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This report describes a new exposure scenario for soil-bound crops as part of the Dutch authorisation procedure for plant protection product. The scenario is based on state-of-the-art knowledge of greenhouse systems and soil-bound cultivation practices. The exposure scenario corresponds to the 90th spatio-temporal percentile of the annual maximum concentration in all ditches that potentially receive input from soil-bound greenhouses. Emission of Plant Protection Products is mainly via excess irrigation water discharged to nearby ditches. 12 representative greenhouses and corresponding ditches were selected, models were parameterised and water concentrations calculated. Based on the ranked concentrations, one greenhouse was selected. Also leaching scenarios for groundwater were developed, using a similar approach. The derived scenarios should be used in combination with degradation half-lives that are measured in greenhouse soils.

Keywords: surface water; groundwater; soil-bound crops; greenhouses; exposure scenarios; environmental risk assessment; Plant Protection Produces, pesticide fate models

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Photo cover: W. Voogt

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Preface

A few years ago the Dutch government decided to initiate an improvement of the methodology for the assessment of effects on aquatic organisms. As part of this improvement, the Dutch government installed two working groups to develop new exposure assessment scenarios for soilless and soil-bound greenhouse crops. This report is produced by the working group for soil-bound greenhouse crops. It describes the development of scenarios specific for soil-bound crops intended to be used in a tiered approach. The main purpose was to develop a new exposure scenario for aquatic organisms in water courses near greenhouses. Also a groundwater leaching scenario was derived.

The report is part 3 of a series of reports on 'Scenarios for exposure of aquatic organisms to plant protection products in the Netherlands' of which part one is:

- Tiktak, A., P.I. Adriaanse, J.J.T.I. Boesten, C. van Griethuysen, M.M.S. ter Horst, J.B.H.J. Linders, A.M.A. van der Linden and J.C. van de Zande, 2012. Scenarios for exposure of aquatic organisms to plant protection products in the Netherlands. Part 1: field crops and downward spraying. RIVM report 607407002.

And part two is:

- Van der Linden A.M.A., E.A. van Os, E.L. Wipfler, A.A. Cornelese, T. Vermeulen, D.J.W. Ludeking, 2015. Scenarios for exposure of aquatic organisms to plant protection products in the Netherlands. Soilless cultivations in greenhouses. RIVM report 607407005.

Summary

As part of the Dutch authorisation procedure for plant protection products, an effect assessment on aquatic organisms in surface water near greenhouses is required. This in turn requires an exposure assessment for these surface waters. In the current Dutch authorisation procedure, emission from greenhouses to surface water is treated in the same way as spray drift deposition. This is not scientifically defensible. For this reason, the exposure assessment methodology for greenhouses needed revision.

This report describes a new exposure scenario for soil-bound greenhouse crops, which is based on state-of-the-art knowledge of greenhouse systems and soil-bound cultivation practices. It corresponds to the 90^{th} spatio-temporal percentile of the annual maximum concentration in all ditches that potentially receive input from soil-bound greenhouses. 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, that consider refinements such as better substance parameters.

The main purpose of the study was to derive a new exposure scenario to protect aquatic organisms in water courses near greenhouses. The working group also derived a groundwater leaching scenario. In accordance with the Dutch decision tree for leaching to groundwater, the endpoint of the leaching assessment was the 90^{th} overall percentile of the annual mean concentration. The considered protection goal was groundwater as a source for drinking water.

For both scenario derivations, greenhouses were classified into 48 categories based on soil type and hydrological situation. For those categories that covered at least 3% of the total area, a representative greenhouse was selected (in total 12) and model simulations were carried out to calculate the exposure concentration for this representative greenhouses. Main considered emission routes were discharge via the drain pipes to surface water and leaching to groundwater. Chrysanthemum was used as the model crop for both scenario derivations, being the major soil-bound crop grown in greenhouses. The concentration distribution was obtained by weighing according to the area covered by each category. The scenarios were selected based on the 90^{th} overall percentile of this distribution.

Calculations were done first with the greenhouse models KASPRO and WATERSTROMEN (Dutch for WATERFLOWS) for inside temperature, evapotranspiration and irrigation. The so-obtained climatic data and groundwater data were then used as boundary conditions for the pesticide fate model PEARL. Groundwater levels were obtained from the Dutch Hydrological instrument (NHI). Soil properties were derived from generally available data sources and pedotransfer functions. For the characterisation of the top 30 cm of the soil, data were derived from measurements in greenhouses. PEARL drain discharge was linked to a metamodel of TOXSWA to calculate PPP concentrations in the discharge receiving ditch.

Aquatic exposure
Frequency distributions were created for six theoretical substances. Only one greenhouse had annual maximum surface water concentrations above the 90^{th} overall percentile for all substances. This greenhouse is situated in the western part of the Netherlands. The corresponding soil type is heavy clay and the groundwater level is between 80 cm and 120 cm. The discharge receiving ditch had a lineic volume of 0.57 m^3 m^{-1} and a water depth at the wet winter situation of 0.26 m ('Westland C' ditch). The corresponding weather year was the 90^{th} percentile of the weather series.

After selection of the greenhouse scenario, a slightly modified version of TOXSWA was used to simulate the concentration dynamics in the greenhouse-ditch system. This version can deal with discharge from greenhouses. An existing hydrodynamic model parameterised for a polder with many greenhouses was used to obtain flow conditions in the ditch. From this polder model, a ditch was

selected with the same properties as the Westland C ditch. Flow velocities were used in the parameterisation of the TOXSWA model. Sediment and suspended solids characteristics were chosen similar to the ditch of the field crop ditch scenario.

Example calculations were done with four example substances. The simulated peak concentrations in surface water were first compared to the peak concentrations in surface water using the current exposure assessment procedure, which comes down to assuming a drift input of 0.1% of the dosage. This comparison revealed that the newly simulated concentrations were up to several orders of magnitudes lower than the concentration resulting from the current exposure assessment. Simulation results were then compared to concentrations derived from monitoring points in surface water adjacent to greenhouses growing soil-bound crops. The newly simulated concentrations were in most cases considerably lower than the monitored values.

The low simulated concentrations can be explained by the high organic matter content of the topsoil in greenhouses, which considerably reduces leaching, even when macropores are present. Furthermore, the higher temperature in greenhouses enhances degradation and hence reduces leaching. To the best of our knowledge, these factors have been well accounted for in the model, so these factors cannot explain the underestimation as compared to the observed concentrations.

A factor that might explain the underestimation is that degradation of substances in greenhouses is lower than in open field soils. Greenhouse soils are sterilised each year using steam or chemicals. This is likely to negatively affect the biological population. So we carried out a sensitivity analysis for the degradation half-life. First, we replaced the geomean *DegT50* from the dossier by the 90th percentile of *DegT50* values in the dossier. This could not explain the difference with monitoring data sufficiently. Literature was then searched for degradation data in greenhouse soils. The limited data available showed longer half-lives in greenhouse soils. Using these half-lives resulted in calculated exposure concentrations that are close to the monitored data. This supports the hypothesis that using open field degradation half-lives in combination with the newly developed scenario is questionable. Experimental verification is needed to clarify the inconsistency between monitoring and calculated exposure concentrations.

Groundwater
Frequency distributions were created for the four FOCUS substances A, B, C and D. A greenhouse in the Eastern part of the Netherlands was selected. The greenhouse is situated on a light sandy clay soil with deep groundwater tables. For this greenhouse, PEARL was parameterised. Simulations with the four example substances showed that the calculated leaching concentrations are considerably lower than for the Kremsmünster scenario, which is used as the first tier in the Dutch decision tree.
The scenarios in this report are restricted to spraying applications. Spraying applications cover the majority of applications in soil-bound crops. The working group expects that the same scenario is applicable for other applications, such as incorporation into the soil.

As described before, degradation is likely to be lower in greenhouse soils resulting from the excessive sterilisation of these soils. As a result, using open field degradation half-lives in combination with the newly developed scenario is questionable. The derived scenario should preferably be used in combination with degradation half-lives that are measured in greenhouse soils. As a lower tier approach, multiplication of the degradation half-life with an adjustment factor would be a possibility as well. This adjustment factor should preferably be derived from a series of degradation studies with both open field soils and greenhouse soils.

Samenvatting

Er is een risicobeoordeling vereist voor het gebruik van gewasbeschermingsmiddelen in kassen in het kader van de Nederlandse toelatingsprocedure van gewasbeschermingsmiddelen. Het bijbehorende beschermdoel is het aquatische ecosysteem in oppervlaktewater. Voor deze risicobeoordeling dienen de blootstellingsconcentraties in oppervlaktewater te worden bepaald. In de huidige procedure wordt de waterconcentratie berekend analoog aan de emissie van spray drift depositie. Omdat deze aanpak niet wetenschappelijk verdedigbaar is, is een aanpassing van het toegepaste blootstellingscenario nodig.

In dit rapport wordt een nieuw blootstellingscenario afgeleid voor gewasbeschermingsmiddelen toegepast in grondgebonden kas-teelten. Het scenario is gebaseerd op state-of-the-art kennis van kas-teelten en de grondgebonden teeltpraktijk in het bijzonder. Met het scenario kan het 90ste percentiel worden bepaald van de jaarlijkse maximum concentraties in sloten als gevolg van het gebruik in grondgebonden kasteelten. Binnen de getrapte blootstellingsbeoordeling van gewasbeschermingsmiddelen vormt het de tweede trap, waarbij de eerste trap een van de FOCUS oppervlaktewater scenario's is en waarbij hogere trappen verfijningen kunnen bevatten zoals die voor de bepaling van stofeigenschappen.

Het afleiden van een nieuw blootstellingscenario vormde de hoofdopdracht van de werkgroep. Daarnaast heeft de werkgroep een grondwater uitspoelingscenario afgeleid, met als beschermdoel grondwater als bron voor drinkwater. In de lijn met de beslisboom voor grondwater, was het eindpunt van de uitspoelingsbeoordeling het 90ste percentiel van de jaarlijks gemiddelde concentratie.

Voor beide scenario's zijn Nederlandse kassen geclassificeerd naar bodemtype en hydrologie. In totaal 48 klassen zijn geïdentificeerd. Aan klassen die minimaal 3% van het totale areaal van de grondgebonden kasteelten vertegenwoordigden werd een teler gekoppeld die deze klasse goed representeert. Vervolgens zijn voor deze representatieve telers de emissieroutes in kaart gebracht en modelsimulatie uitgevoerd. De belangrijkste emissieroutes waren emissie via drains naar oppervlaktewater en bodemuitspoeling naar grondwater. Een van de gewassen die in Nederland veelvuldig in de grond wordt geteeld is chrysant. Dit gewas werd gekozen als modelgewas voor zowel het oppervlaktescenario als het grondwaterscenario. De statistische frequentieverdeling van concentraties werd verkregen met behulp van de berekende concentraties gewogen naar het areaal van de gerepresenteerde klasse. Vervolgens zijn de scenario's geselecteerd op basis van hun representativiteit voor het 90ste percentiel in ruimte en tijd.

In eerste instantie zijn modelsimulaties gedaan met het KASPRO model en het WATERSTROMEN model voor het kwantificeren van de temperatuur in de kas, de verdamping en de irrigatiebehoefte. De berekende waarden vormden vervolgens invoerwaarden voor het bodem-blootstellingsmodel PEARL. Regionale grondwaterstanden werden verkregen van het Nederlandse Hydrologische Instrumentarium (NHI). Bodemparameters werden afgeleid van algemeen beschikbare bronnen en pedotransfer functies. Bodemparameters van de bovenste 30 cm van de bodem zijn verkregen uit metingen in chrysantkassen. De concentratie in de emissie-ontvangende sloot (via de drains) werd tenslotte berekend met een metamodel van TOXSWA.

Blootstellingsconcentraties in oppervlaktewater

Simulaties zijn gedaan voor zes voorbeeldstoffen op basis waarvan cumulatieve frequentieverdelingen zijn opgesteld. Voor één van de representatieve telers gold dat voor alle stoffen de jaarlijkse maximum piek concentratie boven het 90ste percentiel lag. Deze teler is geselecteerd. Het bedrijf ligt in het westen van Nederland op zware klei. Het lokale grondwaterniveau varieert tussen de 80 en 120 cm- mv. De ontvangende sloot is een zogenaamde Westland C sloot en heeft een lineair volume van 0,57 m3 m^{-1} met een bijbehorende natte waterdiepte van 26 cm. Het bijbehorende tijdspercentiel is het 90ste percentiel.

Het geselecteerde scenario werd vervolgens geparameteriseerd in de modellen PEARL en TOXSWA. Het oppervlaktewatermodel TOXSWA is aangepast om puntlozingen te kunnen simuleren. Een bestaand hydrodynamisch model van een polder in het Westland met een groot areaal aan kassen is vervolgens gebruikt om realistische stromingscondities te kunnen simuleren in de ontvangende sloot. De berekende stroomsnelheden zijn gebaseerd op een van de sloten uit het model, die dezelfde eigenschappen had als de Westland C sloot. Eigenschappen van sediment en zwevende deeltjes in de sloot zijn hetzelfde aangenomen als de eigenschappen van de sloot in het akkerbouwscenario.

Voor vier reguliere gewasbeschermingsmiddelen zijn de gesimuleerde jaarlijkse piekconcentraties daarna vergeleken met die van de huidige toelatingsprocedure (wat neerkomt op een drift emissie naar de sloot van 0,1% van de toegediende dosering). Het nieuwe scenario leidde tot piekconcentraties die tot een factor 10.000 lager lagen dan de concentraties die werden berekend met de huidige methodiek. Vervolgens zijn de berekende concentraties vergeleken met monitoringconcentraties gemeten in de buurt van grondgebonden kasteelten. De piekconcentraties berekend met het nieuwe scenario waren in de meeste gevallen lager dan de monitoringconcentraties.

De lage concentraties leken met name te worden veroorzaakt door het hoge organische stof gehalte van de toplaag van de bodem. De aanwezigheid van organische stof verlaagt de uitspoeling van gewasbeschermingsmiddelen aanzienlijk, zelfs wanneer er macroporiën zijn. Echter, dit kon niet het verschil met de monitoring resultaten verklaren.

Een mogelijke verklaring kon worden gevonden in de overschatting van de afbraaksnelheid in kasgronden. In de simulaties is uitgegaan van halfwaardetijden gemeten in open veldgronden. De afbraaksnelheid in kasgronden is mogelijk lager dan in open veldgronden. Kasgronden worden elk jaar gesteriliseerd met stoom of met chemicaliën. Mogelijk heeft dit een negatief effect op the micropopulatie in de bodem en dus op de afbraaksnelheid. Om deze hypothese te toetsen is een gevoeligheidsanalyse naar de halfwaardetijden uitgevoerd. Eerst werd het geometrisch gemiddelde van de halfwaardetijden uit het dossier vervangen door het 90ste percentiel. De nieuwe piekconcentraties konden het verschil tussen de model en de monitoringresultaten niet voldoende verklaren. Vervolgens is er gezocht in de literatuur naar halfwaardetijden in kasgronden. De zeer beperkte beschikbare data lieten lagere afbraaksnelheden zien in kasgronden t.o.v. open veldgronden. Indicatieve berekeningen met halfwaardetijden uit deze literatuur resulteerde in concentraties in dezelfde orde van grootte als de monitoring concentraties.

Grondwater

Cumulatieve frequentieverdelingen zijn opgesteld voor de vier FOCUS stoffen A t/m D. Gebaseerd op deze verdelingen is een bedrijf geselecteerd in het oosten van Nederland waarmee het 90ste percentiel kan worden berekend. Dit bedrijf ligt op een lichte zavelgrond met een lage grondwaterstand. PEARL werd geparameteriseerd voor dit scenario. Indicatieve simulaties met de vier FOCUS stoffen resulteerde in berekende concentraties die aanzienlijk lager lagen dan die van de eerste tier van de Nederlandse beslisboom voor grondwater; het Kremsmünster scenario.

De scenario's in dit rapport zijn in principe afgeleid voor spuittoepassingen. Deze wijze van toepassen wordt meestal gebruikt in grondgebonden teelten. De werkgroep verwacht dat de scenario's ook bruikbaar zijn voor andere toepassingen, zoals bijvoorbeeld inwerken.

Het is aannemelijk dat de afbraaksnelheid in kasbodems lager liggen dan in het open veld. Het gebruik van halfwaardetijden uit het open veld is daarom niet vanzelfsprekend. De werkgroep beveelt daarom aan om de afgeleide scenario's te gebruiken in combinatie met halfwaardetijden gemeten in kasgronden. In een lagere tier kan een correctiefactor worden toegepast. De correctiefactor wordt bij voorkeur afgeleid van een serie van afbraakstudies in open veld en kasgronden.

1 Introduction

1.1 Background

The current Dutch authorisation procedure for plant protection products (PPPs) used in greenhouse crops appears to underestimate the exposure risk in Dutch surface waters (Vermeulen *et al.*, 2010). Currently, in the Netherlands, the emission of plant protection products from greenhouses to surface water is assessed as a diffuse emission process, using a fixed percentage of 0.1%. The emission is treated in the same way as done in drift deposition assessments. Implicitly it is assumed that the emission is independent of the type of greenhouse, cropping system or application method (Linders and Jager, 1997). As other guidance is lacking, the same procedure is often used in environmental exposure assessments for PPPs used in greenhouse crops at the European level and by other Member States. The emission to groundwater from Dutch soil-bound greenhouse crops is calculated according to the methods developed for field crops, using the standard Dutch soil scenario.

Dutch water boards frequently measure concentrations of PPPs that exceed the Environmental Quality Standards for fresh surface water, in areas with a high density of greenhouse horticulture (e.g. Van der Wal *et al.*, 2007, Tolman and Cuypers, 2010, www.pesticidesatlas.nl). Therefore, the Dutch ministries of Economic Affairs (EZ) and of Infrastructure and the Environment (I&M) asked Vermeulen *et al.* (2010) to assess the authorisation procedure of PPPs for greenhouse crops. They showed that it is highly probable that the currently used percentage of 0.1% underestimates the emission from greenhouses to surface water, and that the emissions vary widely between greenhouses as a result of differences in e.g. watering systems and crop characteristics. They focused primarily on substrate cultivation being the major part of greenhouse cropping systems in the Netherlands (80% of area). The other 20% of the area used for greenhouse horticulture in the Netherlands is used for soil-bound cultivation.

Recognizing that the authorisation procedures need to be updated, the ministries of Economic Affairs and of Infrastructure and the Environment initiated two separate working groups, distinguishing between substrate cultivation and soil-bound cultivation. This report is a product of the working group on soil-bound crops.

1.2 Remit of the working group Soil-bound crops

The working group on soil-bound greenhouse crops was established to develop a set of standard scenarios that can be used to assess groundwater and surface water concentrations of PPPs used in soil-bound crops in greenhouses in the Netherlands. The aim was to assess 90th percentile concentrations in groundwater and surface water (i.e. receiving water bodies). Furthermore, a user-friendly tool had to be developed, which enables calculation of the relevant concentrations.

The working group on soil-bound greenhouse crops worked according to the following principles:
- The scenarios and tool were developed in close collaboration with the Dutch working group on substrate cultivation, especially with regard to the selection of the receiving watercourse;
- The working group adopted the approaches of the Dutch working group 'Exposure of Aquatic Organisms' (Tiktak *et al.*, 2012) wherever applicable;
- The developed scenarios should not conflict with EU Regulation 1107/2009;
- A prepresentative of the Dutch Board for the Authorisation of Plant Protection Products and Biocides (Ctgb) was peer of the working group;
- Emission to or via air was not considered;
- the scenarios should become part of a tiered approach;

- The ecotoxilogical relevant concentrations as formulated by the working group on ecological effects (Brock *et al.*, 2011) were used as reference for the exposure assessment.

1.3 Aim of this study

With the final aim to select a 90th percentile scenario for emission to surface water and groundwater from soil-bound crops, the working group took the following steps:
- Provide an overview of soil-bound crops in the Netherlands;
- Define the driving forces for emission to groundwater and surface water;
- Select a number of representative cases (based on the key driving forces), which can be used as a basis for the derivation of the 90th percentile scenarios;
- Parameterise the representative cases;
- Select the greenhouse scenario for surface water and groundwater;
- Parameterisation of the greenhouse scenario and receiving water body;
- Perform example calculations.

These steps are discussed in this report.

1.4 Structure of the report

In Chapter 2 the endpoints of the scenario derivation are discussed for groundwater as well as surface water. Also the approach used is discussed. In Chapter 3 an overview is given of soil-bound greenhouse crops in the Netherlands. Main drivers for emission towards groundwater and surface water are discussed in Chapter 4. Based on the driving forces, representative greenhouses were selected. Chapter 5 discusses the selection procedure. In Chapter 6 the model parameterisation of representative greenhouses is discussed. The greenhouse selection is described in Chapter 7 for groundwater as well as surface water. Chapter 8 discusses the parameterisation of the water body and Chapter 9 is dedicated to a number of example calculations. Chapter 10 and 11 contain a proposal for a tiered approach and the conclusions and recommendations, respectively.

2 Endpoints

Scenario derivation started with the definition of the endpoints for the considered protection goals. For soil-bound crops two protection goals were distinguished: groundwater as source of drinking water and surface water as a habitat for aquatic organisms. The responsible ministries decided that for each protection goal only one scenario should be developed. This implies that the derived scenarios should apply to all soil-bound greenhouse crops. Being the most often grown soil-bound crop, chrysanthemum was used as a model-crop for the scenario development.

The exposure assessment methodology in this report is based on application of PPP by spraying. This application technique covers the majority of the applications in soil-bound greenhouse crops.

Figure 2.1 *A large scale modern greenhouse with chrysanthemums, which is characteristic for the Dutch situation.*

2.1 Protection goal: Groundwater

Groundwater is an important source for drinking water, irrigation water and process water. Leaching to groundwater due to PPP use in soil-bound greenhouse crops may endanger the functioning of groundwater.

European procedures for the evaluation of PPPs aim at protecting the contamination of groundwater above a level of 0.1 μg/l. PPP and metabolite concentrations should not exceed this concentration level. Following the new Dutch evaluation tree for PPP leaching to groundwater (Van der Linden *et al.*, 2004), the working group used the following evaluation criterion for the concentration of PPP in groundwater: the annual leaching concentration at 10 m below surface should not exceed 0.1 μg/l under at least 90% of the area with soil-bound greenhouse crops for at least 50% of the time.

2.2 Protection goal: Surface water

The endpoint of the surface water exposure assessment of aquatic organisms is the 90th percentile of the concentration in surface waters adjacent to greenhouses that potentially receive PPP from soil-bound greenhouse crops.

For the linking between exposure and effect assessment, the working group on aquatic effects has identified multiple Ecotoxicologically Relevant Concentrations (ERC, Brock *et al.*, 2011). Brock *et al.* (2011) proposed that the endpoint of the exposure assessment should be either the annual peak concentration or the annual maximum Time Weighted Average (TWA) value within a calendar year. The working group decided to use the annual peak concentration in water to derive the 90th percentile scenario, which is consistent with the approach of the working group on aquatic exposure (see Tiktak *et al.* (2011c, 2012) for considerations). By using the concentration in water, the selected scenario is only valid for the water layer and cannot be used for the sediment.

The working group decided to use the concentration in water averaged over 100 m of ditch, which is in line with FOCUS (2001) and the approach of the working group on aquatic exposure (Tiktak *et al.*, 2012).

Dutch ditches can be classified into three groups, i.e. *primary* ditches that have a width of 3-6 m at the water surface, *secondary* ditches with a width of 1-3 m and *tertiary* ditches that are smaller than 1 m or that fall temporally dry (Massop *et al.*, 2006). Primary and secondary ditches are considered for the scenario selection. Large water bodies (canals, rivers and lakes) are excluded from the population, because these are usually not situated adjacent to greenhouses. The derived scenario is not considered to be protective for ditches that fall temporary dry.

Part of the population of soil-bound greenhouse crops discharges to the sewage system. The total area that discharges into the sewage system is not known. Furthermore, the sewage treatment plant removal efficiency for PPPs depends on the PPP chemical properties. The responsible ministries decided that discharge to sewage water should not be accounted for, i.e. the entire population of greenhouses with soil-bound crops is considered to discharge towards surface water.

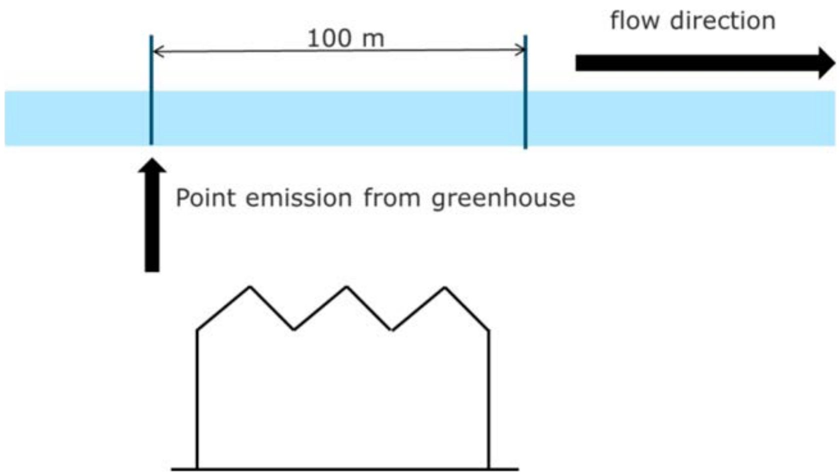

Figure 2.2 *The endpoint of the exposure assessment for PPPs used in greenhouse crops is defined as the annual peak concentration and the TWA over 100 m downstream of the greenhouse discharge point.*

2.3 Procedure for developing the exposure scenario

The development of a scenario is ideally structured according to the following steps:

1. Simulation over multiple years of the PPP fate in greenhouses and ditches using data for the entire population of greenhouses and ditches and models that enable the simulation of all relevant processes.
2. Identify the target overall percentile.
3. Selection of greenhouse and/or ditch that enables the calculation of the target overall percentile for all types of substances (the scenario).
4. Parameterisation of the selected scenario.

Since limited data was available on greenhouses to support step (1) the workgroup used a pragmatic approach by classifying the greenhouses in 12 classes that together represent the entire population of soil-bound greenhouses and parameterise this limited number of representative cases to identify the most appropriate scenario. This approach is used for the exposure scenario as well as the groundwater scenario.

3 Soil-bound greenhouse crops in the Netherlands

EFSA distinguished several construction types that are used for the cultivation of greenhouse crops (Stanghellini, 2009; Van der Linden, 2009). According to their classification, most greenhouses in the Netherlands are glasshouses.

The working group focussed on soil-bound glasshouse cultivation. Soil-bound crops covered 23% of the total greenhouse production area in the Netherlands (situation as of 2007). Within the soil-bound production, chrysanthemum is the dominant crop (Table 3.1). Other major crops are vegetables, lilly, freesia and ‘summer flowers’ (a cluster of smaller herbaceous flowers). Vegetables cover about 25% of the soil-bound crop area. Note that the total area of soil-bound crops is decreasing.

Table 3.1
Types of soil-bound crops and the area of use. Voogt, 2010.

Crops	Area 2007 (ha)	% of total soil-bound
Lettuce, radish, other vegetables	325	15.4
Organic vegetable farming (mainly tomato and pepper)	100	4.7
Small fruit	52	2.5
Chrysanthemums	482	22.8
Freesia	131	6.2
Alstroemeria	81	3.8
Lysianthus	37	1.8
Lilly	197	9.3
Other cut flowers	506	23.9
Amaryllis	70	3.3
Other ornamentals	129	6.1
Total 1	2110	100

Soil-bound crop cultivation in the Netherlands is characterised by intensive cropping systems. Figure 3.1 gives a typical view on a soil-bound greenhouse system. Greenhouses range in size from 0.5 ha to 10 hectare of connected production area. Greenhouses can be highly compartmentalised to allow for flowers in different plant stages or for different varieties and subsequent irrigation needs. The irrigation can therefore be dosed per compartment, often 800-1000 m^2.

[1] According to the latest survey (source: CBS, statline.cbs.nl, assess date 04-02-2014), the area of soil-bound crops in the Netherlands is 1723 ha.

Figure 3.1 *Soil-bound production: Chrysanthemums just planted (left) and shortly before harvest (right).*

Based on soil type and ground water levels, the horticulture areas in the Netherlands can be distinguished in 16 regions. The largest area of soil-bound greenhouse horticulture is in Westland West and Westland East+De Kring. These areas represent 30% of the total area. Other larger clusters of horticulture are found in the River-area (south of Utrecht), South-Holland isles, the Mores+Aalsmeer and North-Holland-North. These areas cover a total 73% of soil-bound greenhouse production in the Netherlands (Table 3.2).

The areas differ in dominant crops that are cultivated. While vegetable production is important in Westland-West and southern areas (provinces of Zeeland, North Limburg and North Brabant), chrysanthemum production dominates the cluster in the River-area. Traditionally flower production is centred around the logistical hub of Aalsmeer, giving large production areas in the province of North Holland. This has been extended to other areas such as the River area where mostly chrysanthemum is grown.

