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A methodology is presented to assess the exposure of aquatic organisms resulting from pesticide applications by sideways and upward spraying in Dutch fruit crops. It is the intention that this methodology will be used in Dutch pesticide registration. The methodology is based on the principle that the endpoint concentration represents a 90th percentile of the statistical population of concentrations to be expected in ditches alongside fruit crops. Furthermore the methodology is founded on the principle that the user should be able to choose between different drift-reduction technology (DRT) classes and between different widths of the crop-free buffer zone. Spray drift is the only exposure route considered in the methodology. The 90th percentile concentration (PEC90) is based on a spatially distributed model that simulates the frequency distribution of the annual maximum concentration of more than 70,000 spatial units (i.e. ditches characterised by waterbody properties and their orientation with respect to the direction of the rows of the fruit trees and to the N-E-S-W direction) for 100 simulation years. This frequency distribution was calculated for different application patterns, different DRT classes and different widths of the crop-free buffer zone. Next, one of the 70,000 spatial units was selected which fulfilled the criterion that it could be used to calculate this PEC90 for all combinations of application patterns, DRT classes and widths by selecting a suitable percentile of its temporal distribution of concentrations. The TOXSWA model (coupled to the hydrological SWQN model simulating water depths and water flow rates) was parameterised for this selected spatial unit to run for 26 years. The first six years were used as a 'warming-up' period and the remaining 20 years for assessing the required temporal percentile. The scenario ditch was 300 m long of which only the 100 m in the middle received a drift load of pesticide. The direction of water flow may change on a daily basis and the water flowing into the 300-m ditch was assumed to be free of pesticide. The median residence time of a droplet of water in the 100-m ditch was about 1 day. The spray drift deposition for the 99% DRT class appeared to be as low as 0.03-0.07% for summer applications. At such low deposition levels the contribution of leaching from drain pipes and of atmospheric deposition may exceed that of the drift deposition.

Keywords: pesticides, spray drift, Drift Reduction Technology, crop-free buffer zone, fruit crops, surface water, aquatic organisms, probabilistic scenario

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Preface

We thank Aaldrik Tiktak (PBL) and Ton van der Linden (RIVM) for their contributions to this work from 2013 to 2015.

Summary

An overview is presented of a recently developed methodology for exposure of aquatic organisms in watercourses after application of pesticides by sideways and upward spraying in Dutch fruit crops. The methodology is not yet final so this is an interim report. More detailed information on the methodology is available in other reports.

The methodology is based on a exposure assessment goal that for a given pesticide application (e.g. spraying of pesticide X during BBCH growth stage Y at a dose Z) results in a so-called 90th percentile exposure concentration (abbreviated PEC90 from 'Predicted Environmental Concentration'); this means that the actual concentrations are expected to be lower in 90% of the cases than this PEC90 and in 10% of the cases thus higher than this PEC90. These 'cases' are the combination of spatial units (i.e. pieces of ditches alongside fruit crops) and of time series of concentrations for each unit. This time series consists of the annual maximum concentrations for the unit considered. The statistical population of spatial units is defined here as all ditches alongside fruit crops in the Netherlands.

Furthermore it was a prerequisite that the end user should be able to choose freely between different drift-reducing techniques (defined as DRT classes for 75, 90, 95, 97.5 and 99% reduction) and between crop-free bufferzones with widths ranging from 0 to 9 m.

Using this methodology requires a calculation for a certain scenario for each regulatory assessment. This scenario is selected in such a way that this calculation generates the required PEC90. The development of the methodology consisted of two steps: (1) selection of this scenario, and (2) parameterisation of this scenario. The scenario selection was based on a simplified approach. The ideal approach would be to build a so-called spatially distributed TOXSWA model which contains hunderds of scenarios in a database (similar to the GeoPEARL model for leaching to groundwater in the Netherlands which contains some 5000 scenarios). The spatially distributed model could then calculate which of the hundreds or thousands scenarios is suitable to generate the PEC90. However, given the scientific state-of-the-art in this field, it is impossible to build such a model within a reasonable time frame.

The simplified approach was based on spray drift as the only exposure route and on a model that consisted of three submodels: (1) a local spray-drift deposition model, (2) a metamodel of TOXSWA, and (3) a spatially distributed probabilistic model that calculates the frequency distribution of the exposure concentration in ditches alongside fruit crops.

The local spray-drift deposition model considers effects of wind speed, air temperature, crop stage, sprayer fan speed, wind direction, drift reducing technique (DRT class) and width of the crop-free buffer zone. This model was parameterised based on measurements of 316 deposition-distance curves for apples in the Netherlands.

The metamodel of TOXSWA was based on a very simple relation between the spray drift deposition and the exposure concentration and calculates for each application scheme the annual maximum concentration in the ditch.

The spatially distributed probabilistic model for the exposure concentration uses (1) a spatial database of Dutch ditches which indicates to which of 44 available hydrotypes the ditch belongs, (2) a spatial database of differences in water depth between summer and winter, (3) frequency distributions of the N-E-S-W orientation of the tree rows of fruit parcels for different meteorological districts in the Netherlands, (4) 20-year time series of hourly averages of meteorological data from 14 Dutch weather stations, (5) the LGN map which indicates where fruit crops are grown in the Netherlands at a resolution of 25 × 25 m. This spatially distributed model resulted in some 70,000 spatial units. Each model calculation was based on 100 application years (based on frequency distributions of

meteorological data that were derived from the 20-year time series). Thus each model calculation generated some 7,000,000 annual maximum exposure concentrations; these were plotted as a cumulative frequency distribution from which the PEC90 could be derived.

Most pesticides in Dutch fruit crops are sprayed once a year. Some pesticides are sprayed 2-3 times per year and captan is sprayed 14-15 times per year. The frequency distribution generated by the spatially distributed model appeared to depend on the number of applications and the application season. Therefore calculations were carried out for five application schemes (one early application, one late application, three early applications, three late applications and 15 applications distributed over the growing season). The frequency distribution appeared to depend also on the DRT class of the application technique (conventional, 50-75-90-95-97.5-99) and the width of the crop-free buffer zone (0-9 m). Thus, the total number of calculations with the spatially distributed model was 5 × 7 × 10 = 350 (at a later stage the conventional and DRT50 classes appeared to be not relevant anymore for the regulatory process so these results will not be further used).

The parameterisation of a scenario linked to a certain spatial unit is a time-consuming activity. Therefore it is efficient to base all calculations for pesticide registration on only one parameterised spatial unit. This one unit was selected by selecting from all 350 calculation results all space-time combinations with concentrations between the 87th and 93rd percentile and to search for a spatial unit that generates for all 350 calculations concentrations in this range. Indeed such a spatial unit could be found. It appeared to be a ditch of the hydrotype 'Betuwe stroomruggrond' with a water depth of 30 cm both in summer and winter, located in the meteo district Herwijnen east of an orchard whose tree rows are in a direction 20^{o} west of the north (using a scale of 360^{o} for the full N-E-S-W circle). This hydrotype has a width of the water surface of 234 cm and a width of the bottom of the ditch of 174 cm.

Each calculation of the spatially distributed model was based on 70,000 spatial units and a time series of 100 years, and generated this 7,000,000 concentrations from which the PEC90 was derived. The selected scenario is based on only one of these 70,000 units. So a link had to be made between the calculation results for the selected scenario and the calculation results from the spatially distributed model. This was done by calculating the temporal frequency distribution for the selected spatial unit (now using 10 000 application years instead of 100 years to ensure sufficient accuracy) and to assess which temporal percentile corresponded with the PEC90. This percentile was further used to derive the PEC90 from a calculation with the parameterised scenario. Thus, for each of the 350 calculations with the spatially distributed model the corresponding temporal percentile was derived; most temporal percentiles were between 40 and 60%).

The next step was to parameterise the scenario for the selected spatial unit. For that purpose, input data for TOXSWA and the SWQN submodel for water flow had to be collected, enabling calculations of the exposure concentrations in the ditch over a period of 26 year on an hourly basis. The first six years are used as a 'warming-up' period for the use of the pesticide and the remaining 20 years are used for the calculation of the PEC90 (based on the derived temporal percentile as described in the previous paragraph). The ditch in the scenario has a length of 300 m; pesticide is applied only to the field alongside the middle 100 m and it is assumed that the water that flows into the system contains no pesticide. Water can flow in two directions (discharge in winter and inflow in summer).

The water flow rate at the boundaries of the system was derived from calculations with the Moria 2.2 model that had been developed especially for the area in which this spatial unit is located. The water flow rate and the water depth in the ditch were calculated with the SWQN model. This model was calibrated to ensure that the simulated water depth fulfilled the requirement of a depth of 30 cm both in winter and in summer. The median residence time of a droplet of water in the 100 m ditch appeared to be about 1 day. This indicates that there will be hardly any accumulation of concentrations resulting from repeated applications with time intervals of at least one week (shorter time intervals hardly occur in practice). The properties of the sediment were based on field measurements at four locations in the Netherlands.

Calculations with a few example pesticides indicated that about half of the applications did not lead to exposure because the wind did not blow in the direction of the ditch in the hour of application. The properties of the sediment appeared to have only a comparatively small effect on the exposure concentration. Furthermore even 15 applications within a year did not lead to significant accumulation of concentrations (as was expected in view of the short residence time of the water in the ditch).

The developed methodology was based on spray drift as the only exposure route. This was based on the assumption that spray drift resulting from sideways and upward spraying in Dutch fruit crops is higher than spray drift resulting from downward spraying in Dutch arable crops. However, it was found that spray drift for applications in a full-grown fruit crop with DRT99 is lower than 0.1% (for a crop-free buffer zone of 9 m even below 0.03%). Previous research showed that contributions of leaching from drain pipes and of atmospheric deposition (due to volatilisation from the treated fields) can be higher than that of the spray-drift deposition in such a case. Exposure resulting from leaching from drain pipes can be relatively easy included in the exposure assessment (using the same approach as applied earlier for downward spray applications in Dutch arable crops). However, including atmospheric deposition in the exposure assessment will require considerable research efforts.

The developed methodology is based on the current use labels in Dutch pesticide registration. These specify the concentration of the formulated product in the spray solution and a maximum amount of formulated product per surface area of the treated field. We recommend to explore the possibility to base the dose (as specified on the use label) on the leaf wall area (LWA); this is defined as two times the distance between the highest and the lowest leaf of the tree multiplied with the total length of the rows of the trees for 1 ha (two times because the tree has two sides). In principle, this LWA approach may lead to a reduction of total use of plant protection products in Dutch fruit crops by about a factor of two (without reduction of efficacy); this would lead to a similar reduction of emissions to the environment. If this switch to the LWA approach would be made, it would become possible (with relatively little efforts) to estimate the frequency distribution of the applied amount per surface area of the treated field. Probably including this frequency distribution in the spatially distributed probabilistic model (instead of the maximum amount) will reduce the PEC90 by 10-25%.

Samenvatting

Dit rapport geeft een overzicht van een recent ontwikkelde methodiek voor blootstelling van waterorganismen in waterlopen na toepassing van gewasbeschermingsmiddelen via zijwaarts en opwaarts spuiten in de Nederlandse fruitteelt. Het is een interim rapport omdat de methodiek nog niet is afgerond. Gedetailleerde informatie over de methodiekontwikkeling is beschikbaar in andere rapporten.

De methodiek is gebaseerd op een blootstellingsdoel dat voor een bepaalde toepassing (b.v. spuiten van middel X tijdens BBCH groeistadium Y met een dosering Z) resulteert in een zogenaamde 90-percentiel blootstellingsconcentratie (afgekort PEC90, van Predicted Environmental Concentration); dit houdt in dat de werkelijke concentraties naar verwachting in 90% van de gevallen lager zijn dan deze PEC90 en in 10% van de gevallen dus hoger dan deze PEC90. Deze ‘gevallen’ zijn opgebouwd uit ruimtelijke eenheden (stukken fruitteelt-sloot) en tijdreeksen van concentraties voor elke eenheid. Hierbij bestaat zo’n tijdreeks uit de jaarlijkse maximale concentraties en is de statistische populatie van ruimtelijke eenheden gedefiniëerd als alle sloten die naast een fruitteelt-perceel liggen in Nederland.

Verder was een uitgangspunt bij de methodiekontwikkeling dat de gebruiker vrij moet kunnen kiezen uit verschillende drift-reducerende technieken (gedefiniëerd als de DRT-klassen voor 75, 90, 95, 97,5 en 99% reductie) en uit gewasvrije bufferzones met breedtes variërend van 0 tot 9 m.

De methodiek houdt in dat voor een toelatingsbeoordeling een berekening moet worden gemaakt voor een bepaald scenario. Dit scenario wordt zodanig geselecteerd dat deze berekening de gewenste PEC90 oplevert. De ontwikkeling van de methodiek bevatte twee stappen: (1) de selectie van dit scenario en (2) de parameterisatie van dit geselecteerde scenario. De selectie van het scenario was gebaseerd op een vereenvoudigde aanpak. De ideale aanpak zou zijn om een zogenaamd ruimtelijk verdeeld TOXSWA model (incl. submodel voor de waterstroming in de sloot) te maken waarin honderden scenario’s via een database beschikbaar zijn (zoals het GeoPEARL model voor uitspoeling naar grondwater waarin ca 5000 scenario’s beschikbaar zijn). Het ruimtelijk verdeelde model zou dan zelf kunnen uitrekenen welk van de honderden/duizenden scenario’s geschikt is om de PEC90 te genereren. Het is echter gezien de stand van de wetenschap onmogelijk om binnen een redelijke termijn zo’n ruimtelijk verdeeld model te maken voor de blootstelling van waterorganismen na toepassingen in de Nederlandse fruitteelt.

De vereenvoudigde aanpak was gebaseerd op spuitdrift als enige blootstellingsroute en op een model dat bestaat uit drie submodellen: (1) een lokaal drift-depositie model, (2) een metamodel van TOXSWA, en (3) een ruimtelijk verdeeld probabilistisch model dat de frequentieverdeling berekent van de blootstellingsconcentratie in sloten langs fruitteeltpercelen.

Het lokale drift-depositie model houdt rekening met windsnelheid, luchttemperatuur, gewasstadium (BBCH), instelling van de spuitapparatuur, windrichting, drift reducerende techniek (DRT klasse) en breedte van de gewasvrije bufferzone. Dit model is gebaseerd op 316 drift-depositie metingen in Nederlandse appelboomgaarden.

Het metamodel van TOXSWA was gebaseerd op een zeer eenvoudige relatie tussen de spuitdrift depositie en blootstellingsconcentratie en berekent voor elk toepassingsschema de maximale concentratie in de sloot binnen een kalenderjaar.

Het ruimtelijk verdeelde probabilistische model voor de blootstellingsconcentratie maakt gebruik van (1) een ruimtelijke database van Nederlandse sloten die voor elke sloot aangeeft tot welk van de 44 beschikbare hydrotypen de sloot behoort, (2) een ruimtelijke database van verschillen in waterdiepte tussen zomer en winter, (3) frequentieverdelingen van de N-O-Z-W oriëntatie van de boomrijen van

fruitpercelen voor verschillende meteodistricten in Nederland, (4) 20-jarige tijdreeksen van uurgemiddelde meteorologische gegevens van 14 Nederlandse meteostations, (5) de landgebruikskaart van Nederland (LGN kaart) die aangeeft waar in Nederland fruitteelt plaatsvindt met een resolutie van 25 × 25 m. Dit ruimtelijk verdeelde model resulteerde in ca 70 000 ruimtelijke eenheden. Elke berekening met het ruimtelijk verdeelde model was gebaseerd op 100 jaren (gebaseerd op frequentieverdelingen van meteorologische gegevens die waren afgeleid uit de meteorologische 20-jaar reeksen). Elke berekening met dit model leverde dus ca 7 000 000 blootstellingsconcentraties op (jaarlijkse maxima); deze werden samengevat in de vorm van een cumulatieve frequentieverdeling en hieruit werd de PEC90 afgeleid.

De meeste gewasbeschermingsmiddelen in de Nederlandse fruitteelt worden eenmaal per jaar gespoten. Enkele middelen worden 2-3 maal per jaar gespoten en captan wordt 14-15 maal per jaar gespoten. De frequentieverdeling van blootstellingsconcentratie bleek af te hangen van het aantal bespuitingen en ook van het toepassingsseizoen. Daarom werden er berekeningen uitgevoerd voor vijf toedieningsschema’s (één maal spuiten vroeg in het seizoen, één maal spuiten laat in het seizoen, drie maal spuiten vroeg in het seizoen, drie maal spuiten laat in het seizoen, en 15 maal spuiten verdeeld over het seizoen). De frequentieverdeling van blootstellingsconcentraties bleek ook af te hangen van de DRT-klasse van de toedieningstechniek (conventioneel-50-75-90-95-97,5-99) en de breedte van de gewasvrije zone (0-9 m). Het totale aantal berekeningen met het ruimtelijk verdeelde model bedroeg dus 5 × 7 × 10 = 350 (later bleek dat de berekeningen voor conventioneel en DRT50 beleidsmatig niet meer relevant waren, dus deze berekeningen worden verder niet gebruikt).

