Emissions of plant protection products from glasshouses to surface water in The Netherlands

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Inhoudsopgave

Summary

In the current authorisation procedure for plant protection products (PPP) in the Netherlands, a fixed percentage of 0.1% is used for the emission of PPPs from covered crops to surface water. This percentage is based on estimates of emissions from glasshouses to surface water in the early 1980's, and is independent of the type of glasshouse, the cropping system, the application method and the crop. The same emission percentage of 0.1% is also used by some other EU member states. For the emission from soil-bound covered crops to groundwater, the authorisation procedure is not different from the procedure for field crops, using a spring application scenario. However, specific scenarios for this assessment are missing. This report investigates whether new approaches would be required since monitoring data form water boards indicate that the emission of PPP and biocides from glasshouse horticulture to surface water may be higher than assumed in the authorisation procedure.

The following aims of the project were formulated:
1. Evaluate whether the current use of a fixed percentage (0.1%) in the authorisation procedure needs changes.
2. Gaining insight into, and describing the pathways and quantities of emissions of plant protection products and biocides from different glasshouse cropping systems to surface water. Emissions to air are only to be considered as long as these influence emissions to surface water.
3. Develop an approach (tool) and scenarios for situations to use this insight for authorisation purposes.
4. Communicate the approach with international authorisation authorities.

Results
Since standardised data from glasshouse emissions were not sufficiently available, a modelled approach was taken. For this the production systems were categorised according to (1) substrate and (2) water flows/ water systems. For the soil bound system the PEARL-model is suggested. For soilless systems the water flows were modelled and accordingly the substance flows. Three application methods were distinguished: addition via water/substrate, plant treatment, fogging treatment. For the moment the smaller crops in terms of area are not considered (bulb forcing, chicory, mushrooms, small fruits)

Covered cropping systems were ordered by their system characteristics in terms of watering system:

	Watering system	**Model crop**
Soil-bound	Sprinkler irrigation	Chrysanthemum
Soilless:		
Production on gullies	Drip irrigation	Cucumber, pepper, rose
Production on benches/tables	Ebb/flow	Kalanchoe
Production on the concrete floor	Ebb/flow	Ficus

For further analysis a major assumption was that the discharge strategy is based on Na^{+}- accumulation, and occasional discharge of larger volumes (as opposed to more or less continuous discharge of smaller volumes).

Calculated extremes in emissions caused by differences in rainfall, sizes of water basin and [Na^+] in the water source for additional water, based on the chosen application scheme for PPPs for <u>one example substance and one application scheme.</u>

Fate model	Calculated for model crop	Low end of emission (% of application)	High end of emission (% of application)
Application via nutrient solution	cucumber	0.03	11
	pepper	0.02	10
	rose	0.11	16
Crop application by spraying	cucumber	0.01	0.5
Crop application in ebb/flow system	ficus	0.01	0.5

Situations are fictitious and differ per crop. The simulations used were aimed at testing the models and performing preliminary sensitivity analysis. The results therefore give insight into the order of magnitude of emissions, but can not be used as scenarios for evaluation purposes. For example, no calculations were made to analyse emissions as function of the moment of application and of discharge – though most extreme situations were avoided, and only a limited variety of water sources was used.

In authorisation procedures for plant protection products it is nowadays quite common to use realistic worst case environmental scenarios for the assessments. It seems logical to use such scenarios also for glasshouse horticulture in the Netherlands as well. The modelled approach indicates that emissions of PPP from substrate growing systems to surface water are highly influenced by the following scenario aspects:

- the cultivation system, soil-bound or soilless;
- the application method of the PPP;
- the tolerance of a crop for Na^+ ions;
- the Na-concentration in the water supplied to the crop (total sodium amount).

Based on these four aspects, the work group proposes to implement the following combinations in the authorisation procedure:

No.	cultivation system	Fate model	Crop type (based on sodium tolerance level)
1	Soil bound	PEARL	-
2	Soilless	Application along with the nutrient solution	Low
3			Medium
4			High
5		Application to the crop canopy; with no direct exposure of the root compartment	Low
6			Medium
7			High
8		Application to the crop canopy; with direct exposure of the root compartment	Low
9			Medium
10			High

Conclusions

The results suggest that the 0.1 % is an underestimation of the actual emissions, and emission vary widely between watering systems and crops. Evaluation of emissions from glasshouses should therefore include differences in watering system and crop characteristics.

