National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

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

Part 1: Field crops and downward spraying

RIVM report 607407002/2012

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Colofon

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Abstract

Scenarios for exposure of aquatic organisms to plant protection products in the Netherlands. Part 1: Field crops and downward spraying

In the current Dutch authorisation procedure for calculating the exposure of surface water organisms to plant protection products, drift deposition is considered to be the only source for exposure of surface water organisms. Although drift can still be considered the most important source, atmospheric deposition and drainage may constitute important sources as well. Therefore, RIVM, PBL Netherlands Assessment Agency, Wageningen UR and the Board for the authorisation of plant protection products and biocides have derived a new procedure in which these two potential sources are included. The new procedure, described in this report, is restricted to downward spray applications in field crops.

Specific Dutch circumstances
The update of the procedure was initiated to bring the Dutch procedure more in line with the EU procedure, which already takes account of drainage. However, typical Dutch adaptations of the procedure remain. In the new procedure, drift is still based on Dutch drift deposition measurements. Characteristic is that the flow velocity of the selected ditch is rather low.

Risk management decisions
Two boundary conditions were used as starting points for deriving the scenario. First, there was the risk management decision that the scenario should be protective for at least 90 per cent of field ditches. Second, it was assumed that all adjacent fields are treated with the same substance and thus contribute to resulting exposure concentrations in the ditch.

Drift reducing measures still important
Currently, when spraying plant protection products on fields along surface water, growers should maintain a crop-free buffer zone and use certified sprayers that reduce spray drift deposition by at least 50 per cent. Example calculations with four substances showed that it is worthwhile to invest in further drift reduction. Calculated impacts on water organisms reduced upon applying higher drift reduction when drift was the dominant factor.

Keywords:
drainage, DRAINBOW, exposure, PEARL, spray drift, surface water, TOXSWA

Rapport in het kort

Scenario's voor blootstelling van waterorganismen aan gewasbeschermingsmiddelen in kavelsloten. Deel 1: Neerwaartse bespuitingen in veldgewassen

In de Nederlandse toelatingsbeoordeling voor gewasbeschermingsmiddelen wordt de blootstelling van waterorganismen te eenzijdig berekend. In de huidige beoordeling wordt namelijk alleen rekening gehouden met de mate waarin deze stoffen het oppervlaktewater bereiken via de verwaaide nevel van de gewasbeschermingsmiddelen (drift). Deze nevel ontstaat nadat de middelen over het land zijn gespoten. Hoewel dit de belangrijkste 'route' is, blijken twee andere routes ook van belang: via de atmosfeer en via de drainagesystemen in de bodem van de landbouwpercelen. Het RIVM heeft daarom in samenwerking met het Planbureau voor de Leefomgeving, Wageningen UR en het College voor toelating van gewasbeschermingsmiddelen en biociden (Ctgb) deze twee routes aan de blootstellingsscenario's toegevoegd. Specifiek gaat het hierbij om neerwaartse bespuiting in veldgewassen (akkerbouw, bloembollen en vollegrondsgroenteteelt).

Grote hoeveelheid oppervlaktewater in Nederland
Deze aanpassing is onderdeel van een herziening van de Nederlandse methode om risico's van gewasbeschermingsmiddelen te berekenen. Dat is nodig om de methode beter overeen te laten komen met Europese toelatingsprocedures voor dergelijke stoffen, waarin drainage al langer wordt meegenomen. De specifiek Nederlandse omstandigheden zoals de ruime hoeveelheden oppervlaktewater en de eigen driftcijfers blijven gehandhaafd. Kenmerkend voor het nieuwe scenario is dat er sprake is van een lage stroomsnelheid in het Nederlandse slootwater, waardoor stoffen relatief lang in het water blijven.

Uitgangspunten
Een van de uitgangspunten van het voorstel is de beleidskeuze dat de berekende maximale concentratie van een stof in negentig procent van de sloten onder de norm ligt. In de berekeningsprocedure wordt ook uitgegaan van belasting van het oppervlaktewater door gebruik op alle naastliggende percelen.

Driftreducerende maatregelen blijven belangrijk
Momenteel zijn telers van veldgewassen verplicht maatregelen door te voeren om de drift langs sloten met minimaal 50 procent te verminderen. Voorbeeldberekeningen met vier stoffen laten zien dat dergelijke driftreducerende technieken belangrijk blijven. In sommige gevallen kunnen aanvullende maatregelen de hoeveelheid drift namelijk nog verder omlaag brengen.

Trefwoorden:
blootstelling, drainage, DRAINBOW, drift, oppervlaktewater, PEARL, TOXSWA

Preface

A few years ago the Dutch government decided to initiate an improvement of the methodology for the assessment of effects of plant protection products on aquatic organisms. As part of this improvement, the Dutch government established two working groups covering both the effects side and the exposure side of the assessment. This report describes the development and parameterisation of the exposure methodology; the effects side of the assessment is described in Brock et al. (2011).

Background reports are published on guidance for the estimation of degradation half-lives in water, the crop-related aspects of crop canopy spray interception, the development of the drainpipe part of the exposure assessment, and the development of the spray drift part of the assessment:

- Boesten, J.J.T.I., P.I. Adriaanse, W. Beltman, M.M.S. ter Horst, A. Tiktak, and A.M.A. van der Linden, 2013. Guidance for using available *DegT50* values for estimation of degradation rates in Dutch surface water and sediment. Report 284 of WOT unit of Alterra, Alterra, Wageningen.
- Van de Zande, J., and M.M.S. ter Horst, 2012. Crop-related aspects of crop canopy spray interception and spray drift from downward directed spray applications in field crops. WUR-PRI report 420, Wageningen, the Netherlands.
- Tiktak, A., J.J.T.I. Boesten, R.F.A. Hendriks and A.M.A. van der Linden, 2012b. Leaching of plant protection products to field ditches in the Netherlands. Development of a PEARL drainpipe scenario for arable land. RIVM report 607407003, RIVM, Bilthoven, the Netherlands.
- Van de Zande, J.C., H.J. Holterman, and J.F.M. Huijsmans, 2012. Spray drift for the assessment of exposure of aquatic organisms to plant protection products in the Netherlands. Part 1: Field crops and downward spraying. WUR-PRI report 419, Wageningen, the Netherlands.

The exposure assessment methodology in this report is restricted to applications with downward spray techniques in field crops. At a later stage, an exposure assessment methodology for applications with upward or sideward spray techniques in fruit crops and tree nurseries will be published.

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

Contents

Summary

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

To the best of our knowledge the surface water scenario presented in this report is the first regulatory scenario that has been derived systematically using probabilistic and geostatistical modelling based on the requirement of a specified spatio-temporal percentile of a concentration distribution (in this case the 90^{th} spatio-temporal percentile of the population of annual peak concentrations in ditches that are at the border and downwind of treated fields and that receive drain water from these treated fields).

The endpoint of the exposure assessment is a spatio-temporal percentile of the annual maximum concentration in all relevant arable field ditches. The spray drift model IDEFICS and a macropore version of the leaching model GeoPEARL were used to simulate the exposure concentration for the entire population of ditches. This resulted in the selection of a 90^{th} percentile scenario. For this scenario, a non-stationary flow version of TOXSWA was parameterised. Most ditch parameters could be derived from national databases. Where information from national databases was not available, parameter values were taken from FOCUS (2001). The selected ditch is a water course typical of river clay areas and has a lineic volume of 0.55 m^{-3} m^{-1} and a water depth at the wet winter situation of 0.23 m. TOXSWA simulations showed that most of the time, the water moves slowly (< 1.5 cm d^{-1}), so the residence time of substances in the ditch can be high.

For the spray drift part of the exposure assessment, new spray drift deposition curves were developed. These curves describe the relation between the distances from the edge of the field and spray drift deposition. The spray drift curve to be used in the exposure assessment depends on crop type, crop development stage and treatment type. A decision tree was built to facilitate the selection of the appropriate curve. Spray drift deposition is calculated using a fixed water depth of 0.1905 m. This is the water depth for a situation where the discharge from the ditch is equal to the base flow. The drift deposition calculated with the new spray drift curves is higher than the spray drift deposition data that is currently used in the Dutch authorisation procedure.

The drainpipe scenario was based on data from a field experiment in a cracking clay soil. Additional data was used to extend this dataset to a 15-year period, so that the exposure assessment could be carried out for a multi-year period (in accordance with FOCUS 2001). This was considered necessary to reduce the effect of time of application of the plant protection product on the predicted exposure concentration. A sensitivity analysis showed that this strategy worked well for most substances. Only in the case of a quickly degrading, very mobile substance did the predicted exposure concentration vary by 50 per cent when the application date was shifted a few days.

So the exposure assessment results in a frequency distribution consisting of 15 annual peak concentrations. An analysis showed that the 63rd percentile of this frequency distribution corresponded well with the overall 90th percentile simulated with GeoPEARL (the target concentration). The target concentration increased with increasing *DegT50* and decreased with increasing K_{om}. The predicted differences of the target maximum concentration were small compared with differences of the leaching concentration as predicted by the convection-dispersion equation (Boesten and Van der Linden 1991). This was judged plausible, because the maximum concentration is primarily caused by preferential flow where the substance bypasses most of the reactive part of the soil profile.

Example calculations carried out for four substances show that the contribution of spray drift to the maximum annual concentration ranged from 40 to 100 per cent when using a sprayer in the minimum required spray drift reduction class of 50 per cent. Spray drift reduction is therefore still an efficient tool in reducing the exposure of aquatic organisms. However, when spray drift is reduced to a drift reduction class of 95 per cent, atmospheric deposition or drainage becomes the dominant source for half of the considered substances.

The low flow velocity in the ditch in combination with low dissipation rates of substances in water caused the concentration of three example substances to build up in the water-sediment layer over the years. As a result, the exposure concentration was above zero during the entire 15-year evaluation period. For two of the example substances, the difference between the maximum concentration averaged over 21 days and the maximum peak concentration was small. This implies that the difference between acute and chronic exposure concentrations is small.

As described earlier, the 63rd percentile of the maximum annual concentration was selected from a time series of 15 years. The simulations showed that the year corresponding to the 63rd percentile differed between the four substances. In some cases, selecting another drift-reducing technology or another time-averaging window caused another year to be selected as well.

1 Introduction

1.1 Background

The risk assessment of plant protection products (PPP) has a long history in the Netherlands. Environmental risk assessment was explicitly introduced in Dutch law in 1962 (Pesticide Act 1962) and has since then been substantiated and defined in more quantitative terms. The Pesticide Act of 1962 was repealed in 2007 and replaced by the Plant Protection Products and Biocides Act of 17-02-2007, which contains articles on environmental risk assessment equivalent to the latest version of the Pesticide Act of 1962.

Risk assessment for aquatic organisms has been part of the authorisation procedure of plant protection products, since 1995 explicitly laid down in a quantitative way in the Decree Environmental Criteria Pesticides, succeeded by the Regulation on Plant Protection Products and Biocides of 26 September 2007. In the Regulation, it is stated that the assessment of the risk for aquatic organisms is according to national specific methodology. The exposure of aquatic organisms is calculated using the TOXSWA model (Adriaanse 1996, Ctgb 2010), taking into account drift as the only source of the plant protection product. Also for drift emissions, national specific drift percentages are taken (Ctgb 2010).

In evaluation procedures at European level, risk assessment for aquatic organisms is slightly different from the procedure in the Netherlands (EU 1991, 2009). Exposure assessment is performed using the TOXSWA model, but with a different version (FOCUS 2001). The main deviations are slightly different dimensions of the edge-of-field water course, different drift emission percentages and the inclusion of runoff and drainage as potential sources of plant protection products.

In 2000 the Water Framework Directive (WFD) was established and put into force (EU 2000). The aim of the WFD is to protect all water bodies and establish good chemical and good ecological quality of the water bodies. The WFD forces national authorities to set standards for water quality which, in contrast to earlier legislation in the Netherlands, have legal liability. This means that responsible authorities have to take measures in order to reach the quality standards if the standards are not met. Measures might include the withdrawal of or change in the authorisation of a plant protection product. In this sense, there is feedback of monitoring results to the authorisation procedure.

The Dutch government considered the current Dutch authorisation procedure as no longer defensible in view of the procedures at European level. Furthermore, questions were raised on the compatibility of the authorisation procedure and the requirements as described in the WFD. For these reasons, the Dutch government decided to initiate an improvement of the methodology for the assessment of the effects of plant protection products on aquatic organisms. In order to establish a comprehensive methodology, the Dutch government initiated six working groups to cover various aspects of the new methodology, including a working group on the exposure of aquatic organisms. The remit of the working group on exposure is given in the following section.

1.2 Remit

As pointed out in the previous section, the Dutch government decided to initiate an improvement of the methodology for the assessment of the effects of plant protection products on aquatic organisms. A working group was established to develop new procedures for exposure assessment in edge-of-field ditches (in line with EU-Regulation 1107/2009). The following boundary conditions were set with respect to the procedures:

- They should be scientifically based and defensible and follow the generally accepted principles of risk assessment as laid down in EU-Regulation 1107/2009.
- They should allow for tiered approaches.
- They should take into account realistic worst case conditions (realistic worst case being more exactly defined as the 90th percentile of the exposure concentration).
- They should deliver various types of concentration for the realistic worst case, the types of concentration being defined by the working group on ecotoxicological effects (in other words: exposure and effect assessment should be adequately linked).

1.3 Structure of report

The remit of the working group states that procedures have to be developed for edge-of-field water courses. The domain of the current scenario is limited to field crops and downward spraying techniques (see Section 2.1). All other scenarios will be reported on later.

The report starts with a description of the endpoint of the exposure assessment and general procedures (Chapter 2). Then a description is given of the databases used for scenario development (Chapter 3). Chapters 4 and 5 describe the selection of the spray drift scenario and the development of the drainpipe scenario, respectively. Simplified models for the behaviour of substances in water courses were used in order to obtain peak concentrations of a substance in surface water. More detailed descriptions of the scenario selection are given in Tiktak et al. (2012b) and Van de Zande et al. (2012). Chapter 6 summarises the parameterisation of ditch properties, and other fixed scenario properties are given in Chapter 7. Chapter 8 describes the drift-reducing measures that can be introduced. Chapter 9 describes the user-defined model inputs. Example calculations are provided in Chapter 10. The scenarios are proposed to be part of a tiered assessment scheme (Chapter 11). Finally, Chapter 12 gives conclusions and recommendations for further investigation and the implementation of the methodologies.

2 Outline of scenario development procedures

This chapter gives an overview of the general procedures that were used to select and parameterise the edge-of-field scenario. First, the endpoint of the exposure assessment is discussed (Section 2.1). The edge-of-field scenario is intended to be a second-tier scenario. Section 2.2 describes the general set-up of tiered assessment schemes; a proposal for a tiered assessment scheme for the exposure of aquatic organisms is presented in Chapter 11. Section 2.3 gives an overview of the scenario development. In contrast to earlier procedures (FOCUS 2001), the current scenario has been derived systematically using probabilistic and geostatistical modelling based on the requirement of a specified spatio-temporal percentile of a concentration distribution (in this case the 90^{th} spatio-temporal percentile of the population of annual peak concentrations in ditches that are at the border and downwind of treated fields and that receive drain water from these treated fields).

2.1 Endpoint of the exposure assessment

2.1.1 Risk management decisions

In line with FOCUS (2000), the responsible Dutch ministries decided that the endpoint of the exposure assessment of aquatic organisms should be the 90^{th} percentile of the concentration in Dutch ditches (see Section 1.2). The ministries also decided that the population of ditches to which this percentile applies should be limited to those ditches that will potentially receive both a spray drift load and a drainpipe load of a plant protection product. Figure 1 gives a schematic representation of this population of ditches. The representation shows that this population may be a small subpopulation of the total population of ditches in the Netherlands.

An authorisation is usually requested for use in a specific crop or crop category. The ministries decided that the crop should be the entry for the exposure assessment. If an authorisation is requested for a crop category, an assessment for all crops within this category must be done and the maximum concentration of these assessments should be used.

The ministries further decided that only one scenario should be developed for field crops in the Netherlands, so the 90^{th} percentile applies to the total area of field crops. An authorisation is, however, usually requested for a specific crop or crop category. The 90^{th} percentile of the concentration can be higher or lower for a specific crop or crop category. The ministries accepted therefore that this scenario may be too conservative for part of these crops or crop categories and not conservative enough for the other part of these crops.

In the Netherlands, ditches are classified into three groups (see Section 3.2), i.e. small or temporarily dry ditches ('tertiary ditches'), ditches narrower than 3 m ('secondary ditches') and ditches wider than 3 m at water level ('primary ditches'). All these ditch types may be edge-of-field ditches. The ministries decided that all these ditch types – including temporarily dry ditches – should be included in the population of ditches. Larger water bodies (ponds, lakes and rivers) were not included in the population, because they are usually not edge-of-field water courses.

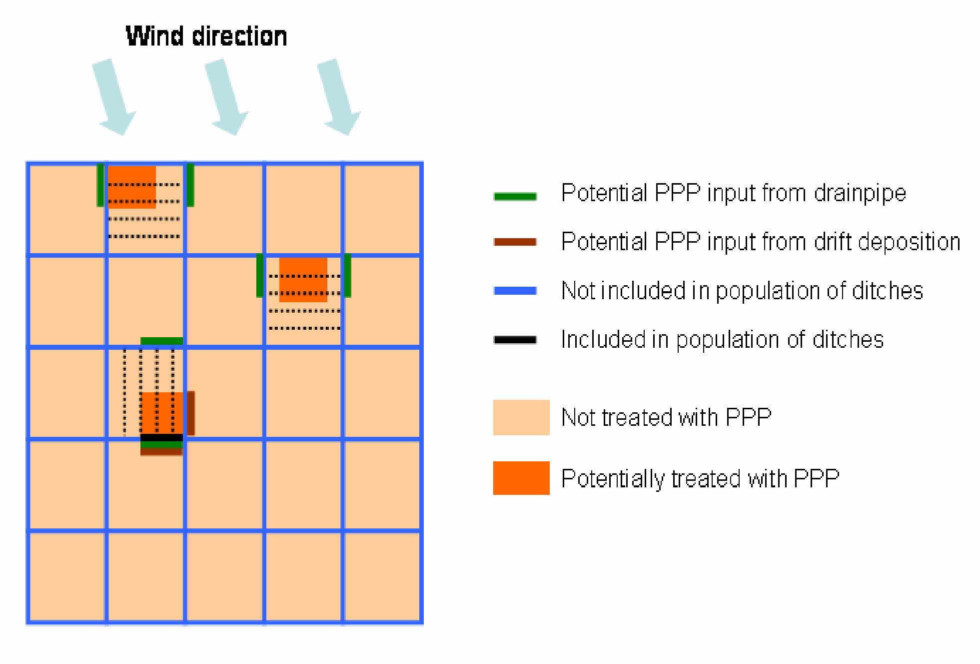


Figure 1 Schematic representation of the population of Dutch ditches (lines in the diagram) to be considered in the estimation of the percentile of the concentration of PPP in the surface water

2.1.2 *Operational decisions*

The spray drift part of the exposure assessment depends strongly on the application technique (downward versus upward and sideward spraying). As will be described in detail in Chapter 4, the spray drift estimates in the scenario calculations will be based on averages of measurements for a certain application technique. It will be ensured that these estimates result in a 90th percentile predicted environmental concentration (PEC) by selecting a certain ditch. The estimates of leaching from drainpipes will be based on a certain soil scenario (Andelst; see Chapter 5 for details).

The exposure assessment methodology in this report is restricted to applications with downward spraying techniques in field crops. At a later stage, an exposure assessment methodology for applications with upward or sideward spraying techniques in fruit crops and tree nurseries will be developed. However, as will be described in Chapter 7, it may also happen in Dutch agriculture that plant protection products are applied with upward or sideward spraying in field crops (e.g. in hop) or with downward spraying in fruit trees (herbicides). Table 1 shows all possible options for the ditch and soil scenarios for these two crop categories plus for the crop category 'permanent grassland' (this last group was added to give a complete overview of Dutch agricultural crops). For permanent grassland, the responsible Dutch ministries have not yet decided whether this should be based only on drained grassland (as was done for the field crops; see previous section).

So the exposure assessment in this report addresses only one of the six combinations of crop categories and application technique (downward spraying in field crops) in Table 1. However, this combination is expected to include the majority of applications of plant protection products in agriculture in the Netherlands.

Table 1 Overview of edge-of field scenarios for exposure of aquatic organisms. This report is limited to downward spraying in field crops (upper-left cell of table).

Crop	Ditch scenario		Soil scenario
	Applications with downward spraying	Applications with upward/sideward spraying	
Field crops	Ditch 601001 (Figure 14) based on downward spray drift measurements and all drained arable land (this report)	Ditch based on upward/sideward spray drift measurements and all drained arable land (to be defined later)	Andelst (this report)
Fruit crops and tree nurseries	To be developed later based on downward spray drift measurements from 2011 and all drained arable land	Ditch based on upward/sideward spray drift measurements and all drained arable land (to be defined later)	Probably Andelst (to be decided later)
Permanent grassland	To be developed later based on downward spray drift measurements and all drained and/or undrained grassland (political choice still to be made).	Not relevant	To be developed later

As mentioned above, our exposure assessment methodology is restricted to downward spray applications in field crops. EFSA (2004) described approaches for aquatic exposure assessment methodologies for non-spray applications including granules and seed treatments. EFSA (2004) showed that dust deposition resulting from such non-spray applications may be significant and should therefore be included in the exposure assessment. Therefore we recommend developing also aquatic exposure assessment methodologies for non-spray applications based on the recommendations of EFSA (2004).

An important step in linking exposure and effect assessment is the identification of the ecotoxicology relevant concentration (ERC). Brock et al. (2011) proposed that the endpoint of the exposure assessment should be the annual peak concentration or the annual maximum time-weighted average (TWA) value within a calendar year. Due to the non-linearity of the relation between soil and PPP parameters on the one hand and predicted environmental concentrations on the other, the result of the selection of a 90th percentile scenario may be different for different ecotoxicologically relevant concentrations. Using the peak concentration for the scenario selection may result in a different scenario from that obtained using a time-weighted average concentration. Taking also the sediment into consideration may again lead to a different scenario. Based on guidance provided by the ELINK workshop (Brock et al. 2009), the working group decided to base the selection on the annual peak concentration in the surface water. The ELINK workshop stated that an effect assessment based on acute toxicity data should always be compared with the peak concentration, whilst in chronic risk assessments in first instance also the peak concentration and under certain conditions a time-weighted average concentration may be used. Given the time constraints, the working group decided not to develop scenarios for the exposure of organisms in the sediment.

An important aspect of the risk assessment applies to the statistical population of exposure concentrations for which the scenario is intended (EFSA 2012). The statistical population has both a spatial and a temporal aspect. With respect to the spatial aspect, the working group decided that the population of ditches should be limited to ditches adjacent to arable land. Figure 2 shows that a large proportion of Dutch arable land (40 per cent) is pipe-drained. We excluded ditches in grassland areas from the population of ditches, because the use of plant protection products in grassland is small compared with use in arable land.

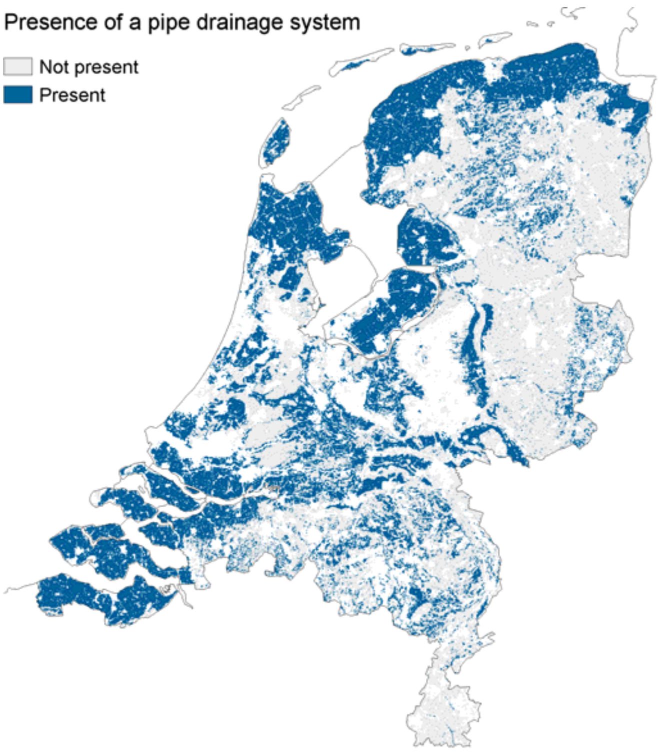


Figure 2 Presence of a pipe drainage system in the Netherlands (Kroon et al. 2001). The 90th percentile of the exposure concentration applies to ditches in the blue area.

As described before, the ERC is a peak or TWA concentration. The peak concentration differs between years. The working group therefore decided that the temporal statistical population of concentration should include multiple years. By simulating multiple years, the influence of application time on the simulated peak concentration is also reduced. Brock et al. (2011) proposed that all peak concentrations within a calendar year should be used, so they applied no time window in the scenario selection procedure. The working group decided that all annual peak concentrations should be used independently, which implies that there is no distinction between space and time.

The working group decided that 100 m of ditch should be used for the evaluation, which is in line with FOCUS (2001). Within a ditch, the substance concentration is variable due to the variability of spray drift deposition. Nevertheless, the working group proposes to use the average substance concentration across the 100 m evaluation ditch. This is a neutral choice: for fish a larger averaging length would have been better and for non-moving organisms a smaller averaging length would have been better (T.C.M. Brock personal communication 2010).

In the case of crop rotations, the working group proposes to base the exposure assessment on the cropping year that generates the highest concentration (see Chapter 11 for details). Let us consider as an example an exposure assessment for applications of a substance in two cropping years. In such a case two scenario calculations have to be carried out (one for the first cropping year and one for the second cropping year) and the highest PEC of the two calculations has to be selected.

2.2 Position in the tiered assessment scheme

As described by EFSA (2010a), tiered approaches are the basis of environmental risk-assessment schemes that support the registration of plant protection products. EFSA (2010a) defines a tier as a complete exposure or effect assessment resulting in an appropriate endpoint (in this case the PEC_{SW}). The rationale of tiered approaches is to start with a simple conservative assessment and to carry out additional, more complex work only if necessary (so implying a cost-effective procedure for both notifiers and regulatory agencies).

The general principles of tiered exposure approaches are (EFSA 2010a):
- Lower tiers are more conservative than higher tiers.
- Higher tiers are more realistic than lower tiers.
- Lower tiers usually require less effort than higher tiers.
- In each tier all available relevant scientific information is used.
- All tiers aim to assess the same exposure goal.

In short, the tiered exposure assessment needs to be internally consistent and cost-effective and to address the problem with increasing accuracy and precision when going from lower to higher tiers. These principles permit moving directly to higher tiers without performing the assessments for all lower tiers (EFSA 2010a).

The definition of a tier by EFSA (2010a) implies that decision flow charts for e.g. estimating model input parameters such as the *DegT50* in water do not contain tiers because these flow charts do not consider a complete exposure assessment resulting in an appropriate endpoint. Therefore we will call such flow charts 'stepped approaches'.

The scenario for downward spraying and field crops described in this report is intended to be a second-tier approach, to be preceded by a first tier consisting of one or more of the FOCUS surface water scenarios. Higher tiers will consider refinements such as better input parameters, emission reduction measures for spray drift, and scenarios that are better targeted to the risk assessment case considered (see Chapter 11).

2.3 Procedure for developing the exposure scenario

The endpoint of the exposure assessment is the 90th percentile of the annual maximum concentration in all ditches that potentially receive plant protection products from spray drift and drainpipes (Figure 1). Crops are usually not sprayed during large rainfall (and drainage) events, so we assumed that the peak concentration is caused by either spray drift or drainage. The advantage of this assumption is that the spray drift and drainpipe scenarios could be developed independently of each other.

The peak concentration resulting from drainage is less sensitive to ditch dimensions than the peak concentration resulting from spray drift. The main reason is that a small volume of drainage water completely refreshes the water initially present in most edge-of-field ditches (Tiktak et al. 2012b). The development of the exposure scenario was therefore structured as follows: (i) selection of a ditch that ranks at the 90th percentile in the cumulative distribution of peak concentrations in surface water resulting from drift input, (ii) selection of the drainpipe scenario, and (iii) parameterisation of the ditch using information from the first two steps. The three steps are further explained below.

2.3.1 Selection of a ditch based on spray drift input

The endpoint of the exposure assessment is a percentile, which can only be determined if the peak concentration is known for the entire population of ditches and for the entire range of possible weather conditions. The spray drift model IDEFICS (Holterman et al.1997) was used to simulate the peak concentration in 66 ditch types and 700 combinations of wind direction and wind speed, resulting in 46,200 possible peak concentrations. These 46,200 peak concentrations together represent the entire population of possible ditches and weather conditions, so that it was possible to derive a cumulative frequency distribution function from which the 90th percentile concentration resulting from spray drift could be derived.

The 90th percentile concentration can occur at different combinations of ditch type and weather conditions, as can be seen from the contour diagram in Figure 3. For instance, the points X=80 per cent, Y=80 per cent and X=60 per cent, Y=97 per cent both yield an overall 90th percentile of the peak concentration. Further selection criteria were therefore necessary. Application of these additional criteria resulted in the selection of one ditch. More details on the development of the spray drift scenario are given in Chapter 4.

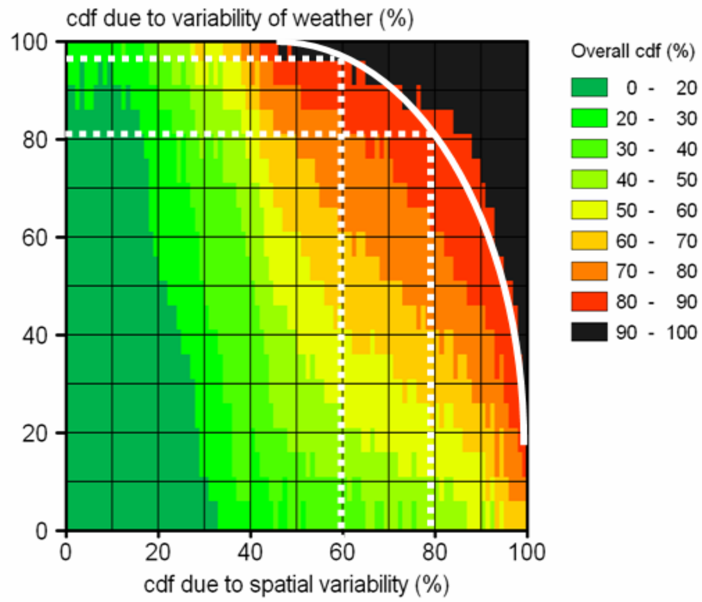


Figure 3 Example contour diagram of the overall percentiles of the peak concentration in ditch water. The X-coordinate corresponds with the percentile of the cumulative spatial distribution and the Y-coordinate with the cumulative distribution due to variability of weather conditions. The solid white line corresponds with the 90th overall concentration. The dashed white lines refer to the example combinations described in the text.

The IDEFICS (version 3.4) simulations were done for a standard situation with a 50 per cent drift-reducing nozzle and with the last nozzle position at 1.375 m from the top of the ditch bank. The 50 per cent drift-reducing nozzle was adopted because this is the minimum requirement for drift-reducing techniques at the moment. We assumed that the selected scenario would also be representative for the 90th percentile concentration if another (e.g. 90 per cent) drift-reducing nozzle had been used. This assumption allows the use of multiple drift-reducing packages in combination with the selected ditch (see Section 7.1 for details).

2.3.2 *Selection of the drainpipe scenario*

The drainpipe scenario was based on data from the Andelst experimental field site (Scorza Júnior et al. 2004), because at this field site sufficient data was available to parameterise the pesticide fate model PEARL. The advantage of taking a real site was that full benefit could be taken of the experimental data, so that a consistent and credible drainpipe scenario could be built.

Drainpipe input is calculated with a new version of the pesticide fate model PEARL (Tiktak et al. 2012a, 2012c). A new version of PEARL was necessary, because the version that is currently used in authorisation procedures (Leistra et al. 2001) does not include a description of preferential flow through macropores. Preferential flow is considered to be the key driver for the peak concentration in drain water.

The Andelst dataset covers a period of approximately one year, so we extended the dataset to a 15-year period using data from nearby monitoring stations. Long-term simulations considerably reduce the effect of application time on drainpipe input. By linking the drainpipe scenario with the ditch selected in the previous section, 15 annual peak concentrations in ditch water could be calculated.

The target for the drainpipe assessment should be the 90th percentile of the peak concentration in ditches adjacent to fields growing field crops that potentially receive input from drainpipes. The overall distribution of the peak concentration is simulated with a spatially distributed version of PEARL that is linked to a metamodel of TOXSWA (Tiktak et al. 2012b). Analogous to the distribution of the peak concentration resulting from spray drift, the overall frequency distribution function of the peak concentration resulting from drainpipe input has a spatial component and a temporal component. The spatial component results in this case from e.g. the distribution of soils and ditches, whereas the temporal component results from variability in the weather between the years. By selecting the Andelst field site, we fixed the spatial percentile, and indirectly also the temporal percentile. This can be seen in the same contour diagram as discussed before (Figure 3): if the X-coordinate is fixed, then only one Y-coordinate corresponds to the overall 90th percentile. For instance, if the spatial percentile is 60 per cent, then the temporal percentile should be 97 per cent.

The relative ranking of locations with respect to the concentration in drain water is substance dependent; hence also the spatial percentile of the Andelst site is substance dependent. Because the spatial percentile is directly linked to the temporal percentile, the target temporal percentile is also substance dependent. Further details on the drainpipe scenario and the derivation of the target temporal percentiles are given in Chapter 5.

2.3.3 Parameterisation of the ditch

The fate of the substance in ditch water is calculated with version 3.2.4 of the TOXSWA model. In this new version a simplified version of a non-stationary flow solution, i.e. simple ditch scenario concept (Opheusden et al. 2011), was recently implemented. The ditch receives input from base flow and drainage simulated with PEARL, and TOXSWA simulates the water depth and the corresponding ditch volume. Section 4.3 describes how a ditch was selected. TOXSWA was parameterised in such a way that most of the time the water level was close to the water level of the selected ditches. This was done by calibration of the height of the weir crest and the distance from the end of the ditch to the weir. Maintaining the water level close to the water level of the selected ditches ensures that the initial concentration in ditch water is consistent with the 90th percentile concentration in all ditches. More details on the TOXSWA parameterisation are given in Chapter 6.

3 Databases for scenario selection

The endpoint of the exposure assessment is the 90th overall percentile of the peak concentrations in ditches that potentially receive input from spray drift and drainpipes. This percentile is derived from the frequency distribution function of the peak concentration for the entire population of ditches and for the entire range of possible weather conditions. Two models were used, i.e. IDEFICS (Holterman et al. 1997) for spray drift deposition and a macropore version of GeoPEARL (Tiktak et al. 2002, 2012c) for drainpipe input. Most parameters for these two models were derived from national databases. These databases are briefly described in this chapter.

3.1 Soil data

A new version of GeoPEARL was developed, which contains a description of preferential flow through macropores (Chapter 5). All macropore parameters were related to data in a database that was originally developed for the spatially distributed nutrient emission model STONE (Kroon et al. 2001, Wolf et al. 2003).

Clay content is a crucial soil parameter for the macropore version of PEARL. In the Netherlands, drained soils can be roughly subdivided into two groups based on clay content, i.e. rigid, non-shrinking, sandy soils with a clay content of less than 8 per cent and shrinking, clay soils with a clay content of over 8 per cent (Figure 4). The clay soils can further be divided into fluvial clays in the centre of the country and maritime clays in the coastal regions. The highest clay contents (> 50 per cent clay) are found in the fluvial deposits.

Organic matter content is another important parameter in pesticide fate models. The lowest values of the organic matter content are found in marine clay soils and slightly higher values are found in fluvial deposits (Figure 4). The organic matter content used within GeoPEARL is the nominal (i.e. most frequently occurring) value within map-units. It is known, however, that organic matter is related to land-use type (De Vries 1999). This causes a systematic bias of the organic matter content for arable soils. How this systematic bias is dealt with, is described in Section 5.5.

The Mean Lowest Groundwater (MLG) level is an important parameter, because macropores are generally limited to this depth (Chapter 5). The MLG level is generally shallow (80–100 cm) in the riverine region and deep in the coastal clay region. Drain depth follows roughly the same spatial pattern, the deepest drains occurring in recently reclaimed polders.