Table 3.2

Areas with presence of soil-bound greenhouse horticulture and their soil characteristics and main crops (Voogt, 2010).

Area name	Area size (ha)	Soil type	Main crop
Westland-West	396	Coastal line with mostly light to very light soils, high to low ground water levels and locally (salty) seepage water	Vegetables and bulb-crops
Westland-oost + de kring	461	Heavier soils than in 'West', mostly poldered area with deep ground water. Some areas with sandy clay and high ground water	Cut flowers, vegetables
Bollenstreek (bulb area)	104	Light to very light soils, high to low ground water levels	Cut flowers
De Venen + Aalsmeer (North Holland - South)	151	Heavy soils, sandy clay and peat. High ground water levels as well as poldered areas with deep ground water	Cut flowers
North Holland - North	138	Light to heavy soils. Mostly low levels of groundwater. Locally seepage water	Mainly cut flowers
Flevoland	49	Light soils to heavy clay. Deep (poldered) ground water levels	All produce
South-East Drenthe	20	Light soils with peat in over layers. Deep ground water levels	Cut flowers, vegetables
South Holland isles + Sealand	159	Light soils to heavy clay. Deep (poldered) ground water levels. Locally seepage water	Vegetables, cut flowers
River-area (near Zaltbommel)	240	Heavy to very heavy clay soils with shallow or deep ground water levels. Complex hydrology with locally seepage water	Chrysanthemum
Betide-East	61	Light soils to clay. Deep (poldered) ground water	Small fruit
North Brabant - North	37	Light soils to clay. High ground water levels or levels at depth of drainage system	Cut flowers, vegetables
North Brabant - Mid.	70	Sandy soils with deep to very deep ground water levels	Cut flowers, vegetables
North Brabant - East	23	Sandy soils with deep to locally high ground water levels	Cut flowers, vegetables
North Limburg Peel horst	69	Sand and sandy clay. Deep to very deep soil water levels	Vegetables
North Limburg Meuse Valley	82	Sandy soils with sandy clay. High to very low ground water levels	Cut flowers, vegetables
Other	48		
Total	2110		

4 Key processes

In the following sections main drivers for emission to surface water and groundwater from greenhouses are discussed. These are the processes that are decisive for the emission to surface water and groundwater. After a general discussion in Section 4.1 and 4.2, crop specific conditions, such as crop rotation, irrigation and application management are discussed in Section 4.3. Crop independent conditions are soil type and hydrology, these are discussed in Section 4.4 and 4.5.

4.1 Main drivers for emission

The main emission route from soil-bound cultivation to groundwater and surface water is the discharge via excess irrigation water. The excess water is leached to groundwater or to drain pipes that discharge to surface water. Overland flow (in case of exceeding the infiltration capacity) can be excluded, since for obvious reasons, growers will avoid over-saturation of the soil and the irrigation intensity and quantity is well controlled. Partitioning between ground- and surface water is driven by the presence of a drainage system and the local groundwater level. Also factors as seepage and direct influx from ditches are involved (Voogt *et al.*, 2006).

Two types of soil-bound greenhouse cultivation types can be distinguished in the Netherlands (Voogt *et al.*, 2009):

- Cultivation without drainage system. This cultivation type can be found mainly on the higher situated sandy soils. Excess irrigation water leaches towards groundwater;
- Cultivation with drains at approximately 90 cm depth with a standard distance of ca. 3.2 m. For this cultivation type the excess irrigation water mainly discharges towards surface water via the drainpipes. Dependent of the local groundwater level, part of the water may be discharged towards groundwater. Also upward seepage may occur and dilute the concentration in the drain water.

Figure 4.1 indicates the main emission routes of PPPs to groundwater and surface water for soil-bound cultivation for the two main cultivation types. In contrast to substrate cultivation, emission via condensation water is considered as an unimportant route to the groundwater and surface water.

The total volume of the excess irrigation water and its daily fluctuations depends on the one hand on the amount and frequency of the water supply and on the other hand on the evapotranspiration.
The applied irrigation strategy in greenhouses depends largely on the crop demand, which is driven mainly by evapotranspiration. Evapotranspiration, in turn, is mainly driven by irradiation and to some extent by specific greenhouse climate control actions like heating, shading and lighting. However, the 'translation' of crop demand into irrigation strategy differs largely between crops due to crop specific requirements. Moreover, the irrigation techniques interfere with these crop specific applications. For example, chrysanthemums, where overhead sprinklers are commonly used for technical and economic reasons, are irrigated every three to five days with 5 – 15 mm per event. Whereas the amaryllis cut flower crop is irrigated with 2 – 10 irrigation rounds per day (seasonal fluctuation), throughout the growing season, with 0.2 – 0.5 mm per event.

An indication of range differences in irrigation strategies and techniques used in soil-bound greenhouse horticulture is given in Table 4.1. The soil-bound crops as listed in Table 3.1 are categorised according to the character of the growth system. Obviously, the total irrigation, crop use, and resulting surplus cannot be quantified as they are too variable. Instead we quantify irrigation surplus as from wet – dry, meaning an extreme surplus (> 30%) to practically no irrigation (0%).

Note that, chrysanthemum has a relatively high irrigation surplus. Hence, it can be considered conservative as compared to other soil-bound crops.

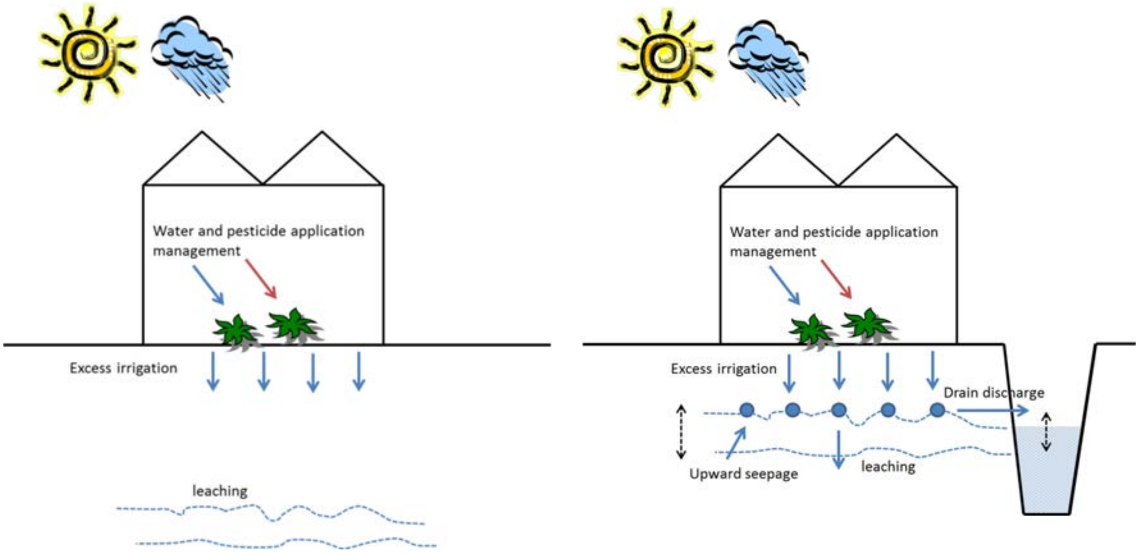

Figure 4.1 *Conceptual model of the main emission drivers from soil-bound horticulture, typical for the Netherlands, i.e. for cultivation without drainage (left) and cultivation with drains (right). The figure indicates the main flow routes of PPP to surface water and groundwater being discharge via drainpipes and leaching of excess irrigation water to groundwater. PPPs are discharged to groundwater and surface water with the excess irrigation water.*

Table 4.1
Soil grown greenhouse crops classified per crop type, irrigation supply and – strategy and the irrigation surplus.

Crop type	Technique	Irrigation strategy		Crop	Irrigation surplus
		frequency	quantity		
		events per day	mm/event		
Plants in rows/beds, low density	Drip irrigation, one drip nozzle per plant, max 3 per m^2	2 - 15	0.2 - 0.5	Tomato, Sweet pepper, Cucumber	rather dry
	Drip irrigation, one drip nozzle per plant, max 6 per m^3	2 - 10	0.2 - 0.5	Rose, Gerbera, Hydrangea (cut flower),	moderate
				Strawberry	rather dry
Plants covering whole surface, high density	Drip irrigation, one drip nozzle per cluster of plants, 10 /m^2	2 - 10	0.2 - 0.5	Lily	moderate
				Alstroemeria, Fresia	dry
Plants in rows, low density	Small scale sprinklers, below crop canopy	0.2 - 1	3 - 5	Tomato, Sweet pepper, Cucumber	moderate
				Helianthus, Delphinium, Anthirinnium, Limonium	moderate
Plants covering whole surface, high density	Broad spray sprinklers, overhead	0.2 - 0.5	3 - 15	Chrysanthemums, Hippeastrum (bulb propagation), Lysianthus	rather wet
				Lettuce, Leafy vegetables, Radish	rather dry

4.2 Differences with field crops

Processes that define the emission of PPP to groundwater and surface water from soil-bound horticultural crops are to some extend similar to field crops. However, there are a number of differences between field crops and greenhouse crops that may have a considerable effect on the water budget and PPP behaviour. The main differences are listed below.

- For field crops the precipitation is strongly temporally variable, whereas in greenhouses the irrigation is strongly regulated and optimized towards the crop water demand. This results in different percolation patterns to groundwater between field and greenhouse crops: greenhouse crops show a peak in summer time, whereas for open field crops a percolation peak is observed in autumn and winter months (Beulke *et al.*, 2010);
- Specific in greenhouse crops, for which drip irrigation is common, localised ponding may occur leading to ununiformed percolation across the area causing heterogeneous flow patterns and high leaching of PPPs to groundwater (Leistra, 1985). This is less probable for field crops;
- Below greenhouses groundwater levels are generally controlled by drains at shorter distances than in field situations;
- In contrast to field crops, the crop cycling in greenhouses is not seasonally affected and for some crop there are many cycles per year;
- The upper 30 cm of the soil is generally enriched with organic matter and tilled every crop cycle;
- The soil is regularly sterilised by steaming;
- In greenhouses inside temperatures are generally higher than outside temperatures especially in winter time. Also the air is more humid than outside. This affects PPP behaviour as compared to field conditions; the high temperatures in greenhouses increase the volatilisation of PPPs as well as the degradation rates in soil especially for compounds with shorter half-lives (Beulke *et al.*, 2010);
- Drift is a negligible source of PPP for greenhouse crops whereas for field crops drift is one of the major routes of PPPs to surface water.

4.3 Crop specific processes (chrysanthemum)

4.3.1 Crop rotation and climatic conditions

Chrysanthemums are grown in modern greenhouses, equipped with adequate heating, irrigation, energy- and black-out screens, CO_2 enrichment and additional artificial lighting is commonly used. The modern greenhouse holdings are large, on average 5 - 6 ha. Set points for greenhouse climate control in chrysanthemum are a temperature of 21-23 ^{o}C (day) and 19 ^{o}C (night). Chrysanthemum is a quickly developing crop, with a growing cycle of approximately 70 - 80 days from planting to harvest. It is a short-day crop, flower induction only starts after 13.5 - 14 hours of complete darkness. So after planting during 11 - 12 days the crops develop vegetatively, in this period as much as possible daylight and additional artificial light is admitted. From day 11/12 on, the maximum hours of daylight is 10 - 11 hours, by completely closing a black-out screen. During the period of low light intensities daylight is supplemented with artificial lighting. The growth cycle of chrysanthemums is rather short and harvest is done in one shift. The production is organised in such a way that throughout the year, almost every work day a section is ready for harvest. Immediately after harvest, this section is prepared and planted again. So plants are grown in sections, with each section containing a different crop development stage. Theoretically, each crop development stage should be treated differently by the grower. This, however, is not very practical. For that reason, growers take different crop development stages together, such that nine different sections remain for crop control (Figure 4.2).


Figure 4.2 *An example of a chrysanthemum crop, with consecutive plant stages, 'moving' in time through the greenhouse (left) and irrigation of a young chrysanthemum crop with overhead sprinklers (right).*

The greenhouse and the soil are in use year-round, producing continuously. Per year 5.2 - 5.5 crop cycles are grown on each plot. To cure and prevent soil-borne diseases and weeds, the soil is steam sterilised once a year. The soil is than heated to 70 ^{o}C over a depth of 50 - 60 cm. This period of sterilisation is started usually in April/May and is executed for each individual compartment, following the harvesting / planting cycle in the greenhouse. Soil tillage before each planting is limited to rototilling 15 cm once a year, before steaming the soil is ploughed to 35 cm.

Once in two years organic matter in form of yard waste compost is supplemented and ploughed in. The quantities are large, 100 – 200 m^3 ha^{-1} but sometimes even 500 - 800 m^3 ha^{-1} (140 - 450 ton/ha) are given per time. On top of that, the crop residuals, including the plant-block is ploughed in after every crop harvest, resulting in another 100 - 150 m^3 ha^{-1} of peat like material, every year. The organic matter content in the top soil is therefore very high and completely different form the original soil.

4.3.2 Irrigation

The irrigation strategy in chrysanthemum differs between growers due to site specific conditions. However, some general characteristics can be observed:

1. Directly after planting, a high quantity of water is irrigated (15 - 20 mm) as the soil has dried out in the previous pre-harvesting period and also to promote connection of the plant-blocks with the surrounding soil.
2. During the first two weeks, the crop is irrigated daily with a low quantity (1 - 2 mm) to create equal wetting of the surface and to stimulate root development.
3. During the largest period the crop is irrigated every 2-3 (summer) or 5-7 (winter) days, with 8 - 12 mm.
4. The last phase of the crop, when the flower buds start to open, during 10 - 14 days the crop is not irrigated at all.

Site specific conditions that affect irrigation strategy are:

1. Ground water table. The majority of the chrysanthemum is grown in polder areas where the natural ground water level is high; however a significant part of the growers are situated where groundwater is deep (> 2 m). With high groundwater tables the irrigation quantity and frequency is lower than average, especially in combination with clay soils. On the contrary, the crops in deep groundwater, which are mainly sandy soils, are irrigated more frequent and sometimes with higher quantities, especially in spring and summer.
2. Soil type. Chrysanthemums are grown on various soil types, ranging from heavy clay till pure sand. As mentioned, the organic matter fraction is quite high in the top soil of 30 cm. Growers on sandy soil tend to have higher than average irrigation intensities.

Irrigation is usually performed during the night hours, under the black-out screen. Almost all growers use rotating broad spectrum sprinklers with a capacity of 1 - 1.5 mm/min.

Investigation among six chrysanthemum growers between 2006 and 2010 showed an annual irrigation variation between 800 mm and 1200 mm. The annual irrigation excess (irrigation minus evapotranspiration) varied between 0% and 50%, depending on soil type, groundwater level and individual management strategy of the grower (Voogt, 2003; Voogt *et al.*, 2006).

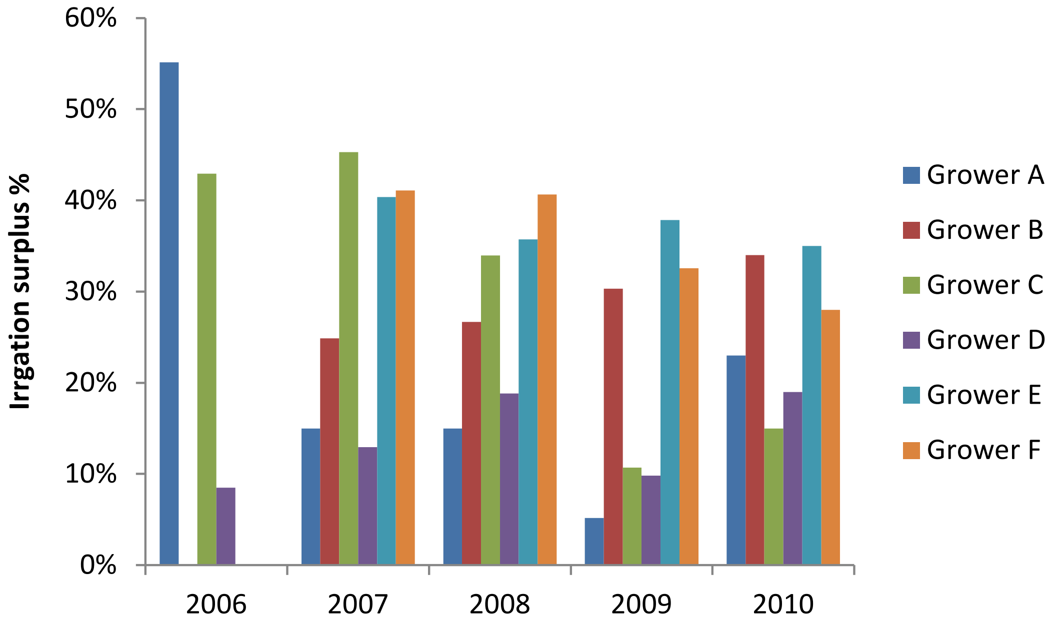

Figure 4.3 *Results of a five years monitoring project on water and fertiliser use and six chrysanthemum greenhouses (Voogt, 2002).*

4.3.3 PPP application

Chrysanthemum production is short-cyclical, leading to about five production cycles per plot each year. A greenhouse will generally contain plots in each phase of the cycle at any time to secure a continuous production at farm level. However, this dynamics influences the PPP application only marginally. Chrysanthemums need protection against fungal infection, insects and root diseases. These pests and diseases are mostly seasonal, while treatment of root diseases is more related to the production cycle:

- Pests are treated either locally with spray application or fogging;
- Upon fungal infection generally the whole greenhouse is treated using spray application;
- Root diseases are treated with soil sterilisation by steaming at the start of the summer (each plot is steamed between plantings, so that during a period of two months the entire greenhouse is treated). Generally after three cycles root diseases reach the risk-intervention threshold as

established by grower's experience, so that the soil is chemically treated before planting of the 4th or 5th cycle. Soil treatment is applied using overhead irrigation or grain application.

Since the plant density is high (> 60/m^2) and in short time the crop covers virtually the whole surface, the interception of the applied substances is high. Soil deposition will be low as was found by Tak and Van der Knaap (1997). A short review of crop canopy interception by chrysanthemum is given in Annex 7.

Table 4.2

A spray-calendar for chrysanthemums could be (this calendar does not use all registered PPPs for Chrysanthemum, but gives an expert judgement of a feasible pest management strategy).

			April				May				June				July				Aug					Sept						Oct				Nov					Dec					Jan					Feb				March		
disease/ plague	**active ingredient**	**application method**																																																					
Root pathogen	etridiazool	soil treatment	x																																										x									
Botrytis	iprodione	spray							x																																													
Botrytis	cyprodinil+ fludioxinil	spray																											x																						x		
Botrytis	fenfexamide	spray																			x																		x														
Rust	mancozeb	spray																																																				
Rust	chloorthalonil	spray																							x	x	x																											
Rust	kresoxim-methyl+boscalid	spray																												x	x	x																					x	x	x
Rust	trifloxystrobin	spray																																x	x	x																		
Aphids	pymetrozine	spray														x						x																																
Aphids	flonicamid	spray	x	x	x																																																	
Aphids	acetamiprid	spray							x																																													
Aphids	thiametoxam	spray												x													x																											
Aphids	imidacloprid	spray																																																				x
Spider mite	bifenazate	spray									x	x	x																																									
Spider mite	acequinocyl	spray																	x	x	x																																	
spider mite	tebufenpyrad	spray			x	x	x																																															
Spider mite	pyridaben	spray																					x	x	x																													
Spider mite	milbemectin	spray																																																				
Spider mite	abamectin	spray												x	x	x																																				x	x	x
Thrips	abamectin	spray	x	x	x						x	x	x																																									
Thrips	spinosad	spray					x	x	x																					x	x	x																						
Thrips	lufenuron	spray													x	x	x				x	x	x																											x	x	x			
Thrips	methiocarb	spray																							x	x	x																											
Thrips	*Beauveria bassiana*	spray																x	x	x																																	x	x	x
Caterpillars	indoxacarb	spray																		x																																			
Caterpillars	methoxifenozide	spray																					x									x																							
Caterpillars	teflubenzuron	spray																							x																													
Leaf miner	abamectinSo	spray									x																																												
Leaf miner	cyromazine	spray																x																																					

4.4 Soil characteristics

One of the important drivers for emission to surface water and groundwater are soil hydrological characteristics and organic matter content. Sensitivity analyses of PPP leaching models have shown that organic matter content is generally the most important soil parameter for leaching of PPP (Tiktak *et al.*, 1994 and Boesten, 1991).

Soil characteristics differ between the main greenhouse horticultural areas (Chapter 3). Although most greenhouses are on light sandy clay soils, greenhouses can be found on all types of Dutch soils. In Table 4.3 the area of soil-bound crops on each soil type is given. The soil map of the Netherlands 1:50,000 was used for the identification and definition of soil types (Bakker and Schelling, 1989). To identify the geographical location of each individual greenhouse (postal address of grower) the CBS agricultural geographical information database GIAB 2008 (Naeff and Smidt, 2009) was used. The cultivated area of each crop could be extracted from the database as well (see Annex 1 for the procedure followed).

In structured soils such as clay soils and peat soils, rapid drainage might occur due to preferential flow through macropores, caused by shrinking and cracking of soils, by plant roots, soil fauna or tillage operations. Macropores can facilitate rapid drainage towards drains by bypassing the reactive unsaturated zone. Under wet conditions soils may be swollen and macropores are closed.

Table 4.3
Area of soil-bound crop cultivation per soil type.

Soil type[2]	Area of soil-bound crops (ha)	Area of soil-bound crops (%)
Peat	135	6.3
Peaty sand	7	0.3
Sand	603	28.1
Light sandy clay	569	26.5
Heavy sandy clay	493	23.0
Light clay	221	10.3
Heavy clay	117	5.4

The upper 25-30 cm of the greenhouse soil is enriched with organic matter and/or sand to improve soil structure (Fig. 4.4). Sonneveld *et al.* (1990) measured organic matter content and clay mass fraction in the upper 25-30 cm of the soil in 75 Dutch greenhouses. Table 4.4 gives an overview of the mean clay and organic matter mass fractions per soil type in the upper soil layer. For reference, the mass fractions are given for open field top soils as derived by Wösten *et al.* (2001). The table shows that the clay fraction is higher as compared to open field crops, especially for sandy soils. Light and heavy sandy clay soils have higher organic matter contents.

[2] Definition according to Bakker and Schelling (1989): peat: organic matter >30% up to 70% dependent of the clay mass fraction; peaty sand: organic matter mass fraction>15% up to 30% dependent of the clay mass fraction; sand: clay mass fraction < 8%; light sandy clay: clay mass fraction 8-17.5%; heavy sandy clay: clay mass fraction 17.5-25%; light clay: clay mass fraction 25-35%; heavy clay: clay mass fraction 35-50%.

Table 4.4
Average clay and organic matter mass fraction in Dutch greenhouses with soil-bound crop cultivation measured in the upper 25-30 cm of the soil. For reference, the mass fractions are given for topsoils of field crops in brackets (Wösten et al., 2001).

Soil type	Number of measurements	Mean clay mass fraction in top soil	(%)	Mean organic matter mass fraction	(%)
Peat	7	37	(30-80)	22	(20-65)
Peaty sand	-	-	(2-7)	-	(15-80)
Sand	24	7	(0)	4	(1-13)
Light sandy clay	16	17	(10-16)	12	(1-6)
Heavy sandy clay	12	14	(18-25)	21	(1-8)
Light clay	4	12	(26-35)	28	(1-6)
Heavy clay	-	-	(50-77)	-	(3-5)

Figure 4.4 *Left: Soil profile (0 - 70 cm) of a heavy sandy clay soil in a greenhouse with chrysanthemum; the top layer between is 0 cm and 30 cm and is heavily enriched with organic matter. Right: Upper 40 cm of a chrysanthemum crop showing the intensively rooted zone between 15 and 20 cm.*

4.5 Hydrology

4.5.1 Local groundwater

Voogt *et al.* (2008) classified greenhouses according to the local groundwater regime and the soil type. Six classes were distinguished. Greenhouse class 1 has a natural groundwater level that is high to very high. The groundwater level decreases gradually for increasing greenhouse class number up to greenhouse class 5, which has a very low groundwater level. In Table 4.5 the main characteristics of each of the classes are given. Dependent of the local groundwater situation, excess water discharges through the drain pipes to surface water, to the regional groundwater, or to both. Upward seepage might dilute concentrations in the drain water.

Soil-bound crops are found mainly in areas with groundwater levels deeper than groundwater table class III. The areal coverage of soil-bound crop cultivation for the greenhouse classes 3b, 4 and 5 are 34%, 48% and 16% of the total area of soil-bound crops, respectively.

Table 4.5
Greenhouse classes characteristics (after Voogt et al., 2008).

Gr. house Class	% of total soil-bound crop area	Groundw. Table class[3]	MHW [4] (cm-sl)	MLW [5] (cm-sl)	Soil type	Emission to	Main characteristics
1	0.9	I,II	<25	<50	Peaty soils	Surface water	The natural groundwater level is high to very high. Excess drain water is pumped to the ditch. Groundwater seepage may occur as well as infiltration from the surrounding surface waters towards the drains.
2	0.3	II	<25	50-80	All types expt. peaty soils	Surface water	The natural groundwater level is high to very high. Excess drain water is pumped to the ditch. Groundwater seepage rarely occurs.
3a	0.5	III	<25	80-120	All types	Mainly surface water	The mean groundwater level is within the root zone, but may vary considerably. Excess drain water is either pumped or drains naturally to nearby ditch. Both seepage as well as infiltration may occur, dependent of the groundwater level. Infiltration from the surrounding surface waters towards the drains may occur.
3b	34.4	III, IV	40-80	80-120	All types	Mainly to surface water	The groundwater level fluctuates, but less than for 3a. Leaching of excess water to groundwater may occur.
4	47.9	V, VI	>40	120-180	All types	Partly surface water, partly groundwater	In winter, the groundwater level is generally lower than 120 cm, but intensive rainfall may increase the water level up to 80 cm. Pumped or natural drainage may periodically occur. High probability of leaching of excess irrigation water to groundwater.
5	16.0	VII, VIII	>80	>180	All types	groundwater	Groundwater level is below 80 cm. No drainage. Only groundwater infiltration occurs.

4.5.2 Receiving ditches

Surface water is abundant in the Netherlands. Especially in the lower Western part of the Netherlands an extensive network of ditches can be found that discharge precipitation water and seepage water from the polders via larger water bodies and rivers towards the sea. Greenhouses are often situated next to water bodies and discharge their excess water via drainpipes.

[3] Definitions are given in Annex 2.
[4] Mean highest groundwater level.
[5] Mean lowest groundwater level.

Figure 4.5 *Typical situation in the western part of the Netherlands; the greenhouses are situated directly next to surface water.*

The digital topographic map of the Netherlands (TOP10 vector) distinguishes between four categories of water courses: (i) *tertiary* water courses, i.e. water courses that are small (< 1 m width) and water courses that fall temporally dry, (ii) *secondary* water courses, with a width of 1-3 m, (iii) *primary* water courses, which have a width between 3 and 6 m and (iv) water courses with a width between 6-12 m. Recently, Massop *et al.* (2006) collected and classified hydrological characteristics of Dutch water courses, while using the TOP10 vector map as a basis. The collected information included the width of the water course, the depth of the water course, bottom width, water depth and width at the water surface. These ditch characteristics refer to a winter wet situation.

Massop *et al.* (2006) further observed a good correspondence between geohydrological characteristics of the subsoil and the characteristics of the water courses. In the Netherlands, 22 so-called hydrotypes can be distinguished with similar geohydrological characteristics (Massop *et al.*, 1997). For each combination of hydrotype and for the four ditch categories of the TOP10 map, they collected ditch characteristics based on field inventories and calculated median values and standard deviations. The ensemble of all median ditch properties together constructs the standard ditch profile. By coupling the map of hydrotypes and the water course categories (TOP10 vector) a spatial distribution of ditch profiles could be derived, with for each hydrotype the length of each water course category as well as specific width and depth characteristics of these water courses.

In Table 4.6 the area cultivated with soil-bound crops is given for each relevant hydrotype (the minimum threshold area used is 30 ha). The hydrotypes Westland D and the Westland DHC cover the largest area of soil-bound crop cultivation. These hydrotypes are found mainly in the Western part of the Netherlands.

The areas per hydrotype listed in Table 4.6 together with the derived standard ditch profiles of Massop *et al.* (2006), construct a comprehensive geographical database of ditch characteristics.

Table 4.6

Area of soil-bound crops for each hydrotype (only the hydrotypes with an area > 30 ha are shown). The names of the hydrotypes are given in Dutch (See for explanation Massop et al., 2006).

