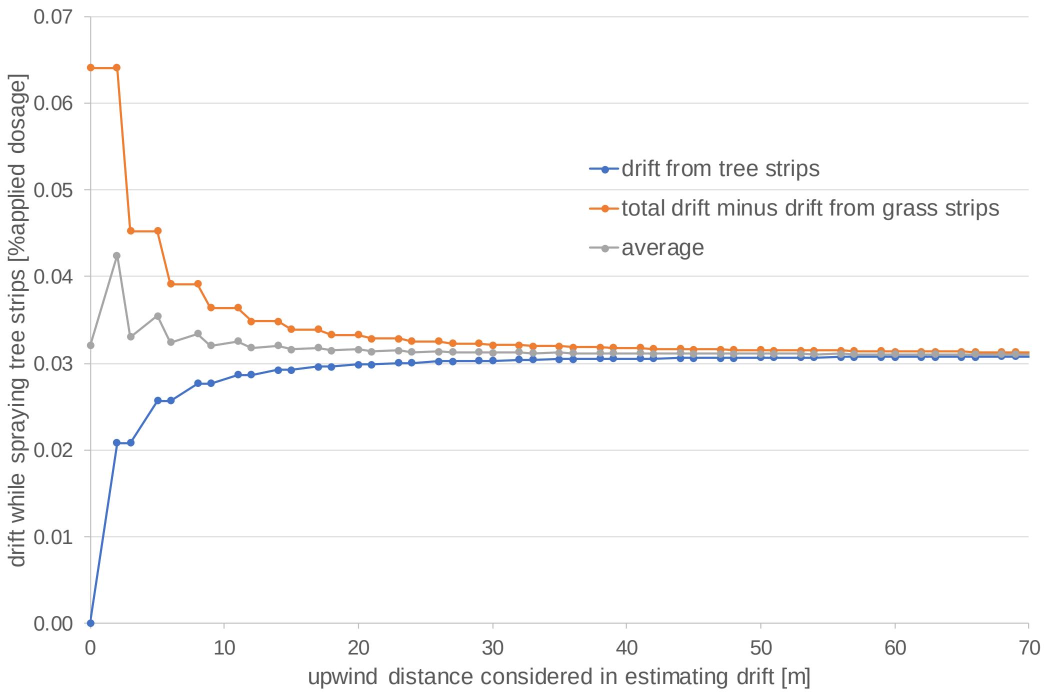

Figure 96 *Treatment of tree strips in a fruit orchard: spray drift deposits exactly at field edge (position A in Figure 94) as a function of the upwind distance of treated ground area. Direct (blue) and indirect (orange) summation of strip contribution and their average (grey).*

Still, a considerable number of strips has to be accounted for to estimate the spray drift deposits for the whole orchard sufficiently accurate. The following empirical method further reduces the number of strip contributions to be computed. Figure 97 shows the spray drift deposits at the field edge (position A) for each treated strip individually. Clearly, consecutive strips (positioned further upwind) will lead to lower drift deposits. The graph shows that, except for grass strip 0, the drift contributions neatly decrease with increasing strip index number. Although the graph is processed for drift at location A, it turns out that for any downwind location similar graphs can be produced.

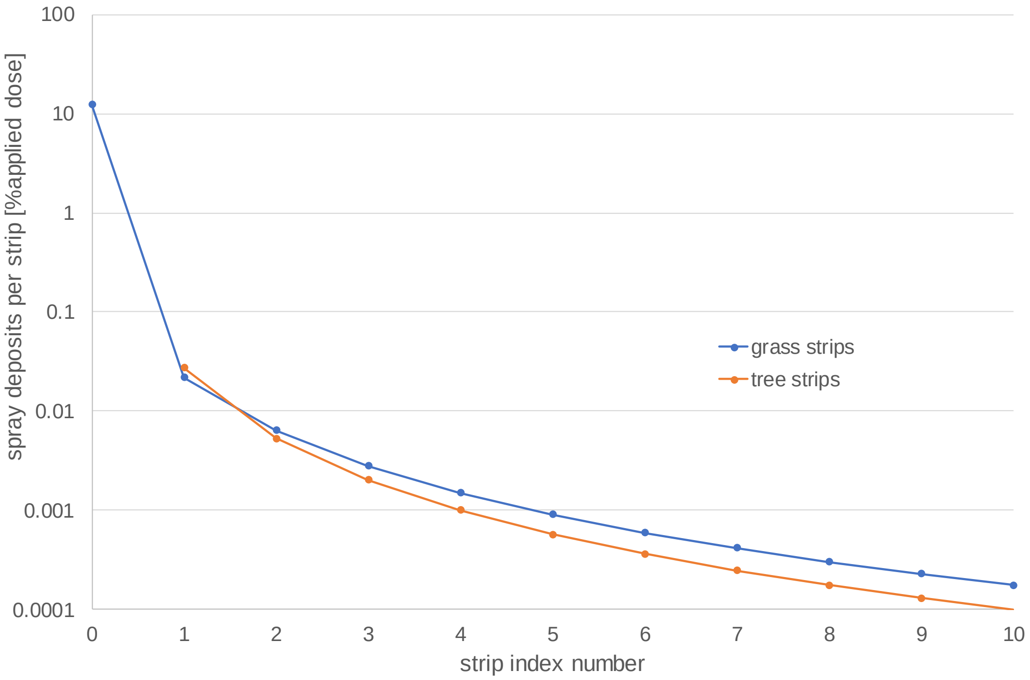

Figure 97 *Contribution to spray drift deposits when spraying single grass or tree strips in a fruit orchard; drift deposits exactly at field edge (position A in Figure 94). Note that the first grass strip has index 0 while the first tree strip has index 1.*

In fact, it turned out that the decay of drift deposits is such that the determination of the contributions to downwind drift deposits of two grass strips (index 0 and 1) and one tree strip (index 1) is sufficient to estimate the contributions of consecutive strips. The following empirical approximation procedure was derived, giving an accurate estimate of the sum of drift deposits when treating all grass strips:

$$D_{g,est} = D_{g0} + D_{g1}/(1 - [U_3/U_2]^r) \quad (14)$$

where r is a constant (empirically determined to be 1.51). This equation requires the computation of only U_0, U_1, U_2 and U_3; D_{g0} and D_{g1} are derived from these (using Eq.(7)). For grass strips the contribution D_{g0} of strip 0 has to be added explicitly, mainly due to the fact that it is too close to the field edge for the approximation procedure to cope with.

For estimating drift deposits when spraying tree strips, a similar expression can be used:

$$D_{t,est} = D_{t1}/(1 - [U_2/U_1]^s) \quad (15)$$

where s is a constant (empirically determined to be 2.88). Note that there is no strip 0 for tree strips. This equation only requires U_1 and U_2, while D_{t1} is derived from these (using Eq.(8)).

Simulations for all countrywide spatial configurations and random wind directions show that the relative error in downwind spray drift deposits due to the approximation method is less than 0.2% for grass strips and less than 1.2% for tree strips. For tree strips the relative error is slightly higher than for grass strips, since the absolute deposits on a waterbody surface is much less when spraying tree strips (as the spray edge is location x_1 rather than location x_0).

Headland side

The above derivations are applicable to the situation where wind direction is more or less perpendicular to the direction of the tree rows, as indicated in Figure 94 and in Figure 98, left-hand graph. In other cases, when wind direction is mainly parallel to the tree rows, Figure 98 graph on the right-hand side, a different approach must be followed.

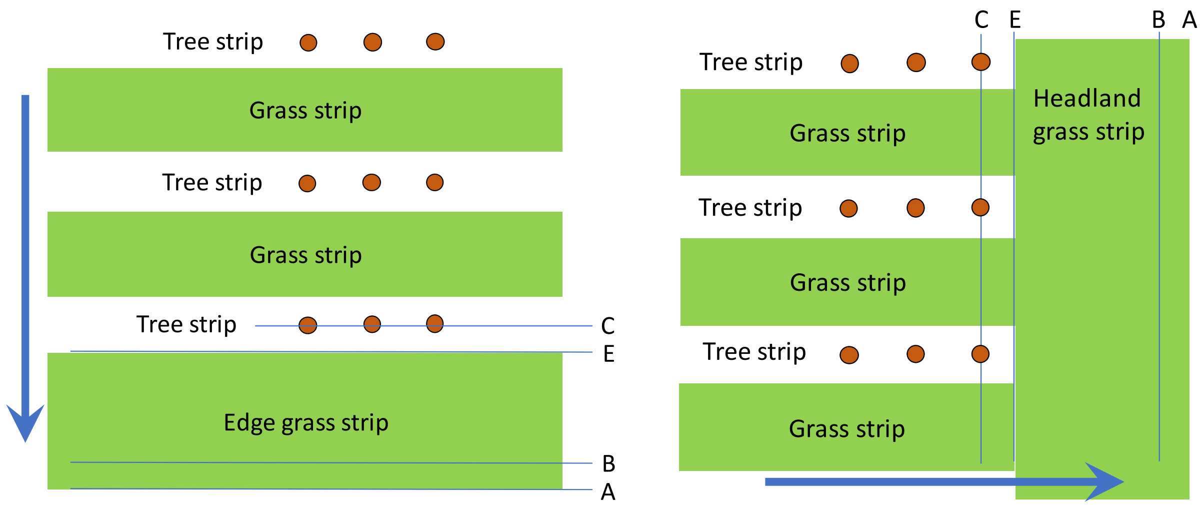

Figure 98 *Schematic layout of fruit tree orchards with tree strips and grass strips (view from above); A is field edge, B is spray edge, C is row of last trees, E is edge of first tree strip; arrow indicates direction of spray drift (i.e. wind direction); left: wind direction perpendicular to tree rows, spray drift is computed from series of contributions of subsequent strips; right: wind direction is parallel to tree rows, spray drift is computed as weighted areal contribution (see text for explanation).*

For the spray drift contribution due to treatment of the headland the computation is similar to that for grass strip 0, except the distance between points B and E can be different. However, the interrow grass strips are parallel now and start at point E ranging upwind to the other end of the orchard. Each interrow grass strip contributes equally to the downwind drift deposits. Their cumulative contribution equals the whole area treatment (from point E and upwind), multiplied by the areal fraction β (a constant between 0 and 1) covered by grass. For tree rows that are 3 m apart and grass strips with width of 2 m, β = 2/3. Hence, the total drift deposits on the water surface are given by:

$$D_{g,tot} = D_{g0} + \beta . \frac{1}{p-q} . \int_p^q f(x - x_1) . dx \qquad (16)$$

where x_1 is the location of point E in the graph on the right of Figure 98.

For tree strips, no headland contribution occurs, while the areal coverage is 1-β. This yields:

$$D_{t,tot} = (1 - \beta) . \frac{1}{p-q} . \int_p^q f(x - x_1) . dx \qquad (17)$$

Note that in integrals in the latter two equations are equal to Eq.(6), but the location of x_1 in this case is for the headland side rather than alongside the outer tree row.