Parameterisatie van een scenario behorend bij een bepaalde ruimtelijke eenheid is een tijdrovende zaak. Het is dus efficiënt om alle berekeningen in kader van de toelating te baseren op slechts één ruimtelijke eenheid (een soort grootste gemene deler van alle 350 berekeningen met het ruimtelijk verdeelde model). Deze ene ruimtelijke eenheid werd geselecteerd door uit alle 350 berekeningsresultaten de ruimte-tijd combinaties te selecteren die blootstellingsconcentraties genereerden die tussen het 87 en 93 percentiel lagen en te zoeken naar ruimtelijke eenheden die voor alle 350 berekeningen concentraties in dit bereik genereerden. Het bleek inderdaad mogelijk om een eenheid te vinden die hieraan voldeed. De geselecteerde ruimtelijke eenheid was een sloot van het hydrotype ‘Betuwe stroomruggrond’ met een waterdiepte van 30 cm zowel in zomer als in winter, gelegen aan de oostzijde van een boomgaard met een richting van de boomrij die 20^{o} ten westen van het noorden ligt (uitgaande van 360^{o} voor de volledige noord-oost-zuid-west cirkel) en gelegen in het meteodistrict Herwijnen. Dit hydrotype heeft een breedte van het wateroppervlak van 234 cm en een breedte van de bodem van de sloot van 174 cm.

Elke berekening met het ruimtelijk verdeelde model was gebaseerd op 70 000 ruimtelijke eenheden en een tijdreeks van 100 jaar, en genereerde dus 7 000 000 concentraties waaruit de PEC90 werd afgeleid. Het geselecteerde scenario gaat uit van slechts één van die 70 000 eenheden. Er moest dus een verband gelegd worden tussen de uitkomst voor het geselecteerde scenario en de uitkomst voor het ruimtelijk verdeelde model. Dit gebeurde als volgt: voor de geselecteerde ruimtelijke eenheid werd de temporele frequentieverdeling van concentraties berekend (nu uitgaande van 10 000 i.p.v. 100 toepassingsjaren om voor voldoende nauwkeurigheid te zorgen) en vervolgens werd berekend welk temporeel percentiel overeenkwam met de PEC90. Dit temporele percentiel werd verder gebruikt om de PEC90 af te leiden uit een berekening voor het geparameteriseerde scenario. Elk van de 350 berekeningen met het ruimtelijke model leverde zo een temporeel percentiel op (de meeste lagen tussen de 40 en de 60%).

Vervolgens werd het scenario voor de geselecteerde ruimtelijke eenheid geparameteriseerd. Dit hield verzameling in van invoergegevens voor het TOXSWA model en het SWQN submodel voor de waterstroming, die het mogelijk maakten om de blootstellingsconcentratie in de sloot over een periode van 26 jaar op uurbasis te berekenen. De eerste 6 jaar hiervan worden gebruikt als een ‘opwarmperiode’ voor het gebruik van het betreffende gewasbeschermingsmiddel en de laatste 20 jaar voor de berekening van de PEC90 (gebaseerd op het temporele percentiel zoals beschreven in de vorige alinea). De sloot in het scenario is 300 m lang en alleen de 100 m in het midden worden belast met het middel. Het water kan twee kanten op stromen (afvoer in winter en aanvoer in zomer). Er wordt aangenomen dat het water dat het systeem instroomt geen gewasbeschermingsmiddel bevat.

De waterstroomsnelheid aan de randen van de sloot werd afgeleid uit berekeningen met het Moria 2.2 model; dit model is speciaal ontwikkeld voor het gebied waarin deze ruimtelijke eenheid ligt. De waterstroomsnelheid en waterdiepte in de sloot werd berekend met het SWQN model. Dit model werd gekalibreerd om ervoor te zorgen dat de gesimuleerde waterdiepte voldeed aan de eis van een diepte van 30 cm in zowel zomer als winter. De mediane verblijftijd van een druppel water in de 100 m sloot bleek ongeveer 1 dag te zijn. Dit houdt in dat er slechts in geringe mate accumulatie van concentraties kan optreden bij herhaalde toepassingen met tussenpozen van minstens een week (kortere tussenpozen komen vrijwel niet voor in de praktijk). De eigenschappen van het sediment werden gebaseerd op veldmetingen van vier locaties in Nederland.

Berekeningen met enkele voorbeeldstoffen gaven aan dat ca de helft van de toepassingen niet tot blootstelling leidden omdat de wind niet in de richting van de sloot blies in het uur van toepassing. Verder bleken de eigenschappen van het sediment geen grote invloed te hebben op de berekende concentraties en bleek er zelfs bij 15 toepassingen per jaar geen noemenswaardige accumulatie van concentraties op te treden (conform de verwachting gezien de korte verblijftijd van het water in de sloot).

De ontwikkelde methodiek gaat uit van spuitdrift als de enige blootstellingsroute. Dit was gebaseerd op de aanname dat spuitdrift bij zij- en opwaartse bespuitingen in de Nederlandse fruitteelt hoger ligt dan bij neerwaartse bespuitingen in de akkerbouw. Het bleek echter dat de spuitdrift depositie voor DRT99 bij bespuitingen in een volgroeid gewas lager uitkomt dan 0.1% (bij een gewasvrije bufferzone van 9 m zelfs beneden 0,03%). Eerder onderzoek heeft aangetoond dat de bijdragen van uitspoeling uit drainpijpen en van atmosferische depositie na vervluchtiging bij zo’n lage drift depositie hoger kunnen zijn dan die van de drift. Blootstelling via uitspoeling uit drainpijpen kan relatief eenvoudig worden toegevoegd (gebruikmakend van dezelfde aanpak als eerder gevolgd voor neerwaartse bespuitingen in de akkerbouw). Dit ligt moeilijker wat betreft atmosferische depositie; dit zal een aanzienlijke onderzoeksinspanning vergen.

De ontwikkelde methodiek gaat uit van de huidige gebruiksvoorschriften. Deze specificeren de concentratie geformuleerd product in de spuitoplossing en een maximale hoeveelheid geformuleerd product per oppervlak van het behandelde veld. Wij bevelen aan om de mogelijkheid te onderzoeken om in het gebruiksvoorschrift de dosering te baseren op het ‘blad-muur oppervlak’; dit is gedefinieerd als tweemaal de afstand tussen de onderste en bovenste bladeren van de fruitboom vermenigvuldigd met de totale lengte van de rijen van de bomen op één hectare (tweemaal omdat de boom twee kanten heeft). Deze aanpak heeft de potentie om het totale gewasbeschermingsmiddelverbruik in de Nederlandse fruitteelt met ongeveer een factor twee te verlagen met behoud van effectiviteit; dit leidt uiteraard tot een vergelijkbare verlaging van de emissies. Indien wordt overgegaan tot deze aanpak, dan kan met relatief geringe inspanning een frequentieverdeling geschat worden van de toegediende hoeveelheid per oppervlak van het behandelde veld. Vermoedelijk leidt gebruik van deze frequentieverdeling (i.p.v. de maximale hoeveelheid) tot een verlaging van de PEC90 van 10-25%.

1 Introduction

1.1 Background

Around 2007 the Dutch government initiated a considerable amount of activities to improve the Dutch pesticide risk assessment for aquatic organisms. A series of workgroups were started dealing with the effect assessment, the handling of multi-stress, emissions from soilless and soil bound covered crops and interpretation of monitoring results for regulatory use.

Then also a workgroup was started to revise the Dutch exposure assessment of aquatic organisms. The current Dutch exposure assessment is based on spray drift only and this was considered inappropriate after the development of the FOCUS surface water scenarios 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). So the focus was on including drainpipes (runoff may be included at a later stage). Between 2007 and 2012 an exposure assessment procedure for downward spraying in field crops was developed which resulted in a series of reports (Tiktak et al., 2012a, 2012b; Van de Zande et al., 2012) and a β-version of the DRAINBOW software package. Between 2013 and now, an exposure assessment procedure for sideways and upward spraying in fruit crops was developed.

After the finalisation of the procedure for downward spraying in field crops, two weaknesses in the approach were discovered: (i) ditches that fall temporarily dry were included in the spatial population of water bodies and this is considered inappropriate now because EFSA (2013a) indicated that the current effect assessment is valid for permanent water bodies only; (ii) the spatial population of water bodies was limited to ditches that receive both input from spray drift and drainpipes based on the assumption that these ditches would have higher exposure concentrations than ditches that receive input from either spray drift or drainpipes whereas Van de Zande et al. (2012) have shown that this assumption may be incorrect.

As follows from the above, the aim of the work was to develop an exposure assessment for sideways and upward spraying in fruit crops, taking into consideration the lessons learned from the work on downward spraying in field crops. The developed exposure assessment methodology is summarized in this document. Details on different aspects of the methodology can be found in Holterman et al. (2016, 2018a, 2018b), Wipfler et al. (2018) and Van de Zande et al. (2018). Furthermore this report contains results of a number of example calculations.

As will be explained in Section 2.1, the development of the methodology is not yet finished because of complications related to the inclusion of leaching from drainpipes. So this report should be considered as an interim-report. An earlier draft of this interim-report was discussed in a workshop on 22/23 May 2017 in which this work was presented to experts from industry, consultants and research institutes. Their feedback and suggestions for improvement were considered in this final version of this interim-report and will be further considered in the finalisation phase of this methodology.

1.2 The exposure assessment goal

As described by EFSA (2010a), regulatory exposure assessments for plant protection products have to be based on well-defined exposure assessment goals. Definition of such goals includes the following elements (Boesten, 2017): (i) the Ecotoxicologically Relevant type of Concentration (ERC), (ii) the temporal dimension of this type of concentration, (iii) the type of spatial unit (acronym SU), (iv) the spatial dimension of this type of spatial unit, (v) the spatial population of spatial units (acronym

SPSU[1]), (vi) the multi-year temporal population of concentrations (acronym TPC), (vii) the percentile to be taken from the spatio-temporal population of concentrations (acronym STPC). The ERC was defined as the concentration of freely dissolved chemical. Its temporal dimension includes different options, such as the annual maximum concentration and the annual maximum of a time-weighted average concentration (see EFSA, 2013a, p. 109-120 for more details). The type of SU was defined as a ditch. Its spatial dimension was defined by specifying that (i) it carries permanently water and has a maximum width of the water surface of 6 m, (ii) the full width of the ditch is considered, (iii) the effect assessment applies to a ditch of a length of 100 m, and (iv) the average concentration over this 100 m is used for the effect assessment. The SPSU was defined as all units adjacent to Dutch orchards sprayed with this pesticide (which has the consequence that also units receiving no pesticide input are included in the SPSU). The TPC was defined as the ERC values of all years of a certain spatial unit (non-controversial because fruit crops are permanent crops). The percentile to be taken from the STPC was an overall 90th percentile, without further restrictions in the space-time domain (as recommended by EFSA, 2013a). See Figure 1 for a schematic overview of these seven elements of the exposure assessment goal together with the selected descriptions of these elements.

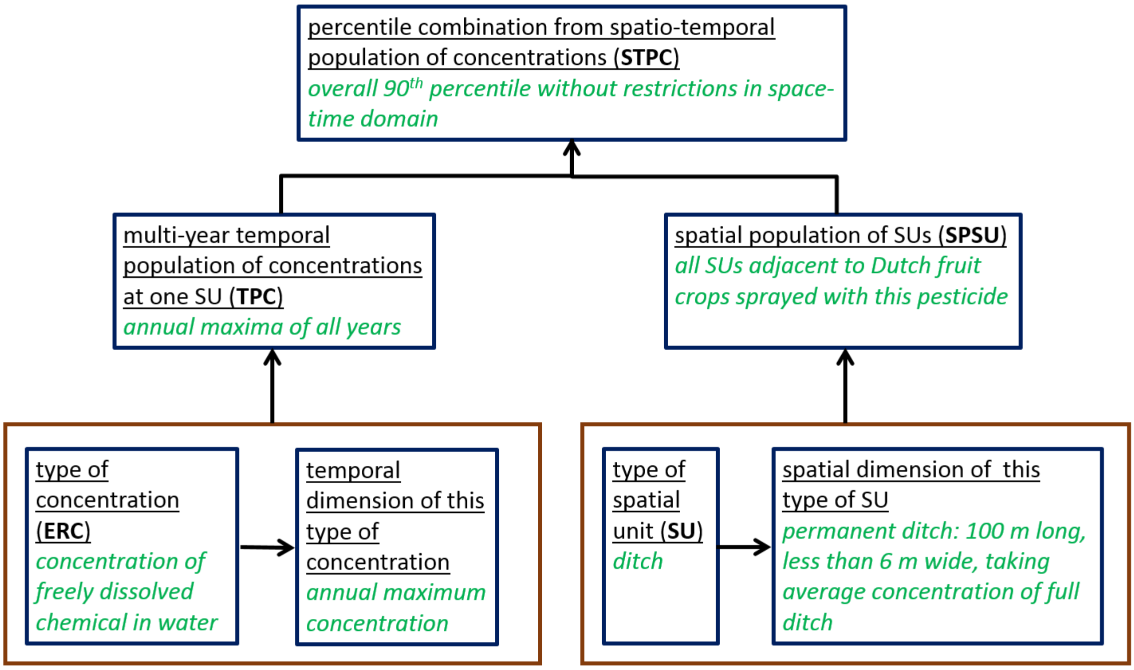

Figure 1 *Schematic overview of the dependencies between the seven elements of the definition of the exposure assessment goal, including the description of these elements. The seven elements are underlined and their descriptions are in italic.*

Although the temporal dimension includes different options, the scenario selection procedure as presented in this work was based only on the annual maximum concentration, i.e. the same approach as followed for the scenario for downward spraying in field crops; see Tiktak et al. (2012a, p. 17) for detailed considerations on this aspect.

[1] See p. 48 for a list of the abbreviations.

2 Early considerations

2.1 The role of other exposure routes

The scenario for downward spraying in field crops (further abbreviated to "*d-fi* scenario") included emission from drainpipes using an approach based on (i) simulations with GeoPEARL for a range of substances considering all ditches adjacent to field crops (including the temporarily dry ditches) and on (ii) a scenario parameterised for the 'Andelst' location. These simulations showed that about the 60^{th} percentile in time at the 'Andelst' location corresponded well (Tiktak et al., 2012b) with the desired overall 90^{th} percentile. The parameterisation of the emission from drainpipes at this 'Andelst' location was based on an extensive field experiment (Scorza et al., 2005). The drainpipes appeared to contribute significantly to the exposure concentrations in the *d-fi* scenario (Tiktak et al, 2012a).

The workgroup proposed in 2013 to the responsible ministries to use also this Andelst drainpipe scenario as part of the scenario for sideways and upward spraying in fruit crops (called "*su-fr* scenario") as a quick solution based on the assumptions (i) that the contribution from spray drift would be much larger for *su-fr* than for *d-fi* and (ii) that the Andelst scenario would be conservative for *su-fr* because fruit crops would be predominantly grown on soils with a lower clay content than Andelst which has about 30% clay (the clay content is the most important factor driving the preferential flow in GeoPEARL). In 2015, it was decided not to include the drainpipe at all, based on the assumption that spray drift would dominate anyhow (with the caveats that in parallel supporting calculations should be done on the drainpipe contribution based on fruit-crop pixels of GeoPEARL and on the spray-drift contribution based on DRT99, i.e. Drift-Reducing Technology with 99% reduction). Thus, the exposure assessment methodology described in the chapters 3 and 4 considers only spray drift. Recently, we discovered that the drainpipe contribution cannot be ignored (see Section 5.1). Therefore, in chapter 5 an approach for the drainpipe contribution is proposed which is similar to the one followed by Tiktak et al. (2012b).

Tiktak et al. (2012a) included atmospheric deposition in the *d-fi* scenario by using conservative default values for this deposition based on the vapour pressure of the substance as recommended by FOCUS (2008). Example calculations for four substances showed that atmospheric deposition was the main exposure route for one of these substances for DRT95 (see their Figure 64 on p. 103). The difference in the level of sophistication between spray drift and drainpipe leaching on the one hand and atmospheric deposition on the other hand in the approach by Tiktak et al. (2012a) is enormous. We considered it difficult to justify to combine a very sophisticated probabilistic approach for spray drift with a simplistic conservative approach for atmospheric deposition. The possible contribution of atmospheric deposition is discussed in Chapter 6.