Hydrotype	Area of soil-bound crop cultivation (ha)	Percentage of total soil-bound crops (%)
Betuwe-komgronden	51	2.3
Betuwe-stroomruggronden	30	1.3
Dekzand profiel	92	4.2
Duinstrook	271	12.4
Nuenengroep profiel	77	3.5
Open profiel	71	3.2
Peeloo profiel	39	1.7
Tegelen/Kedichem profiel	80	3.5
Westland-C-profiel	219	10
Westland-D-profiel	584	26.6
Westland-DC-profiel	95	4.3
Westland-DH-profiel	117	5.3
Westland-DHC-profiel	339	15.5
Westland-HC-profiel	124	5.6

5 Selection procedure and the selection of representative greenhouses

5.1 Scenario selection procedure

Local hydrology and soil type can be considered as two main driving forces for emission to groundwater and surface water from soil-bound crops. In addition, they vary across the country and enable the spatial and temporal variability of PPP concentrations in water bodies to be quantified explicitly. Other driving forces are considered to be based on main practices and expert knowledge. Irrigation depends heavily on the management decision by the grower and the crop type. In view of the limited availability of data regarding water management strategies and the unpredictability of these strategies, the working group decided to account for one irrigation strategy only, being a realistic conservative one for chrysanthemum as a model-crop.

The working group decided to classify the population of greenhouses and receiving ditches in the Netherlands into a limited number of emission classes with different local hydrology and soil type in order to derive a 90th percentile scenario.

The following procedure was followed:
1. Soil-bound crop growers were geo-referenced and classified according to their local hydrologic situation and soil type using the soil map of the Netherlands 1: 50,000.
2. One grower was selected for each of the most abundant classes.
3. For each selected grower, a suit of models was parameterised to calculate concentrations in surface water for a number of model-substances over 20 year.
4. Cumulative frequency distributions were created of the groundwater concentration and the concentration in ditch water to obtain the 90th percentile.
5. The greenhouse was selected that supports best the selection of a 90th overall percentile for the model substances used.

In line with the FOCUS scenarios for field crops, application pattern and crop type were not considered to be part of the scenario. These must be defined by the user.

The selection of the representative greenhouses is discussed in this Chapter, i.e. step 1 and step 2. Step 3 is discussed in Chapter 6 and step 4 and 5 in Chapter 7.

5.2 Areal coverage of greenhouse-soil type classes

To derive the areal coverage of the greenhouse-soil type classes, the population of greenhouses with soil-bound crops was classified according to the greenhouse classes as proposed in Table 4.3. Local soil types were derived from the CBS agricultural geographical information database GIAB 2008 (Naeff and Smidt, 2009) and the soil map of the Netherlands, i.e. for each soil-bound crop grower in the Netherlands, the area of cultivation was collected as well as the soil type and local hydrology. In Table 5.1 the percentage of areal coverage for each of the classes is given. Greenhouses with high groundwater levels, i.e. greenhouse classes 1, 2 and 3a, are scarce whereas lower and intermediate water levels occur more frequently. Almost half of all soil-bound crops are grown in greenhouses of class 4.

Table 5.1

Percentage of areal coverage per greenhouse class and soil type as compared to the total area of soil-bound crops. The greenhouse class-soil combinations with a coverage > 3% are indicated in yellow. In Table 4.5 the greenhouse class definitions were explained.

	Greenhouse class						
Soil type	**1**	**2**	**3a**	**3b**	**4**	**5**	**Grand Total**
Heavy clay	0.0%	0.1%	0.0%	1.8%	3.4%	0.2%	5.4%
Heavy sandy clay	0.0%	0.0%	0.1%	7.2%	12.8%	2.9%	23.0%
Light clay	0.0%	0.1%	0.0%	1.5%	5.9%	2.8%	10.3%
Light sandy clay	0.0%	0.0%	0.0%	10.4%	12.4%	3.5%	26.3%
Loam	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%
Peat	0.9%	0.0%	0.3%	4.6%	0.5%	0.0%	6.3%
Peaty sand	0.0%	0.1%	0.0%	0.1%	0.2%	0.0%	0.3%
Sand	0.0%	0.1%	0.1%	8.8%	12.6%	6.5%	28.1%
Grand Total	**0.9%**	**0.3%**	**0.5%**	**34.4%**	**47.9%**	**16.0%**	**100.0%**

5.3 Selection of representative greenhouses

Twelve greenhouse class-soil combinations could be identified with coverage larger than 3% of the total area with soil-bound crops. These can be found in the yellow boxes of Table 5.1. Representative growers were selected for each greenhouse class-soil combination, while using the selection criteria below:

- The grower should be located on soil with a soil type and groundwater table class similar to the combination that it represents. For the geographical reference of the grower we used the postal address of the grower as provided by GIAB;
- The location of the grower could be considered as representative for the selected class (expert opinion);
- The minimum area of soil-bound crops grown was 1.5 ha.

For example, for the combination light sandy clay and greenhouse type 3b (areal coverage 10.4%) a grower in the Westland area was selected. This grower grows 2 ha of chrysanthemum.

In Figure 5.1 the location of the representative growers is projected on a map of Dutch soil types (a) and groundwater table classes (b). The greenhouse size (area of soil-bound crops), the soil type, groundwater table class and crops type of each representative greenhouse are given in Table 5.2. The last column gives the local hydrotype, relevant for the ditch characteristics.

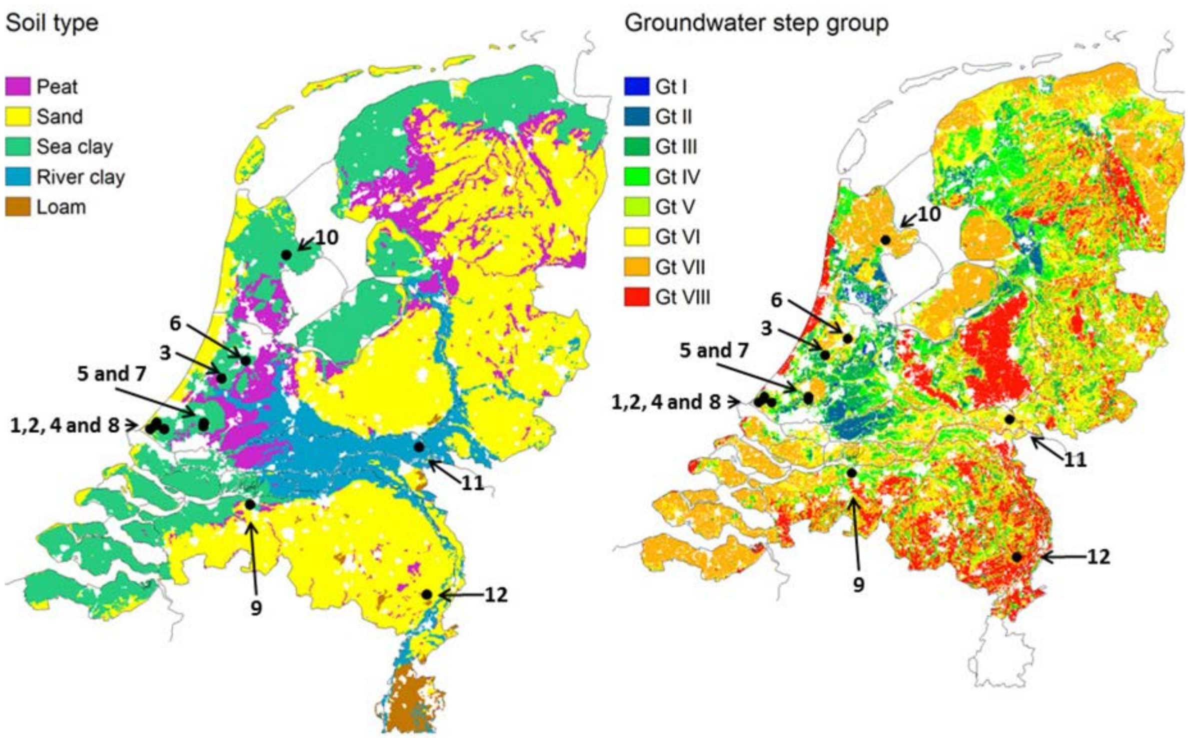

Figure 5.1 *Selected representative greenhouses nr 1 to 12 projected on the soil type map and the groundwater map with table classes (table class definitions are provided in Annex 2).*

Table 5.2
Characteristics of the selected representative greenhouses. The geographical location of the greenhouses is given in Figure 5.1. The names of the hydrotypes are given in Dutch (See for explanation Massop et al., 2006).

Greenh. nr	size (ha)	Soil type	Groundw. Table class[6]	Crop type	Hydrotype
1	1.716	Heavy sandy clay	IIIb	Chrysanthemum	Westland DHC
2	2.1	Light sandy clay	IIIb	Chrysanthemum	Duinstrook
3	1.8119	Peat	IIIb	Altroemeria and other flowers	Westland HC
4	10.7	Sand	IIIb	Vegetables	Westland D
5	5	Heavy clay	IV	Chrysanthemum	Westland C
6	2	Heavy sandy clay	IV	Vegetables	Westland C
7	4	Light clay	IV	Flowers	Westland C
8	1.98	Light sandy clay	IV	Chrysanthemum	Westland D
9	6.24	Sand	IV	Chrysanthemum	Westland DH
10	3.8	Heavy sandy clay	V	Freesia	Westland DC
11	5.24	Light sandy clay	V	Freesia and other flowers	Betuwe komgronden
12	3.85	Sand	V	Chrysanthemum	Dekzand profiel

6 Definitions of the groundwater table classes are given in Annex 2.

6 Model parameterisation of the selected greenhouses

In this Chapter the parameterisation of the selected representative greenhouses is explained, as listed in Table 5.2. The endpoint of the calculations is the concentration in the discharge receiving ditch. The representative greenhouses are all assumed to cover 1 ha and to grow chrysanthemum.

6.1 Models used

The greenhouse model WATERSTROMEN was used to calculate the daily ingoing and outgoing water flows of a greenhouse, while using weather data such as temperature, radiation and precipitation as input of the KNMI weather station in the Bilt (Voogt *et al.*, 2012).

The model KASPRO (De Zwart, 1996) was used to calculate the dynamically varying temperature in the greenhouse based on incoming radiation, outside temperature and standard set points for heating, ventilation, screening, lighting e.g.

The PPP fate model PEARL calculated the concentration in the water leaching to groundwater and surface water. PEARL is generally used in the PPP authorisation procedures and policy evaluations. It is a one-dimensional multilayer model that describes the fate of a PPP in the soil plant system (including transformation products) (Leistra *et al.*, 2000; Tiktak *et al.*, 2000; Van den Berg *et al.*, 2006). For calculation of the hydrology PEARL is linked to the Soil Water Atmosphere Plant model (SWAP, Kroes *et al.*, 2008). Recently, PEARL has been extended with a macropore option. For the concepts used in PEARL to calculate the transport via macropore flow we refer to Kroes *et al.* (2008) and Tiktak *et al.* (2011a, b).

TOXSWA (Adriaanse, 1996, Adriaanse *et al.*, 2014) was used to simulate the substance fate within the water body. Details of the TOXSWA model are discussed in Chapter 8. In the scenario selection phase, a metamodel of TOXSWA was used, which calculated the dilution of emitted concentration from drainpipes over the volume of a ditch on a daily basis (see also Tiktak *et al.*, 2011c). The metamodel does not account for upstream water fluxes except for drain fluxes from the upstream catchment. It has been calibrated to the FOCUS D3 scenario which assumes a drainage flux over the total length of the receiving ditch.

6.2 Conceptual model

Although each of the representative greenhouses is specific, a general conceptual model for greenhouse emission towards groundwater and surface water was used, which is depicted in Figure 6.1. The greenhouse excess irrigation water leaches through the matrix and the macropores to groundwater or discharges via drains to surface water or discharge tank, dependent of the local groundwater situation (seepage or infiltration). The drain pipes may discharge towards a ditch; however, more often a collection reservoir with a controlled water level is used, especially in areas with high water levels. The latter is assumed in the simulations. Run-off was simulated towards macropores only. No overland flow was considered.

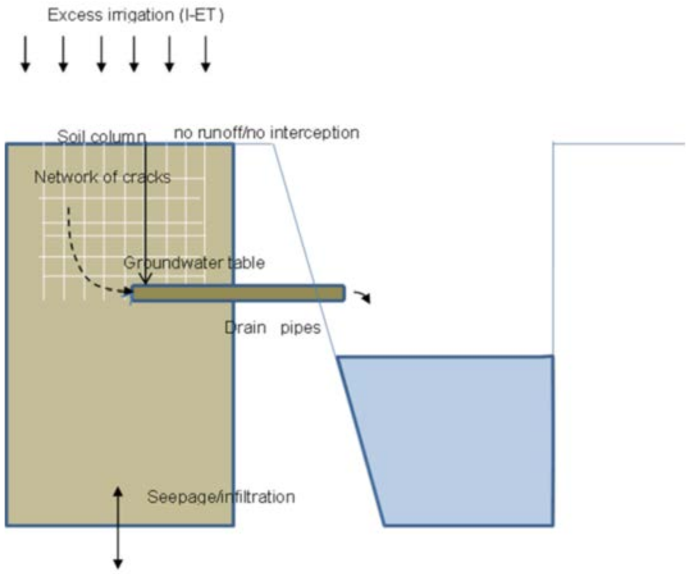

Figure 6.1 *Conceptual model of the water fluxes related to emission from soil-bound crops to groundwater and surface water. The drain pipes may discharge towards a ditch, however, more often a collection reservoir with a controlled water level is used (in Dutch: onderbemalingsput), especially in areas with high water levels. In the conceptual model, we assumed a point source emission from the greenhouse to the ditch (outlet situation at the upper boundary of the ditch section).*

6.3 Above ground processes

As mentioned in Section 4.2.2, the irrigation surplus used in chrysanthemum crops varies widely and may range between 5% and 50%. This variation is due to a number of conditions such as season, actual weather, soil properties and hydrology. Also technical factors like the irrigation system, water quality and crop specific aspects are important. An irrigation surplus, which means a higher irrigation quantity than the evapotranspiration is common practice in greenhouse horticulture for three reasons:

1. The water uptake among individual plants varies strongly, as well as the local water supply of irrigation systems. Van der Burg and Hamaker (1987) found a value for the coefficient of variation of 6.8-18.7% for the water supply and 14.4% for the water uptake. Sonneveld and Voogt (2009) reported work of Heemskerk, in which the distribution of the water supply by sprinkler irrigation systems was measured. The coefficient of variation of precipitation was 22%. Thus, also with sprinkler irrigation systems an ample water supply is necessary to equalise effects of dry spots. Calculations in a model with an unequal distribution of the water supply of a sprinkler irrigation system for a chrysanthemum crop learned that with a coefficient of variation of the sprinkler irrigation system of 27% an overdose of water 22% is necessary to supply all plant sufficiently with water (Assinck and Heinen, 2001). This resulted in a leaching fraction of 20% of the water supplied, which is in good agreement with experiences in practice (Sonneveld and Voogt, 2009).
2. Besides the variation inherent in the design and the technical lay-out of the irrigation system, the unequal water distribution is strongly aggravated by clogging of drippers and nozzles. This clogging is often caused by precipitation of constituents from the primary water used and from the fertilisers added or from the growth of algae, bacteria or fungi. If the concentration of any mineral in the water supplied is higher than the uptake, the residual salt accumulates in the root environment and must be leached by extra water supply. Na^+ and Cl^- are the ions often abundantly present in water, but sparingly absorbed by most greenhouse crops. Therefore, these ions often determine the leaching requirements.

Thus the water supply during crop eventually results from three main factors being:

- The uptake of the crop and the evaporation of the soil surface;
- The heterogeneity from differences by the plant as well as the irrigation system;
- The required leaching determined by the water quality and the accepted salt accumulation in the root zone.

The water supply during cultivation can be formulated as follows:

$$S_w = \frac{E}{(1-I)(1-LF)} \qquad (6.1)$$

in which S_w (mm yr^{-1}) is the water supply, E (mm yr^{-1}) is the estimated transpiration of the crop (-) is the inequality factor (Voogt and Sonneveld, 2009), and LF (-) is the leaching fraction.

Hence, regarding potential leaching, the irrigation surplus cumulated over time is an important parameter. This irrigation surplus is the net result of the total irrigation minus the evaporation. This is of course not exactly the same as the leaching rate, since the soil buffer capacity and vertical water fluxes determine the eventual leaching process. However, over time, the irrigations surplus is a quick and simple indicator for potential leaching. As described in Section 5.1, we decided to use one basic water management strategy for the model calculations. The working group decided to take a realistic worst-case approach, i.e. the irrigation excess is assumed to be 30%. From several monitoring projects, data is available from intensively grown chrysanthemum crops in the Netherlands (Figure 4.3). These data support the hypothesis that an irrigation strategy with 30% irrigation surplus is a realistic choice for a conservative water management scenario.

The WATERSTROMEN model (Voogt *et al.*, 2012) calculates the irrigation water and evapotranspiration on a daily basis, based on meteorological data. The irrigation water is provided every two to five days with an intensity of 0.5 mm per minute, uniformly over the soil surface. The irrigation follows the general characteristics of the irrigation strategies used by growers, which implies that the four stages as mentioned in Section 4.2 are applied for each section of the greenhouse (nine sections in total). Since the water from the drainpipes is generally collected in a storage tank before being discharged towards the surface water, for the model calculation the irrigation is averaged over all sections.

Evapotranspiration was calculated for an average year, being 2009 according to (Voogt *et al.*, 2006), while accounting for the four chrysanthemum development stages. The calculated annual evaporation of this average year was 709 mm yr^{-1} and the annual irrigation was 1000 mm yr^{-1}.

6.4 Soil characteristics

Soil columns of 1.60 m of depth were considered and discretised in layers with a thickness of 1 cm (top segment) to 10 cm (bottom segment). Soil properties at the selected sites were obtained from the 1: 250,000 soil map of the Netherlands that refer to 21 generalised soil profiles as defined and described by Wösten *et al.* (2001). Wösten *et al.* (2001) defined for each of these soil profiles the average soil structure as well as the soil physical properties. In Table 6.1 the generalised soil profiles that belong to each selected greenhouse are shown.

The soil physical properties apply to the entire soil profile, i.e. the soil matrix and the macropores. To extract the soil hydraulic conductivity of the matrix from the combined conductivity, the method of Jarvis *et al.* (1995) was followed, i.e. a boundary pressure head was introduced, being -5 cm. The combined relative conductivity at this pressure was assumed to be representative for the saturated conductivity of the matrix. For further details see Tiktak *et al.* (2011c).

The soil structure of the root zone is known to be improved by adding organic matter and clay at a regular basis. Sonneveld *et al.* (1990) measured organic matter content and clay content in 75 samples in the Netherlands, of which the mean values are provided in Table 4.2. Since (ground-) water concentrations are known to be sensitive towards organic matter and clay content (because they affect sorption processes as well as the development of macropores) the enriched soil textures were used in the model simulations. We used the mean values of the measured soil textures per soil type. The organic matter and clay content of the soil types heavy sandy clay, light clay and heavy clay were clustered in order to obtain sufficient data points. The organic matter and clay content values used in the simulations are shown in Table 6.1 as well.

Since information on soil physical properties is lacking for the enriched root zone, the soil physical properties of peaty sand (B15) for the top soils were used for all selected greenhouses. This soil type has a high conductivity (81.3 cm d^{-1}) and saturated porosity (0.53). See for further details of top-soil B15, Wösten *et al.* (2001).

Table 6.1
Soil and macropore characteristics of the selected greenhouses.

Greenh. nr	Soil type	Soil type [7]	Macropores?	Topsoil texture	
				Clay fraction (%)	OM fraction (%)
1	Heavy sandy clay	16	Yes	21	14
2	Light sandy clay	15	No	17	12
3	Peat	1	No	37	22
4	Sand	19	Yes	7	4
5	Heavy clay	17	Yes	21	14
6	Heavy sandy clay	16	Yes	21	14
7	Light clay	16	Yes	21	14
8	Light sandy clay	15	No	17	12
9	Sand	9	No	7	4
10	Heavy sandy clay	15	No	17	12
11	Light sandy clay	15	No	17	12
12	Sand	12	No	7	4

6.5 Macropores

Structured soils may contain macropores caused by shrinking and cracking of soils. To allow for the simulation of PPP leaching through macropores three flow domains were considered, i.e. the soil matrix, macropores in the internal catchment domain and macropores in the bypass domain. Macropores in the internal catchment domain were assumed to be unconnected. They end at various depth and force the macropore water to penetrate deeper into the soil matrix. In the bypass domain macropores were assumed to be connected and to penetrate deep into the soil. Water that flows into these macropores bypasses the reactive unsaturated part of the soil, leading to rapid drainage towards drainpipes and groundwater. Macropores could be either permanent or temporary (due to shrinking of soils).

Figure 6.2 gives a schematic representation of the macropore volume as a function of depth. The depth of the plough layer (Z_{Ah}) was assumed to be 0.30 m. The bottom depth of the internal catchment domain (Z_{Ica}) was assumed to be equal to the drain depth, i.e. 0.9 m. The bottom of the permanent macropores was set equal to the local mean lowest groundwater level.

[7] Wösten *et al.* (2001). The selected soil types refer to: 1: peaty soils ('koopveengronden'); 9: sandy soil ('podzolgronden'), 12: silty sandy soils ('enkeerdgronden'); 15: homogeneous sandy clay soils; 16: homogeneous light clay soils; 17: heavy clay soils; 19: clay on sand.

We used the built-in pedotransfer functions of PEARL which are explained in Tiktak *et al.* (2012). The following parameters were set equal to the recommended value:

- The runoff extraction ratio: 0.125 (-);
- The fraction of sorption sites in the bypass domain: 0.02 (-);
- dispersion length in the micropore domain: 0.05 (m).

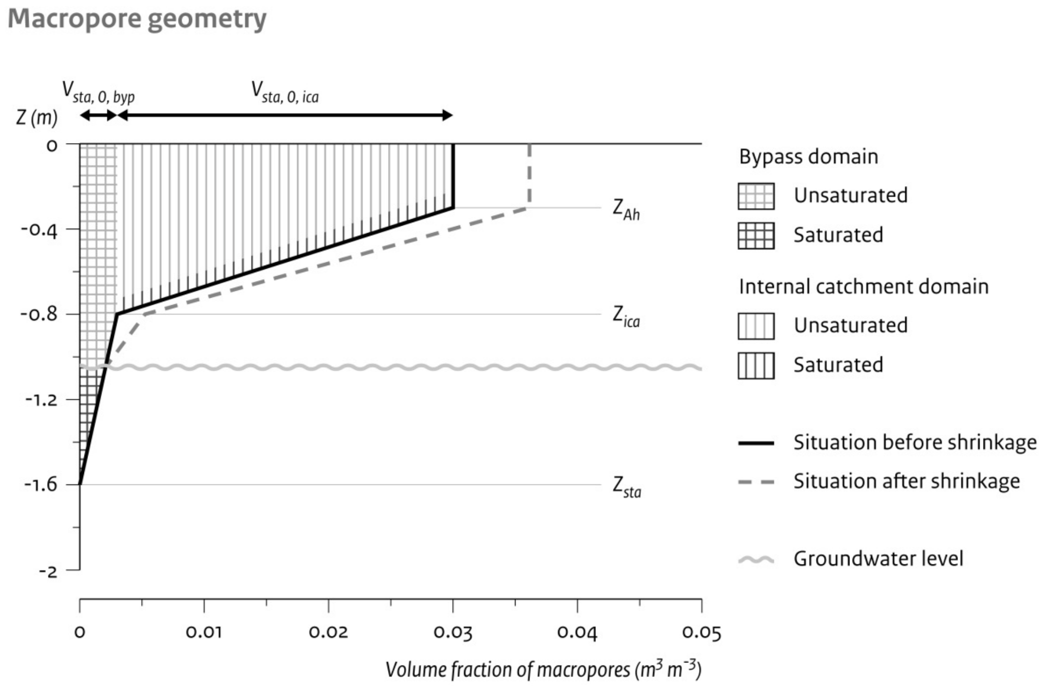

Figure 6.2 *Schematic representation of the macropore volume. Z_{Ah} (m) is the depth of the plough layer, Z_{ica} (m) is the bottom depth of the internal catchment domain, Z_{sta} (m) is the bottom depth of the static macropores (figure from Tiktak et al., 2011a).*

6.6 Drain pipes

For greenhouses in regions with higher groundwater levels, i.e greenhouses 1-9, drain pipes were situated at a standard depth of 90 cm below soil surface at a standard distance of 3.2 m. The drains discharged into the nearby surface water. Excess water from greenhouses 10-12 flows mainly to groundwater.

No site specific information was available on the drainage resistance of the drains. Therefore, the drainage resistance was obtained from the relationship derived by Hooghoudt (1940) for a homogeneous profile:

$$\gamma_{\text{drain}} = \frac{\gamma_{\text{entry}} + L_{\text{drain}}^2}{8KD_{\text{eq}} + 4K(\varphi_{\text{gwl}} - \varphi_{\text{drain}})} \tag{6.2}$$

where:

- γ_{entry} is the entry resistance (d),
- γ_{drain} is the drainage resistance (d),
- v is the distance between the drains (m),
- K is the hydraulic conductivity (m d^{-1}),
- φ_{gwl} is the phreatic groundwater level midway between the drains (m),

- φ_{drain} is the drainage level (m),
- D_{eq} is the equivalent thickness that accounts for the head loss near the drains caused by converging flows (m).

We assumed that the entry resistance γ_{drain} is small as well as the difference between phreatic and drainage level. Eqn. 6.2 therefore reduces to:

$$\gamma_{\text{drain}} = \frac{L_{\text{drain}}^2}{8KD_{\text{eq}}} \tag{6.3}$$

L_{drain} is 3.2 m and D_{eq} is estimated to be 0.75 m. Eq. (6.3) can be used to calculate the matrix flow as well as macropore flow, where the hydraulic conductivity (m d^{-1}) of the matrix is calculated according to Jarvis *et al.* (1995) and the hydraulic conductivity of the macropores is calculated with:

$$K_{\text{mp}} = 14.4 \cdot 10^8 w_{\text{mp}}^2 / d_{\text{pol}} \tag{6.4}$$

w_{mp} is the effective macropore width at soil surface and d_{pol} (m) is the effective diameter of the soil polygons:

$$w_{\text{mp}} = d_{\text{pol}}\left(1 - \sqrt{1 - v_{\text{mb}}}\right) \tag{6.5}$$

And

$$d_{\text{pol}} = 2 \cdot 10^{\left(0.409 - 0.133 f_{\text{om}} / 1.724 + 0.034 f_{\text{clay}} - 3\right)} \tag{6.6}$$

V_{mb} is the volume fraction of the macropores, f_{om} (%) is the mass fraction of organic matter and f_{clay} (%) is the clay content (see for further details Kroes *et al.*, 2008, Chapter 6 and Tiktak *et al.*, 2011c, p. 67).
De drainage resistance of the ditch is much higher than the drain, therefore the direct discharge to the ditch was assumed to be negligible.

6.7 Lower boundary condition

A bottom boundary flux was imposed on the soil column. This bottom boundary flux accommodates for regional groundwater flow and is hardly affected by local water management (i.e. water management in the greenhouse). For the simulation of the bottom boundary flux, a Cauchy condition has been selected in which the bottom boundary flux is calculated using the hydraulic head difference between the phreatic groundwater and the groundwater in the underlying semi-confining aquifer:

$$q_{\text{bot}} = \frac{\phi_{\text{aqf}} - \phi_{\text{gwl}}}{\gamma_{\text{aqt}}} \tag{6.7}$$

where q_{bot} (m d^{-1}) is the bottom boundary flux, ϕ_{aqf} (m) is the hydraulic head of the semi-confining aquifer, ϕ_{gwl} (m) is the phreatic head and γ_{aqt} (d) is the vertical resistance of the aquitard.

Daily values of the hydraulic head of the semi-confining aquifer and the vertical resistance of the semi-confining aquifer were obtained from a regional groundwater model named 'Netherlands Hydrological Instrument' abbreviated to NHI (for details refer to http://www.nhi.nu/nhi_uk.html). The basis of NHI is a state-of-the-art coupling of a groundwater model (MODFLOW), an unsaturated zone model (a metamodel of SWAP referred to as metaSWAP) and a surface water model (MOZART-DM). The resolution of the groundwater model is 250 by 250 meters and groundwater flow is computed on daily basis.

For each of the 12 greenhouses in Section 5.3, a unique grid cell was selected from the NHI-results. We used the following selection criteria:
- The groundwater depth class of the NHI-grid cell had to be the same as the groundwater depth class of the greenhouse;
- The soil type of the NHI-grid cell had to be the same as the soil type of the greenhouse;
- The distance between the greenhouse (based on postal code) and the centre of the grid cell had to be as small as possible.

For each of the 12 greenhouses, the SWAP model was parameterised in exactly the same way as the MetaSWAP model within NHI. This was done because the aim was to describe the regional groundwater flow as good as possible. So all model inputs such as crop parameters, soil physical properties, soil thickness, daily precipitation, lower boundary condition, drainage resistance, etcetera were directly taken from the NHI. Typical results of a SWAP simulation for the entire simulation period are shown in Figure 6.3. Notice that this simulation applies to a field crop situation *outside the greenhouse*, and not to the groundwater level in the greenhouse itself.