Annex 7 Spray drift model constants

For conventional upward and sideways spray applications in avenue tree nurseries, the constants for computing the spray drift deposits using Eq.(1) in Section 5.1.1 are shown in Table 41. Using these constants, the resulting spray deposits are given in % of applied spray dose.

Downwind drift deposits for the corresponding drift reducing techniques are obtained by multiplying the reference drift value (at a certain position x) by 1-R where R is the relative drift reduction given by Eq.(2) in Section 5.1.1. The constants in the latter equation are given in Fout! Verwijzingsbron niet gevonden. for different avenue tree growth stages and the available drift reducing techniques.

Table 41 *Parameters for spray drift curves for conventional application techniques in upward and sideways spray applications in avenue tree nurseries.*

Orchard	Tree type	A_0	A_1	B_0	B_1	C_0
		[%]	[m^{-1}]	[%]	[m^{-1}]	[-]
Avenue tree nursery	High trees	0.607	0.0107	81.215	0.3932	0
	Transplanted trees	8.817	0.2109	322.454	0.9490	6.649
	Spindle trees	1.991	0.1821	158.128	1.1742	26.764

Table 42 *Parameters for reduction curves for all crop types and crop stages; available drift reducing techniques.*

Crop	Crop stage	Tech	P_0	P_1	Q_0	Q_1	S_0
			[-]	[m^{-1}]	[-]	[m^{-1}]	[-]
Avenue tree nursery	High trees	DRT50	-1.5876	0.2169	0.8731	0.0854	0.5412
		DRT75	-0.2985	0.3216	1.4969	0.0451	-0.3537
		DRT95	-0.1980	0.1914	0.5930	0.0269	0.5035
	Transplanted trees	DRT50	-1.7771	0.3728	0.8096	0.0460	0.1160
		DRT90	-2.7792	0.4350	0.9444	0.0684	0.4947
	Spindle trees	DRT50	-4.3700	0.8477	0.6140	0.0150	0.0694
		DRT90	-9.3217	1.1092	0.6181	0.0636	0.5086

For conventional downward spray applications below fruit and avenue trees, the same drift curve is applicable (Eq.(3) in Section 5.1.2). So there is only one set of constants, which are shown in Table 43 below. Downwind drift deposits for the corresponding drift reducing techniques are obtained by multiplying the reference drift value (at a certain position x) by 1-R where R is the relative drift reduction given by Eq.(2) in Section 5.1.1. The constants in the latter equation are given in Table 44 for the available drift reducing techniques; these are valid for all tree types in avenue tree nurseries and for fruit orchards.

Table 43 *Parameters for spray drift curve for conventional application technique in downward spray applications in fruit orchards and avenue tree nurseries.*

Orchard	Tree type	A_0	A_1	B_0	B_1	C_0
		[%*] [1]	[-]	[%*] [1]	[-]	[m]
Avenue tree nursery & fruit orchard	All tree types	0.470	-1.6082	63.076	-8.9884	1.202

[1] Actually, the units of A_0 and B_0 depend on the parameters A_1 and B_1, respectively, and cannot be given here exactly, but these units correspond to percentage of the applied dose. Therefore, these are displayed as %*.

Table 44 *Parameters for reduction curves for all crop types and crop stages; available drift reducing techniques.*

Crop	**Crop stage**	**Tech**	**P_0**	**P_1**	**Q_0**	**Q_1**	**S_0**
			[-]	**[m^{-1}]**	**[-]**	**[m^{-1}]**	**[-]**
Avenue tree nursery & fruit orchard	All tree types	DRT50	0.6696	-0.4245	0	0	0.3246
		DRT75	-1.7261	-1.5142	0.8364	-0.2372	0.3340
		DRT90	0.3490	-0.1968	0	0	0.6397

Annex 8 Sediment characterisation

The sediment properties used for the example calculations are based upon measured sediment properties in ditches alongside Dutch arable crops fields (Adriaanse et al., 2015). From the measured sediments, location Willemstad (lower organic matter content and relatively higher bulk density) was selected because simulations with these sediment properties resulted in the highest PEC90 in the water layer. The corresponds to the selection made for upward and sideways applications in fruit orchards by Boesten et al. (2021).

Table 45 provides the default sediment discretization and Table 46 provides the refined sediment discretization which is recommended to be used for substances with a high sorption coefficient. Currently the DRAINBOW software tool offers the option to use the refined sediment discretization for substances with a $Koc_{sediment}$ value equal or larger than 30 000 L kg^{-1} [11].

Table 45 *Sediment discretization (standard) and sediment properties based on Willemstad sample location.*

Sediment horizon ID	Thickness of the sediment horizon	Number of numerical layers in the sediment horizon	Dry bulk density	Organic matter content	Porosity	Tortuosity
	(m)		(kg m^{-3})	(kg kg^{-1})	(m^3 m^{-3})	(-)
1	0.004	4	320	0.124	0.83	0.73
2	0.006	3	320	0.124	0.83	0.73
3	0.01	2	490	0.101	0.78	0.67
4	0.03	3	490	0.101	0.78	0.67
5	0.02	1	490	0.101	0.78	0.67
6	0.03	1	490	0.101	0.78	0.67

Table 46 *Sediment discretization (for substances with a high sorption coefficient) and sediment properties based on Willemstad sample location.*

Sediment horizon ID	Thickness of the sediment horizon	Number of numerical layers in the sediment horizon	Dry bulk density	Organic matter content	Porosity	Tortuosity
	(m)		(kg m^{-3})	(kg kg^{-1})	(m^3 m^{-3})	(-)
1	0.00024	8	320	0.124	0.83	0.73
2	0.00012	2	320	0.124	0.83	0.73
3	0.0001	2	320	0.124	0.83	0.73
4	0.00024	2	320	0.124	0.83	0.73
5	0.0003	1	320	0.124	0.83	0.73
6	0.0015	2	320	0.124	0.83	0.73
7	0.004	2	320	0.124	0.83	0.73
8	0.0035	1	320	0.124	0.83	0.73
9	0.01	2	490	0.101	0.78	0.67
10	0.03	3	490	0.101	0.78	0.67
11	0.02	1	490	0.101	0.78	0.67
12	0.03	1	490	0.101	0.78	0.67

[11] Note that a solid underpinning of this approach and assessment of the relation between the numerical error, the grid refinement and the run time of the model is missing. The numerical error is however such that the water concentration is overpredicted and hence the provided concentrations are protective.

Annex 9 Check soundness of dosage adjustment factors upward and sideways spraying in avenue trees.

In the fruit orchard drainpipe parameterization of the soil hydrology model SWAP two scenarios are computed: one assuming the whole area is tree strip and the second assuming the whole area is grass strip. Afterwards, the two results (i.e. drain water flow) are combined while weighting according to the actual spatial factors for tree strips (1/3) and grass strips (2/3). As substance processes in soil are non-linear for most pesticides[12], the consequence of the approach for the soil hydrology is that separate solute simulations with PEARL for the tree strips and grass strips are required as well. This is needed to ensure that the solute mass fluxes are proportional to the drain water fluxes.

One way to check whether the dosage adjustment factors for upward and sideways spraying in avenue trees used in the SWAP-PEARL parameterisation are correct is to compare the solute mass balances as result of the selected approach with an approach in which the dosage for the grass strip (in reality a bare soil path in between the tree rows) and the tree strip are corrected for the spatial distribution. In this approach, the resulting water and solute fluxes are added up without considering the spatial distribution of the two strips in the tree nursery, as this is already implicitly accounted for by the factors used. In this case areal weighting factors[13] of 0.2333 (0.35*1.3) and 0.7667 (0.65*2/3) should be applied for the path strips and tree strips, respectively. However, this approach implicitly assumes that the average deposits are spread out evenly over the entire area of the tree nursery. This approach is only justified if all substance processes in the soil would be linear (that is, proportional to the concentration). The check can therefore only be done using a substance for which linear sorption is assumed. This approach will be referred to as 'calculation set 1'.

The second and selected approach ('calculation set 2) is to use the actual dosages and consider the areal distribution of the path strips (between tree rows) and tree strips in the tree nursery when combining the drainage water and solute fluxes from the separate strips into fluxes valid for the entire tree nursery. Therefore, the dosages of 76.67% of the applied mass on the tree strip and 23.33% on the path strip should be multiplied by the inverse of their respective areal coverage factors to get the dosages for the whole field area. For an imaginary tree nursery of only path strips the dosage as mentioned on the pesticide label and to be applied in the tree nursery, is multiplied by a factor of 0.35 (i.e. 23.33%*3/2 = 35% of the intended dosage) and for an imaginary tree nursery of only tree strips the dosage is multiplied by a factor 2.3 (i.e. 76.67*3/1 = 230% of the intended dosage). The dosage adjustment factors of 0.35 for the path strip and 2.3 for the tree strip are applied irrespective of the spraying technique.

The following input was used in PEARL. Substance properties of example substance I_n (see Boesten et al., 2021 for substance properties) were taken, however, the DegT50 was set to 1000 d (assuming persistence), the K_{om} was set to 100 L/kg (assuming mobility) and the Freundlich coefficient was set to 1 (assuming linear sorption). The substance was applied once a year on April 23rd in the tree nursery with a dosage of 1 kg ha^{-1} (note that it is assumed that this is the dosage provided on the pesticide product label, so used in the entire tree nursery). Interception fractions used for both approaches are 0.848 for the tree strip and 0.0 for the path strip (see section 6.2).

Most important model input (dosages used) and model output (the cumulative substance mass in the drain for the period 1991 -2005) are summarized in Table 47.

[12] Note, that for most contaminants, including pesticides, sorption isotherms have experimentally shown to be nonlinear (*e.g.* Beltman et al., 2008).

[13] 65% interception on the trees of the tree nursery and 35% on the bare soil is assumed. Interception is defined here as the fraction of all sprayed liquid, that is deposited on the trees.

Table 47 *Summary of model input and model output of simulations with PEARL for calculation set 1 (spatial distribution path strip and tree strips accounted for via dosage) and calculation set 2 (spatial distribution path strip and tree strips accounted for via combining water and solute fluxes calculated by PEARL for the two strips).*

	Calculation set 1	Calculation set 2
	Model input	
Dosage path strip (kg ha^{-1})	0.2333	0.35
Dosage tree strip (kg ha^{-1})	0.7337	2.3
	Model output	
Cumulative mass in drain in the period 91-05; grass strip (g)	1616.5	2425.0
Cumulative mass in drain in the period 91-05; tree strip (g)	3547.7	10642.7
Cumulative mass in drain in the period 91-05; entire orchard(g)	5164.2	5164.3[14]

Both calculation sets finally result in the same value for the cumulative mass in the drains of the tree nursery in the period 1991-2005. This check shows that the approach followed to account for the spatial distribution of the bare soil and tree strips in the tree nursery is correct.