2.2 Handling of spray-drift emission reduction measures

Reduction of spray drift by special application techniques or introduction of a crop-free buffer zone is an essential element of the regulatory exposure assessment. The assessment is based on the so-called drift-reduction matrix shown in Figure 2. So a farmer or company can choose between combinations of a certain DRT class and a crop-free buffer zone. The crop-free zone is defined as the distance between the centre of the last tree row and the top of the ditch bank; its agronomic minimum is 3 m (which thus corresponds with a zero buffer width). For sideways and upward spraying in Dutch fruit crops, DRT75 and DRT90 are the minimum spray-drift reduction techniques (DRT75 only for a crop-free zone of at least 4.5 m) whereas DRT95 is quite usual (some 40% of the applications) and DRT97.5 and DRT99 are less common. So it was a boundary condition within the development of the exposure assessment that at the end the user/notifier should be able to select any of the options shown in Figure 2.

Crop-free buffer zone (m)	0	1	2	3	4	5	6	7	8	9
Crop-free zone (m)	3	4	5	6	7	8	9	10	11	12
DRT75										
DRT90										
DRT95										
DRT97.5										
DRT99										

Figure 2 *The drift-reduction matrix consisting of rows for the DRT-options and of columns for the options for the widths of the crop-free zones. The empty cells are all possible combinations. The grey cells indicate combinations that are considered unacceptable by the Dutch government.*

2.3 Assessment of the dosage

The exposure assessment procedure as developed here is based on application rates in terms of mass of active ingredient applied per surface area of the treated field (so in kg/ha). The label of a pesticide registered for application in Dutch fruit crops specifies for emulsifiable concentrate (EC) formulations the mass fraction (in %) or the volume fraction (in % or in mL/100 L) of the formulated product in the spray solution. For wettable powder formulations the label specifies the mass of formulated product to be applied in 100 L spray solution. Newer labels (from about 2015 onwards) specify additionally the maximum application rate in terms of mass of formulated product per surface area of treated field (kg/ha). The Ctgb bases the application rate used in the exposure assessment on the maximum application rate as specified on these newer labels. For the older labels the Ctgb calculates this application rate assuming that 1500 L spray solution is applied per hectare which is assumed to be the maximum volume of spray solution in practice (https://english.ctgb.nl/plant-protection/documents/assessment-framework-ppp/2016/10/28/8.-appendices-spray-volume-list-v2.0-in-english-em2.1). In practice, the actual volume of spray solution is 150-300 L/ha for apples, pears and cherries and 200-500 L/ha for smaller fruit crops like berries.

It may happen in practice that a fruit grower sprays less than 1500 L/ha but applies nevertheless the maximum application rate (kg/ha) either based on the 1500 L/ha for the older labels or based on the maximum rate as specified on the label for the newer labels (personal communication H. Brouwer & C. van Griethuijsen, 2016). For the exposure assessment as developed here this does not matter because this is based on the maximum application rate, irrespective of the volume of spray solution that is applied per hectare.

Already for many years it has been suggested to change the dose expressions on the label for fruit crops into a dose expression that is based on the area of the tree leaf canopy and the row spacing instead of the area of the treated field because the leaves are the target for the pest control (Toews et al., 2016). EPPO (2012) developed the Leaf Wall Area (LWA) parameter. The LWA is defined as the surface area of 'leaf wall' per surface area of treated field (m^2/ha). The LWA is commonly calculated as:

$$LWA = 2\, h\, r \quad \text{Equation 1}$$

where h is the height (m) of the treated canopy defined as the average distance from the highest leaf to the lowest leaf of a tree and where r (m/ha) is the total length of the tree rows per surface area of treated field. This r is calculated by dividing the surface area of the treated field (10 000 m^2 because of the 'ha' in the unit of *r*) by the distance between the tree rows in m; so e.g. a distance of 3 m gives *r* = 3333 m/ha. The factor 2 in the equation is needed because each tree has two sides.

The dose in this LWA-concept is defined as the mass of formulated product applied per surface area of treated field (so in kg/ha) for a reference LWA value of 10 000 m^2/ha. The actual mass applied per surface area treated field is then proportional to the actual LWA. So in this concept the mass applied per surface area treated field is adapted to the distance between the rows and height of the leaf canopy. EPPO supports this trajectory and recommends to use this LWA-based dose approach for plant protection products in pome fruit, grapevine and high growing vegetables (EPPO, 2016). This LWA-based dose approach has thus the large advantage that a lower dose can be used if the LWA is lower than the maximum value. See Van de Zande et al. (2018) for a more detailed discussion on the LWA-concept.

The maximum LWA in Dutch fruit crops is about 24 000 m^2/ha whereas a median LWA is likely to be about 12 000 m^2/ha. So in principle switching to the LWA-based approach could lead to reduction of the total use of plant protection products in Dutch fruit crops by something like a factor 2. This would of course also decrease the total drift deposition onto the ditches by this factor. Therefore we recommend to explore the possibilities for switching to LWA-based label instructions in Dutch fruit crops.

2.4 Estimation of the application times

The date of application may in principle have a large effect on the outcome of the exposure assessment. Tiktak et al. (2012a) proposed user-specified application dates for the *d-fi* scenario. For Dutch fruit crops, the label specifies usually the crop stage in terms of the BBCH. We considered it therefore more appropriate to base the application date on the BBCH (or the BBCH range). This has the advantage that possible controversies between notifier and Ctgb on this aspect are avoided. The consequence is that the exposure assessment methodology has to include the relationship between the BBCH and the calendar dates. Further details on this relationship are described in Annex 1. Furthermore, rules had to be defined for labels that specify repeated applications (see also Annex 1).

We propose to use the same relationship between BBCH and calendar date for all simulation years in the scenario. This relationship is based on data for apples between 1999 and 2010 (see Table 11 of Van de Zande et al., 2018). In principle it would be more accurate to include a course of time of the BBCH that depends on e.g. a temperature sum (so faster crop development in warmer years). However (as will be described later) the spray drift deposition depends of course also strongly on crop development (much more drift for bare trees than trees covered with leaves) and this crop development is also characterised in terms of the BBCH. Thus the possible errors resulting from the fixed relationship between BBCH and calendar date are likely to be small.

2.5 Spraying schemes

Apples and pears are by far the most abundant fruit crops in the Netherlands (about 8000 ha apples and 9000 ha pears, together covering 85% of the surface area of Dutch fruit crops in 2016). The typical application schemes for apple and pear in the Netherlands (Figure 3) show that (i) most pesticides are applied once per year, (ii) a few pesticides are applied 2-3 times and (iii) captan is applied 14-15 times. This is relevant for the scenario selection procedure because the ERC has been defined as the annual maximum concentration. Thus the probability density function of the ERC for e.g. 15 applications may differ strongly from the probability density function of the ERC for 1 application. This is further explained in the next sections.

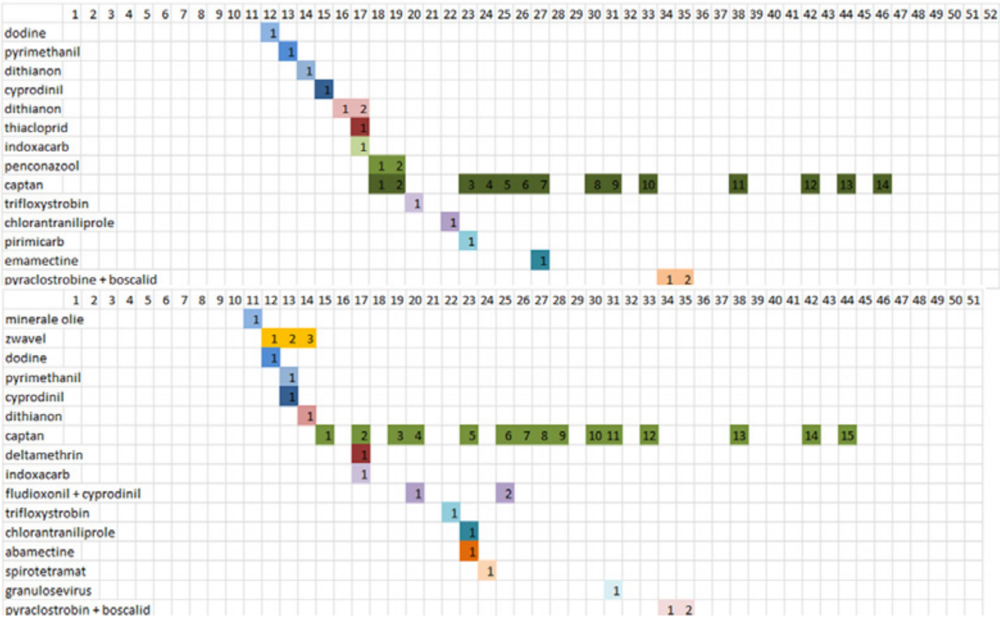

Figure 3 *Typical application schemes for apple (top) and pear (bottom) in the Netherlands. The columns are week numbers and each coloured cell is an application.*

3 Modelling of spray-drift deposition

3.1 Overview of role of spray-drift deposition in the exposure assessment

Based on the exposure assessment goal, the aim is to select a time-location combination from the STPC that gives the 90th percentile. Given the choices described above, the best approach would be to build a spatially-distributed model for exposure in surface water based on TOXSWA and a probabilistic spray-drift model for different DRT-techniques and different distances of the crop-free buffer zone (so following an approach similar to GeoPEARL). However, this would require parameterisation of TOXSWA and this spray-drift model for hundreds of locations. This is not yet feasible. Therefore a more pragmatic approach was adopted similar to that for the *d-fi* scenario (Van de Zande et al., 2012).

This approach consisted of the following steps:
development of a sophisticated local spray-drift deposition model based on a combination of physical concepts and empirical data (section 3.2)
combination of this model with a very simple metamodel of TOXSWA for linking spray-drift depositions to concentrations (section 3.3)
development of a spatially distributed probabilistic model for exposure concentrations based on spray-drift input only, using all relevant Dutch GIS information currently available and based on the combination of this local spray-drift model and the TOXSWA metamodel (section 3.4.1)
simulations with this spatially distributed model to generate a STPC that can be used to select a single ditch-orchard combination which can generate the desired 90th percentile of this STPC (section 3.4.2)
more detailed simulations with this model to assess the TPC for this single ditch-orchard system (section 3.4.2)
assessment of the percentile of this TPC that corresponds with the 90th percentile of the STPC (section 3.4.2), which is called 'the required temporal percentile' in the last step of this list
using the TPC to generate time series of spray-drift depositions to be used for multi-year simulations with TOXSWA (section 3.4.2)
parameterisation of TOXSWA for this single ditch-orchard system for a time series of 26 years, of which 6 years are warming up years (section 3.5)
using this TOXSWA scenario for this ditch-orchard system to extract the required temporal percentile from the 20-year time course of concentrations in surface water (section 3.5).

In the next sections the main elements of this approach are briefly described.

3.2 The local model for spray-drift deposition

The model is described in detail by Holterman et al. (2016, 2018a). Spray drift is modelled as an exponential decay function of the distance between the last tree row and the ditch. The spray drift is a function of:
wind speed
air temperature
orchard size and canopy density (so crop development, described in terms of the BBCH)
sprayer fan speed
wind direction
drift reduction technique (DRT class).

The model was parameterised based on measurements of 316 deposition-distance curves (5456 deposit values) for apples in the Netherlands (Van de Zande et al., 2018).

Figure 4 illustrates the effect of the DRT class on the deposition in the model.

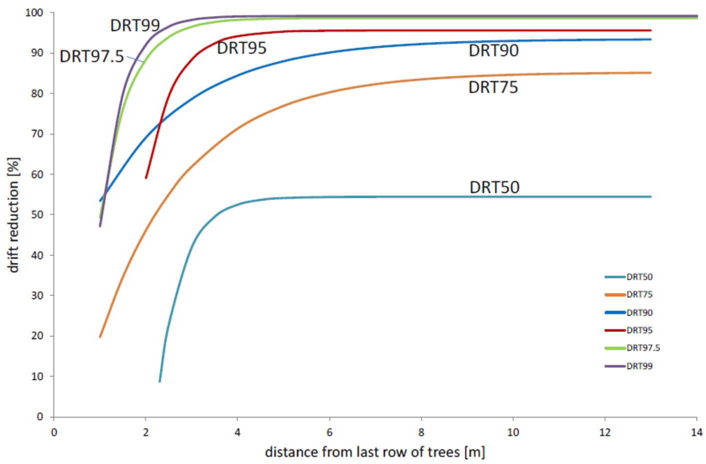

Figure 4 *Effect of drift-reducing technology class on the relationship between drift reduction and distance from the last row of trees (for trees with fully developed leaves).*

3.3 The TOXSWA metamodel for spray-drift input

Exposure concentrations in the ditch (PECs) were derived from the spray-drift deposition with a metamodel of TOXSWA which was based on the assumption that the increase in the concentration by a spray-drift event is simply the spray-drift deposition divided by the average water depth of the ditch. As described in Section 1.2, the ERC is the annual maximum concentration. In case of repeated applications within one calendar year, the metamodel has two extreme options: (1) a decline that is so fast that the concentration just before the next application is zero again and (2) no decline at all, which has the consequence that the concentrations of the different spray-drift events sum up (see Figure 5).

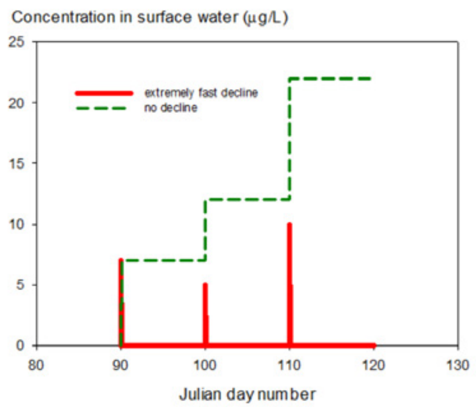

Figure 5 *Concentration in surface water as a function of time as calculated with the TOXSWA metamodel considering three spray-drift events that increase the concentration by 7, 5 and 10 µg/L. The solid line is the concentration based on the assumption of extremely fast decline and the dashed line is based on no decline between the applications.*

3.4 Geographically distributed spray-drift model to assess the STPC

3.4.1 Geographical aspects of the modelling approach

The following databases formed the basis of the geographically distributed spray-drift model:
spatial database of Dutch ditches based on the TOP10 vector map of water courses in the Netherlands, consisting of 66 different 'hydrotypes' including a description of their geometry (e.g. water depth in winter); see Massop et al. (2006)
spatial database of differences in water depth of the ditches between winter and summer (divided into 9 classes)
frequency distributions of the N-E-S-W orientation of the tree rows of fruit crops (divided into 18 classes) for different meteo districts in the Netherlands
hourly 20-year time series of meteorological data of 14 Dutch weather stations (wind speed, wind direction, air temperature, relative air humidity)
the LGN land use map indicating the areas where fruit crops are grown with a resolution of 25×25 m.

The ditches adjacent to fruit crops were determined using the TOP10 vector map of water courses in the Netherlands combined with the LGN land use map based on the criterion that the distance between the water course and the field with the fruit crop (orchard) should be less than 10 m.

The Netherlands were divided into 14 meteo districts. From the data on wind speed and wind direction frequency distributions were made for each district. Only daytime values of wind speed and wind direction were included in the population because spraying during the night is unlikely; wind speeds above 5 m were not included either because spraying at such wind speeds is no good agricultural practice. The simulations were based on these frequency distributions, so the 20-year time series were not used as such.

The lengths of the different ditch hydrotypes adjacent to fruit crops were calculated for each district. Only the so-called primary and secondary ditches were considered; the so-called tertiary ditches were excluded because most of them do not carry permanently water. So only 44 of the in total 66 different hydrotypes were included. The length of each hydrotype was divided into four equal pieces which each corresponded with one side of the orchard (see Figure 6). The spray-drift deposition for these four types of orientation differed: for ditch types 2 and 4 the standard minimum crop free zone of 3 m was used and for ditch types 1 and 3 this zone was set at 6 m (to mimic the procedure that the farmer turns his tractor and spraying machinery at the end of each tree row).

So there were 14 districts, 18 classes of orientation of the tree rows, 44 hydrotypes, 9 classes of differences between winter and summer water level, and 4 types of ditch orientations. This gives 14 × 18 × 44 × 9 × 4 = 399 168 combinations. However, most of these combinations do not occur, and we ended up with some 70,000 combinations, so these are our spatial units (SUs). Simulations were made for 100 'stochastic years' for each SU to achieve sufficient accuracy.