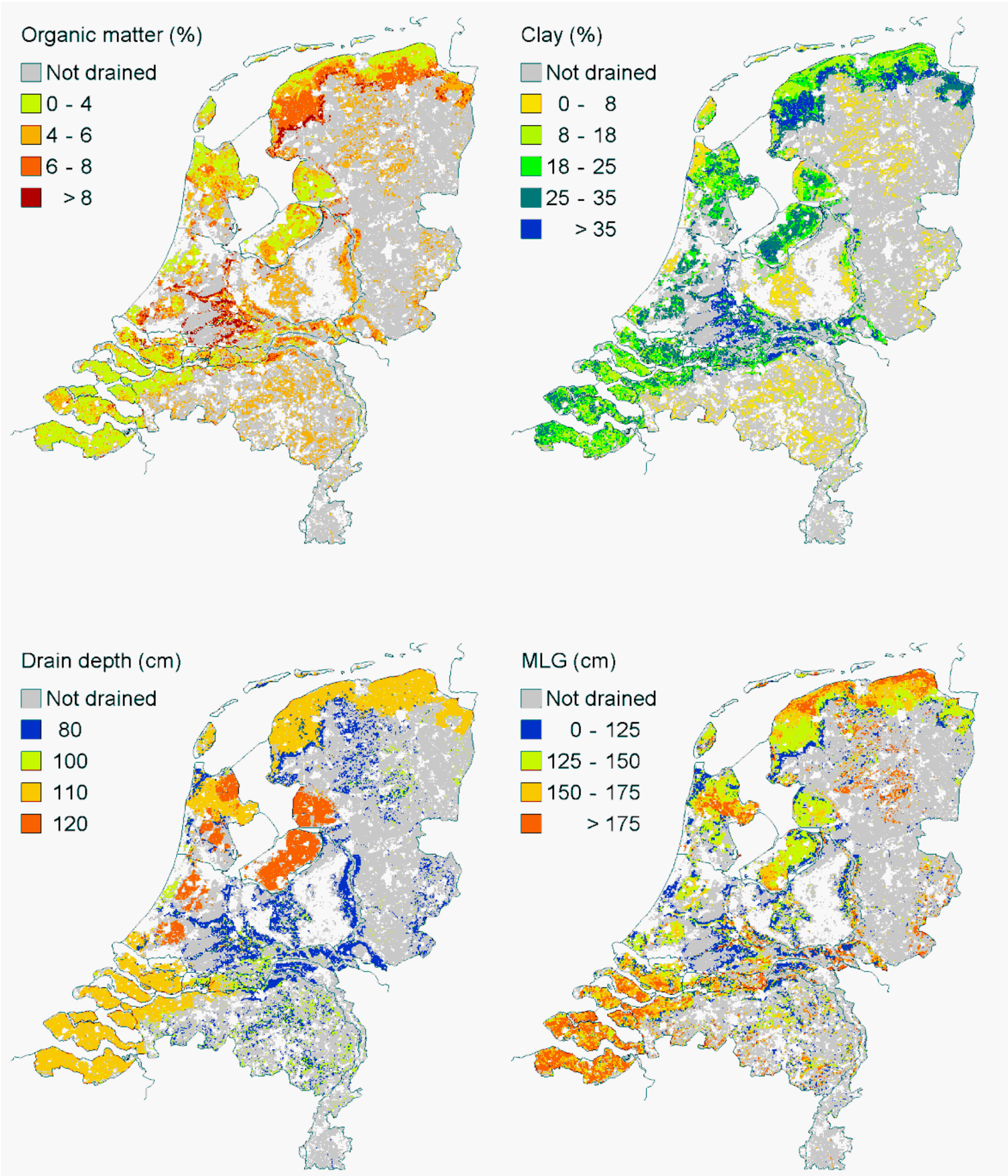


Figure 4 Basic data for the GeoPEARL model. MLG refers to the Mean Lowest Groundwater level. Only drained soils are shown, because the population of interest is limited to these soils (Section 2.1).

3.2 Dimensions of water courses

To calculate the concentration of the substance in the water, the models need information about ditch dimensions, such as the width of the water surface and the water depth (Figure 5). Some information about the width of the water courses can be found on the digital topographical map of the Netherlands (TOP10 vector). This information is too generic for our purpose, however, because water courses are shown in three broad categories only, i.e. small or temporarily dry water courses ('tertiary ditches'), water courses that have a width of less than 3 m ('secondary ditches'), water courses that have a width of 3–6 m ('primary water courses') and water courses that have a width of 6-12 m.

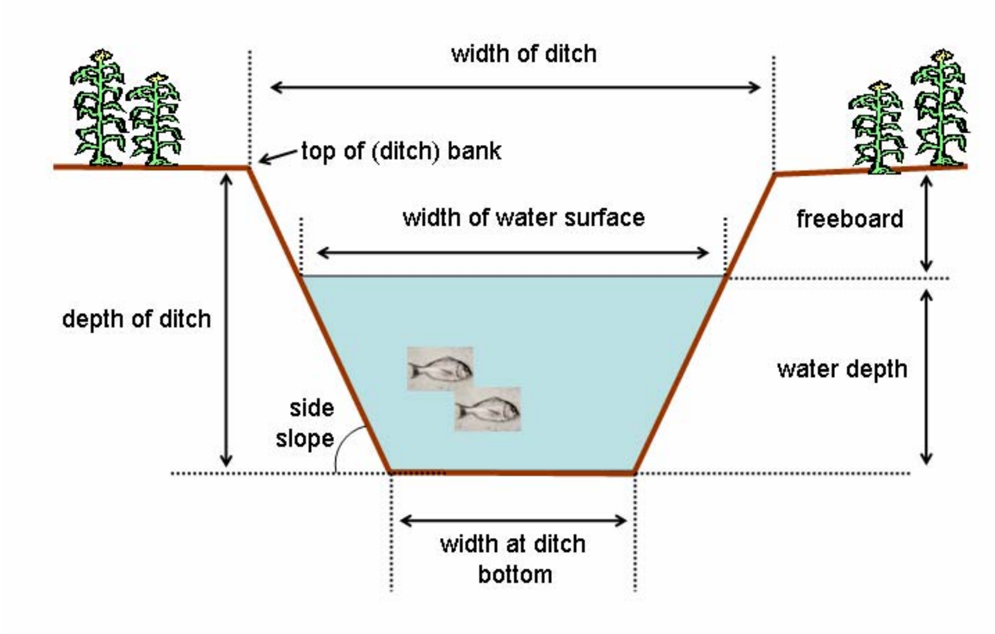


Figure 5 Characteristics of water courses described in Massop et al. (2006)

A more detailed description of ditch characteristics was obtained from Massop et al. (2006). Based on field inventories, they showed that there is a good correspondence between the geohydrological characteristics of the subsoil and ditch characteristics. Geohydrological characteristics are available for 22 so-called hydrotypes. For each combination of hydrotype and for three ditch classes shown on the digital topographical map, they calculated median values and standard deviations of the ditch characteristics, as shown in Figure 5. The ensemble of all median ditch properties is called a standard ditch profile, so the total number of standard ditch profiles was 66.

Maps of both hydrotypes and ditch classes are available, so that it was possible to establish the spatial distribution of the ditch profiles. The spatial distribution of two important ditch characteristics, i.e. the water depth and the water volume per unit ditch length (the lineic volume) is shown in Figure 6. The spatial pattern is plausible with high water volumes in the clay region and low water volumes in the sand region.

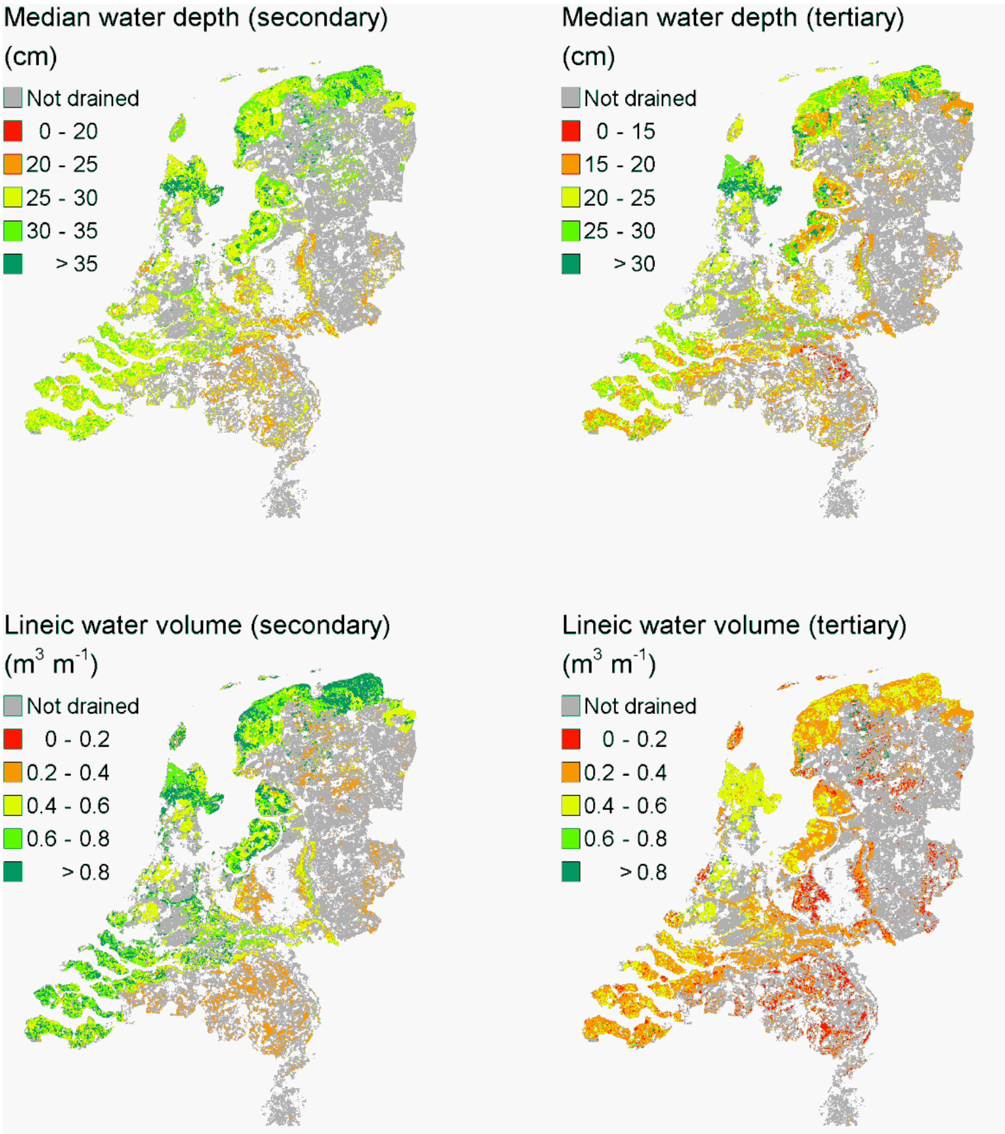


Figure 6 Median water depth in water courses (upper panel) and lineic water volume (lower panel). Figures are shown for secondary and tertiary water courses as shown on the Dutch digital topographical map. Values are for a so-called 'wet winter period'. Note the different legends.

3.3 Spray drift

The spray drift database is based on field measurements of spray drift that were performed between 1988 and 2005 (Van de Zande et al. 2012). The aim of the measurements was to determine the effect of drift-reduction technologies (DRT) compared with generally used application techniques (referred to as the reference spray technique). This was done for three crop categories, (i) field crops including bare soil surface, (ii) fruit crops (apples) in the full leaf situation and in the dormant situation, and (iii) nursery trees of different sizes. For each of these three categories, a reference spray technique and several drift-reduction techniques were defined. For each crop category, several drift-reduction technologies are available; these technologies were generalised into four classes of spray drift reduction, i.e. 50 per cent, 75 per cent, 90 per cent and 95 per cent drift reduction (see also Section 8.1).

Drift measurements
All drift measurements were carried out according to the ISO standard 22866 (ISO 2006) adapted for the situation in the Netherlands (CIW 2003). Spray drift deposition was measured on ground surface at the downwind edge of an experimental field with a crop. The measurements were done regularly during the growing season to obtain an 'average crop season' with respect to crop height and canopy density. Spray drift measurements were carried out by adding the fluorescent dye Brilliant Sulfo Flavine (BSF; 3.0 g L^{-1}) and a surfactant (Agral; 0.1 per cent) to the spray agent. All drift measurements were carried out in at least eight replicates.

Reference spray technique for downward directed spraying
The reference spray technique in field crop spraying is the use of a boom sprayer, applying 300 L ha^{-1} using TeeJet XR11004 spray nozzles (3 bar spray pressure, medium spray quality; Southcombe et al. 1997) with a boom height of 50 cm. The sprayed swath width is 24 m. For arable crop spraying with boom sprayers, 124 measurements are used to determine the spray drift curve of the reference spray technique for a (potato) crop situation.
Twenty-four measurements are used for a bare soil surface/low crop situation. Average wind speed during the measurements is 3.4 m s^{-1} at 2 m height for the crop situation and 3.2 m s^{-1} for the bare soil surface situation. Average wind direction perpendicular to the field edge is 4 ^{o} for the crop situation and 3 ^{o} for the bare soil surface situation.

Drift-reduction technologies for downward-directed spraying
In the database, data is available for the following spray drift-reduction technologies:
- air assistance on a boom sprayer;
- nozzle types of the classes 50 per cent, 75 per cent and 90 per cent drift reduction;
- end nozzle effect to prevent overspray at the field edge;
- low boom height with two nozzle types;
- low boom height with two nozzle types and additional air assistance;
- Släpduk system with two nozzle types;
- air assistance system (Hardi Twin Force) with two nozzle types;
- band sprayer in sugar beet and maize;
- shielded spray boom with two nozzle types;
- barrier vegetation of different heights;
- tunnel sprayer for bed-grown crops when spraying a field crop.

Drift deposition curves
For each of the three crop types, drift deposition curves were generated for the reference spray technique and for four classes of drift reduction techniques (50 per cent, 75 per cent, 90 per cent, 95 per cent drift reduction). The curves were generated by fitting a double exponential function (this function is described in Section 4.1) to the experimental data. Figure 7 shows the spray drift curves for the reference spray technique and for the different crop classes. The differences in spray drift from downward-directed boom sprayer applications in field crops and upward- and sideward-directed spray applications in fruit crop and nursery tree crops can clearly be seen. Further details are given in Section 7.1.

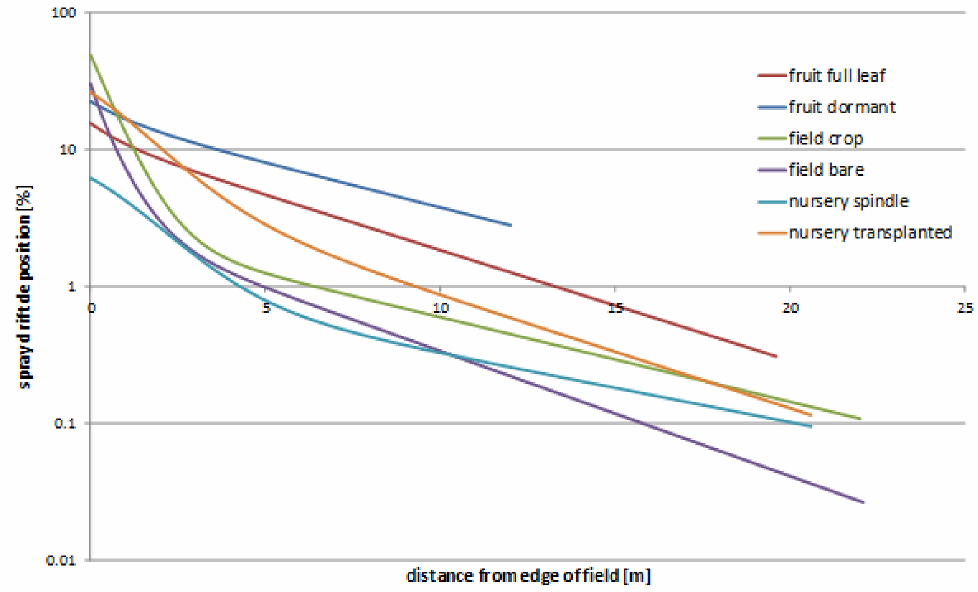


Figure 7 Spray drift curves for the reference spray techniques in field crop spraying (boom sprayer) in a developed crop and bare soil/low crop situation, fruit crop spraying in the full leaf and dormant tree situation (cross-flow fan sprayer) and nursery tree spraying in the full leaf stage of spindle and transplanted trees (axial fan sprayer). Edge-of-field defined as 3 m from last tree row for fruit crops, 2 m from last tree row for nursery trees and 0.5 m from the last nozzle position for field crops.

4 Selection of the spray drift scenario

Drift percentages used in the authorisation procedure in the Netherlands are usually derived from measurements of spray drift deposition. For the scenario selection, however, the spray drift model IDEFICS (Holterman 1997) was used as a starting point. This chapter starts with a description of the adopted approach (Section 4.1). Section 4.2 describes the dependence of the exposure concentration on wind speed, wind angle and ditch dimensions as simulated with IDEFICS. Finally, the selected scenario is described in Section 4.3. A full description of the scenario selection procedure can be found in Van de Zande et al. (2012).

4.1 Approach

The spray drift model IDEFICS (Holterman et al. 1997) was used as a starting point for the scenario selection. Drift percentages used in the authorisation procedure in the Netherlands are usually derived from measurements of spray drift deposition. The use of IDEFICS was considered acceptable because the correlation between spray drift measurements and calculations with IDEFICS is generally close. Furthermore, the measurements do not cover all possible combinations, so extrapolation is necessary in any case.

The amount of spray drift deposition on surface water is influenced by the wind speed, the angle of the wind with the surface water and the width of the surface water. Because these are variable, the following procedure was used:

1. Standard drift deposition sets in a cross-wind were established using the simulation model IDEFICS (version 3.4) to account for the effect of wind speed. Twenty simulations were done with increasing wind velocity, ranging from 0.25 m s^{-1} up to 5.00 m s^{-1} in 0.25 m s^{-1} increments.
2. For each simulation, drift deposition was fitted using the sum of two exponential functions. The resulting fit was used for further calculations.
3. Deposits on surface water were computed for each of the 66 ditch types and for 35 wind angles (-85° – +85° from perpendicular, in 5° increments);
4. Each situation was given a weight factor based on the frequency distribution of wind speeds and the length of the different ditches.

The standard simulation with IDEFICS uses the following criteria:

- downward spray application;
- boom height 50 cm above the crop (100 cm above soil surface);
- wind direction perpendicular to the ditch;
- 50 per cent drift-reducing nozzle (DG11004), operated at 3 bar, dose 300 L ha-1;
- last nozzle position 1.375 m from the top of the bank (0.5 m upwind from crop edge);
- air temperature 15°C, relative humidity 60 per cent, neutrally stable atmosphere.

The use of the 50 per cent drift-reducing nozzle was adopted because this is the minimum current requirement for drift-reduction techniques along water courses.

The runs resulted in 20 datasets of drift deposition (percentage of areic mass applied) versus distance from the treated crop. Double exponential functions $\{a_1\exp(b_1x)+a_2\exp(b_2x)\}$ were fitted to the data to reduce the computational effort for the further scenario selection. The fits of the double exponential curves were considered acceptable in view of the scenario selection. Figure 8 shows an example. Note that the vertical axis has a logarithmic scale. A maximum wind speed of 5 m s^{-1} was used, because above this wind speed spray application is not allowed in the Netherlands (except in rare crop-threatening situations).

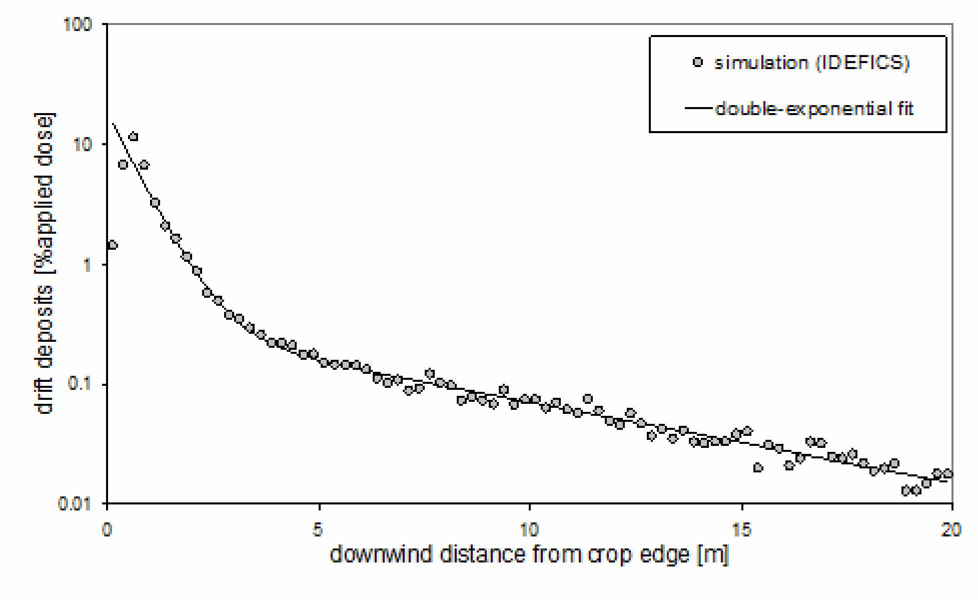


Figure 8 Downwind deposits of spray drift for an application in a potato crop using a 50% drift-reducing (DG11004) nozzle in a cross-wind with an average speed of 3 m s^{-1}. Dose is defined as mass per area (areic mass).

4.2 Impact of wind speed, wind angle and ditch dimensions

Wind speed varies from day to day and also across the day. As wind speed affects the spray drift deposition on surface water, the distribution of wind speed over time should be taken into account when deriving the 90th percentile concentrations in surface water resulting from spray drift. Figure 9 gives the frequency distribution of hourly average wind speeds over a period of ten years for the meteorological station Haarweg in Wageningen. Two distributions are given: (i) the distribution for all hourly average wind speeds, and (ii) the distribution for all hourly average wind speeds for the period between sunrise and sunset. The polynomial fitted through the second distribution was used for further calculations. The curve for the Haarweg location was used for the entire area of the Netherlands, because such detailed information was not readily available for each location in the Netherlands at the time of the selection. The period between sunrise and sunset was considered a good approximation of the period of the day where spray applications in the open field are possible or performed.

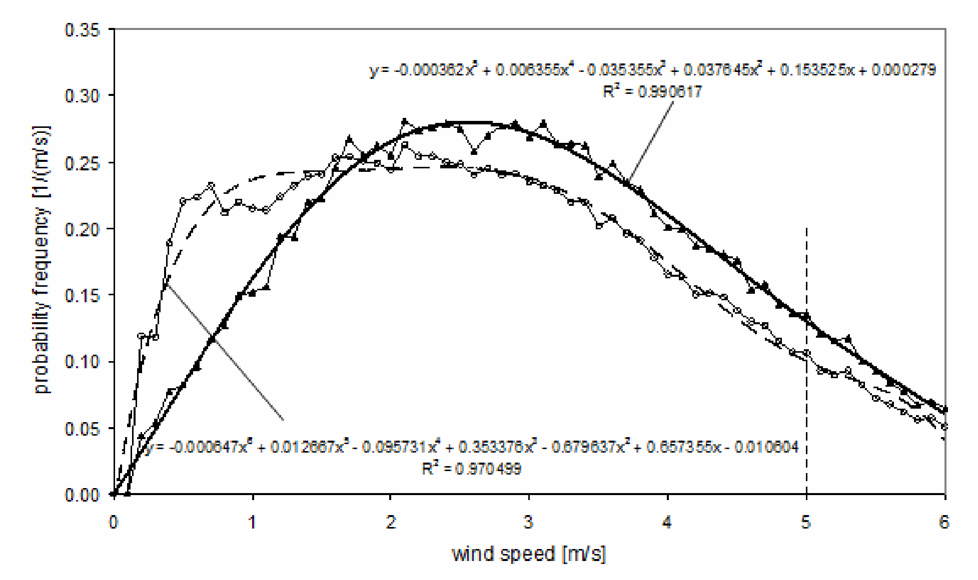


Figure 9 Frequency distribution of hourly averaged wind speeds at 2 m height; ten-year averages for meteorological station 'Haarweg', Wageningen. Circles: distribution for natural day (24 h); triangles: distribution for daylight hours only. Dashed curve: polynomial fit for former distribution; bold curve: polynomial fit for latter distribution.

The standard drift deposition curve is for the situation in which the wind direction is perpendicular to the ditch. For every other wind direction, drift droplets have to cover a longer distance from the point of release to the surface water. The additional distance is calculated from the width of the spray-free zone according to:

$$d_{add} = d\left(\frac{1}{\cos(\theta)} - 1\right) \qquad (1)$$

where d (m) is the distance from the point of release to the deposition point when wind direction is perpendicular to the ditch, d_{add} (m) is the additional travel distance, and θ (rad) is the wind direction angle relative to a cross-wind (perpendicular) direction. On the other hand, the stretch over which a substance may be deposited on the surface water is also greater. The increase may be calculated with the same formula, taking the width of the surface water as input:

$$w_{add} = w\left(\frac{1}{\cos(\theta)} - 1\right) \qquad (2)$$

where w (m) is the width of the surface water, and w_{add} (m) is the additional length over which spray drift may be deposited.

The average drift deposition on surface water over width x is the integral of the deposition over width x divided by this width. It turns out that the deposition per square m surface water decreases with increasing wind direction angle, see Figure 10. At angles above 90°, droplets are not moving towards the ditch and drift deposition is zero.

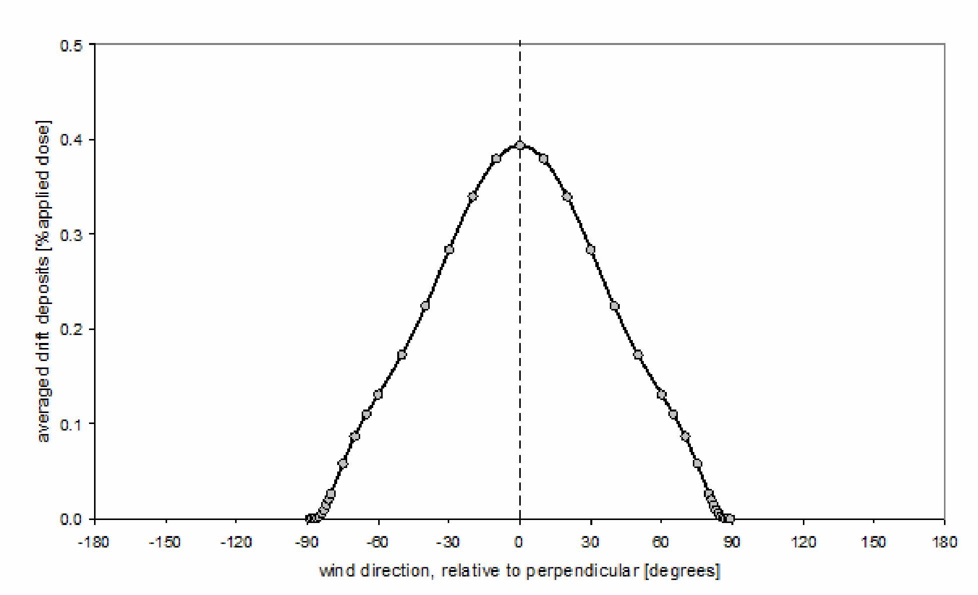


Figure 10 Example of drift deposition on surface water as a function of wind direction (relative to perpendicular). Dose is defined as mass per area (areic mass).

As described in Section 3.2, ditches in the Netherlands can be categorised into 66 classes, each defined by their width and depth. If the water level in the ditch is known and it is assumed that drift deposited on the water is immediately homogeneously distributed over the entire volume of water, then the initial peak concentration in the surface water can be calculated. For the scenario selection, water depth was assumed to be at 'normal water level' (see Chapter 6). The peak concentration is then equal to the average mass deposited per surface area divided by the average water depth. As described earlier, we decided to use the peak concentration for the selection of the scenarios.

4.3 Selection of the scenario for downward spraying

The combination of 66 ditch profiles, 35 wind directions and 20 wind speeds gives a total number of 46,200 different situations, each with its own peak concentration in the water. Figure 11 gives the cumulative frequency distribution of all these peak concentrations.

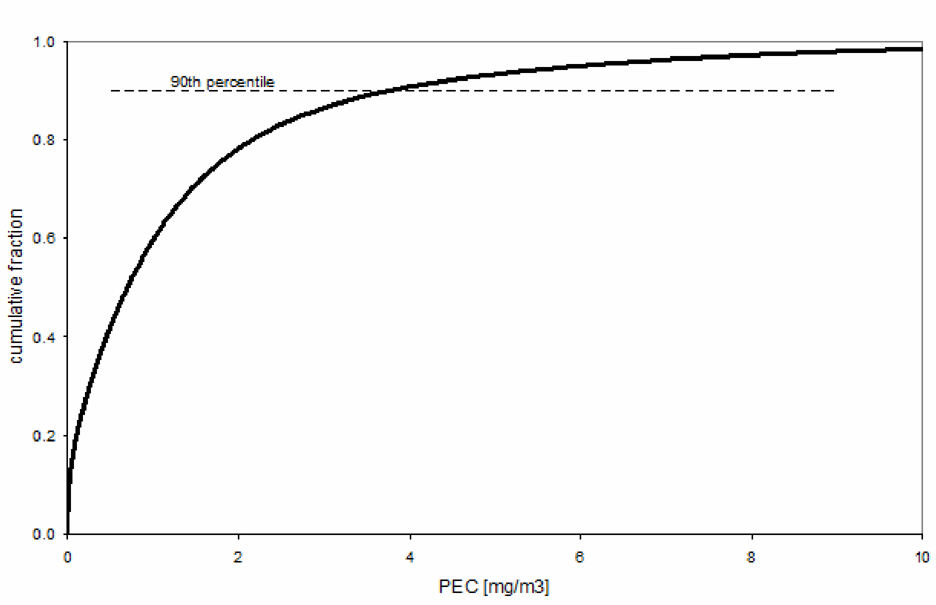


Figure 11 Cumulative frequency distribution of all possible peak concentrations in surface water

The selection of a realistic worst case condition (i.e. the 90th percentile) requires that weights be assigned to the possible peak concentrations. This was done as follows:

- Certain types of ditch are more abundant than others, so weights have to be attributed to the abundance of ditch types. For each of the 66 ditch classes the abundance is known for each grid cell of 1 km2 in terms of total length and total volume. Because we are interested in the assessment of effects on aquatic organisms, the length of the ditches was used as a weighting factor.
- The management decision (see Section 2.1) that a ditch should potentially receive both drift and drainage from artificial drains, limits the population of ditches to only those ditches that are in artificially drained areas. A map of areas that are drained is shown in Figure 2 and this information was used in the selection. So ditches outside the drained areas were assigned a weight of zero.
- Primary, secondary and tertiary ditches may all be edge-of-field ditches. There is no information on the proportion of each ditch type being edge-of-field ditches, so this aspect could not be taken into account during the selection. This implies that no weight was attached to the type of ditch. Notice, however, that primary ditches do generally not receive input from drainpipes; this group of ditches is therefore implicitly eliminated from the population.
- For the total population of ditches, it was assumed that there is no preferred angle between the ditch and the wind direction, so each angle has equal chance to occur and thus there is no weighting due to angle. Although there is a main wind direction in the Netherlands, this assumption is considered valid because we have no evidence for a preferred direction of ditches in the Netherlands.

Peak concentrations, weighted according to the procedure above, were plotted in a contour diagram (Figure 12). The X-coordinate in this diagram corresponds with the percentile of the cumulative spatial distribution (resulting from ditch properties) and the Y-coordinate with the cumulative distribution due to variability of weather conditions (wind speed and wind angle). The figure indicates that several combinations of wind characteristics and ditch characteristics may lead to the same peak concentration. For example, the points X=80 per cent, Y=80 per cent and X=60 per cent, Y=97 per cent both yield an overall percentile of 90 per cent.

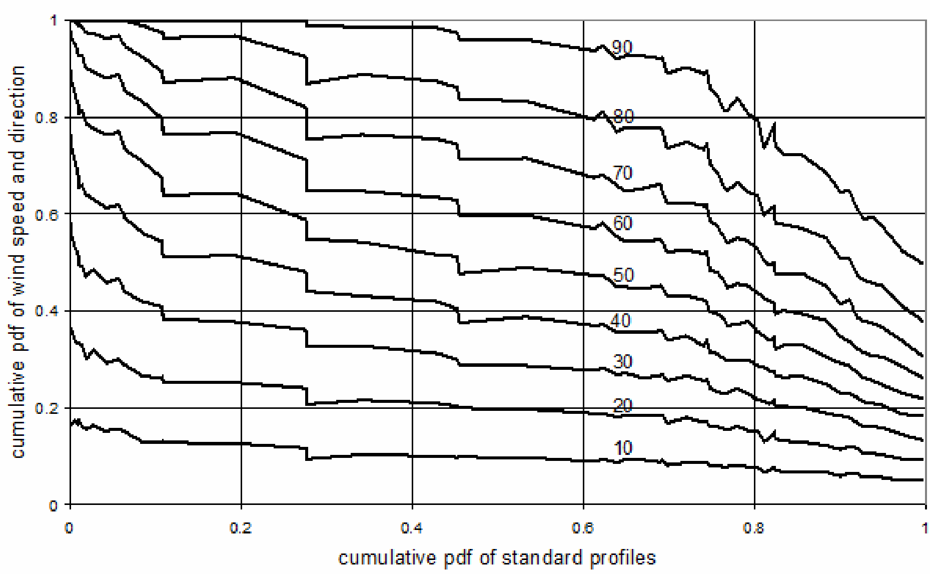


Figure 12 Contour diagram of percentiles of weighted concentrations. The horizontal axis arranges the ditches on their average concentration whereas the vertical axis arranges the effects of wind speed and direction. The lines in the diagram have equal probability of occurrence. The diagram is limited to ditches in drained areas in the Netherlands.

The endpoint for the exposure assessment is the 90th overall percentile, so a combination of water body type, wind speed and wind direction should be chosen from the contour line labelled 90. As there are many possibilities, further selection was necessary. Criteria for further selection were:

- The combination should be within 3 per cent of the target value (so between the 87th and 93rd percentile).
- The wind speed should be between 3.25 and 3.5 m s-1.
- The wind angle should be within 10 o of perpendicular.
- The ditch should be a ditch that is found in areas where land use is predominantly arable.
- The ditch should be a tertiary or a secondary ditch, because primary ditches usually do not receive input from drains.

The final selection was based on expert judgement, taking into account the relative abundance of field crops. Preference was given to a ditch that is typical for the region where the drainpipe scenario is located, as this would yield a coherent scenario. Table 2 and Figure 13 give the most important characteristics of the selected ditch.

Table 2 Characteristics of the ditch for the downward-directed spraying scenario

	Ditch properties
Code	601001
Hydroregion	river clay area
Hydrotype	Betuwe backland
Ditch type	secondary ditch
Width top ditch (m)	4.20
Width bottom ditch (m)	2.16
Width water (m)	2.62
Water depth at the wet-winter situation (m)	0.23
Lineic volume (m^3 m^{-1})	0.550
Slope (horizontal:vertical)	1

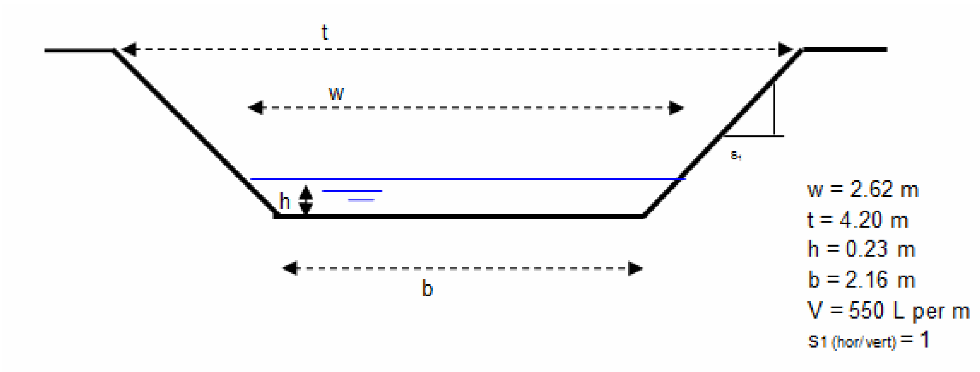


Figure 13 Dimensions of the ditch for the downward-directed spraying scenario (code 601001), where w is the width of the water surface, h is the water depth, b is the width of the bottom of the ditch, t is the width of the top of the ditch, s1 is the side slope (horizontal/vertical), and V is the lineic volume of the water in the ditch.