Using the approach of calculation set 1 on substances with non-linear sorption will result in erroneous estimates of the substance mass in the drain water.

The approach of calculation set 2 is preferred and therefore selected as this approach uses the true substance depositions on the different strips in the tree nursery.

This approach tested in this annex and described in Section 6.2 is implemented in the software tool DRAINBOW in such a way that the user can just fill in the application scheme on the label of the pesticide product. DRAINBOW automatically applies the adjustment factors for the dosages when creating the input files for the two PEARL simulations (path strip and tree strip). The post processing needed to combine the drainage water and solute fluxes from the separate strips into fluxes valid for the entire tree nursery, such that the spatial distribution of the path strips and tree strips in the tree nursery are accounted for, is also done automatically when using the DRAINBOW software tool.

[14] Calculated as follows: (2/3)*2425.0 + (1/3)*10642.7. Note that the PEARL postprocessing program made for summing hourly fluxes uses rounded values of the factors (i.e. 0.667 and 0.333). Using these rounded values on the hourly fluxes finally results in a cumulative mass of 5161.5 gram.

Annex 10 Tables of PEC_{90}, T_{90} and Zeta

In the tables below, all PEC_{90} values correspond to an applied dose of 1 $kg \cdot ha^{-1}$ per spraying event.

Table 48 *PEC_{90} values [$mg \cdot m^{-3}$] for upward and sideways applications in avenue tree nurseries, for all 1000 countrywide simulations. Tree type: HGH = high avenue trees, TR = transplanted trees, SP = spindles; Cfbz = crop-free buffer zone; conv = conventional application technique.*

Tree type	**Appl tech**	**Cfbz [m]**	**Number of applications per year**									
			1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
HGH	conv	0	35.74	49.87	59.51	63.96	68.60	72.52	76.33	77.48	78.06	80.60
		1	25.92	33.44	40.23	43.80	47.37	49.95	52.01	53.39	53.59	55.11
		2	19.79	26.51	29.98	31.56	33.09	34.68	36.42	36.87	38.20	39.26
		3	15.36	21.09	24.86	26.94	28.56	29.40	29.80	30.12	30.30	30.35
		4	10.74	14.50	17.25	18.79	19.89	20.63	20.98	21.22	21.32	21.40
		5	7.66	10.38	12.14	13.36	14.18	14.74	15.04	15.14	15.22	15.36
		6	5.62	7.62	8.89	9.69	10.39	10.78	10.92	11.09	11.17	11.26
		7	4.27	5.75	6.80	7.42	7.86	8.12	8.28	8.33	8.43	8.50
		8	3.44	4.54	5.37	5.79	6.15	6.31	6.44	6.50	6.58	6.58
		9	2.91	3.78	4.38	4.78	5.01	5.11	5.19	5.26	5.32	5.32
HGH	DRT50	0	16.32	24.56	29.48	32.55	35.09	36.74	38.95	39.73	41.07	41.34
		1	9.70	13.98	16.54	18.47	19.56	20.66	21.71	22.44	22.95	23.52
		2	6.71	9.14	10.27	11.17	11.92	12.63	13.21	13.71	14.00	14.13
		3	5.05	6.84	7.99	8.65	9.25	9.70	9.87	10.01	10.05	10.10
		4	3.18	4.33	5.06	5.51	5.90	6.15	6.32	6.40	6.41	6.47
		5	2.15	2.91	3.41	3.68	3.96	4.07	4.22	4.28	4.29	4.34
		6	1.54	2.05	2.39	2.58	2.79	2.91	2.95	3.00	3.02	3.05
		7	1.15	1.56	1.80	1.96	2.08	2.15	2.19	2.21	2.23	2.25
		8	0.95	1.24	1.45	1.55	1.63	1.67	1.70	1.72	1.74	1.74
		9	0.89	1.06	1.19	1.29	1.35	1.38	1.39	1.41	1.42	1.42
HGH	DRT75	0	8.12	10.29	11.69	13.06	13.95	14.30	14.96	15.52	15.78	16.00
		1	6.67	8.72	9.34	10.26	11.10	11.36	11.91	12.40	12.81	12.99
		2	5.58	7.45	8.55	8.86	9.10	9.37	9.63	9.96	10.23	10.46
		3	4.92	6.50	7.50	8.18	8.46	8.65	8.72	8.78	8.82	8.82
		4	3.86	5.13	5.87	6.49	6.73	6.91	6.98	7.03	7.04	7.07
		5	3.12	4.09	4.72	5.19	5.40	5.54	5.61	5.63	5.66	5.69
		6	2.58	3.39	3.85	4.20	4.38	4.48	4.53	4.56	4.60	4.62
		7	2.23	2.85	3.24	3.51	3.63	3.72	3.74	3.79	3.81	3.81
		8	2.11	2.49	2.79	2.99	3.09	3.13	3.18	3.20	3.22	3.22
		9	2.03	2.25	2.49	2.62	2.70	2.74	2.76	2.79	2.79	2.81
HGH	DRT95	0	2.02	2.82	3.36	3.61	3.86	4.13	4.29	4.42	4.49	4.54
		1	1.47	1.86	2.23	2.42	2.61	2.75	2.88	2.93	2.99	3.08
		2	1.14	1.52	1.71	1.79	1.87	1.95	2.01	2.05	2.13	2.19
		3	0.94	1.24	1.45	1.58	1.65	1.69	1.71	1.73	1.74	1.74
		4	0.71	0.93	1.09	1.18	1.24	1.27	1.29	1.30	1.30	1.31
		5	0.60	0.74	0.85	0.92	0.96	0.99	1.00	1.01	1.01	1.02
		6	0.51	0.62	0.69	0.76	0.77	0.80	0.80	0.81	0.81	0.82
		7	0.46	0.56	0.61	0.63	0.65	0.66	0.67	0.67	0.67	0.68
		8	0.44	0.51	0.54	0.55	0.56	0.57	0.57	0.57	0.58	0.58
		9	0.43	0.48	0.49	0.50	0.50	0.50	0.50	0.51	0.51	0.51

Tree type	**Appl tech**	**Cfbz [m]**	**Number of applications per year**									
			1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
TR	conv	0	18.36	26.75	32.13	35.49	38.34	40.25	42.39	43.44	44.66	44.94
		1	11.72	15.64	18.73	20.65	22.07	23.25	24.19	24.80	25.55	26.02
		2	8.64	11.45	12.85	13.57	14.30	14.97	15.71	16.04	16.42	16.91
		3	6.70	9.13	10.64	11.58	12.14	12.55	12.72	12.84	12.94	12.94
		4	4.88	6.62	7.81	8.52	8.91	9.18	9.28	9.41	9.42	9.47
		5	3.70	5.05	5.97	6.54	6.84	7.05	7.12	7.20	7.22	7.27
		6	2.87	3.94	4.66	5.10	5.38	5.54	5.60	5.65	5.69	5.73
		7	2.28	3.12	3.68	4.01	4.28	4.40	4.46	4.50	4.54	4.57
		8	1.82	2.48	2.91	3.17	3.42	3.52	3.56	3.61	3.65	3.67
		9	1.44	1.99	2.32	2.52	2.74	2.82	2.87	2.91	2.95	2.95
TR	DRT50	0	10.55	17.17	20.29	22.62	23.71	25.60	26.74	28.08	28.81	29.28
		1	5.52	8.22	9.66	10.64	11.33	12.10	12.51	13.13	13.68	13.82
		2	3.80	5.09	5.66	6.12	6.50	6.91	7.21	7.46	7.63	7.72
		3	2.89	3.91	4.56	4.95	5.22	5.43	5.50	5.57	5.62	5.62
		4	2.05	2.77	3.23	3.53	3.70	3.83	3.87	3.92	3.92	3.95
		5	1.56	2.10	2.48	2.71	2.83	2.91	2.94	2.96	2.98	3.00
		6	1.23	1.66	1.97	2.16	2.25	2.31	2.33	2.35	2.37	2.38
		7	0.98	1.34	1.60	1.75	1.84	1.88	1.90	1.92	1.94	1.94
		8	0.80	1.10	1.32	1.43	1.52	1.55	1.57	1.59	1.60	1.60
		9	0.67	0.91	1.09	1.17	1.26	1.29	1.31	1.32	1.33	1.34
TR	DRT90	0	4.00	8.58	9.89	11.35	12.13	12.42	13.43	13.95	14.40	15.02
		1	1.10	2.55	3.07	3.41	3.76	3.94	4.07	4.30	4.45	4.61
		2	0.58	0.88	1.03	1.16	1.26	1.32	1.36	1.43	1.47	1.53
		3	0.39	0.52	0.60	0.66	0.69	0.71	0.74	0.75	0.77	0.78
		4	0.31	0.38	0.39	0.42	0.43	0.44	0.45	0.45	0.45	0.46
		5	0.26	0.36	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
		6	0.26	0.36	0.37	0.38	0.38	0.38	0.38	0.38	0.38	0.38
		7	0.25	0.35	0.37	0.38	0.38	0.39	0.39	0.39	0.39	0.39
		8	0.25	0.31	0.37	0.38	0.38	0.38	0.38	0.39	0.39	0.39
		9	0.22	0.30	0.35	0.36	0.37	0.37	0.37	0.37	0.37	0.38
SP	conv	0	5.04	7.11	8.53	9.22	9.96	10.57	11.03	11.26	11.42	11.52
		0.5	3.87	5.51	6.47	7.11	7.72	8.15	8.45	8.72	8.89	8.96
		1.5	2.70	3.41	4.08	4.38	4.73	5.01	5.26	5.40	5.44	5.61
		2.5	2.09	2.78	3.08	3.22	3.38	3.49	3.58	3.70	3.80	3.89
		3.5	1.75	2.32	2.64	2.91	3.02	3.09	3.12	3.15	3.15	3.16
		4.5	1.37	1.82	2.10	2.31	2.39	2.45	2.48	2.48	2.49	2.51
		5.5	1.09	1.47	1.70	1.88	1.95	1.99	2.02	2.02	2.04	2.05
		6.5	0.88	1.20	1.40	1.54	1.61	1.64	1.66	1.67	1.68	1.69
		7.5	0.71	0.97	1.16	1.27	1.33	1.36	1.37	1.39	1.40	1.40
		8.5	0.58	0.80	0.95	1.03	1.10	1.12	1.14	1.15	1.16	1.16
SP	DRT50	0	2.84	4.49	5.31	5.82	6.24	6.67	6.90	7.23	7.44	7.55
		0.5	1.88	2.94	3.42	3.84	4.03	4.32	4.50	4.75	4.88	4.96
		1.5	1.12	1.48	1.74	1.93	2.05	2.15	2.24	2.30	2.34	2.41
		2.5	0.83	1.10	1.21	1.27	1.33	1.38	1.43	1.47	1.51	1.55
		3.5	0.69	0.91	1.04	1.14	1.18	1.21	1.22	1.23	1.23	1.24
		4.5	0.55	0.73	0.83	0.91	0.94	0.96	0.97	0.98	0.98	0.98
		5.5	0.45	0.59	0.68	0.75	0.78	0.79	0.80	0.80	0.81	0.81
		6.5	0.36	0.49	0.57	0.63	0.65	0.66	0.67	0.67	0.68	0.68
		7.5	0.30	0.41	0.48	0.53	0.55	0.56	0.56	0.57	0.57	0.57
		8.5	0.25	0.34	0.40	0.44	0.46	0.47	0.48	0.48	0.49	0.49