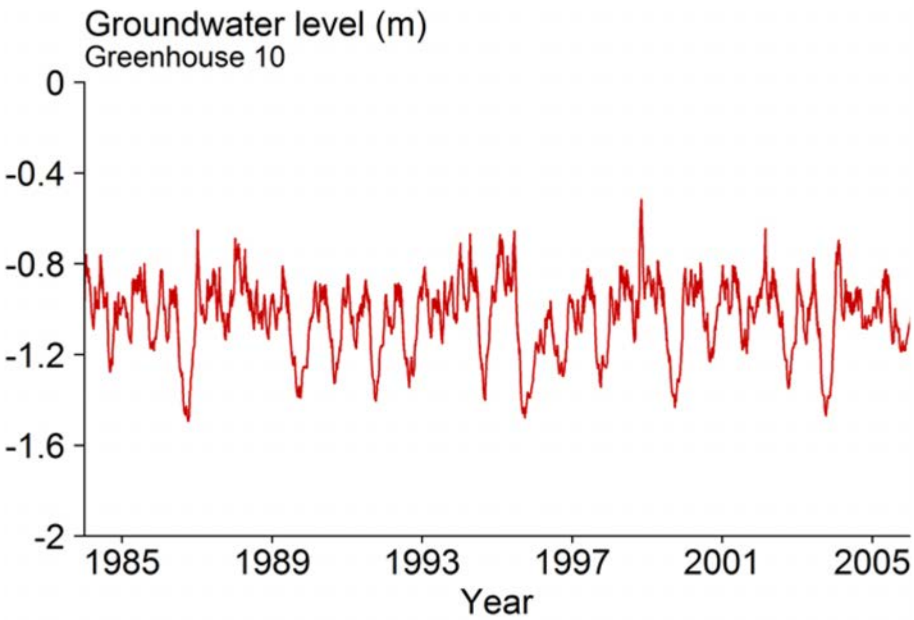

Figure 6.3 *Simulated groundwater level below soil surface with SWAP for a field crop situation outside Greenhouse 10. This simulation reflects the effect of the regional groundwater level.*

In earlier leaching assessments, the bottom boundary flux was described in a more generalised way, i.e. an annual average bottom flux was used on which a sine function was added (Tiktak *et al.*, 2002). We judged this boundary condition inappropriate for simulating drainpipe leaching, because drainage water flow is to a large extent driven by the groundwater level. Another reason for simulating the lower boundary condition as good as possible is shown in Figure 6.4. In Dutch polders, the bottom boundary flux is often upwards (upward seepage, Section 4.4.1). In such cases, drainage water from the greenhouse will be diluted by water from the surrounding regional groundwater. So regional groundwater flow (and hence the lower boundary condition) has a significant effect on the simulated concentration in the drain pipe.

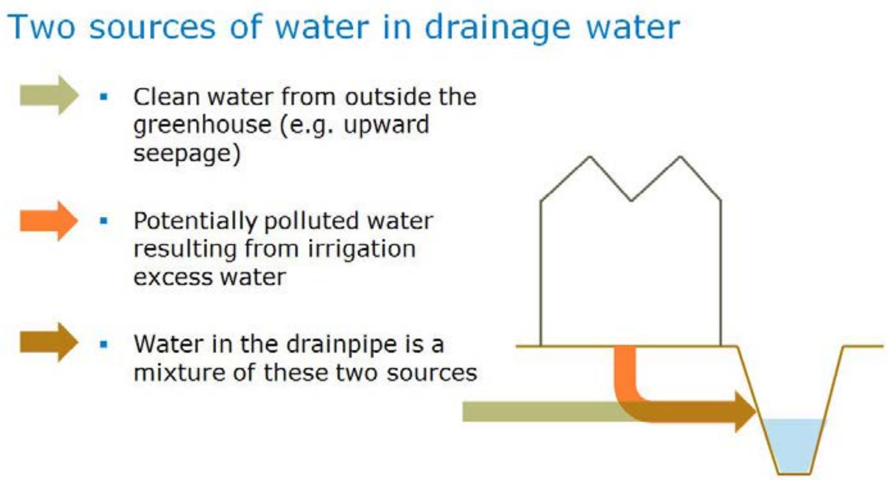

Figure 6.4 *The concentration of PPP in the drainpipe may be diluted by seepage water. Water from the greenhouse (orange) is mixed with clean water from outside the greenhouse.*

6.8 Parameterisation of the TOXSWA metamodel

The TOXSWA metamodel described by Tiktak *et al.* (2012) was used to simulate PPP fate in the receiving water course and to calculate the Ecotoxicological Relevant Concentration, i.e. the peak concentration over 100 m of receiving ditch for each of the selected greenhouses. The metamodel calculates in principle the dilution of emitted concentration from drainpipes over the volume of a ditch on a daily basis. The calculated concentration is equal to the concentration in the drainpipes as long as the total volume discharges is larger than the volume of the ditch. The metamodel does only account for upstream water fluxes as coming from similar drain fluxes at the upstream catchment. The upstream catchment is assumed to be treated as well.

The treated area was considered to be one ha, whereas the area of upstream catchment was assumed two ha and the upstream catchment was assumed to be treated as well. Ditch lineic volumes (volume per unit length) were obtained from the hydrotype map and the corresponding ditch classes (Massop *et al.*, 2006). Being the type of water course that most regularly receives water from greenhouses, secondary ditches (width 1-3 m) were used for the scenario selection procedure. The metamodel was used only to support the scenario selection procedure, i.e. the selected scenario in a next step was parameterised while using TOXSWA, a model which is better equipped to simulate all relevant PPP fate processes in surface water (Chapter 8). It was assumed that the metamodel is suitable for the ranking of the greenhouses according to their vulnerability.

6.9 Water balances and surface water concentrations for the twelve representative greenhouses

6.9.1 Water balances

For each of the 12 representative greenhouses, hydrodynamic simulations with SWAP were carried out over the entire simulation period (1985-2005). The water balances of the simulations are shown in the Figures 6.5 and 6.6. Two cases are shown, i.e. a case where the irrigation excess was 20% (a best case situation with respect to leaching) and a situation where the irrigation excess was 50% (a worst case situation with respect to leaching). Notice that the irrigation schedule selected for our scenario is in-between these two values; the purpose of this section is to show the extremes.

In the 20 per cent irrigation excess case, approximately 900 mm of irrigation water is given each year. Evapotranspiration is approximately 700 mm, so the annual irrigation surplus amounts to 200 mm. These numbers are the same for all greenhouses because they are controlled by the irrigation schedule, which is considered to be independent of the greenhouse (Section 4.2.2). However, drainage and seepage flow differ considerably between greenhouses. Drainage is mainly via the drains but can also occur through the soil-matrix to the ditch, in case no drainpipes exist (greenhouse 10-12). For the first five greenhouses, annual seepage is upwards, and drainage is larger than 200 mm. The most extreme case is greenhouse 4 where upward seepage is 700 mm and drainage 900 mm. This greenhouse is situated in the Westland region where clay is generally situated on top of a sandy layer. In greenhouses 8-12, almost all excess water is routed towards the groundwater. Greenhouse 1, 5, 6 and 7 are prone to preferential flow. These greenhouses are situated on soils with a finer texture, i.e. heavy sandy clay and clay soils. In greenhouses where the subsoil is predominantly sandy, flow is predominantly through the soil matrix. Notice that the greenhouse with the highest drainage hardly shows any preferential flow. The reason is that the drains of this greenhouse are situated in a sandy layer.

In the 50 per cent irrigation excess case (Figure 6.6), the general pattern is the same, but the fluxes are higher: Irrigation is 1400 mm a^{-1}, so with an evapotranspiration of 700 mm a^{-1}, the irrigation excess is almost 700 mm a^{-1}.

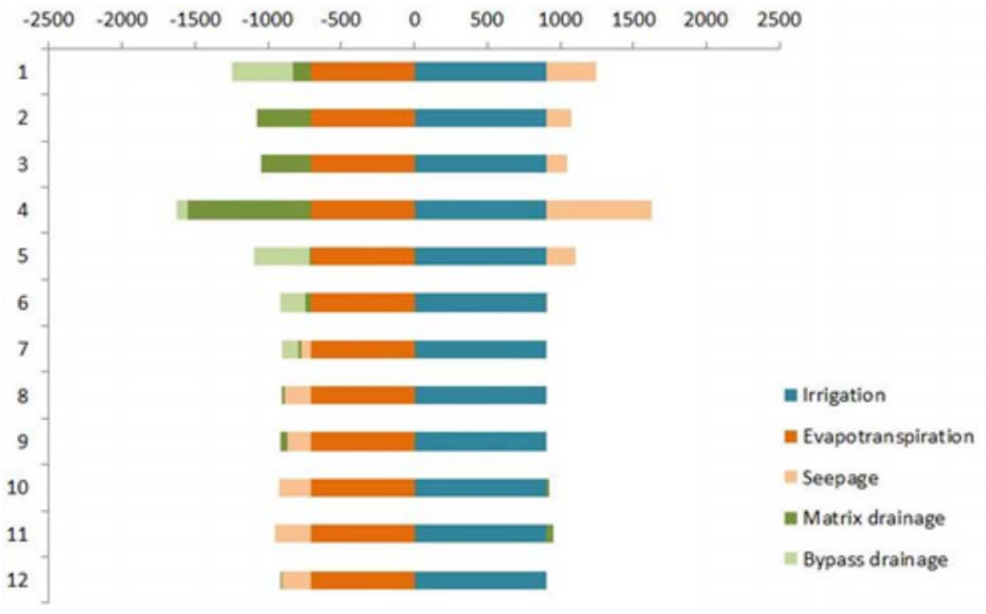

Figure 6.5 *Long-term average water balance of the 12 representative greenhouses with an irrigation excess of 20 per cent (i.e. best case situation with regard to PPP leaching). On the X-ax the greenhouse number is projected and on the y-axis the fluxes are expressed in mm a^{-1}.*

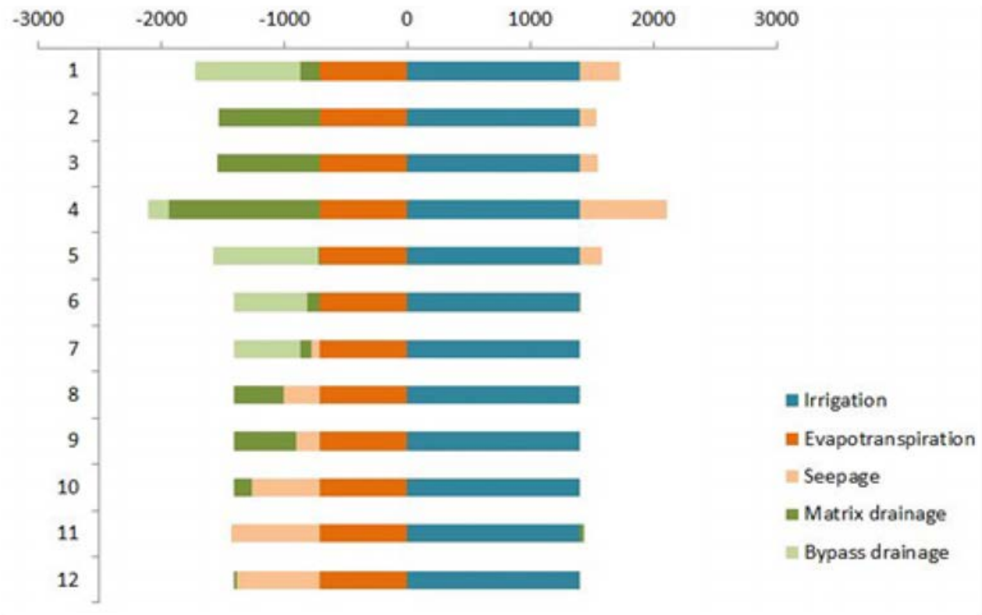

Figure 6.6 *Long-term average water balance of the 12 representative greenhouses with an irrigation excess of 50 per cent (i.e. best case situation with regard to PPP leaching). On the X-ax the greenhouse number is projected and on the y-axis the fluxes are expressed in mm a*$^{-1}$.

In most of the greenhouses, the groundwater level is just above drain level throughout the entire simulation period (see the blue line in Figure 6.7 where an example is shown for greenhouse 5 and an irrigation excess of 20 per cent). However, for many of the greenhouses, temporal variability of the groundwater level was expected as this was enforced by the lower boundary condition. Much of this temporal variability could be reproduced in simulation where we replaced the year round irrigation regime by natural rainfall (red line in Figure 6.7). This confirms the theory that the hydrological cycle in the greenhouse is almost completely dominated by local management.

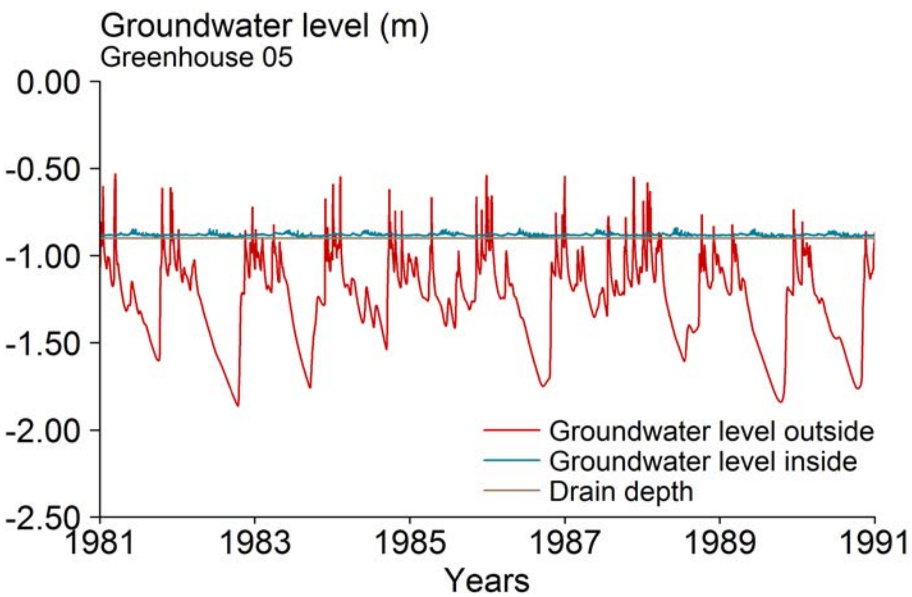

Figure 6.7 *Simulated groundwater level below for surface in greenhouse 5 using the year round irrigation schedule (blue line) and natural rainfall and evapotranspiration (red line). The irrigation excess was 20 per cent.*

6.9.2 Example substances concentrations in the ditch

The concentration in surface water of six example substances was simulated for all 12 greenhouses. The properties of these substances were in principle equal to FOCUS substance D, only the degradation half-life (*DegT50*) and the coefficient for sorption on organic matter (K_{om}) of these substances were varied as shown in Table 6.2. The substances were sprayed annually at a dose of 1 kg ha^{-1} to the crop canopy; interception was calculated by the model using the default parameters suggested by EFSA (2012). Notice that in reality multiple annual applications occur; the purpose of these simulations is only to show the difference between the greenhouses and the effect of irrigation.

Table 6.2
Properties of the six example substances.

Substance	*DegT50* (d)	K_{om} (dm^3 kg^{-1})
P1	10	10
P2	60	60
P3	60	20
P4	120	120
P5	30	60
P6	120	240

Figure 6.8 shows examples of the surface water concentration in the ditch adjacent to greenhouse 4. We simulated two cases, i.e. 20 per cent irrigation excess and 50 per cent irrigation excess. With 50 per cent irrigation excess, the concentration in ditch water is almost a factor of ten higher. In the 50 per cent case, water management in the greenhouse dominates the concentration in ditch water, while in the 20 per cent case the regional water model is an important factor. This can be seen from the temporal pattern: in the 20 per cent case, the pattern is irregular (caused by natural variation); while in the second case peaks are seen every year (due to the regular irrigation gifts).

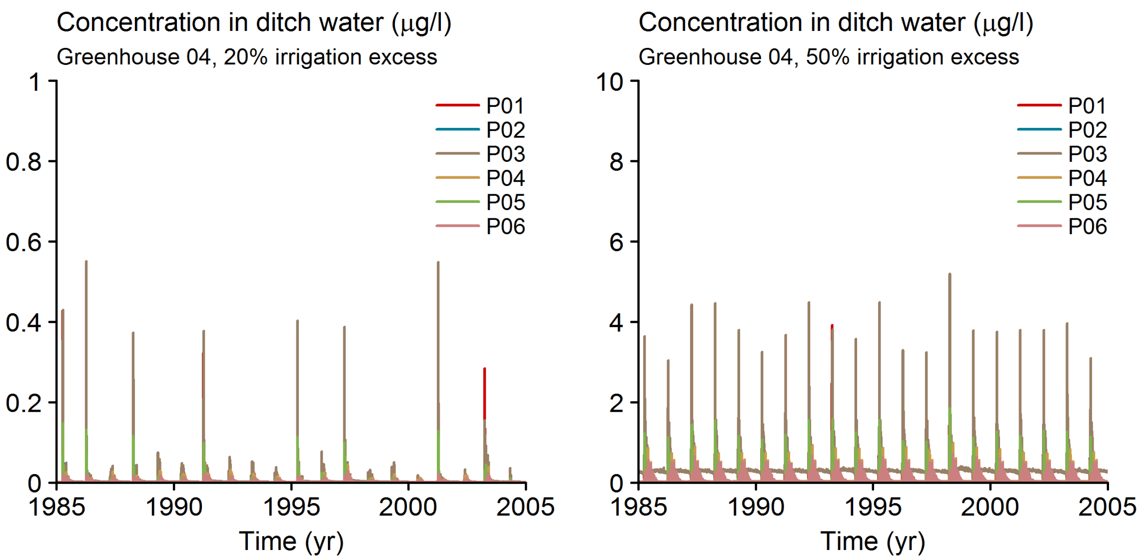

Figure 6.8 *Concentration of six example substances (properties shown in Table 6.2) in the ditch adjacent to greenhouse 4. Left: case with 20% irrigation excess. Right: case with 50% irrigation excess.*

7 Greenhouse selection

7.1 Surface water

7.1.1 Procedure

The target of the exposure assessment is the 90th percentile of the peak concentration in surface waters adjacent to greenhouses growing soil-bound crops. So we need a procedure to simulate the frequency distribution of all peak concentration in surface waters adjacent to these greenhouses. This was done as follows:

- Simulations were done with PEARL and the TOXSWA metamodel for all 12 representative greenhouses described in Chapter 5. Each simulation gives 20 annual peak concentrations, so the number of points that were available for the construction of a cumulative frequency distribution is 20 (number of years) times 12 (the number of greenhouses) = 240;
- All data points were sorted to obtain a cumulative frequency distribution;
- Each greenhouse represents an area (Section 5.2), which was used as a weighting factor.

From each cumulative frequency distribution, the 90th percentile was selected and the corresponding greenhouse was looked up. Tiktak *et al.* (2012) showed that the ranking of locations (in this case greenhouses) is substance dependent. This implies that a greenhouse that is sufficiently conservative for one substance may not be conservative for another substance. For this reason we performed simulations for all six substances in Table 6.2 and selected the greenhouse that was sufficiently conservative for these substances.

For the PEARL simulations, we assumed annual applications to the crop canopy of 1 kg/ha on April 1 each year (see Section 6.9.2 for details). An irrigation excess of 30% was used (Section 6.3).

7.1.2 Results

The overall frequency distribution of the concentration of the six example PPPs in ditch water is shown in Figure 7.1. For five substances, the frequency distributions start at 56%, which means that for 56% of the greenhouse-year combinations, the drainage concentration is zero. Closer inspection reveals that mainly greenhouses 1, 4, 5, 6, 7 give non-zero concentrations. These are greenhouses situated on fine textured soils where preferential flow occurs (Section 6.9.2). The only substance that behaves differently is substance P03. This substance is relatively mobile (K_{om} equals three times *DegT50*), which implies that transport through the soil matrix is to be expected.

The next step is to find the greenhouses that show concentrations above the 90th overall percentile. For that purpose, we plotted the frequencies of Figure 7.1 (i.e. all substances, all years and all greenhouses) as a function of greenhouse number (Figure 7.2). The figure zooms in on the 50th to 90th overall percentiles. For convenience only temporal percentiles > 50 are plotted. Greenhouse 1,4,5,6,7 have overall percentiles above 90. Greenhouse 5 has the lowest number of concentrations below the 90th percentile. This greenhouse was selected.

The final step is to select the weather year. The weather year should be chosen so that it is sufficiently conservative for all substances. In Figure 7.2, the various temporal percentiles are indicated by colours (weather year 1 corresponds to the 2.5th temporal percentile, year 2 to the 7.5th percentile, etc.). The figure shows that the 90th temporal percentile has to be selected to ensure that the overall percentile is greater than 90%. So the final selection is greenhouse 5 in combination with the 90th temporal percentile (i.e. weather year 18).

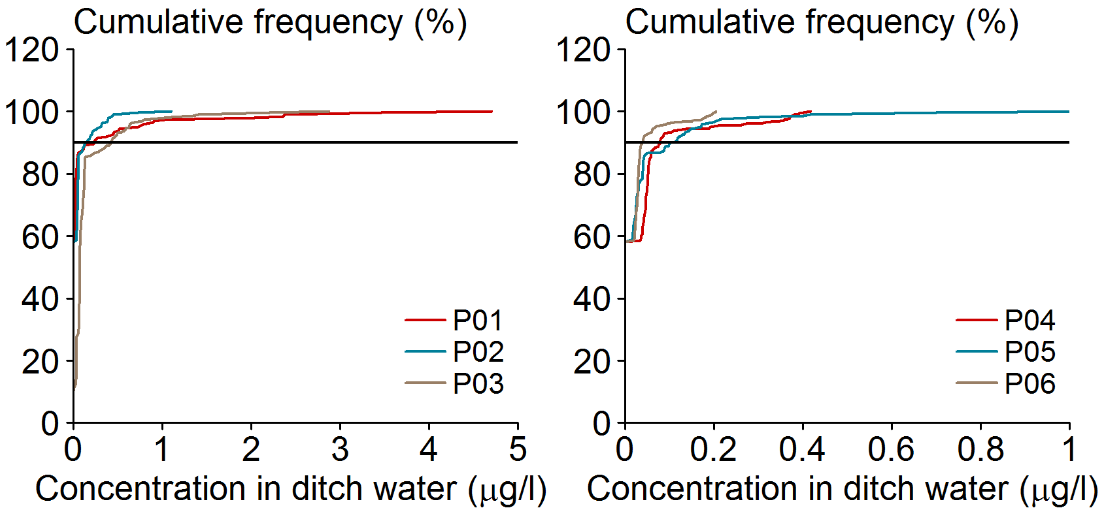

Figure 7.1 *Cumulative frequency distribution of the peak concentration for six example substances in surface water adjacent to greenhouses growing soil-bound crops. Properties of the six example PPPs are shown in Table 6.2. The black horizontal line corresponds to the 90th overall percentile.*

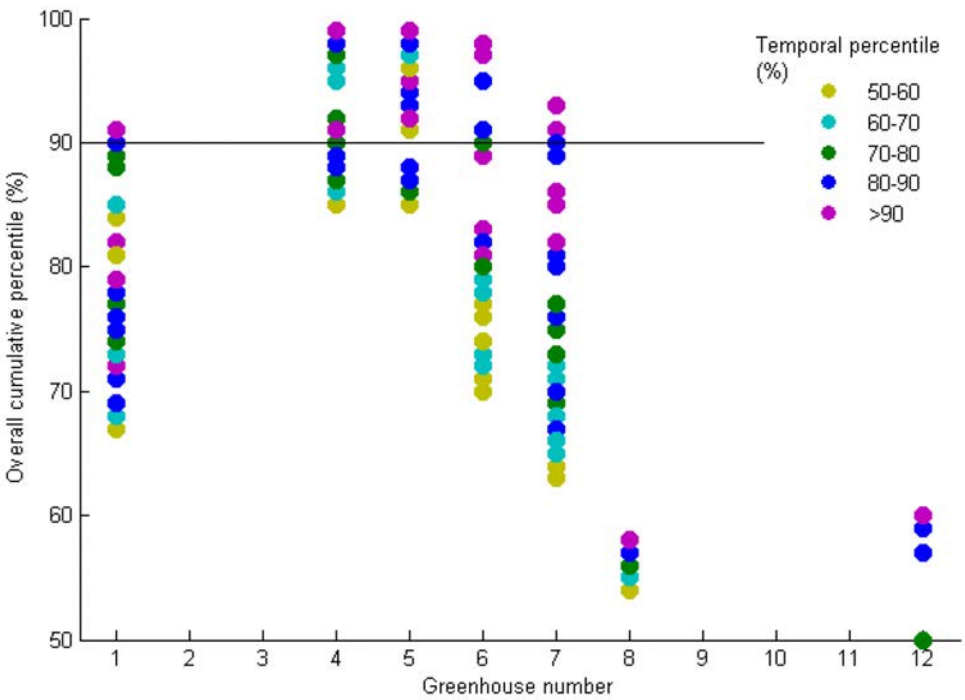

Figure 7.2 *Cumulative frequency distribution of the peak concentration of the six example substances in surface water adjacent to greenhouses as a function of greenhouse number. Only greenhouse 4, 5, 6 and 7 show concentrations above the 90th overall percentile. The selected scenario is greenhouse 5 in combination with the 90th temporal percentile.*

7.2 Groundwater

7.2.1 Procedure

Following the decision tree for groundwater risk assessment for field crops in the Netherlands, the annual leaching concentration at 10 m depth should not exceed the drinking water criterion of 0.1 µg/L under realistic worst case conditions. The working group used the following criterion:

The average annual concentration in groundwater should be less than 0.1 µg/L for at least 90^{th} of the population (in time and space). The leaching concentration is calculated at 1 m depth (conservative approach).

The scenario selection procedure for groundwater was essentially the same as the procedure for the selection of surface water scenarios. To determine the 90^{th} percentile, for the representative greenhouse classes, the overall percentile was calculated for the FOCUS groundwater substances A to D (FOCUS, 2000). Again we simulated annual applications of 1 kg/ha on April 1 and an irrigation excess of 30%.

7.2.2 Results

The simulated annual leaching concentrations at 1 m depth were low tot very low for all substances. Figure 7.3 shows the cumulative frequency distribution for the substances A to D. These distributions were constructed from simulated leaching concentrations of the 12 representative greenhouses over 20 years of simulations. Each greenhouse has been weighted according to the area of greenhouses that is represented (areas are given in Table 5.2). Only the metabolite of substance C showed concentrations up to 0.117 µg/L. The simulated concentrations for the other substances were lower. The 90^{th} percentile of substance D was zero. Greenhouse 4, 5, 6, 7, 10 and 11 have concentrations that are within the 87^{th} -93^{th} percentile range of overall concentrations. Representative greenhouse 11 was selected as being the most representative scenario. The 90^{th} temporal percentile was considered to be conservative enough to predict a 90^{th} overall percentile.

Figure 7.3 *Cumulative frequency distribution of the leaching concentrations at 1 m depth calculated for the 12 representative greenhouses over 20 year, for the FOCUS groundwater substances A to D.*

To assess the relative vulnerability for leaching of soil-bound horticulture, we compared the 90^{th} percentile from soil-bound horticulture (chrysanthemum) to the 90^{th} percentile of the FOCUS Kremsmünster scenario- winter cereals for the FOCUS substances A to D (FOCUS, 2000). The

Kremsmünster scenario is the first tier for leaching assessment from field crops in the Netherlands. We used the model FOCUS_PEARL_4_4_4 to run the Kremsmünster simulations. Table 7.1 gives the 90th percentile concentration for both Kremsmünster and soil-bound greenhouse crops. The simulated 90th percentile concentrations for soil-bound crop were considerably lower than the Kremsmünster 90th percentile concentrations. This shows that the Kremsmünster simulated concentrations are conservative as compared to greenhouse leaching concentrations. The low leaching concentrations in greenhouses are likely due to the higher temperature in the greenhouses together with the high organic matter content in the upper soil layer.

Table 7.1
90th percentile concentrations of the FOCUS substances A to D for the Kremsmünster – winter cereals scenario (field crops) and calculated for the 12 representative greenhouses. The Kremsmünster scenario is conservative as compared to the greenhouse calculations.

Substance name	90th overall percentile leaching concentration	
	Kremsmünster-winter cereals	Greenhouses-chrysanthemum
FOCUS A	7.83	0
FOCUS B	5.61	0.002
FOCUS C-metabolite	26.85	0.074
FOCUS D	0.32	0

7.3 Chrysanthemum as a model crop

With the selection of the scenarios for surface water and groundwater, the question rises whether the scenario, which is based on chrysanthemum, is representative for other soil grown crops as well. Chrysanthemum has a relatively high irrigation surplus, which can be considered as conservative as compared to other crops. However, the organic matter content in chrysanthemum cultivation is relatively high. PPP leaching is known to be negatively correlated to organic matter.