4.4 Multiple applications

The spray drift scenario selection was based on a single application. In practice, several treatments during the growing season are common. Van de Zande et al. (2012) performed Monte Carlo simulations to investigate whether the selected spray drift scenario is also appropriate for multiple applications. Two extreme cases were investigated, i.e.:

1. The concentration in the surface water does not decrease after an application within a growing season, so the PEC caused by subsequent applications within a growing season builds up.
2. The concentration in the surface water decreases to zero between subsequent applications.

The Monte Carlo simulations were performed as follows. For each of the 66 standard ditches, 500 'events' were simulated in which an event is defined as a set of ten repeated applications within a single growing season. One event results in a single PEC value, because the maximum concentration within a year has to be taken. The total number of results was 33,000. These results were plotted in a cumulative frequency distribution and compared with the frequency distribution resulting from a single application (Figure 14).

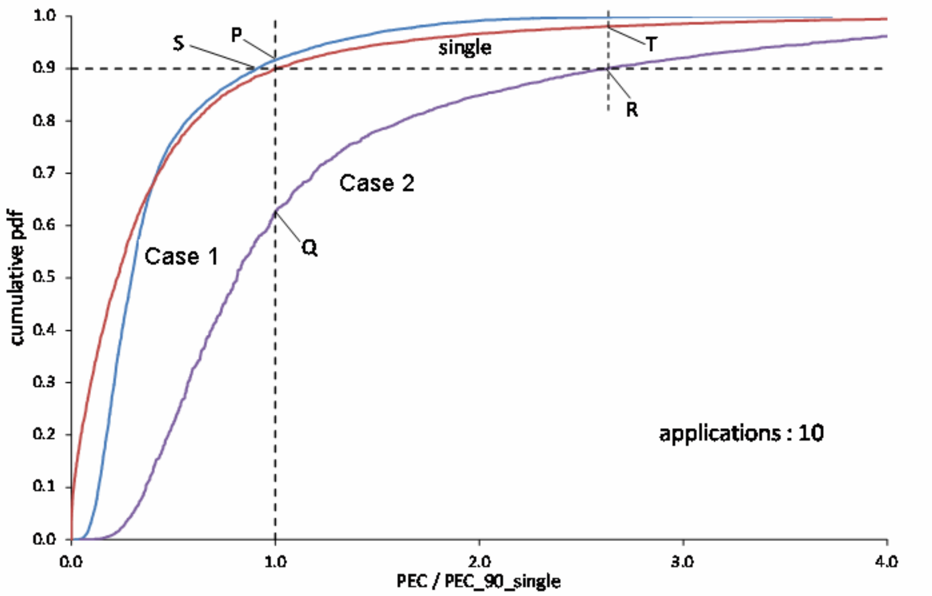


Figure 14 Cumulative probability density function (pdf) showing PEC values (relative to PEC90 of a single application) for ten spray applications. Red curve: cumulative pdf for single application; blue curve: for case 1 after ten applications; purple curve: for case 2 after ten applications. Points P, Q, R, S and T: see text.

The red line is the frequency distribution resulting from a single annual application and corresponds to the frequency distribution plotted in Figure 11. The frequency distribution for case 1 (the case in which the concentration builds up) is slightly steeper than the frequency distribution resulting from a single application, which implies that the frequency distribution resulting from multiple applications shows less variability. This was expected, because within a year, applications may be carried out under favourable or unfavourable weather conditions. This has an averaging effect on the final PEC, because only this final PEC is used for generating the frequency distribution. The 90th percentile of the PEC resulting from case 1 (point S) is about 10 per cent lower than the 90th percentile resulting from a single application. Also, the 90th percentile of the concentration distribution for the single application corresponds to a higher percentile of the concentration distribution for case 1 (about 92nd percentile: point P). It can therefore be concluded that the spray drift scenario based on a single application is only slightly too conservative for case 1.

In case 2, the frequency distribution has shifted towards a larger (relative) value (purple line). Also in this case, individual applications within a year vary because of different wind conditions. However, in this case the concentration drops to zero after an application and the maximum annual concentration is determined only by the most unfavourable application. As a result, the 90th percentile of the concentration distribution for case 2 (point R) is much higher (by almost a factor of three) than the 90th percentile concentration resulting from a single application, so the scenario based on a single application may generate a PEC value that is much too low for case 2 (the 90th percentile concentration for the single applications corresponds only to the 60th percentile of the concentration distribution for the multiple application, point Q).

The above findings indicate that the scenario based on single applications may not be sufficiently conservative for multiple applications. This can be solved by taking a higher percentile of the concentration distribution resulting from single applications. In case 2, for example, the 98^{th} percentile of the concentration distribution resulting from a single application would have to be selected (point T). As it is to be expected that an even higher percentile needs to be selected if more than ten applications within a growing season are simulated, this results in an extremely conservative scenario for single applications and for case 1. We therefore recommend developing a procedure in which the percentile to be selected depends on the number of applications and the type of substance.

Note that the findings reported here are different from those described in FOCUS (2001). First, FOCUS considered only case 1 (where a shift towards a less conservative percentile occurs) and not case 2 (where a shift towards a more conservative percentile occurs). Second, FOCUS (2001) assumed a normal distribution of wind speed and wind direction for a single spray drift event and considered only a single surface water system. We simulated the ensemble population of 66 surface water systems using a uniform distribution of the wind angle and a distribution of the wind speed based on hourly values during daytime taken from weather station in Wageningen. Thus we consider our simulations more realistic. Figure 14 shows that our curve for the single event deviates strongly from a normal distribution (it can probably be described better with a lognormal distribution).

4.5 Conclusions

A systematic procedure was followed in order to select a ditch covering realistic worst case conditions with respect to exposure from downward-directed drift deposition. The selection resulted in a number of possibilities. Application of additional plausibility criteria reduced the number of ditches chosen to one. The selected ditch is a secondary water course typical of river clay areas with a water width of 2.6 m, a water depth of 0.23 m, and a lineic volume of 0.550 m^3 m^{-1} (code 601001). It should be noted that this is the water depth at the so-called wet winter situation (Massop et al. 2006).

The selection was based on a single application. It was shown that this scenario may not be sufficiently conservative for multiple applications, particularly if the concentration does not build up between subsequent applications within a growing season. We therefore recommend developing a procedure in which the percentile to be selected depends on the number of applications within a growing season and the type of substance.

5 Selection of the drainpipe scenario

This chapter summarises the selection of the drainpipe scenario to be included in the exposure scenario for field crops and downward spraying. A more detailed description can be found in Tiktak et al. (2012b). The aim of the study reported in this chapter was to parameterise a drainpipe exposure model for realistic worst case conditions. Realistic worst- case conditions are defined as the 90th percentile of all ditches that potentially receive PPPs from drainpipes. Here, the population of ditches is not limited to ditches that receive both a spray input and a drainpipe input, because there is no relationship between wind direction and drainpipe orientation.

5.1 Approach

Drainpipe exposure is calculated with a new version of the pesticide fate model PEARL (Tiktak et al. 2012a, 2012c). A new version of PEARL was necessary, because the version that is currently used in authorisation procedures (Leistra et al. 2001) does not include a description of preferential flow through macropores. Preferential flow is considered to be the key driver for the peak concentration in drain water. Central in the new model is a description of the geometry of macropores and the presence of a so-called internal catchment domain. This internal catchment domain consists of macropores that end above drain depth (Figure 15).

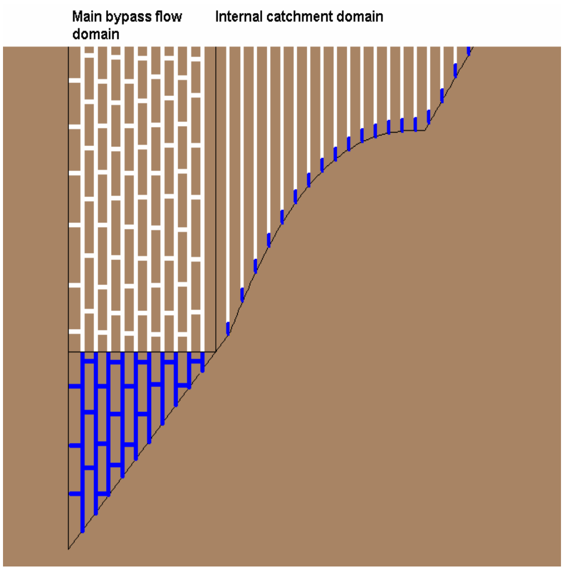


Figure 15 Schematic representation of the two macropore domains, i.e. the main bypass flow domain, which transports water deep into the soil profile, possibly leading to rapid drainage, and the internal catchment domain, in which infiltrated water is trapped in the unsaturated soil matrix at different depths.

PEARL was applied to the Andelst experimental field site (Section 5.2). Soil and hydrological data from this field site were the basis for the drainpipe scenario. The advantage of using data from this site is that full benefit could be taken of the experimental data, so that a consistent and credible drainpipe scenario could be build. The dataset covers one year of data. The working group decided, however, that the simulations should be done for a long-term period, so we extended the Andelst dataset to a 15-year period using data from the weather station De Bilt and a nearby groundwater study (Section 5.3). By doing long-term simulations, the effect of application time on drainpipe exposure is reduced considerably. The result of the PEARL simulation for the drainpipe scenario will be 15 annual peak concentrations.

The target for the drainpipe exposure assessment is the 90th percentile of the peak concentration in ditches adjacent to arable land that potentially receive input from drainpipes. The overall frequency distribution of the peak concentration resulting from drainpipe exposure has a spatial component and a temporal component. By selecting the Andelst field site, we fixed the spatial percentile, and indirectly also the temporal percentile (Figure 3). A spatially distributed version of PEARL referred to as GeoPEARL was used to determine which temporal percentile corresponds to the overall 90th percentile of the exposure concentration in all ditches (Section 5.4). A standard GeoPEARL assessment consists of PEARL simulations for 6,405 map units (Tiktak et al. 2002, 2003, 2012c). The target temporal percentile was selected by combining the overall frequency distribution obtained with GeoPEARL with the temporal frequency distribution obtained for the Andelst scenario (Section 5.5). The target temporal percentile is substance dependent. How this substance dependence is dealt with in the exposure assessment is described in Section 5.6.

Soil pH was a parameter neither in the selection of the soil profile nor in the comparison of the Andelst scenario with GeoPEARL. It is therefore unknown whether the Andelst scenario is sufficiently conservative for ionising substances. As a consequence, assessments for substances showing pH-dependent behaviour should be based on conservative estimates of the substance properties.

5.2 Application of PEARL to the Andelst dataset

PEARL was tested against data from the Andelst field site. It is currently the only Dutch dataset where sufficient data is available to parameterise and test all modules of the preferential flow version of PEARL. The field study is described in detail by Scorza Júnior et al. (2004). The application of PEARL to the Andelst dataset is described in detail by Tiktak et al. (2012a).

We showed that most parameters could be obtained from direct measurements or from commonly available data sources using pedotransfer functions; only three parameters related to the preferential flow model needed calibration, i.e. the volume of macropores at soil surface, the fraction of the internal catchment domain at soil surface, and the runoff-extraction ratio (see Tiktak et al. 2012a for a description of these parameters). After calibration, the model could describe the rapid breakthrough of the substances fairly well (Figure 16). This was not possible with the chromatographic flow version of PEARL (Scorza Júnior and Boesten 2005), even if the soil physical properties and the dispersivity were set to physically unrealistic values.

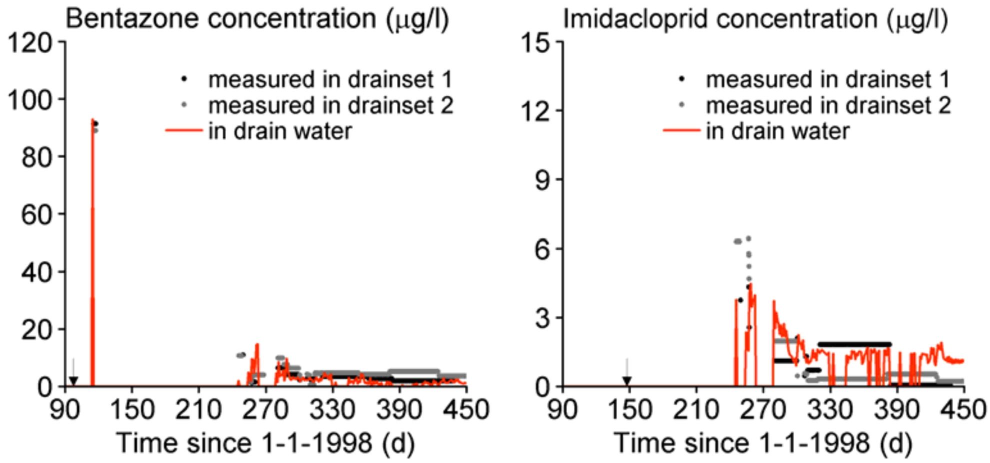


Figure 16 Measured and simulated concentration of bentazone (left) and imidacloprid (right) in drain water for two drainsets as a function of time at the experimental field site Andelst. Each drainset consisted of three connected drainpipes.

5.3 Parameterisation of the drainpipe scenario

The Andelst dataset covers a period of approximately one year. To reduce the effect of application time on the predicted environmental concentration, the working group decided that the exposure assessment should be carried out over a long-term period. We therefore extended the Andelst dataset to a 15-year dataset, using data from weather station De Bilt and from a neighbouring groundwater bore hole. During the application of the hydrological model to the long-term dataset, it became clear that actual transpiration was underestimated in a number of years. This was due to the shallow root length distribution observed at the Andelst field site. The working group judged transpiration reduction implausible for this site and therefore decided that the distribution of root length should be constant with depth. See Tiktak et al. (2012b) for additional considerations.

The result of the PEARL simulation for the drainpipe scenario will be 15 annual peak concentrations (see Figure 17 for an example). Figure 17 also shows the predicted initial concentration in the adjacent ditch as calculated with a metamodel of TOXSWA (Tiktak et al. 2012b). The figure shows a dilution factor of 30-50 per cent, indicating that the maximum concentration often occurs during relatively small drainage events.

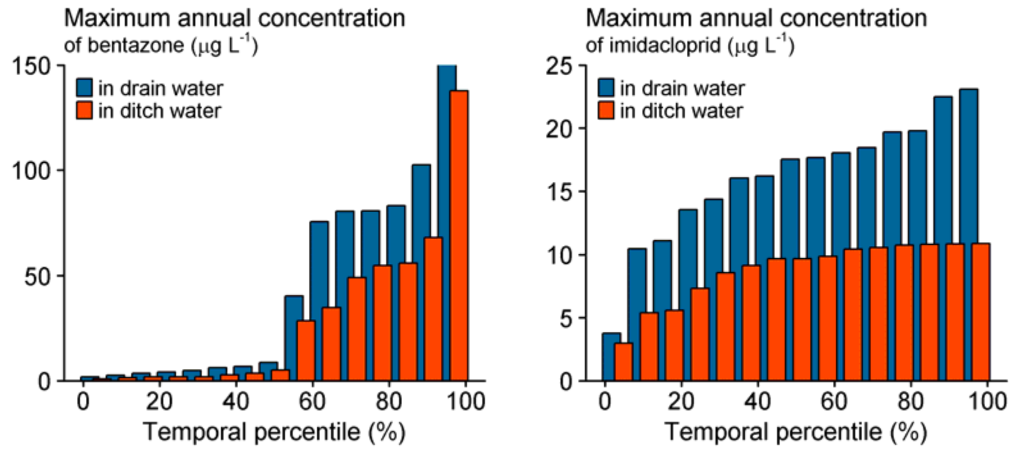


Figure 17 Predicted cumulative frequency distribution of the maximum annual peak concentration for bentazone (left-hand panel) and imidacloprid (right-hand panel). The blue bars show the concentration in drain water, the red bars show the predicted initial concentration in the adjacent ditch, using a metamodel of TOXSWA. This metamodel is described in Tiktak et al. (2012b).

5.4 Calculation of the overall 90th percentile with GeoPEARL

The assessment at the Andelst site results in a temporal frequency distribution consisting of 15 annual peak concentrations. The temporal percentile that predicts the same concentration as the overall 90th percentile is called the target percentile. The overall 90th percentile was obtained with a preferential flow version of the spatially distributed pesticide fate model GeoPEARL. A GeoPEARL run consists of PEARL runs for 6,405 map units (Tiktak et al. 2002). GeoPEARL was combined with a metamodel of TOXSWA (Tiktak et al. 2012b), so that it is possible to simulate the initial concentration in all Dutch ditches.

The first step was to derive values for the preferential flow parameters of GeoPEARL. The parameterisation of the macropore parameters is based on two sources, i.e. a series of pedotransfer functions and two field experiments. The pedotransfer functions developed in this study are obtained from a wide range of clay soils. The correlation between generally available soil parameters (clay content and organic matter content) and preferential flow parameters was generally close. Three macropore-related parameters had to be taken directly from the Andelst field site. (These are the same parameters that also needed calibration at the Andelst site.) Two of these parameters (the fraction of the internal catchment domain and the runoff extraction ratio) are extremely important for the peak concentration in drain water. We consider this an important limitation of the current parameterisation, because it is uncertain if this single field site is sufficiently representative of the entire area of drained arable soils.

Despite these limitations, the predicted spatial pattern of the concentration in drainage water is plausible, with high drainage concentrations in clay soils and low drainage concentration in sandy soils (Figure 18). At first sight, the two maps are comparable. There are, however, significant differences between them. In the northern clay area, for example, the predicted concentration in drain water shows opposite spatial patterns for the two chemicals. In this region, organic matter increases from north to south, but the hydraulic conductivity decreases from north to south. Apparently, for weakly sorbing substances, drainage conditions are optimal if the boundary hydraulic conductivity is low, whereas moderately sorbing substances are also sensitive to organic matter content.

The lesson is that the ranking of locations is substance dependent. A scenario that is sufficiently conservative for one substance may therefore not be sufficiently conservative for another substance. The consequence is that this substance dependence must be dealt with in the scenario selection procedure.

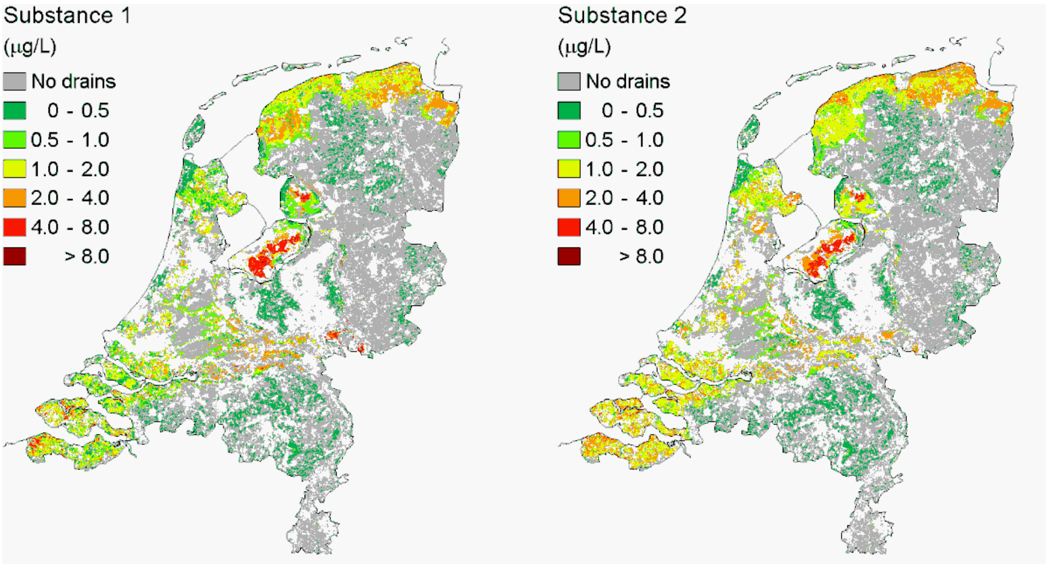


Figure 18 Median value of the predicted maximum annual concentration of two example substances in drainage water. The degradation half-life in soil is 10 days for substance 1 and 40 days for substance 2, the coefficient for sorption on organic matter is 10 dm^3 kg^{-1} for substance 1 and 40 dm^3 kg^{-1} for substance 2.

The 90^{th} percentile of the concentration in ditch water is obtained from the overall cumulative frequency distribution function of the peak concentration in field ditches. For the construction of this overall frequency distribution, all peak concentrations are used, so the number of data points of the frequency distribution is 6,405 (the number of map units) × 20 (the number of years) × 2 (the number of ditch types within one map unit) = 256,200. There are two ditch types within a map unit because a distinction is made between secondary and tertiary ditches (see Tiktak et al. 2012b for details). Weighting factors were assigned to each data point, based on the lineic length of the water courses (Figure 19). An additional weighting factor is introduced to account for the fraction of arable land within each map unit. This was considered necessary, because the population should include arable land only, and the map units are generally not homogeneous with respect to land use.

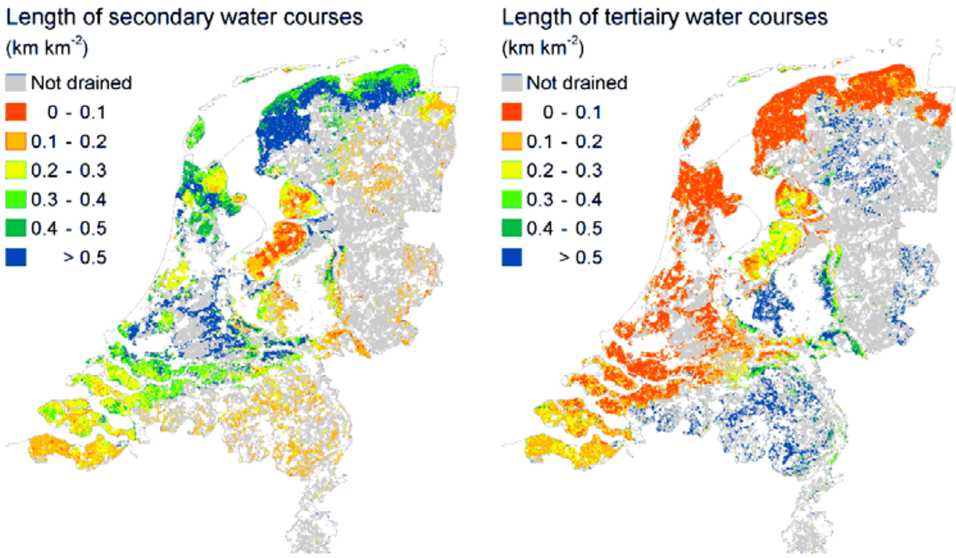


Figure 19 Length of secondary water courses (left) and tertiary water courses (right). The figure shows regions with pipe-drained soils only.

5.5 Selection of the target temporal percentile

The drainpipe scenario is based on the Andelst field site. As shown in Section 5.3, the exposure assessment results in 15 annual maximum concentrations (Figure 17). GeoPEARL was used to calculate the 90th percentile of the exposure concentration in all ditches adjacent to arable land (Section 5.4). In this section, we will derive which of the 15 annual peak concentrations corresponds best to the 90th percentile of the exposure concentration in all ditches (the target temporal percentile).

5.5.1 Method

As discussed before, simulations with the Andelst scenario give 15 annual peak concentrations. GeoPEARL was used to determine which of these annual peak concentrations corresponds to the 90th percentile of the exposure concentration in all ditches. This was done as follows:

1. GeoPEARL was run for a 20-year period, so 20 annual peak concentrations were obtained for each map unit.
2. A cumulative distribution function (cdf) of all annual peak concentrations was constructed in which each peak concentration was given a weight proportional to the total ditch length associated with the corresponding GeoPEARL plot, and the 90th percentile was calculated from this overall cdf (red line in Figure 20).
3. For the Andelst scenario, a cdf of the 15 annual maximum concentrations was created (green line in Figure 20).
4. The target temporal percentile is the temporal percentile that predicts the same concentration as the 90th percentile of the overall cdf. This percentile can be found by following the arrows A, B and C in Figure 20. In our example, the target temporal percentile to be used in the exposure assessment is 20 per cent.

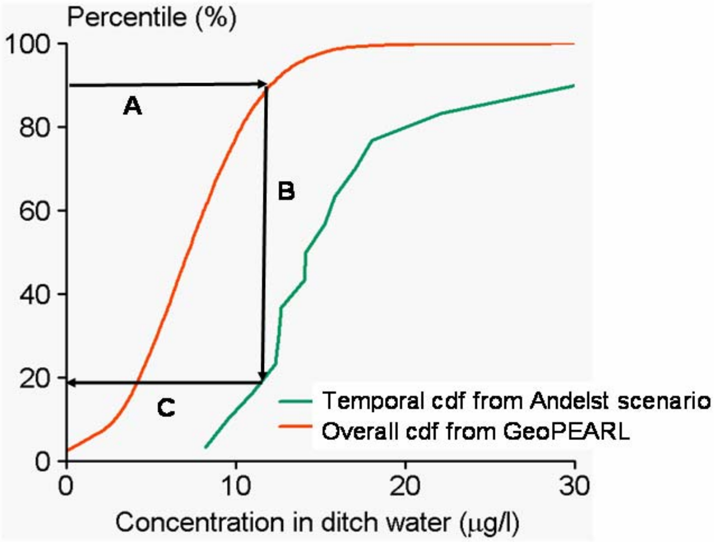


Figure 20 Procedure to derive the target temporal percentile to be used in the exposure assessment. For the Andelst scenario, the target temporal percentile predicts the same concentration as the 90th percentile of the overall cumulative distribution function (red line).

The spatial percentiles can only be calculated in an appropriate way if the differences between the GeoPEARL runs and the Andelst scenario are small. Therefore, in both the GeoPEARL runs and the runs for the Andelst scenario, substances were annually applied to the soil surface on 7 April. All substance properties (except *DegT50* and K_{om}) were set equal to the default value of FOCUS substance D as reported in FOCUS (2000). Furthermore, the depth dependence of degradation (f_z) was set to the FOCUS default values. Finally, no crop canopy interception was assumed.

Table 3 Substances included in the calculation of the target temporal percentile (green is included, grey is not included). The bold numbers in the table are the substance IDs.

	K_{om} (L kg^{-1})						
DegT50 (d)	10	20	30	60	120	240	480
10	**1**	**4**	**8**	**13**	**19**	**26**	**33**
20	**2**	**5**	**9**	**14**	**20**	**27**	**34**
30	**3**	**6**	**10**	**15**	**21**	**28**	**35**
60		**7**	**11**	**16**	**22**	**29**	**36**
120			**12**	**17**	**23**	**30**	**37**
240				**18**	**24**	**31**	**38**
480					**25**	**32**	**39**

The selected temporal percentile should be sufficiently conservative for all relevant substances. However, due to the non-linearity of the relation between soil parameters, substance properties and predicted environmental concentrations, the ranking of climate and soil property combinations is different for different substances (Section 5.4). As a consequence, a temporal percentile derived for one substance may not be sufficiently conservative when applied to another substance. To overcome this problem, the target temporal percentile was calculated for 39 substances with different degradation half-lives and sorption coefficients (Table 3). The temporal percentile to be used for the exposure assessment will be based on the temporal percentiles derived for the 39 substances.

5.5.2 *Correction for organic matter in arable soils*

The organic matter content at the Andelst site is lower (2.1 per cent) than most values in the GeoPEARL database (Tiktak et al. 2012b). This is likely to be caused by scale differences: the Andelst scenario represents a single field, whereas the soil properties in the GeoPEARL database are nominal values for 456 soil types in the 1:50,000 soil map (De Vries 1999). Organic matter content is extremely variable within these soil types (Figure 21). Part of this variability is caused by differences in land uses within a soil type. De Vries (1999) showed, for example, that calcareous clay soils have a mean organic matter content of 2.3 per cent (which is quite close to the value for the Andelst scenario) when situated in arable land but 6.2 per cent when situated in grassland.

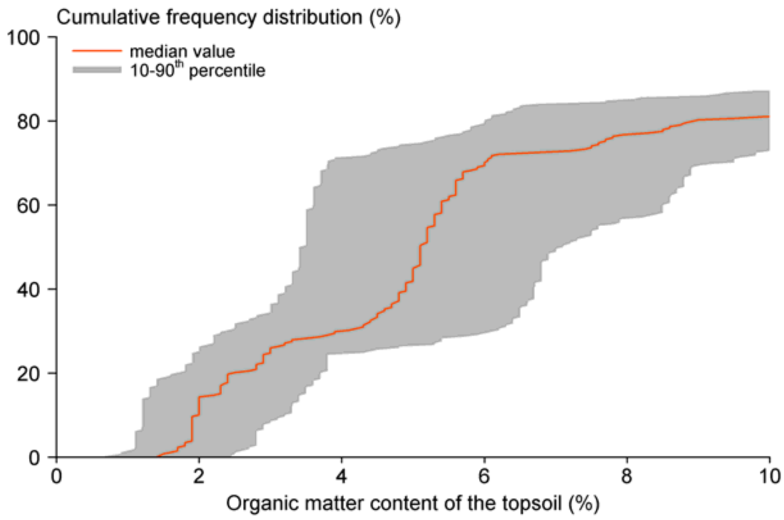


Figure 21 Cumulative frequency distribution of organic matter in the topsoil. The red line is the median value as present in the GeoPEARL database. The gray area is the interval bounded by the 10th and the 90th percentile within each map unit.

The drainpipe scenario should apply to arable soils. For this reason, the working group decided that a correction should be made for the systematic difference between organic matter content in GeoPEARL soil types and arable soil types. As a starting point, we assumed that the 10th percentile of the organic matter content within a GeoPEARL soil type corresponds to the organic matter content of arable land within this soil type. This is a best-guess solution given the limited time available. It is not clear whether this proposal will overestimate or underestimate the actual organic matter content of arable land.

The average ratio of the median value of organic matter within each soil type and the 10th percentile of organic matter is 1.56 (Figure 21). In order to convert the Andelst soil (which is an arable profile corresponding to the 10th percentile) to a typical GeoPEARL profile soil (which is a mixture of arable and grassland soils corresponding to the nominal value of organic matter content within each map soil type), the organic matter content of the Andelst soil was multiplied by this factor. Note that this scaling has been done only for the purpose of the calculation of the temporal percentiles. In the final simulations, the organic matter content was kept at its original value of 2.1 per cent, which is, as indicated, typical of an arable soil.

5.5.3 *Results*

We started the analysis with a visual comparison of the two cumulative frequency distribution functions, i.e. the overall cumulative frequency distribution of the predicted concentration in ditch water and the temporal frequency distribution of the predicted concentration at the scaled Andelst scenario (i.e. the Andelst scenario with an organic matter content multiplied by 1.56).

Results for six example substances are shown in Figure 22. These results show that the cumulative frequency distribution functions are generally steeper for substances with a high K_{om} value (a steeper frequency distribution function means that the differences between the years and/or locations are smaller). A similar conclusion was found for the temporal frequency distribution function of bentazone and imidacloprid at the Andelst field site (Tiktak et al. 2012a).

The temporal frequency distribution function at the scaled Andelst scenario shows a stronger response to substance properties than the overall cumulative distribution. This is caused by the fact that sensitivity to substance properties is location dependent. Because the overall distribution consists of a large number of locations, the overall distribution will still show significant variability, even if the variability at individual locations is negligible.

Figure 22 can be used to calculate the target temporal percentile. The target temporal percentile is the temporal percentile at the scaled Andelst scenario that predicts the same concentration as the 90^{th} percentile of the overall cdf. This percentile can be looked up by following the green arrows in Figure 22. Results for all 39 substances are shown in Table 4. As expected from Figure 22, the target temporal percentile decreases with increasing K_{om} and with increasing *DegT50*. For substances with a high K_{om} and *DegT50*, the target temporal percentile is zero. This means that for these substances, the target concentration will be higher than the concentration at the 90^{th} overall percentile. Why this is the case is explained in Section 5.6.

Table 4 Target temporal percentile for the 39 example substances. The target temporal percentile is the temporal percentile at the scaled Andelst scenario that predicts the same concentration as the 90^{th} percentile of the overall frequency distribution function.

	K_{om} (L kg^{-1})						
DegT50 (d)	10	20	30	60	120	240	480
10	77.8	75.6	75.1	65.8	59.5	56.7	50.3
20	77.8	73.6	70.9	65.2	59.2	56.7	43.4
30	77.6	72.6	70.7	65.8	50.5	56.8	43.4
60	-	55.3	55.8	65.3	59.9	55.8	50.9
120	-	-	35.0	22.9	25.5	28.0	14.4
240	-	-	-	37.9	9.5	4.9	3.5
480	-	-	-	-	50.9	6.9	0.0

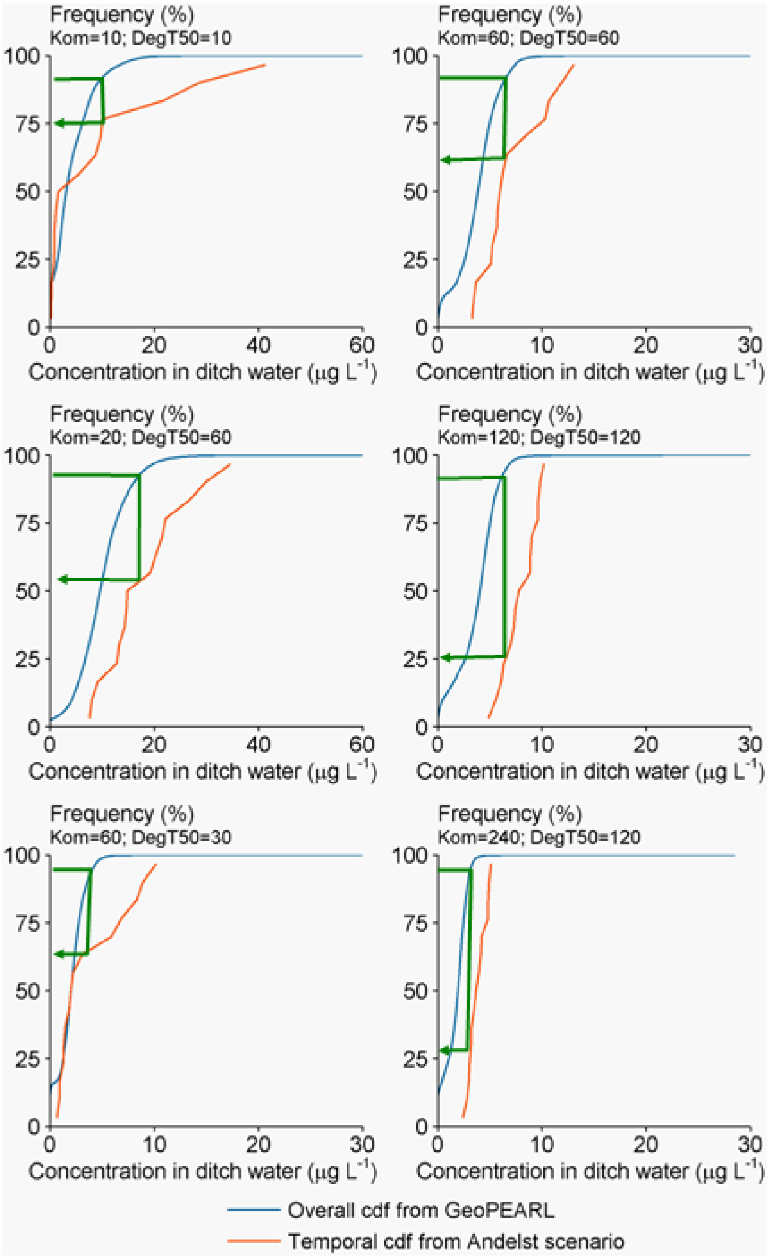


Figure 22 Comparison of the overall cumulative distribution function (cdf) from the GeoPEARL run and the temporal distribution function for the 15 years at the scaled Andelst scenario (i.e. organic matter multiplied by 1.56). The green lines indicate the target temporal percentile. The green arrows are only indicative; see Table 4 for exact values.

5.6 Temporal percentile to be used in the exposure assessment

As shown in Section 5.6, the target temporal percentile is substance dependent. One possible solution to this problem would be to include all these temporal percentiles in the software tool DRAINBOW and let the software tool automatically select the temporal percentile. There are, however, uncertainties in the selection of the temporal percentile. One uncertainty results from the use of the simplified lower boundary condition in GeoPEARL: it consists of a long-term average soil water flux on which a sine-function with fixed amplitude is imposed (Kroon et al. 2001). Additional analyses of the effect of the lower boundary condition showed that due to the use of fixed lower boundary conditions, the differences between the years were underestimated by GeoPEARL. In view of this uncertainty, the working group considered it more appropriate to use only one temporal percentile in DRAINBOW. This temporal percentile should be sufficiently conservative for the majority of substances. Figure 23 shows the ratio between the predicted concentration for a certain temporal percentile at the Andelst scenario and the overall 90th percentile concentration predicted by GeoPEARL. This figure shows that the use of the 63rd temporal percentile is sufficiently conservative for most substances. The working group judged the overestimation of the exposure concentrations for substances with high K_{om} and high *DegT50* acceptable because of the uncertainties associated with (i) the selection of the 10th percentile of the organic matter content within map units and (ii) the effect of the lower hydrological boundary condition.