Tree type	Appl tech	Cfbz [m]	Number of applications per year									
			1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
SP	DRT90	0	0.93	1.97	2.30	2.55	2.77	2.87	2.98	3.12	3.21	3.34
		0.5	0.49	0.94	1.11	1.22	1.33	1.39	1.42	1.48	1.53	1.58
		1.5	0.29	0.33	0.38	0.41	0.43	0.46	0.49	0.50	0.51	0.51
		2.5	0.23	0.30	0.31	0.31	0.32	0.32	0.33	0.33	0.33	0.34
		3.5	0.21	0.29	0.30	0.31	0.31	0.31	0.31	0.31	0.31	0.31
		4.5	0.20	0.27	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.30
		5.5	0.19	0.25	0.28	0.28	0.29	0.29	0.29	0.29	0.29	0.29
		6.5	0.17	0.22	0.26	0.27	0.27	0.27	0.27	0.27	0.27	0.28
		7.5	0.15	0.20	0.23	0.25	0.25	0.25	0.26	0.26	0.26	0.26
		8.5	0.14	0.18	0.21	0.22	0.23	0.23	0.23	0.23	0.24	0.24

Table 49 *T_{90} values for upward and sideways applications in avenue tree nurseries, for all 1000 countrywide simulations. Tree type: HGH = high avenue trees, TR = transplanted trees, SP = spindles; Cfbz = crop-free buffer zone; conv = conventional application technique. For T_{90}s above 0.9 the adjustment procedure is applicable, using ζ for drift enhancement (Section 5.2.5).*

Tree type	Appl tech	Cfbz [m]	Number of applications per year									
			1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
HGH	conv	0	0.721	0.600	0.546	0.500	0.496	0.530	0.666	0.766	0.954	1
		1	0.749	0.623	0.574	0.536	0.548	0.580	0.672	0.901	1	1
		2	0.779	0.693	0.647	0.603	0.593	0.626	0.789	1	1	1
		3	0.807	0.766	0.856	1	1	1	1	1	1	1
		4	0.811	0.765	0.834	1	1	1	1	1	1	1
		5	0.815	0.770	0.813	1	1	1	1	1	1	1
		6	0.815	0.773	0.817	1	1	1	1	1	1	1
		7	0.811	0.773	0.843	1	1	1	1	1	1	1
		8	0.809	0.775	0.872	1	1	1	1	1	1	1
		9	0.807	0.783	0.904	1	1	1	1	1	1	1
HGH	DRT50	0	0.737	0.628	0.566	0.529	0.514	0.507	0.564	0.583	0.737	0.796
		1	0.759	0.651	0.586	0.551	0.519	0.514	0.536	0.564	0.601	0.714
		2	0.787	0.694	0.626	0.587	0.569	0.580	0.615	0.694	0.814	1
		3	0.821	0.773	0.803	1	1	1	1	1	1	1
		4	0.823	0.775	0.801	1	1	1	1	1	1	1
		5	0.823	0.777	0.812	1	1	1	1	1	1	1
		6	0.821	0.779	0.813	1	1	1	1	1	1	1
		7	0.813	0.786	0.843	1	1	1	1	1	1	1
		8	0.811	0.790	0.934	1	1	1	1	1	1	1
		9	0.835	0.815	1	1	1	1	1	1	1	1
HGH	DRT75	0	0.705	0.576	0.518	0.565	0.736	1	1	1	1	1
		1	0.731	0.632	0.550	0.561	0.713	1	1	1	1	1
		2	0.757	0.691	0.730	0.752	0.892	1	1	1	1	1
		3	0.791	0.770	1	1	1	1	1	1	1	1
		4	0.795	0.770	1	1	1	1	1	1	1	1
		5	0.800	0.772	0.967	1	1	1	1	1	1	1
		6	0.803	0.790	1	1	1	1	1	1	1	1
		7	0.809	0.805	1	1	1	1	1	1	1	1
		8	0.835	0.834	1	1	1	1	1	1	1	1
		9	0.869	0.886	1	1	1	1	1	1	1	1

Tree type	Appl tech	Cfbz [m]	Number of applications per year									
			1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
HGH	DRT95	0	0.725	0.607	0.554	0.505	0.491	0.533	0.580	0.694	0.856	1
		1	0.749	0.625	0.578	0.545	0.555	0.588	0.726	0.899	1	1
		2	0.773	0.697	0.661	0.630	0.634	0.684	0.839	1	1	1
		3	0.800	0.766	0.926	1	1	1	1	1	1	1
		4	0.801	0.770	0.940	1	1	1	1	1	1	1
		5	0.819	0.790	1	1	1	1	1	1	1	1
		6	0.825	0.827	1	1	1	1	1	1	1	1
		7	0.795	0.978	1	1	1	1	1	1	1	1
		8	0.813	0.988	1	1	1	1	1	1	1	1
		9	0.898	0.932	0.954	0.969	0.980	0.986	0.992	0.995	0.997	0.998
TR	conv	0	0.737	0.625	0.565	0.525	0.518	0.514	0.563	0.603	0.738	0.796
		1	0.757	0.642	0.590	0.554	0.537	0.536	0.555	0.575	0.660	0.791
		2	0.779	0.697	0.648	0.607	0.594	0.617	0.715	0.842	1	1
		3	0.799	0.770	0.876	1	1	1	1	1	1	1
		4	0.797	0.763	0.899	1	1	1	1	1	1	1
		5	0.799	0.762	0.894	1	1	1	1	1	1	1
		6	0.801	0.762	0.872	1	1	1	1	1	1	1
		7	0.805	0.762	0.845	1	1	1	1	1	1	1
		8	0.811	0.765	0.823	1	1	1	1	1	1	1
		9	0.815	0.770	0.813	1	1	1	1	1	1	1
TR	DRT50	0	0.749	0.655	0.590	0.550	0.507	0.515	0.521	0.575	0.625	0.684
		1	0.763	0.667	0.603	0.559	0.525	0.521	0.506	0.537	0.603	0.615
		2	0.785	0.698	0.634	0.593	0.575	0.593	0.625	0.694	0.814	1
		3	0.807	0.775	0.843	1	1	1	1	1	1	1
		4	0.799	0.770	0.872	1	1	1	1	1	1	1
		5	0.795	0.762	0.932	1	1	1	1	1	1	1
		6	0.795	0.759	0.927	1	1	1	1	1	1	1
		7	0.795	0.756	0.915	1	1	1	1	1	1	1
		8	0.799	0.758	0.904	1	1	1	1	1	1	1
		9	0.805	0.759	0.870	1	1	1	1	1	1	1
TR	DRT90	0	0.765	0.694	0.620	0.586	0.550	0.506	0.521	0.525	0.536	0.607
		1	0.773	0.710	0.647	0.597	0.574	0.542	0.514	0.525	0.526	0.547
		2	0.805	0.721	0.655	0.615	0.587	0.558	0.528	0.536	0.527	0.557
		3	0.839	0.798	0.807	0.876	1	1	1	1	1	1
		4	0.785	0.966	1	1	1	1	1	1	1	1
		5	0.697	1	1	1	1	1	1	1	1	1
		6	0.721	1	1	1	1	1	1	1	1	1
		7	0.747	1	1	1	1	1	1	1	1	1
		8	0.769	1	1	1	1	1	1	1	1	1
		9	0.777	0.840	1	1	1	1	1	1	1	1
SP	conv	0	0.725	0.605	0.549	0.501	0.501	0.535	0.609	0.694	0.905	1
		0.5	0.733	0.622	0.557	0.519	0.518	0.530	0.560	0.635	0.753	0.895
		1.5	0.751	0.635	0.591	0.549	0.551	0.579	0.672	0.802	0.938	1
		2.5	0.768	0.705	0.675	0.647	0.670	0.732	0.925	1	1	1
		3.5	0.789	0.773	1	1	1	1	1	1	1	1
		4.5	0.789	0.766	1	1	1	1	1	1	1	1
		5.5	0.789	0.765	1	1	1	1	1	1	1	1
		6.5	0.793	0.763	0.966	1	1	1	1	1	1	1
		7.5	0.796	0.752	0.928	1	1	1	1	1	1	1
		8.5	0.801	0.756	0.894	1	1	1	1	1	1	1

Tree type	Appl tech	Cfbz [m]	Number of applications per year									
			1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
SP	DRT50	0	0.747	0.651	0.587	0.543	0.518	0.522	0.521	0.575	0.650	0.716
		0.5	0.750	0.658	0.590	0.554	0.513	0.514	0.514	0.574	0.624	0.670
		1.5	0.759	0.655	0.603	0.575	0.555	0.549	0.564	0.575	0.599	0.714
		2.5	0.771	0.707	0.666	0.630	0.634	0.661	0.790	1	1	1
		3.5	0.789	0.779	1	1	1	1	1	1	1	1
		4.5	0.789	0.781	1	1	1	1	1	1	1	1
		5.5	0.789	0.772	1	1	1	1	1	1	1	1
		6.5	0.789	0.759	1	1	1	1	1	1	1	1
		7.5	0.791	0.762	0.967	1	1	1	1	1	1	1
		8.5	0.795	0.751	0.932	1	1	1	1	1	1	1
SP	DRT90	0	0.767	0.704	0.635	0.588	0.563	0.529	0.507	0.517	0.515	0.566
		0.5	0.773	0.710	0.647	0.602	0.575	0.549	0.519	0.511	0.514	0.535
		1.5	0.793	0.684	0.647	0.618	0.592	0.601	0.664	0.693	0.770	0.796
		2.5	0.718	1	1	1	1	1	1	1	1	1
		3.5	0.719	1	1	1	1	1	1	1	1	1
		4.5	0.741	1	1	1	1	1	1	1	1	1
		5.5	0.761	1	1	1	1	1	1	1	1	1
		6.5	0.773	0.913	1	1	1	1	1	1	1	1
		7.5	0.779	0.830	1	1	1	1	1	1	1	1
		8.5	0.786	0.790	1	1	1	1	1	1	1	1

Table 50 *Adjustment factors ζ for upward and sideways applications in avenue tree nurseries, for all 1000 countrywide simulations. Tree type: HGH = high avenue trees, TR = transplanted trees, SP = spindles; Cfbz = crop-free buffer zone; conv = conventional application technique. For ζ<1 the corresponding* T_{90} *is below 0.9 and no adjustment procedure is required (Section 5.2.5).*