Thus the geographically distributed spray-drift model simulates the concentration in all ditches adjacent to fruit crops for the entire area of the Netherlands using some 70,000 SUs and 100 'stochastic years'.

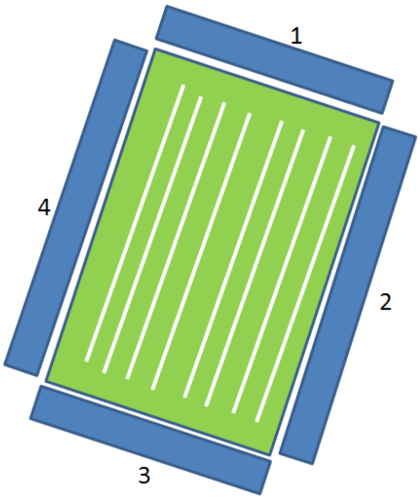

Figure 6 *Schematic representation of the distribution of the ditches over the four sides of the orchard. The line segments indicate the direction of the tree rows. It is assumed that all sides have equal length so it would have been more appropriate to represent the orchard as a square instead of a rectangle.*

3.4.2 Simulation procedure

The intention of the methodology was to have one single ditch-orchard scenario that can be run for any substance and any application scheme. It is impossible to perform calculations of the STPC for all possible combinations of application times (see Figure 3). So it was decided to calculate STPCs for 1, 3 or 15 applications per year. For the 1 and 3 applications, both 'early' and 'late' applications were simulated (see Table 1 for the application dates).

During the development of the exposure assessment methodology, it became clear that the residence times of water in the ditch of the selected scenario are so short that significant accumulation of concentrations due to repeated applications is unlikely to occur (see Section 4.3). Therefore the STPCs were calculated only for the fast-decline option in the metamodel (in fact STPCs for the no-decline option are available but will not be reported). Thus there remain five options for calculating the STPC as shown in Table 1 (E1-L1-E3f-L3f-S15f) and these will be further called 'the basic application schemes'.

The scenario selection procedure consisted of two steps. The first step was to generate cumulative frequency distributions (abbreviated '*cfd*') of the STPC for (i) each of the basic application schemes E1-L1-E3f-L3f-S15f, (ii) each of the DRT classes (conventional-50-75-90-95-97½-99), and (iii) each of the widths of the crop-free buffer zones (0-9 m), so 5×7×10= 350 *cfd*-curves (later it appeared that the conventional, 50 and 75 DRT classes were not relevant anymore and then these distributions were discarded). The exposure assessment goal for each combination of basic application scheme, DRT class and width of the buffer zone (further called "*bas-DRT-w* combination") was the 90th percentile concentration derived from the STPC.

Table 1 *Overview of the basic application schemes and their characteristics. The 'f' in the acronym stands for 'fast', indicating that the concentration was calculated assuming fast dissipation between the application dates, so assuming no accumulation.*

acronym of application scheme	E1	L1	E3f	L3f	S15f
number of applications	1	1	3	3	15
application season	early	late	early	late	full season
application dates in simulations for full spatio-temporal population of concentrations	4 May	29 Aug.	4 May 11 May 18 May	29 Aug. 5 Sept. 12 Sept.	17 June 24 June …. 16 Sept. 23 Sept.
ranges of week numbers represented by basic application schemes	1-22 45-52	23-44	1-22 45-52	23-44	

Figure 7 shows the *cfd* curves for all basic application schemes in combination with a zero buffer zone and DRT90 as an example. The curves for E1 and L1 have about 50% zero values caused by wind directions from the field to the ditch during spraying. Curve E1 shows higher PEC values than curve L1 as expected because spray drift when spraying bare trees is higher than spray drift when spraying onto trees in full leaves. The lines for three applications (E3f and L3f) show about 15% zero values; this is understandable because the likelihood that three applications give zero values is about 0.5^3 = 0.125, so 12.5%. In case of the 15 applications it is of course extremely unlikely that the maximum of the 15 drift events is zero and it is understandable that the shape of the *cfd* curve approaches the shape of a normal distribution.

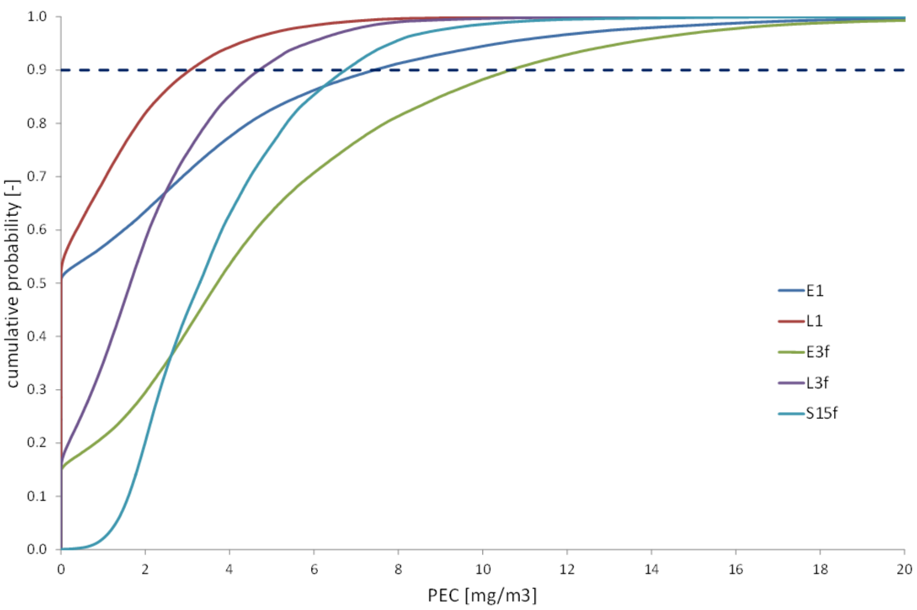

Figure 7 *The cfd curves of the STPC of all five basic application schemes as indicated for DRT90 and a zero buffer zone.*

The aim was to have at the end one single SU that could form the basis for exposure calculations for all these *bas-DRT-w* combinations. Each combination will have its own time percentile at this one SU corresponding with the overall 90th percentile PEC of this combination. To achieve this goal, all time-space combinations that were in the range between the 87th and 93rd percentile for each *bas-DRT-w* combination were combined and a suitable single SU was selected. As a final step, TOXSWA was fully parameterised for this SU. Because the scenario calculations at the end will be for a limited number of years, it was the intention to select a SU with preferably a time percentile close to the median. The background of this is that the error in the estimated median from a limited sample population is smaller than the error in an extremer percentile (e.g. the 80th).

The selected SU (used for all *bas-DRT-w* combinations) had the following properties:
ditch with hydrotype “Betuwe stroomruggrond” (secondary ditch, code 601002), a water level of 30 cm both in winter (October to March) and in summer (April to September), a width of the water surface of 234 cm and a width of the bottom of the ditch of 174 cm.
ditch at the east side of the orchard (parallel to the direction of the trees).
direction of the tree rows was 20° to the west of the north direction (degrees based on 360° for full north-east-south-west circle, see Figure 8).
meteo district Herwijnen in the hydrological district Rivierenland.

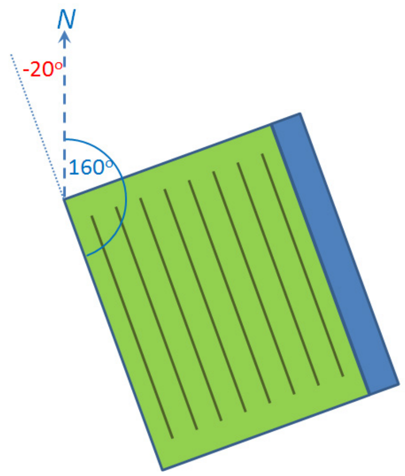

Figure 8 *Orientation of selected SU. The green part is the orchard and the blue part is the ditch. The line segments indicate the direction of the tree rows.*

The second step of the simulations was as follows. For each of the 350 *bas-DRT-w* combinations, stochastic simulations were carried out for this selected SU for 10 000 stochastic years, thus generating a TPC for this system.

Figure 9 shows as an example the *cfd* curves of the TPCs for DRT90 and a zero buffer zone. Now the curves for E1 and L1 show some 37% zero values, so less than 50%. This is the consequence of the orientation of the selected ditch (Figure 8) which is more orientated downwind of the dominant SW wind direction in the Netherlands. The curves for E1 and L1 are approximately straight lines, which indicates that these distributions are approximately uniform. The shape of the curve for S15f is now close to a normal distribution.

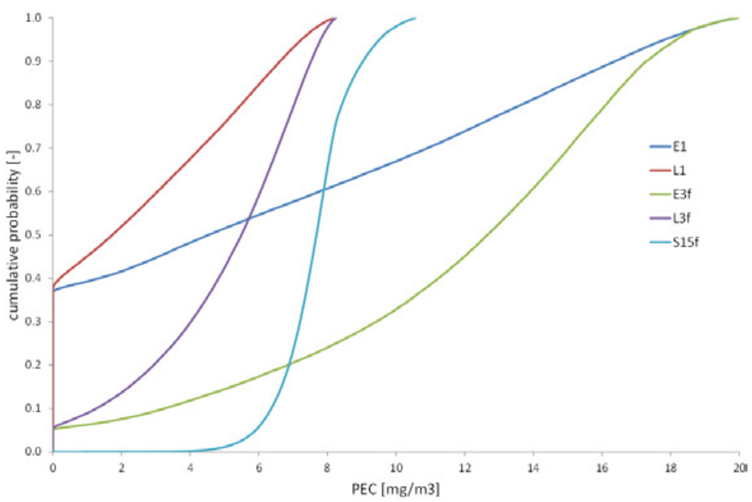

Figure 9 *The cfd curves of the TPC of all five basic application schemes as indicated for DRT90 and a zero buffer zone.*

Thus we have a *cfd* of the STPC and a *cfd* of the TPC of the selected SU for all these 350 *bas-DRT-w* combinations. These were used to derive the required temporal percentile of the selected SU corresponding with the overall 90th percentile from the STPC. This was done as shown in Figure 10: from the STPC the concentration was derived which corresponds with the overall 90th percentile ("P90" in the figure) and this was used to determine the corresponding temporal percentile of the TPC ("T90" in the figure). Thus for each basic scenario we now know the required temporal percentile that will give the overall 90th percentile.

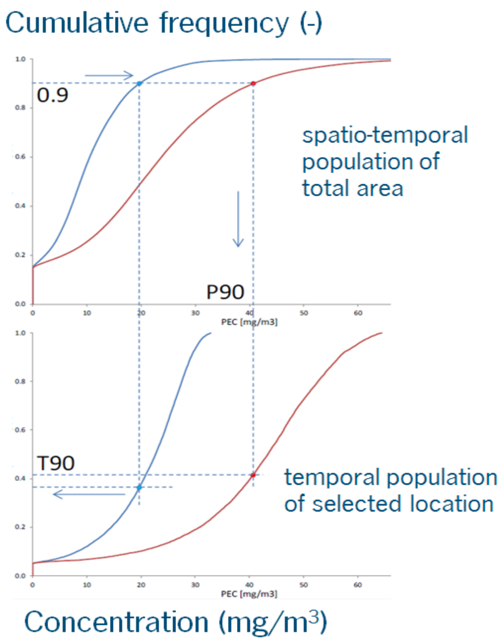

Figure 10 *Illustration of procedure to estimate the time percentile of the exposure concentration from the combination of the cumulative frequency distributions of (i) the STPC and (ii) the local TPC. The red and blue lines are populations for two different bas-DRT-w combinations.*

3.5 Use of the STPC and the TPC to parameterise the exposure scenario

It appeared that there were considerable differences between the *cfd*s of the TPC as a function of the week number; this is understandable in view of the large differences between the E and the L scenarios in Figure 9. Therefore for the parameterisation of the spray drift, *cfd*s of the TPC were calculated for weekly intervals (see Table 1 for the ranges of the week numbers linked to the different basic application schemes). These weekly *cfd*s of the TPC were used as the basis for the spray-drift input to TOXSWA as described below. However, STPCs were available only for the basic application schemes. So the temporal percentile that was used as the endpoint, was based on its corresponding basic scenario and was assumed to be constant for the range of week numbers shown in Table 1. The temporal percentiles for the different combinations of scenarios, DRT classes and crop-free buffer zones ranged between 10 and 70% but were mostly between 40 and 60% (Figure 11).

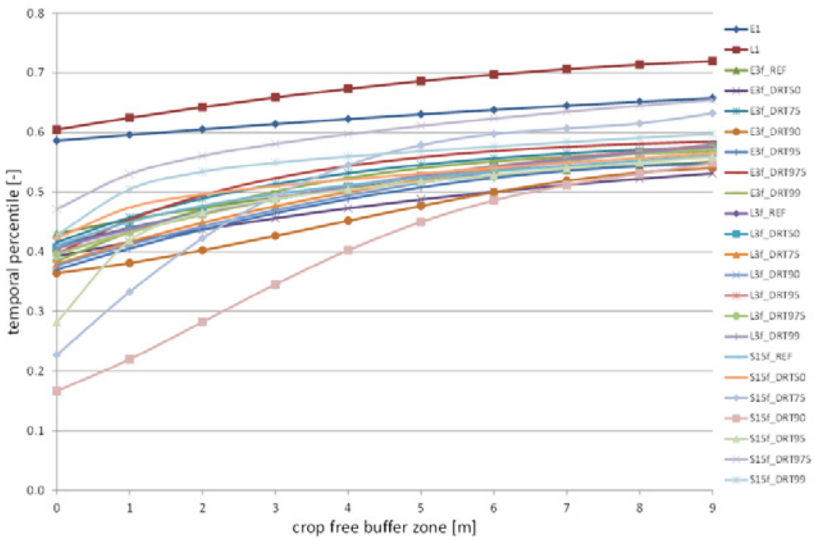

Figure 11 *Temporal percentile for the selected spatial unit (SU) corresponding to an overall 90th percentile as a function of the width of the crop-free buffer zone. The 23 lines shown are for the different combinations of application schemes (L1, E1, L3, E3, S15) and DRT classes (0-50-75-90-97½-99).*

So for each exposure assessment, we have now the appropriate *cfd* of the TPC and the required temporal percentile. TOXSWA was parameterised for this ditch-orchard system to run for 26 years (1985-2010) of which the first 6 are warming-up years and the last 20 are used for the calculation of the exposure endpoint. TOXSWA cannot use concentrations as input but requires spray-drift deposition values instead. So all concentrations obtained from the TOXSWA metamodel were transferred into spray-drift deposition values using the water depth of 30 cm of the selected combination of hydrotype and water level difference between winter and summer. Next step was to estimate the spray-drift deposition values to be used in the 26-year TOXSWA simulations. For the single applications (basic application schemes E1 and L1) the deposition values of the 20 evaluation years were assumed to be equal to the 2.5th, 7.5th, …, 92.5th and 97.5th percentile of the *cfd* of the TPC using the following equation for the relationship between the percentile and the rank number of a sample population of *N* samples:

$$p_i = 100 \frac{i - \frac{1}{2}}{N} \qquad \text{Equation 2}$$

where p_i is the percentile of rank number *i* (see Appendix 13 of FOCUS, 2009). We tested first the alternative to calculate the spray drift with the local spray drift model using the weather data in the hour of application but this resulted in far too large differences between the sample distribution of these 20 draws and the 'true' TPC. The allocation of the percentiles to the different years was done by an arbitrary more or less random procedure (based on the wind direction in the meteo file on the day of application). The spray-drift depositions of the 6 warming up years were assumed to be equal to the 8.3th, 25th, 41.7th, 58.3th, 75th and 91.7th percentiles of the *cfd* of the TPC, using Equation 1 with N = 6. For the multiple applications a similar (although somewhat more complicated) procedure was used.

So the TOXSWA output consists of 20 annual maximum concentrations. The required temporal percentile (mentioned at the start of this section) is an input parameter for TOXSWA and TOXSWA subsequently selects the exposure concentration from the *cfd* of these 20 concentrations by taking the value closest to the required temporal percentile (using Equation 1).

The above procedure for estimating spray drift based on the 'true' TPC has the advantage that drift is not influenced by the weather conditions at the hour of application. So extreme weather conditions at a certain moment will not have any effect on the drift estimates. This leads to a more robust time series of these annual maximum concentrations in TOXSWA.

As a test of the parameterised spray-drift deposition model for the selected ditch-orchard combination, simulations were made for applications on all calendar days of the year. Results in Figure 12 show that there is a gradual course of the depositions as a function of the application time. The spray-drift deposition is minimal in summer when the trees are in full leaf. One would expect that DRT99 would give a deposition that is ten times smaller than DRT90. This is indeed the case in summer but in winter the difference is about a factor 4-5. Usually, in winter drift reducing techniques are less reducing than in summer. Consequently, the differences between DRT90 and DRT99 are less in winter than in summer.