Radish is known to be grown on sandy soils with lower organic matter contents than common for chrysanthemum. The growth conditions of radish are relatively dry (see also Table 4.1). Taking radish as a model crop, we calculated the peak concentration in the water again with PEARL and the meta-TOXSWA model for representative Greenhouse 2 (sandy soil) for the six example substances of Table 6.3, while taking the irrigation surplus the same over the years, but less than for chrysanthemum. Also, the soil texture and hydraulic characteristics were assumed to be as of the original soil. The irrigation surplus of radish was considered to be 10%, i.e. the irrigation was 634 mm and the evapotranspiration was 569 mm.

For all substances, except for substance 3, the calculated concentrations in the ditch water were less than 10^{-4} µg/l. For substance 3, concentrations varied between 0.006 µg/L and 0.034 µg/L. These results confirm that chrysanthemum can be used as a conservative crop as compared to other crops.

The concentration of PPP that leached to groundwater was calculated while assuming greenhouse 11 to be representative. The soil texture and hydraulic characteristics were assumed be as of the original soil. The leaching concentration was less than 10^{-4} µg/l for all substances A to D.

8 Model parameterisation of the ditch

8.1 Approach

In Chapter 7, greenhouse 5 was selected including the corresponding ditch, being a Westland C type, secondary ditch. The Westland C secondary ditch has a lineic volume of 0.57 m^3m^{-1}. Figure 8.1 provides the mean ditch characteristics that belong to Westland C secondary ditch according to Massop *et al.* (2006). Model simulations were performed with the TOXSWA- metamodel. This model basically simulates the effect of dilution of the incoming drain water by the water volume in the ditch. The detailed PPP fate model TOXSWA (Adriaanse *et al.*, 1996) will be used to simulate realistic concentration dynamics in the parameterised scenario. This model allows for a more realistic representation of greenhouse ditch hydrology and multiple pesticide fate processes, while accounting for dilution processes as well as PPP transport, degradation and sorption processes.

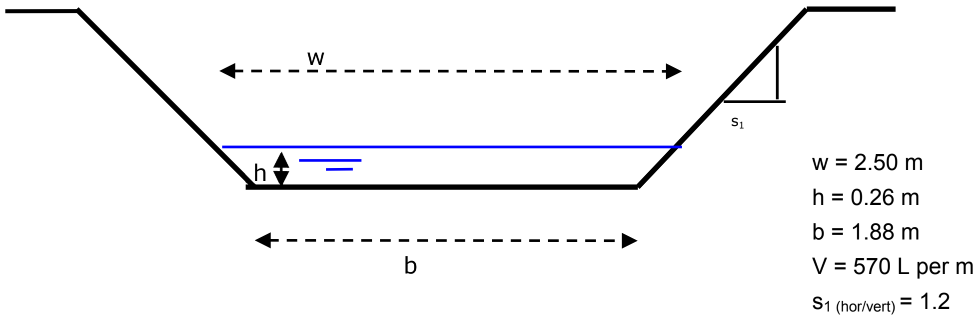

Figure 8.1 *Dimensions of the Westland C ditch, where w is the width of the water surface, h is the water depth, b is the width of the bottom of the ditch, s_1 is the side slope (horizontal/vertical), and V is the lineic volume of the water in the ditch. The water depth corresponds to a winter wet situation.*

To obtain the realistic and dynamic water velocities, the working group could make use of a calibrated hydrodynamic model, i.e. the model (1D/2D SOBEK Rural) of the Oude Campspolder, a polder situated in the Delfland management area between Rotterdam and The Hague. The detailed calibrated hydrodynamic model provides daily water discharge and water depth for 137 water segments within the Oude Campspolder model, for the period 2000-2006. The workgroup is indebted to the Water board of Delfland providing the model.

The following approach has been adopted by the working group to derive realistic ditch velocities:

1. Assess the velocity distribution of the water courses within the Oude Campspolder, while taking a sub-population of segments with similar lineic volumes as the Westland C ditch.
2. Select a segment that corresponds to the selected greenhouse hydrotype and of which the segment velocities reflect the overall distribution of velocities of the sub-population.
3. Parameterise TOXSWA so that the dimensions of greenhouse ditch correspond with the Westland C secondary ditch, given the velocity dynamics of the selected segment.

8.2 Oude Campspolder model

A quantitative overview on ditch properties and surface water velocity distributions in edge-of-field ditches is not readily available. The reason is that hydrodynamic modelling generally emphasises the management of large rainfall events for which a correct simulation of high flow events is necessary. In addition, water boards often monitor water flux velocities in the larger water bodies of their managed area, which are generally not the water bodies that receive water from greenhouse horticulture.
The Oude Campspolder model constructed by the Water board of Delfland is an exception since it was developed to study and simulate water quality; hence special attention was paid to periods of low water flow. Moreover, the considered polder has a high density of greenhouse horticulture, i.e. the model was considered useful to fill in the knowledge gap on velocity distributions in Dutch (polder) ditches.

The Oude Campspolder model is a calibrated hydrodynamic model (1D/2D SOBEK Rural) of the Oude Campspolder, a polder situated in the Delfland control area between Rotterdam and The Hague. The detailed calibrated hydrodynamic model provides daily water discharge and water depth for 137 so-called ditch segments within the Oude Campspolder model for the period 2000-2006.

Figure 8.2 *The Delfland control area is situated between Rotterdam and The Hague. The borders of Oude Campspolder are marked with a red line.*

8.2.1 Model description

The Oude Campspolder model has been parameterised to simulate water quality. The calibrated hydrodynamic model is relatively detailed and provides daily water discharge and water depth for 137 ditch segments, with individual cross-sections, over the period 2000-2006.

This Oude Campspolder encompasses an area of approximately 2 ha. The dominant land use is agriculture, with greenhouse horticulture being the most important agricultural land use. Part of the polder is used as a business park. The polder is located within the municipalities Westland and Midden

Delfland, between Rotterdam and The Hague. The dominant soil texture in the polder is sandy clay. The dominant hydrotypes are the Westland DHC and Westland D profile. The elevation of the polder is between 0.25 m above sea level at the eastern side of the polder to 1.15 m below sea level at the Western side of the polder. The water level in the ditches is maintained approximately at 1 m below soil surface.

Three lateral inlet points at the Northern part of the polder (connected to the Hoefpolder) take in water with an intake volume varying between 0.005 and 0.007 $m^3 s^{-1}$ in summer and 0.001 $m^3 s^{-1}$ in winter. Two other inlet points are situated at the Western side of the polder, with an intake volume of 0.004 and 0.01 $m^3 s^{-1}$ in summer and a discharge of 0.001 $m^3 s^{-1}$ in the winter periods. Water is discharged at the south-eastern side of the polder via two pumping stations.

The SOBEK 1D/2D RR model is a hydrodynamic simulation model that is able to simulate multiple rainfall runoff processes (http://www.deltares.nl/nl/software/108282/sobek-suite/1168708). The model has been parameterised for the period of 1 January 2000 to 31 December 2006. The calculated time step was 5 min. Eight local meteorological stations in and around the polder provided precipitation time series. Evaporation was provided to the model on a daily basis as well as water temperature and solar radiation and is applied to the entire study area. Seepage fluxes were assumed to be negligible. The effects of discharges from greenhouses were modelled using the SOBEK greenhouse module that allows for a specific rainfall collection basin. The model network is shown in Figure 8.3.

The model consists of 137 ditch segments with individual ditch profiles and slopes; the length of each segment varies between 1 and 240 meter. The total length of simulated ditch segments is 13 km. The water volume per unit ditch length (lineic volume) that is exceeded for only 10% of the time, varies between 0.05 and 43 $m^3 m^{-1}$.

The bed slopes of the ditch segments in the Oude Campspolder model varied between -0.001 m m^{-1} and +0.003 m m^{-1}. 89% of the ditch segments had a slope of 0.0 m m^{-1}. Of the total length of ditch segments, 91% has a bed slope of 0.0 m m^{-1}.

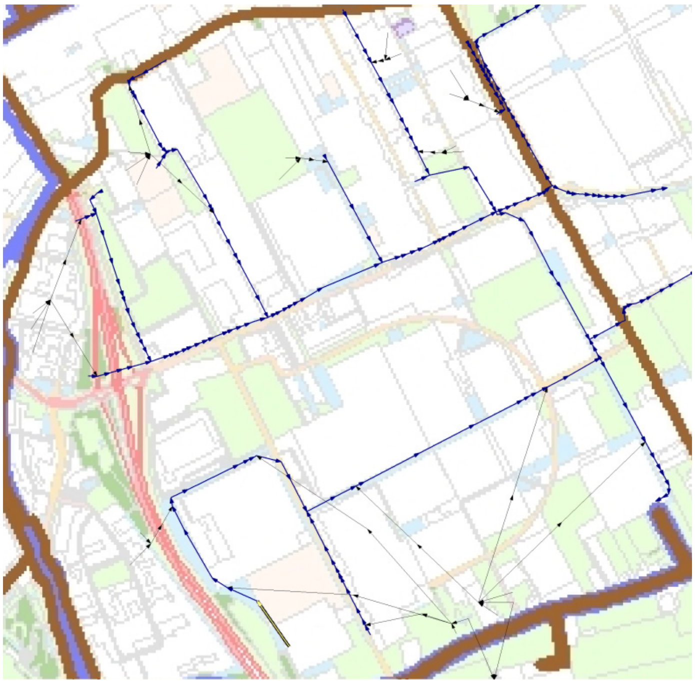

Figure 8.3 *Model schematisation of the Oude Campspolder. The model consists of 137 ditch segments with individual ditch profiles and slopes. The arrows indicate the flow directions.*

8.2.2 Daily velocities

The simulated daily velocities in the model segments are driven by the variable intake volumes and discharge volumes of the polder, precipitation and evapotranspiration. Ditch velocities vary between small negative values up to larger than 10 cm s^{-1}. Figure 8.4 shows a histogram of the simulated velocities (daily averaged values) in the ditch segments of Oude Campspolder. The frequency of occurrence is highest for velocities lower than 0.1 cm s^{-1}. Maximum velocities can be higher than 10 cm s^{-1}. Smaller segments tend to have larger velocities as compared to the overall population of segments. Flow in an opposite direction rarely occurs. The lineic volume of the segments was derived by taking the water depth during the wet situation. This was assumed the water depth that only is exceeded for 10% of the time[8].

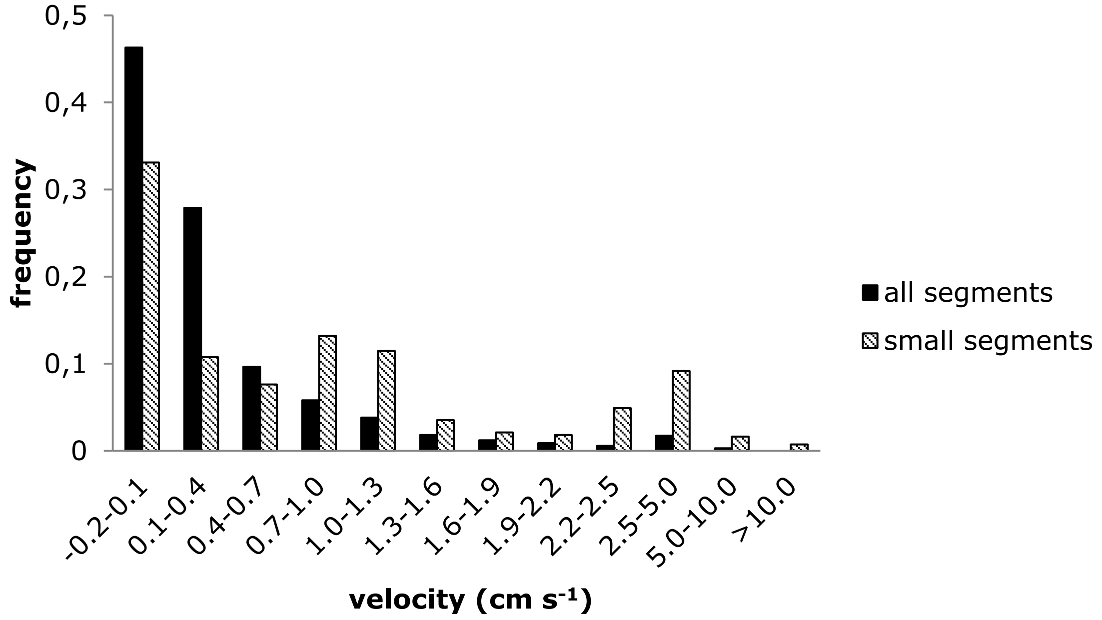

Figure 8.4 *Histogram of simulated daily velocities in all the ditch segments of the Oude Campspolder over the simulated period from 1-January-2000 to 31-December-2006. For all segments (solid) and for segments with a lineic volume smaller than 0.84 m^3 m^{-1} (shaded).*

8.3 Selection of a representative segment

Eight model segments were selected with a lineic volume between 490 and 840 L m^{-1}, while using the water depth that is only exceeded for 10% of the time. The Westland C ditch has a lineic volume of 570 L m^{-1}. In Table 8.1, the lineic volume of each of these segments is provided. For each segment, we assessed whether the velocity distribution was coherent with the overall velocity distribution of the ensemble of ditches and contained a certain variability. Based on a first assessment, two of the selected segments were excluded because they were situated at one of the inlets of the polder and showed mainly constant (forced) fluxes lower than 0.1 cm s^{-1}.

In Figure 8.5, frequency distributions of velocities are shown. Also the frequency distribution of the velocity of the ensemble of selected segments is provided. Segments 4, 5 and 6 show a significant shift towards higher velocities as compared to the other segments. These three segments were

[8] This approach enabled the comparison to the winter wet depths of the Westland C ditch as defined by Massop *et al.* (2006).

considered less conservative, i.e. the low frequency of low velocities (<0.1 cm s^{-1}) lead to a higher chance that the incoming mass flux of PPP is diluted by the (fresh) water flux. Following this rationale, segment 1 was the segment with the highest frequency of low velocities, i.e. the most vulnerable segment of the Oude Campspolder segment population. It is the segment of which the distribution is nearest to the overall distribution of all segments. This segment was selected to provide the daily velocities in the receiving ditch. In Figure 8.6 the discharges of segment 1 over the simulated period, i.e. 1 January 2000 to 31 December 2006. The median discharge is 51 m^3 d^{-1}, the average discharge is 890 m^3 d^{-1}.

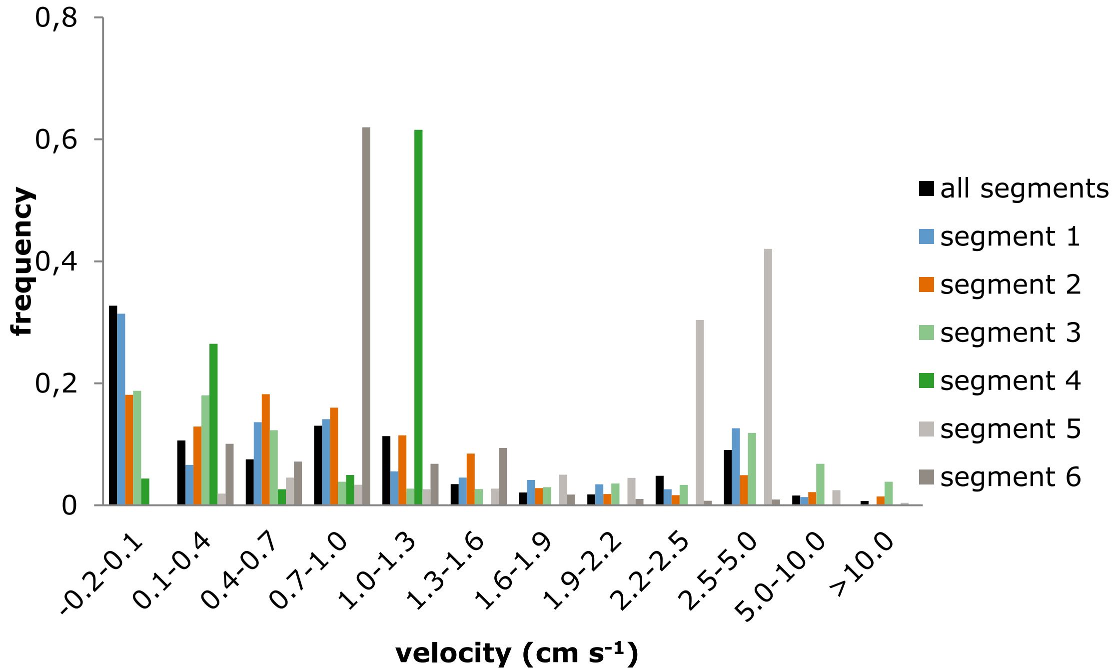

Figure 8.5 *The frequency distribution of velocities in small segments in the Oude Campspolder. 'all segments' refers to the eight iselected segments with a lineic volume between 490 and 840 L* m^{-2}*. The velocities distribution is obtained from the Oude Campspolder model and covers daily velocities between 1 January 2000 and 31 December 2006.*

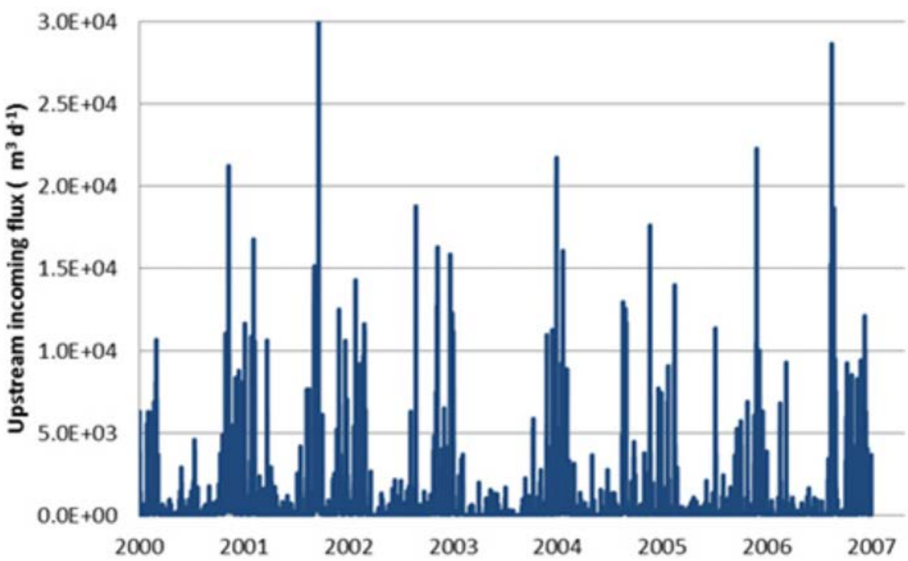

Figure 8.6 *Upstream incoming water fluxes or discharges of segment 1. These fluxes are used in the surface water fate simulation.*

Table 8.1
Lineic volumes of the selected segments.

Segment nr.	Lineic volume (L m^{-2})
1	795
2	575
3	835
4	400
5	590
6	860
7	640
8	490

8.4 Parameterisation of TOXSWA

PPP fate in the water body was simulated with the TOXSWA model (TOXic substances in Surface Waters) (Adriaanse, 1996; Adriaanse and Beltman, 2009). The model has been developed to calculate PPP concentrations in surface water and sediment. Recently, the model has been extended with an option to simulate the formation and fate of parents and metabolites (Adriaanse *et al.*, 2014). The model calculates water fluxes within a ditch, a stream or a pond as well as PPP behaviour in an edge-of -field water body. TOXSWA considers transport, degradation, the formation of transformation products, sorption to sediment and suspended solids and volatilisation. The transformation rates cover the combined effect of hydrolysis, photolysis and biodegradation. Transformation and volatilisation are assumed to be temperature dependent. Sorption to sediment and suspended solids is described by the Freundlich equation.

8.4.1 Conceptual model

We assumed a ditch with a length of 400 m. The ditch dimensions are constant along the ditch and correspond to the characteristics of the Westland C secondary ditch (Figure 8.1). The simulated ditch consisted of a water layer and a sediment layer.

At the lower boundary of the ditch a weir was assumed. The water flux within the ditch was forced via the (time-varying) external upstream water flux from Section 8.3, given as an upper boundary condition to the model. No external discharge was considered from external fields draining into the ditch. Precipitation and evaporation were not considered by the model. Water leaves the ditch via the weir, located at the lower boundary of the ditch. The bed-slope over the length of the ditch was assumed to be zero, which is consistent with 91% of the slopes observed in the Oude Campspolder. The non-stationary velocity fluxes within the water body were calculated by solving the water balance over de water body. The discharge-water level relationship (*Q*-*h*) was approximated by assuming that $\partial Q(x,t)/\partial x$ is constant over the length of the ditch, i.e. the water level is constant over the length of the ditch (Van Opheusden *et al.*, 2011).

The applicability of the approximated solution has been assessed by comparing the discharge calculated with the approximation to non-stationary model simulations (Annex 3). The non-stationary model solves the water conservation equation and the momentum conservation equation simultaneously. The assessment revealed that the approximation was sufficient, especially for low flow situations, that are known to be more vulnerable to high concentrations than high flow situations (see further Annex 3).

The discharge from greenhouses to the ditch was simulated as a point source at the upper boundary of the ditch by adding the discharge volume flux to the upstream water flux of the water layer. The PPP mass that is discharged by the greenhouse was simulated as an incoming mass flux at the upper boundary of the ditch. No other sources of PPP were considered. The average incoming flux was 14 m^3 d^{-1}.

In TOXSWA, PPP within the water layer is subject to convective and dispersive transport, volatilisation, degradation, sorption to suspended material and exchange with the sediment layer via diffusion. The substance balance was solved over the first 150 m of evaluation ditch; 100 m for calculation of the Ecotoxicologically Relevant Concentration and 50 m to eliminate the boundary-effect at the lower boundary (at the lower boundary it is assumed that, $\partial c / \partial x = 0$, i.e. dispersion over the lower boundary is neglected).

Exchange with the sediment layer occurred via diffusive transport at the water-sediment interface. The TOXSWA sediment layer has a specific thickness of 10 cm and is characterised by bulk density, porosity and organic matter content. These parameters were assumed to be constant over the sediment layer, i.e. there is no gradient along or perpendicular to the ditch. Within the sediment layer, the PPP concentration could vary along and perpendicular to the length of the ditch due to diffusive transport and adsorption. No exchange of water nor PPP between sediment and groundwater was assumed (Neumann boundary condition).

The area of greenhouses that may discharge towards a ditch depends on the greenhouse density and the total length of ditches that potentially receive discharge from greenhouses. The area of greenhouses and the corresponding ditch length have been studied for six high density greenhouse areas in the Netherlands (see Annex 5). The assessment revealed that for the studied areas there is approximately 100 m of nearby ditch per 1 ha of greenhouses. However, the number of discharge points was unknown. As a best guess it was assumed that there is one discharge point per 100 m of ditch

The working group had no information regarding the treatment of the upstream area of a discharge point. We therefore assumed the upstream area of the ditch to be untreated and the horticultural area of one grower to be 100% treated, so 1 ha of treated crops discharges to the 100 m evaluation ditch.

8.4.2 Weir characteristics

At the upper boundary of the model, a weir is situated. Weir properties consist of the weir width and the height of the weir crest. Conform FOCUS (2001) and the field crop scenario (Tiktak *et al.*, 2012), the width of the weir is set to 50 cm. The height of the weir crest has been calibrated so that the lineic volume that is exceeded only for 10% of the time equals the lineic volume of the Westland C secondary ditch, i.e. 570 L m^{-1}. The calibrated weir crest height for the evaluation ditch was 0.16 m.

8.4.3 Sediment and suspended solid properties

For the sediment and suspended solid properties we used the values as derived for the evaluation ditch for field crops. These are based on a limited dataset and expert opinion. We assumed no macrophytes. We refer for further details to Tiktak *et al.* (2012).

Table 8.2
Sediment and suspended solid characteristics.

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 (-)

8.4.4 Temperature

The TOXSWA model used monthly averaged values of the water temperature in the ditches to calculate the effect of temperature on the rate coefficient of volatilisation and transformation of PPP. 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 weather station ’the Bilt’ as provided by KNMI.

9 Example calculated surface water concentration and comparison to monitoring data

9.1 Example substances

Example calculations were done with four example substances. These substances are frequently used in chrysanthemum. For each of them, surface water exposure concentrations were calculated, while using the selected greenhouse scenario as well as the selected receiving ditch as derived and discussed in the previous chapters. Substances and application schemes are given in Table 9.1. Application schemes were based on the Table of Intended Use. In contrast to open field crops, the link between application timing and crop development stage is not straightforward. The reason is that different crop stages are present in the greenhouse, which are often treated simultaneously when a pest or disease is detected (Section 4.3). This means that the interception fraction can range from 0% for one greenhouse segment to 100% for another segment. For the example calculations, we made the practical assumption that 50% of the applied dose is intercepted by the canopy. This is a conservative estimation as is substantiated in Annex 7. Dissipation from the crop canopy was simulated with the built-in routines of PEARL using the default substance properties described in EFSA (2012), i.e. the dissipation half-life was set to 10 days and the wash-off factor was set to 0.1 mm^{-1}. The substance properties were derived from literature or assessment reports (see for detail Annex 5).

Table 9.1
Example substances applied to chrysanthemum.

Active substance	Application scheme	Metabolites considered
Insecticide 1	1 and 8 May 0.07 kg to the crop canopy with 50% interception	-
Insecticide 2	1 and 8 Sept 0.6 kg applied to the soil surface	Met1_I2, Met2_I2
Fungicide 1	1, 8 and 15 Oct 0.5 kg to the crop canopy with 50% interception	Precursor: F1_prec
Fungicide 2	1 April 16 kg, applied to the soil surface	-

9.2 Predicted exposure concentrations

In Figure 9.1 to 9.3 the concentration dynamics in the ditch are shown for the example substances. The green lines represent the concentration in the ditch over the simulated period 2000 to 2007. The black lines provide the incoming mass from the drains. The concentration dynamics follows the discharge loosely, but it is much more variable over time. The variable upstream inflow adds to the dynamics as it changes the level of dilution and the velocity of outflow of the substance over the downstream boundary of the ditch.

Insecticide 1 has the highest discharged mass, fungicide 1 the lowest. Insecticide 1 e.g. has a half-life in soil of 118 days whereas insecticide 2, fungicide 1 and 2 have a half-life in soil of 4.2 days, 37.4 days and 5.4 days, respectively.

The variability over the simulated years is moderate. The ratio between the highest and the lowest annual peak concentration varies between 1.3 for fungicide 2 and 4.3 for insecticide 2.

The Predicted Environmental Concentration (PEC) is the 90th temporal percentile of the annual peak concentration in water. Values are given in Table 9.2. Concentrations in drainage water are added for reference. Although the ditch adds variability, the calculated peaks appear to be not sensitive to the ditch dynamics in the sense that the peaks in the drainage water follow the same trend as the concentration peaks in the ditch. In Table 9.2 also PECs based on the current Dutch registration procedure are provided. According to the current Dutch registration procedure for PPPs used in greenhouses (both soil-bound and soilless crops), a deposition value to surface water is considered of 0.1% of the dose rate (Linders and Jager, 1997). This value of 0.1% of the dose is similar to drift deposition for open field crops. The 0.1% of the dose rate is input to the TOXSWA model as deposition to the standard TOXSWA ditch. According to the current registration procedure, only the spring scenario of TOXSWA is used for calculation for glasshouse uses, which is a conservative approach (Ctgb, 2014).

The PECs calculated with the new scenarios are considerably lower than those calculated with the current scenario. The current PEC is 4 to 1000 times higher. The question arises whether the PECs calculated with the newly derived scenarios are conservative enough. Therefore, the new PECs were compared to observed concentrations in Dutch water courses. This is described in the next section.

Table 9.2
PEC of the example substances according to the new scenarios, the corresponding drain water concentration and the PEC according to the current assessment procedure.