Tree type	Appl tech	Cfbz [m]	Number of applications per year									
			1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
HGH	conv	0	0.493	0.651	0.768	0.823	0.881	0.931	0.979	0.994	1.001	1.033
		1	0.532	0.640	0.760	0.824	0.889	0.937	0.975	1.000	1.004	1.032
		2	0.599	0.740	0.824	0.862	0.902	0.944	0.990	1.002	1.038	1.067
		3	0.678	0.850	0.983	1.060	1.120	1.151	1.166	1.178	1.184	1.185
		4	0.682	0.832	0.970	1.050	1.108	1.148	1.166	1.178	1.183	1.187
		5	0.684	0.834	0.954	1.044	1.104	1.145	1.167	1.175	1.180	1.190
		6	0.688	0.837	0.955	1.034	1.105	1.145	1.158	1.175	1.183	1.192
		7	0.694	0.840	0.973	1.053	1.111	1.147	1.169	1.175	1.188	1.197
		8	0.713	0.853	0.989	1.058	1.121	1.148	1.170	1.181	1.194	1.193
		9	0.742	0.880	1.001	1.086	1.135	1.155	1.173	1.189	1.201	1.200
HGH	DRT50	0	0.437	0.608	0.718	0.789	0.848	0.887	0.940	0.958	0.990	0.996
		1	0.463	0.606	0.703	0.781	0.825	0.870	0.913	0.943	0.964	0.987
		2	0.552	0.674	0.740	0.800	0.851	0.900	0.940	0.974	0.995	1.003
		3	0.685	0.825	0.942	1.012	1.079	1.129	1.147	1.162	1.166	1.172
		4	0.682	0.821	0.937	1.011	1.079	1.121	1.151	1.166	1.166	1.177
		5	0.690	0.827	0.946	1.012	1.085	1.115	1.152	1.168	1.172	1.183
		6	0.702	0.835	0.949	1.015	1.094	1.139	1.153	1.171	1.179	1.188
		7	0.708	0.859	0.971	1.047	1.108	1.145	1.167	1.172	1.187	1.194
		8	0.742	0.881	1.009	1.073	1.125	1.149	1.171	1.182	1.194	1.195
		9	0.848	0.926	1.024	1.104	1.152	1.174	1.183	1.194	1.205	1.205

Tree type	Appl tech	Cfbz [m]	Number of applications per year									
			1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
HGH	DRT75	0	0.599	0.734	0.829	0.925	0.986	1.011	1.057	1.096	1.114	1.129
		1	0.620	0.779	0.827	0.906	0.980	1.002	1.050	1.093	1.129	1.145
		2	0.653	0.830	0.943	0.974	1.000	1.028	1.056	1.092	1.121	1.146
		3	0.726	0.906	1.032	1.123	1.158	1.183	1.193	1.201	1.206	1.206
		4	0.718	0.894	1.010	1.112	1.151	1.181	1.191	1.200	1.201	1.206
		5	0.727	0.887	1.010	1.106	1.148	1.177	1.191	1.195	1.200	1.207
		6	0.743	0.907	1.015	1.103	1.148	1.172	1.185	1.192	1.202	1.207
		7	0.779	0.925	1.037	1.118	1.153	1.179	1.185	1.200	1.206	1.206
		8	0.865	0.958	1.057	1.129	1.162	1.179	1.196	1.202	1.210	1.210
		9	0.950	0.994	1.086	1.142	1.174	1.187	1.199	1.208	1.210	1.216
HGH	DRT95	0	0.489	0.641	0.755	0.808	0.862	0.921	0.956	0.985	0.999	1.010
		1	0.552	0.647	0.766	0.830	0.892	0.937	0.984	1.000	1.018	1.049
		2	0.624	0.769	0.853	0.892	0.930	0.966	0.996	1.017	1.055	1.082
		3	0.712	0.873	1.005	1.088	1.135	1.166	1.178	1.188	1.195	1.195
		4	0.719	0.877	1.008	1.091	1.135	1.170	1.182	1.193	1.195	1.199
		5	0.781	0.903	1.013	1.097	1.140	1.172	1.187	1.190	1.197	1.204
		6	0.840	0.945	1.030	1.126	1.149	1.178	1.187	1.193	1.202	1.206
		7	0.897	1.024	1.100	1.140	1.168	1.181	1.195	1.200	1.208	1.211
		8	0.931	1.085	1.148	1.167	1.182	1.195	1.205	1.206	1.214	1.214
		9	0.989	1.075	1.134	1.197	1.204	1.204	1.211	1.214	1.217	1.218
TR	conv	0	0.451	0.609	0.720	0.791	0.852	0.894	0.941	0.963	0.990	0.996
		1	0.506	0.617	0.725	0.795	0.847	0.891	0.926	0.949	0.977	0.995
		2	0.606	0.733	0.808	0.848	0.891	0.931	0.976	0.996	1.019	1.050
		3	0.692	0.866	0.992	1.073	1.122	1.158	1.172	1.183	1.191	1.191
		4	0.689	0.861	0.999	1.084	1.130	1.163	1.175	1.190	1.191	1.198
		5	0.682	0.857	0.998	1.087	1.134	1.167	1.178	1.191	1.194	1.201
		6	0.675	0.851	0.991	1.078	1.133	1.166	1.178	1.187	1.196	1.203
		7	0.676	0.845	0.979	1.063	1.130	1.159	1.174	1.184	1.196	1.202
		8	0.677	0.838	0.964	1.046	1.124	1.154	1.167	1.183	1.195	1.199
		9	0.672	0.836	0.956	1.027	1.115	1.147	1.164	1.181	1.195	1.195
TR	DRT50	0	0.407	0.597	0.691	0.765	0.799	0.861	0.899	0.943	0.967	0.982
		1	0.451	0.599	0.687	0.750	0.796	0.849	0.877	0.919	0.957	0.966
		2	0.577	0.689	0.749	0.804	0.851	0.903	0.941	0.973	0.995	1.005
		3	0.695	0.854	0.974	1.051	1.104	1.147	1.162	1.175	1.184	1.184
		4	0.698	0.864	0.990	1.076	1.124	1.161	1.173	1.187	1.187	1.195
		5	0.694	0.863	1.007	1.091	1.136	1.169	1.178	1.188	1.195	1.203
		6	0.691	0.861	1.006	1.096	1.142	1.167	1.179	1.189	1.200	1.203
		7	0.678	0.855	1.003	1.092	1.144	1.167	1.179	1.191	1.202	1.201
		8	0.673	0.850	1.000	1.081	1.141	1.163	1.179	1.192	1.200	1.202
		9	0.674	0.843	0.989	1.059	1.135	1.159	1.176	1.191	1.197	1.202
TR	DRT90	0	0.312	0.575	0.643	0.731	0.777	0.794	0.857	0.890	0.918	0.957
		1	0.285	0.544	0.630	0.692	0.758	0.790	0.815	0.860	0.889	0.920
		2	0.461	0.566	0.632	0.706	0.760	0.795	0.812	0.858	0.881	0.916
		3	0.739	0.821	0.917	0.992	1.029	1.063	1.098	1.120	1.142	1.157
		4	0.903	1.031	1.039	1.103	1.140	1.158	1.173	1.187	1.188	1.198
		5	0.840	1.184	1.219	1.227	1.229	1.232	1.234	1.235	1.236	1.237
		6	0.834	1.164	1.202	1.218	1.219	1.219	1.221	1.221	1.221	1.223
		7	0.820	1.122	1.198	1.222	1.232	1.239	1.239	1.239	1.239	1.239
		8	0.795	1.007	1.179	1.206	1.205	1.228	1.233	1.237	1.239	1.240
		9	0.748	0.987	1.132	1.184	1.202	1.210	1.213	1.216	1.223	1.228

Tree type	Appl tech	Cfbz [m]	Number of applications per year									
			1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
SP	conv	0	0.478	0.635	0.753	0.811	0.874	0.927	0.966	0.986	1.000	1.009
		0.5	0.475	0.630	0.729	0.797	0.863	0.911	0.943	0.973	0.992	1.000
		1.5	0.554	0.645	0.759	0.811	0.874	0.923	0.969	0.994	1.001	1.033
		2.5	0.646	0.796	0.871	0.904	0.947	0.978	1.001	1.035	1.062	1.087
		3.5	0.727	0.901	1.014	1.113	1.152	1.178	1.189	1.197	1.197	1.203
		4.5	0.719	0.895	1.020	1.120	1.156	1.183	1.194	1.198	1.202	1.208
		5.5	0.701	0.889	1.012	1.118	1.156	1.176	1.193	1.195	1.204	1.209
		6.5	0.692	0.878	1.009	1.109	1.152	1.176	1.190	1.195	1.204	1.206
		7.5	0.678	0.853	1.006	1.097	1.147	1.170	1.180	1.193	1.203	1.203
		8.5	0.673	0.846	0.998	1.076	1.142	1.164	1.179	1.192	1.201	1.202
SP	DRT50	0	0.423	0.607	0.704	0.767	0.819	0.875	0.905	0.946	0.974	0.988
		0.5	0.430	0.603	0.687	0.765	0.800	0.857	0.892	0.940	0.966	0.980
		1.5	0.528	0.627	0.723	0.797	0.845	0.883	0.920	0.941	0.959	0.986
		2.5	0.642	0.779	0.847	0.881	0.922	0.955	0.990	1.014	1.043	1.070
		3.5	0.736	0.904	1.014	1.111	1.150	1.178	1.188	1.196	1.198	1.203
		4.5	0.736	0.916	1.032	1.126	1.160	1.182	1.197	1.204	1.205	1.210
		5.5	0.723	0.906	1.030	1.127	1.163	1.180	1.196	1.200	1.207	1.211
		6.5	0.701	0.884	1.019	1.119	1.161	1.178	1.193	1.199	1.208	1.208
		7.5	0.687	0.878	1.009	1.109	1.155	1.174	1.187	1.198	1.207	1.207
		8.5	0.680	0.853	1.006	1.098	1.149	1.169	1.184	1.196	1.204	1.206
SP	DRT90	0	0.325	0.585	0.662	0.724	0.783	0.811	0.838	0.878	0.901	0.939
		0.5	0.364	0.579	0.660	0.720	0.777	0.811	0.829	0.863	0.889	0.920
		1.5	0.668	0.662	0.749	0.805	0.842	0.889	0.945	0.966	0.988	0.993
		2.5	0.832	1.020	1.049	1.066	1.071	1.079	1.100	1.116	1.130	1.141
		3.5	0.842	1.144	1.189	1.201	1.210	1.219	1.223	1.227	1.230	1.233
		4.5	0.829	1.118	1.189	1.207	1.215	1.224	1.230	1.234	1.235	1.236
		5.5	0.814	1.041	1.171	1.197	1.210	1.212	1.220	1.227	1.229	1.230
		6.5	0.791	1.002	1.142	1.183	1.204	1.211	1.216	1.216	1.218	1.223
		7.5	0.757	0.977	1.110	1.169	1.189	1.206	1.211	1.216	1.218	1.220
		8.5	0.739	0.943	1.079	1.150	1.181	1.196	1.208	1.211	1.217	1.219