As a consequence of the used approach, the DegT50 of a substance in water is a prerequisite and therefore needs to be available in an authorisation dossier. DegT50s in water may be derived from, amongst other, transformation studies in water / sediment systems and hydrolysis studies. A DegT50 derived from transformation studies of the PPP in water / nutrient solutions, as used in covered cropping systems, would be preferable. However, such studies seem to be lacking at the moment. Likewise uptake of PPPs in the crop, and DegT50 in substrates and could be further investigated and used in the calculations.

1 Introduction

1.1 Background

1.1.1 Current state of regulation in The Netherlands

In the current authorisation procedure for plant protection products (PPP) in the Netherlands, a fixed percentage of 0.1% is used for the emission of PPPs from covered crops to surface water. An emission of 0.1% of the application rate is used to assess the risk for aquatic organisms. This percentage is based on estimates of emissions from glasshouses to surface water in the early 1980's, and is independent of the type of glasshouse, the cropping system, the application method and the crop. The same emission percentage of 0.1% is also used by some other EU member states. For the emission from soil-bound covered crops to groundwater, the authorisation procedure is not different from the procedure for field crops. However, specific scenarios for this assessment are missing.

The legal framework for emission reduction in glasshouses in The Netherlands is laid down in the Regulation Glasshouse Horticulture (in Dutch, Besluit Glastuinbouw). This framework focuses on limiting the use of fertilisers by limiting N and P application rates to crops. Specific prescribed measures for reducing emissions are:
- Compulsory collection and use of the condensation water.
- Discharge of recirculation water is only allowed when the concentration of Na^+ exceeds a threshold level. This level is dependent on the crop, allowing for physiological differences.
- The use of high quality water sources to minimise the frequency of discharging recirculation water.

In the regulation the emission of PPPs is not specified as such, by virtue of the supposition that measures to reduce the emission of fertilisers will also result in reduced emissions of plant protection products.

1.1.2 Recent findings in surface water

Water boards frequently measure the occurrence of PPP and biocides in surface water near and in glasshouse horticultural areas. For example, Teunissen (2005) summarises the results for a number of glasshouse areas over the period 2000 - 2004. From these results is was concluded that concentrations of plant production products regularly exceed the Environmental Quality Standards for fresh surface water in glasshouse horticultural areas up tot 100 times. Results from water board Zuiderzeeland for 2006 and 2007 showed that 7 active ingredients exceed the standards in surface water (s.a., 2007). Water board Rijnland concluded in 2006 that the water quality problems in glasshouse areas have not changed significantly over the past three years. Extreme (up to thousands and even tens of thousands times the standard) and frequent standard exceedings still occur (Kesslerová, 2007). Most standard exceedings are caused by insecticides and acaricides, followed by fungicides. An overview of recent monitoring results can be found in the pesticides' atlas (in Dutch: Bestrijdingsmiddelenatlas), which is an online tool that relates monitoring results to water quality standards and displays the results on maps (www.pesticidesatlas.nl).

According to these monitoring data, it is shown that the exceedings occur both in areas with older glasshouses and in newly developed glasshouse areas (Teunissen, 2005; Van der Wal *et al.*, 2007), suggesting that replacement of glasshouses over time will not automatically solve the emission and water quality problems.

The monitoring data also indicate that the emission of PPP and biocides from glasshouse horticulture to surface water are likely to be higher than assumed in the current authorisation procedure.

1.2 Aims of project

The following aims of the project were formulated:
1. Evaluation of the current use of a fixed percentage (0.1%) in the authorisation procedure.
2. Gaining insight into, and describing the pathways and quantities of emissions of plant protection products and biocides from different glasshouse cropping systems to surface water. Emissions to air are only to be considered as long as they influence emissions to surface water.
3. Develop an approach (tool) and scenarios for situations to use this insight for authorisation purposes.
4. Communicate the approach with international authorisation authorities.