	Insecticide 1	Insecticide 2	Met1-I2	Fungicide 1	Fungicide 2
90th percentile concentration new scenario (ug/L)	0.015	$3.0\ 10^{-6}$	0.0016	0.0045	0.007
Corresponding concentration in drain water (ug/L)	0.017	$5.8\ 10^{-6}$	-	0.0049	0.008
90th percentile concentration current scenario (ug/L)	0.066	0.413	0.103	0.681	7.45

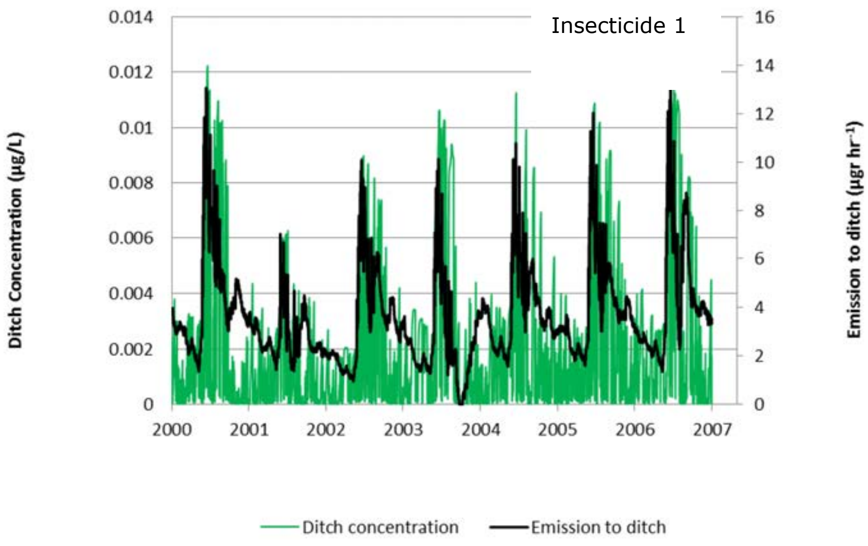

Figure 9.1 *Emission to the ditch (black line) and ditch concentration averaged over 100 m (green line) of insecticide 1over the simulated period, i.e. 2000-2007.*

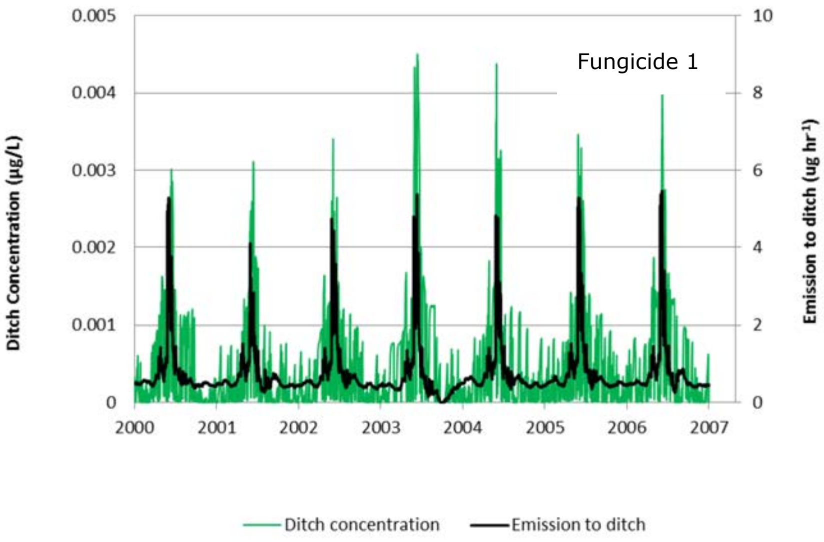

Figure 9.2 *Emission to the ditch (black line) and ditch concentration averaged over 100 m (green line) of fungicide 1 over the simulated period, i.e. 2000-2007.*

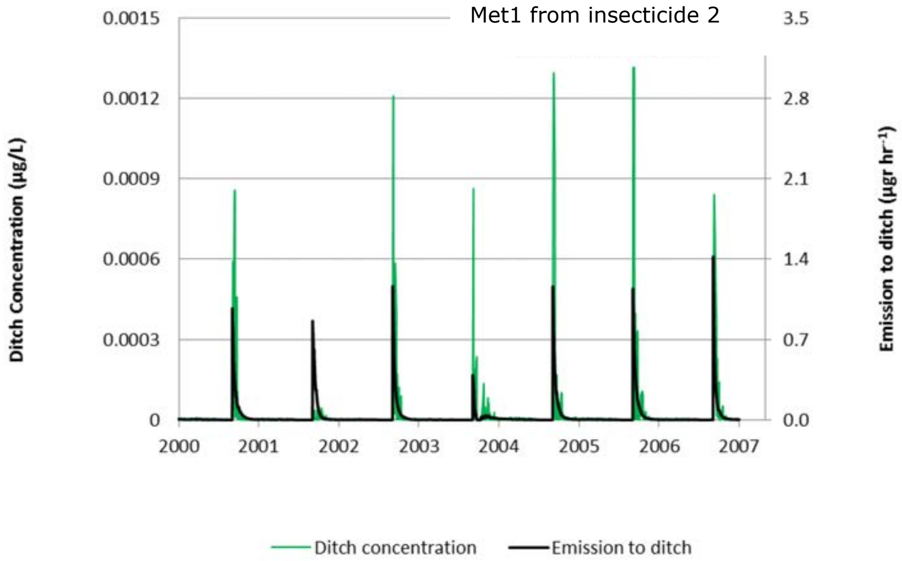

Figure 9.3 *Emission to the ditch (black line) and ditch concentration averaged over 100 m (green line) of the metabolite of insecticide 2 over the simulated period, i.e. 2000-2007.*

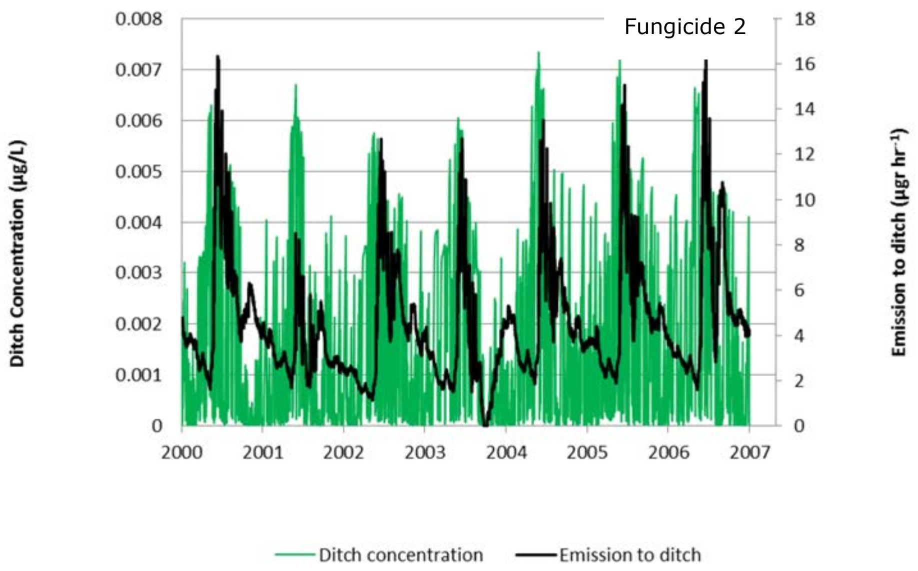

Figure 9.4 *Emission to the ditch (black line) and ditch concentration averaged over 100 m (green line) of fungicide 2 over the simulated period, i.e. 2000-2007.*

9.3 Comparison to monitoring data

In the Netherlands, soil-bound cultivation and soilless cultivation co-exists mostly within one catchment. Therefore, monitoring data that can be assigned to PPP use in soil-bound crops only, are scarce.
Monitoring data was obtained from the water board 'Rivierenland' over the period 2009-2012. The list of monitoring concentrations is given in Annex 6. Greenhouses in the managed area of Rivierenland are known to grow soil-bound crops, e.g. chrysanthemum, lily, and freesia. Monitoring data was obtained from four monitoring points, of which the upstream area was covered with greenhouses for more than 80% (personal communication Water board Rivierenland). Then, the CBS Agricultural Geographical Information database (GIAB, Naeff and Smidt, 2009) was consulted to identify the crops that were grown in the greenhouses. This resulted in a percentage of soil-bound cultivation for each monitoring location as provided in Table 9.3.

Table 9.3
Upstream catchment area, percentage of greenhouses and percentage soil-bound cultivation for each of the selected monitoring locations.

Monitoring location	Catchment area (ha)	Percentage greenhouse	Percentage soil-bound
A	12	80%	90%, 10% unknown
B	50	85%	65%, 35% unknown
C	7	85%	45%, 65% unknown
D	50	65%	100%

We compared the monitoring concentrations with the PECs according to the new scenarios in Table 9.4. In total 6 to 12 measurements were available per substance and per location. Given that the simulated PECs represent the 90th percentile peak concentration, the measured concentrations were expected to be lower than the PECs. However, in all monitoring locations and for all substances, the model predictions were lower than the measured values. In three cases, the model predictions were below the detection limit of the respective substance. For these substances and for measurements with concentrations below the detection limit, the correspondence between the measurements and the simulations remains unknown.

For insecticide 1, 27 of the 36 measured concentrations were above the calculated concentration. This PPP is applied to a wide range of crops. Hence, the measured concentrations cannot be attributed to soil-bound cultivated crops only. For insecticide 2, all concentrations were either above the calculated concentration or below the detection limit. Fungicide 1 had concentrations above the calculated concentration in 1 monitoring location only; all other concentrations were below the detection limit. Also for Insecticide 2 and Fungicide 1 the monitoring concentrations cannot be attributed to soil-bound crop only. Fungicide 2, is the only substance that can to a large extent be attributed to soil grown crops. Of this PPP all available concentrations were higher than the corresponding PEC or below the detection limit. Fungicide 2 is mainly used in chrysanthemum and other cut flowers. 54% of this PPP is used on Chrysanthemum and 75% of all emissions to surface water are due to use in soil-bound cultivation crops (Vijver *et al.*, 2006). Other crops are flower bulbs and lettuce. For this substance 33% up to 90% of the measurements were above the new PEC. Hence, comparison to monitoring data of Fungicide 2 suggest that the calculated concentrations of the new scenario are too low as compared to monitoring data.

Table 9.4
Comparison of calculated and measured concentration data for the example substances. Monitoring concentrations are given in Annex 6.

		Concentrations above the calculated concentration**			
	Monitoring location	A	B	C	D
	Available data	7	11	12	6
substance	Calculated concentration (µg/L)				
Insecticide 1	0.015	3 (43%)	11 (100%)	8 (67%)	5 (83%)
Insecticide 2	3.0 e^{-6*}	3 (43%)	5 (45%)	5 (41%)	2 (33%)
Fungicide 1	0.0045*	0 (0%)	0 (0%)	2 (16%)	0 (0%)
Fungicide 2	0.007*	5 (71%)	10 (90%)	4 (33%)	5 (83%)

* Below the detection limit.

** Concentration that are below the detection limit are considered to be below the calculated concentration.

9.4 Appropriate substance properties

To investigate the mechanism behind the low PECs, the applied substance properties were reconsidered. The PEC is known to be sensitive to substance properties, especially half-life (*DegT50*) and sorption coefficient (K_{om}). These are generally measured in the lab; the geomean value is used in the exposure calculations. Soils used in the lab studies are soils with standard properties (OECD 307, 2002).

A first hypothesis was that the geomean values of substance properties are not representative for the Rivierenland region. To assess this hypothesis, calculations were performed for fungicide 2 with conservative estimates of the substance properties, i.e. a 90th percentile *DegT50* in soil and a 10th percentile Kom in soil and sediment. These values were based on four *Kom* and *DegT50* measurements in the dossier; the *DegT50* increased from 5.4 days to 17 days and Kom decreased from 2099 L/kg to 580 L/kg. Also the dose was made more conservative, in the sense that it was set equal to the advised dose. The applied dose of fungicide 2 was increased from 16 kg/ha to 20 kg/ha. An overview of the calculated concentrations is provided in Table 9.5. Also the highest monitoring concentrations are given for reference. Measured concentrations were still above the calculated concentrations.

A second hypothesis was that substance properties measured in greenhouse soils differ from those measured in field soils. In greenhouses, soils are generally enriched with organic matter and sterilised. The sterilisation affects the available microbial population and hence it is probable that it affects biological degradation rates as well. Moreover, the redox conditions will be changed by steam sterilisation, as the reduction potential will increase. Few studies are available that quantify the degradation and sorption conditions in greenhouse soils. To assess hypothesis 2, substance properties measured in greenhouse soils were sought in scientific literature. Only Matser *et al.* (1996) quantified half-lives in greenhouses for amongst other PPPs, fungicide 2. These measurements provide an indication of possible fungicide 2 degradation rates. Derived *DegT50* values were 142 d, 178 d, 115 d and 46 d for sandy clay soil, clay soil, sandy soil and peat soil, respectively. These *DegT50* values are considerably higher than those from the lab studies. A third calculation was performed with the geomean of these measured values, being 107.5 days. The so-obtained PEC was above the monitoring concentrations, but in the same order of magnitude as the highest measured concentration.

The recalculations of the PEC with DegT50's measured in greenhouse soils, suggest that the newly developed scenarios should be used in combination with substance properties measured in greenhouse soils. More research is needed to underpin this hypothesis.

Table 9.5

The effect of substance properties of fungicide 2 on the PEC and comparison to monitoring data.

case		*DegT50* (d)	K_{om} (L/kg)	Surface water concentration of fungicide 2 (µg/L)		Ratio measured /calculated in case 2
1	Geomean, 16 kg applied (as on the label)	5.4	2099	0.007		-
2	90th percentile DegT50 and 10th percentile Kom, 20 kg applied	17	580	0.277		-
3	DegT50 from Matser *et al.* (2006) and 10th percentile Kom, 20 kg applied	107.5	580	2.466		
	Measured concentration above case 2 (13%).			0.31	(4 Sept. 2012, location A)	1.1
				1.7	(24 March 2009, location B)	6.1
				0.81	(8 Sept. 2009, location B)	2.9
				0.82	(2 May 2012, location B)	2.9
				0.8	(10 July 2013, location B)	2.9

10 Proposal for a tiered assessment scheme

10.1 Surface water

We propose to use the greenhouse scenario in this report as part of the tiered assessment scheme presented in Figure 10.1. The scenario is Tier 2 in this scheme, in combination with conservative assumptions shown in the Tier 2 box, which can be refined in Tier 3 and Tier 4. Tier 3 contains options that use still the same scenario but with refined inputs. Tier 4 contains options based on a different scenario. Notice that the structure of the tiered assessment scheme is the same as that for field crops as presented in Tiktak *et al.* (2012). In Tier 4 specific crop management conditions may be used. This can be for instance a specific application techniques (low volume, fogging), specific treatment of certain cropping stages (i.e. young plants, full grown crop). Also improved irrigation strategies for reducing leaching (i.e models, lysimeters, soil moisture sensors) may be used.

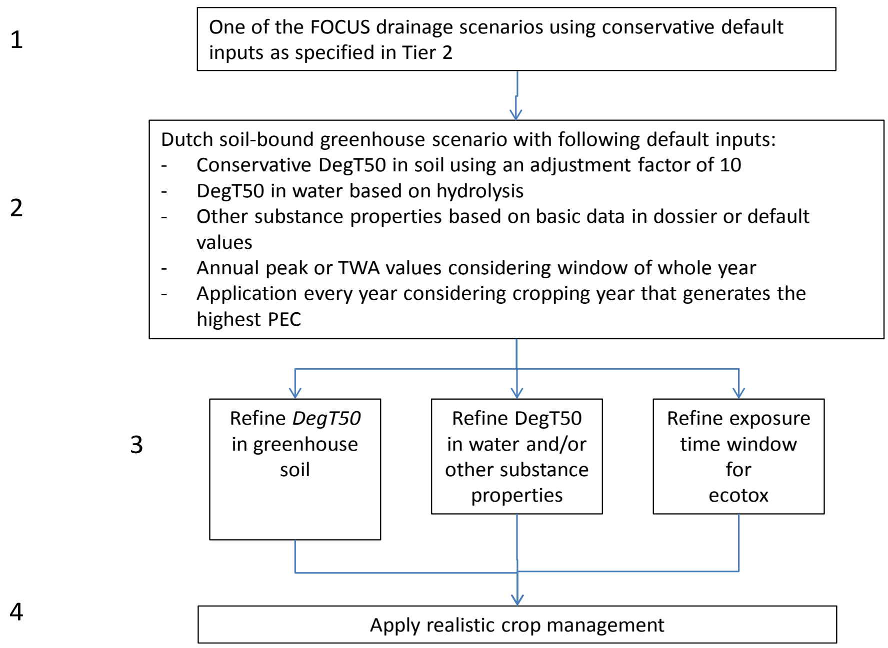

Figure 10.1 *Proposed tiered assessment scheme for the exposure assessment of aquatic organisms in the Dutch pesticide authorisation procedure. The flow chart applies to both peak concentrations and to TWA concentrations.*

As described before, degradation is likely to be lower in greenhouse soils resulting from the excessive sterilisation of these soils. The first conservative assumption is therefore to correct available degradation half-life in the substance dossier half-life for this difference by applying a default adjustment factor. This factor should preferably be derived from a series of degradation studies with both open field soils and greenhouse soils. As long as such studies are not available, we propose multiplying the degradation half-lives obtained from open field soils by a default factor of 10 (this factor is a conservative estimate derived from Matser *et al.*, 1996). Tier 3 offers the possibility to submit degradation studies with greenhouses soils.

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 waters (Boesten *et al.*, 2014). In Tier 3, this conservative approach can be refined following procedures described by Boesten *et al.* (2014). 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 also offers the possibility to use higher-tier option for other substance properties such as long-term sorption kinetics (see FOCUS, 2009 for guidance on the assessment of these kinetic parameters and also for refinement of other substance parameters).

The third conservative assumption is that in the case of 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 fourth conservative assumption is that the whole calendar year is used for assessing the annual peak concentration or the annual maximum TWA value. This is a 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 or summer) if this can be justified on the basis of ecotoxicological considerations.

The scenario is based on simulations for chrysanthemums. This can be refined by developing a crop-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 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 consider 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 scenario in combination with (i) the same *DegT50* in soil as used in Tier 2 and (ii) the same *DegT50* in water as used in Tier 2. The scenario has not yet been selected from the list D1 to D6. We recommend basing selection on the basis of calculation with a range of model substances for the Tier 2 scenario and a few suitable FOCUS drainage scenarios. To reduce work load for applicants and evaluators, we recommend basing Tier 1 on the same FOCUS scenario as selected for open field crops.

10.2 Groundwater

FOCUS Kremsmünster is proposed to be used as a first tier, the greenhouse scenario as the second tier. As degradation is likely to be lower in greenhouse soils, again a conservative assumption is to correct available degradation half-lives in the substance dossier by applying a default adjustment factor, while using the same value of 10 as for surface water. Higher tiers may offer the possibility to submit degradation studies with greenhouses soils. To ensure consistency, we propose to use both scenarios in combination with the same half-life in soil.

To show the effect of using the adjustment factor for the half-life in soil, 90th percentile concentrations were calculated with Kremsmünster -winter cereals and with the greenhouse scenario. Results are shown in Table 10.1

Table 10.1

90^{th} percentile concentrations of the FOCUS substances A to D for the Kremsmünster – winter cereals scenario (field crops) and greenhouse scenario for groundwater.

Substance name	90^{th} overall percentile leaching concentration (μg/L)	
	Kremsmünster-winter cereals	Greenhouses-chrysanthemum
FOCUS A	143.66	17.36
FOCUS B	147.7	32.34
FOCUS C-metabolite	96.51	40.95
FOCUS D	95.9	2.96

11 Conclusions and recommendations

As part of the Dutch authorisation procedure for plant protection products, an assessment of their effects on aquatic organisms in surface water near greenhouses is required. This in turn requires an exposure assessment for these surface waters. In the current Dutch authorisation procedure, input from greenhouses is treated in the same way as spray drift deposition. This is not scientifically defensible. For this reason, the exposure assessment methodology for greenhouses needed revision.

In greenhouses, crops can be grown in soil or on substrate. Both cultivation types require a different exposure assessment methodology. This report describes a new exposure scenario for soil-bound crops, which is based on state-of-the-art knowledge of greenhouse systems and soil-bound cultivation practices. The exposure scenario for substrate cultivation is described in Van der Linden *et al.* (2015). The exposure scenario described in this report corresponds to the 90th spatio-temporal percentile of the annual maximum concentration in all ditches that potentially receive input from soil-bound greenhouses. 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.

The remit of the working group was to develop one scenario, independent of the crop grown. For scenario development, the working group had to choose a crop. We selected chrysanthemum since this is the major soil-bound crop grown in greenhouses. Moreover, chrysanthemum has a relatively high irrigation surplus compared to other soil-bound crops and can therefore be considered conservative (This was confirmed in later simulations).

The main purpose of this study was to derive exposure scenarios for surface water. In addition, groundwater leaching scenarios were derived. Conform the Dutch decision tree for leaching, the endpoint of the leaching assessment was the 90th overall percentile. Conclusions regarding the scenario selection, parameterisation and validation for surface water are provided in Section 11.1 to 11.3. In Section 11.4 conclusions are drawn regarding the groundwater leaching scenario. The chapter ends with a number of identified uncertainties and the use of the scenarios in a tiered approach (Section 11.5-11.7).

11.1 Scenario selection

The endpoint of the exposure assessment should be the 90th overall percentile of the annual maximum concentration in all ditches that potentially receive input from soil-bound greenhouses. This implies that the concentration distribution in all relevant ditches has to be simulated first. In contrast to open field crops, only limited data is available for greenhouse crops. For this reason, we used a pragmatic approach in which we classified the greenhouses into a limited number of categories based on soil type and hydrological situation. For each of these categories a representative greenhouse was selected and a simulation was carried out with a suite of models to get the exposure concentration for this representative greenhouse. The concentration distribution was obtained by weighing according to the area of each category and the exposure scenario was selected from this distribution.

Based on soil-texture, eight different soil types were distinguished ranging from sandy soils to heavy clay soils. The number of hydrological classes was six. These classes were based on the local hydrological situation. Greenhouses situated in regions with shallow groundwater are generally tile-drained and excess irrigation water is primarily discharged into the neighbouring surface water. In regions with deep groundwater tables, no artificial drains are present and most of the irrigation excess is routed into the groundwater. The total number of categories is 6x8=48; however, we only considered those categories that represented at least 3% of the total area of soil-bound crops (i.e. 12 categories).

For each of the 12 selected categories, an existing and representative greenhouse was selected. For these greenhouses, simulations were done to calculate daily irrigation, evapotranspiration and temperatures. This was done with the greenhouse models WATERSTROMEN (Dutch for WATERFLOWS) and KASPRO. Groundwater levels were obtained from the Dutch Hydrological instrument (NHI). The so-obtained climatic data and groundwater data were used as boundary conditions for the pesticide fate model PEARL. We used the recently developed preferential flow version of this model since some of the greenhouses were on heavy clay soils. Soil properties were derived from generally available data sources and pedotransfer functions. The only exception was the top 30 cm of the soil, where we used data derived from measurements in greenhouses. This was important, since greenhouse soils are generally enriched with organic matter. PEARL was linked to a metamodel of TOXSWA to calculate PPP concentrations in the neighbouring ditch.

The selected greenhouse should be sufficiently conservative for all relevant substances, so we created frequency distributions for six theoretical substances. Only one greenhouse delivered surface water concentrations above the 90th overall percentile for all these substances. This greenhouse is situated in the Western part of the Netherlands. The soil type is heavy clay and the groundwater level is generally between 80 cm and 120 cm. This implies that excess irrigation water is routed to either the surface water or the groundwater, depending on the groundwater level at the time of discharge. The neighbouring ditch has a lineic volume of 0.57 m^3 m^{-1} and a water depth at the wet winter situation of 0.26 m ('Westland C' ditch). After selecting a greenhouse, also the weather year had to be selected. The simulations revealed that only the 90th percentile of the weather series assured delivering concentrations above the 90th overall percentile for all six substances.

11.2 Scenario parameterisation

In the next step, realistic flow conditions for the pesticide fate model TOXSWA had to be assigned to the selected ditch. A slightly modified version of TOXSWA was used, which can deal with discharge from greenhouses. This was necessary, since discharge from greenhouses is a point source rather than a non-point source as is the case for spray drift deposition.

Flow conditions are routinely simulated by Dutch water boards for flood prediction using the rainfall-runoff model SOBEK. To get flow conditions for TOXSWA, we used a SOBEK model for a polder with many greenhouses. From this polder model, a ditch was selected with the same properties as the scenario ditch and flow conditions were introduced into TOXSWA.

Sediment and suspended solids characteristics were chosen similar to the field crop ditch as for the open field scenarios. These characteristics are based on a limited dataset and expert opinion. As the water concentration in the ditch is known to be sensitive to organic matter content, we recommend performing an extended survey in Dutch ditches to better parameterise the sediment and suspended solids properties. The length of the simulated ditch was 400 m. The concentration was evaluated over the first 100 m downstream of the discharge point. The discharge point discharges the drainage water of 1 ha. No upstream treatment was assumed.

11.3 Validation of the new exposure scenario

Example calculations were done with four example substances. For the purpose of our simulations, substance properties were taken from standard assessment reports. The simulated peak concentrations in surface water were first compared to the peak concentrations in surface water using the current exposure assessment procedure, which comes down to assuming a drift input of 0.1% of the dosage. This comparison revealed that the newly simulated concentrations were up to several orders of magnitudes lower than the concentration resulting from the current exposure assessment. Simulation results were then compared to concentrations derived from monitoring points in surface water adjacent to greenhouses growing soil-bound crops. Also here, the newly simulated concentrations were in most cases considerably lower than the monitored values.

The low simulated concentrations can be explained by the high organic matter content of the topsoil in greenhouses, which considerably reduces leaching, even when macropores are present. Furthermore, the higher temperature in greenhouses enhances degradation and hence reduces leaching. To the best of our knowledge, these factors have been well accounted for in the model, so these factors cannot explain the underestimation of the observed concentrations.

A factor that might explain the underestimation is that degradation of substances in greenhouses is lower as compared to open field soils. Greenhouse soils are sterilised each year using steam or chemicals. This is likely to negatively affect the biological population. So we carried out a sensitivity analysis for the degradation half-life. First, we replaced the geomean *DegT50* from the dossier by the 90^{th} percentile of *DegT50* values in the dossier. Although the simulated concentration increased, this was not enough. We therefore searched the literature for degradation data in greenhouse soils. The limited data available showed longer half-lives in greenhouse soils. Using these half-lives resulted in exposure concentrations that are close to the monitored data and therefore confirmed our hypothesis that using open field degradation half-lives in combination with the newly developed scenario is questionable.

11.4 Groundwater leaching assessment

Although the main purpose of the study was to derive a new exposure scenario for aquatic organisms, the working group also derived a groundwater leaching scenario. Conform the Dutch decision tree for leaching to groundwater, the endpoint of the leaching assessment is the 90^{th} overall percentile in combination with a 90^{th} weather year. A greenhouse in the Eastern part of the Netherlands was selected. The greenhouse is situated on a light sandy clay soil with deep groundwater tables. For this greenhouse, PEARL was parameterised. Simulations with four example substances (FOCUS substances A, B, C and D) showed that the calculated leaching concentrations are considerable lower than for the Kremsmünster scenario, which is used as the first tier in the Dutch decision tree. This is likely to be caused by the more regular pattern of irrigation as compared to natural rainfall, by higher temperatures in greenhouses and by the high organic matter content of the topsoil in greenhouses. Please note that also in the case of groundwater leaching, degradation is likely to be lower as compared to open field soil because of the excessive sterilisation in greenhouse soils.

11.5 Other uncertainties

Section 11.3 showed that differences between degradation half-lives in greenhouses and open-field soils are likely to be an important cause for the underestimation of the simulated concentrations. We therefore recommend carrying out a series of degradation experiments with greenhouse and open-field soils to underpin these assumptions. In addition to this, the working group identified some other issues, which could be resolved.

First, there is uncertainty resulting from the greenhouse soil properties. Soils in greenhouses are generally enriched with organic matter and in some cases also with clay. The dataset from which we derived the greenhouse soil properties was rather small. Since the simulations are extremely sensitive to the organic matter content of the topsoil, we recommend extending this dataset to better underpin the parameterisation of the topsoil in soil-bound greenhouses.

Uncertainty further arises because we estimated the hydrological parameters using pedotransfer functions that were derived for open field soils. It is not yet known whether these pedotransfer functions also apply to greenhouse soils. For instance, the pedotransfer functions for macropore flow in PEARL relate the macropore volume to organic matter content and clay fraction of the topsoil. In greenhouses, this topsoil is enriched with organic matter and clay and is not representative for the entire soil column. Reconsideration of these pedotransfer functions is necessary to reduce uncertainty about leaching in greenhouses.

Irrigation excess in chrysanthemum can range between 20% and 50% depending on grower's practice. In the exposure scenario, a 30% irrigation excess was chosen, being a realistic worst-case assumption. Simulations revealed, however, that the predicted concentrations can be up to 10 times higher with 50% irrigation excess than with 20% irrigation excess. The working group therefore recommends making an additional inventory of irrigation practices and reconsider this choice after these results have become available.

Crops in greenhouses are grown in sections, with each section containing a different crop development stage. This will introduce variability in crop interception and leaching, since both bare soil and full grown crops are present. However, for the purpose of modelling, crop properties were averaged. The working group recommends setting up a study to investigate the effect of this averaging procedure on drainpipe leaching.

11.6 Using the scenarios

The scenarios in this report are restricted to spraying applications. Although some soil fungicides are incorporated into the soil, spraying applications cover the majority of applications in soil-bound crops. In theory, different exposure assessment methodologies would have to be developed for such applications (see e.g. EFSA, 2010). However, the working group does not expect that a different scenario would have been selected for such applications and therefore recommends using the current scenarios also for soil fungicides.

Chrysanthemum has a relatively high irrigation surplus as compared to other soil-bound crops. Since this gives a reasonable worst-case scenario, we recommend using the scenarios as derived for chrysanthemum for applications in all soil-bound crops. Crop-interception and wash-off are, however, crop dependent. We therefore recommend deriving crop specific interception and wash-off tables so that the user can calculate the dosage arriving at the soil and introduce these values directly into the model.