Table 51 *Downward applications in avenue tree nurseries, 40 countrywide simulations. Values of PEC_{90}, T_{90} and ζ for 4 application techniques and 1-10 spray applications per year. Conv = conventional application technique. For T_{90} >0.9 the adjustment procedure is applicable, using ζ for drift enhancement (Section 5.2.5)*

	Number of applications per year									
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
PEC90										
Conv	0.205	0.266	0.300	0.314	0.322	0.324	0.327	0.327	0.328	0.328
DRT50	0.091	0.119	0.130	0.133	0.135	0.135	0.136	0.136	0.136	0.136
DRT75	0.058	0.071	0.077	0.081	0.083	0.084	0.084	0.084	0.084	0.085
DRT90	0.031	0.041	0.043	0.044	0.045	0.045	0.045	0.045	0.045	0.045
T90										
Conv	0.781	0.833	1	1	1	1	1	1	1	1
DRT50	0.757	1	1	1	1	1	1	1	1	1
DRT75	0.789	0.947	1	1	1	1	1	1	1	1
DRT90	0.741	1	1	1	1	1	1	1	1	1
Zeta										
Conv	0.783	0.971	1.086	1.133	1.161	1.168	1.178	1.179	1.180	1.180
DRT50	0.836	1.062	1.156	1.187	1.199	1.205	1.206	1.208	1.208	1.208
DRT75	0.854	1.011	1.091	1.137	1.164	1.174	1.178	1.180	1.181	1.188
DRT90	0.853	1.106	1.173	1.199	1.210	1.212	1.215	1.216	1.217	1.217

Table 52 *PEC$_{90}$ values [mg·m^{-3}] for downward applications on grass strips below a fruit tree orchard, for all 400 countrywide simulations. Conv = conventional application technique; cfbz = crop-free buffer zone.*

Appl tech	**Cfbz [m]**	**Number of applications per year**									
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
conv	0	0.155	0.183	0.198	0.208	0.211	0.214	0.215	0.218	0.221	0.222
	1	0.160	0.191	0.204	0.212	0.215	0.221	0.224	0.225	0.226	0.228
	2	0.161	0.195	0.206	0.214	0.220	0.225	0.229	0.232	0.234	0.235
	3	0.162	0.197	0.210	0.215	0.223	0.228	0.233	0.236	0.239	0.240
	4	0.166	0.200	0.214	0.218	0.226	0.232	0.237	0.240	0.243	0.244
	5	0.167	0.203	0.216	0.221	0.229	0.234	0.240	0.244	0.246	0.247
	6	0.169	0.204	0.219	0.223	0.231	0.237	0.242	0.246	0.248	0.249
	7	0.170	0.206	0.220	0.224	0.232	0.238	0.243	0.248	0.250	0.251
	8	0.171	0.207	0.222	0.225	0.234	0.239	0.245	0.249	0.251	0.253
	9	0.171	0.209	0.223	0.227	0.235	0.240	0.246	0.250	0.253	0.254
DRT50	0	0.068	0.079	0.084	0.089	0.092	0.093	0.094	0.094	0.094	0.094
	1	0.070	0.083	0.088	0.090	0.092	0.094	0.094	0.094	0.094	0.095
	2	0.071	0.086	0.091	0.093	0.094	0.094	0.094	0.094	0.095	0.095
	3	0.073	0.088	0.092	0.094	0.095	0.096	0.097	0.097	0.098	0.098
	4	0.074	0.090	0.094	0.096	0.097	0.099	0.099	0.100	0.100	0.100
	5	0.075	0.092	0.096	0.098	0.099	0.100	0.101	0.102	0.102	0.102
	6	0.076	0.093	0.098	0.099	0.101	0.102	0.102	0.103	0.103	0.104
	7	0.077	0.093	0.099	0.100	0.102	0.103	0.104	0.104	0.105	0.105
	8	0.078	0.094	0.100	0.101	0.102	0.104	0.105	0.105	0.106	0.106
	9	0.078	0.095	0.100	0.102	0.103	0.105	0.106	0.106	0.106	0.107
DRT75	0	0.041	0.046	0.049	0.051	0.052	0.053	0.053	0.053	0.053	0.054
	1	0.041	0.048	0.050	0.051	0.053	0.053	0.053	0.053	0.054	0.054
	2	0.043	0.049	0.051	0.052	0.053	0.053	0.053	0.054	0.054	0.054
	3	0.043	0.050	0.052	0.053	0.053	0.054	0.054	0.054	0.054	0.055
	4	0.044	0.051	0.053	0.054	0.055	0.055	0.055	0.056	0.056	0.056
	5	0.045	0.052	0.054	0.055	0.056	0.056	0.057	0.057	0.057	0.057
	6	0.046	0.053	0.055	0.056	0.057	0.057	0.058	0.058	0.058	0.058
	7	0.047	0.054	0.056	0.057	0.057	0.058	0.059	0.059	0.059	0.059
	8	0.047	0.055	0.057	0.058	0.058	0.059	0.059	0.059	0.060	0.060
	9	0.048	0.055	0.058	0.058	0.059	0.060	0.060	0.060	0.060	0.060
DRT90	0	0.023	0.026	0.028	0.030	0.030	0.031	0.031	0.031	0.031	0.031
	1	0.024	0.028	0.029	0.030	0.030	0.031	0.031	0.031	0.031	0.031
	2	0.024	0.029	0.030	0.030	0.030	0.031	0.031	0.031	0.031	0.031
	3	0.024	0.029	0.030	0.031	0.031	0.031	0.031	0.031	0.031	0.031
	4	0.025	0.030	0.031	0.031	0.032	0.032	0.032	0.032	0.032	0.032
	5	0.025	0.030	0.031	0.032	0.032	0.032	0.032	0.032	0.033	0.033
	6	0.026	0.031	0.032	0.032	0.033	0.033	0.033	0.033	0.033	0.033
	7	0.026	0.031	0.033	0.033	0.033	0.033	0.033	0.034	0.034	0.034
	8	0.026	0.032	0.033	0.033	0.033	0.034	0.034	0.034	0.034	0.034
	9	0.026	0.032	0.033	0.034	0.034	0.034	0.034	0.034	0.034	0.034

Table 53 *T_{90} values for downward applications on grass strips below a fruit tree orchard, for all 400 countrywide simulations. Conv = conventional application technique; cfbz = crop-free buffer zone. For T_{90}s above 0.9 the adjustment procedure is applicable, using ζ for drift enhancement (Section 5.2.5).*

Appl tech	**Cfbz [m]**	**Number of applications per year**									
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
conv	0	0.625	0.506	0.469	0.468	0.439	0.440	0.408	0.474	0.672	1
	1	0.613	0.484	0.411	0.364	0.312	0.312	0.290	0.268	0.235	0.238
	2	0.600	0.468	0.378	0.322	0.281	0.260	0.246	0.240	0.225	0.201
	3	0.591	0.461	0.370	0.289	0.257	0.236	0.232	0.218	0.207	0.191
	4	0.595	0.458	0.369	0.288	0.256	0.229	0.228	0.213	0.205	0.187
	5	0.596	0.457	0.370	0.288	0.255	0.231	0.224	0.213	0.201	0.187
	6	0.595	0.459	0.369	0.287	0.256	0.231	0.219	0.213	0.198	0.183
	7	0.595	0.460	0.372	0.286	0.255	0.226	0.216	0.213	0.199	0.182
	8	0.595	0.457	0.371	0.285	0.253	0.226	0.220	0.209	0.198	0.184
	9	0.594	0.459	0.375	0.288	0.254	0.224	0.219	0.213	0.202	0.185
DRT50	0	0.612	0.615	1	1	1	1	1	1	1	1
	1	0.580	0.568	0.777	1	1	1	1	1	1	1
	2	0.567	0.529	0.574	0.933	1	1	1	1	1	1
	3	0.558	0.499	0.480	0.502	0.549	0.846	1	1	1	1
	4	0.559	0.493	0.476	0.473	0.520	0.732	1	1	1	1
	5	0.562	0.493	0.477	0.449	0.476	0.670	1	1	1	1
	6	0.558	0.490	0.477	0.440	0.487	0.625	0.983	1	1	1
	7	0.562	0.483	0.472	0.433	0.453	0.564	0.905	1	1	1
	8	0.565	0.489	0.474	0.426	0.441	0.572	0.814	1	1	1
	9	0.565	0.491	0.474	0.425	0.431	0.569	0.778	1	1	1
DRT75	0	0.642	0.564	0.513	0.534	0.566	0.585	0.593	0.583	0.547	0.684
	1	0.613	0.541	0.477	0.439	0.431	0.405	0.364	0.318	0.326	0.330
	2	0.597	0.523	0.447	0.393	0.335	0.292	0.244	0.217	0.212	0.192
	3	0.580	0.504	0.418	0.354	0.287	0.237	0.197	0.165	0.138	0.121
	4	0.578	0.503	0.419	0.350	0.281	0.236	0.201	0.164	0.133	0.113
	5	0.577	0.499	0.421	0.346	0.278	0.238	0.198	0.163	0.137	0.108
	6	0.576	0.497	0.418	0.342	0.272	0.235	0.200	0.165	0.136	0.110
	7	0.573	0.497	0.416	0.343	0.276	0.240	0.201	0.166	0.139	0.113
	8	0.571	0.493	0.418	0.341	0.272	0.233	0.201	0.168	0.141	0.114
	9	0.575	0.494	0.420	0.337	0.270	0.239	0.203	0.169	0.139	0.115
DRT90	0	0.617	0.799	1	1	1	1	1	1	1	1
	1	0.575	0.722	1	1	1	1	1	1	1	1
	2	0.553	0.649	1	1	1	1	1	1	1	1
	3	0.544	0.592	0.714	1	1	1	1	1	1	1
	4	0.542	0.583	0.686	1	1	1	1	1	1	1
	5	0.540	0.565	0.675	1	1	1	1	1	1	1
	6	0.544	0.563	0.665	1	1	1	1	1	1	1
	7	0.543	0.564	0.671	0.871	1	1	1	1	1	1
	8	0.546	0.557	0.659	0.816	1	1	1	1	1	1
	9	0.541	0.555	0.652	0.755	1	1	1	1	1	1

Table 54 *Adjustment factor ζ for downward applications on grass strips below a fruit tree orchard, for all 400 countrywide simulations. Conv = conventional application technique; cfbz = crop-free buffer zone. For ζ<1 the corresponding T_{90} is below 0.9 and no adjustment procedure is required (Section 5.2.5).*