Figure 24 shows the 63rd temporal percentile of the predicted peak concentration as a function of substance properties. This concentration increases with increasing *DegT50* and decreases with increasing K_{om}. A similar trend is found in models based on the convection-dispersion equation (Boesten and Van der Linden 1991). They observed that the leaching concentration in groundwater differed by four orders of magnitude in a smaller range of *DegT50* and K_{om} values. Compared with those differences, the observed differences in Figure 24 are small. The maximum concentration in drain water is primarily caused by preferential flow, where the substance bypasses most of the reactive part of the soil.

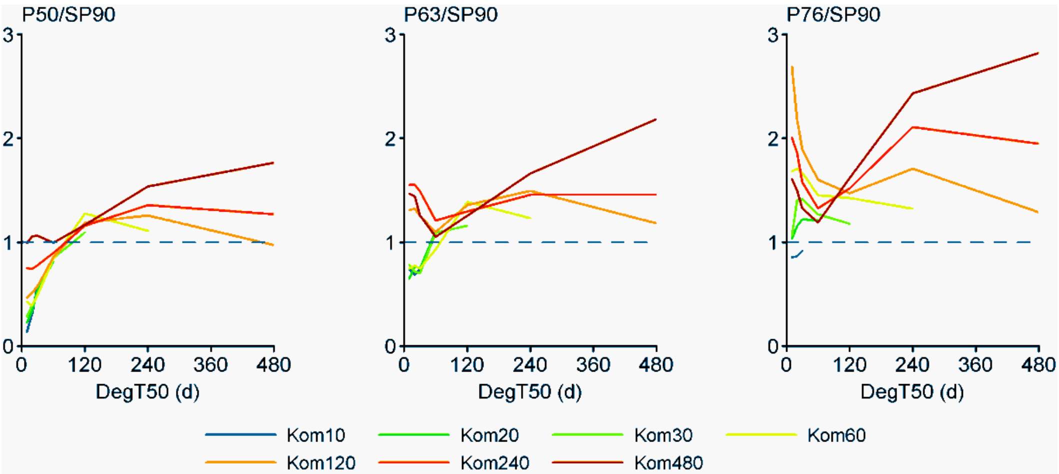


Figure 23 Ratio of the predicted concentration for a certain temporal percentile at the Andelst scenario and the overall 90th percentile concentration predicted by GeoPEARL

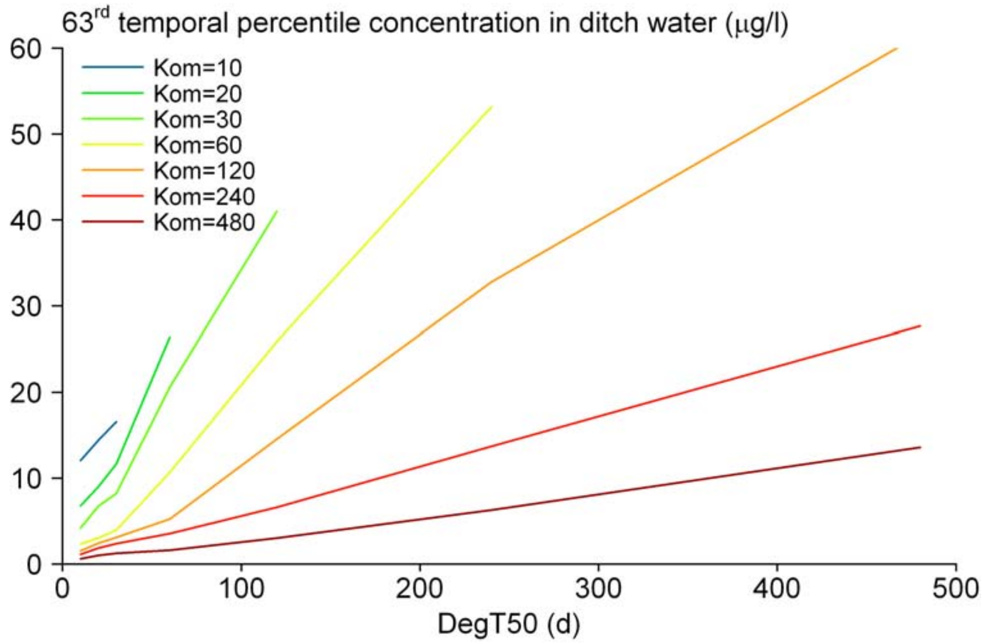


Figure 24 63rd temporal percentile of the peak concentration in the adjacent ditch. The figure is based on simulations with 39 hypothetical substances with properties shown in Table 3.

5.7 Conclusions

As part of the proposed revised assessment procedure of exposure of aquatic organisms, a drainpipe scenario was developed that corresponds to the 90th overall percentile of the exposure concentration in Dutch ditches that potentially receive input from drainpipes. This scenario is based on data from an experimental field site on a cracking clay soil.

The assessment at the Andelst field site results in a temporal frequency distribution consisting of 15 annual peak concentrations. The target temporal percentile (i.e. the percentile for which the predicted concentration is equal to the overall 90th percentile in all ditches adjacent to arable land that receive input from drainpipes) decreased with increasing K_{om} and *DegT50* and its value ranged between 10 per cent and 43.3 per cent. The predicted differences of the target maximum concentration were small compared with differences of the leaching concentration as predicted by the convection-dispersion equation (Boesten and Van der Linden 1991). This was judged plausible, because the maximum concentration is primarily caused by preferential flow where the substance bypasses most of the reactive part of the soil profile.

6 TOXSWA parameterisation of scenarios

The fate of substances in water is simulated with the TOXSWA model (Adriaanse 1996, Adriaanse and Beltman 2009). In order to run TOXSWA, a range of characteristics relating to the dimensions, sediment and organic components (Section 6.2), water temperature (Section 6.3) and hydrology (Section 6.4) of the ditches is required to parameterise the scenario. TOXSWA also needs the dimensions of the water course. These dimensions result from the scenario selection procedure and are given in Chapter 4. Note that the ditch profiles that we have adopted are realistic profiles rather than the rectangular ditch profiles used by FOCUS (2001).

6.1 Conceptual model

The water body system simulated by TOXSWA consists of a water layer and a sediment layer. The water layer permanently carries water. In line with FOCUS (2001), the water layer contains suspended solids, but no macrophytes. Furthermore, precipitation into the ditch and evaporation from the ditch are not taken into account. The sediment layer is characterised by its bulk density, porosity and organic matter content. We assumed no depth dependence of these properties for the Dutch scenario. In the water layer the substance concentration varies in the horizontal direction, but we assumed no variability in the lateral and vertical directions. In the sediment layer, the substance concentration is variable in both the horizontal and vertical directions. Seepage is not considered in the scenario, so advective and dispersive transport in the sediment is not taken into account. The exchange of substances across the water-sediment interface takes place by diffusion.

In 2011, the TOXSWA model has been reprogrammed and the description of the hydrology is based upon improved numerical solutions of the water balance and momentum equations. A simplified version of the non-stationary flow solution, i.e. the 'simple ditch' concept has been implemented, in which the water level is assumed to be horizontal (Opheusden et al. 2011). This new version of the TOXSWA model is used to simulate variations in water levels, discharge and exposure concentrations. A weir located downstream of the 100 m evaluation ditch maintains the water level in the ditch at a minimum depth (Figure 25).

In TOXSWA, a 1,300 m long ditch is simulated (Figure 25). However, only the average concentration in the part of the ditch from 200 m to 300 m is used for the evaluation. The choice of a 100 m length is in line with FOCUS (2001). The choice to use the average substance concentration in the 100 m evaluation ditch is neutral: for fish a larger averaging length would have been better and for non-moving aquatic organisms a shorter averaging length would have been better (Section 2.1.2). The distance from the end of the 100 m evaluation ditch to the weir is set to 1,000 m (FOCUS 2001). Consequently, variations in water levels and discharge were simulated for the full length of the ditch. To save computation time, variations in exposure concentrations were simulated for the first 350 m of ditch only. Agricultural fields along the first 300 m of ditch (i.e. the 2 ha upstream catchment and the 1 ha adjacent field in Figure 25) are treated. FOCUS (2001) assumed also a 2 ha upstream catchment and a 1 ha adjacent field but assumed that the upstream catchment was untreated. However, we consider Dutch upstream catchments too small to justify without further scientific analysis that they are untreated. Therefore the proposed scenario is based on the assumption that also the 2 ha upstream catchment is treated at the same time and with the same dosage as the adjacent field. We will consider the effect of this assumption in a sensitivity analysis (see Section 10.5).

An additional 50 m ditch with an untreated 0.5 ha adjacent field was simulated to take into account the effect of longitudinal dispersion over the lower boundary of the 100 m evaluation ditch. An analysis showed that simulation of an extra 50 m ditch was sufficient to get concentrations close to the concentrations simulated for an infinitely long ditch. Longitudinal dispersion is calculated using Fischer's equation (Fischer et al. 1979):

$$E_{phys} = c\frac{\bar{u}^2 w^2}{du^*} \qquad (3)$$

where E_{phys} ($m^2\ s^{-1}$) is the physical dispersion coefficient, $\bar{u}$ ($m\ s^{-1}$) is the average cross-sectional flow velocity, w (m) is the width of the channel, d (m) is the depth of the channel, u^* ($m\ s^{-1}$) is the shear velocity, and c (-) is a coefficient.

Fischer's original equation uses a value for *c* of 0.011, which is representative of large streams (tens of metres wide and one or more metres deep). For the Dutch scenario the value for *c* was set at 0.028. This value is calibrated using measured values of dispersion in Dutch field ditches, brooks and small rivers from the literature.

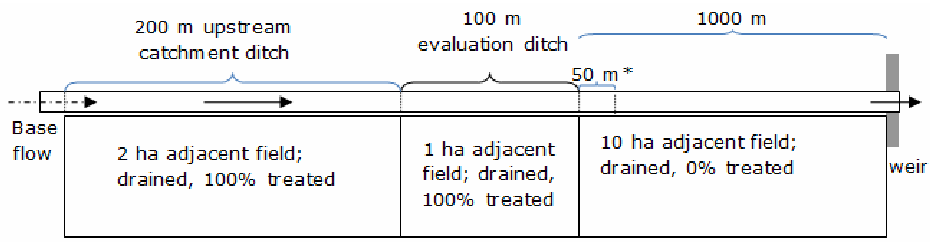


Figure 25 Schematic layout of the 100m evaluation ditch in TOXSWA with adjacent field, upstream catchment and weir. Pesticide fate in an extra 50 m was simulated to take into account the effect of dispersion over the lower boundary of the 100 m evaluation ditch.

The ditch receives input from base flow and drainage. An analysis with PEARL showed that the base flow is very small for the heavy clay soils of interest, so we assumed a very small and constant value (5 L d^{-1} or 5 10^{-5} $m^3\ m^{-1}\ d^{-1}$). Drainage fluxes were calculated by the PEARL model (Chapter 5). Because of the considerations above, they were assumed to originate from both the upstream catchment and the adjacent field.

6.2 Suspended solids and sediment components

The concentration of suspended solids and the properties of the sediment were derived from national databases. Where national databases were considered inappropriate, data from FOCUS (2001) were used. Properties are shown in Table 5 and are further explained in the sections below. TOXSWA makes it possible to deal with macrophytes. As a conservative assumption, we assumed no macrophytes to be present, as macrophytes tend to adsorb chemicals.

Table 5 Sediment and suspended solid characteristics of the Dutch scenario

Characteristic	Value
Concentration of suspended solids in the water layer	11 g m^{-3}
Mass fraction of organic matter in suspended solids	0.090 kg kg^{-1}
Sediment layer depth	0.1 m
Mass fraction of organic matter in sediment	0.090 kg kg^{-1}
Bulk density of the sediment	800 kg m^{-3}
Porosity	0.68 m^3 m^{-3}
Tortuosity	0.56 (-)

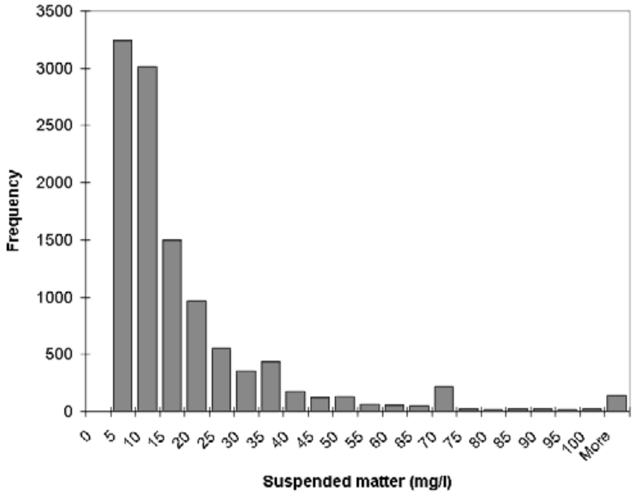
6.2.1 *Suspended solids*

The concentration of suspended solids was derived from two databases, namely the ‘bulk database’ maintained by the Ministry of Infrastructure and the Environment, and the Limnodatabase Neerlandica (STOWA 2010, personal communication E.T.H.M. Peeters). The first database contains data from the 26 Dutch Water Boards on larger water bodies and ditches. The second database contains data on the ecological quality of surface waters measured by regional water managers.

Summary statistics of the two databases, including the subset of 16 ditch locations of the bulk database, are given in Table 6; the frequency distribution is given in Figure 26. To avoid bias by extreme values, the median value of the Limnodatabase Neerlandica (11 mg L^{-1}) is proposed for the scenario. This value corresponds well to the median value of the bulk database (10 mg L^{-1}). The value of 5 mg L^{-1} (the median value of the subset of 16 ditch locations of the bulk database) is not considered, because this value represents a small part of the country only and it is not sure if this value is a good approximation of the value for the entire population of ditches to be considered in the exposure assessment. The organic matter content of suspended solids is assumed to be equal to the organic matter content of the top layer of the sediment.

Table 6 Suspended solid concentrations measured in Dutch surface waters

	Number of locations	Number of data points	Concentration (mg L^{-1})		
			Minimum	Maximum	Median
Bulk database, ditches, 2005–2009	16	272	1.0	320	5.0
Bulk database, surface waters, 2009	1523	11,160	0.0	1070	10.0
Limnodatabase Neerlandica, ditches, 1985–2005	861	12,394	0.0	860	11.0



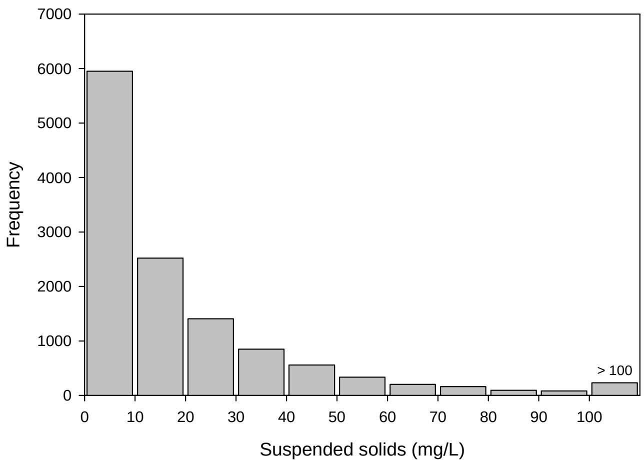


Figure 26 Frequency distribution of the concentration of suspended solids in surface waters in the Netherlands based on data from the bulk database (left) and the Limnodatabase Neerlandica (right). The left-hand figure applies to the year 2009; the right-hand figure applies to the period 1985-2005.

6.2.2 Sediment properties

Only two studies with data on the sediment properties of field ditches in the Netherlands were found (Table 7). These data were considered inappropriate to parameterise the sediment of the Dutch scenario, because the number of data points is small. Also, ten data points are from peat areas, which are generally not part of the population of ditches to be considered in the exposure assessment, because the dominant land use in these regions is grassland. Also, peat areas are generally not pipe-drained. For this reason, we decided to use the sediment properties of the current FOCUS scenarios (FOCUS 2001), which are based on data from experimental ditches (constructed for sandy soils) in the Netherlands and expert judgement.

Table 7 Sediment characteristics of the upper 10 cm of sediment in Dutch ditches from two studies

	Wet bulk density (kg dm^{-3})	Organic matter content (%)	
Three ditches in peat nature areas	0.45–1.60	20.5–47.7	Arts and Smolders (2008a,b)
Four ditches in other nature areas	0.45–1.60	0.9–10.3	Arts and Smolders (2008a,b)
Five peat sediment ditches and two peat on sand sediment ditches	Not available	3–56	Schrier-Uijl et al. (2010)

We increased the porosity from 0.60 m^3 m^{-3} as used by FOCUS (2001) to 0.67 m^3 m^{-3}, because the original value is not consistent with the organic matter content of 0.09 kg kg^{-1} and the bulk density of 800 kg m^{-3} when realistic values are substituted for the density of organic matter and the mineral phase (Korevaar 1983, see the calculation procedure below). The organic matter content was not changed, because organic matter is expected to have a large effect on the predicted exposure concentration in water. Results of the calculation procedure are given in Table 5.

The calculation of the porosity starts with the following equation (Korevaar 1983):

$$\varepsilon = 1 - \phi_{om} - \phi_{\min} \tag{4}$$

where ε (m^3 m^{-3}) is the porosity of the sediment, φ_{om} (m^3 m^{-3}) is the volume fraction of organic matter and φ_{min} (m^3 m^{-3}) is the volume fraction of the mineral phase. The volume fraction of organic matter of the sediment is calculated according to:

$$\phi_{om} = \frac{\rho}{\rho_{om}} m_{om} \tag{5}$$

where ρ is the bulk density of the sediment (kg m^{-3}), ρ_{om} is the density of the organic matter in sediment, and m_{om} (kg kg^{-1}) is the mass fraction of organic matter in sediment. The density of the organic matter in sediment is assumed to be equal to the density of the organic matter in soil and assumed to be 1,400 kg m^{-3} (Korevaar 1983). The volume fraction of the mineral phase of the sediment is calculated according to:

$$\phi_{min} = \frac{\rho}{\rho_{min}} \left(1 - m_{om}\right) \tag{6}$$

where ρ_{min} is the density of the mineral phase of the sediment (kg m^{-3}), which is assumed to be equal to the mineral density of soil of 2,650 kg m^{-3} (Korevaar 1983).

In the new scenario, no depth dependence of sediment properties is assumed, because no field data were found on vertical variability in the top 10 cm of the sediment. Taking the average of the 10 cm is considered worst case for exposure in the water layer above the sediment, because the highest organic matter content and porosity of the top millimetres is 'diluted', resulting in less sorption in the top millimetres and less diffusion to the sediment. In the existing Dutch surface water scenario (Beltman and Adriaanse 1999), depth dependence was taken into account, because it was accepted at that time to use data from the experimental ditches at the Sinderhoeve, the Netherlands.

The tortuosity factor, λ (-), controls the diffusion of chemicals into the sediment, and is estimated according to Boudrau (1996):

$$\lambda = \frac{1}{1 - \ln\left(\varepsilon^2\right)} \qquad (7)$$

The diffusion coefficient of the substance in water was set to its default value, i.e. 4.3 10^{-5} m^2 d^{-1} (Jury et al. 1983).

6.3 Temperature

Values of the water temperature are needed for the calculation of the volatilisation and transformation of the substance. TOXSWA uses monthly values, which are to be input into the model. We assumed that the temperature in ditch water equals the air temperature. Mean monthly temperatures were calculated on the basis of the daily minimum and maximum air temperatures of the meteorological dataset of the Andelst parameterisation in PEARL. The factor for the effect of temperature on the rate coefficient of transformation in water and sediment is calculated with the Arrhenius equation (see Equation 7.6 in Leistra et al. 2001) and applied over the entire range of mean monthly temperatures used as input in TOXSWA.

6.4 Hydraulic characteristics of selected ditches

In TOXSWA, two types of surface water can be specified: a pond and a water course. A set of parameters defining the water flow dynamics determines whether a water course behaves like a ditch or a small stream. The Dutch scenario parameterisation of TOXSWA is such that slowly moving water in the ditch is simulated. In accordance with FOCUS (2001); the width of the weir was set to 50 cm and the bottom slope of the ditch to 0.0001.

As mentioned before, the water level needs to be simulated and is dependent on the height of the weir crest, the distance from the end of the ditch to the weir and the drainage fluxes simulated with PEARL. The target water depth and water volume follow from the scenario selection and are listed in Table 2. These figures are valid for a so-called 'wet winter period', which means that the frequency of exceeding the mean highest groundwater level is approximately 30 days per year. For the dimensioning of weirs and water courses, discharge norms and freeboard norms are defined (Table 8) by engineers. These definitions were therefore used to parameterise the height of the weir crest. Similar to the FOCUS ditch scenarios, the weir is assumed to be located 1,000 m downstream of the 100 m evaluation ditch (Figure 25).

We started with the assumption that the normal water level can be directly related to the values for the 'wet winter period' in Table 2, because the frequency of exceeding the mean highest groundwater level (30 days a year) is roughly the same as the frequency of exceeding the normal water level (10 to 20 days a year). This implies that the height of weir crest was parameterised in such a way that the target water depth in Table 2 (0.23 m) was reached or exceeded on 10–20 days a year. This was done as follows. First, a cumulative frequency distribution was created from the 15 years of simulated discharge in the centre of the 100 m evaluation ditch. The reason for selecting the drainage in the centre of the evaluation ditch is that this value also represents the average discharge in the 100 m evaluation ditch. From the cumulative frequency distributions, the discharge values corresponding to the 94.5th temporal percentile and the 97.3rd percentile were read (Figure 27). These temporal percentiles correspond to the 10-20 days criterion mentioned above. Next step was to calibrate the discharge-water depth relation in such a way that the discharge corresponding to the normal water level was between the 94.5th and 97.3rd temporal percentile (Figure 27).

Table 8 Definitions of discharge norms and freeboard norms used for dimensioning Dutch water courses (Cultuurtechnisch Vademecum 1988 p. 549)

Design discharge	Discharge reached or exceeded on one or two days a year.
Half of the design discharge	Discharge reached or exceeded on 10 to 20 days a year.
High water level	Water level at design discharge, so the water level reached or exceeded one or two days a year on average.
Normal water level	Water level at half the design discharge, so the water level reached or exceeded on 10 to 20 days a year.

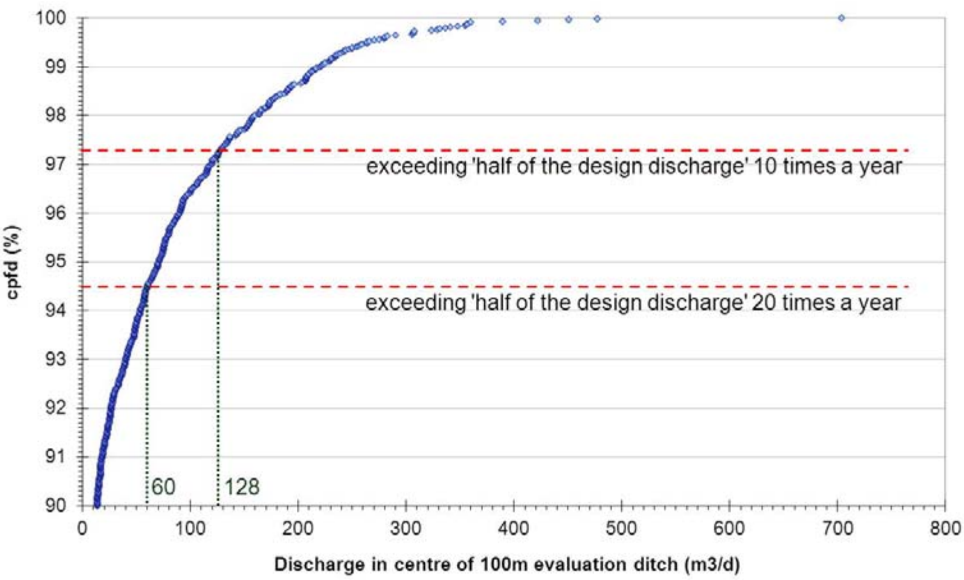


Figure 27 Cumulative frequency distribution (cdf) of the discharge in the centre of the 100 m evaluation ditch over the 15 years of simulations

Figure 27 shows the cumulative frequency distribution of the 15-year simulated discharge in the centre of the 100 m evaluation ditch. The 94.5th percentile of discharge corresponds to 60.0 $m^3\ d^{-1}$ and the 97.3th percentile of discharge corresponds to 128.2 $m^3\ d^{-1}$. Figure 28 shows the discharge–water depth (Q-h) relation after calibration of the height of the weir crest (30 cm).

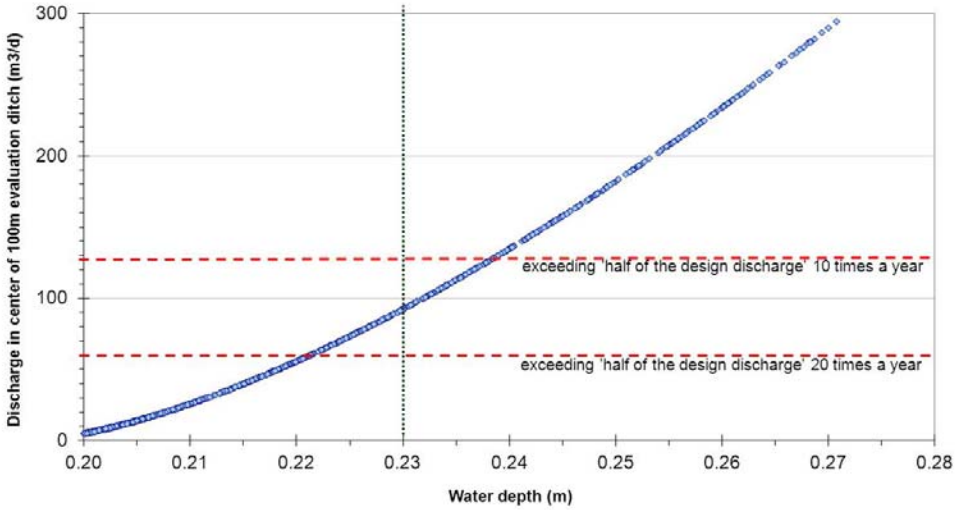


Figure 28 Q-h relation as result of the calibration of the height of the weir crest (30 cm)

Figures 29 to 32 give information on the simulated water depth, discharge and flow velocities as a function of time. For about 64 per cent of the time, the average discharge in the 100 m evaluation ditch is lower than 10 L d^{-1} and flow velocities are very low (1–1.5 cm d^{-1}). Average daily residence times in the evaluation ditch are for about 13 per cent of the time between 1 and 10 days. During rainfall events, flow velocities are calculated to be in the order of a few cm per second, which is according to Dutch experts realistic for this type of polder ditch in the Netherlands.

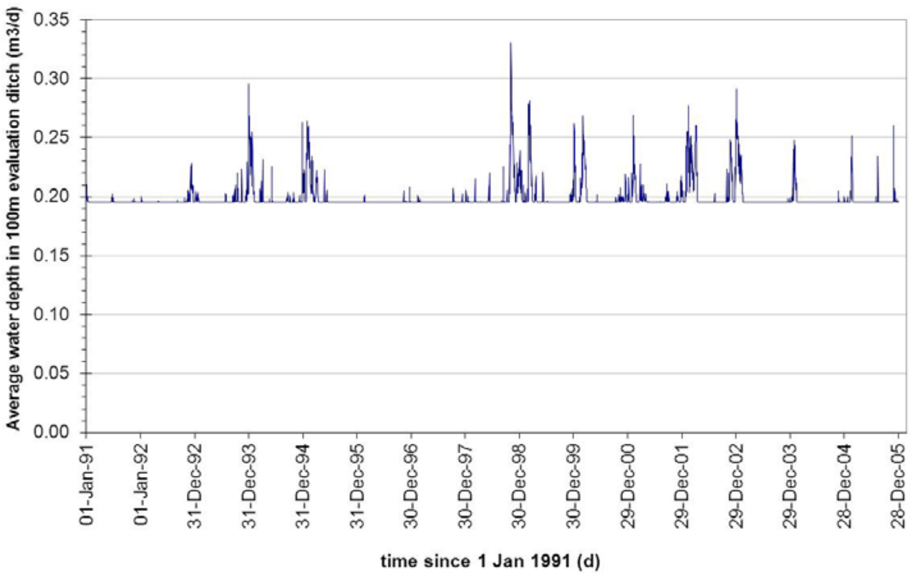


Figure 29 Water depth in the centre of the 100 m evaluation ditch as function of time (1 Jan. 1991 – 31 Dec. 2005) and as result of the calibration of the height of the weir crest (27 cm)

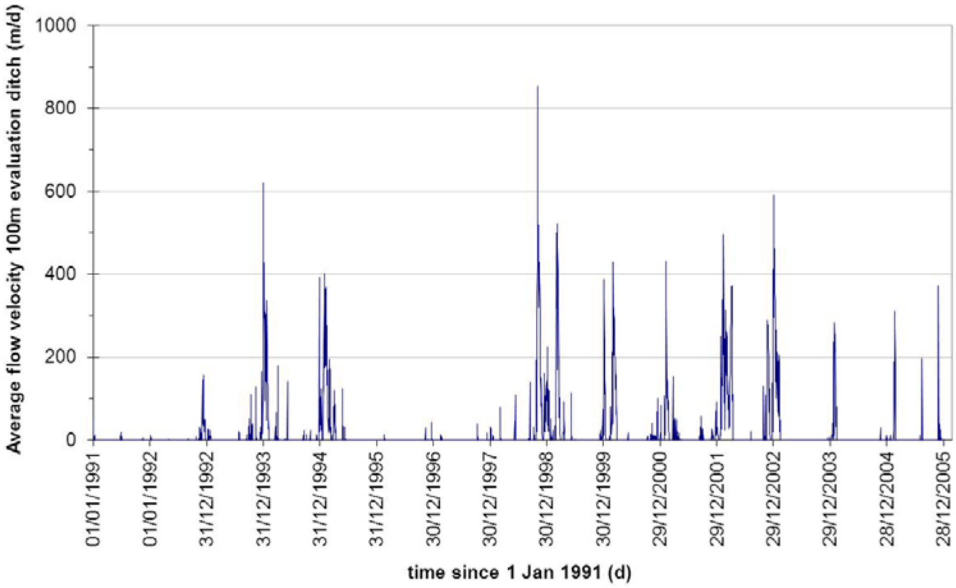


Figure 30 Flow velocity in the centre of the 100 m evaluation ditch as function of time (1 Jan. 1991 – 31 Dec. 2005) and as result of the calibration of the height of the weir crest (30 cm)

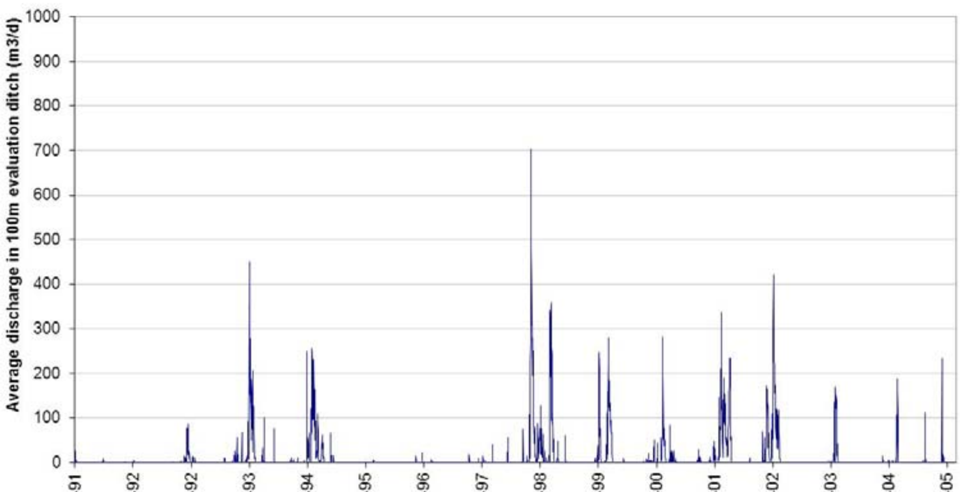


Figure 31 Discharge in the centre of the 100 m evaluation ditch as function of time (1 Jan. 1991 – 31 Dec. 2005) and as result of the calibration of the height of the weir crest (30 cm)

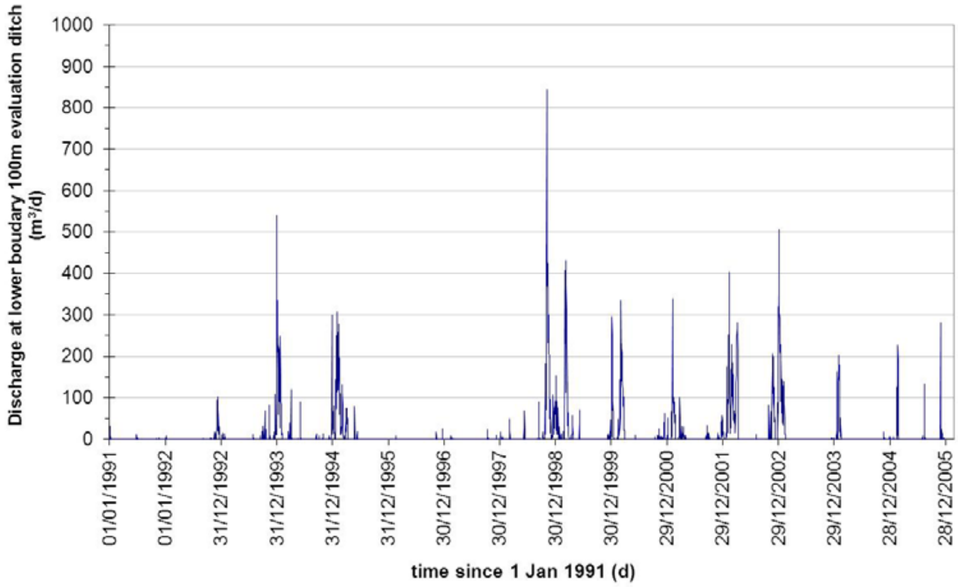


Figure 32 Discharge (leaving the 100 m evaluation ditch at the lower boundary) as function of time (1 Jan. 1991 – 31 Dec. 2005) and as result of the calibration of the height of the weir crest (30 cm)

Figure 33 gives the annual water balances (1991–2005) for the full length of the ditch for which the hydrology is calculated (1,300 m). As mentioned in Section 6.1, base flow is generally small, so input of water by drainage and outflow of water at the downstream end of the ditch are the main water balance components. Annual drainage and outflow are almost equal, which implies that the storage change is generally small. In two years (1996 and 1997), drainage fluxes and outflow were practically zero. This explains the low flow velocities for these two years as shown in Figure 30.