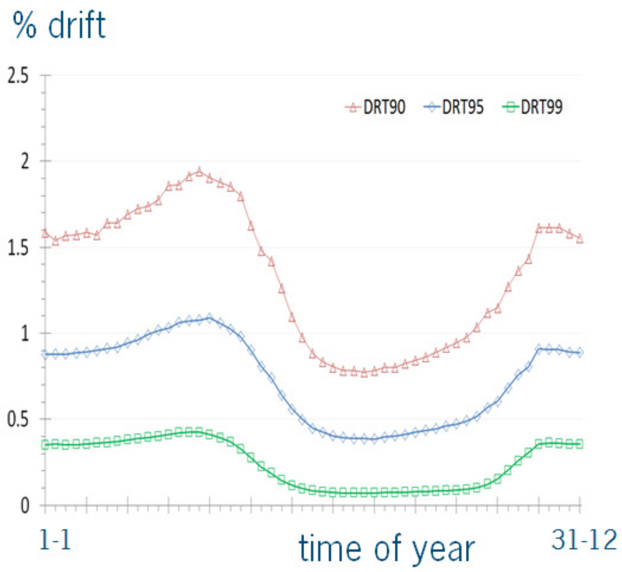

Figure 12 *Spray-drift deposition as a function of application time corresponding with the 90th percentile of the STPC for single applications with zero crop-free buffer zone and DRT90, DRT95 and DRT99 as indicated.*

4 Parameterisation of TOXSWA for the selected scenario

4.1 Position of the ditch in the landscape

Based on geographical data, the distance between the ditches was estimated at 140 m and the length of a ditch parallel to the tree rows of an orchard was estimated at 100 m (rounded numbers; see Wipfler et al., 2018, for details). The total length of the simulated ditch was 300 m of which the middle 100 m was assumed to be treated with pesticide (Figure 13). It was assumed that the water that flew into the ditch from either side contained no pesticide.

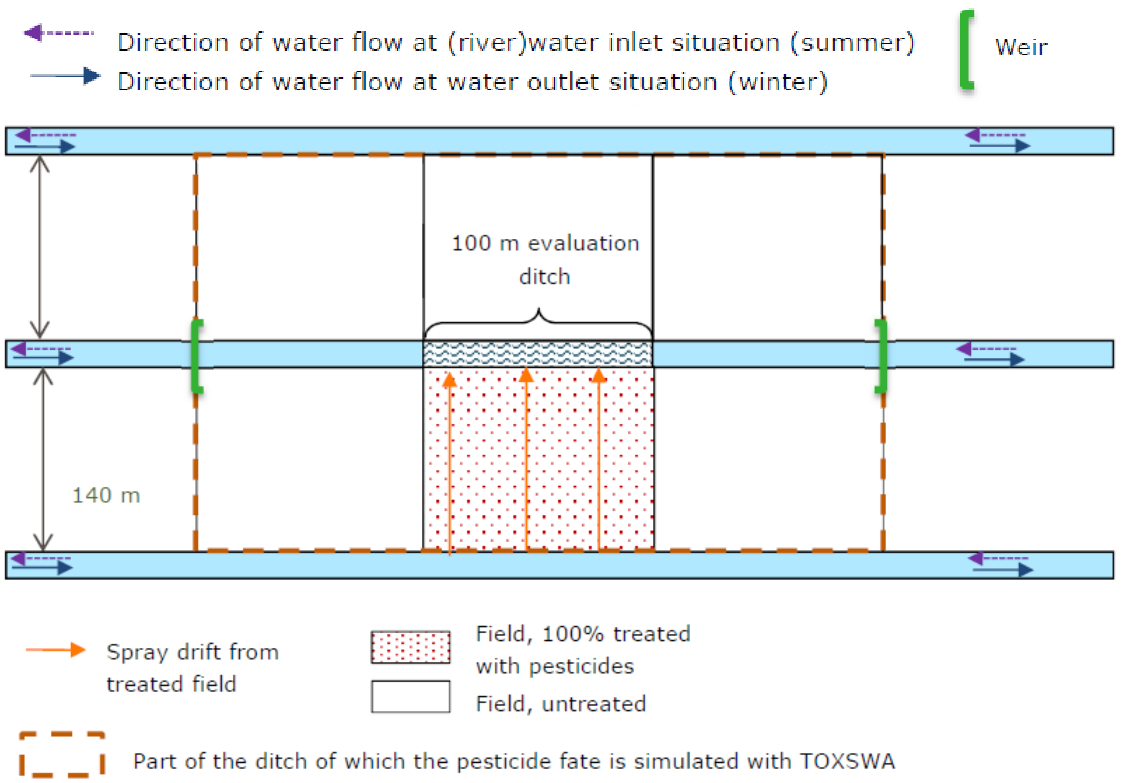

Figure 13 *Schematic representation of the position of the evaluation ditch in the landscape.*

4.2 Parameterisation of the water flow rates

As described above, the scenario selection procedure included the water depth of the ditch. This is the most important hydrological property of the ditch because the maximum concentration occurring after a spray-drift event is inversely proportional to this water depth. However, also the water flow rates in the ditch may have a considerable effect on the annual maximum concentration in case of repeated applications. Therefore considerable attention was payed to the parameterisation of this flow rate. Wipfler et al. (2018) describe this parameterisation in detail, so here only a brief summary is given.

The water flow rate was based on simulations with the Moria 2.2 model (Borren and Hoogewoud, 2014). This is a groundwater model specially developed and calibrated for the Rivierenland area. The model has a resolution of 250 x 250 m and solves per grid cell the daily water balance based on exchange fluxes with adjacent grid cells, incoming precipitation and outgoing evapotranspiration and also the exchange with surface water bodies such as ditches or ponds. The model has been calibrated for the period 01-04-2002 to 01-04-2011; over this period daily groundwater-surface water exchange fluxes are available for five areas within Rivierenland, i.e. the Betuwe-Linge area, the Bommelerwaard, the Lek and Linge area, the Maurikse wetering area and the Tielerwaard.

To obtain flow rates that are as realistic as possible for ditches at the edge of fruit orchards, only grid cells were selected that were located in a unit ('peilvak') that has (1) >15% fruit crops, (2) >50% of secondary water courses (width < 3 m), and (3) "Betuwe stroomruggronden" as the dominant hydrotype. At the end 110 grids remained. From the daily elements of the water balance, a time series of daily water flow rates in the ditch were derived for each unit for the period 2002-2011 using a simple model. These time series was used to feed a direct sampling technique which generated a time series of daily flow rates for the 26-year period needed for the TOXSWA simulations. A typical characteristic of the derived flow velocities is that the flow direction alternates seasonally due to changes in precipitation and water demand.

4.3 Calibration of the hydrological submodel of TOXSWA

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 for the 26-year period (see Wipfler et al., 2018, for details), using the flow rates from the previous section as boundary conditions. The model described the water flow in the 300-m long ditch segment between the two weirs in Figure 13 (these weirs maintain the water depth at the required level, one for each direction of flow). The time course of the water depths was calibrated based on the requirement that both the winter and summer water depth should be 30 cm. It was assumed that the 83rd percentile of the winter water depths should be 30 cm and that the 50th percentile of the summer and winter water depths are equal (these 83rd and 50th percentiles were based on the definitions in the spatial databases mentioned at the start of Section 3.4.1). Resulting water depths in Figure 14 show that the minimum water depth is about 27 cm and that occasionally water depths up to about 40 cm occur. The 50th percentile of the summer and winter water depths was 28 cm.

As described before, it was assumed in the scenario development that the residence time of the water in the ditch was so short that accumulation of concentrations due to repeated applications is unlikely to occur. This is illustrated by the frequency distribution of the monthly average residence times in the period March-June shown in Figure 15 and the frequency distribution of instantaneous residence times for the full calendar years shown in Figure 16. The period March-June was selected for Figure 15 because then most applications occur (Figure 3) and because then residence times are likely to be longer than in winter. Figure 15 gives a median residence time slightly higher than 1 d for the March-June period whereas Figure 16 gives a median residence time of about 0.5 d for the full calendar year, so indeed the residence time for the March-June period is longer than for the remainder of the calendar year.

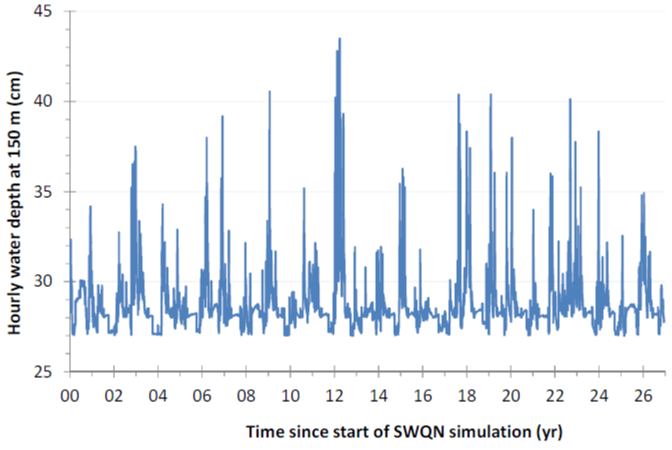

Figure 14 *Simulated water depth as a function of time for the 26-year period. Note that the vertical axis starts at 25 cm.*

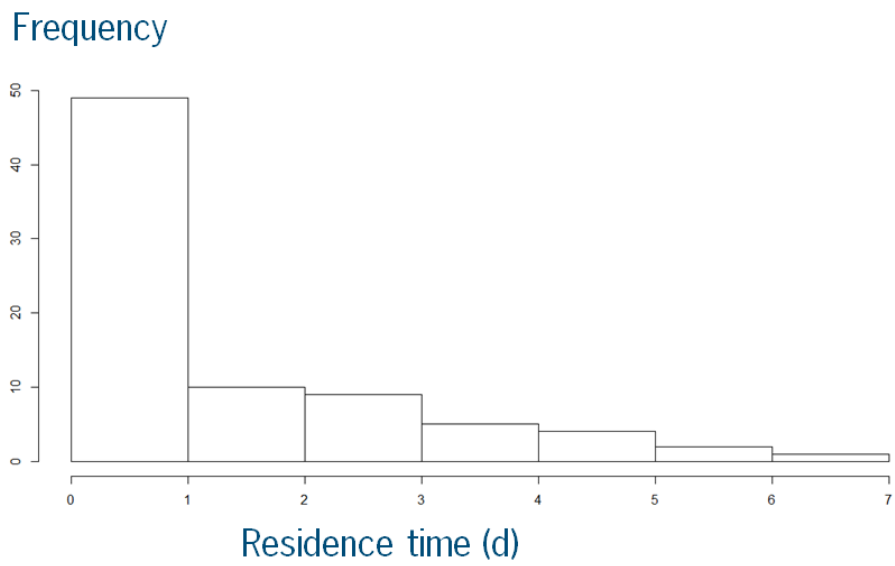

Figure 15 *Frequency of monthly average residence times in the 100-m evaluation ditch for the period March-June in the 20 simulation years used for evaluation.*

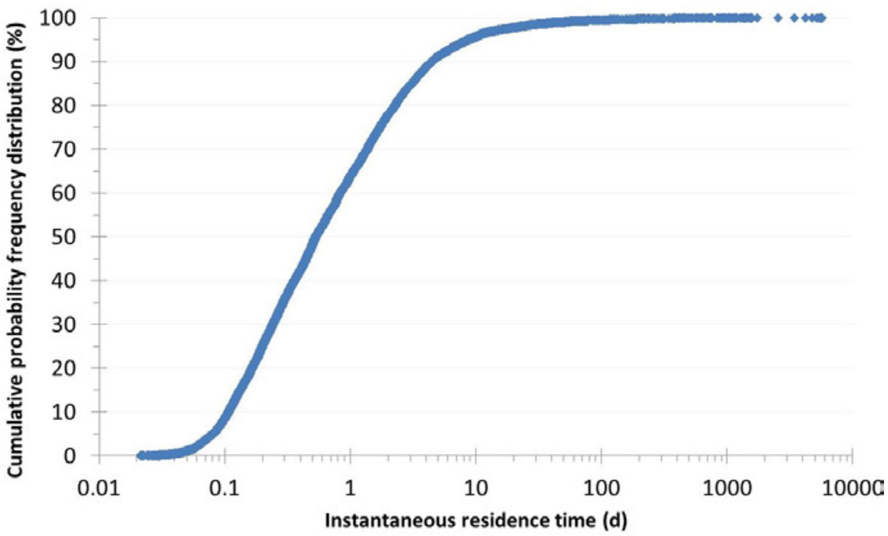

Figure 16 *Cumulative frequency distribution of the residence time in the 100-m evaluation ditch for the 20 simulation years used for evaluation.*

4.4 Estimation of other TOXSWA input parameters

TOXSWA requires as input the properties of the sediment. From the available Dutch measurements of sediment properties, measurements at four locations were selected because of their relevance for Dutch fruit crops. The two locations with the highest and the lowest organic matter content were selected and these were used to assess the sensitivity of the exposure endpoint to the sediment properties (see Wipfler et al., 2018, for details). Results in Table 2 show that the lowest organic matter content (at Willemstad) is somewhat higher than the 9% used in the FOCUS surface water scenarios.

Table 2 *Properties of the sediment from the two selected locations.*

Layer	Organic matter content (%)		Dry bulk density (kg/L)	
	Willemstad	Benschop	Willemstad	Benschop
0-1 cm	12	22	0.32	0.12
1-10 cm	10	24	0.49	0.20

4.5 Results of a few example runs

Runs with a few example substances are shown here to illustrate the procedure to obtain the exposure endpoint. The first example considered here is a threefold application of a very strongly sorbing (K_{OM} = 139 000 L/kg) and very persistent insecticide (I_P). It was applied annually on 29 April, 6 May, 13 May at a rate of 0.0075 kg/ha with a DRT90 spraying technique and 3 m crop free zone. The simulated spray-drift depositions shown in Table 3 are in about half of the 60 cases zero because then the wind direction is from the ditch to the field. In this case, the combination of the *cfd* curves from the STPC and the local TPC (as illustrated in Figure 10) indicated that the desired time percentile was 36. Thus the 36th percentile was calculated from the 20 numbers in the last column of Table 3 and this appeared to be about 49 ng/L.

Table 3 *Spray-drift depositions and resulting annual maximum concentrations as calculated with the spray-drift deposition model and with TOXSWA for three applications of a very strongly sorbing and very persistent insecticide (I_P) using the sediment properties from Benschop.*

Year nr	Drift deposition (% of applied dose) on			Annual maximum concentration in water (ng/L)
	29 April	6 May	13 May	
1	2.3	0.4	4.3	73
2	3.1	4.6	4.3	75
3	0	0	0	0
4	3.8	5.0	0	82
5	0	0.5	0	7
6	0	0	1.1	16
7	3.1	0	0	49
8	0	3.3	0	53
9	0	0	4.5	72
10	5.2	0	0	84
11	2.1	0	0	32
12	2.5	0	0	39
13	4.1	1.6	3.8	60
14	0.6	3.8	0	60
15	5.5	1.6	0	91
16	2.0	0	3.9	63
17	0	4.8	0	78
18	1.6	0	0	25
19	0	3.5	0	56
20	2.8	0	0	43

The second example considers the effect of the sediment properties, using either those of Benschop or of Willemstad (see Table 2). This comparison was carried out again for insecticide I_P. This was considered suitable because of its extremely high sorption. Results in Figure 17 show that the difference between the annual maximum concentrations was no more than about 20-30% whereas the difference between the organic matter content of the top 1 cm was about a factor 2 (Table 2). Further analysis revealed that this difference of 20-30% was caused by the difference in the organic matter content of the suspended solids (which is in TOXSWA equal to that in the top layer of the sediment).

This is illustrated in Figure 18 for a typical simulation year. During the year, the differences between the two curves is surprisingly small. Adriaanse et al. (2013) showed that penetration into the sediment is proportional to the product of the organic-matter content and the dry bulk density. This product is 3.8% kg/L for Willemstad and 2.6% kg/L for Benschop (for the 0-1 cm layer); the ratio of these numbers is about 1.5. So this does not explain the small differences between the curves in Figure 18.