Appl tech	**Cfbz [m]**	**Number of applications per year**									
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
conv	0	0.714	0.830	0.896	0.938	0.952	0.966	0.970	0.984	0.996	1.000
	1	0.690	0.810	0.863	0.896	0.911	0.935	0.945	0.952	0.954	0.963
	2	0.669	0.795	0.839	0.872	0.894	0.916	0.932	0.945	0.951	0.954
	3	0.657	0.784	0.834	0.853	0.883	0.905	0.925	0.937	0.946	0.951
	4	0.658	0.782	0.833	0.850	0.880	0.902	0.923	0.935	0.945	0.950
	5	0.657	0.782	0.833	0.849	0.879	0.901	0.922	0.936	0.944	0.950
	6	0.657	0.782	0.834	0.849	0.878	0.902	0.920	0.935	0.943	0.949
	7	0.655	0.781	0.834	0.848	0.878	0.899	0.919	0.935	0.943	0.948
	8	0.656	0.781	0.836	0.847	0.878	0.898	0.920	0.934	0.943	0.949
	9	0.654	0.784	0.836	0.847	0.878	0.898	0.920	0.935	0.944	0.949
DRT50	0	0.832	0.957	1.015	1.073	1.110	1.126	1.135	1.138	1.138	1.139
	1	0.799	0.943	0.995	1.016	1.042	1.057	1.062	1.065	1.065	1.071
	2	0.775	0.929	0.975	1.000	1.010	1.014	1.015	1.016	1.017	1.025
	3	0.760	0.916	0.956	0.978	0.989	1.000	1.007	1.012	1.014	1.015
	4	0.754	0.911	0.955	0.973	0.986	0.998	1.004	1.009	1.013	1.014
	5	0.753	0.911	0.954	0.969	0.982	0.996	1.002	1.008	1.011	1.013
	6	0.746	0.906	0.953	0.967	0.983	0.995	1.000	1.006	1.010	1.012
	7	0.752	0.902	0.952	0.965	0.980	0.992	1.000	1.005	1.009	1.010
	8	0.750	0.903	0.951	0.963	0.978	0.993	0.999	1.004	1.007	1.009
	9	0.750	0.904	0.951	0.963	0.976	0.992	0.999	1.004	1.006	1.009
DRT75	0	0.772	0.868	0.910	0.951	0.972	0.983	0.988	0.990	0.990	0.997
	1	0.761	0.864	0.902	0.926	0.946	0.956	0.959	0.959	0.968	0.974
	2	0.760	0.859	0.891	0.912	0.921	0.929	0.931	0.937	0.946	0.951
	3	0.748	0.853	0.882	0.900	0.906	0.911	0.917	0.919	0.923	0.927
	4	0.749	0.855	0.885	0.900	0.906	0.913	0.919	0.921	0.922	0.926
	5	0.750	0.854	0.886	0.900	0.905	0.914	0.919	0.922	0.924	0.924
	6	0.751	0.854	0.887	0.900	0.905	0.915	0.920	0.924	0.926	0.926
	7	0.747	0.855	0.888	0.900	0.905	0.916	0.921	0.924	0.927	0.928
	8	0.744	0.854	0.889	0.899	0.905	0.915	0.922	0.925	0.927	0.929
	9	0.746	0.854	0.888	0.899	0.905	0.916	0.923	0.926	0.928	0.929
DRT90	0	0.879	0.993	1.049	1.113	1.139	1.151	1.157	1.160	1.161	1.162
	1	0.845	0.986	1.023	1.058	1.081	1.092	1.097	1.099	1.100	1.100
	2	0.817	0.976	1.008	1.025	1.041	1.048	1.052	1.053	1.054	1.054
	3	0.802	0.966	0.993	1.009	1.017	1.019	1.022	1.023	1.024	1.026
	4	0.798	0.963	0.991	1.006	1.013	1.016	1.020	1.022	1.023	1.024
	5	0.796	0.960	0.991	1.004	1.010	1.014	1.018	1.021	1.023	1.024
	6	0.797	0.958	0.990	1.001	1.007	1.013	1.017	1.021	1.023	1.023
	7	0.794	0.958	0.990	1.000	1.005	1.011	1.016	1.020	1.022	1.023
	8	0.791	0.955	0.989	0.999	1.003	1.009	1.015	1.019	1.022	1.023
	9	0.787	0.954	0.989	0.997	1.002	1.009	1.014	1.019	1.022	1.023

Table 55 *PEC_{90} values [mg·m^{-3}] for downward applications on tree strips below a fruit tree orchard, for all 400 countrywide simulations. Conv = conventional application technique; cfbz = crop-free buffer zone.*

Appl tech	**Cfbz [m]**	**Number of applications per year**									
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
conv	0	0.0279	0.0362	0.0386	0.0424	0.0438	0.0455	0.0474	0.0481	0.0489	0.0497
	1	0.0216	0.0271	0.0295	0.0316	0.0327	0.0343	0.0355	0.0362	0.0370	0.0376
	2	0.0183	0.0219	0.0236	0.0252	0.0263	0.0275	0.0282	0.0290	0.0295	0.0299
	3	0.0159	0.0193	0.0206	0.0215	0.0222	0.0232	0.0239	0.0243	0.0246	0.0248
	4	0.0132	0.0160	0.0173	0.0179	0.0185	0.0193	0.0199	0.0202	0.0205	0.0206
	5	0.0113	0.0137	0.0147	0.0152	0.0157	0.0163	0.0168	0.0171	0.0173	0.0175
	6	0.0097	0.0118	0.0127	0.0132	0.0134	0.0140	0.0145	0.0147	0.0149	0.0150
	7	0.0085	0.0102	0.0111	0.0116	0.0117	0.0122	0.0126	0.0128	0.0130	0.0131
	8	0.0075	0.0090	0.0099	0.0103	0.0104	0.0108	0.0110	0.0113	0.0114	0.0115
	9	0.0067	0.0080	0.0088	0.0091	0.0093	0.0096	0.0098	0.0100	0.0101	0.0102
DRT50	0	0.0166	0.0206	0.0223	0.0237	0.0249	0.0260	0.0269	0.0275	0.0279	0.0281
	1	0.0136	0.0167	0.0180	0.0191	0.0199	0.0208	0.0215	0.0221	0.0225	0.0227
	2	0.0118	0.0140	0.0150	0.0158	0.0168	0.0173	0.0179	0.0184	0.0186	0.0189
	3	0.0104	0.0126	0.0135	0.0139	0.0144	0.0151	0.0155	0.0157	0.0159	0.0160
	4	0.0088	0.0106	0.0114	0.0118	0.0122	0.0127	0.0131	0.0133	0.0134	0.0135
	5	0.0075	0.0091	0.0098	0.0101	0.0104	0.0108	0.0112	0.0114	0.0115	0.0116
	6	0.0065	0.0079	0.0085	0.0088	0.0090	0.0093	0.0097	0.0098	0.0099	0.0100
	7	0.0057	0.0069	0.0075	0.0078	0.0079	0.0082	0.0084	0.0086	0.0087	0.0088
	8	0.0051	0.0061	0.0066	0.0069	0.0070	0.0072	0.0075	0.0076	0.0077	0.0077
	9	0.0045	0.0054	0.0059	0.0062	0.0062	0.0065	0.0066	0.0067	0.0068	0.0069
DRT75	0	0.0114	0.0139	0.0146	0.0158	0.0168	0.0173	0.0176	0.0178	0.0179	0.0180
	1	0.0104	0.0123	0.0130	0.0139	0.0148	0.0153	0.0156	0.0159	0.0160	0.0160
	2	0.0094	0.0111	0.0116	0.0126	0.0132	0.0136	0.0139	0.0140	0.0142	0.0142
	3	0.0086	0.0103	0.0111	0.0113	0.0119	0.0123	0.0125	0.0126	0.0127	0.0128
	4	0.0076	0.0090	0.0098	0.0100	0.0104	0.0108	0.0110	0.0111	0.0112	0.0113
	5	0.0067	0.0080	0.0087	0.0089	0.0092	0.0095	0.0097	0.0099	0.0099	0.0100
	6	0.0059	0.0071	0.0077	0.0079	0.0082	0.0084	0.0086	0.0088	0.0088	0.0089
	7	0.0053	0.0063	0.0069	0.0071	0.0073	0.0075	0.0077	0.0078	0.0079	0.0079
	8	0.0048	0.0057	0.0062	0.0064	0.0065	0.0068	0.0069	0.0070	0.0071	0.0071
	9	0.0043	0.0051	0.0056	0.0058	0.0059	0.0061	0.0062	0.0063	0.0064	0.0065
DRT90	0	0.0064	0.0079	0.0083	0.0089	0.0094	0.0098	0.0101	0.0102	0.0103	0.0104
	1	0.0057	0.0068	0.0072	0.0076	0.0080	0.0084	0.0086	0.0087	0.0088	0.0089
	2	0.0051	0.0060	0.0063	0.0068	0.0071	0.0073	0.0075	0.0076	0.0077	0.0078
	3	0.0046	0.0055	0.0059	0.0060	0.0063	0.0066	0.0067	0.0068	0.0068	0.0068
	4	0.0040	0.0048	0.0052	0.0053	0.0055	0.0057	0.0058	0.0059	0.0060	0.0060
	5	0.0035	0.0042	0.0046	0.0047	0.0049	0.0050	0.0052	0.0052	0.0053	0.0053
	6	0.0031	0.0037	0.0041	0.0042	0.0043	0.0045	0.0046	0.0046	0.0047	0.0047
	7	0.0028	0.0034	0.0037	0.0038	0.0039	0.0040	0.0041	0.0041	0.0042	0.0042
	8	0.0025	0.0030	0.0033	0.0034	0.0035	0.0036	0.0037	0.0037	0.0038	0.0038
	9	0.0023	0.0027	0.0030	0.0031	0.0031	0.0032	0.0033	0.0034	0.0034	0.0034

Table 56 *T_{90} values for downward applications on tree strips below a fruit tree orchard, for all 400 countrywide simulations. Conv = conventional application technique; cfbz = crop-free buffer zone. For T_{90}s above 0.9 the adjustment procedure is applicable, using ζ for drift enhancement (Section 5.2.5).*