A working group of experts was installed in 2007 to carry out this project. The working group consisted of:

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1.3 Set-up of project

The Working Group uses the following approach to reach the aims of the project:

Phase I	Orientation - The working group started with inventories of cropping systems and emission routes, and suggested some clustering to come to workable schemes for further quantitative analyses (Paragraph 1.4 and Cuijpers et al., 2008).
Phase II	Scenario Development – ordering of diversity in systems and techniques, developing models for water flow and PPP flow, and developing scenarios for authorisation purposes.
Phase III	Tool building – translating models and scenarios to a workable tool for authorisation purposes.

This report covers the findings of Phase II of the project. A summary of the findings of Phase I is given in Paragraph 1.4.

The results will be used by:
- The Working Group Exposure Water Organisms for further calculations of concentrations in surface water.
- The ministries of LNV, VROM and V&W for communication with stakeholders.
- The ministries of LNV, VROM and V&W for the implementation in pesticide authorisation procedures.

The legal context of the project is given by:
- EU Directive 91/414.
- The Water Framework Directive (WFD; 2000/60/EC).

1.3.1 Readers' guide

This report covers Phase II of the project: model and scenario development.

Through a number of inventories and interviews the diversity in covered cropping systems was analysed. This led to insight into the diversity in technical systems, emission routes and discharge strategies (Chapter 2). This diversity was then clustered and ordered to describe model systems for further analyses (Chapter 2). The two principal systems (soil-bound and soilless) were further analysed for their general water flows (Chapter 3). Using the WATERSTROMEN model (Chapter 4.1), the water fluxes for different model crops were calculated using climatic and system variation (Chapter 4.2). These calculated water fluxes were then introduced in the model for SUBSTANCE FATE to calculate emissions (Chapter 5). First steps for creating scenarios for registration purposes are presented in Chapter 6. Chapter 7 presents conclusions and recommendations.

1.4 Summary Phase I: Orientation

Table 1.1 Summary of the findings of Phase I of the project. This phase involved a number of items, leading to key-insights for the remainder of the study:

Item	**Result**	**Key – insight**
Availability of data on emissions	There are few data on emissions from covered cropping systems	Data on emissions are too limited for quantitative analyses of emission routes. A modelling approach is needed. Existing date can possibly be used to qualitatively check the models.
Overview of cropping systems		A classification of the different cropping systems seems possible. Ordering principles would be: • Substrate versus soil-bound production • Volumes of water flows
Overview of application methods		A classification of the different application methods seems possible. The ordering principle would be (for substrate systems): • applying plant protection product via the substrate (water supply) versus crop application by spraying or fogging
Theoretical emission routes from covered cropping systems	Schemes of emission routes (also presented in this report: par 2.3)	Routes need to be prioritised/ranked according to their contribution to the total emission to focus the working group's effort.
Water flow in cropping systems	A water flow model exists (Bezemer and Voogt, 2008) for the purpose of water and nutrient management in covered cropping systems	The water flow model quantifies water fluxes on a daily basis and this seems detailed enough to quantify the emissions of PPP from covered cropping systems
Substance flow	A preliminary model was developed to understand basic processes of degradation over time in different system reservoirs.	It seems possible to quantify the emissions of plant protection products from substrate cropping systems by coupling a pesticide fate model to the water flow model. The PEARL model (Tiktak et al., 2000; Leistra et al., 2001) seems adequate to model leaching from soil-bound production systems. It is however necessary to develop scenarios for covered cropping systems.

The following approach was adopted for the remainder of the project:

- Categorise production systems according to (1) substrate and (2) water flows/ water systems.
- Design a tool for authorisation purposes based on a model for water flows and a model for substance flows.
- Models should cover three application methods: addition via water/substrate, plant treatment, fogging treatment
- Use the PEARL-model for soil-bound production systems – create scenarios for climate and 'rain fall' for glasshouses.
- For the moment the smaller crops in terms of area are not considered (bulb forcing, chicory, mushrooms, small fruits) (Cuijpers *et al.*, 2008).

2 Diversity in covered cropping systems

2.1 Brief overview of covered cropping systems

EFSA distinguishes several construction types which are used in the cultivation of covered crops (Stanghellini, 2009; van der Linden, 2009). The most important construction type in the Netherlands falls in the category Glasshouse. An overview of the area of different types of covered crops is given in the following table (CBS, 2009).