As described before, degradation is likely to be lower in greenhouse soils resulting from the excessive sterilisation of these soils. As a result, using open field degradation half-lives in combination with the newly developed scenario is invalid. We therefore recommend using this scenario preferably in combination with degradation half-lives that are measured in greenhouse soils. As a lower tier approach, multiplication of the degradation half-life with an adjustment factor would be a possibility as well. This adjustment factor should preferably be derived from a series of degradation studies with both open field soils and greenhouse soils.

11.7 Position in tiered approach

The current scenarios are intended to be Tier 2 scenarios. We recommend using this scenario in combination with an adjustment factor for the difference between open field soils and greenhouse soils (see Section 10.6). For the surface water exposure assessment, we propose to develop also a Tier 1 scenario based on one of the FOCUS surface water drainage scenarios. For the groundwater leaching assessment, the working group proposes to use the Kremsmünster scenario as a first tier. These tiers would be in agreement with proposals for open field crops (Tiktak *et al.*, 2012) and the Dutch decision tree for groundwater (Van der Linden *et al.*, 2009). To ensure consistency in the proposed tiered approach, we propose using these scenarios in combination with the same *DegT50* in soil as used in Tier 2 (i.e. including an adjustment factor for the difference between open field soils and greenhouse soils, and – in the case of the surface water exposure assessment – the same *DegT50* in water as used in Tier 2 (see Boesten *et al.* (2014) for details).

In Tier 3, the estimation procedure for both *DegT50* in soil and *DegT50* in water could be refined. The first has a direct impact on drainpipe leaching. The second will affect the decline of the concentrations in surface water (see Tiktak *et al.*, 2012 for details). An appropriate refinement for *DegT50* in soil would be to use *DegT50* values measured in greenhouse soils. Refinements for the estimation of *DegT50* in surface water are described in Boesten *et al.* (2014).

12 Main recommendations

This chapter provides the main recommendations for refining, validating and completing the proposed exposure assessment. Additional recommendations can be found in Chapter 10.

1. **Carry out degradation experiments with greenhouse soils.**
   Degradation in is likely to be lower in greenhouse soils resulting from the excessive sterilisation of these soils. As a result, using half-lives from open field soils in combination with the newly developed scenario is questionable. We therefore recommend deriving an adjustment factor for the difference between greenhouse soils and open field soils. This safety factor should be derived from a series of degradation studies with both open field soils and greenhouse soils for a range of relevant substances. We therefore recommend carrying out these degradation experiments and develop these safety factors.

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 drainage scenarios. We further recommend developing the higher tiers of the proposed assessment scheme. The tiered approach should preferably be in line with the proposed tiered assessment scheme for open field crops. It should be tested whether the proposed tier 1 provides a more conservative estimation than tier 2.

3. **Carry out additional field experiments.**
   The current scenario has been developed using the best available knowledge about greenhouse soils, greenhouse management and leaching. However, currently there is no field experiment available for testing. To increase confidence in the new scenarios, we recommend carrying out a field experiment. Because the decline of the substance concentration in the ditch is important for the effect side of the risk assessment, we recommend measuring also the fate of substance in ditch water.

Acknowledgements

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Model versions used in this report

- WATERSTROMEN model: 5.8
- Kaspro 2012
- PEARL: kernel 3.1.3
- SWAP: 3.2.34
- TOXSWA: 3.3.1 R
- SOBEK: 2.0

List of Abbreviations

CBS	Statistics Netherlands
Ctgb	Board for the authorisation of plant protection products and biocides
EFSA	European Food Safety Authority
ERC	Ecotoxicologically Relevant Type of Concentration
EU	European Union
FOCUS	Forum for Co-ordination of pesticide fate models and their use
GIAB	Statistics Netherlands, agricultural geographical information
KASPRO	Greenhouse Process model
KMNI	Royal Dutch Meteorological Institute
MHW	Mean Highest groundwater level
MLW	Mean Lowest groundwater level
NHI	Dutch Hydrological Instrument
OECD	Organisation for Economic Co-operation and Development
PBL	Netherlands Environmental Assessment Agency
PEARL	Pesticide Emission At Regional and Local Scales
PEC	Predicted Environmental Concentration
PPP	Plant Protection Product
RIVM	National Institute of Public Health and the Environment
TOP10 vector	Digital topographic map of the Netherlands
TOXSWA	Toxic Substances in Water. Model that simulates pesticide fate in surface water
TWA	Time Weighted Average

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Annex 1 Geographical information of soil-bound crops in the Netherlands

Greenhouse horticulture crops in the Netherlands are either grown on substrate or on soil. To obtain geographical information on the areal coverage of soil-bound crops the CBS agricultural geographical information (GIAB) database of 2008 was used. The data in the GIAB database is based on growers information collected in the framework of annual surveys. The database contains the postal address of each grower as well as information on crop type and corresponding area. The percentage of substrate grown crops is provided as well, however, not all of the growers have provided this percentage.

The procedure that was used to derive the areal of soil grown horticulture crops was as follows:

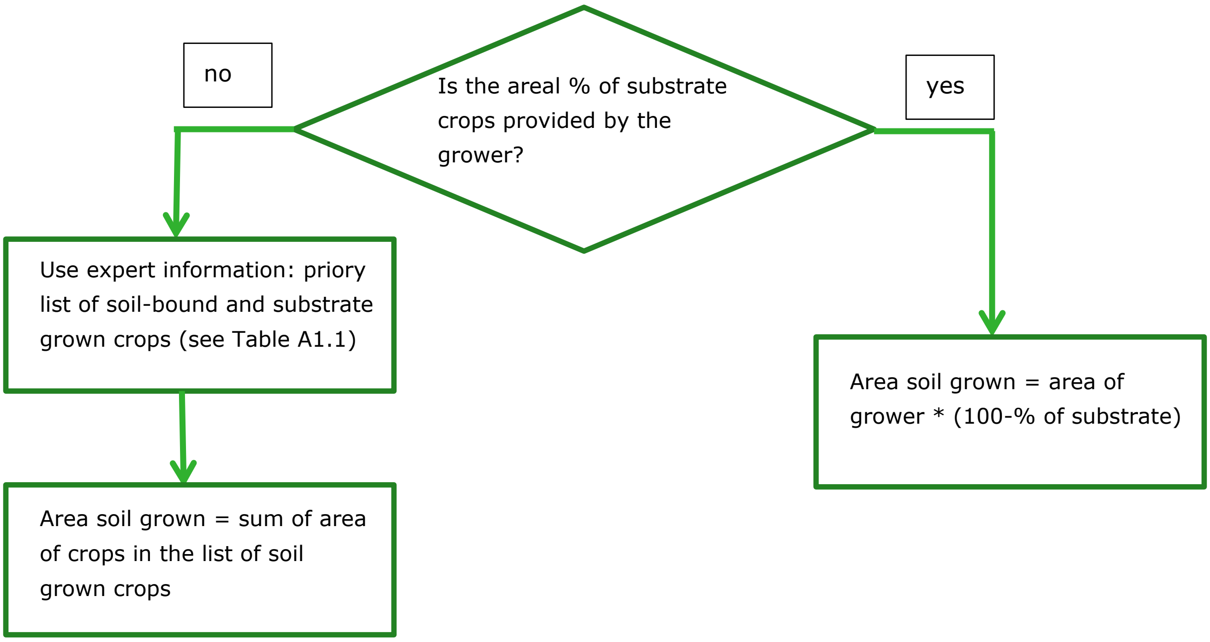

Table A1.1

The division of crops over soil-bound greenhouse horticulture and substrate greenhouse horticulture.

Substrate	Soil-bound
Anthurium (cut flowers)	Alstroemeria (cut flowers)
Aubergines	Amaryllis bulbs
Bedding plants	Chrysanthemum (cut flowers)
Carnations (cut Flowers)	Cut flowers (other)
Cherry-tomatoes	Eustoma russellianum (cut flowers)
Cucumbers	Flower and bulb nursery crops (other)
Flowering pot plants : anthurium	Flower seeds in glasshouses
Flowering pot plants: kalanchoe	Freesias (cut flowers)
Flowering pot plants: other	Fruit in glasshouse
Flowering pot plants: phaleanopsis	Lillies (cut flowers)
Flowering pot plants: spatiphyllum	Starting material flower and bulb nursery crops
Foliage plants: dracaena	Strawberry in plastic tunnels
Foliage plants: ficus	Tree nursery
Foliage plants: other	Tree nursery propagation
Gerberas (cut flowers)	Vegetable seeds in glasshouse
Green sweet pepper	Vegetables (other) incl. melon
Orchids (cut flowers)	
Red pepper	
Rose (cut flowers)	
Starting material vegetables	
Strawberry in glasshouse	
Sweet pepper (other)	
Tomatoes	
Vine tomatoes	
Yellow sweet pepper	

Annex 2 Groundwater table classes in the Netherlands

Groundwater table class maps describe the seasonal fluctuations of the phreatic water levels in the Netherlands. A groundwater table is based on the mean highest (MHW) and the mean lowest water (MLW) table. The mean highest water table is defined as the mean value of the three shallowest groundwater levels measured over 8 years. The mean lowest water table is defined as the mean value of the three deepest groundwater levels measured over 8 years.

The relationship between groundwater table class and mean highest and mean lowest water table is given in the table below:

Groundwater level below soil surface (cm)	Groundwater level class						
	I	II	III	IV	V	VI	VII
MHW	-	-	<40	>40	<40	40-80	>80
MLW	<50	50-80	80-120	80-120	>120	>120	>160

Annex 3 Assessment of approximate solution for ditch hydrology

TOXSWA approximates the non-stationary hydrological situation by solving the water balance while assuming that the traveling waves are negligibly small and the water level is increasing or decreasing over the full length of the ditch (horizontal water level). To validate the approximation the calculated water level and water discharge over the length of the ditch is verified against simulations of a non-stationary model that solves the water conservation equation and the momentum conservation equation simultaneously (Van Opheusden *et al.*, 2011). The latter model is better equipped to predict the development of traveling waves within the ditch and approximates better the non-stationary behaviour in a straight channel. The approximated solution is assumed to deviate further from the non-stationary flow solution in case of large and abrupt changes in the incoming water fluxes at the lower boundary, as the traveling waves may become important to describe the hydrological situation in a ditch.

From the daily varying velocities of the selected segment in the Oude Campspolder, we selected two consecutive days in which the differences in the incoming discharge fluxes (*Q)* at x=0 m between the days were the largest, i.e. one case with an increase in the incoming flux and one case with a decrease in the incoming flux. These two cases were used for the verification exercise by applying the discharge changes at the upper boundary in the model (Table A3.1) similar to the parameterized ditch in Chapter 8, the ditch had a length of 400 m. At the lower boundary a weir was assumed. The slope of the ditch is zero m m^{-1} ditch length. Properties of the weir and the cross-section of the ditch are provided in Section 8.4 of this report.

Table A3.1
Two cases were simulated, Case 1 with a discharge increase and Case 2 with a discharge fall.

	Day 1	Day 2
Case 1	Q = 0.017 m^3 s^{-1}	Q = 0.4012 m^3 s^{-1}
Case 2	Q = 0.4012 m^3 s^{-1}	Q = 0.059 m^3 s^{-1}

Verification of calculated discharges
After a discharge increase or decrease, the velocity fluxes in the ditch change and small waves start to travel over the length of the ditch and dissipate rapidly. In Figure 1, the development of the waves over the length of the ditch is shown as calculated by the non-stationary flow model for Case 1. The lines show the discharges at 1 min, 11 min and 26 min after the increase. The approximation is represented by the dotted lines. For the non-stationary model a number of additional parameters were needed, i.e. the Manning coefficient, assumed to be 25 $m^{1/3}s^{-1}$ and constant along the ditch, and the momentum correction factor, β =1.2. The non-stationary model clearly simulates the development of small waves that dissipate over time, whereas the approximation does not. In less than 10 min, both solutions develop towards the situation in which $dQ(x,t)/dx$ is constant for x = 0 to 400 m. This confirms the validity of the approximation. Initially, $dQ(x,t)/dx$ is less for approximated solution than for the non-stationary solution. The difference between both solutions diminish over time. A stationary state is derived after approximately one hour.

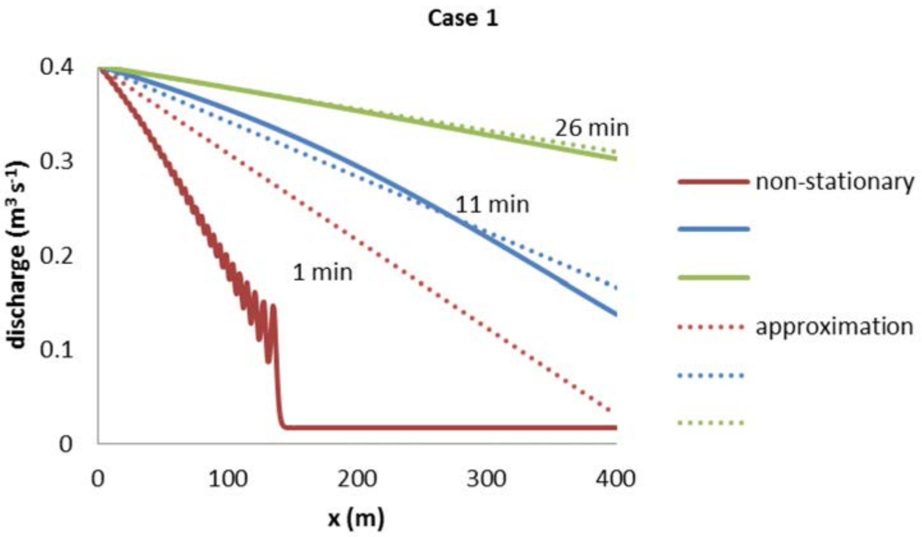

Figure A3.1 *Discharge over the length of the ditch for Case 1 as simulated with the non-stationary model (solid line) and the approximation (dotted line); 1 min, 11 min and 26 min after the change in discharge. X is the location along the ditch. At x = 0 m, the water discharges are given as a boundary condition and at 400 m the weir is located.*

In Figure A3.2, the discharge is given over the weir for Case 1 and 2, respectively. The change in discharge starts at t = 0 hr. The figures show that there is an initial difference between the weir discharge of the non-stationary solution and the approximation in calculated discharge. De difference decreases and after 1 hr the difference is 2.2% and 3.5% of the non-stationary solution, for Case 1 and 2 respectively. This was judged as acceptable.

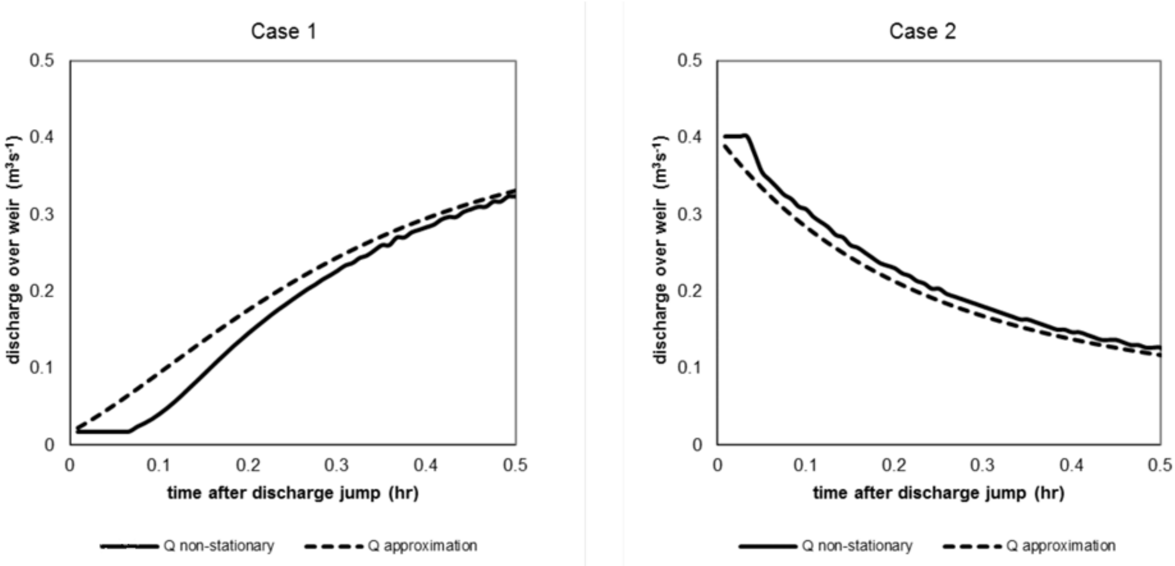

Figure A3.2 *Discharge over the weir for Case 1 and 2 as calculated with the non-stationary model (solid line) and the approximation (dotted line).*

Verification of calculated water levels

In Figure A3.3, the water level over the length of the ditch is projected for a number of water flux velocities at steady state, for v = 0.1 cm s^{-1}, 0.9 cm s^{-1} and 10 cm s^{-1}. For reference, the velocity distribution of the selected and parameterised ditch as discussed in Section 8.4 is given in Figure A3.4.

The black, green and blue colours refer to the water velocities of 0.1 cm s^{-1}, 0.9 cm s^{-1} and 10 cm s^{-1}, respectively. The solid lines refer to the non-stationary flow simulation and the dotted lines refer to the approximation. The solid lines in the figure show that for velocities larger than ca. 1 cm s^{-1}, the water level declines over the length of the ditch. Hence, the assumption of a horizontal water level is not supported. The total volume in the ditch is underestimated by the approximation. The larger the discharge the larger the difference between the non-stationary model and the approximation.

For the intended use of the model in the risk assessment, we judged the calculated deviation as acceptable, i.e. for these large velocities the ditch is no longer vulnerable to PPP emission form the greenhouses. For the low velocities, which represent the vulnerable situation, the approximated solution gives an adequate prediction of the water depth in the ditch. In addition, the approximation gives a conservative approach, since it underestimates the total volume of water in the ditch and therefore overestimates the concentration in the ditch.

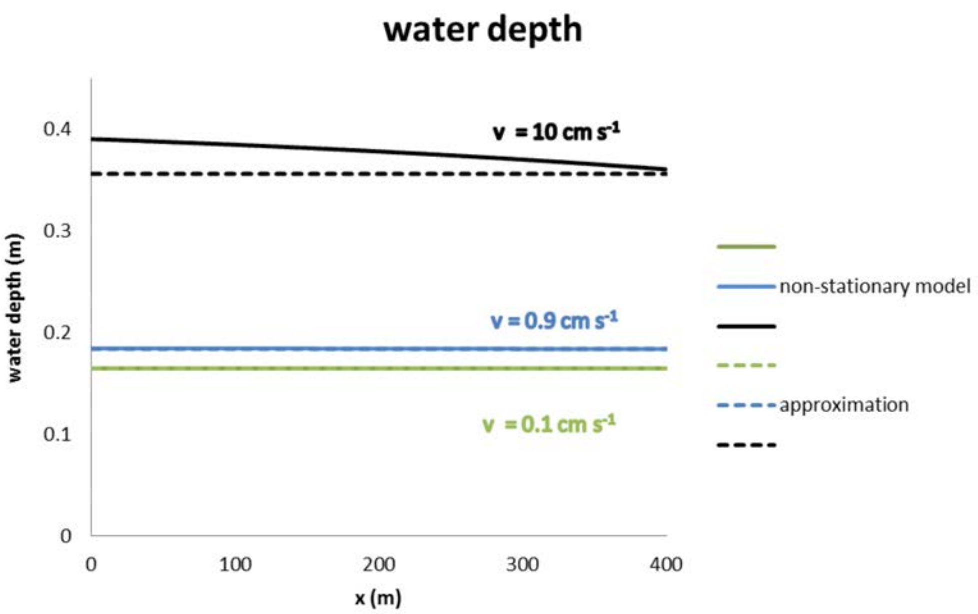

Figure A3.3 *The water depth over the length of the ditch calculated with the full non-stationary model and the approximation. The non-stationary model shows an decline in the direction of the weir. The larger the discharge in the ditch, the steeper the decline. The approximation assumes a constant water level over the length of the ditch.*

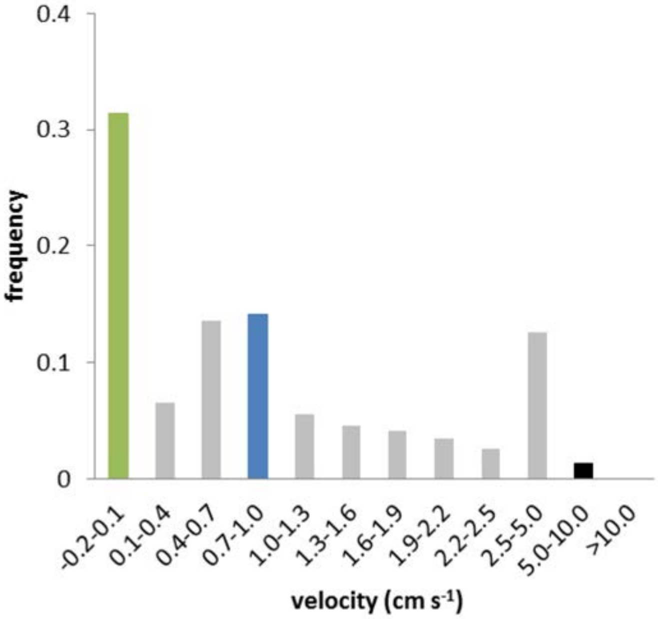

Figure A3.4 *Velocity distribution of the selected and parameterised ditch (see Chapter 8). The green, blue and black columns refer to the water depths as given in Figure A3.3.*

Annex 4 Properties example substances

Four example substances were used in the example simulations. Substance properties were derived from literature or from the list of endpoints (LoEP). Only the relevant substance parameters were assumed to be substance dependent all other parameters were assumed to be substance independent.

These are listed below:

- 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 (2012)
- Depth dependency of degradation in soil as proposed by FOCUS (2000)
- Uptake factor for plants: 0.0 (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 $\times 10^{-4}$ m^2 d^{-1} (FOCUS 2000)
- Reference diffusion coefficient in air: 0.43 m^2 d^{-1} (FOCUS 2000)
- Reference temperatures for diffusion, vapour pressure, water solubility, sorption, transformation rates in soil and water: 20 ^{o}C
- Reference moisture content for degradation: pF 2
- *DegT50* for degradation in sediment: no degradation was assumed, the half-life was set to 1000 d.
- K_{om} for sorption in the sediment and for sorption to suspended solids: the same value as for soil was assumed. See Table A4.1
- Freundlich exponent for sediment: the same value was assumed as for soil
- Half-life for degradation on plant surfaces: 10 d (EFSA, 2012). DegT50 due to penetration: 1000 d.

Table A4.1

Parameters that were assumed to be substance dependent.

	Sub 1 Insecticide 1	Sub 2 Fungicide 1 (precursor)	 Fungicide 1	Sub 3 Insecticide 2	 M03 (Met1_I2)	 M04 (Met2_I2)	Sub 4 Fungicide 2	
		PAR --> met: 1.0 mol/mol		Soil (mol/mol): Water (mol/mol):	PAR --> M03: 0.549 M03 --> M04: 0.293 PAR --> M03: 0.225 M03 --> M04: 0.236			
molar mass (g/mol)	255.7	313.3	299.3	225.3	241.3	184.3	301.1	
pKa	None	none	none	none	none	none	none	
DegT50 in soil at 20°C, pF = 2 in top soil (d)	117.7	1	37.4	2.8	4.22	2.1	5.4	
DegT50 in water at 20°C (d)	83.4	1.3	393	7.5	103.6	48.3	15	
water solubility (mg/L)	613	2	90.1	27	27	27	0.708	In case data were not available the metabolite property was assumed to be the same as the parent
saturated vapour pressure (Pa)	4.00E-10	2.30E-06	2.30E-06	1.50E-05	1.50E-05	1.50E-05	6.77E-4	In case data were not available the metabolite property was assumed to be the same as the parent
Kom,soil (L/kg)	123	178.6	Kom,ac [$]: 714.2	383	18	29.4	2099	
			Kom,base : 13.4					
Freundlich exponent	0.783	0.975	0.94	0.83	1.0	0.83	0.95	

[$] pH dependent sorption has not been considered, i.e. Kom,base is applied for high and as well as low pH's

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Annex 5 Estimation of ditch length per ha greenhouse in the Netherlands

Analysis performed by R. Smidt (Alterra) for the working group.

Introduction
Glasshouses for agricultural use in the Netherlands are spread over the country. Provinces have restricted areas where new glasshouses preferably may be concentrated and existing glasshouses may extend (Figure A5.1). Outside these areas extension of the excisting glasshouses is limited or prohibited.

Many of the glasshouses have surface water nearby. Emission of environmental pollutants, like crop protection products or fertilizers, may occur with the discharge of water to nearby water courses. The objective of the study was to estimate the total length of receiving water bodies as compared to the total area of greenhouses in regions with a high density of greenhouses.

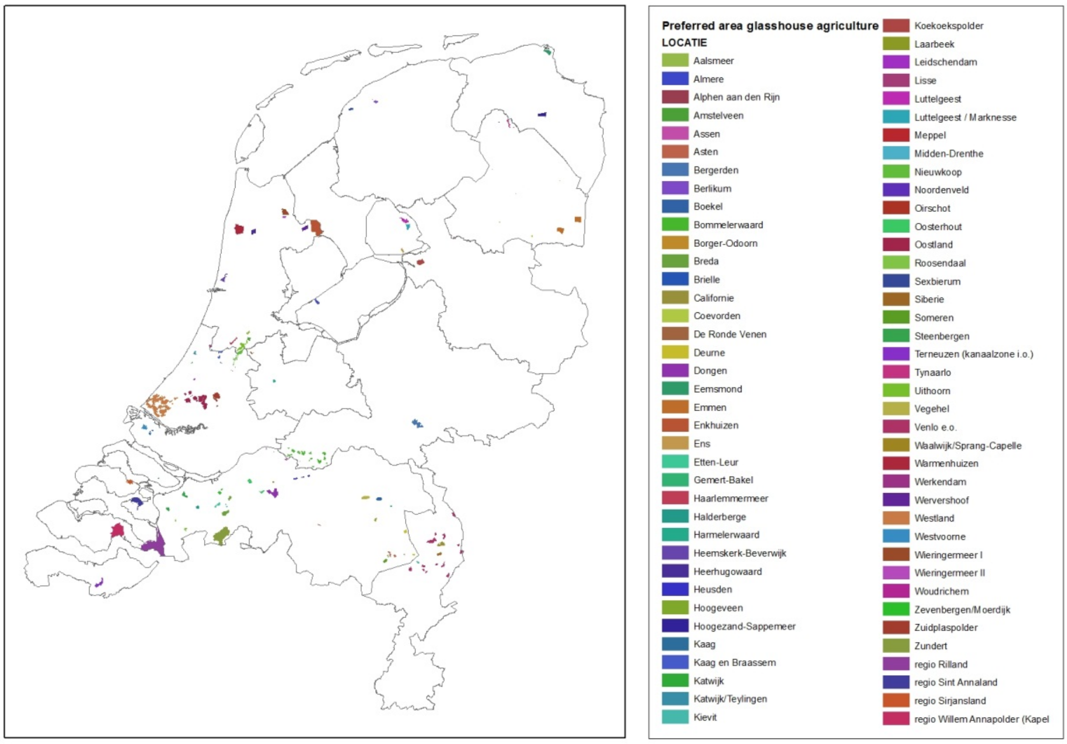

Figure A5.1 *Preferred area for agricultural glasshouse in the Netherlands (LEI/Alterra 2011).*

Materials and Methods
To derive the length of water courses in the neighbourhood of agricultural used glasshouses, the area of glasshouses nearby the agricultural holdings was calculated, followed by the determination of the length of water courses next to greenhouses. The derivation was made geographically in a GIS-system (ArcGIS, Esri, NL).

Three data files were used:
- TOP10NL: a map with the area and geo-location of glasshouses and surface water

- GIAB: a map this (geo-)information of agricultural holdings
- A map with preferred regions for greenhouse horticulture as defined by the Dutch provinces

TOP10NL
TOP10NL is a digital topographical file from the Dutch Cadastre, Land Registry and Mapping Agency, which can be used on a scale level between 1:5,000 and 1:25,000. The TOP10NL data model contains a collection of topographical base objects, at a scale of 1:10,000, which have been included as object classes. Each geographical object has its own unique code and is specified further by means of attributes and attribute values.
- Code 701 glasshouses
- Code 600: drain or small ditch; may be dry for a certain period of a year
- Code 601: ditch smaller than 3 meter (whole year containing water)
- Code 602: ditch 3 – 6 meter wide
- Code 611: surface water wider than 6 meter. Within this code 611 the (interconnected) ditches were selected via the attribute 'Type water' these values were set to 'water course'. The basins, often present in the glasshouse-area, are excluded.

Code 600 to 602 are line elements; code 611 and 701 are polygons. Each part of the topographic map is updated every 4-6 years by the Cadaster.