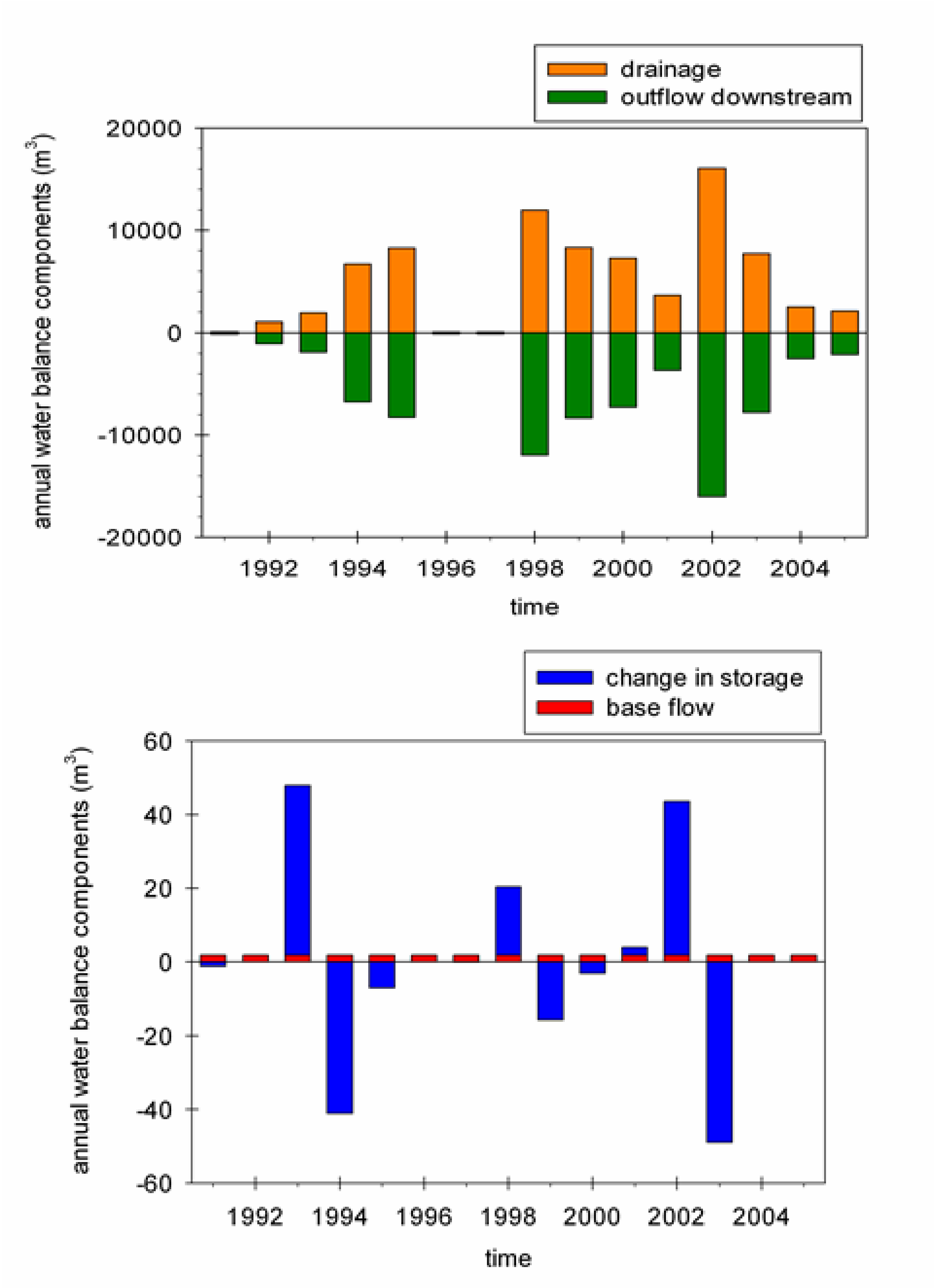


Figure 33 Annual water balance for the period 1991–2005. Top panel: Major water balance components (input by drainage and outflow at the downstream end of the ditch). Bottom panel: Minor water balance components (base flow and storage change). Storage change is defined as the difference between water storage at the beginning of the year and water storage at the end of the year. Note the different scales of the y-axis.

The hydrological simulations of the 1,300 m ditch result in a closed water balance; the numerical water balance error is therefore not shown. The TOXSWA model gives output of the water balance of the first 350 m of the ditch (Figure 25). A small water balance error does occur in the water balance for this first 350 m, because in the simple ditch concept, the water level has been simplified to a horizontal water level over the entire ditch. The water level is calculated on the basis of water level changes, Δh. For trapezoidal cross-sections and a sloping ditch bottom this results in water depths being a function of the distance to the downstream weir. This implies that an identical change in water level results in an increase in the change in water volume in the ditch (see Figure 34). For rectangular cross-sections this phenomenon does not occur.

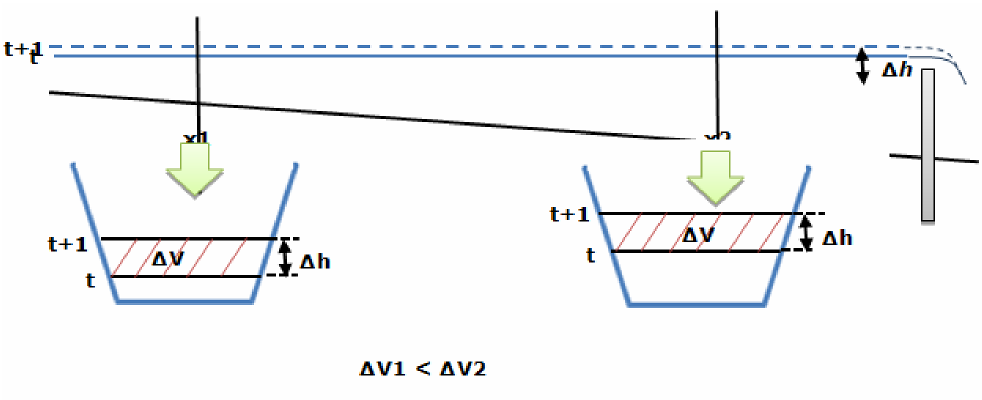


Figure 34 An identical change in water volume at two different locations results in a different change of the water level at these two locations, when using the simple ditch concept.

Because the change of water volume is not constant along the length of the ditch, a small water balance error occurs in the water balance of the first 350 m ditch (i.e. the increase of depth at the beginning of the ditch leads to less increase of volume than at the end of the ditch, where the width of water surface larger). It was found that the maximum water balance error for the 350 m ditch is 0.45 per cent of the ditch volume, which was judged acceptable.

7 Parameterisation of other scenario properties

This chapter describes scenario properties related to spray drift (Section 7.1), interception (Section 7.2), atmospheric deposition (Section 7.3) and the crops for the PEARL model (Section 7.4). This report is limited to downward spraying in field crops. Nevertheless, an overview of the link between crop-treatment class and spray drift parameterisation is given for upward and sideward spraying as well.

7.1 Spray drift parameterisation

As described in Section 2.1, the spray drift curve to be selected for the exposure assessment depends on the application technique. Different spray drift curves are therefore available for downward-directed spraying techniques (Section 7.1.1) and upward- and sideward-directed spraying techniques (Section 7.1.2).

The crops for which an authorisation for the use of a plant protection product can be requested are listed in the Definitielijst Toepassingsgebieden Gewasbeschermingsmiddelen (in this report referred to as the DTG-list). The full list is presented in Van de Zande and Ter Horst (2012). The relation between the spray drift curve to be selected and entries in the DTG-list is shown in Table 9. In the table, a distinction is made between herbicide treatments (H), fungicide treatments (F) and insecticide treatments (I), as the spray drift curve to be selected may differ between treatments (for example, hop is sprayed downward in the case of herbicide treatments and sideward in the case of fungicide and insecticide treatments).

The distance between the spray boom and the top of the ditch bank affects the spray drift deposition; definitions of distances are given in Figure 35.

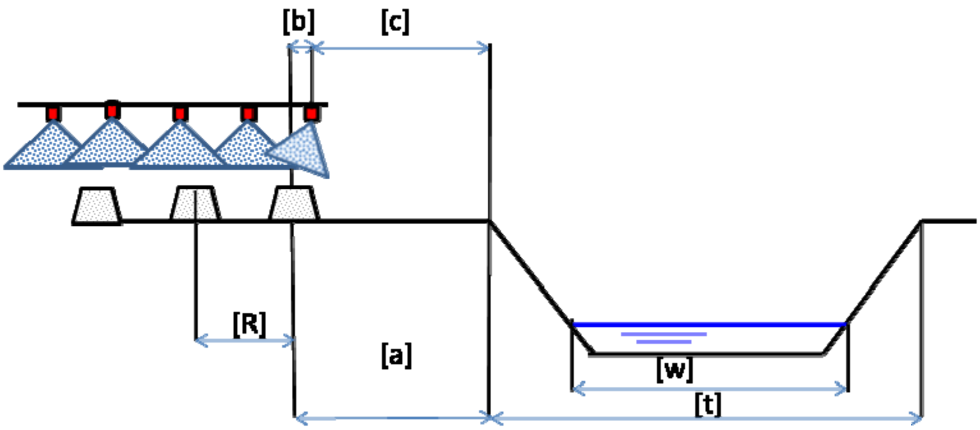


Figure 35 Definitions in the spray drift parameterisation used throughout this report. [a] is the distance between the top of the ditch bank and the centre of the last plant row (i.e. the total crop-free zone), [b] is the distance between the last nozzle position and the centre of the last crop row, [c] is the distance between the last nozzle position and the edge of the ditch, [R] is the distance between the crop rows, [w] is the width of the water surface, and [t] is the width of the ditch (i.e. the distance between the top of the banks).

An authorisation has to requested for a crop. If an authorisation is requested for a cultivation category, a crop subcategory or a crop category, an assessment for all crops within this category must be done and the maximum of these assessments should be used.

Table 9 Relation between the spray drift curve to be selected in the exposure assessment and the crop (category) in the adapted DTG-list (Van de Zande and Ter Horst 2012). The numbers in the final three columns refer to the spray drift curves in Figures 36 and 37.

Cultivation category[1]	Crop category, crop subcategory or crop[1]	H[2]	F[2]	I[2]
1. Arable crops	Cereals (1.3)	DW1	DW1	DW1
	Grass seed crops (1.6)	DW1	DW1	DW1
	Potatoes (1.1)	DW3	DW3	DW3
	Hops (1.11.1.4)	DW1	US2	US2
	Other arable crops	DW2	DW2	DW2
2. Culture grassland	All cultivated grassland	DW1	DW1	DW1
3. Fruit crops	Strawberries (3.2.1) and cranberries (3.2.2.4)	DW3	DW3	DW3
	Other small fruit crops (3.2.2, 3.2.3 and 3.2.4) that are one or two years old	DW3	DW3	DW3
	All other fruit crops including small fruit older than two years	DW2	US2	US2
4. Vegetables	Spinach family (4.1.3)	DW2	DW2	DW2
	Leaf vegetables (4.1) excluding spinach family, onion family (4.6), root crops vegetables (4.5.2), asparagus (4.7.1.1), Jerusalem artichoke (4.5.3.3) and leek (4.7.1.6)	DW3	DW3	DW3
5. Herbs	Poppy seed and caraway seed (5.5)	DW1	DW1	DW1
	Medicinal root crops (5.4)	DW3	DW3	DW3
	Others herbs	DW2	DW2	DW2
7. Ornamental crops	Improvement culture and seed production (7.7)	DW1	DW1	DW1
	Flower bulbs and corm flowers (7.1)	DW3	DW3	DW3
	Tree nursery (7.3) except spindle trees, transplanted trees and high avenue trees	DW3	DW3	DW3
	Spindle trees (7.3.1.1), transplanted trees (7.3.1.2) and high avenue trees (7.3.1.3)	DW1	US1	US1
	Other ornamental crops	DW2	DW2	DW2
10. Uncropped area	Temporarily uncropped area including edge-of-field strips	DW1	DW1	DW1

1) The numbers refer to the number in the DTG-list.

2) H is herbicide treatment, F is fungicide treatment and I is insecticide treatment.

3) DW is downward spraying; US is upward and sideward spraying.

7.1.1 *Downward-directed spraying*

In the case of downward-directed spraying, distinctions in the spray-drift parameterisation are made at three levels:

1. At the first level, a distinction is made on the basis of the minimum agronomic crop-free zone, i.e. the distance between the last row and the edge of the ditch bank (distance [a] in Figure 35). Notice that this minimum crop-free zone is determined by agronomic practices, and cannot be changed by policymakers. The minimum agronomic crop-free zone is 25 cm, 50 cm or 75 cm.
2. At the second level, a distinction is made between spraying a developed crop and spraying a bare soil/low crop situation. This is done because spray drift deposition from spraying a developed crop canopy is higher than from spraying a bare soil surface/small crop situation (see also Section 3.3). The distinction between fully-grown crops and low crops is made on the basis of crop height.
3. A final refinement is made based on the last nozzle position on the spray boom relative to crop row (distance [b] in Figure 35).

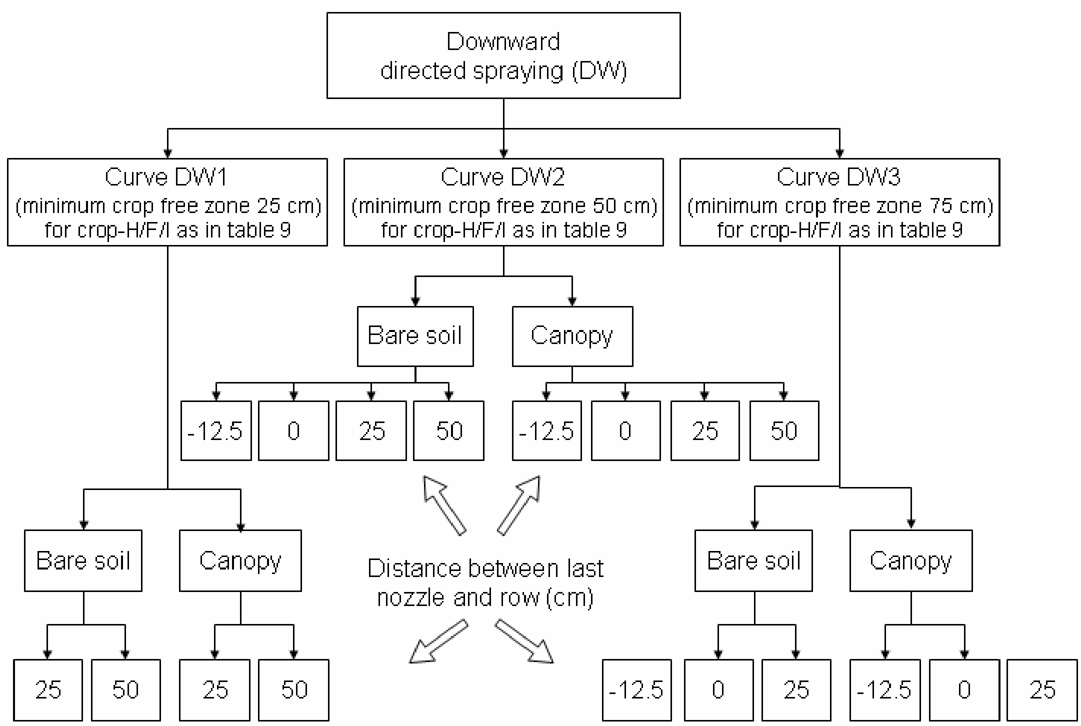


Figure 36 Assessment of spray drift for downward-directed spraying. A differentiation is made for crop-treatment classes (Table 9), growth situations and last nozzle position (Table 10). In the second row, H is herbicide treatment, F is fungicide treatment and I is insecticide treatment. A positive value of the 'distance between last nozzle and row (cm)' means that the last nozzle is positioned inside the last plant row; a negative value means that the last nozzle is positioned outside the last plant row.

Dependence of spray drift on crop height

Crop height is important for spray drift, as drift from spraying of a developed crop canopy is higher than from spraying of a bare soil surface/small crop situation (Section 3.3). This distinction is made based on plant height. When plant height is less than 20 cm, the bare soil curve is to be used, whereas the developed crop canopy drift curve is to be used in all other cases. Depending on the phenological development of the crop this distinction between bare soil surface/short crop and developed crop canopy is specified by a BBCH code for crop growth stage (BBCH, 2001). This BBCH crop growth stage, from which the distinction between short crop and developed crop canopy is made, depends on the crop type. For cereals the distinction is e.g. made at BBCH 31 (first node at least 1 cm above tillering node, in the stem elongation stage), and for maize at BBCH 15 (five leaves unfolded). The BBCH codes for distinguishing between short crop and developed crop situations are given in van de Zande et al. (2012) for all crops.

Starting point of the spray drift curve
The positioning of the last nozzle defines the starting point of the drift curve. For each of the crop categories, a differentiation can be made in the position of the last nozzle on the spray boom in relation to the last crop row (distance [b] in Figure 35). Last nozzle-to-row distances for the different crops are typically 12.5 cm outside the last crop row, on top of the last crop row, 25 cm inside the last crop row and 50 cm inside the last crop row/outside edge of the crop (Table 10). This means that the spray drift calculations for the 300 different crops on the DTG-list can be limited to nine specific crop categories.

Table 10 Specific crop type categories defined by minimum agronomic crop-free zone and last nozzle position for downward-directed sprayed crops

Minimum agronomic crop-free zone (m) [a]	Distance between nozzle and row[1] (m) [b]	Distance between nozzle and edge of ditch (m) [c=a+b]
0.25	0.25	0.50
0.25	0.50	0.75
0.50	-0.125	0.375
0.50	0.0	0.50
0.50	0.25	0.75
0.50	0.50	1.00
0.75	-0.125	0.625
0.75	0.0	0.75
0.75	0.25	1.00

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

7.1.2 *Sideward- and upward-directed spraying*

Sideward- and upward-directed spraying is carried out for fungicide and insecticide treatments in fruit crops and nursery trees (Table 9). The spray drift assessment is differentiated at two levels:

1. At the higher level, a distinction is made between spraying in nursery trees, with a minimum agronomic crop-free zone of 2 m (Curve US1), and fruit crops (Curve US2), with a minimum agronomic crop-free zone of 3 m.
2. At the second level, a distinction is made on the basis of growth stage. For nursery trees, a differentiation is made between spindle trees, high alley trees and transplanted trees. For fruit crops, different spray drift curves are available for the situation before 1 May, when the crop is dormant or has little leaf development, and for the situation after 1 May, when the crop is at full leaf stage.

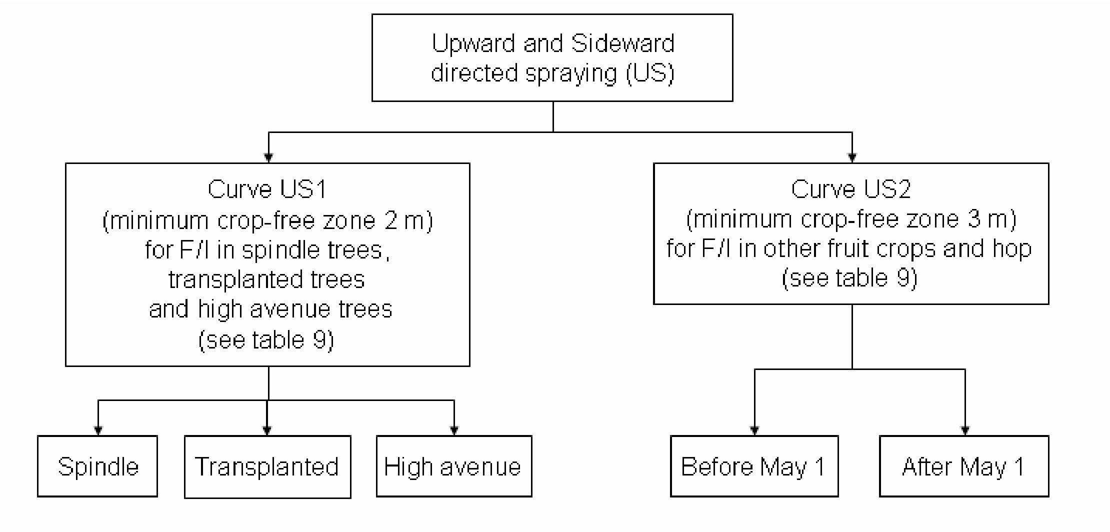


Figure 37 Assessment of spray drift for sideward- and upward-directed spraying. Differentiations are made for crop-treatment classes (Table 9) and growth situations. In the second row, H is herbicide treatment, F is fungicide treatment and I is insecticide treatment.

7.1.3 Effect of variability of water volume

The spray drift deposition is calculated for a fixed water table height of 19.05 cm. This is the water depth for a situation where the discharge in the ditch is equal to base flow (Section 8.3). A fixed water table height is justified because the variation in water table height is generally less than 3 cm with little change in water volume (Section 6.4). The calculated spray drift deposition applies to the evaluation point situated 5 m downstream of the start of the evaluation ditch. This is a conservative assumption for the evaluation.

7.2 Interception

Crop development influences the spray deposition on soil surface underneath the canopy and the interception of the spray by the canopy. Spray interception data, expressed as percentages of the applied areic mass, for the different crop development stages are taken from Anonymous (2011); see Table 11. Each of the DTG-list crops is linked to a FOCUS crop with the accompanying interception value per crop growth stage. Full details of this link are given in Van de Zande et al. (2012).

Table 11 Spray interception (percetage of applied dosage) by crop type and growth stage (BBCH) (after Anonymous 2011)

BBCH code*	00–09	10–19	20–29	30-39	40–89	90–99
Beans	0	25	40	40	70	80
Cabbage	0	25	40	40	70	90
Carrots	0	25	60	60	80	80
Cotton	0	30	60	60	75	90
Grass	0	40	60	60	90	90
Grass, established	90	90	90	90	90	90
Linseed	0	30	60	60	70	90
Maize	0	25	50	50	75	90
Oilseed rape	0	40	80	80	80	90
Onions	0	10	25	25	40	60
Peas	0	35	55	55	85	85
Potatoes	0	15	50	50	80	50
Soybean	0	35	55	55	85	65
Cereals	0	25	50	70	90	90
Strawberries	0	30	50	50	60	60
Sugar beet	0	20	70	70	90	90
Sunflower	0	20	50	50	75	90
Tobacco	0	50	70	70	90	90
Tomatoes	0	50	70	70	80	50

* 00–09 is bare soil until emergence, 10–19 is leaf development, 20–29 is tillering, 30–39 is stem elongation, 40–89 is flowering and 90–99 is senescence to ripening.

The seasonal trend of the crop development stage depends to a large extent on climatological conditions. The link between crop development stage and time for average Dutch conditions is given by Van de Zande and Ter Horst (2012). Table 12 shows some examples of the seasonal trend of crop development stage (represented by the BBCH code) and time. Time is given in periods of half months, where the first half of the month refers to days 1–15 and the second half to the rest of the month.

Table 12 Growth phases (BBCH code) and period during the season (half month periods) for Dutch potatoes (starch, seed and consumption potatoes), summer and winter wheat. Growth phases for other crops are given in Van de Zande and Ter Horst (2012).

BBCH code	0-9	10-19	20-29	30-39	40-89	90-99
Seed potatoes	Mar2 to Apr2	May1 to May2	Jun1 to Jun2	Jul1	Jul2	Aug1
Starch potatoes	Mar2 to Apr2	May1 to May2	Jun1 to Jun2	Jul1	Jul2 to Aug1	Aug2 to Oct2
Consumption potatoes	Apr1 to Apr2	May1 to May2	Jun1 to Jun2	Jul1	Jul2 to Aug2	Sep1 to Oct1
Summer wheat	Mar1	Mar2	Apr1	Apr2 May1	May2 to Jul1	Jul2 to Sep1
Winter wheat	Oct1 to Nov2	Dec1 to Dec2	Jan1 to Mar2	Apr1 May2	Jun1 to Jul2	Aug1 to Aug2

7.3 Atmospheric deposition

FOCUS (2008) developed a first-tier approach for estimating the deposition of plant protection products on edge-of-field surface waters due to volatilisation after application on the adjacent field, if drift mitigation is required. In the absence of better information and lack of time to develop more sophisticated scenarios, this approach will also be used in the Dutch scenario. The procedure applies only to the scenario parameterisation; it is assumed that it has little effect on the scenario selection procedure. In the approach it is assumed that the wind blows perpendicular to the direction of the ditch, which is a worst-case assumption.

The volatilisation is only considered to be relevant for compounds with a vapour pressure higher than 10^{-4} Pa when applied to the soil and for compounds with a vapour pressure higher than 10^{-5} Pa when applied to the crop. The deposition on the water due to volatilisation after application is expressed as the cumulative fraction of the dosage deposited during the first 24 h after application of the substance. The FOCUS air deposition percentages at 1 m distance from the treated crop are presented in Table 13. These deposition percentages are defined as mass of substance deposited on water per surface area of water divided by mass of substance applied per surface area of agricultural land, multiplied by 100.

Table 13 Percentages of atmospheric deposition to edge-of-field surface waters (from FOCUS 2008). These percentages are valid at 1 m distance from the treated crop.

Range of vapour pressure	Plant	Soil
VP < 10^{-5} Pa	0	0
10^{-5} Pa < VP < 10^{-4} Pa	0.09	0
10^{-4} Pa < VP < 5 10^{-3} Pa	0.22	0.22
5 10^{-3} Pa < VP < 10^{-2} Pa	1.56	1.56
10^{-2} Pa < VP	expert judgement	expert judgement

Based on this, we propose the following procedure:

1. Estimate which fraction of the dose is deposited on the soil and which fraction is intercepted by the plant if the saturated vapour pressure at 20 °C is between 10^{-5} and 10^{-4} Pa; otherwise there is no need for estimation of this fraction as follows from the percentages in Table 13; we recommend using the FOCUS interception tables for the interception percentages (see FOCUS website).
2. Use the exponential distance relationships shown in Figure 38 and, combined with above reference values at 1 m, calculate from these the total areic mass, *M* (mg m^2), that is deposited on the water surface.
3. Introduce into the TOXSWA scenario a deposition event that starts at the time of application and has a constant deposition rate during the next 24 h corresponding to this total areic mass.

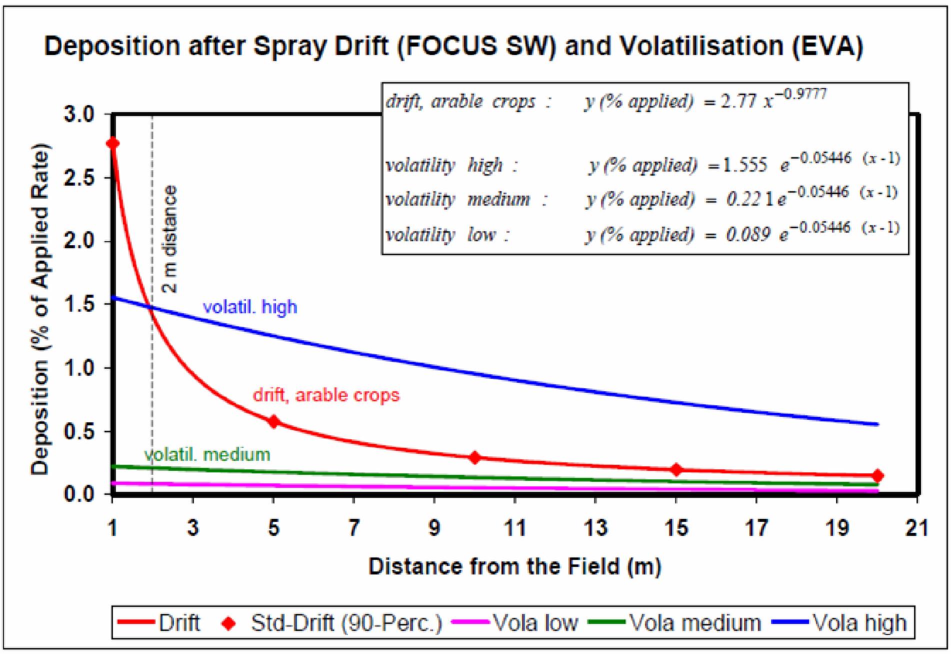


Figure 38 Copy of Figure 5.4-1 of FOCUS (2008) showing deposition as a function of the distance to the treated field. The classification 'low', 'medium', and 'high' corresponds to 0.09, 0.22 and 1.56% deposition, respectively.

As shown by Table 13, the procedure does not hold for compounds with a vapour pressure greater than 10^{-2} Pa at 20 °C (Section 5.4.4 in FOCUS 2008).

As described before, this is a lower-tier approach for the Dutch scenario based on the idea that it is better to include atmospheric deposition than to ignore it. FOCUS (2008) described some options for higher-tier approaches. For the next version of the Dutch scenario, the development of more realistic scenarios is foreseen (e.g. coupling of emissions calculated with the PEARL model to atmospheric dispersion and deposition calculated with the OPS model developed by RIVM).

7.4 PEARL parameterisation

The PEARL simulations described in this report considered winter wheat only, because this is the crop that was grown at the Andelst field site. However, the working group considered simulations in which winter wheat was not appropriate in all cases, because many plant protection products are applied in spring, when winter wheat is already well developed. For this reason, the final scenario will be run in combination with crops described by FOCUS (2009). We selected the Hamburg scenario for this purpose, because this scenario is in the same FOCUS climatic zone as the Andelst scenario. All crop properties were taken from the FOCUS database, except for the crop factor, which was recalculated to match Makkink reference evapotranspiration (Feddes 1987). This means that the crop factors were multiplied by a factor of 1.0-1.3, depending on the time in the growing season (see Table 5 in Feddes 1987). Resulting crop factors are shown in Table 14.

Table 14 Crop factors relative to Makkink reference evapotranspiration (f_{crp}) as a function of crop development stage (DVD) for five FOCUS crops. The date ranges are emergence dates to harvest dates.

Winter cereals (01 Nov to 10 Aug)		Spring cereals (01 Apr to 20 Aug)		Maize (05 May to 20 Sep)		Sugar beets (15 Apr to 08 Oct)		Potatoes (10 May to 15 Sep)	
DVD	f_{crp}	DVD	f_{crp}	DVD	f_{crp}	DVD	f_{crp}	DVD	f_{crp}
0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
0.65	0.2	0.47	0.9	0.63	1.2	0.78	1.2	0.56	0.7
0.75	1.1	1.00	0.9	1.00	1.2	1.00	1.2	1.00	0.7
1.00	1.1								

The crop type has little effect on the simulated concentration in the drainpipe (Tiktak et al. 2012b). In view of the available time, the working group therefore decided that the drainpipe scenario would be made available with two crops only, namely a winter crop and a summer crop. Here, a winter crop is defined as a crop that is present during the period 1 November-31 March, whether it is planted or seeded before winter or is a perennial plant. Winter cereals and sugar beets were considered the most appropriate crops, because these two crops are predominantly grown on soils where preferential flow is important. Also, the crop factors for these two crops are relatively close to the crop factor of winter wheat at the Andelst field site.

The software tool DRAINBOW automatically determines whether a crop is a summer crop or a winter crop. Table 15 shows the DTG-list crops that are identified as winter crops; all other crops are assumed to be summer crops. Notice that the crop selection does not have a direct effect on the application time, as this still needs to be introduced by the user.

Table 15 Overview of DTG-list crops that are identified as winter crops (Van de Zande and Ter Horst 2012). All crops that are not in the list are assumed to be summer crops.

Cultivation category	Crop category, crop subcategory or crop*	
1. Arable crops	1.3.1	All winter cereals
	1.6	All grass seed crops
	1.7.1.2	Caraway
	1.7.1.5	Winter rapeseed
	1.9.2	Green manure crops
	1.10.1.2	Alfalfa
	1.11.1.6	Elephant grass
2. Culture grassland	2.	All crops
3. Fruit crops	3.	All herbicide treatments in fruit crops
4. Vegetables	4.4.1.2	Brussels sprouts
	4.4.3.2	Kale
	1.6.1.3	Second year bulb onions
	4.7.1.1	Asparagus
5. Herbs	5.5.1.1	Caraway seed
7. Ornamental crops	7.1.1.1	Winter flower bulbs (hyacinth, tulip, narcissus and crocus)
	7.1.1.3	Winter bulb flowers (hyacinth, tulip, narcissus and crocus)
	7.4	Perennial crops
10. Uncropped area	10.1	Temporarily uncropped terrain including edge-of-field strips

* The numbers refer to the number in the DTG-list.

8 Drift-reduction measures

This chapter describes the drift-reduction measures that can be introduced into the model. The chapter starts with an overview of the current rules and regulations (Section 8.1). Then, we describe how these drift-reducing technologies can be introduced into DRAINBOW (Section 8.2). Finally, Section 8.3 shows an example of calculated spray drift deposition on surface water.

8.1 Drift-reduction technology – current rules and regulations

Currently, spray drift mitigation measures are taken on the basis of certified drift-reduction technologies (DRTs) originating from the Water Pollution Act (LOTV, Anonymous 2000, 2007) and differentiation in crop-free buffer zones. Conventional boom sprayers cannot be used within 14 m of a water course. Within 14 m of the water course, the following measures have to be taken when spraying with a boom sprayer:

1. the use of drift-reducing spray nozzles (minimum 50 per cent drift reduction class);
2. the use of drift-reducing end nozzles; and
3. a maximum boom height of 50 cm above the crop canopy.

In addition to the use of a DRT, a crop-free buffer zone has to be respected for crops in class DW3 of Figure 36 (these crops are referred to in LOTV brochures as 'intensively sprayed crops'). This crop-free buffer zone is 75 cm, which means that the total crop-free zone is 150 cm (the total crop-free zone consists of the minimum agronomic crop-free zone and the crop-free buffer zone; see Figure 39). For crops in class DW1 (in LOTV brochures referred to as grass and cereals) and class DW2 ('other crops'), the crop-free buffer zone is zero, which means that the total crop-free zone is equal to the minimum agronomic crop-free zone (25 cm for class DW1 and 50 cm for class DW2). For crops in class DW3, the width of the crop-free buffer zone can be reduced to 0 cm when additional drift-reducing measures are taken, such as additional air assistance on the boom sprayer, a catch crop at the edge of the field or the use of a shielded sprayer for bed-grown crops. For organically grown crops no crop-free buffer zone is required.

Following the LOTV, additional drift-reducing techniques (CIW 2003) and spray nozzles (Anonymous 2001) can be certified in the four drift-reduction classes 50 per cent, 75 per cent, 90 per cent and 95 per cent drift reduction. Certified techniques are allowed to be used with smaller crop-free buffer zones. However, further restrictions can be prescribed to the use of a PPP. For a number of PPPs it is mandatory to use spray nozzles from the 75 per cent and/or 90 per cent drift reduction classes. Based on these requirements, the farmer has to equip his sprayer with the appropriate drift-reduction nozzles or maintain wider crop-free buffer zones.

The downward spray techniques were grouped within the LOTV into the DRT classes as shown in Table 16.

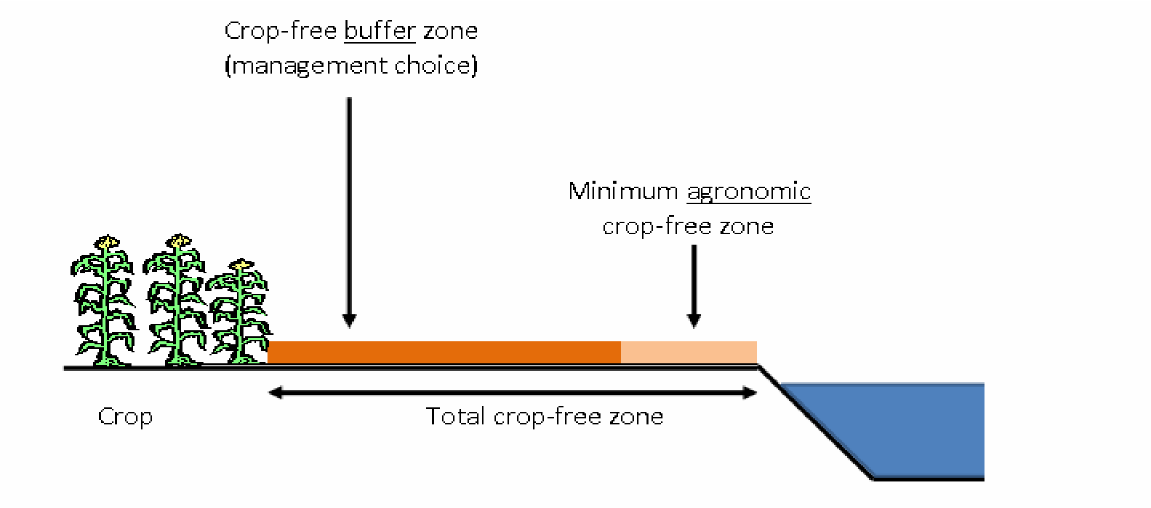


Figure 39 Schematic representation of a crop with total crop-free zone, minimum agronomic crop-free zone and crop-free buffer zone

Table 16 Listed downward-directed spray DRT in different drift-reduction classes

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

* For each drift-reduction class an appropriate technique was selected (marked with *) to calculate a drift deposition curve as a representative curve for that class and to be used for spray drift deposition on surface water (Section 3.3).

8.2 A matrix approach for drift-reducing measures

The drift-reducing technologies described above do not lead to similar or stepwise decreasing spray drift exposure of the surface water, because they are generally combined with different widths of crop-free buffer zone. It is therefore not possible to develop a stepped approach for drift-reducing measures. As an alternative, we developed a matrix approach. The columns of this matrix contain various classes for the width of the crop-free buffer zone; the rows contain the drift-reduction classes (Table 17). Spray drift deposition decreases from the upper left-hand corner of the matrix to the lower right-hand corner (see arrows). The header of the matrix shows the crop-free buffer zone. As shown in Figure 39, the minimum agronomic crop-free zone must be added to obtain the total crop-free zone, so the total crop-free zone depends on the drift curve.