Figure 17 shows furthermore that there is a very close relationship between the annual maximum spray drift and the annual maximum concentration; the background of this is that the maximum concentration in TOXSWA is mainly determined by the quotient of drift and water depth and fluctuations in the water depth are limited (Figure 14*)*. The TOXSWA metamodel as used for the scenario selection assumes that the annual maximum concentration equals the annual maximum drift deposition divided by the water depth of the ditch (see Section 3.3). This water depth is assumed to be constant in time in this metamodel. For the scenario selection procedure it is essential that the ranking of the concentrations generated by the metamodel corresponds well enough with the ranking produced by TOXSWA, i.e. they should show good correlation (see EFSA, 2010b, p.42 and Tiktak et al., 2012b, p. 72 for ranking considerations of other metamodels). Thus the excellent correlation shown in Figure 17 is support for the correctness of the TOXSWA metamodel. In Figure 19 all three applications of each year are considered for Benschop sediment (so not only the drift event that gives the annual maximum); the figure shows that the correlation was good for all applications. The lower left corner of the figure shows that TOXSWA simulates sometimes non-zero concentrations even if the drift deposition is zero. This is caused by some carry over of pesticide residues from the previous application (the three applications are at weekly intervals).

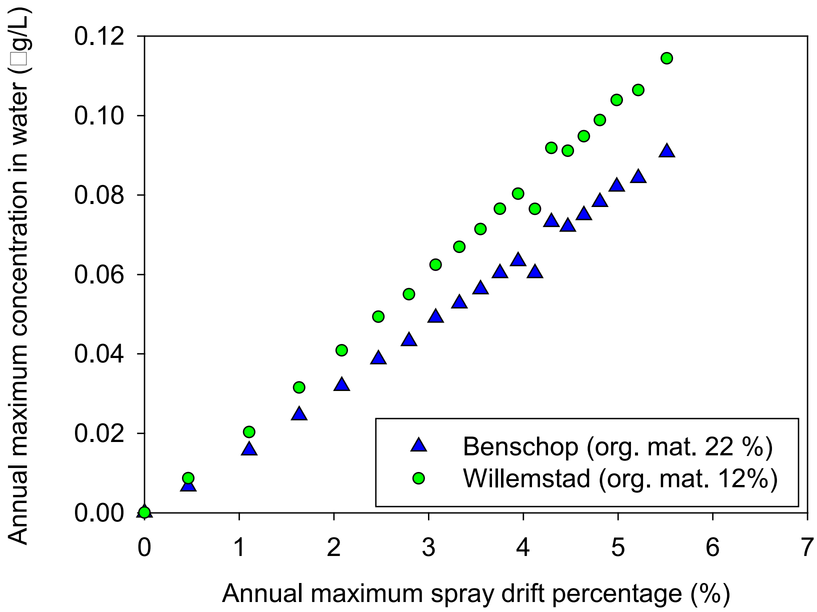

Figure 17 *Effect of sediment properties on the 20 annual maximum concentrations as simulated with TOXSWA as a function of the annual maximum spray drift deposition for insecticide I_P which was applied annually on 29 April, 6 May, 13 May at a rate of 0.0075 kg/ha with a DRT90 spraying technique and 3 m crop free zone.*

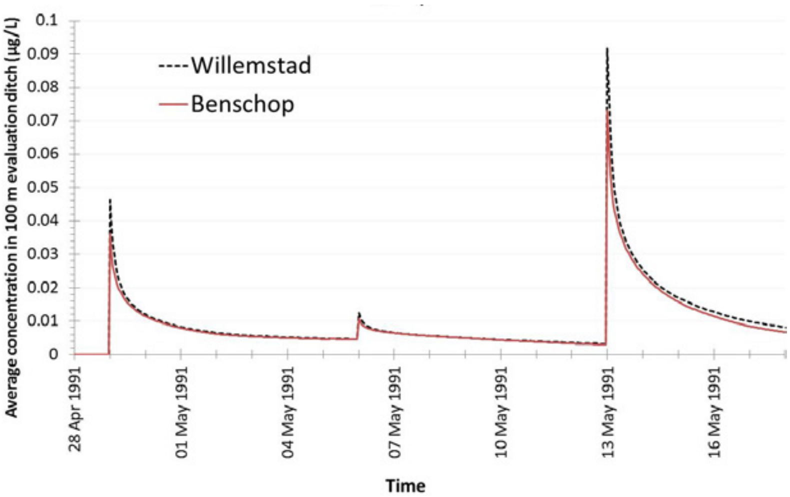

Figure 18 *Effect of sediment properties on time course of the concentration of insecticide I_P in the evaluation ditch in the simulation year 1991.*

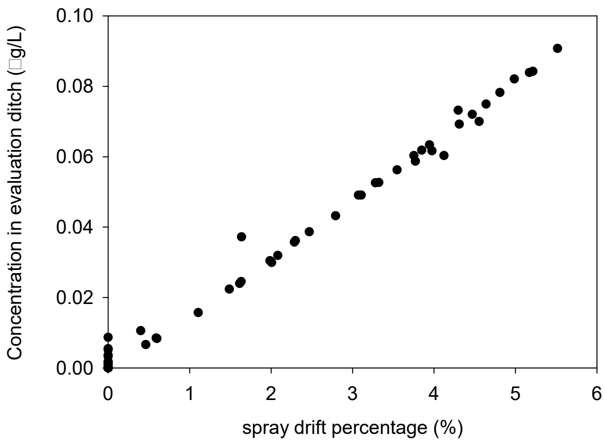

Figure 19 *Concentration in the evaluation ditch as simulated with TOXSWA immediately after application as a function of the spray drift deposition for insecticide I_P which was applied annually on 29 April, 6 May, 13 May at a rate of 0.0075 kg/ha with a DRT90 spraying technique and 3 m crop free zone. Sediment properties of Benschop were used. The difference with the Benschop data in Figure 17 is that in the above graph data for all applications are shown whereas Figure 17 showed only the applications that generated the annual maximum concentrations.*

The third example is a run with a fungicide F with 15 applications per year (starting at 30 April with a minimum interval of 7d with a dose of 1.8 kg/ha, DRT90 and 3 m crop free zone) to illustrate the short residence times of pesticides in the scenario ditch. In reality, this fungicide has a very short half-life in water due to hydrolysis but for this run, the half-life was set at 1000 d to illustrate the effect of the short hydraulic residence times on the time course of the concentration in water. The K_{OM} of this substance was 56 L/kg. The results in Figure 20 show that the concentration peaks had decreased nearly always to low values at the next application, even in a year with relatively long residence times (bottom graph). The figure further illustrates the probabilistic nature of the spray-drift depositions: in the top graph the 15 applications cause 9 concentration peaks and in the bottom graph they cause 10 concentration peaks; so 5-6 applications caused no concentration peaks because the wind was in the direction from the ditch to the field. Furthermore the figure shows higher exposure concentrations in spring than in summer which is caused by the fact that the spray drift deposition is higher in spring than in summer (see DRT90 curve in Figure 12).

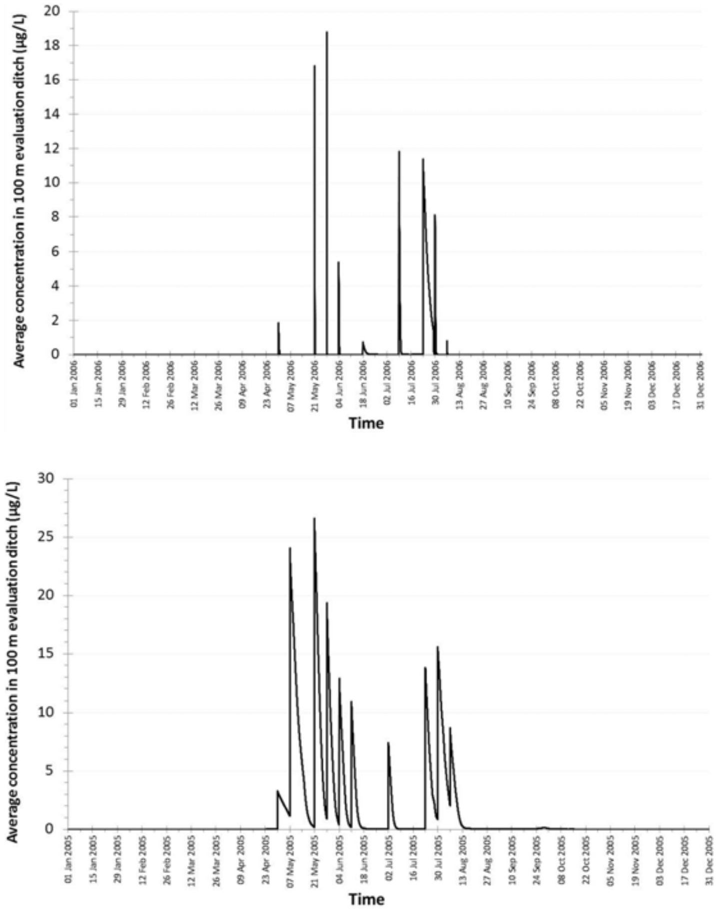

Figure 20 *Concentration of fungicide F in water as a function of time. Top graph is for 2006 which is the year of the target percentile and bottom graph is for 2005 which was a year with relatively long residence times. Calculations were for 15 applications of 1.8 kg/ha each, starting at 30 April with an interval between the applications of 7 days; the DRT class was DRT90, the half-life in water was 1000 d and sediment properties from Benschop were used.*

5 Approach for including drainpipes in the exposure assessment

5.1 Introduction

As described in Section 2.1, it was decided in 2015 not to include drainpipe leaching with the caveat that this approach had to be checked for the highest DRT class (DRT99). Figure 12 shows that spray-drift deposition for a single summer application for DRT99 and a zero buffer zone was as low as 0.07%. Tiktak et al. (2012a) described example calculations for four substances for the *d-fi* scenario (see their p. 85-92) and the spray-drift deposition for DRT95 for these substances ranged from 0.08-0.11%. The drainpipe appeared to contribute significantly to the exposure for these example calculations (p. 103). So the DRT99 in the *su-fr* scenario corresponds to even lower spray-drift deposition than the DRT95 in the *d-fi* scenario. This indicates that the contribution from the drainpipe to the exposure in fruit crops cannot be ignored. Please note that all these deposition percentages are for a zero crop-free buffer zone; for a 9-m buffer zone these percentages are smaller (as is illustrated by Figure 21 which shows about a factor 2-3 difference for the L1 basic scenario; note the logarithmic vertical axis) and the relative contribution of the drainpipe thus larger.

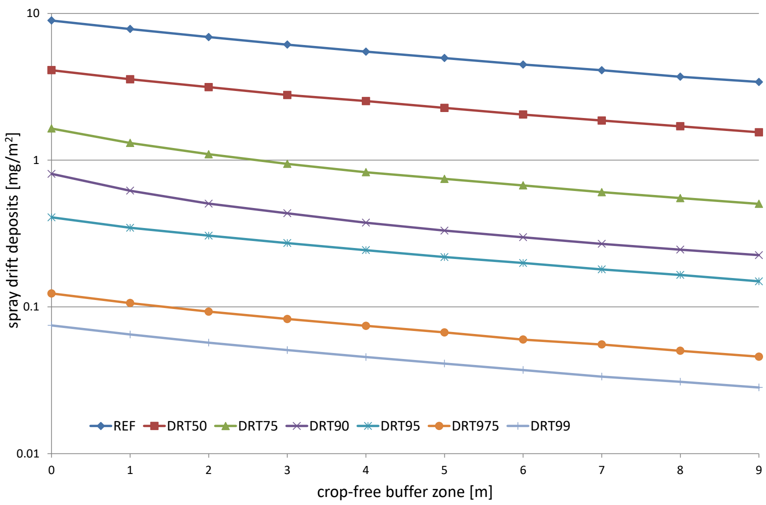

Figure 21 *Effect of the width of the crop-free buffer zone on the spray-drift deposition as calculated for the L1 basic scenario for different DRT classes.*

The consequence of this is that the *su-fr* exposure methodology described in the Chapters 3 and 4 has to be adapted to include the contribution of the drainpipe. It is proposed to use an approach that is similar to the one followed for the *d-fi* scenario. Therefore this approach is first summarised and thereafter the proposed modifications for the *su-fr* scenario are described.

5.2 Summary of drainpipe exposure assessment in *d-fi* scenario

The approach in the *d-fi* scenario was to (i) select a spray-drift space-time combination corresponding with a 90th percentile concentration (more or less similar to the approach for the *su-fr* scenario as described in Chapters 3 and 4), and (ii) to select a drainpipe space-time combination corresponding with a 90th percentile concentration (Tiktak et al., 2012a). Thus the assumption was that the combination of these two 90th percentiles would give also a 90th percentile for the combined exposure routes. Note that the SPSU of the *d-fi* scenario was based on ditches that received both input from spray drift and drainpipe. So the SPSU contained only ditches with drainpipes.

To be able to approximate concentrations in the ditch, GeoPEARL was coupled to a TOXSMA metamodel that simulates the time course of the concentration in the ditch assuming a perfectly-mixed reservoir (so considerably more sophisticated than the TOXSWA metamodel for spray-drift input described in Section 3.3).

GeoPEARL calculations were carried out for the total area of arable crops in the Netherlands for a range of substances considering all ditches adjacent to field crops; this was done for a single application time in spring. The calculations were limited to ditches which had drainpipes. It appeared that ditches with widths > 3 m (so-called primary water courses) had almost no drainpipes so these were excluded. Thus a STPC was obtained (see Tiktak et al., 2012b, for a detailed description). Subsequently a scenario was parameterised for the 'Andelst' location and the TPC at this location was calculated with PEARL in combination with this TOXSWA metamodel for the same range of substances. Next, for each substance the required temporal percentile for Andelst was derived from these two populations, using the same procedure as in Figure 10. After analysing the temporal percentiles of all these substances, it was concluded that a 63rd time percentile at Andelst was sufficiently conservative. So the 63rd percentile was selected from the times series of annual maximum concentrations that was generated by TOXSWA.

5.3 Proposed approach for the *su-fr* scenario

As described in Section 2.1, the workgroup assumed in 2013 that Dutch fruit crops are grown on soils with lower clay contents than field crops. This hypothesis was tested by comparing the frequency distribution of the clay content of Dutch field crops with that of Dutch fruit crops (based on the GeoPEARL parameterisation). This comparison was limited to soils that had drainpipes. The result in Figure 22 shows that the clay contents for the fruit crops are systematically slightly higher than those for the field crops.

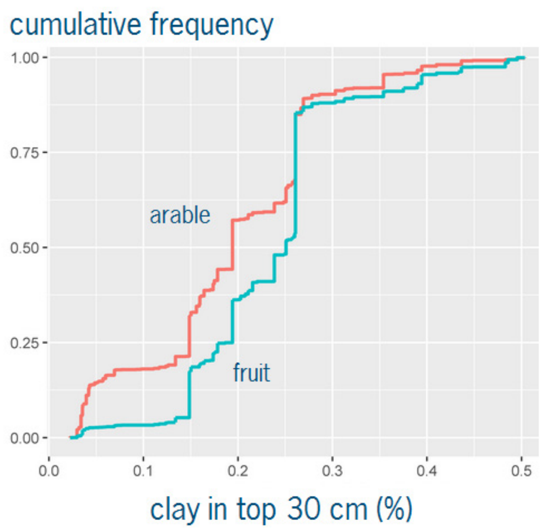

Figure 22 *Comparison of the cumulative frequency distributions of the clay content in the top 30 cm of (i) Dutch field crops with drainpipes and (ii) Dutch fruit crops with drainpipes.*

The Andelst soil has 28% clay in the top layer which corresponds to about the 90th percentile of the distribution in Figure 22. According to the Dutch soil map this is a light clay (Figure 23) and the USDA classification of this soil is a silty clay loam (so with a clay content too low to be classified as a clay). Comparison of the Dutch soil map of Figure 23 with the fruit-crop land use map (map not shown) indicated that in the band of this light clay between Andelst and Randwijk there are spots with more than 15% surface area fruit crops and even the research station for fruit crops in Randwijk is located in this band of light clay. So the Andelst soil is likely to be a suitable candidate for the *su-fr* scenario.