Table 2.1 Areas occupied by covered crops in the Netherlands (CBS, 2009).

Soil-bound cultivation (glasshouses)	2.306 ha
Soilless cultivation (glasshouses)	6.716 ha
Plastic cover "umbrella"	1.350 ha (all small fruits – including uncovered production as well)
Temporary plastic tunnels	500 ha (rough estimate of 'summer flowers' with seasonal use of tunnels)
Permanent plastic tunnels	62 ha (strawberries)
Cells (bulbs)	20 ha
Mushrooms	77 ha
Cells (chicory)	7 ha

The working group focussed on the glasshouse cultivation because it covers the vast majority of the covered crop area. Other cropping systems were not considered in detail.

2.2 Watering systems

Within the construction type of Glasshouses, the cropping systems and watering systems vary highly. Systems differ in technical dimensions, substrate types, water supply and climate control. Over the years a number of principles have become more generally adopted. Some of these principles can be used for clustering for the purpose of understanding the emission routes in these 'classes' of cropping systems. This classification is based on the differences in the watering system. We used the following principles for ordering:

Table 2.2 Ordering of covered cropping systems by their system characteristics.

	Watering system
Soil-bound	Sprinkler irrigation
Soilless:	
Production on gullies	Drip irrigation
Production on benches/tables	Ebb/flow
Production on the concrete floor	Ebb/flow

This clustering led to the following insight into use of these systems (Table 2.3).

Table 2.3 Types of covered cropping systems and the area of use.

cropping system	**most important crops**	**area 2007 (ha)** (CBS, 2009)
soil cultivation	lettuce, radish, chrysanthemums, freesia, alstroemeria, lysianthus, amaryllis, berries, summer flowers, organic vegetable farming	vegetables: 740 (100 ha organic) flowers: 1566
production on substrate	tomato, pepper, cucumber, aubergine, courgette, rose, gerbera, anthurium, bulb forcing, strawberry	vegetables: 3310 flowers: 863
ebb/flow irrigation on tables or concrete floors	pot plants and orchids (no further distinction given in current surveys)	pot plants: 2543

Appendix II gives an overview of areas of the most important crops and the development over the last years. The following figures give an impression of the different systems.

Figure 2.1 Soil bound production: Chrysanthemums just planted (left) and shortly before harvest (right)

Figure 2.2a Drip irrigation on substrate: Substrate slabs, lying on gullies to recirculate the surplus solution. Left cucumber on perlite and right sweet pepper on rockwool.

Figure 2.2b Drip irrigation on substrate: Rose production in an "arch-system".

Figure 2.3 Ebb-flow irrigation on tables: kalanchoe

Figure 2.4 Ebb-flow irrigation on a concrete floor: ficus (right on picture).

2.3 Emission routes

All theoretically possible emission routes to air, soil, groundwater and surface water were recorded (Cuijpers *et al.*, 2008). A general overview of emission routes in the production unit is given in Figure 2.5 and of the accommodation unit in Figure 2.6.