Table 17 Matrix structure for the calculation of spray drift deposition on surface water for downward-directed spray techniques in annual crops

Crop-free buffer zone (m)	0.00	0.25	0.50	0.75	1.00	1.25	1.50	→
Total crop-free zone DW1	0.25	0.50	0.75	1.00	1.25	1.50	1.75	→
Total crop-free zone DW2	0.50	0.75	1.00	1.25	1.50	1.75	2.00	→
Total crop-free zone DW3	0.75	1.00	1.25	1.50	1.75	2.00	2.25	→
standard	→	→						
DRT 50	↓							
DRT 75	↓							
DRT 90								
DRT 95								

The matrix can be used to 'map' the spray drift deposition (Table 18). If for a given combination of DRT and crop-free buffer zone, the spray drift deposition leads to a predicted environmental concentration (PEC) that is higher than the Regulatory Acceptable Concentration (RAC), the following cell is evaluated. The evaluation route is from the upper left corner of the matrix (standard spray technique and smallest crop-free buffer zone) to the lower right corner (drift reducing technology 95 per cent and widest acceptable crop-free buffer zone).

Table 18 Evaluation matrix of combinations of drift-reduction classes and width of crop-free buffer zones. Red means no authorisation possible because the resulting PEC exceeds the RAC. Green means authorisation possible because the resulting PEC is below the RAC. Arrows show the direction of the evaluation.

Crop-free buffer zone (m)	0.00	0.25	0.50	0.75	1.00	1.25	1.50	→
standard							→	
DRT 50						↓ →		
DRT 75					↓ →			
DRT 90				↓ →				
DRT 95		→	↓					

Combinations that are not allowed because of additional regulations (for example, requirements set by the LOTV) may be blocked (Table 19). In the example below, a crop-free buffer zone of at least 0.5 m is required. The consequence is that the combination of the DRT of 95 per cent and a crop-free buffer zone of 25 cm is not allowed, despite the fact that the calculated PEC is below the RAC (Table 18).

Table 19 Evaluation matrix of combinations of drift-reduction classes and width of crop-free buffer zones. Red means no authorisation possible because the resulting PEC exceeds the RAC. Green means authorisation possible because the resulting PEC is below the RAC. Grey means that this combination cannot be chosen because of additional regulation. Arrows show the direction of the evaluation.

Crop-free buffer zone (m)	0.00	0.25	0.50	0.75	1.00	1.25	1.50	→
standard							→	
DRT50						↓ →		
DRT75					↓ →			
DRT90				↓ →				
DRT95			↓→					

8.3 Spray drift deposition on surface water – an example

As an example, spray drift deposition for the ditch (Figure 13) is presented for the cropped situation (Table 20) and for the bare soil situation (Table 21). This example applies to spraying a crop in crop category DW3 with the position of the last nozzle at -12.5 cm (Figure 36). This means that the distance from the last nozzle to the edge of the field is at least 62.5 cm (75 cm minimum agronomic crop-free zone minus 12.5 cm; Table 10).

Spray drift deposition is calculated using the dimensions of the ditch for the downward spraying scenario (code 601001) and a fixed water depth of 19.05 cm. This is the water depth at 205 m in the Dutch scenario ditch (so at 5 m in the 100 m evaluation ditch; see Figure 25) for a situation where the discharge in the ditch is equal to the base flow (5 L/d). The working group made this decision because this would lead to a conservative approach for the evaluation ditch and a less conservative approach for the 200 m long upstream catchment ditch.

Table 20 Spray drift deposition (percentage of applied areic mass) as a function of class of spray drift-reduction technology and width of crop-free buffer zone in a potato crop situation (crop category DW3 with the position of the last nozzle at -12.5 cm). The values were calculated for the ditch using a fixed water depth of 19.05 cm.

Total crop-free zone (m)	0.75	1.50	2.00	3.00	4.00	5.00	6.00
Crop-free buffer zone (m)	0.00	0.75	1.25	2.25	3.25	4.25	5.25
Standard	5.03	2.74	2.06	1.45	1.18	1.00	0.86
DRT50	1.75	1.14	0.99	0.82	0.70	0.60	0.51
DRT75	1.01	0.60	0.54	0.47	0.42	0.37	0.33
DRT90	0.68	0.30	0.24	0.20	0.19	0.17	0.16
DRT95	0.48	0.11	0.08	0.07	0.07	0.07	0.06

Table 21 Spray drift deposition (% of applied areic mass) as a function of class of spray drift-reduction technology and width of crop-free buffer zone in the bare soil/low crop situation for a potato field (crop category DW3 with the position of the last nozzle at -12.5 cm). The values were calculated for the ditch using a fixed water depth of 19.05 cm.

Total crop-free zone (m)	0.75	1.50	2.00	3.00	4.00	5.00	6.00
Crop-free buffer zone (m)	0.00	0.75	1.25	2.25	3.25	4.25	5.25
Standard	3.19	1.99	1.59	1.15	0.90	0.72	0.58
DRT50	0.96	0.71	0.61	0.47	0.37	0.29	0.23
DRT75	0.69	0.48	0.42	0.34	0.27	0.22	0.17
DRT90	0.47	0.31	0.26	0.20	0.17	0.14	0.12
DRT95	0.37	0.10	0.07	0.05	0.05	0.04	0.04

9 User-defined input

The DRAINBOW user interface allows the change of a limited number of parameters only. This chapter gives a short overview of these parameters.

9.1 Overview of DRAINBOW user interface

Figure 40 shows the set-up of the DRAINBOW software tool. The only inputs that can be specified by the user are (i) the crop for which an authorisation is requested, (ii) the substance properties, (iii) the application schedule, and (iv) the drift mitigation measures (i.e. combination of crop-free buffer zone and DRT). Summary reports of the most important model outputs and graphs of the average concentration in the water layer of the 100 m evaluation ditch as a function of time can be viewed.

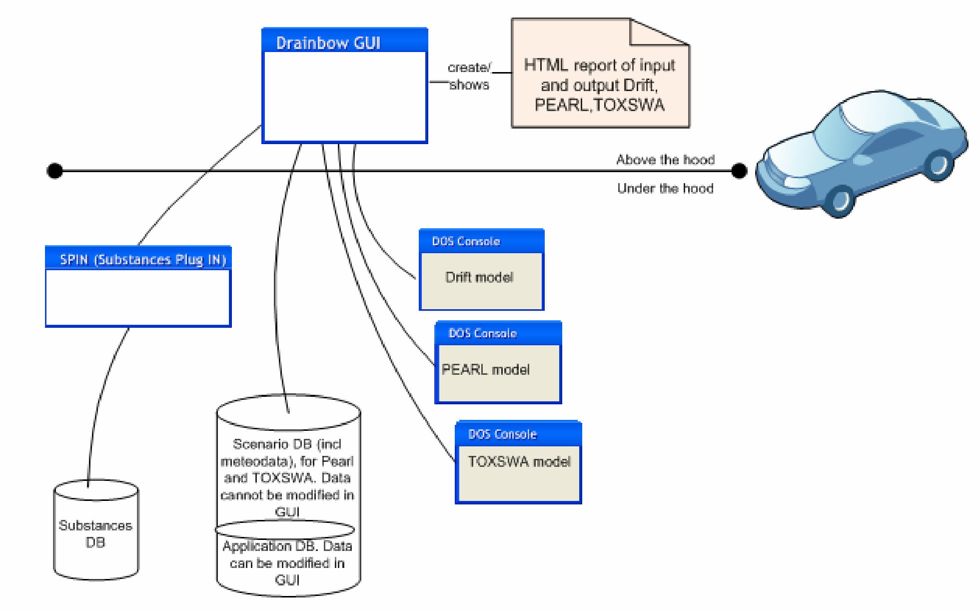


Figure 40 Schematic overview of the set-up of the DRAINBOW model

DRAINBOW includes an application database and a substance database for the management of properties of parent substances, metabolites and transformation schemes. The substance database is generic and can be used with future releases of SWASH and PEARL as well, so the user does not need to specify the substance properties again for other Dutch authorisation models. Unlike present tools like FOCUS-TOXSWA and FOCUS-PEARL, DRAINBOW does not permit viewing or modification of the scenario properties of soil, crop and weather. The user is, however, able to view all ASCII input files for PEARL and TOXSWA. Furthermore DRAINBOW includes a drift model and executables of the models SWAP, PEARL and TOXSWA. In launching a DRAINBOW assessment, the user initiates the following sequence of actions: (i) writing input files for PEARL and TOXSWA, (ii) starting a PEARL simulation, (iii) starting a TOXSWA simulation (which uses the PEARL output of drainage), and (iv) preparation of summary data that can be viewed by the user.

9.2 Crop type, application schedule and drift mitigation options

As described in Chapter 7, the spray drift part of the exposure assessment depends strongly on the application technique (downward- versus upward- and sideward-directed spraying). The exposure assessment is therefore a function of both the application technique and the crop category (EFSA 2010a). The spray drift input further depends on crop height, which in turn depends on the crop development stage. This crop development stage is crop-dependent. To avoid user-subjectivity in the exposure assessment, all these relationships are fixed in the user interface of DRAINBOW; the user enters the following parameters only:

- the time-window for which the peak and TWA concentrations are calculated;
- the crop for which registration is being requested;
- the application schedule (application dates and dosage);
- the drift-reduction class;
- the width of the crop-free buffer zone.

Some parameters must be set to conservative values in Tier 2 (see Chapter 11 for an overview of the proposed tiered assessment scheme and possible refinements):

- The time-window for which the peak concentration is calculated must be set to the whole calendar year.
- In the case of crop rotations, the cropping year that generates the highest concentration must be chosen.
- The DRT and the width of the crop-free buffer zone must be set to those values that generate the minimum permissible drift reduction.

Notice that in contrast to SWASH (FOCUS 2001), DRAINBOW does not contain a Pesticide Application Timer. We assumed that by simulating multiple years, the influence of application time on the simulated peak concentration would be reduced. This assumption was tested for six substances with different properties as shown in Table 22. In this test, spray drift deposition was set to zero. An annual application of 1 kg ha^{-1} in sugar beet was simulated and no crop interception was assumed. For each substance 365 runs were carried out. In the first run, an annual application was carried out at 1 January, in the second run at 2 January, etc. In each run, the application was repeated each year on the same date. Results are shown in Figure 41.

Table 22 Substance properties for the five example substances shown in Figure 41

Substance	*DegT50* (d)	K_{om} (L kg^{-1})
A	10	10
B	60	20
C	30	60
D	60	60
E	300	120
F	120	240

Of particular interest is the variability of the peak concentration within one week. The maximum difference between the predicted peak concentrations within a week is generally less than 25 per cent, except for the mobile and quickly degrading substance A, where the difference is 50 per cent. This is caused by the relatively large sensitivity of this substance to the timing of the first runoff event after application, which was expected. The decrease of the concentration in March is caused by ploughing. Ploughing removes part of the substance from the mixing layer and hence reduces runoff into the macropores.

We switched off spray drift deposition, so the presented examples are worst-cases for the effect of application time. Nevertheless, application time may affect the exposure assessment and be a possible source of subjectivity. It is a risk manager’s choice whether the maximum factor of two that is introduced by this subjectivity is considered acceptable.

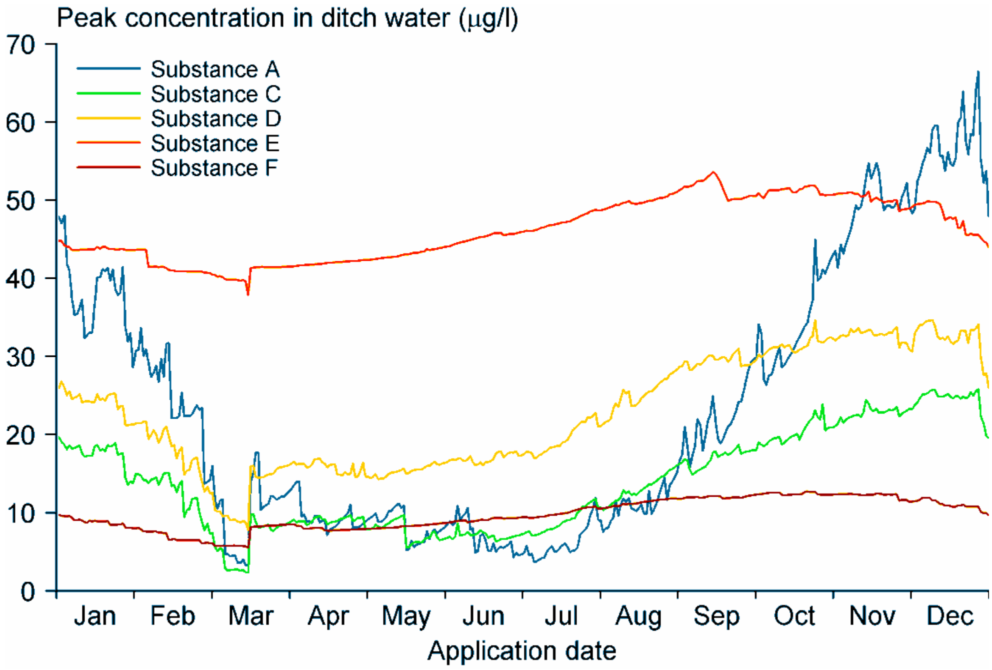


Figure 41 Effect of application date on the simulated target peak concentration, i.e. the peak concentration in the year corresponding to the 63rd percentile

9.3 Substance properties

Table 23 gives an overview of the substance properties that can be entered by the user. The default values given in the second column should be used, unless the user has scientific evidence that the given default values are not appropriate for the substance under consideration.

For the following parameters, conservative values must be introduced in Tier 2:
- The degradation half-life in water must be based on the longest hydrolysis *DegT50* measured above pH 7 (Boesten et al. 2013).
- In case of pH-dependency of the sorption coefficient and/or degradation half-life in soil, conservative values have to be introduced for these two parameters.

These parameters can be refined in Tier 3, provided sufficient scientific information is available. See Chapter 11 for details.

Table 23 describes properties of parent substances in soil, surface water and sediment. However, DRAINBOW can also simulate the formation and behaviour of metabolites in soil, surface water and sediment. The default values in Table 23 are also valid for metabolites. We provide here no guidance on the formation fraction; the estimation of this has to be based on existing guidance at EU level (e.g. FOCUS 2006).

Table 23 Substance properties that can be introduced in the DRAINBOW graphical user interface with default values and guidance for Tier 1 and Tier 2 assessments (see Chapter 11 for details on the proposed tiered assessment scheme)

Input parameter	Default value	Guidance to be followed or reference
molar mass (g mol^{-1})	None	-
pK_a	None	Not used because conservative K_{om} should be used.
DegT50 at 20 °C, pF = 2 in top soil (d)	None	EFSA (2010b); FOCUS (2006; 2009)
DegT50 in water at 20 °C (d)	None	Boesten et al. (2013)
DegT50 in sediment at 20 °C (d)	None	Boesten et al. (2013)
DegT50 on plant surface due to uptake and degradation (d)	10	EFSA (2011)
DegT50 due to penetration (d)	1000	-
water solubility (mg L^{-1})	None	-
Canopy process option	Calculated	-
saturated vapour pressure (mPa)	None	-
$K_{om,soil}$ (L kg^{-1})	None	Boesten et al. (2012); Mensink et al. (2008)
Reference concentration for sorption on soil (mg L^{-1})	1	Tiktak et al. (2000)
Freundlich exponent for sorption on soil (-)	0.9	Boesten et al. (2012)
Molar enthalpy of sorption (kJ mol^{-1})	0	FOCUS (2000)
pH-shift for pH-dependent substances	None	Not used because conservative K_{om} should be used.
Desorption rate coefficient (d^{-1})	0.0	Not used because too complex for Tier 1 and Tier 2. Refinement according to FOCUS (2009) possible in Tier 3
Ration between Freundlich coefficient at equilibrium sites and non-equilibrium sites	0.0	Not used because too complex for Tier 1 and Tier 2. Refinement according to FOCUS (2009) possible in Tier 3
Factor for the effect of soil water content on degradation (-)	0.7	Anonymous (2011)
Arrhenius activation energy for degradation in soil (kJ mol^{-1})	65.4	EFSA (2007) for substance-specific value
Arrhenius activation energy for degradation in sediment (kJ mol^{-1})	65.4	-
Arrhenius activation energy for degradation rate in surface water (kJ mol^{-1})	75	Deneer et al. (2010)
Wash-off factor (mm^{-1})	0.1	EFSA (2011)
Transpiration-stream concentration factor (-)	0.5	FOCUS (2009)

Molar enthalpy of vaporisation (kJ mol^{-1})	95	Anonymous (2011)
Molar enthalpy of dissolution (kJ mol^{-1})	27	Anonymous (2011)
Gas diffusion coefficient (m^2 d^{-1})	0.43	Anonymous (2011)
Water diffusion coefficient (m^2 d^{-1})	0.43×10^{-4}	Anonymous (2011)
$K_{om,suspended\ solids}$ (L kg^{-1})	None	Use $K_{om,soil}$ if specific data are lacking
Reference concentration for sorption on suspended solids (mg L^{-1})	1	Same value as for sorption to soil
Freundlich exponent for sorption on suspended solids (-)	0.9	If specific data are lacking, use values for soil
$K_{om,sediment}$ (L kg^{-1})	None	Use $K_{om,soil}$ if specific data are lacking
Reference concentration for sorption on sediment (mg L^{-1})	1	Same value as for sorption to soil
Freundlich exponent for sorption on sediment (-)	0.9	If specific data are lacking, use values for soil
Coefficient for linear sorption on macrophytes (L kg^{-1})	None	Not used because the amount of macrophytes is set to zero in the NL scenario

10 Examples

Example calculations were done with the Dutch scenario for four substances in two different crops. The substances were selected by Brock et al. (2011). The dosage and application pattern selected for each substance – crop combination is considered representative for the Dutch agricultural practice (Table 24). The half-life and sorption coefficient of the four substances are shown in Table 24 as well. The full list of substance properties and justification for their use are given in Appendix 1. For each substance, calculations are done for two classes of drift-reduction technology (DRT): 50 per cent and 95 per cent.

Table 24 Substance, dosages and application patterns used for the example calculations

Substance	I_N	I_P	F_P	H_T
Substance type	insecticide	insecticide	fungicide	herbicide
Substance group	neonicotinoids	pyrethroids	phenyl-pyridinamines	triazinones
Crop	lilies	lilies	potatoes	potatoes
Application times and dosages	0.07 kg/ha on 1 May 0.07 kg/ha on 8 May	20 applications of 0.005 kg/ha starting 1 May with intervals of 7 days	15 applications of 0.2 kg/ha starting 1 June with intervals of 7 days	0.105 kg/ha on 1, 8 and 15 May
DegT50 in soil	118 d	50 d	72 d	10 d
DegT50 in water	1000 d	1000 d	3.7 d	1000 d
K_{om} in soil	131 L kg^{-1}	138,820 L kg^{-1}	1138 L kg^{-1}	36 L kg^{-1}

Results are given in the following sections. Concentrations of dissolved substance in the water layer of the ditch are reported, so the reported concentrations do not include the mass of substance sorbed to suspended solids.

Results in this section are based on preliminary versions of SWAP and PEARL. For this reason, results in this report differ slightly from the exposure data that are used in the effects assessment (Brock et al. 2012).

10.1 Substance I_N in lilies

Results of the application of substance I_N in lilies for 50 per cent DRT (drift deposition 0.0476 mg m^{-2}) and 95 per cent DRT (drift deposition 0.0056 mg m^{-2}) are shown in Figures 42–46.

In autumn and winter regular inflow of drainage water containing substance I_N causes small peaks in the concentration in the ditch (Figures 42 and 44). Drainage events may lead to either higher or lower concentrations in the ditch. A drainage event leads to higher ditch concentrations if the concentration in the ditch before the drainage event was lower than the concentration in the drain water. The degree of increase of the concentration in the ditch depends on both the concentration in the drain water and the amount of drain water. A drain event with a limited amount of water but a high concentration may have the same effect on the concentration in the ditch as a drain event with a large amount of water but a slightly higher concentration than the concentration in the ditch. Drainage leads to lower ditch concentrations in the event that the concentration in the ditch before the drainage event was higher than the concentration in the drain water. The degree of the dilution of the ditch water depends again on both the amount of drain water and the concentration of the drain water.

For 50 per cent DRT, the annual maximum peak in the concentration in the ditch is mainly caused by spray drift (1994, 2000 and 2001 are exceptions), whereas the annual maximum peak in the concentration in the ditch for 95 per cent DRT is usually caused by drainage. For both 50 per cent and 95 per cent DRT, the same amounts of water and substance mass enter the ditch by drainage, because the mitigation measure affects only the spray drift deposition, but it does not affect the deposition of pesticide on the soil and plant. Annual maximum peak concentrations in the ditch are usually much lower for the 95 per cent DRT scenario (Figure 43). For the years 1994, 2000 and 2001 the difference in the annual maximum peak concentrations between 50 per cent DRT and 95 per cent DRT are smaller than for the other years. In these three years the annual maximum peak concentrations for 50 per cent DRT are caused by drainage events. Although the amount of water and substance of the drainage event causing the peak are the same for both 50 per cent DRT and 95 per cent DRT, the annual maximum peak concentration in these years is lower for 95 per cent DRT than for 50 per cent DRT. This is due to the fact that the concentration in the ditch just before the drainage event is lower for 95 per cent DRT than for 50 per cent DRT.

Figure 45 shows that during the 15-year evaluation period, the largest part of the mass of substance I_N enters the ditch by drainage and not by spray drift. However for 50 per cent DRT, drainage does not often lead to the maximum peak concentration in a year. This is because concentrations in the drainage water are not large compared with the peak concentration in the ditch caused by spray drift. However, the amount of drainage water entering the ditch is often large and that is why the total mass of I_N entering the ditch by drainage is much larger than the mass entering the ditch by spray drift.

Substance I_N mainly leaves the ditch through outflow of water (Figure 45). Degradation half-lives in water and sediment were set to 1,000 d, so degradation is negligible. The sorption coefficient for sediment ($K_{om,sed}$) was assumed to be the same as the $K_{om,soil}$, namely 131 L kg^{-1}. This is a low value with respect to pesticide fate in surface water and I_N transports in and out of the sediment are therefore minor parts of the mass balance. Volatilisation is zero (saturated vapour pressure of 7 10^{-7} Pa) and is therefore not plotted in Figure 45.

Regular supply of substance to the ditch via drainage in the autumn and winter period in combination with negligible degradation and low discharges in spring and summer caused a constant presence of substance I_N in the ditch in the period 1991–2005.

In Figure 46, the average concentration of substance I_N in the 100 m evaluation ditch is compared with the concentration averaged over 21 days (TWA21). The annual maximum of this concentration is used for the calculation of chronic exposure (Brock et al. 2011). The relative difference between the two types of concentration (the annual maximum peak and the annual maximum TWA) is relatively small for this substance (approximately 15 per cent).

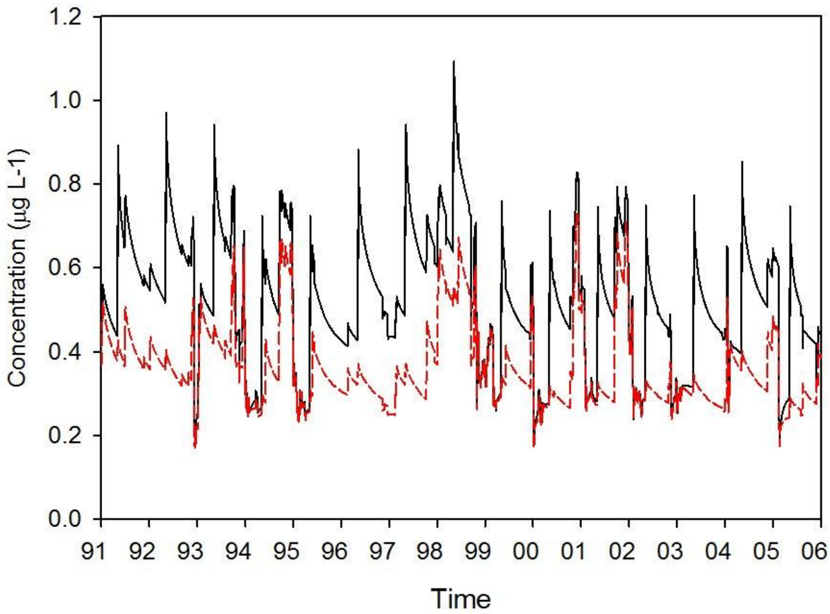


Figure 42 Average concentration of substance I_N in the water of the 100 m evaluation ditch as function of time for the period 1991-2005 and for two classes of DRT

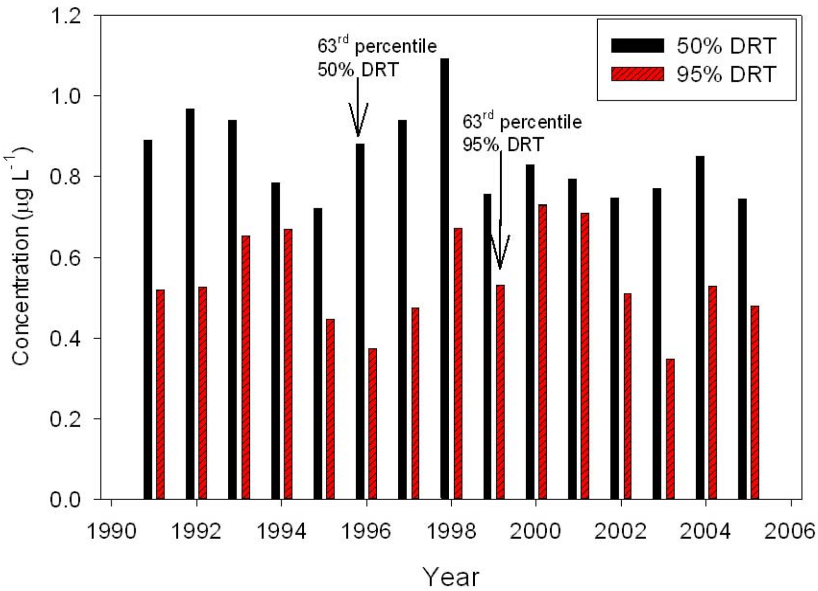


Figure 43 Annual maximum concentration of substance I_N in the 100 m evaluation ditch for two classes of DRT. The arrows indicate the 63rd percentile concentration for each class of DRT.

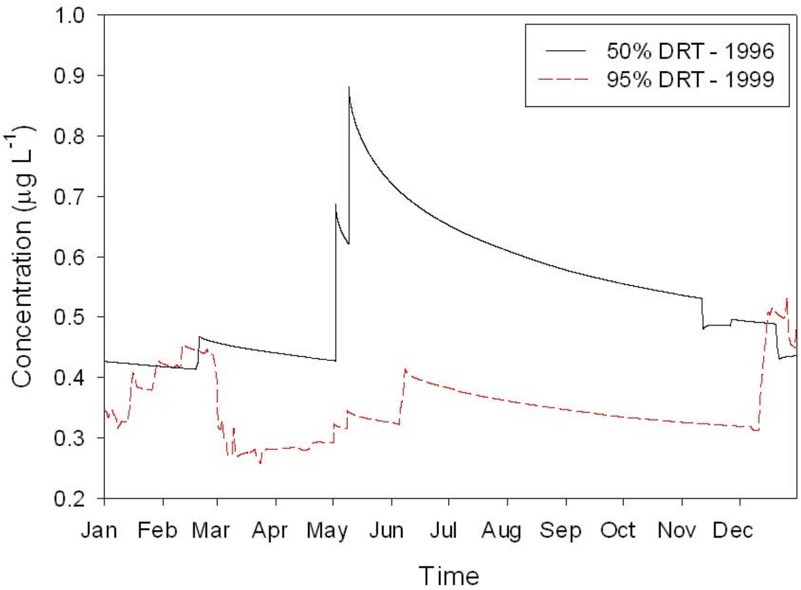


Figure 44 Average concentration of substance I_N in the water of the 100 m evaluation ditch as function of time for two classes of DRT and for the year in which the 63rd percentile concentration was found. Note that the year in which the 63rd percentile concentration was found differs per DRT percentage.

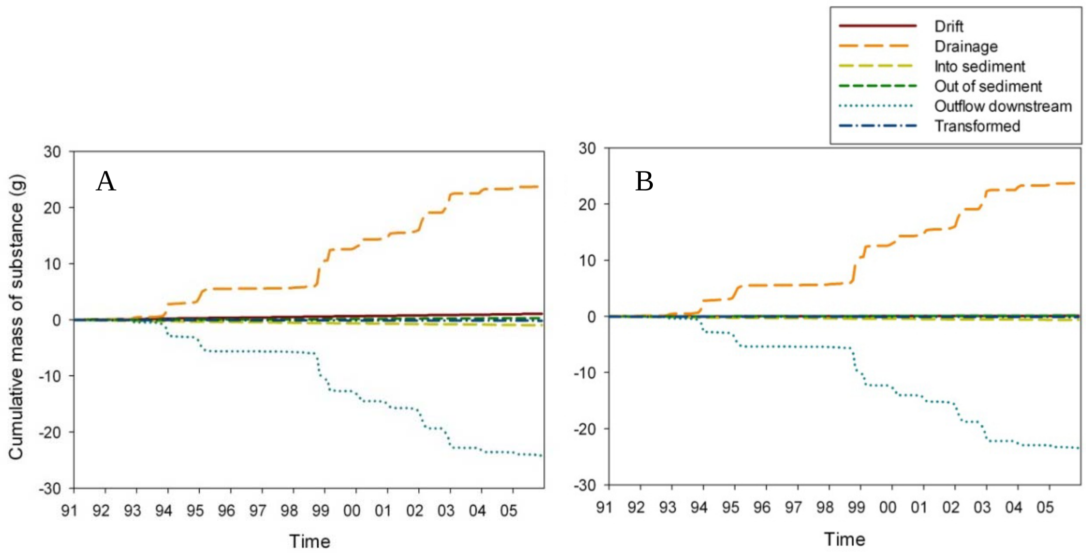


Figure 45 Cumulative monthly mass balances of substance I_N for 50% DRT (A) and 95% DRT (B). Negative values indicate transport out of the water layer.

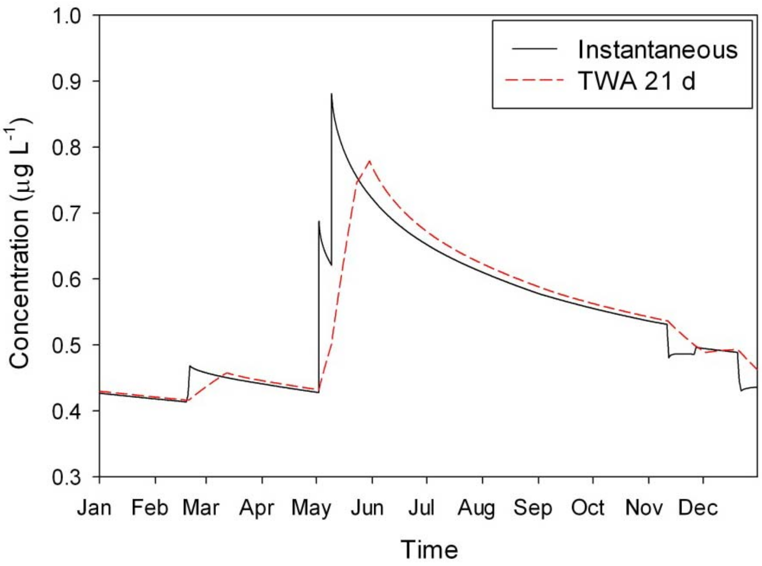


Figure 46 Average concentrations (instantaneous and TWA21 d) of substance I_N in the water of the 100 m evaluation ditch as function of time for 50% DRT and for the year in which the 63rd percentile concentration was found

10.2 Substance I_P in lilies

Results of the application of substance I_P in lilies are shown in Figures 47–51. For 50 per cent DRT, drift deposition was 0.00345 mg m^{-2} from 1 May to 12 June and 0.00545 mg m^{-2} from 19 June to 11 September. For 95 per cent DRT, these figures amount to 0.0004 mg m^{-2} and 0.0005 mg m^{-2}, respectively.

The 20 applications and thus the 20 drift events cause a regular pattern of peaks in the concentration in the period May–September (Figures 47 and 49). The sorption coefficient of substance I_P in soil is very large ($K_{om,soil}$ = 138,820 L kg^{-1}); hence the concentration in drainage water is very low. Drift is therefore the main source of exposure in the ditch (Figure 50), even at 95 per cent DRT. There is a tenfold difference in drift deposition between 50 per cent DRT and 95 per cent DRT and therefore differences in concentrations in the ditch between 50 per cent and 95 per cent DRT are also about tenfold (Figure 48).

The sorption coefficient in the sediment is set equal to the very large sorption coefficient in soil. This explains why the concentration after a spray drift event drops quickly (Figure 49). Almost the entire amount of substance entering the ditch by spray drift deposition is transported to the sediment by diffusion and is bound to the organic matter of the sediment. Part of the substance in the pore water of the sediment is supplied back to the water by diffusion (Figure 50). This process is driven by the difference in concentration in the water layer and the sediment pore water. The part diffusing from the sediment to the water is equal to the part transported out of the ditch (Figure 50). Degradation is negligible, as degradation half-lives in water and sediment are both set to 1,000 days.

Back diffusion from the sediment to the water layer is also visible in the time curves of the concentration. Figure 49 shows a decrease in concentration in February due to a drainage event with relatively clean drain water compared with the water in the ditch (so resulting in dilution of the ditch water). After this dip in the concentration, the concentration in the ditch increases again despite the fact that drainage or drift events do not occur in this period. We examined sediment concentrations and mass balances and found that back diffusion from the sediment is responsible for this increase in the concentration. Despite the fact that substance supply to the ditch via drainage was practically zero, the concentration substance I_P in the ditch never dropped to zero in the period 1991–2005. This is due to back diffusion of the substance from the sediment to the water layer in combination with negligible degradation in both compartments and low discharges in spring and summer.

For substance I_P, the concentration averaged over 21 days is considerably smaller than the instantaneous concentration (Figure 51). This is caused by the extremely fast decrease of the concentration after application (which is due to strong sorption of the substance to the sediment as described above). The resulting difference between the annual maximum TWA21 value and the annual maximum peak concentration is therefore large (approximately 50 per cent).

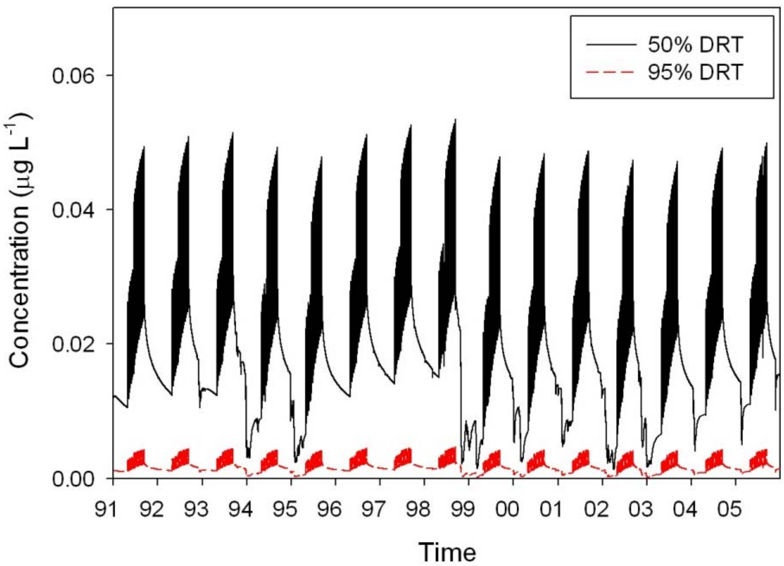


Figure 47 Average concentration of substance I_P in the water of the 100 m evaluation ditch as function of time for the period 1991–2005 and for two classes of DRT

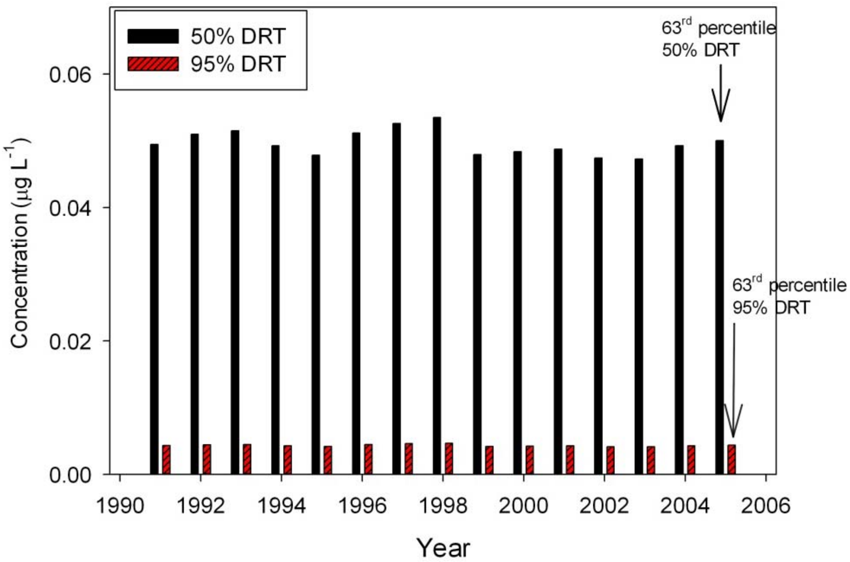


Figure 48 Annual maximum concentration of substance I_P in the 100 m evaluation ditch for two classes of DRT. The arrows indicate the 63rd percentile concentration for each class of DRT.