Appl tech	**Cfbz [m]**	**Number of applications per year**									
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
conv	0	0.544	0.376	0.259	0.212	0.163	0.136	0.126	0.103	0.093	0.084
	1	0.561	0.391	0.285	0.228	0.178	0.159	0.146	0.129	0.126	0.119
	2	0.588	0.412	0.306	0.250	0.210	0.198	0.180	0.179	0.177	0.176
	3	0.615	0.472	0.377	0.310	0.275	0.281	0.288	0.296	0.308	0.312
	4	0.620	0.481	0.394	0.328	0.288	0.296	0.322	0.341	0.367	0.391
	5	0.627	0.492	0.413	0.346	0.305	0.313	0.343	0.371	0.415	0.467
	6	0.629	0.499	0.427	0.360	0.313	0.327	0.370	0.410	0.462	0.535
	7	0.632	0.501	0.434	0.381	0.323	0.340	0.371	0.414	0.525	0.618
	8	0.636	0.510	0.449	0.399	0.337	0.360	0.390	0.448	0.568	0.747
	9	0.642	0.514	0.456	0.411	0.351	0.374	0.411	0.501	0.603	0.889
DRT50	0	0.532	0.349	0.241	0.186	0.152	0.137	0.135	0.133	0.133	0.124
	1	0.554	0.379	0.267	0.207	0.170	0.158	0.155	0.159	0.161	0.158
	2	0.582	0.405	0.302	0.236	0.217	0.194	0.201	0.210	0.218	0.226
	3	0.607	0.469	0.375	0.308	0.280	0.300	0.322	0.339	0.367	0.383
	4	0.616	0.477	0.399	0.330	0.295	0.319	0.342	0.371	0.405	0.463
	5	0.624	0.490	0.412	0.346	0.309	0.320	0.361	0.407	0.470	0.541
	6	0.628	0.493	0.425	0.364	0.319	0.324	0.374	0.407	0.487	0.638
	7	0.634	0.506	0.440	0.383	0.324	0.346	0.384	0.441	0.545	0.676
	8	0.636	0.509	0.445	0.396	0.336	0.352	0.417	0.474	0.558	0.791
	9	0.636	0.518	0.457	0.414	0.353	0.378	0.392	0.484	0.626	0.963
DRT75	0	0.506	0.315	0.199	0.170	0.192	0.244	0.346	0.542	0.933	1
	1	0.536	0.351	0.245	0.201	0.216	0.250	0.300	0.396	0.574	0.753
	2	0.562	0.396	0.275	0.259	0.271	0.296	0.341	0.392	0.604	0.833
	3	0.594	0.449	0.384	0.311	0.339	0.418	0.550	0.757	1	1
	4	0.604	0.464	0.405	0.331	0.342	0.412	0.487	0.670	1	1
	5	0.612	0.475	0.420	0.350	0.351	0.382	0.471	0.662	1	1
	6	0.618	0.484	0.430	0.371	0.353	0.393	0.468	0.616	0.982	1
	7	0.622	0.492	0.444	0.391	0.358	0.384	0.473	0.586	0.886	1
	8	0.630	0.504	0.451	0.410	0.358	0.393	0.478	0.609	0.907	1
	9	0.634	0.511	0.461	0.420	0.373	0.407	0.471	0.602	1	1
DRT90	0	0.513	0.335	0.222	0.174	0.160	0.174	0.195	0.223	0.256	0.292
	1	0.542	0.363	0.256	0.201	0.188	0.197	0.217	0.244	0.266	0.310
	2	0.566	0.398	0.288	0.264	0.241	0.257	0.275	0.337	0.398	0.482
	3	0.594	0.454	0.388	0.312	0.316	0.398	0.471	0.614	0.983	1
	4	0.602	0.468	0.406	0.337	0.340	0.389	0.481	0.621	0.897	1
	5	0.611	0.478	0.422	0.350	0.345	0.395	0.478	0.613	1	1
	6	0.617	0.484	0.433	0.374	0.357	0.382	0.465	0.620	1	1
	7	0.623	0.496	0.441	0.395	0.356	0.379	0.460	0.616	0.965	1
	8	0.627	0.502	0.455	0.411	0.355	0.418	0.463	0.634	1	1
	9	0.633	0.508	0.462	0.426	0.364	0.406	0.468	0.590	0.969	1

Table 57 *Adjustment factor ζ for downward applications on tree strips below a fruit tree orchard, for all 400 countrywide simulations. Conv = conventional application technique; cfbz = crop-free buffer zone. For ζ<1 the corresponding T_{90} is below 0.9 and no adjustment procedure is required (Section 5.2.5).*

Appl tech	**Cfbz [m]**	**Number of applications per year**									
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
conv	0	0.513	0.655	0.696	0.763	0.788	0.819	0.853	0.865	0.879	0.893
	1	0.539	0.664	0.719	0.770	0.797	0.836	0.863	0.881	0.901	0.914
	2	0.588	0.691	0.742	0.792	0.826	0.864	0.885	0.910	0.926	0.939
	3	0.636	0.758	0.810	0.841	0.870	0.909	0.935	0.951	0.963	0.970
	4	0.645	0.766	0.823	0.851	0.878	0.915	0.943	0.960	0.972	0.980
	5	0.654	0.777	0.835	0.861	0.886	0.920	0.949	0.966	0.978	0.987
	6	0.659	0.782	0.843	0.871	0.888	0.925	0.955	0.971	0.983	0.991
	7	0.663	0.783	0.849	0.881	0.893	0.929	0.955	0.972	0.988	0.995
	8	0.668	0.788	0.858	0.890	0.900	0.936	0.958	0.976	0.990	0.998
	9	0.672	0.792	0.861	0.896	0.906	0.939	0.963	0.982	0.992	1.000
DRT50	0	0.567	0.695	0.750	0.798	0.839	0.873	0.904	0.924	0.938	0.945
	1	0.576	0.698	0.751	0.796	0.829	0.870	0.899	0.924	0.939	0.949
	2	0.613	0.715	0.768	0.808	0.857	0.882	0.914	0.937	0.951	0.962
	3	0.652	0.776	0.830	0.856	0.888	0.929	0.952	0.966	0.976	0.982
	4	0.656	0.778	0.837	0.863	0.890	0.931	0.954	0.969	0.979	0.988
	5	0.661	0.782	0.843	0.869	0.893	0.929	0.956	0.973	0.985	0.992
	6	0.662	0.784	0.849	0.877	0.896	0.927	0.958	0.973	0.986	0.996
	7	0.665	0.791	0.854	0.885	0.895	0.934	0.958	0.976	0.990	0.997
	8	0.670	0.792	0.858	0.892	0.902	0.935	0.964	0.980	0.990	0.999
	9	0.670	0.796	0.863	0.899	0.908	0.942	0.959	0.980	0.994	1.000
DRT75	0	0.644	0.777	0.814	0.883	0.937	0.968	0.986	0.996	1.000	1.008
	1	0.654	0.771	0.813	0.870	0.924	0.957	0.976	0.989	0.997	0.999
	2	0.671	0.784	0.814	0.883	0.930	0.957	0.975	0.985	0.997	1.000
	3	0.695	0.816	0.881	0.898	0.942	0.973	0.990	0.999	1.005	1.012
	4	0.693	0.812	0.878	0.897	0.936	0.968	0.985	0.996	1.003	1.010
	5	0.687	0.808	0.878	0.898	0.932	0.959	0.981	0.996	1.000	1.010
	6	0.684	0.807	0.875	0.903	0.928	0.958	0.979	0.993	1.000	1.011
	7	0.686	0.808	0.879	0.907	0.927	0.954	0.979	0.992	1.000	1.008
	8	0.686	0.807	0.879	0.910	0.922	0.955	0.978	0.992	1.000	1.010
	9	0.688	0.809	0.879	0.913	0.926	0.955	0.976	0.992	1.001	1.011
DRT90	0	0.614	0.749	0.790	0.839	0.886	0.927	0.952	0.968	0.979	0.986
	1	0.636	0.751	0.793	0.839	0.887	0.924	0.949	0.966	0.976	0.984
	2	0.660	0.766	0.806	0.871	0.905	0.938	0.958	0.976	0.986	0.993
	3	0.687	0.811	0.874	0.890	0.929	0.967	0.983	0.995	1.000	1.005
	4	0.687	0.808	0.875	0.895	0.932	0.962	0.982	0.994	1.000	1.007
	5	0.686	0.810	0.877	0.897	0.929	0.961	0.981	0.994	1.000	1.008
	6	0.686	0.806	0.879	0.903	0.929	0.956	0.979	0.994	1.000	1.008
	7	0.687	0.809	0.878	0.907	0.926	0.953	0.977	0.993	1.000	1.009
	8	0.686	0.811	0.880	0.912	0.923	0.959	0.977	0.994	1.001	1.010
	9	0.689	0.811	0.882	0.916	0.924	0.956	0.976	0.991	1.000	1.010

Annex 11 Solutions to the matching problem

In Section 5.2.5 the local adjustment procedure is described, to overcome the problem that sometimes the locally selected spatial configuration does not match the countrywide exposure level PEC_{90}. The presented solution to this 'matching problem' is not the only way to deal with it. In the working group various solutions have been discussed. In this annex four potential solution procedures are discussed, and why the working group thinks the spray drift enhancement method is the best.

Four different solutions for the above-mentioned matching problem of local cpdf to countrywide cpdf came forward:

a. selecting a different local configuration,
b. using 90^{th} percentile drift deposition curves rather than mean curves;
c. having multiple local selections for different circumstances;
d. adjusting spray drift in the local situation.

Each of these solution routes will be shortly discussed in the following paragraphs.

Solution a
For the avenue tree scenarios only 12 watercourses are available to select from. In principle the summer water level could be part of the selection to obtain more flexibility. However, the final selection would be very specific and could be rather uncommon in practice. But what is more important, it is likely that each choice would suffer from the same shortcomings: there will be one or more situations for which the selected watercourse does not cover the countrywide PEC_{90}. For instance, selecting a more sensitive ditch would better fit to higher PEC_{90} values, yet for lower PEC_{90}s a temporal percentile of 0 would become possible, which is as bad as a temporal percentile of 1. So the matching problem remains (for another set of scenarios).

Solution b
Until now the drift exposure simulations were carried out using averaged drift curves, i.e. at mean drift levels. Obviously, drift curves at a 90^{th} percentile exposure level would result in higher drift deposits and one might think that the PEC_{90} values would be covered then, thus fixing the matching problem. However, the 90^{th} percentile drift curves would be used for the countrywide scenarios as well, which would lead to increased PEC^{90} values also. In the end, the same matching problem remains. Additionally, using 90^{th} percentile drift values can be considered 'worst case' per se. To which protection level this would lead in the method using countrywide PEC_{90} and a local T_{90}, is not clear, yet it will be much higher than 90% and probably too conservative.

Solution c
In addition to solution a, one might select different local configurations for various subsets of circumstances. Although this would probably solve the problem of matching local T_{90} to countrywide PEC_{90}, clearly it is far from ideal to have more than one local selections. Just to mention one new problem: each selection would require its own parameterisation of drift, drainage and fate models.

Solution d
The final option involves an adjustment factor to enhance drift deposits on the local watercourse in such a way, then the new situation would give a T_{90} of exactly 90%. Although it may seem strange to artificially enhance drift deposits above its maximum value for that ditch, in fact it is equivalent to raising the applied dosage with the same factor (for the local situation only). All exposure routes (drift deposition, drainage emission, atmospheric deposition) will be enhanced (directly or indirectly) by the same factor, so their mutual balance remains. Besides, the simulations showed that the enhancement factor was at most 1.24 (see Section 5.2.5), which is reasonably low.

Thus option d was considered the best solution to the matching problem.

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Report WPR-1092

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