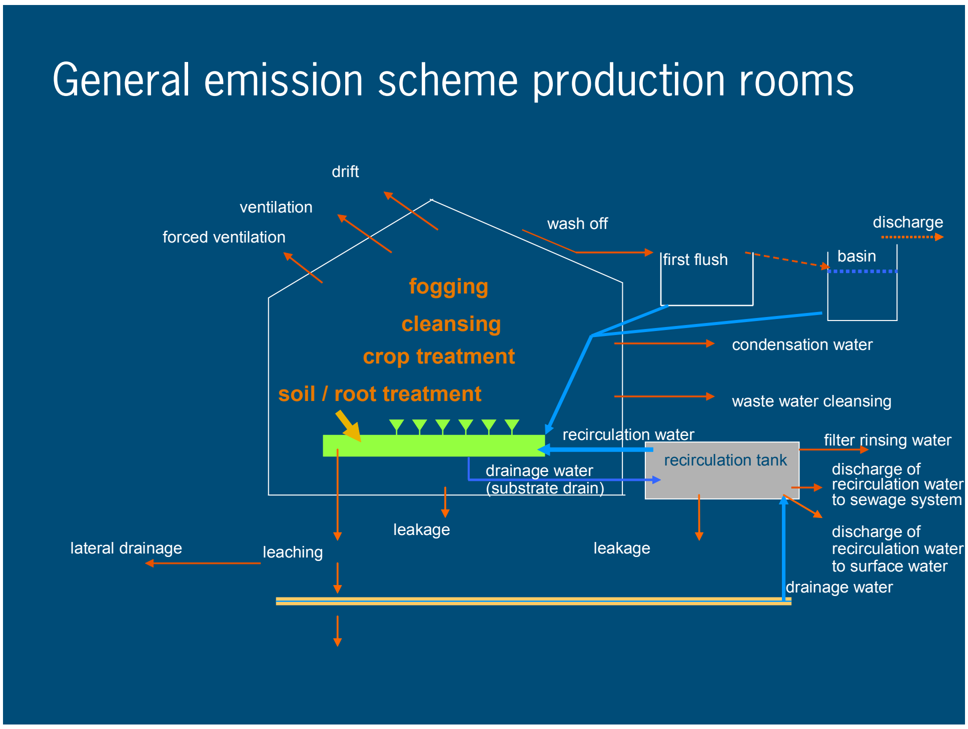


Figure 2.5 Theoretical emission routes from a covered crop system – the production unit

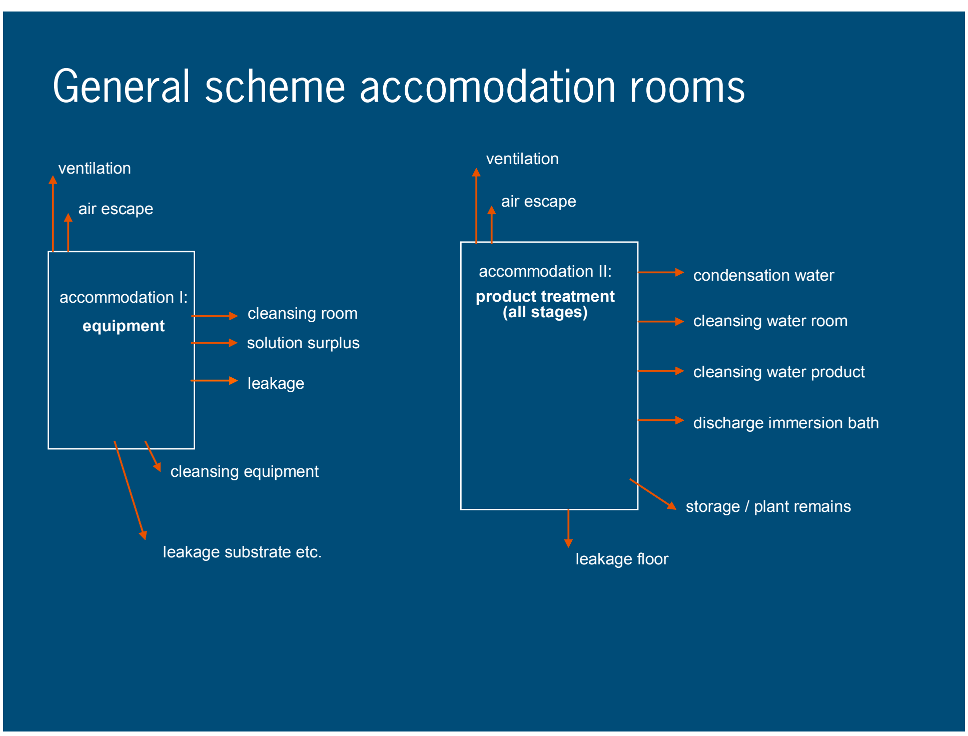


Figure 2.6: Theoretical emission routes from a covered crop system – the accommodation unit

The emission routes may vary in importance between the different production systems. The most significant differences between glasshouse systems would be the leaching to groundwater for soil bound production and the different levels of recirculation and discharge. These differences are quantified in Chapters 4 and 5. Appendix III gives the emission routes for the two production systems: substrate based and soil bound cultivation.

2.3.1 Ordering principle for emission routes

The theoretical emission routes may differ strongly with respect to their contribution to total emission. For the soilless cropping systems selection criteria were established to further focus the effort of the working group. Quantifying and modelling all routes would simply be too laborious for the time given, while understanding the main emission routes was likely to yield insight into the larger part of the total emission.