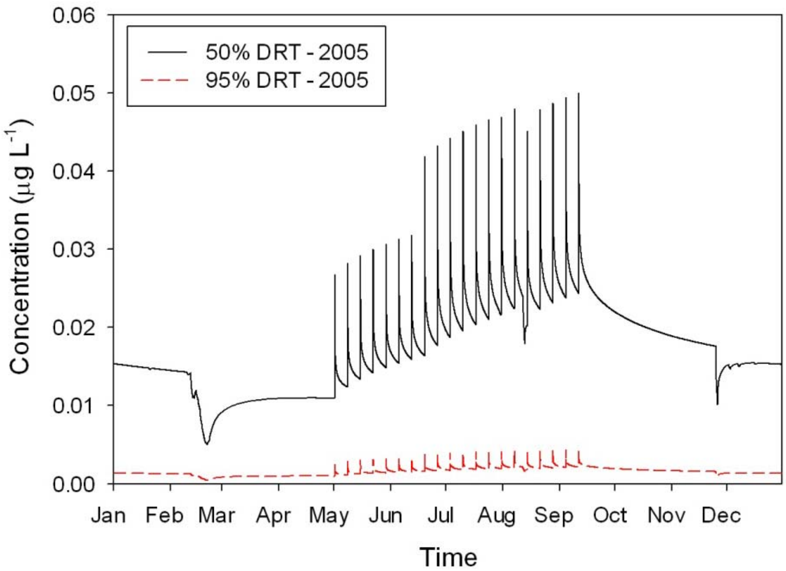


Figure 49 Average concentration of substance I_P in the water of the 100 m evaluation ditch as function of time for two classes of DRT and for the year in which the 63rd percentile concentration was found

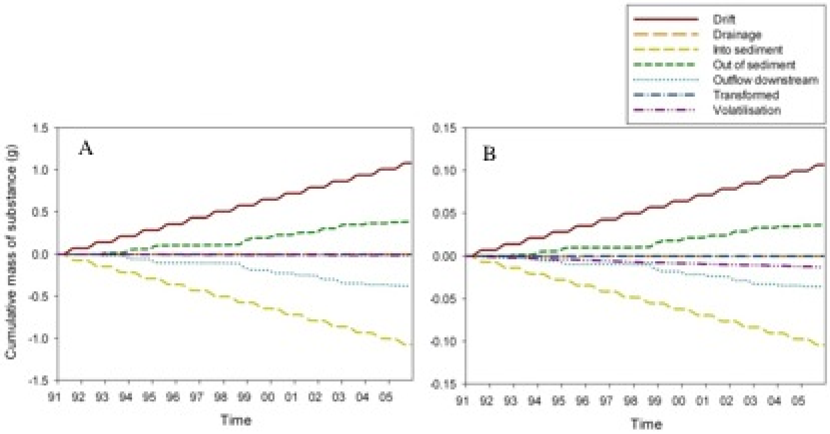


Figure 50 Cumulative monthly mass balances of substance I_P for 50% DRT (A) and 95% DRT (B). Negative values indicate transport out of the water layer. Note the tenfold difference in the cumulative mass of substance of the two graphs.

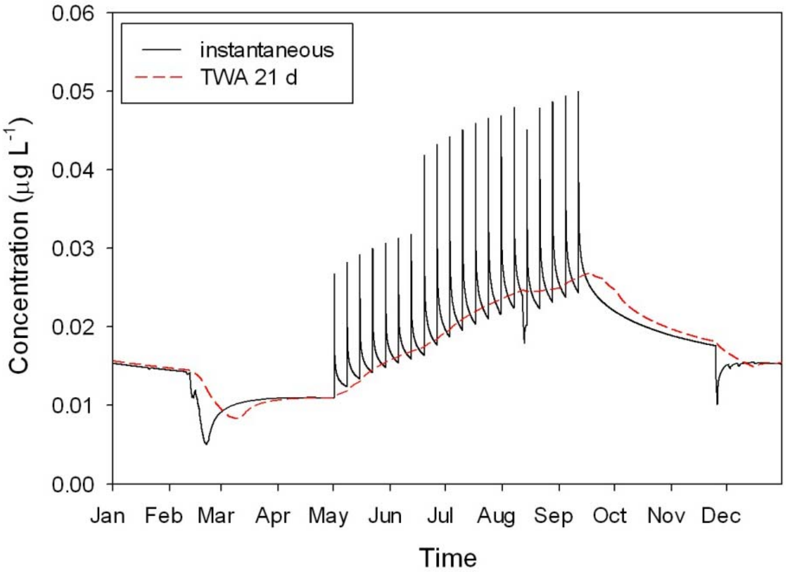


Figure 51 Average concentrations (instantaneous and TWA21) of substance I_P in the water of the 100 m evaluation ditch as function of time for 50% DRT and for the year in which the 63rd percentile concentration was found

10.3 Substance F_P in potatoes

Results of the application of substance F_P in potatoes are shown in Figures 52-56. Drift deposition for 50 per cent DRT was 0.142 mg m^{-2} on 1 June and 0.228 mg m^{-2} from 8 June until 7 September. For 95 per cent DRT, these figures amount to 0.020 mg m^{-2} and 0.022 mg m^{-2}, respectively.

The 15 applications and thus the 15 drift events cause a regular pattern of peaks in the concentration in the period June–September (Figures 52 and 54). For 95 per cent DRT the annual maximum concentration is often found one day after the last application (8 September). This is because the increase of the concentration due to atmospheric deposition, which is deposited after the first

24 hours of application (Section 7.3), exceeds the decrease of concentration due to dissipation processes like degradation, volatilisation and sorption.

The half-life in water of substance F_P is small ($DegT50_{water}$ = 3.7 d at 25°C) and the saturated vapour pressure is rather large (P_{sat} = 7.5 10^{-3} Pa), so degradation and volatilisation are major dissipation processes (Figure 55), causing a rapid decrease of the concentration in water after a spray drift event (Figure 54). Fast degradation in the water and volatilisation are also the reasons that the peaks in concentration do not differ from one application to the next application. This is different from substance I_P, where accumulation of substance in the water occurs and is due to slow degradation and low volatilisation.

The sorption coefficient in soil of substance F_P is rather large ($K_{om,soil}$ = 1138 L kg^{-1}) and consequently the concentration in drainage water is low. The combination of fast degradation in water and minor input of substance F_P in the ditch by drainage is the reason that annual peak concentrations in water do not differ much from year to year. This is also different from substance I_P, where differences in annual maximum peak concentration exist for the 15-year simulation period (compare Figures 48 and 53). Although substance I_P does not enter the ditch via drainage, concentrations in the ditch are diluted by the drain water. The effect of the dilution of the concentration of substance F_P in the ditch by relatively 'clean' drain water is less than for substance I_P.

Spray drift is the dominant source of substance F_P in the ditch (Figure 55) in the 50 per cent DRT scenario, whereas atmospheric deposition is the dominant source in the case of 95 per cent DRT. This is because atmospheric deposition is a function of vapour pressure only (section 7.3) and therefore the mitigation measure decreases the spray drift deposition only.

Due to the extremely fast decrease of the concentration after a spray event, the concentration averaged over 21 days is much lower than the instantaneous concentration. As a result, the annual maximum TWA concentration is 80 per cent lower than the annual maximum peak concentration (Figure 56).

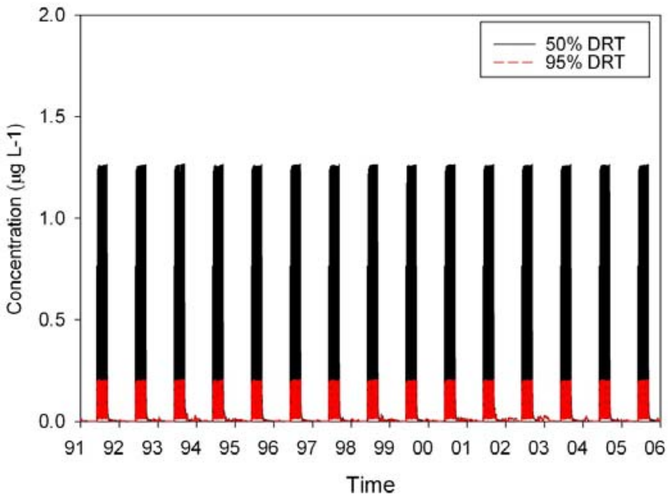


Figure 52 Average concentration of substance F_P in the water of the 100 m evaluation ditch as function of time for the period 1991–2005 and for two classes of DRT

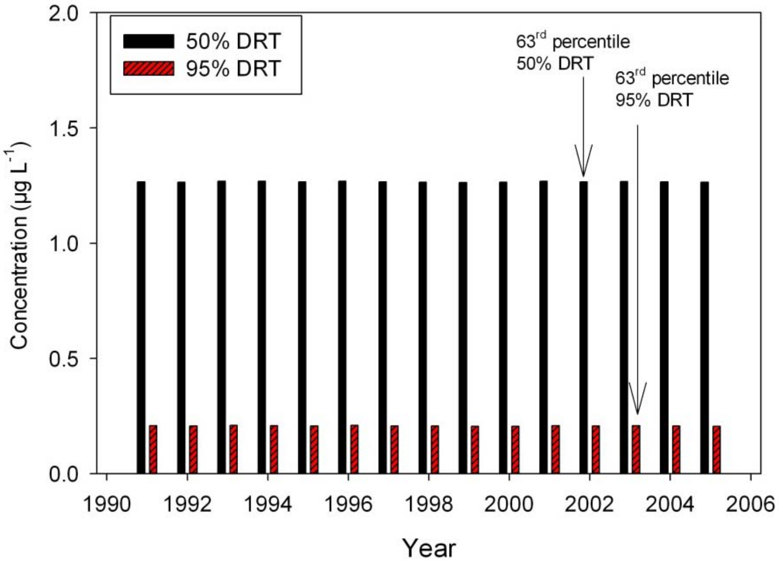


Figure 53 Annual maximum concentration of substance F_P in the 100 m evaluation ditch for two classes of DRT. The arrows indicate the 63rd percentile concentration for each class of DRT.

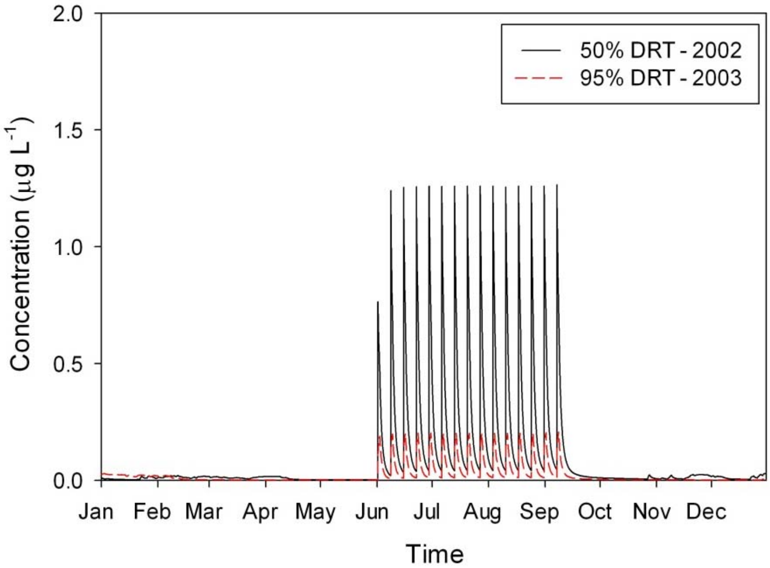


Figure 54 Average concentration of substance F_P in the water of the 100 m evaluation ditch as function of time for two classes of DRT and for the year in which the 63rd percentile concentration was found. Note that the year for which the 63rd percentile concentration was found differed between the two DRT percentages.

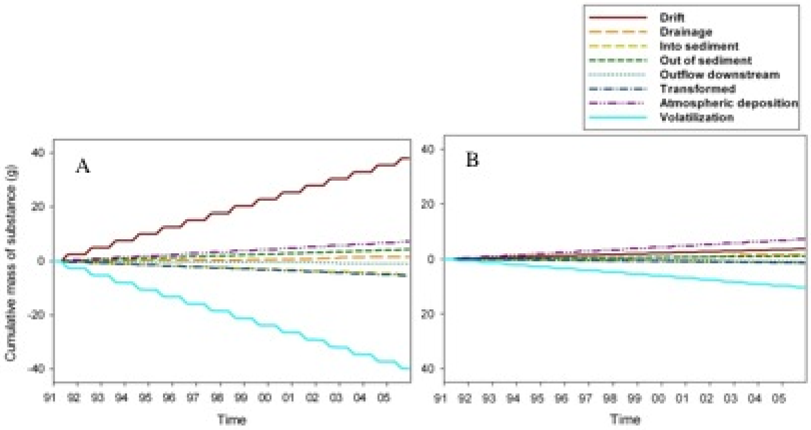


Figure 55 Cumulative monthly mass balances of substance F_P for 50% DRT (A) and 95% DRT (B). Negative values indicate transport out of the water layer.

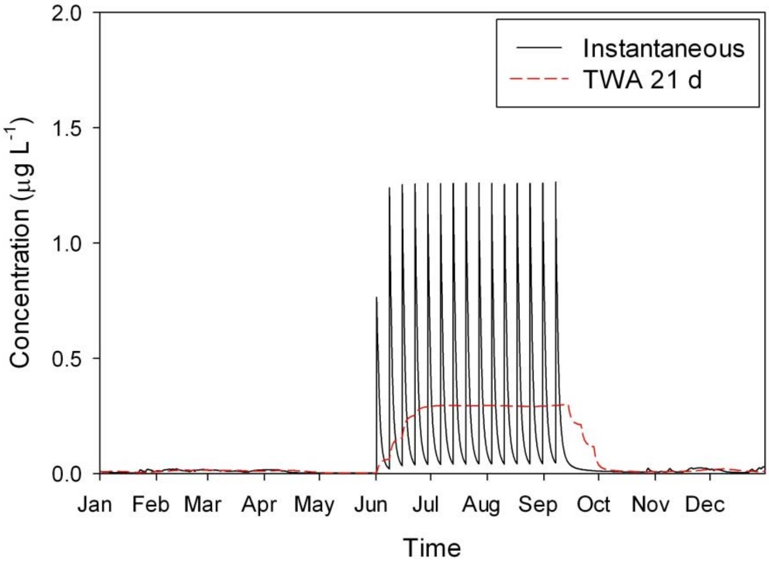


Figure 56 Average concentrations (instantaneous and TWA21) of substance F_P in the water of the 100 m evaluation ditch as function of time for 50% DRT and for the year in which the 63rd percentile concentration was found

10.4 Substance H_T in potatoes

Results of the application of substance H_T in potatoes for 50 per cent DRT (drift deposition 0.0746 mg m^{-2}) and 95 per cent DRT (drift deposition 0.0105 mg m^{-2}) are shown in Figures 57–61. For both 50 per cent DRT and 95 per cent DRT, the annual maximum peak concentration in the ditch is mainly caused by spray drift. For 95 per cent DRT the annual maximum concentration is often found one day after the last application (16 May). This is because the increase of the concentration due to atmospheric deposition deposited within 24 hours after application exceeds the decrease of concentration due to dissipation processes like degradation, volatilisation and sorption.

It is interesting to compare the results of substance I_N and substance H_T. For 95 per cent DRT, annual maximum peaks in the concentration of substance I_N in the water were often caused by drainage. This is not the case for substance H_T, although substance H_T is more mobile in soil ($K_{om,soil}$ = 36 L kg^{-1}). Substance H is, however, less persistent in soil than I_N. For this reason, less substance H_T is found in drainage water than I_N.

Figure 60 shows that during the 15-year evaluation period, the largest part of the mass of substance H_T entered the ditch by drainage and not by spray drift. However, drainage does not lead to the maximum peak concentration in a year. This is because concentrations in the drainage water are not large compared with the peak concentration in the ditch caused by spray drift. Notice further that substance H_T mainly leaves the ditch by way of the outflow of water because the dissipation processes of degradation, sorption to sediment and volatilisation are less substantial due to specific properties of substance H_T ($DegT50_{water}$ = 1000 d; $K_{om,sed}$ = 36 L kg^{-1}; P_{sat} = 9 10^{-5} Pa).

A regular supply of substance to the ditch via drainage in the autumn and winter period in combination with negligible degradation, volatilisation and sorption and low discharges in spring and summer caused a constant presence of substance H_T in the ditch in the period 1991–2005. The minimum value in concentration for both drift-reducing technique percentages is 0.03 µg L^{-1}, which occurred on 3 March 1999.

Due to the relatively slow decrease of the substance concentration after application, the substance concentration averaged over 21 days is almost equal to the instantaneous substance concentration (Figure 61). As a result, the maximum TWA concentration is only a few percentage points lower than the annual maximum peak concentration.

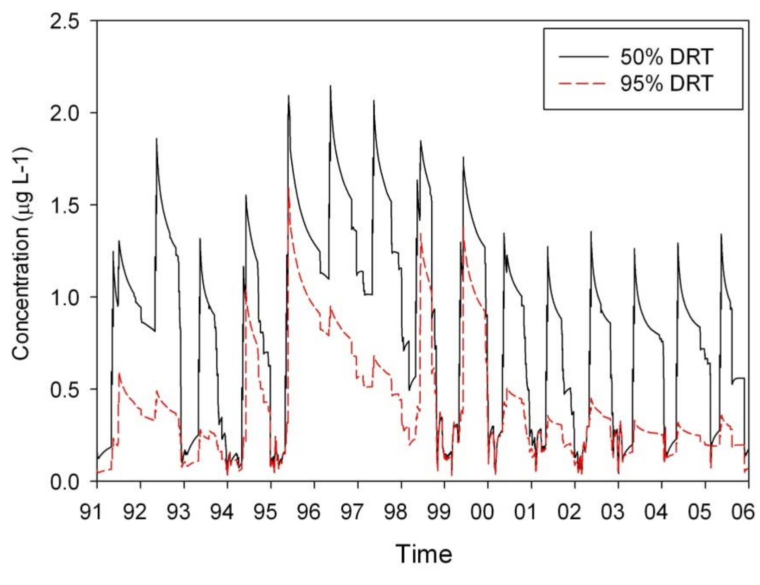


Figure 57 Average concentration of substance H_T in the water of the 100 m evaluation ditch as function of time for the period 1991–2005 and for two classes of DRT

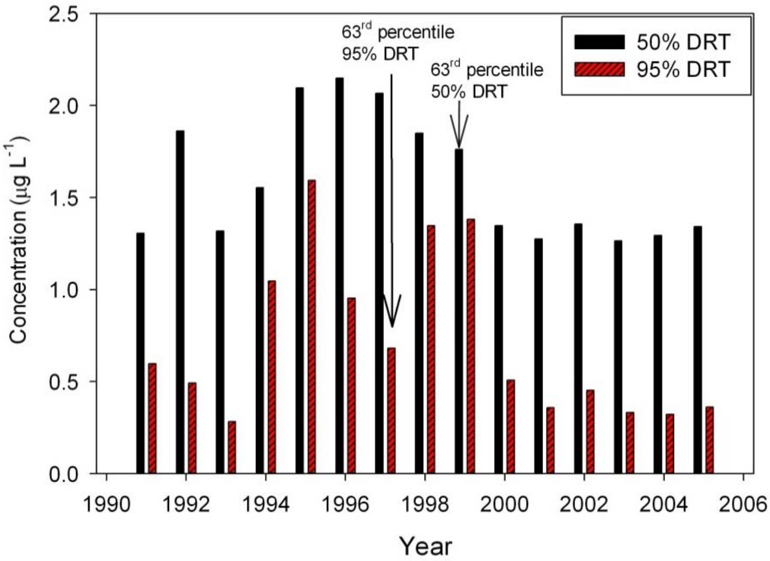


Figure 58 Annual maximum concentration of substance H_T in the 100 m evaluation ditch for two classes of DRT. The arrows indicate the 63rd percentile concentration for each class of DRT.

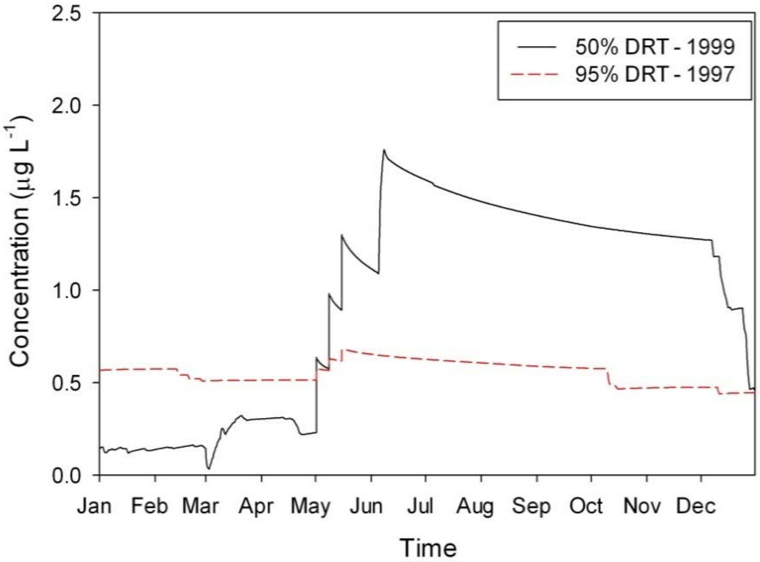


Figure 59 Average concentration of substance H_T in the water of the 100 m evaluation ditch as function of time for two classes of DRT and for the year in which the 63rd percentile concentration was found. Note that the year in which the 63rd percentile concentration was found differs per DRT percentage.

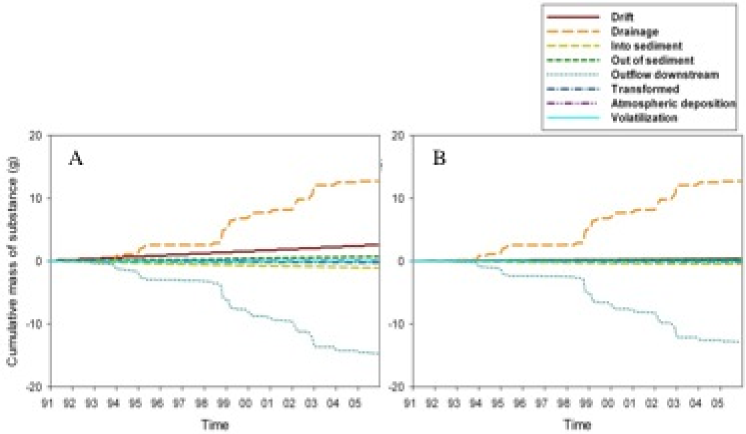


Figure 60 Cumulative monthly mass balances of substance H_T for 50% DRT (A) and 95% DRT (B). Negative values indicate transport out of the water layer.

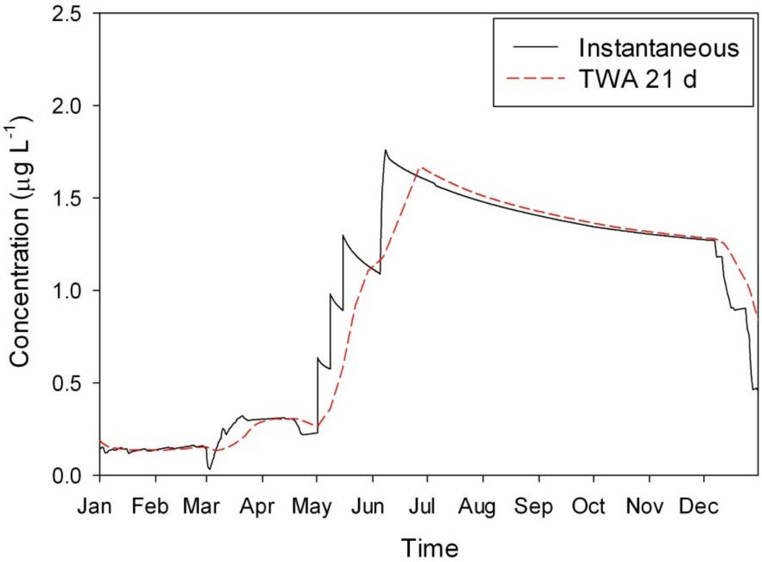


Figure 61 Average concentrations (instantaneous and TWA21) of substance H_T in the water of the 100 m evaluation ditch as function of time for 50% DRT and for the year in which the 63rd percentile concentration was found

10.5 Effect of assumptions on treatment of upstream catchment

In the proposed scenario, the 2 ha upstream catchment is treated at the same moment and with the same dosage as the adjacent field. To evaluate this scenario assumption, results from this scenario were compared with a case where a treatment ratio of 0 per cent was assumed for the upstream catchment. In view of the available time, the simulations were limited to three substances (I_N, F_P and I_P) and for 50 per cent DRT. These three cases may not be completely representative of the entire population of substances and application patterns.

Results of the analysis are shown in Figure 62. Differences between the predicted concentrations in the evaluation ditch are 9 per cent for substance I_N, 0.4 per cent for substance F_P and 11 per cent for substance I_P.

The sensitivity analysis shows that in the case of a substance with a fast degradation rate in water and moderate sorption (substance F_P), treating only the adjacent field and treating both the adjacent field and the upstream catchment give similar results. However, for a substance with slow degradation rate and moderate sorption (substance I_N), treating both the upstream catchment and the adjacent field give higher concentrations than treating only the adjacent field. For a substance with a slow degradation rate and a high sorption coefficient (substance I_P), treating both the upstream catchment and the adjacent field also give higher concentrations than treating only the adjacent field. One could expect a small difference in concentration between 100 per cent and 0 per cent treated for a strong sorbing pesticide because the largest part of the pesticide disappears into the sediment. However, diffusion from the sediment back to the water layer causes an extra input of pesticide from the upstream catchment ditch to the evaluation ditch in the case of 100 per cent treated upstream catchment.

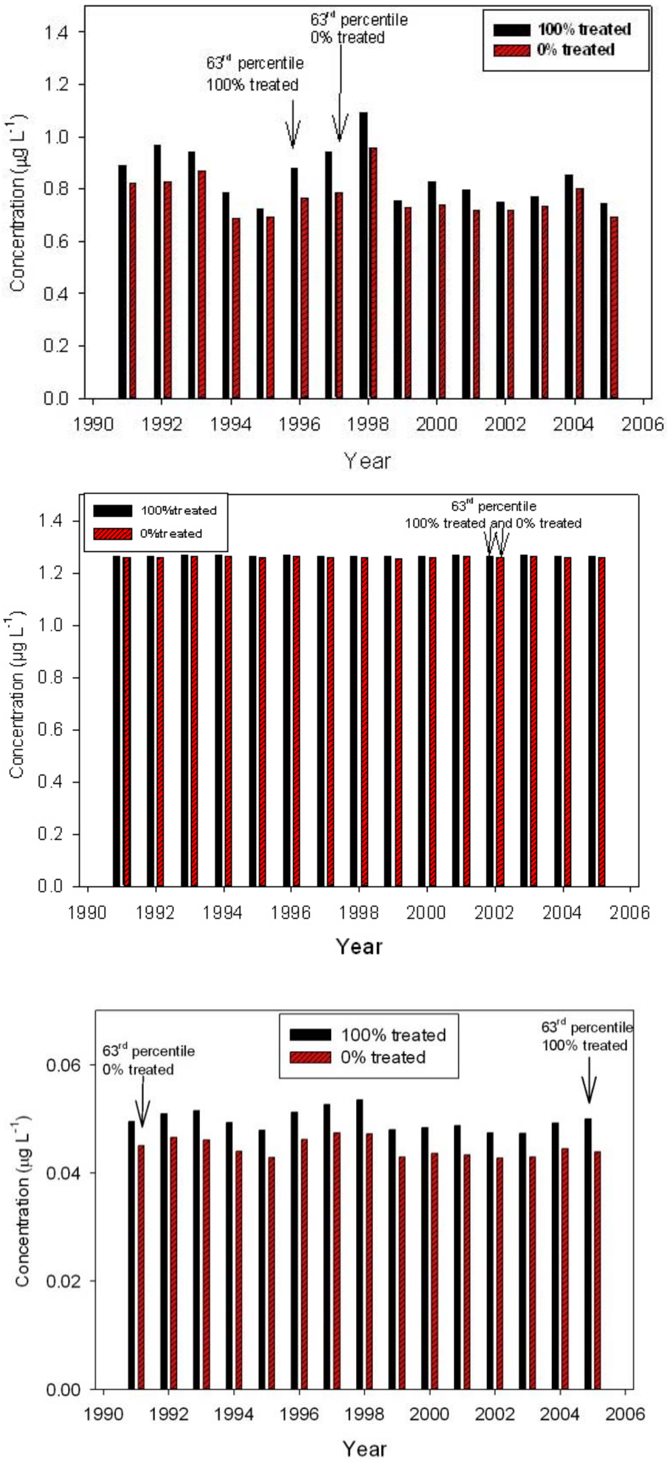


Figure 62 Annual maximum concentration of substance I_N (top), substance F_P (middle) and substance I_P (bottom) in the 100 m evaluation ditch for an untreated upstream catchment and for an upstream catchment with a treatment ratio of 100%. The arrows indicate for each case the 63rd percentile concentration.

10.6 Sensitivity of the exposure concentration to *DegT50* in water

The calculations shown in Figures 47–51 were based on a *DegT50* in water and sediment of 1,000 days (conservative approach). For pyrethroids such as lambda-cyhalothrin, dissipation half-lives in water shorter than one day have been reported in outdoor mesocosms (Maund et al. 2008) and it has been suggested that alkaline hydrolysis in the water near the surface of macrophytes and phytoplankton is considered to be the main dissipation process for lambda-cyhalothrin (Leistra et al. 2004). It is therefore relevant to assess the effect of using a more realistic half-life for the water on the exposure concentrations for substance I_P. Figure 63 shows that, because of the repeated applications, lowering the *DegT50* in the water from 1,000 d to 1 d considerably reduces the build-up of the exposure concentrations. For such substances it may therefore be important to use higher-tier mesocosm experiments for estimating the *DegT50* in the water layer (Tier 3 in the proposed tiered assessment scheme of chapter 11).

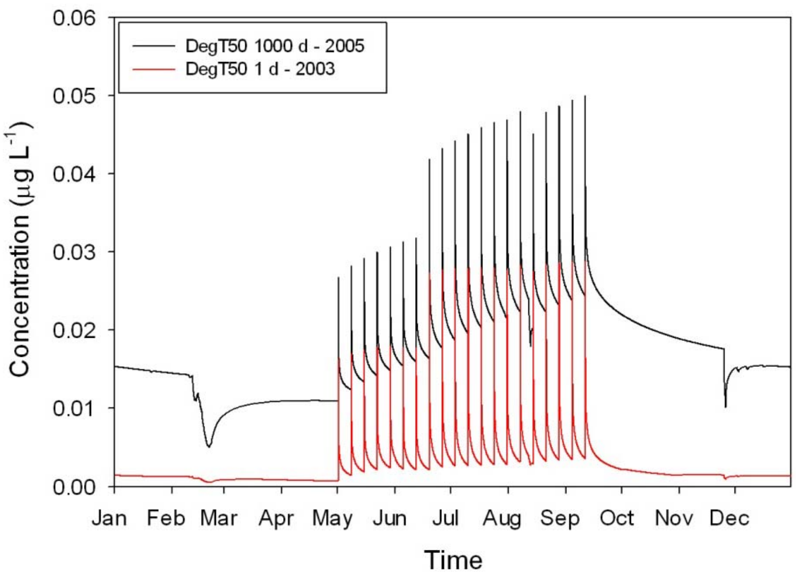


Figure 63 Concentration of substance I_p in water as function of time for the year where the 63rd percentile is found using a $DegT50_{water}$ of 1 d and 1,000 d.

10.7 Conclusions

Example calculations were carried out for four substances in two different crops. These examples show that the fate of the substance in the ditch depends to a large extend on the substance properties, the selected DRT (50 per cent or 95 per cent) and the properties of the selected scenario.

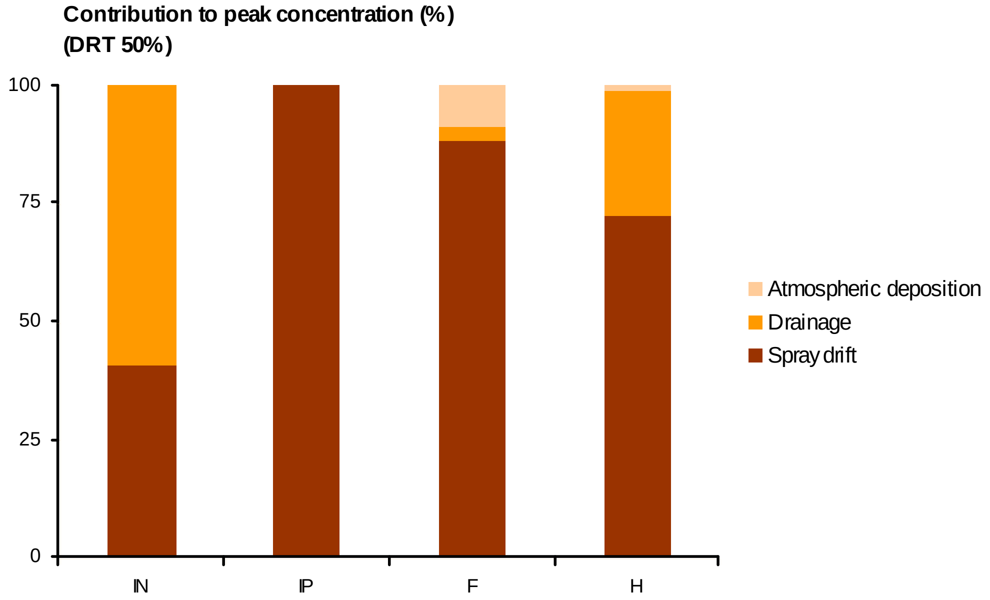
The combination of substance properties and DRT determines whether spray drift, drainage or atmospheric deposition is the main cause of the maximum annual peak concentration. With 50 per cent DRT, the peak concentration is always caused by spray drift deposition. However, the contribution of drainage and atmospheric deposition may be significant, as shown in Table 25 and Figure 64. The contribution of drainage ranges from 60 per cent for substance I_N to 0 per cent for substance I_P, whereas the maximum contribution of atmospheric deposition was 9 per cent (substance F_P). With 95 per cent DRT, the other two causes become relatively more important. The contribution of drainage is 97 per cent in the case of substance I_N (a moderately sorbing, persistent substance) and 68 per cent in the case of substance H_T. For substance F_P (a volatile substance), the contribution of atmospheric deposition was 54 per cent. This conclusion may hold for many other substances, as approximately 40 per cent of substances that are on the Dutch market have a saturated vapour pressure above 10^{-4} Pa (Van der Linden et al. 2011). For substance I_P, spray drift was still the only cause of the annual maximum concentration. For those cases where drainage or atmospheric deposition is the dominant cause of the peak concentration, spray drift mitigation options cannot reduce the concentration any further.

Table 25 The 63rd percentile of the maximum annual concentration (µg L^{-1}) for the four example substances. Calculations were done for two classes of DRT (50% and 95%), for a situation where spray drift switched off ('Drainage and atmospheric deposition only' column) and for a situation where atmospheric deposition was switched off as well ('Drainage only').

	DRT 50%	DRT 95%	Drainage and atmospheric deposition only	Drainage only
Substance I_N	0.884	0.532	0.521	0.521
Substance I_P	0.050	0.004	0.000	0.000
Substance F_P	1.303	0.207	0.150	0.039
Substance H_T	1.761	0.681	0.481	0.461

The mass balances showed that spray drift was the dominant source for substances with a high sorption coefficient in soil (substance F_P and substance I_P), whereas drainage was the dominant source for the more mobile substances (I_N and H_T). This was true for both the 50 per cent DRT and the 95 per cent. Note, however, that when drainage is the dominant source, this does not necessarily mean that drainage is also the main cause of the peak concentration, as the substance may be transported in drainage water at relatively low concentrations.