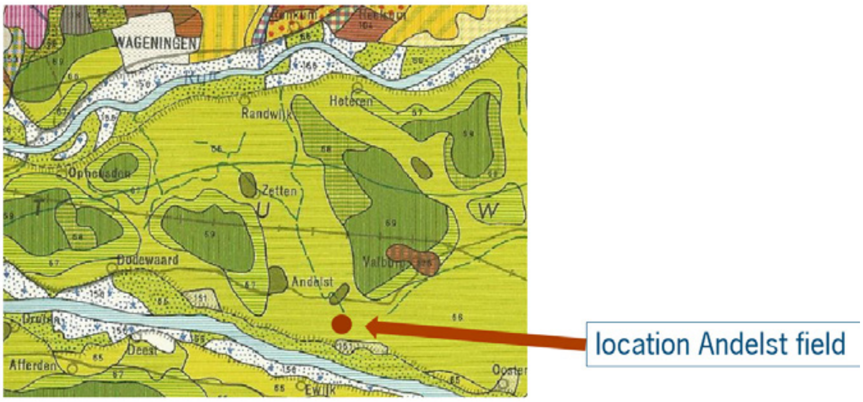

Figure 23 *The Dutch 1:25000 soil map indicating the location of the Andelst field. The soil map unit in which this location is located, is described in the legend of the map as 'somewhat sandy and light clay' with a clay content between 25 and 35%.*

So the first step of the selection procedure is to perform calculations with GeoPEARL coupled to the TOXSWA metamodel described in the previous section. These calculations should be performed for all ditches with drainpipes adjacent to fruit crops, using the same range of substance properties as for the *d-fi* scenario and using the definition of the type of spatial unit as described in Section 1.2 (i.e. ditches with permanent water and a width <6 m; so excluding the temporarily dry ditches that were included in the *d-fi* scenario). It is proposed to perform these calculations with the recently developed GeoPEARL version based on an improved organic-matter map (Van den Berg et al., 2017).

The second step is to assess the percentage of these types of ditches adjacent to fruit corps that have drainpipes (weighted based on the length of the ditches). This is needed because the SPSU consists both of the ditches with and without drainpipes. Let us assume that 50% of the ditches have drainpipes and 50% have no drainpipes. The overall target percentile is 90% but this refers to all ditches whereas 50% of the ditches have zero contribution from the drainpipe. As a consequence the target percentile for the STPC in these GeoPEARL calculations is then the 80th percentile instead of the 90th percentile (see EFSA, 2013b, Appendix I, for the equation describing this percentile calculation procedure).

So based on these GeoPEARL calculations the target exposure concentration in the ditch corresponding with the overall 90th percentile concentration resulting from drainpipe leaching should be established.

Van den Berg et al. (2017) indicated that there are considerable uncertainties in the organic matter content of the top layer in fruit crops in GeoPEARL. The background is that the organic matter content in GeoPEARL depends on the land use (either arable crops or grassland) and that the fruit crops do not fit into one of these categories: they consist usually of a strip of bare soil of 1-1½ m wide and a grass strip of about 2 m wide. Van den Berg et al. (2017) recommend a review of available data after having made a distinction between organic-matter content measured in the bare soil strip and organic-matter content in the grass strip in these fields.

The next step is to parameterise the PEARL scenario for the Andelst location. The crop parameters could be based on apples for FOCUS Hamburg. The meteorological time series could be based on the meteo station Herwijnen (which was also used for the spray drift; see section 3.4.2). Further procedures could be similar to the *d-fi* scenario as described by Tiktak et al. (2012b).

In the *d-fi* scenario there were 15 evaluation years and 5 warming-up years; so the spray-drift deposition calculation procedure will need to be adapted (using again Equation 1). Furthermore the calibration of the SWQN model will probably need to be repeated as well. These adaptations seem straightforward (but some complications cannot be excluded).

It is proposed to follow the same approach as in the *d-fi* scenario for the combination of the drainpipe and spray-drift input, i.e. derive for each exposure route a space-time combination that corresponds with a 90th percentile concentration and combine these two combinations intelligently. This could be done by combining the Andelst drainpipe scenario with the selected ditch-orchard-district system described in Section 3.4.2. There is then still the problem that the spray-drift and drainpipe procedures prescribe different temporal percentiles of the TOXSWA concentrations as the endpoint of the exposure assessment. So a choice has to be made between these percentiles. It is proposed to decide this based on the results of TOXSWA calculations: options include (i) conservative solution based on the highest concentration of the two percentiles, (ii) determine which of the exposure routes is dominant (based on two additional TOXSWA runs, one with only spray drift input and one with only drainpipe input) and use the corresponding temporal percentile, (iii) assess the relative contribution of each exposure route and calculate an average temporal percentile using these relative contributions as a weight.

In the workshop of 22/23 May 2017 (see Section 1.1), doubts were expressed whether the approach of combining a 90th percentile based on spray drift with a 90th percentile based on drainpipe leaching would be appropriate for obtaining an overall 90th percentile. We recommend therefore to underpin this assumption by further analysis.

In the scenario calculations with PEARL for Andelst, there is still an issue with the partitioning of the dose over the grass and the bare soil and the wash-off from the grass. For fruit crops, an interception percentage of 50-65% is used in the Dutch leaching assessment (based on Appendix C of EFSA, 2014), so 35-50% is assumed to be deposited on the soil surface (no wash off from plant leaves is assumed to occur in the Dutch leaching assessment). EFSA (2014) gives 90% interception for permanent grass. Thus it is a point of debate which interception percentage should be used for fruit crops in the Dutch leaching assessment. Jan van de Zande (personal communication, 2017) performed numerous measurements of deposition below fruit trees during the growing season. For conventional spray techniques, the average deposition percentage for the bare soil strip was about 60% of the dose and the average deposition percentage for the grass strip was about 40% of the dose, which gives a field average of 0.67 × 40% + 0.33 × 60% = 47%, which is somewhat higher than the 35% from EFSA (2014). For the newer spray techniques (DRT classes 95-97.5-99) there is a trend of more deposition onto the bare soil strip compared to the grass strip because these techniques are more directed at the trees. EFSA (2014) proposes 50% deposition for sideways and upward spray applications for apples without leaves (background is that such applications are directed to the apple trees). In view of the foregoing, it is proposed to assume for PEARL calculations a deposition onto the soil of 50% for sideways and upward spraying in fruit crops irrespective of the application time.

6 Possible contribution of atmospheric deposition

As described in Section 2.1, Tiktak et al. (2012a) included atmospheric deposition in the *d-fi* scenario by using conservative default values for this deposition based on the vapour pressure of the substance as recommended by FOCUS (2008). Their Table 13 and Figure 38 indicate that this results in a deposition of about 0.2% of the dose if the vapour pressure of the substance exceeds 10^{-4} Pa (this 0.2% is introduced into TOXSWA as a constant rate over the first 24 h after application). Figure 24 indicates that about 40% of the pesticides have a vapour pressure higher than 10^{-4} Pa. As described in Section 5.1, the spray drift deposition for DRT99 and a crop-free buffer zone of 9 m may become as low as about 0.02-0.03%. So using the conservative default values from FOCUS (2008) in combination with our sophisticated spray drift approach seems inappropriate. However, it seems necessary to gain more insight into more realistic estimates of the contribution of atmospheric deposition.

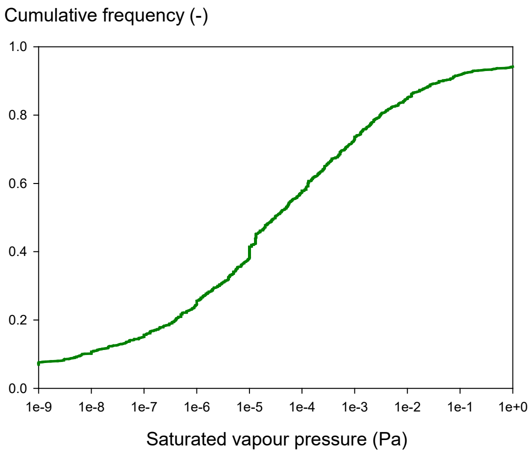

Figure 24 *Cumulative frequency of saturated vapour pressures of pesticides taken from the FOOTPRINT database (version of 29 May 2015).*

Within the scope of a Water Framework Directive project on the quality of surface water at the catchment scale, Jacobs and Van den Berg (2009) and Van den Berg et al. (2011) presented the results of calculations of atmospheric deposition of a plant protection product with the coupled PEARL-OPS model onto a network of Dutch ditches in the Klazienaveen-Zwartemeer catchment (total surface of the area is about 10 km^2) after spray applications to the plant surface of sugar beets in the catchment. These calculations were intended to demonstrate the possibilities of the coupled PEARL-OPS model (F van den Berg and CMJ Jacobs, personal communication, 2017). In these sample calculations they assumed an application of 1 kg/ha of fenpropimorph on 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 May 2003 onto one of ten fields within this area, in a randomly selected order. The surface area of the sugar beet fields ranged from about 2 to 30 ha (Figure 25). The saturated vapour pressure of fenpropimorph was assumed to be 2.2 mPa and its water solubility 4.3 mg/L (both at 20°C). The logarithm of its K_{om} was 3.13. Penetration into the leaf tissue and phototransformation on the leaf surface were taken into account using first-order kinetics, with half-lives of 0.66 and 0.433 d, respectively. The atmospheric deposition was characterised by the cumulative mass deposited per surface area of ditch over the first 14 days of May. Meteo data were taken from meteorological station 'De Bilt' in the centre of the Netherlands. The wind direction at this meteorological station varied between 1 and 14 May 2003 between south west and north east. To the best of our knowledge, these are the only simulations available of atmospheric deposition of pesticides in the Netherlands using sophisticated models such as PEARL and OPS. Therefore these simulations are quite valuable for the assessment of the potential significance of atmospheric deposition of pesticides onto Dutch ditches.

The PEARL simulations were carried out with an option that not only considers volatilisation as a dissipation process on plant leaves, but also the competing processes penetration into the plant tissue and photo-transformation on the plant leaves. This resulted in an average of 25% volatilisation of each dosage within a few days (ranging between 19 and 33%, depending on the day of application). In field experiments in the Netherlands Leistra et al. (2005, 2006) found 12% volatilisation of fenpropimorph after application to sugar beets and 7% volatilisation after application to potatoes. So let us assume that a 10% cumulative volatilisation of fenpropimorph from plant surfaces is realistic for Dutch conditions. This means that the simulated depositions onto the ditches may need to be divided by a factor of 2.5 to obtain realistic values.

Figure 26 shows that the simulated cumulative deposition is less than 1 g/ha for about 30% of the ditches, about 1-3 g/ha for about 35% of the ditches, about 6 g/ha for 20% of the ditches and about 10-20 g/ha for about 15% of the ditches. So a 90th spatial percentile in this landscape geometry would be in the order of 10 g/ha which corresponds with 1% of the dose of 1 kg/ha. Keeping in mind that we have to divide by a factor of 2.5, we get 0.4% deposition. This is close to the default deposition of 0.22% as recommended by FOCUS (2008) for substances with a saturated vapour pressure above 10^{-4} Pa, as shown in Table 13 of Tiktak et al. (2012a). So these simulations confirm that a deposition of a few tenths of percent of the dose may occur. This is in the same order of magnitude as the spray drift deposition for DRT99 (Figure 12). So these results indicate that atmospheric deposition cannot be ignored in this exposure assessment of aquatic organisms after spray applications in Dutch fruit crops. We recommend therefore to develop realistic exposure scenarios for atmospheric deposition. However, it is foreseeable that this will require considerable multi-year research efforts given the required complexity to obtain 90th percentiles of the atmospheric deposition rates for applications in Dutch fruit crops.

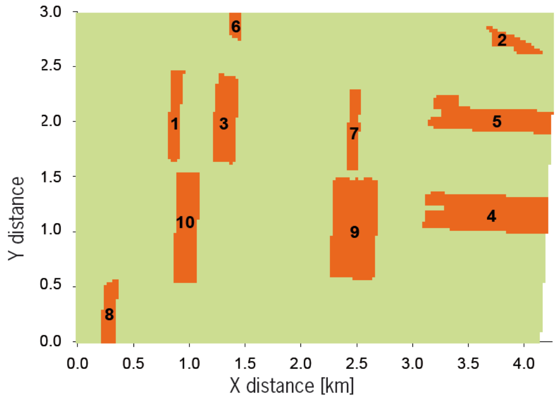

Figure 25 *Location and size of the treated sugar beet fields. The Y axis is in the direction from south to north. The number of each field indicated the day number in May 2003 in which the field was sprayed with fenpropimorph at a rate of 1 kg/ha (so 1 means application on 1 May).*

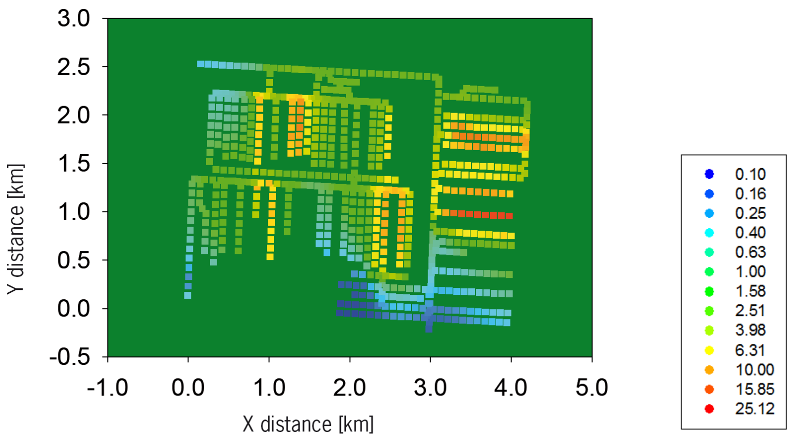

Figure 26 *Cumulative mass deposited per surface area of ditch between 1 and 10 May 2003. The numbers are in g/ha.*

7 Discussion, conclusions and recommendations

As described in Section 2.3, this exposure assessment methodology is based on the current Dutch labels for application of plant protection products in fruit crops which specify the concentration of formulated product in the spray solution together with a maximum mass of formulated product per surface area of the treated field. We recommend to explore the possibility of switching to labels with application rates based on the LWA (leaf wall area) approach because this may lead to a large reduction of use of plant protection products in Dutch fruit crops (see Section 2.3) and consequently also to a large reduction of emissions to the environment.

This exposure assessment methodology assumes that the application rate is fixed to the maximum value specified on the label. Also in case of an LWA approach this principle of a maximum application rate may be used by taking the maximum LWA occurring in practice (about 24 000 m^2/ha).
The exposure assessment goal aims at a 90^{th} percentile concentration taken from a spatio-temporal statistical population of concentrations in ditches alongside fruit crop parcels (Section 1.2). If the LWA approach would be introduced, it would be possible to determine the frequency distribution of the LWA for Dutch apples and pears with relatively little efforts. Thus, it would be possible to assess this 90^{th} percentile concentration by including this LWA frequency distribution in the spatially distributed probabilistic model. This would result in a more realistic frequency distribution of the exposure concentrations to be expected in these ditches. As described in Section 2.3, the median LWA is expected to be about 12 000 m^2/ha. In combination with the maximum LWA of 24 000 m^2/ha, we expect that including such a probabilistic LWA will decrease the resulting 90^{th} percentile concentration by 10-25%.

In the scenario calculations it is assumed that a spray drift event generates a deposition that is constant over the length of each ditch. Van de Zande et al. (2018) measured spatial variability in spray drift deposition over 100 m length along the row side of the orchard, based on drift depositions onto 200 strips of a length of 0.5 m. They found coefficients of variation of these depositions ranging between 40 and 80%, i.e. a very large variability. As described in Section 1.2, the average concentration over 100 m is used as endpoint for the effect assessment, so TOXSWA simulates the average concentration in the 100-m evaluation ditch (see Figure 13). So ignoring this spatial variability is expected to have little effect on the endpoint of the exposure assessment (although it may be worthwhile to check this by TOXSWA simulations for e.g. a 7-day time-weighted average concentration).

As described in Section 1.2, 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. It can be expected that there is a close relationship between a TWA peak concentration and an instantaneous peak concentration but it may be worthwhile to check this by TOXSWA simulations for a range of substance properties and application times.

As described in Section 4.1, it is assumed that only the 100 m evaluation ditch is treated with pesticide. In a realistic fruit-orchard system at landscape level, there may be pesticide applications in other orchards as well, which lead to drift loads onto other ditches connected to the evaluation ditch. This may lead to higher concentrations in the evaluation ditch. We recommend to test the effect of this by scenario calculations in which 300 m ditch length is treated instead of 100 m (see Figure 13).

As described in Section 5.1, the spray drift deposition for DRT99 and a crop-free buffer zone of 9 m may become as low as about 0.02-0.03%. For such low drift deposition levels, leaching from drainpipes may contribute significantly to the exposure assessment. We recommend therefore to include this contribution in the exposure assessment. Given the considerable uncertainties in the estimation procedure for the organic matter content of the top layer in fruit crops in GeoPEARL (Section 5.3), we recommend to review available Dutch data of this organic matter content as part of the procedure of including the contribution of leaching from drainpipes. As the Andelst scenario (developed for leaching from drainpipes for Dutch arable crops) seems also suitable for fruit crops (Section 5.3), we recommend to use this scenario (modified as needed) also for the fruit crops.