Since emission of plant protection products from the glasshouse to surface water was assumed to follow water fluxes (Phase I, Cuijpers *et al.*, 2008), the order of magnitude of water flows could be used as a guiding principle for ordering the emission routes. Table 2.4 gives the order of magnitude of the cumulative water flows. Using this simplification, the effect of concentration differences in the water system and in emission routes were not used as ordering principles. The selection of emission routes for further analyses included the following considerations:

1. The emission routes from accommodation units were not considered. Current legislation on construction of these units, cleaning and use of excess product seem to marginalise these emission routes (Besluit Glastuinbouw).
2. Drift emission from glasshouses to surface water is considered negligible, due to compulsory precautionary measures during and shortly after application.
3. Soil-based cropping systems are considered via the PEARL-model.

Table 2.4: Ranking emission routes by their water flow (non-soil based cropping systems)

1. discharge of recirculation water:	expected highest contributor to total emission*	
2. condensation water – if not re-used:	1000	m^3 ha^{-1}**
3. discharge of filter water:	250	m^3 ha^{-1}***
4. leakage – 1.5 % of water supply:	150	m^3 ha^{-1}***
5. end of year discharge (vegetables):	60 - 80	m^3 ha^{-1}*
6. wash off at end of year clean up:	10	m^3 ha^{-1}
7. overspill from rain water basin (after First Flush)		****

*Figures give an indication of the order of magnitude rather than a set volume. * see paragraph 2.4, ** 1 L/m^2 on 100 days / year, *** estimates model WATERSTROMEN,*

**** not considered in context of this report*

Based on the above overview and considerations, the working group focused on the following emission routes for soilless cropping systems:

- discharge of recirculation water;
- discharge of filter water;
- leakage of recirculation water (considered not to reach surface water).

2.4 Discharge strategies

Discharge water is expected to be the main route of emissions from non-soil based cropping systems. However, an adequate inventory of water discharge quantities is not available. Only recently some studies tried to quantify discharges by surveying discharges at the farm level (Cuijpers, pers. com. Kruger, 2008). These studies were hampered by inadequate definitions of emission types and differences in awareness on leaching and discharge at the growers' level. The results indicate that discharge volumes vary from approximately 25 to over 3000 m^3 per ha per year. An approximation of the 90th percentile water discharge is 1500 – 2000 m^3 ha^{-1} yr^{-1}, for both ornamentals and vegetables grown on soilless cultivation systems. These data provide an indication of the range of discharge and should not be used for further analysis.

2.4.1 Principles of discharge strategies

Discharges are a means to steer the nutrition balance of the recirculation water. The main reason for imbalance is the accumulation of non-nutrients in the recirculation water. A quantifiable parameter for this imbalance, used as legally accepted reason for discharge, is the Na^+-level in the recirculation water (Sonneveld and Voogt, 2009). Scientific attention however has shifted towards other, yet undefined, growth-hampering substances (De Kreij et al. 2004; Van Os et al., 2004); pers. comm. Bram van der Maas) and growers may also use other steering parameters for discharging recirculation water. Other reasons for discharge such as mistakes in management, unforeseen happenings like system failures in the distribution unit or damages were not taken into account in the analyses. The working group has decided to use the current understanding on Na^+ as the leading principle for discharge.

Na^+ is not, or only marginally, taken up by the plants and, therefore if present in supply water, it accumulates in the recirculation water. Since Na^+ is only a contamination in the commercial fertilizers currently used at very low level, almost all Na^+ will only enter the system along with the water. Water may be obtained from different sources. Indications on the Na^+ contents of different water sources are:

- Condensation water ([Na^+] ~0 mmol dm^{-3}). Due to transpiration of the crop and by outside air cooled glass panels there is condensation on the glass. The collection and reuse of condensation water is compulsory.
- Rainwater ([Na^+] ~0 - 0.2 mmol dm^{-3}). Along the sea coast rainwater may contain some sodium. The size of the tanks or basins varies between 500 m^3 ha^{-1} (minimum commitment by legislation, Besluit Glastuinbouw) to about 3000 m^3 ha^{-1}. Dependent on the size of the tanks rainwater may cover a large part and even up to 100% of the water need at a nursery. It can be imagined that long dry periods empty the tanks and lead to the need of using additional water. As those dry periods cannot be forecasted an additional source is always available. During long wet periods the basin may get completely filled and surplus rainwater discharges directly into the surface water. In some cases the surplus water can be stored in deeper aquifers (20 - 70 m deep).
- Reversed osmosis water (RO; [Na^+] ~0 - 0.2 mmol dm^{-3}). Nowadays the most important additional water source. Mostly groundwater is pumped up, filtered and desalinated by membranes. The brine (about 50%) is pumped back in the (same) groundwater layer.
- Well water ([Na^+] ~0 - >>5 mmol dm^{-3}). Cheap water, but in the western part of The Netherlands mostly of poor quality because of high salt contents (brackish water). In the eastern part quality is much better and is often used instead of or in addition to rainwater.
- Surface water ([Na^+] ~1 - > 5 mmol dm^{-3}). Availability is mostly good, but quality is poor. It often contains a too high salt concentration and moreover, besides PPP and pathogens also soluble organic matter, and therefore it needs intensive purification before use.
- Tap water ([Na^+] ~1.8 mmol dm^{-3}). Quantity is not a problem, but quality for hydroponically grown plants is poor. Tap water contains too much sodium for optimal plant growth. Furthermore, tap water is rather expensive.

To reduce Na^+ accumulation growers will preferably use water sources with low Na^+ levels.
The tolerance for Na^+ or Cl^- as well as the specific effects on production or produce quality differs among crops. As a result of many years of salinity research, maximum acceptable Na^+ concentrations, or threshold values for the root environment are defined for each crop (Sonneveld and Voogt , 2009). Above these values the risk of yield decrease or reduction of produce quality becomes significant. From these values, Na^+ concentrations are defined (legal Na levels), which are legally accepted as levels above which discharge is allowed. These legal Na levels are generally lower than the threshold values (Besluit Glastuinbouw,2002). At the same time, the capacity of crops to absorb Na^+ differs greatly. In terms of water fluxes this can be expressed as uptake concentration in mmol l^{-1}. This uptake concentration is highly positively correlated with the ambient concentration in the root environment (Voogt and Sonneveld, 1996). So obviously the highest Na uptake is realized at the legal Na levels. Consequently crop specific maximum acceptable Na^+ concentrations for water sources were defined (Voogt, 2009)

When Na^+ concentration rises different strategies can be adopted to keep the Na^+ concentration below critical levels. These strategies may range from daily discharge of small quantities to a number of larger discharges throughout the year (Figure 2.7).

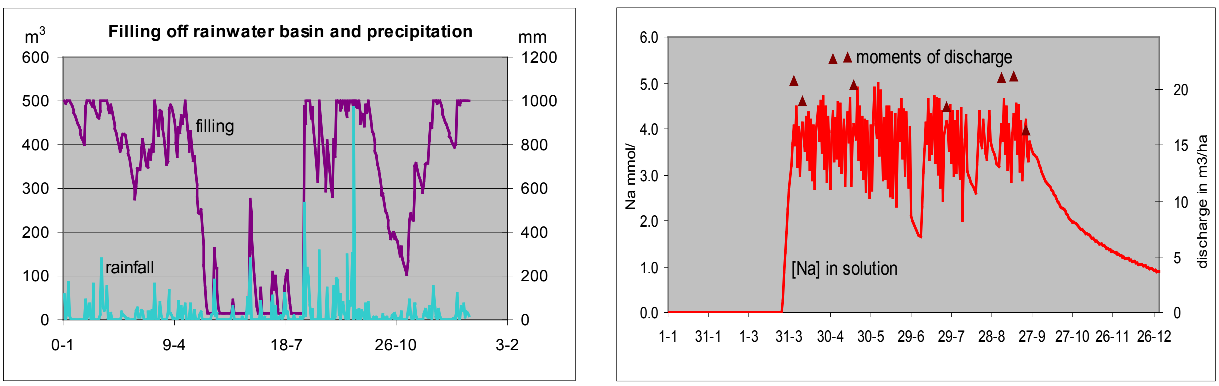


Figure 2.7 Strategy of discharge, see explanation below.