Repeated applications cause accumulation in the water-sediment system for three substances (I_N, I_P and H_T). This is primarily caused by the limited dissipation of these substances in the water layer and by the low discharge in spring and summer. Only in the case of substance F_P, the half-life in water and the vapour pressure were sufficiently high to remove the substance before the next application. These three substances were still present in the water layer during autumn and winter time, so their concentration was above zero during the entire evaluation period of 15 years. This is due to a combination of factors, namely (i) characteristics of the substances, causing limited dissipation in the water layer, (ii) low discharge in spring and summer causing limited outflow of the substance, (iii) constant supply of substance to the ditch by drainage in autumn and winter, and (iv) diffusion of substance from the sediment to the water layer in the case of relatively strongly sorbing substances.



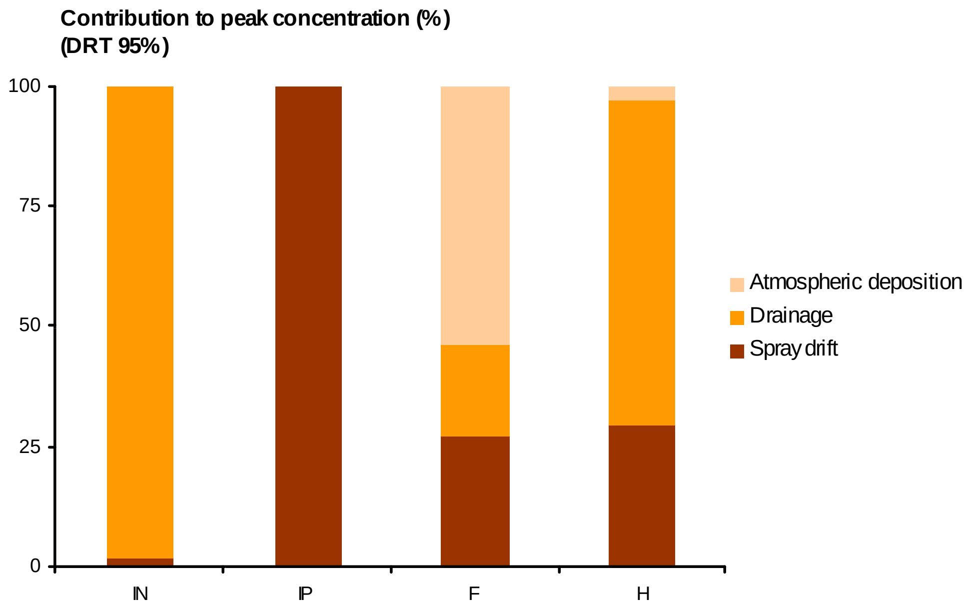


Figure 64 Contribution of spray drift, drainage and atmospheric deposition to the 63rd percentile of the maximum annual concentration in surface water for 50% DRT (top panel) and 95% DRT (lower panel).

The simulations showed that for two substances (I_N and H_T), the maximum concentration averaged over 21 days is close to the maximum annual peak concentration. These concentrations are used in the effect assessment as a measure of chronic and acute exposure, respectively (Brock et al. 2011). This is again caused by the relatively low dissipation rate of these substances and by the low discharge in spring and summer. The lowest ratio between the annual maximum concentration averaged over 21 days and the annual maximum peak concentration was 0.2 and was found for substance F_P. This substance also has the highest dissipation rate in water.

As described earlier, the 63rd percentile of the maximum annual concentration was selected from a time series of 15 years. The simulations showed that the year corresponding to the 63rd percentile differed between the four substances. In some cases, selecting another drift-reduction technology or another averaging period caused another year to be selected. This may complicate the interpretation of the combined exposure to multiple substances, as the time-course of the exposure concentration differs between the years.

11 Proposal for a tiered assessment scheme

As described previously, the proposed scenario is restricted to downward spray applications in field crops. We propose to use this scenario as part of the tiered exposure assessment scheme shown in Figure 65. The scenario is Tier 2 in this scheme in combination with six conservative assumptions and one neutral simplifying assumption (all shown in the Tier 2 box), which can be refined in Tiers 3 and 4. Tier 3 contains options that use still the same scenario but with refined inputs. Tier 4 contains options based on a different scenario.

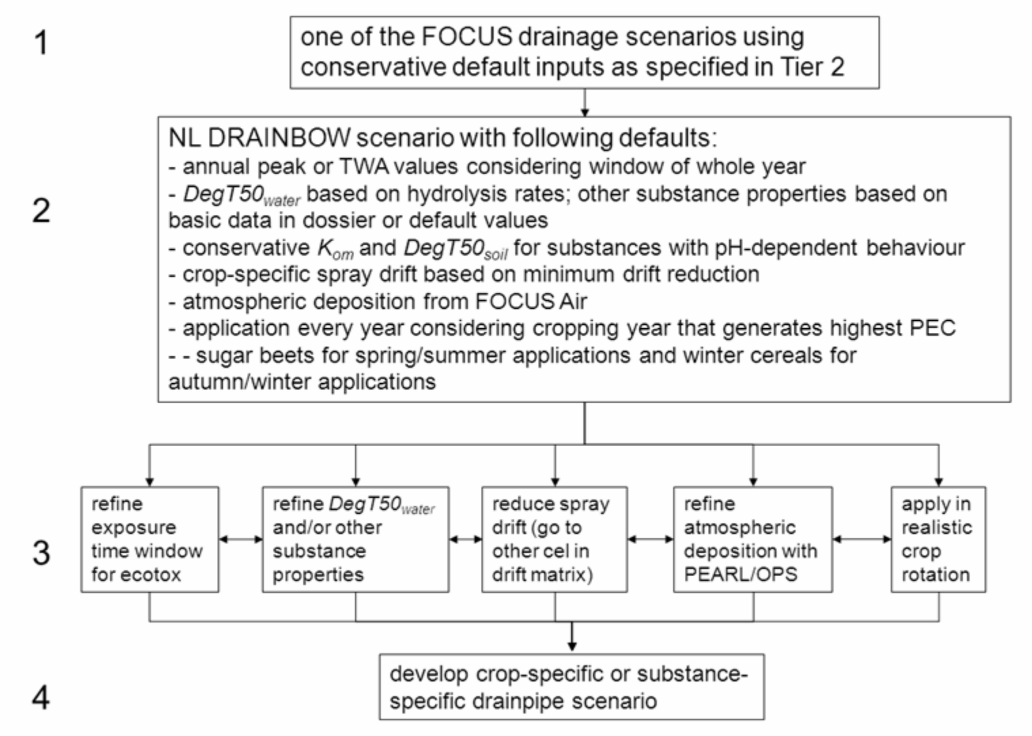


Figure 65 Tiered scheme for the exposure assessment of aquatic organisms in the Dutch pesticide registration procedure. The flow chart applies both to peak concentrations and to TWA concentrations. The arrows between the boxes in Tier 3 imply that is possible to move between the boxes.

The first conservative assumption is that the whole calendar year is used for assessing the annual peak concentration or the annual maximum TWA value. This is the default approach proposed by Brock et al. (2011). In Tier 3 this assumption may be refined by restricting this time window to part of the calendar year (for example spring and summer) if this can be justified on the basis of ecotoxicological considerations.

The second conservative assumption is to base the *DegT50* in water on the longest hydrolysis *DegT50* measured above pH 7, which is a conservative approach for Dutch surface water (Boesten et al. 2013). In Tier 3 this conservative approach can be refined following procedures described by Boesten et al. (2013). Possible refinements include using microbial degradation rates measured in surface water samples and use of outdoor mesocosms to estimate the degradation rate in water. Tier 3 offers also the possibility to use higher-tier options for other substance properties such as long-term sorption kinetics (see FOCUS 2009 for guidance on assessment of these kinetic parameters and also for refinement of other substance parameters).

The third conservative assumption is to assume a minimum level of drift-reduction measures, which can be refined in Tier 3 using the matrix approach (see Chapter 8).

The fourth conservative assumption is the use of the default atmospheric deposition figures taken from FOCUS Air, which can be refined in Tier 3 with calculations using the PEARL model for simulating volatilisation from soil and plants and using the OPS model for simulating the transport in the atmosphere and the deposition on surface water (Jacobs et al. 2011). Admittedly, this procedure has not yet been developed so this box in the scheme is not yet operational. It is also somewhat uncertain whether a more sophisticated PEARL/OPS approach will result in lower atmospheric deposition for all substances.

The fifth conservative assumption is that the exposure assessment has to be based on the cropping year that generates the highest PEC. Let us consider as an example (taken from EFSA, 2011) an exposure assessment for applications of a substance in the following two cropping years:
A: 1 kg/ha in maize and 0.5 kg/ha in carrots;
B: 0.7 kg/ha in sugar beet.
The application sequence for year A is complicated but realistic. This sequence indicates that the exposure assessment cannot be based on a certain crop but has to be based on a cropping year instead because otherwise the scenario calculations would underestimate the PEC. In the case of multi-year applications, as shown in the above example, separate scenario calculations have to be carried out for Tier 2 for each application year and the highest PEC of all the calculations has to be selected. So in the case of the above example two scenario calculations have to be carried out for Tier 2 (one for cropping year A and one for cropping year B) and the higher PEC of the two calculations has to be selected. This can be refined in Tier 3 by calculations with a realistic crop rotation. The procedure for performing calculations for a realistic crop rotation has not been developed but this can be done with limited effort. We recommend developing this calculation procedure.

The sixth conservative assumption is that in case of the pH-dependency of K_{om} and/or *DegT50*, Tier 2 calculations have to be based on conservative values of these parameters. This can be refined by developing a substance-specific scenario in Tier 4. Admittedly, no easy-to-use tool is yet available to select such a scenario, so this refinement is not easy to implement.

The last (neutral) assumption in Tier 2 is that the crop is either winter cereals or sugar beet for all field crops depending on the application time. As described before, only one scenario was selected based on the total area of field crops in the Netherlands and this one scenario was parameterised both for winter cereals and for sugar beet. As indicated in Section 2.1, this is a risk management decision. It is expected that the Tier 2 scenario is appropriate ‘on average’ when considering different crops. So for some of the crops it will be too conservative and for others it will not be conservative enough. EFSA (2011) developed crop extrapolation factors to ensure that a lower-tier scenario is always more conservative than a higher-tier scenario. The calculation of these crop extrapolation factors requires the calculation of the 90^{th} spatio-temporal percentile for a large number of crops. In view of the available time, this has not been done.

This last assumption can be refined by developing a crop-specific scenario in Tier 4 (with a fifty-fifty change that the PEC is more conservative or less conservative). No easy-to-use tool is yet available to select such a scenario, so this refinement is not easy to implement.

The flow chart contains a Tier 1 which consists of one of the six FOCUS surface water scenarios based on input via drainage (D1 to D6). This is considered appropriate to profit as much as possible from zonal and EU exposure assessments that have already been carried out. To ensure consistency in the tiered approach, we propose to use this FOCUS scenario in combination with (i) the same *DegT50* in water as used in Tier 2 (or a more conservative value), (ii) the crop-specific spray drift as used in Tier 2 (or a more conservative spray drift input) and (iii) the atmospheric deposition as used in Tier 2. The scenario has not yet been selected from the list D1 to D6. We recommend basing the selection on calculations with a range of model substances for the Tier 2 scenario and a few suitable FOCUS drainage scenarios.

12 Discussion and conclusions

As part of the Dutch authorisation procedure for plant protection products, an assessment of their effects on aquatic organisms in surface water adjacent to agricultural fields is required. This in turn requires an exposure assessment for these surface waters. In the current Dutch authorisation procedure, spray drift is the only source of plant protection products. This is scientifically not defensible, nor in line with EU procedures. For this reason, a new exposure scenario has been developed, which also takes into account drainage and atmospheric deposition. This scenario corresponds to the 90^{th} spatio-temporal percentile of the annual maximum concentration in all ditches that receive input from spray drift and drainpipes. The scenario is intended to be a second-tier approach, to be preceded by a first tier consisting of one or more of the FOCUS surface water scenarios and succeeded by higher tiers considering refinements such as better input parameters and drift-reduction measures.

The exposure assessment methodology in this report is restricted to applications with downward spraying techniques in field crops. Table 1 gives an overview of all possible combinations of spraying technique and crop type. Scenarios for other spraying techniques will be developed and reported later. Our exposure assessment methodology does not apply to non-spray applications (seed treatments and granules), and so we recommend developing appropriate aquatic exposure methodologies based on the recommendations in EFSA (2004).

To the best of our knowledge, the surface water scenario presented in this report is the first regulatory surface water scenario that has been derived systematically using probabilistic and geostatistical modelling based on the requirement of a specified spatio-temporal percentile of a concentration distribution (in this case the 90^{th} spatio-temporal percentile of the population of annual peak concentrations in ditches that are at the edge and downwind of treated fields and that receive drain water from these treated fields).

12.1 Scenario development

The endpoint of the exposure assessment is a spatio-temporal percentile of the annual maximum concentration in all relevant arable field ditches, so the exposure concentration distribution had to be simulated first. The spray drift model IDEFICS and a macropore version of the leaching model GeoPEARL were used for this purpose. This resulted in the selection of a 90^{th} percentile scenario. For this scenario, a non-stationary flow version of TOXSWA was parameterised.

Only one scenario was selected based on the total area of field crops in the Netherlands. It is expected that this scenario is appropriate ‘on average’ when considering different crops. So for some crops it will be too conservative and for others it will not be conservative enough. EFSA (2011) developed crop extrapolation factors to ensure that a lower-tier scenario is always more conservative than a higher-tier scenario. We recommend calculating these crop extrapolation factors for all relevant Dutch crops (as described in the so-called DTG-list).

Soil pH was a parameter neither in the selection of the soil profile nor in the comparison of the Andelst scenario with GeoPEARL. It is therefore unknown whether the Andelst scenario is sufficiently conservative for ionising substances. As a consequence, in assessments for substances showing pH-dependent behaviour, conservative estimates of the substance properties should be used. As indicated in Chapter 11, the exposure assessment can be refined by developing a substance-specific scenario in Tier 4. No easy-to-use tool is yet available for selecting such a scenario, so the development of such a tool could be a research priority for the coming years.

12.2 Spray drift

The spray drift model IDEFICS was used to simulate the peak concentration in 66 ditch types and 700 combinations of wind direction and wind speed. These combinations together represent the entire population of possible ditches and weather conditions, so that it was possible to derive a cumulative frequency distribution function from which the 90th percentile concentration could be derived. This concentration can occur at different combinations of ditch type, wind direction and wind speed, so additional criteria were needed to select the scenario ditch. Application of these additional criteria resulted in the selection of a water course typical of river clay areas, which has a lineic volume of 0.55 m^{-3} m^{-1} and a water depth at the wet winter situation of 0.23 m.

For the spray drift part of the exposure assessment, new spray drift deposition curves were developed. These curves describe the relation between the distances from the edge of the field and spray drift deposition. For the reference (non-drift reducing) technique and for the 50 per cent drift-reducing techniques, the spray drift deposition curves are based on a large number of experiments. This large number ensures that the spray drift curves are reliable. The spray drift deposition curves for the 75 per cent, 90 per cent and 95 per cent drift-reducing nozzle types are based on relatively few comparative measurements between the drift-reducing technique and the reference. To increase the robustness of spray drift curves for these classes of drift-reducing techniques, additional measurements should be carried out.

The spray drift curve to be used in the exposure assessment depends on crop type, crop development stage and treatment type. A flow chart was built to facilitate the selection of the appropriate curve. Spray drift deposition is calculated using a fixed water depth of 0.1905 m. This is the water depth for a situation where the discharge in the ditch is equal to base flow. The drift deposition calculated with the new spray drift curves is higher than the drift deposition calculated in the current Dutch authorisation procedure. There are two reasons for this (Van de Zande et al. 2012): (i) the spray drift database was updated with new data, and (ii) the dimension and the position of the new ditch differ from the old Dutch standard ditch.

The Dutch ministries decided that the exposure scenario should correspond to the 90th percentile of the annual maximum concentration in all field ditches that receive input from spray drift and drainpipes. Calculations for the spatial population of all ditches showed a distinctly higher 90th percentile concentration than calculations for the population of only the ditches that receive water from drainpipes. Strongly sorbing pesticides will not show leaching from drainpipes. So the limitation of the population to ditches that receive water from drainpipes has led to the selection of a scenario that generates a lower concentration for such compounds due to dilution compared with ditches without input from drainpipes.

The spray drift scenario was based on a single application within a year. It was shown that this scenario may not be sufficiently conservative for multiple applications, particularly when the concentration in the ditch does not build up between subsequent applications within a growing season. It was further shown that this weakness can be overcome by taking a higher percentile of the concentration distribution resulting from single applications. However, if only one such percentile were selected for all application patterns, the assessment would become extremely conservative for single applications or for cases where the concentration in the ditch builds up between applications. We therefore recommend developing a procedure in which the percentile to be selected depends on the number of applications and the type of substance.

As described in Section 2.1.1, the Ministries decided that small, temporarily dry ditches (‘tertiary ditches’) should also be included in the exposure assessment. Our selection of the spray drift scenario was based on water depths in the wet-winter situation. This resulted in a 90th percentile ditch that belonged to the class of secondary ditches (which permanently carry water). Figure 31 of Van de Zande et al. (2012) shows that the PEC increases sharply if the water depth decreases and goes to infinity for zero water depth. If we would have used a water depth based on the spring situation, the water depth would probably have got a larger weight in the scenario selection procedure than the weight of the temporal variations of the spray drift. Possibly this would have led to selection of a tertiary ditch as the 90th percentile case. This in combination with a realistic simulation of the water level fluctuations in such ditches (which fall dry in most of the years in summer) would have led to a 90th percentile PEC that is likely to be at least a factor of two higher than the PEC resulting from the proposed procedure. So there is no reasonable certainty that the proposed procedure generates an adequate 90th percentile PEC for the population of ditches including the tertiary ditches. On the other hand it is questionable whether it is meaningful to include these tertiary ditches in the exposure assessment goal because the proposed effect assessment (Brock et al. 2011) is based on permanent water bodies.

12.3 Drainage

The drainage part of the assessment is based on data from a field experiment in a cracking clay soil (the Andelst dataset). Additional data was used to extend this dataset to a 15-year period, so that the exposure assessment can be carried out for a period of multiple years (in accordance with FOCUS 2001). This is necessary to reduce the effect of application time on the predicted exposure concentration. A sensitivity analysis showed that this strategy worked well for most substances. However, in the case of a quickly degrading, very mobile substance, the predicted exposure concentration varies by a factor of two when changing the application data within a period of one week. Risk managers should decide whether this maximum factor of two that is introduced by this subjectivity is considered acceptable.

The exposure concentration resulting from drainage and derived from the GeoPEARL simulations has a spatial component and a temporal component. By selecting the Andelst field site as the basis of the exposure scenario, the spatial percentile was fixed and indirectly also the temporal percentile. An analysis showed that the 63rd percentile of the frequency distribution function consisting of 15 annual peak concentrations corresponded well with the overall 90th percentile simulated with GeoPEARL (the target concentration), so this 63rd percentile has to be selected for the risk assessment. This concentration increases with increasing *DegT50* and decreases with increasing K_{om}. Predicted differences of the target maximum concentration between substances are small compared with differences of the leaching concentration as predicted by the convection-dispersion equation. This is plausible, because the maximum concentration is primarily caused by preferential flow where the substance bypasses most of the reactive part of the soil profile.

The Andelst field experiment has played a crucial role in the development of the drainpipe exposure scenario. It is currently the only Dutch dataset in which sufficient data is available to parameterise and test all modules of the preferential flow version of PEARL. To increase confidence in the model, we recommend carrying out some additional field experiments, in which the fate of substances in the adjacent ditch is also measured.

The MACRO model (Larsbo et al. 2005) is currently the only preferential flow model that is used for the evaluation of substances at EU level. A benchmark of PEARL with MACRO would lead to increased confidence in the two models.

The organic matter content of arable soils in GeoPEARL is underestimated. This was corrected for in an ad-hoc way when estimating the temporal percentiles to be used in the exposure assessment (see Tiktak et al. 2012b for details). There is considerable uncertainty in this ad-hoc correction procedure. The development of an organic matter content map for arable soils will avoid such problems, so we recommend developing such a map.

12.4 Exposure in the ditch

The simulations with IDEFICS and GeoPEARL result in the selection of a 90th percentile scenario. For this scenario, a non-stationary flow version of TOXSWA was parameterised. Most ditch parameters were obtained from national databases. Where information from such databases was not available, parameter values were taken from FOCUS (2001). TOXSWA simulations showed that most of the time, the water moves slowly (< 1.5 cm d^{-1}), so the residence time of substances in the ditch is relatively high as compared to FOCUS (2001).

The current version of TOXSWA does not include a description of evaporation from and direct precipitation on the ditch. In reality, evaporation does occur and the water in the ditch will often be replaced by fresh water from the upstream catchment. This may result in overestimation of the residence time of substances in the evaluation ditch. The working group therefore recommends developing a TOXSWA version that includes a description of these two water balance terms.

The TOXSWA model uses monthly average air temperatures and assumes that the temperature in the water and the sediment equals this monthly temperature. This approach is not in balance with the level of sophistication of the rest of the exposure scenario and may lead to inaccurate simulation of degradation rates and volatilisation rates. Therefore we recommend developing a TOXSWA module that is based on daily meteorological data.

When estimating the K_{om} for sediment and suspended solids for the example substances, we were unable to find guidance at EU level other than to use the K_{om} measured for soil. In view of the importance of this K_{om} for the exposure of strongly sorbing pesticides, we recommend underpinning this guidance by a literature review in which all available K_{om} values measured on sediments are compared with the K_{om} values from soils.

12.5 Example calculations

Example calculations carried out for four substances in two crops showed that the contribution of spray drift to the maximum annual peak concentration ranged from 40 to 100 per cent when using a sprayer in the minimal required spray drift reduction class of 50 per cent. Spray drift reduction is therefore still an efficient tool for reducing the exposure of aquatic organisms. However, when spray drift is reduced to a higher spray drift reduction class (95 per cent), atmospheric deposition or drainage may become the major cause of the peak concentration. In such a case, further spray drift mitigation options will not reduce the peak concentration any further.

The low flow velocity in the ditch in combination with low dissipation rates of substances in water caused the concentration of three example substances to build up in the water sediment layer over the years. As a result, the exposure concentration was above zero during the entire 15-year evaluation period. For two of the example substances, the difference between the maximum concentration averaged over 21 days and the maximum peak concentration was small. This implies that the difference between acute and chronic exposure concentration may be small.

As described earlier, the 63rd percentile of the maximum annual concentration was selected from a time series of 15 years. The simulations showed that the year corresponding to the 63rd percentile differed between the four substances. In some cases, selecting another drift-reduction technology or another averaging period caused another year to be selected.

12.6 Development of other tiers

The current scenario is intended to be a Tier 2 scenario. We propose to develop also a Tier 1 scenario based on one of the six FOCUS surface water scenarios, which include input via drainage (D1 to D6). This is considered appropriate to profit as much as possible from zonal and EU exposure assessments that have already been carried out. To ensure consistency in the proposed tiered approach, we propose to use this FOCUS scenario in combination with (i) the same *DegT50* in water as used in Tier 2 (or a more conservative value), (ii) the crop-specific spray drift as used in Tier 2 (or a more conservative spray-drift input) and (iii) the atmospheric deposition as used in Tier 2.

The current scenario includes a description of deposition on edge-of-field surface waters due to volatilisation directly after application. This is a lower-tier approach based on the idea that it is better to include atmospheric deposition than to ignore it. This can be refined in a higher tier with calculations using PEARL for simulating volatilisation from soil and plant and using the OPS model for simulating transport in the atmosphere and deposition on surface water. We recommend making this tier available. Because the PEARL/OPS scenarios have not yet been developed, it is not yet known whether they are less conservative than the atmospheric deposition estimates from FOCUS Air. Therefore the use of the FOCUS Air estimates in the second tier may need revision once the PEARL-OPS scenarios have become available.

Calculations with one of the four example substances showed that the *DegT50* in water had a large effect on the decline of the concentrations in the scenario. Therefore the refinement of the estimation procedure for the *DegT50* in water (which is part of the third tier) is expected to play an important role in exposure assessments based on the proposed methodology. Therefore we recommend including this refinement in future assessments of the impact of the introduction of the proposed methodology in the Dutch pesticide registration procedure.

The current methodology cannot handle realistic crop rotations. This is a conservative approach, which can be refined by calculations with a realistic crop rotation in Tier 3. The calculation procedure for a realistic crop rotation has not been developed. We recommend developing this calculation procedure.

The tiered flow chart requires conservative estimates of K_{om} and *DegT50* in the second tier if these substance parameters are a function of soil properties such as the pH. The flow chart allows for selecting substance-specific scenarios in the fourth tier. Without appropriate software, it will be difficult for notifiers to apply this fourth tier. Therefore we recommend further development of this tier.

13 Main recommendations

This chapter provides the main recommendations for refining and completing the proposed exposure assessment. Additional recommendations can be found in Chapter 12.

1. **Develop scenarios for other application techniques and crops.**
   The exposure assessment methodology in this report is restricted to application with downward-spraying techniques in field crops. To extend the exposure assessment methodology to all possible combinations, we recommend also developing scenarios for the other combinations of spraying technique and crop type as included in Table 1. Our exposure assessment methodology does not apply to non-spray applications (e.g. seed treatments and granules). Therefore we recommend developing also aquatic exposure assessment methodologies for non-spray applications based on the recommendations of EFSA (2004).

2. **Develop the other tiers of the proposed exposure assessment scheme.**
   The current scenario is intended to be a Tier 2 scenario. We propose developing also a Tier 1 scenario, which is based on one of the six FOCUS surface water scenarios that include input via drainage. We further recommend developing the higher tiers of the proposed assessment scheme in Chapter 11 (substance properties, atmospheric deposition and realistic crop rotations). See section 12.3 for details.

3. **Carry out additional field experiments.**
   The Andelst field experiment has played a crucial role in the development of the drainpipe exposure scenario. Field experiments in which the input by both spray drift and drainage is measured are not available in the Netherlands. To increase confidence in the exposure model, we recommend carrying out such field experiments. Because the decline of the substance concentration in the ditch is important for the effect side of the risk assessment, we recommend measuring alsothe fate of substances in ditch water.

List of abbreviations

BBCH	Biologische Bundesanstalt und Chemische Industrie, a detailed coding system for indicating the phenological development stage of plants
cdf	cumulative distribution function
COLE	Coefficient of Linear Extensibility
Ctgb	Board for the authorisation of plant protection products and biocides
DegT50	degradation half-life
DRAINBOW	Drainage and Spray Drift Burden Of Water
DRT	drift-reduction technology
DTG	Definitielijst Toepassingsgebieden Gewasbeschermingsmiddelen
DW1	Downward-directed spraying with a minimum cropfree zone of 25 cm
DW2	Downward-directed spraying with a minimum cropfree zone of 50 cm
DW2	Downward-directed spraying with a minimum cropfree zone of 75 cm
EFSA	European Food Safety Authority
ELINK	Linking aquatic exposure and effects
ERC	ecotoxicologically relevant type of concentration
EU	European Union
FOCUS	Forum for Co-ordination of pesticide fate models and their Use
GeoPEARL	The spatially distributed version of the PEARL model
IDEFICS	IMAG program for Drift Evaluation for Field sprayers by Computer Simulation
KMNI	Royal Dutch Meteorological Institute
K_{om}	coefficient for sorption on organic matter
LoEP	List of Endpoints
LOTV	Lozingenbesluit Open Teelt en Veehouderij
MLG	Mean Lowest Groundwater level
PBL	Netherlands Environmental Assessment Agency
PEARL	Pesticide Emission At Regional and Local scales
PEC	predicted environmental concentration
PPP	plant protection product
RIVM	National Institute for Public Health and the Environment
SOT	Standaard Opzet Toelatingsbeschikkingen
TOXSWA	Toxic Substances in Water. Model that simulates pesticide fate in surface water
TWA	time-weighted average
WFD	Water Framework Directive

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Appendix 1 Properties of the example substances

The example substances in this report are real substances. The responsible ministries, however, wanted their names to be listed anonymously. For this reason, a code has been assigned to the substances as follows:

- Substance I_N is an insecticide from the substance group neonicotinoids.
- Substance I_P is an insecticide from the substance group pyrethroids.
- Substance F_P is a fungicide from the substance group phenylpyridinamines.
- Substance H_T is a herbicide from the substance group triazinones.

Brock et al. (2011) use the same substances and substance codes, so that the link between the two reports is clear.

Substance properties were derived from the literature or from the list of endpoints (LoEP). Only the most important substance parameters were assumed to be substance dependent. All other parameters were assumed to be substance independent, and their values have been taken from the literature. The substance independent data are listed first.

Parameters that were assumed to be substance independent

- E_a for degradation in soil: 65.4 kJ/mol (EFSA 2007);
- Factor *B* describing moisture dependency of degradation in soil: 0.7 (FOCUS 2000);
- E_a for hydrolysis in surface water: 75 kJ/mol (Deneer et al. 2010);
- Wash-off factor: 0.1 mm-1 conservative value based on EFSA (2011);
- Depth dependency of degradation in soil as proposed by FOCUS (2000);
- Uptake factor for plants: 0.5 (FOCUS 2000);
- Molar enthalpy of vaporisation: 95 kJ/mol (FOCUS 2000);
- Molar enthalpy of dissolution: 27 kJ/mol (FOCUS 2000);
- Molar enthalpy of sorption: 0 kJ/mol (FOCUS 2000);
- Reference diffusion coefficient in water: 0.43 ×10-4 m2 d-1 (FOCUS 2000);
- Reference diffusion coefficient in air: 0.43 m2 d-1 (FOCUS 2000);
- Reference temperatures for diffusion, vapour pressure, water solubility, sorption, transformation rates in soil and water: 20 oC;
- Reference moisture content for degradation: pF 2;
- *DegT50* for degradation in sediment: we assumed no degradation, so the half-life was set to 1,000 d;
- K_{om} for sorption in the sediment and for sorption to suspended solids: we assumed the same value as for soil as listed in the table below;
- Freundlich exponent for sediment: we assumed the same value as for soil;
- Half-life for degradation on plant surfaces: 10 d: FOCUS (2001) proposed a default half-life for foliar dissipation of 10 d; EFSA (2008) proposed a default half-life of 10 d based on Willis & McDowell (1987); however, EFSA (2010c) proposed a half-life of 30 d referring to a USDA database; PEARL distinguishes between (i) the half-life for degradation on the plant surface, (ii) the half-life for penetration into plant surfaces, and (iii) volatilisation from plants. The defaults mentioned above refer to dissipation, i.e. the sum of all these processes. Therefore we selected the highest default value (30 d). To obtain a consistent parameterisation in PEARL we used a half-life of 30 d for degradation on plant surfaces and of 1,000 d for penetration into the plant surfaces. Please note that during the course of our work EFSA (2011) was published, which recommends a half-life of 10 d. As described in Table 23, we recommend using 10 d for future exposure assessments based on EFSA (2011).

Parameters that were assumed to be substance dependent

		F_P	I_P	I_N	H_T
Crop		potatoes	lilies	lilies	potatoes
Application times and dosages	Values	15 applications of 0.2 kg/ha starting 1 June with intervals of 7 days	20 applications of 0.005 kg/ha starting 1 May with intervals of 7 days	0.07 kg/ha on 1 May 0.07 kg/ha on 8 May	0.105 kg/ha on 1, 8 and 15 May
	Source/ comment	Ctgb	Ctgb	Ctgb	Ctgb
per cent crop interception at application times	Values	1 Jun 0.50 8 Jun 0.50 15 Jun 0.50 22 Jun 0.50 29 Jun 0.50 6 Jul 0.50 13 Jul 0.50 20 Jul 0.80 27 Jul 0.80 3 Aug 0.80 10 Aug 0.80 17 Aug 0.80 24 Aug 0.80 31 Aug 0.80 7 Sep 0.50	1 May 0.25 8 May 0.25 15 May 0.25 22 May 0.25 29 May 0.25 5 Jun 0.40 12 Jun 0.40 19 Jun 0.60 26 Jun 0.60 3 Jul 0.60 10 Jul 0.60 17 Jul 0.60 24 Jul 0.60 31 Jul 0.60 7 Aug 0.60 14 Aug 0.60 21 Aug 0.60 28 Aug 0.60 4 Sep 0.60 11 Sep 0.60	1 May 0.25 8 May 0.25	1 May 0.15 8 May 0.15 15 May 0.15
	Source/ comment	procedure in Section 7.2	procedure in Section 7.2	procedure in Section 7.2	procedure in Section 7.2
Molar mass (g/mol)	Value	465.1	449.9	255.7	214.3
	Source/ comment	LoEP	LoEP	LoEP and Tomlin (2003)	LoEP and Tomlin (2003)
pK_a	Value	7.34	-	-	-
	Source/ comment	footprint PPDB (accessed 15 December 2010): weak acid			

		F_p	I_P	I_N	H_T
DegT50 at 20 °C, pF = 2 in top soil (d)	Value	72	50	118	10
	Source/ comment	geomean of lab studies from LoEP	geomean of lab studies from LoEP	geomean of lab studies standardised to field capacity from LoEP; consistent with observed persistence in Andelst field experiment	median of lab studies standardised to field capacity from LoEP
DegT50 in water due to hydrolysis (d)	Value	3.7 at 25 °C	1,000	1,000	1,000
	Source/ comment	LoEP: 3.6 d at pH=7 and 3.7 d at pH=9 at 25 °C	LoEP: degradation not significant at pH=6.9 and *DegT50* approx. 1 week at pH=9	LoEP: *DegT50* > 1 year at pH=7 and approximately 1 year at pH=9 and 25 °C	LoEP: at pH=7 and pH=9 stable over 34 d at 25 °C
Water solubility (mg L^{-1})	Value	0.135 at 20 °C	0.005 at 20 °C	610 at 20 °C	1,050 at 20 °C
	Source/ comment	Tomlin (2003) at pH 7; LoEP were considered less reliable because of differences between FOCUS STEP 3 calculations and values in the database	LoEP: 0.004 mg L^{-1} at pH 5, 0.005 at pH 7 and 0.004 at pH 9 (all at 20 °C)	Tomlin (2003); LoEP: same value, independent of pH in range 4 to 9	Tomlin (2003); LoEP reports the same value stating 'same for pH 4 – 9' and additionally values of 1,210 to 1,280 mg L^{-1} at 23–25 °C and pH 5 to 9
Saturated vapour pressure (mPa)	Value	7.5 at 25 °C	0.0002 at 20 °C	4×10^{-7} at 20 °C	0.09 at 20 °C
	Source/ comment	Tomlin (2003); LoEP gives same value but 20 °C	LoEP and Tomlin (2003)	LoEP: 4×10^{-7} at 20 °C 9×10^{-7} at 25 °C Tomlin (2003): 9×10^{-7} at 25 °C	Tomlin (2003) gives 0.058 at 20 °C; LoEP gives 0.12 at 20 °C; average selected

		F_P	I_P	I_N	H_T
K_{om} (L kg^{-1}) for soil	Value	1,138	138,820	131	36
	Source/ comment	LoEP: average K_{oc} of 1,958 L kg^{-1}; this was divided by 1.724. pH of soils (unknown measurement method) was 6.0 to 7.7	mean of values from LoEP	LoEP: average K_{oc} of 225 L kg^{-1}; this was divided by 1.724	average of values from LoEP with K_f values above 0.3 L kg^{-1} because lower values are considered too inaccurate; K_{oc} value of 61 L kg^{-1} divided by 1.724
Freundlich exponent (-) for soil	Value	0.65	0.9	0.80	0.9
	Source/ comment	LoEP gives four values with average of 0.65 and range from 0.62 to 0.68	default value because no measurements were reported in LoEP	average of 12 values ranging from 0.74 to 0.89 in LoEP	default value because LoEP contains only three defensible values

Appendix 2 Model versions used in this study

This study was done with preliminary model versions that may deviate slightly from the model versions that will be incorporated into DRAINBOW. The following model versions were used:
- GeoPEARL 4.4.4;
- IDEFICS 3.4;
- PEARL 3.1.2;
- SWAP 3.2.32;
- TOXSWA 3.2.4 (19 October 2011);
- Wageningen UR Drift Calculator 1.5.

Differences between the model versions in this study and the final model version will be reported when DRAINBOW is released for use in authorisation procedures.

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