GIAB
Agricultural holdings are registered by the Dutch Ministry of Economic Affairs, Agriculture and Innovation. They have to take part in the collective data inquiry of the Ministry, which agriculture and horticulture statistics are published by LEI/CBS annually (2011).

In the 'Geographical information system of agricultural holdings' (in Dutch: geografisch informatie systeem agrarische bedrijven called: GIAB), Alterra has geo-referred the holdings to the XY-coordinates of the main building of the holdings, for use in GIS-analysis. In GIAB each holding is linked to a geographical point, the shape and area of the parcels and glasshouses is not available (LEI/CBS). Information on the size of the glasshouse area in use by the holding was used to select the holdings with greenhouse horticulture (under glass). The actualization of the agricultural data is chosen to be 2009 as a compromise between the most recent and best fit with the actualization grade of the topographical data.

Preferred regions of greenhouse horticulture
For this study, regions were selected with a high areal density of glasshouses. High concentration of glasshouses in a close setting (high density) can be found in the provincial preferred regions for concentrating greenhouses and horticulture (Figure A5.1). For this study 6 regions were selected and assumed to be representative for areas with a high concentration of greenhouses, see Figure A5.2:
- Westland
- Oostland
- Zuidplaspolder
- Aalsmeer
- Koekoekspolder (Kampen)
- Bommelerwaard (selection of 3 large regions)

In the following these areas will be referred to as 'study area'.

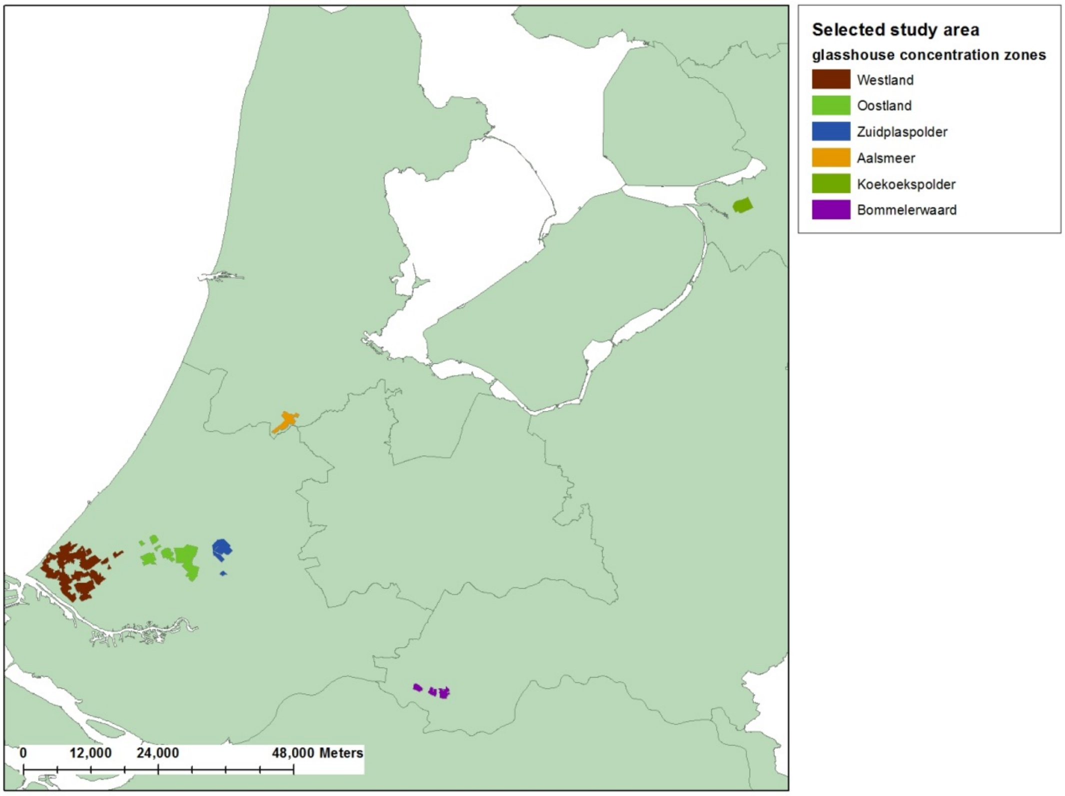

Figure A5.2 *Selected area of preferred regions for greenhouse/ horticulture.*

Methodology
The length of ditches that potentially receive water from greenhouses was determined was determined in three steps:
1. Selection of agriculturally used glasshouses (as compared to glasshouses used for other purposes) out of glasshouses (form TOP10) for the 6 study regions;
2. Derivation of a selection distance for estimating the length of receiving surface water;
3. Selection of surface water influenced by the agricultural glasshouses in the study areas.

Step 1: Selection of agriculturally used glasshouses
In the topographical data of the Top10NL map the shape and location of glasshouses are registered as geographical polygons. Greenhouses of the holdings were assumed to be close to their registered addresses in GIAB. Glasshouses can be either used for agricultural purposes or other purposes. It was assumed that the glasshouses of the Top10NL map that were at X m of distance to the registrated holding addresses were used fort agricultural purposes. The distance was calibrated, such that the area of horticulture glasshouses selected in the topographical data is equal to the area as present in the Agricultural Statistics of the CBS/LEI data (and therefore also in) GIAB. The selection was made on a national scale.

- Total area of glasshouse in Top10NL was 13.464 ha.
- Total area agricultural used glasshouse in GIAB was10.354 ha
- The calibrated distance between glasshouse area and GIAB points was 100 m

Then the total area of glasshouse selected as agricultural used glasshouse was 10.363 ha (= within 100 m from GIAB point).

Figure A5.3 *Aerial photo of a glasshouse region (step 0).*

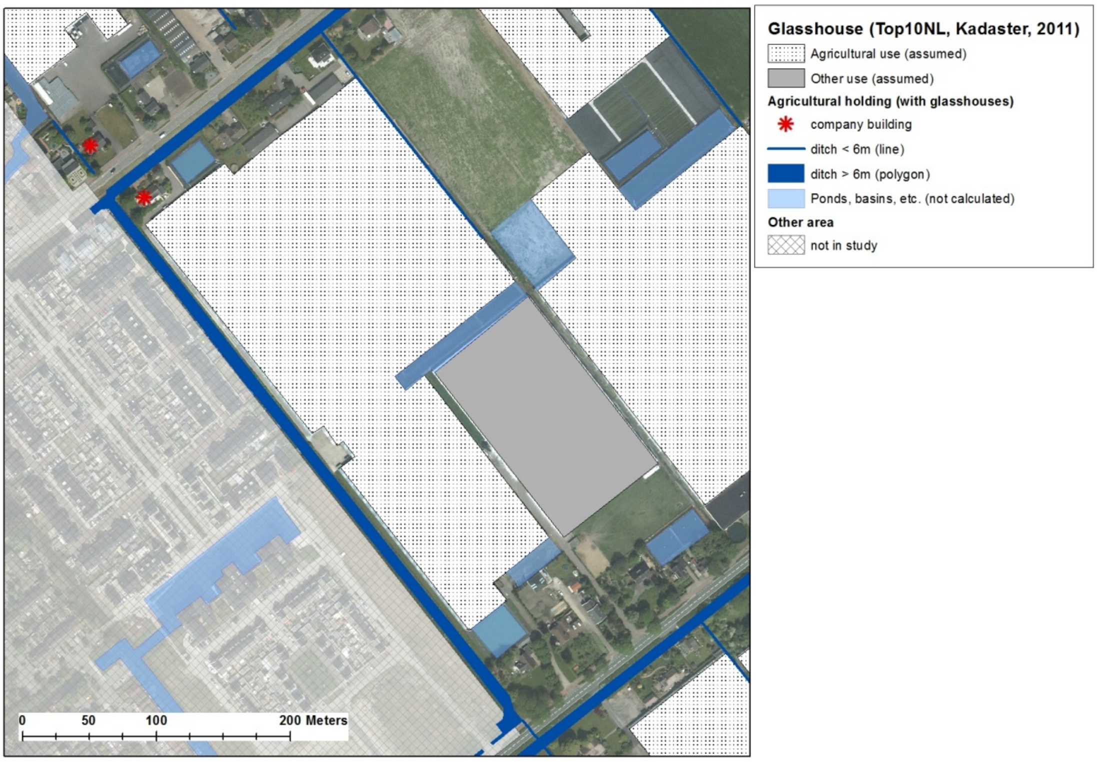

Figure A5.4 *Schematic representation of surface water and greenhouse (step 1).*

In Figure A5.3 and Figure A5.4 an example of the selection of agricultural used glasshouses is given. First a blank aerial picture (Figure A5.3) is shown with the area of interest presented as a clear view and the area outside the study area as double crossed. In Figure A4.4 the GIAB-point of the agriculture holding is shown. Also the selected greenhouse (dotted) and the unselected glasshouses (grey) are presented over the aerial photo. The surface water in the figure is coloured blue. The basins near the greenhouses is indicated as light blue. These water basins are excluded from the surface water system in the calculation.

Step 2: Selection of the potentially receiving ditches: derivation of the maximum distance
For selecting the length of surface water in the direct neighbourhood of glasshouses in the study areas, a maximum distance between the glasshouses and the receiving water courses needed to be defined. An approach was taken at the national scale.

Figure A5.5 shows that, on a national scale, within 10 meters distance nearly all of the possible amount of glasshouses near water is reached. Increasing the selection distance does not add many glasshouses. So, the selection distance for this study is set to 10 meter. In other words, ca. 90% of the glasshouses in the Netherlands are situated within 10 m of distance to surface water.

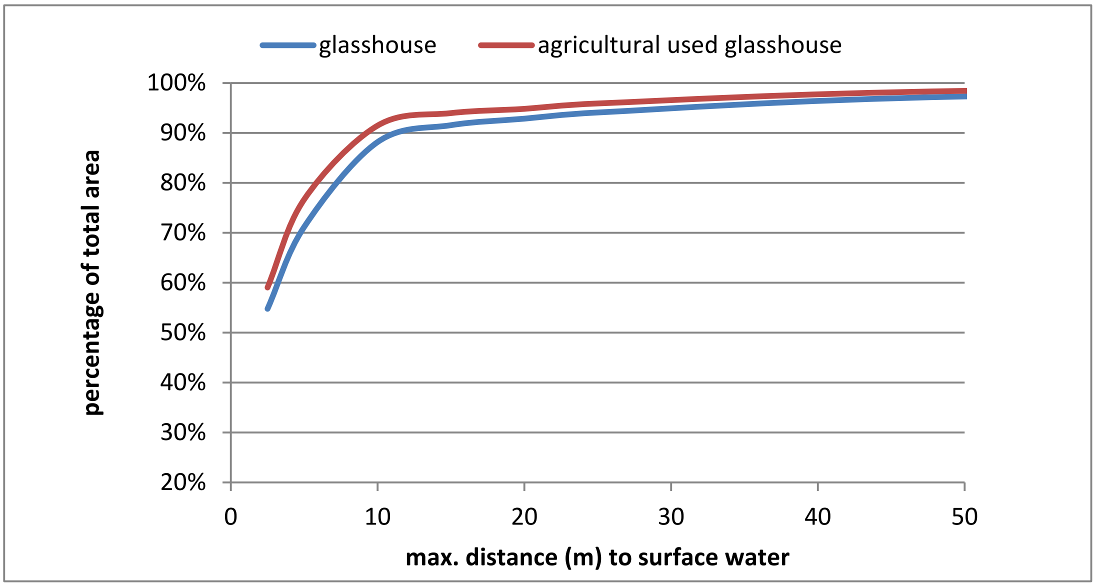

Figure A5.5 *Share of total area (agricultural used) glasshouse at a given distance from surface water (Focussed area: the Netherlands).*

Step 3: Selection of surface water influenced by the agricultural used glasshouses in the study areas
In the example as presented in Figure A5.3 and A5.4 the distance factor of 10 m is applied in the GIS-analysis and the results are shown in **Figure A5.**6. All surface water is expressed in length of ditch. In case of the polygon-shaped larger ditches (Top10NL code 611), the lengths of the selected part of the ditch was calculated as being only half of the perimeter.

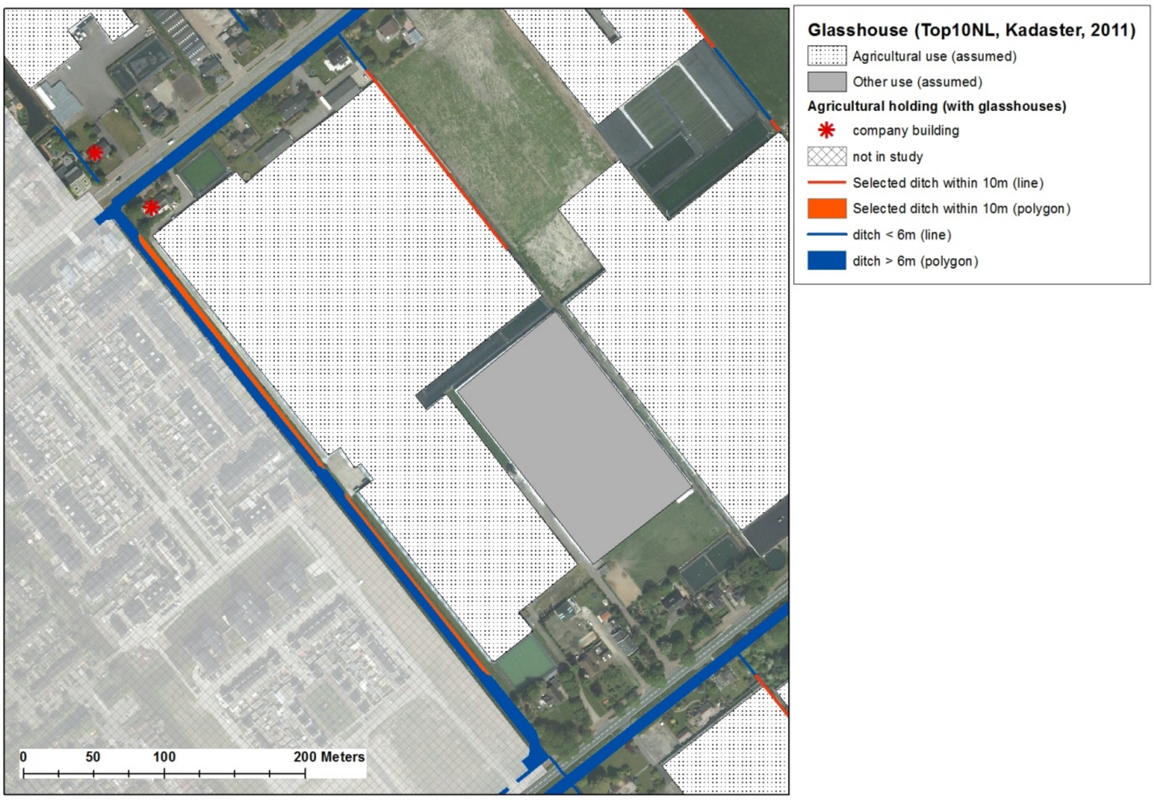

Figure A5.6 *Selected ditch-length near the greenhouse.*

RESULTS

The three step procedure was now applied to the six study areas. The results are provided in Table A5.1 and Table A5.2. In Table A5.1 an overview is given of the selected study regions, including the total area and glasshouse area (including glasshouse not in use for horticulture). Also the ditch length are provided. In Table A5.2 the area specific for agriculturally used glasshouses, here referred to as greenhouses, is provided as well as the length of the ditches within 10 m of the greenhouses. Then, the length of ditches is calculated per ha of greenhouse for the separate study areas and the average over all areas. The length of the ditch per ha 'greenhouse' lays between 91 m and 136 m, with an average of 124 m. An overall length set to 100 m for all greenhouses in the Netherlands appairs to be a good approximation for the scenario calculations.

Table A5.1
Topographical description of the study regions.

		area of interest (ha)		length (km)/ditch type			
no.	**location**	**study area**	**glasshouse**	**> 6 m**	**3 - 6 m**	**< 3 m**	**Trenches or drains* (km)**
1	Westland	5365	2953	164.8	86.6	323.9	1.8
2	Oostland	2515	1258	52.5	33.6	184.6	3.9
3	Zuidplaspolder	891	278	7.2	19.3	61.9	3.8
4	Aalsmeer	642	247	24.0	10.2	40.8	1.2
5	Koekoekspolder	630	107	10.6	7.9	67.8	3.8
6	Bommelerwaard	556	191	0.6	8.5	50.9	7.4
Totals		10599	5034	259.7	166.0	729.8	21.8

* less than half a year containing water.

** incl. those not in use for agricultural purposes.

Table A5.2
Results of the spatial analysis and selection of agricultural used glasshouses (referred to as 'greenhouse').

		Green-house	ditch-length (km) within 10 m of greenhouse			Totals *	Green-house vs. ditch	ditch vs. green-house
			ditch type					
no.	**location**	**(ha)**	**> 6 m**	**3 - 6 m**	**< 3 m**	**(km)**	**ha/km**	**km / ha**
1	Westland	**2750**	90.6	67.5	215.2	373	7.4	0.136
2	Oostland	**1066**	18.0	11.8	85.5	115	9.2	0.108
3	Zuidplaspolder	**229**	0.3	1.7	20.2	22	10.3	0.97
4	Aalsmeer	**226**	6.6	2.2	15.5	24	9.3	0.107
5	Koekoekspolder	**74**	2.7	1.2	6.6	11	7.0	0.143
6	Bommelerwaard	**177**	0.0	2.1	14.0	16	11.0	0.91
Totals/ average		**4523**	118.3	86.5	357	562	8.1	0.124

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Annex 6 Monitoring data Waterboard Rivierenland

date	Fungicide 2 µg/l	Insecticide 1 µg/l	Fungicide 1 µg/l	Insecticide 2 µg/l
		Monitoring location 1		
11-4-2012	0.07	0.02	< 0,02	< 0,01
2-5-2012	0.02	< 0,01	< 0,02	< 0,01
2-7-2012	0.05	0.01	< 0,02	< 0,01
4-9-2012	0.31	0.11	< 0,02	< 0,01
9-7-2013	< 0,01	< 0,01	< 0,02	0.25
19-8-2013	< 0,01	7.4	< 0,02	0.5
30-9-2013	0.03	0.12	< 0,02	0.06
		Monitoring location 2		
24-3-2009	1.7	0.18	< 0,02	0.12
27-5-2009	0.15	0.39	< 0,02	0.37
16-7-2009	0.03	0.54	< 0,02	0.03
8-9-2009	0.81	0.31	< 0,02	0.87
11-4-2012	0.26	0.02	< 0,02	< 0,01
2-5-2012	0.82	0.03	< 0,02	< 0,01
2-7-2012	0.07	0.07	< 0,02	< 0,01
4-9-2012	0.04	1.4	< 0,02	0.22
10-7-2013	0.8	0.08	< 0,02	< 0,01
21-8-2013	0.05	0.11	< 0,02	< 0,01
2-10-2013	< 0,01	0.14	< 0,02	< 0,01
		Monitoring location 3		
24-3-2009	0.12	0.34	0.03	0.19
27-5-2009	< 0,01	0.25	0.12	0.7
16-7-2009	0.02	0.55	< 0,02	0.4
17-8-2009	0.02	0.09	< 0,02	0.02
8-9-2009	< 0,01	0.03	< 0,02	0.03
11-4-2012	< 0,01	0.03	< 0,02	< 0,01
2-5-2012	< 0,01	0.02	< 0,02	< 0,01
2-7-2012	< 0,01	0.01	< 0,02	< 0,01
4-9-2012	< 0,01	0.05	< 0,02	< 0,01
10-7-2013	< 0,01	< 0,01	< 0,02	< 0,01
21-8-2013	< 0,01	0.01	< 0,02	< 0,01
2-10-2013	0.01	< 0,01	< 0,02	< 0,01
		Monitoring location 4		
16-7-2009	< 0,01	0.92	< 0,02	0.01
8-9-2009	0.12	0.08	< 0,02	0.06
11-4-2012	0.08	0.03	< 0,02	< 0,01
2-5-2012	0.05	< 0,01	< 0,02	< 0,01
2-7-2012	0.01	0.02	< 0,02	< 0,01
10-9-2012	0.01	0.02	< 0,02	< 0,01

Annex 7 Interception

In this report an interception is assumed of applied plant protection products (PPP) by the crop of 50% (Chapter 9.1). The fraction of the intercepted substances depend on the applied spraying volume, the technique used and to the extend of the soil surface that is covered by the crop leafs. This leaf coverage will likely depend on the age and development stage of the crop at one hand and the plant density and planting system on the other. Considering the planting system, greenhouse crops can be divided into two categories: row oriented and surface covering. Row oriented crops, for example tomatoes, are planted in rows with row distances varying from 0.6 – 0.8 m and densities of 1.5 – 3 plants/m^2 greenhouse surface. Surface covering crops are planted (chrysanthemum) or sown (radish). In these cases virtually the whole soil surface is covered with plants, planting densities vary from 50 (chrysanthemum) to > 200 (radish) plants/m^2. In soil-bound greenhouse crops, there are hardly crops representing the category row oriented crops, the vast majority are surface covering crops.

Greenhouse crops develop rapidly which mean that the soil surface will be covered by leafs rapidly. A useful indicator for the interception by foliage is the LAI (Leaf Area Index). For efficient light interception, values for LAI of 3 (m^2m^{-2}) are considered as the optimum values for net photosynthesis of crops, which presumably will be also the value where interception of applied PPP's might approach the highest rates. Systematical research on the relation between LAI or any other crop parameter with canopy interception or soil deposition after spray applications could not been found. Bor *et al.* (1994) showed for row oriented crops 11% and 22% soil deposition for plant rows and paths respectively at LAI 0.12 and values of 0.5% and 4.6% at LAI 0.12. However Crum *et al.* (1991) reported average soil deposition of 22% at an LAI of 2.6. A detailed study on the effect of various application techniques on soil deposition in chrysanthemum was carried out by Tak and van der Knaap (1997). The total deposition varied between 2 and 17% of the applied quantity in full grown chrysanthemum crops. 80% of the total deposition was captured in the paths against 20% in the beds. In the beds the deposition was never higher than 5% of the total deposition. Moreover, the trials were carried out on chrysanthemum crops with a higher percentage of the surface attributable to paths (20%) than in today commercial crops (< 10%). So likely the deposition will be even less than 5% in today full grown chrysanthemum crops.

Nevertheless, chrysanthemum crops will have a low LAI and henceforth high deposition rate just after planting. From the start of the crop the plant will develop rapidly and total coverage of the surface will be reached rather soon. Finally a high LAI will be reached. Lee, (2002) reported the following LAI values for chrysanthemum: at the start 0.4, 1.5 (15 days), 2.5 (25 days) and finally > 4. However this was recorded in a 80 days growing cycle, modern chrysanthemum last only 65 – 70 days. The rapid development is also illustrated by the figures derived from Meinen *et al.* (2014), showing that right after planting the LAI is 0.4 and light interception is 25%. After 20 days, with a LAI of 2.5 almost complete light interception is reached (Fig. A7.1). So within three weeks from planting full coverage of the soil surface is reached and it can be assumed that the interception of applied PPP's from that moment until the end of the cropping period is maximum and soil deposition will be limited. Since the average cropping cycle is 65 days, in 30% of the time of each crop there is a lower interception. In a commercial greenhouse all plant stages will be equally represented as there are plantings 5 days a week throughout the year. Since the plant stages (vegetative phase, flower bud initiation and flowering stage) are well controlled by climate and day-length, the growing cycles are quite equal throughout the year and so a steady state condition will be reached in each chrysanthemum greenhouse, with 70% of the surface area with plants at full coverage stage and 30% of the area with a surface coverage gradually increasing from 25% to 100%.

An extrapolation for such a steady state condition in a commercial chrysanthemum greenhouse was made using the data for LAI en light interception development from Meinen (2014) and the data on the cropping cycle as described in Chapter 4.3. The result show an average rate for the light interception for the whole chrysanthemum crop of 84% (Figure A7.2). It may be assumed that this parameter can be used as indicator for the crop interception of applied spraying solution as well. Therefore 80% interception by leaf cover or 20% soil deposition will be a good estimation for applied spraying volume and substances. In reality this will be lower as young planted crops will not be treated or less frequent since they arrive from nurseries virtually free from pests and diseases. So for chrysanthemum the assumed interception of 50% in this study is a quite conservative estimation.

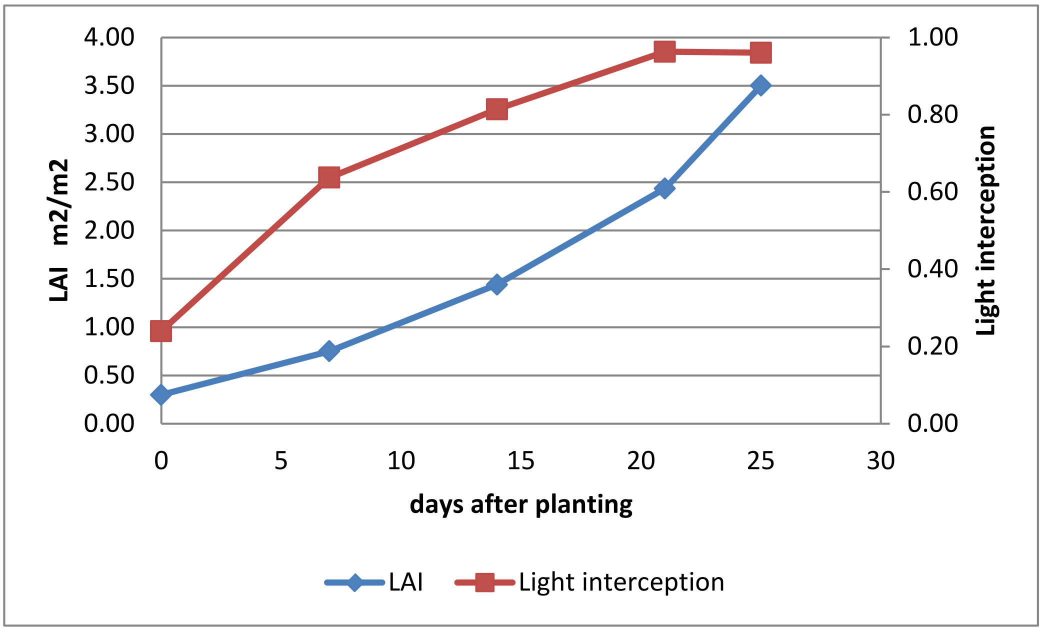

Figure A7.1 *Development of the leaf area index (LAI) and the fraction of light interception by the crop canopy in the early stages of a chrysanthemum crop (data from Meinen et al., 2014).*

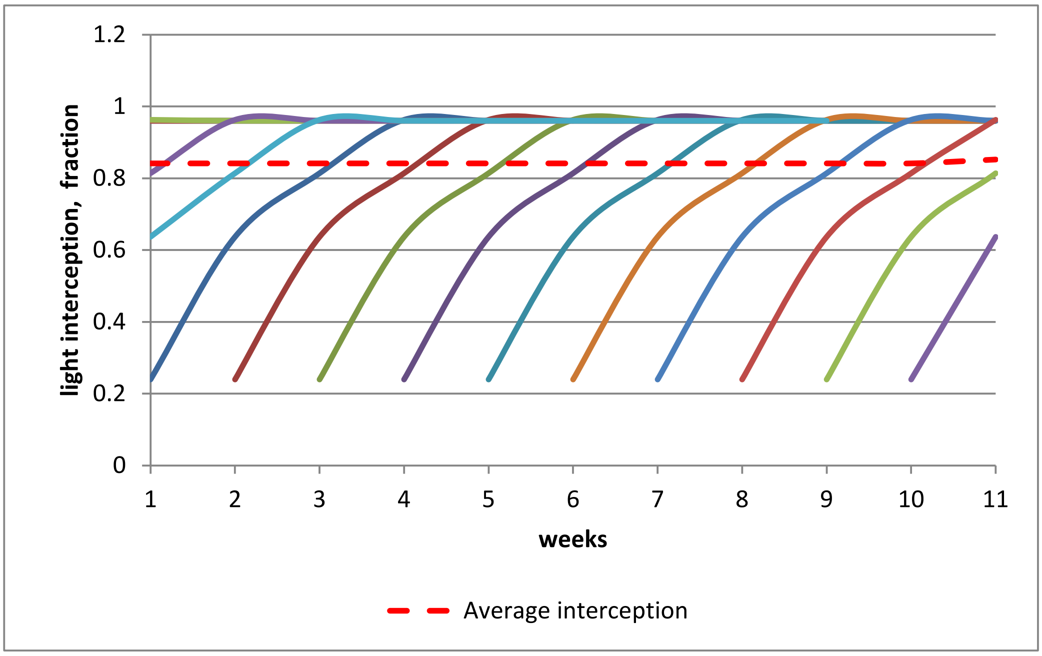

Figure A7.2 *Extrapolation of the light interception during of a chrysanthemum crop in a randomly taken 11 week period in a steady state cropping cycle in commercial practice, based on data from Meinen et al. (2014).*

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