In Chapter 6, it was shown that the contribution of atmospheric deposition may be significant for pesticides with saturated vapour pressures in the order of 1 mPa and higher. Therefore we recommend to develop exposure scenarios that include atmospheric deposition. We recommend not to use the default atmospheric deposition values from FOCUS (2008) for the exposure assessment of aquatic organisms in ditches adjacent to Dutch fruit crops because the level of sophistication of the estimation procedure of these values is inconsistent with the level of sophistication of the estimation of the drift deposition as presented in this work and also inconsistent with the level of sophistication of the estimation of the leaching from drainpipes as proposed.

In the workshop of 22/23 May 2017, doubts were expressed whether the approach of combining a 90^{th} percentile based on spray drift and a 90^{th} percentile based on drainpipe leaching would be appropriate for obtaining an overall 90^{th} percentile. It is foreseeable that similar concerns will be raised when additionally atmospheric deposition is included in the exposure assessment. Therefore we recommend to underpin by further analysis the assumption that an overall 90^{th} percentile can be assessed by combining 90^{th} –percentile contributions from individual exposure routes.

Considering all available data, we recommend to assume that 50% of the dose is deposited on the soil for sideways and upward spraying in fruit crops irrespective of the application time (see end of Section 5.3).

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Abbreviations

bas-DRT-w combination	combination of basic application scheme, DRT class and width of the buffer zone
cfd	cumulative frequency distribution
d-fi scenario	aquatic exposure scenario for downward spraying in field crops
DRT	drift-reducing technology
ERC	Ecotoxicologically Relevant type of Concentration
LWA	leaf wall area
SPSU	spatial population of spatial units
STPC	spatio-temporal population of concentrations
SU	spatial unit
su-fr scenario	aquatic exposure scenario for sideways and upward spraying in fruit crops
TPC	temporal population of concentrations
TWA	time-weighted average

Annex 1 Determination of the application times based on BBCH for sideways and upward spraying in fruit

Large fruit crops

To estimate application times based on the BBCH code (van de Zande et al., 2018) a relationship between the BBCH and the calendar dates (expressed here in Day Of Year; DOY) is needed. The fixed relation between the BBCH code and the DOY that is used is based on data for apples between 1990 and 2010 (van de Zande et al., 2018) and given in Figure 27. BBCH-DOY relations of other fruit crops and hop are not available.

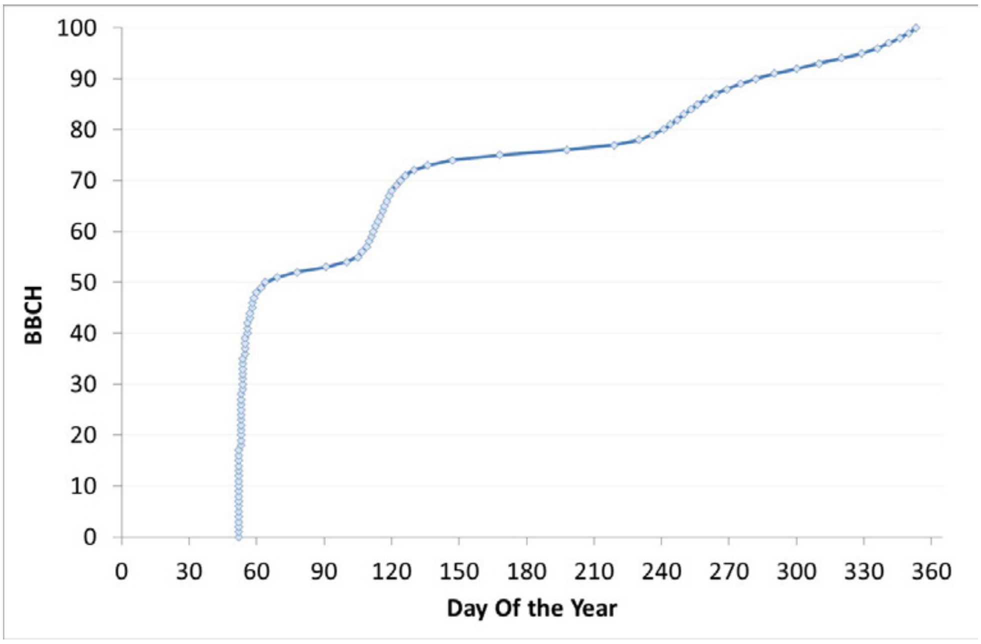

Figure 27 *Relation between the BBCH code and the Day Of the Year (DOY) for apples and used in the Drift model for fruit and hops.*

In Figure 27 two periods can be distinguished. These periods are:

1. BBCH 0; dormancy[2] (period DOY 342 t/m 365 + 1 t/m 51)
2. BBCH 1-97; crop development (DOY 52 t/m 341)

For the estimation of the application times a distinction between these two periods is made because the determination of the start application date differs for these two period.

To determine application times based on BBCH code calculation rules are established and given below:

1. The application interval given on a label is a range (e.g. 7 – 14 d). The minimum application interval is used for estimation of the application times.

2. 'Applications within period BBCH 1-97; crop development': First application is on the first day of the period characterized by a begin BBCH.

[2] Dormancy is defined here as the period between BBCH 97 (All leaves fallen) and BBCH 1 (Beginning of leaf bud swelling: buds visibly swollen, bud scales elongated, with light coloured patches).

3. ‘Applications within period BBCH 1-97; crop development’: Option to include applications in more than one application block[3].

4. ‘Applications within period BBCH 0; dormancy’: determine the start date of the first application based on the ‘Number of days after BBCH 97 on which the first application should start’.

5. ‘Applications within period BBCH 0; dormancy’: Application blocks not possible.

6. In case of *n* applications, application dates of the subsequent applications are determined by using the minimum interval only (i.e. Application date of application, *n*, is found on: *start date + (n-1)**minimum interval*).

7. If the application scheme inserted by the user, does not fit in to the application period possible (using the BBCH-DOY relation and the calculation rules above), the software tool DRAINBOW will give an error message that tells the user to change the application scheme.

Using the BBCH-DOY relation of Figure 27 (see Table 4: Figure 27 tabulated) for the determination of the application dates triggers two complications:

A. One BBCH number cover a larger period (several days)
B. The period between 2 sequential BBCH number covers more than one day

Examples are given below:

A. One BBCH number cover a larger period (several days)

Example: BBCH codes 1 up to and including 15 start all on DOY 52

i. User input <u>start</u> BBCH -> 1 and user input end BBCH -> 15. Question: start and end DOY cannot be found on the same day; how to deal with this in DRAINBOW?

B. The period between 2 sequential BBCH number covers more than one day

Example: BBCH 51 starts on DOY 69, BBCH 52 starts on DOY 78 (Table A1 in ANNEX1).

ii. User input <u>start</u> BBCH -> 51. Question: Which DOY in the range 69-77 should be coupled to start BBCH 51?
iii. User input <u>end</u> BBCH -> 51. Question: Which DOY in the range 69-77 should be coupled to end BBCH 51?

Rules are devised that should be applied for these two special situations:

A. One BBCH number covers a larger period (several days)

- DRAINBOW gives an error message: ‘start and end BBCH fall on the same date, please expand your BBCH interval’

B. The period between 2 sequential BBCH number covers more than one day

- User input is a <u>start</u> BBCH: Use the first DOY in the range.
- User input an <u>end</u> BBCH: Use the last DOY in the range.

Note that method described above is also applicable for downwards spraying under fruit.

[3] “application blocks” are introduced to manage application schemes containing two or more series of applications separated by a period without applications. Introducing a longer period without applications in the GAP table, is usually done to prevent problems with resistance.

Table 4 *BBCH-DOY relation (model fit) for apples as used in the drift model for fruit.*

BBCH	DOY	BBCH	DOY	BBCH	DOY
0	52	38	55	76	198
1	52	39	55	77	219
2	52	40	56	78	230
3	52	41	56	79	236
4	52	42	56	80	241
5	52	43	57	81	244
6	52	44	57	82	247
7	52	45	58	83	250
8	52	46	58	84	253
9	52	47	59	85	256
10	52	48	60	86	260
11	52	49	62	87	264
12	52	50	64	88	269
13	52	51	69	89	275
14	52	52	78	90	282
15	52	53	91	91	290
16	52	54	100	92	300
17	52	55	105	93	310
18	53	56	107	94	320
19	53	57	109	95	329
20	53	58	110	96	336
21	53	59	111	97	341
22	53	60	112	98	346
23	53	61	113	99	350
24	53	62	114	100	353
25	53	63	115		
26	53	64	116		
27	53	65	117		
28	53	66	118		
29	54	67	119		
30	54	68	120		
31	54	69	122		
32	54	70	124		
33	54	71	126		
34	54	72	130		
35	54	73	136		
36	55	74	147		
37	55	75	168		

Small fruit crops and hop
In principle the same method for estimation of the application times can be used for small fruit crops and hop. However, the BBCH-DOY relationship for apples (Figure 27) is not applicable. Instead the growing period of hop and small fruit is defined by a start and end date defined in van de Zande et al., 2018. Currently it is not fully sorted out how to estimate application times. However it is clear that an additional rule should be added to prevent the spraying of insecticide/fungicides in hop from September onwards:

1. Spraying of insecticide/fungicides in hop is not possible from September onwards. Operational definition: if Hop and if upwards and sideways spraying and if BBCH > 81 (d244) --> give message: “upwards and sideways spraying of insecticides and fungicides in hop is not allowed from September (BBCH 81) and onwards”

Implementation of the determination of the application times based on BBCH for large fruit crops in the software tool DRAINBOW

As described a differentiation is made between two different periods in a year:

1. BBCH 0; dormancy (period DOY 342 t/m 365 + 1 t/m 51)
2. BBCH 1-97; crop development (BBCH 1 t/m 97; DOY 52 t/m 341)

Table 5 gives per period (BBCH 0 and BBCH 1-97) the user input into the application screen for large fruit crops in DRAINBOW.

Table 6 specifies the parameters that are calculated or determined by DRAINBOW.

Table 5 *User input into the proposed application screen for large fruit crops in the software tool DRAINBOW.*

Description	BBCH 1-97; crop development	BBCH 0; dormancy
Start BBCH	☑	
End BBCH	☑	
Number of applications	☑	☑
Min. Application interval (d)	☑	☑
Number of BBCH blocks/periods	☑	
Number of days between the BCCH blocks/periods (d; i.e. number of days without applications)	☑	
Number of days to 1st application after BBCH 97 (needed to define the start of the first application in this period)		☑
Fixed input (via Error! Reference source not found.)		
Julian day number start date at BBCH =0		☑
Total number of days in the 'BBCH 1-97; crop development' (DOY 52-353)	☑	

Table 6 *Parameters to be calculated or determined by DRAINBOW.*

Description	BBCH 1-97; crop development	BBCH 0; dormancy
Start DOY	☑	☑
End DOY	☑	
Length of the total BBCH period	☑	
Julian day number of the applications (n=1 to N)	☑	☑
Julian day number of the first day of the BBCH period for k= 1:P_{BBCH}	☑	

A calculation example is given to illustrate how application times within the BBCH 1-97 crop development period are estimated.

Suppose the following application scheme: three series of applications separated by a 21 day period without applications. Each series contains two applications with a minimum application interval of 7 days. The start of the first application is indicated by BBCH 68 (and the last application cannot be later than BBCH 97). The application scheme fits with the '*BBCH 1-97; crop development'* period and next it will be explained using the application scheme specified above how application times are estimated using the rules given before.

As a first step the Julian DOY of the start and end dates need to be established using Table 4:

- Start date = DOY 120
- End date = DOY 341

As a second step the length of the total BBCH period specified (including the first day of application) is calculated:

- Length of the total BBCH period = 341 – 120 + 1 = 222 days

Next it needs to be checked whether the application scheme fits within the length of the total BBCH period (222 days):

- 3 intervals of 7 days + 2 intervals of 21 days = 63 days (fits in 222 day period)

As an intermediate step the Julian day number of the first day of each application series can be determined, with the first application starting on the start BBCH (=start DOY):

- 1st series: DOY 120
- 2nd series: DOY 148 (120 + 7 + 21)
- 3rd series: DOY 176 (149 + 7 + 21)

Then the Julian day number for each application in each series is calculated as follows:

- 1st series: 1st application - DOY 120, 2nd application – DOY 127
- 2nd series: 1st application - DOY 148, 2nd application – DOY 155
- 3rd series: 1st application - DOY 176, 2nd application – DOY 183

Figure 28 depicts the calculation procedure described above.

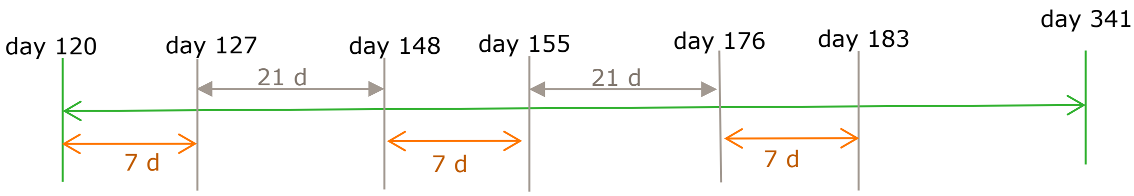

Figure 28 *Using a time line to illustrate the calculation procedure of application times of the example described above.*

Figure 29 shows the proposed application screen for large fruits in DRAINBOW. First step in this screen is to add an application scheme in the section 'Browse application scheme' using the '+' button. Next, user input according Table 5 and Table 6 is done at the right-hand side of the screen. By clicking the calculate button the result of the calculation of the application times is given in the section 'Overview applications' (bottom, left-hand side of the screen).

Proposal for the application screen for large fruit crops

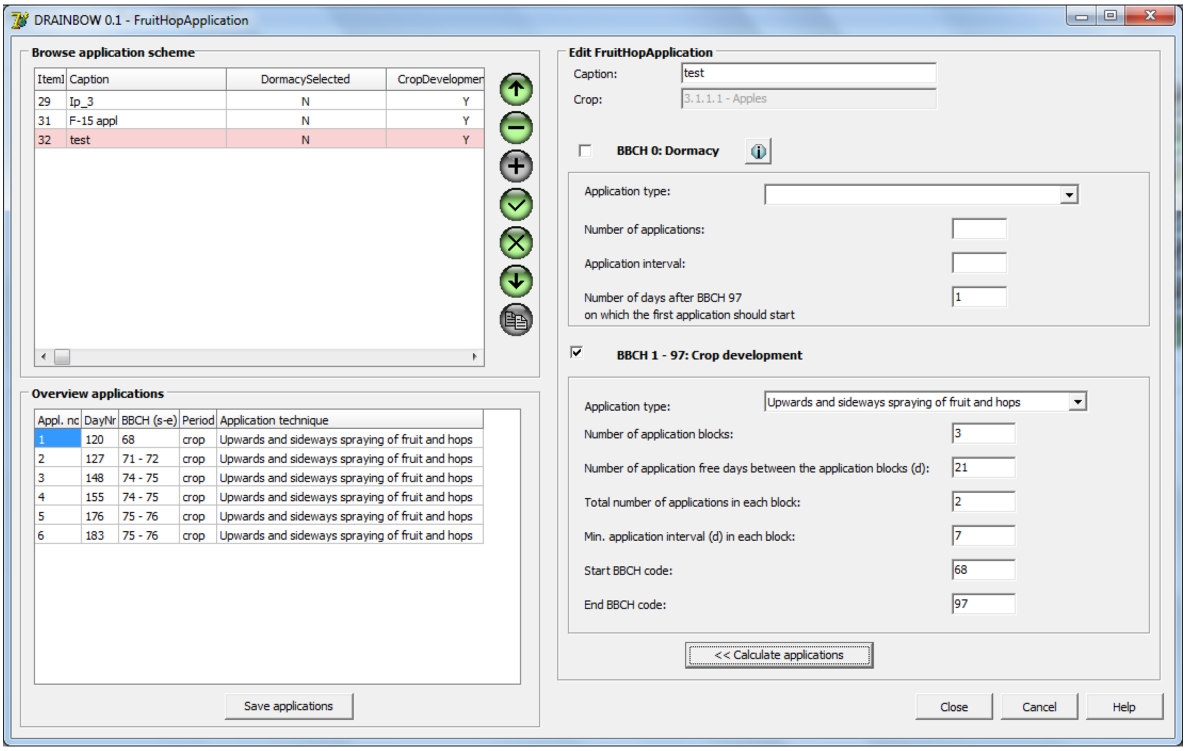

Figure 29 *Caption from the DRAINBOW application screen for large fruit crops (proposal). Note that the caption refers to hop as well. The screen was designed before it became clear that a BBCH-DOY relation is not available for hop.*

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Wageningen Environmental Research
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The mission of Wageningen University and Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 5,000 employees and 10,000 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.

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