Explanation of Fig. 2.7: for rose two figures are presented to show discharge of water with nutrients from the closed, recirculating system. In the left figure, the X-axis gives the time during one year, while the Y1-axis gives the contents of the rainwater basin in m^3, the Y2-axis is precipitation in mm. In the right figure, the X-axis is the same as right , while the Y1-axis gives the $[Na^+]$ in the recirculating solution and the Y2-axis the discharge in m^3 ha^{-1}.
In January, water from the rainwater basin is used as the only supply (left figure purple line). Rainwater is assumed not to contain Na^+ (figure right, red line). In February, it rains (left figure blue line), and the basin is filled to its – for this example – maximal capacity of 500 m^3. In March there is little rain, so the basin is empty by early April. At this moment additional water is supplemented. The additional water is tap water with 1.8 mmol dm^{-3} Na^+. $[Na^+]$ soon reaches the threshold level of 4 mmol dm^{-3} for rose (right figure red line). The triangles show the moments and quantities of discharge. Upon discharge the $[Na^+]$ drops, but because of the high water uptake of crop and the little uptake of $[Na^+]$ by the crop, $[Na^+]$ rises again to a level of 4 mmol dm^{-3} followed by discharge. At the end of June there is substantial rainfall, the basin is filled up again and less additional water is needed. In July and August extra (tap)water is needed again, resulting in a number of discharges. In October the rainfall increases, the water use of the crop reduces and the basin is filled again. From that moment there is no need for additional water. With rainwater as the only water source discharge of recirculation water is not needed anymore.

2.5 Summary of ordering principles

Accordingly, we selected and ordered the total scope of emissions from glasshouse cultivation along the following line:

1. Cultivation system: focus limited to glasshouse production
2. Ordering of watering systems: soil bound, drip irrigation, ebb/flow on tables and ebb/flow on floors
3. Focus on emission routes: system discharge, filter cleaning and leakage
4. Discharge strategy based on Na^{+}- accumulation
5. Discharge: occasional discharge of bigger volumes (as opposed to more or less continuous discharge of smaller volumes)

Based on these ordering decisions we continued with identifying water fluxes (Chapter 3), quantifying water fluxes for a number of model crops (Chapter 4) and modelled substance fate (Chapter 5).

3 Identifying water fluxes

For building understanding on emission routes and for modelling purposes the diversity described in Chapter 2 was simplified by focusing on water routes generally present in covered cropping systems and developing flow charts of these. The proposed schemes are based on interviews with growers and installers.

3.1 Flow charts for soilless systems

Water fluxes in glasshouses are a result of the construction of the glasshouse, the set-up of the growing system, the crop, management decisions of the grower and the availability of water sources of good quality In detail all production systems are different, but overall there is much similarity. For crops grown on substrates, there is a general scheme for water fluxes (Figure 3.1). Rainwater from the roofs is collected in tanks or basins and used for watering the crop. Before use it is mixed with fertilisers and often pumped into a daily storage tank. From there it is pumped to the plants and flows via the substrate and conducts. Plants take up water and nutrients, the surplus flows, by gravity, to the drain water collection tank. From there it is pumped to the workroom to be filtered and disinfected. After disinfection it is stored in a so-called "clean water tank". The "clean water tank" is the buffer for making a new solution mix with rainwater and nutrients to be pumped to the plants again. If there is not enough water available in the basin, an additional water source is used. For this, there are a number of sources such as tap water, surface water, well water and reversed osmosis water (see Chapter 2). Such additional water sources are called 'supply water'. Another water source is the condensation at the glasshouse construction. Condensation water is collected from the inner side of the glass panels and flows directly into the "clean water tank". Outgoing water fluxes are the uptake by the crop and evaporation, leakage out of the system, discharge of drain water and the filter cleaning water which flows into the waste water tank. This waste water tank is only used in glasshouses that discharge into a sewage system. When a sewage system is not available discharge can take place directly into the surface water.

In practice water systems can vary on the following aspects:

- Type of filter (sand filter or alternative (usually smaller));
- Volume of waste water tank (here 50 m^3 ha^{-1});
- Volume of basin: 500 m^3/ha (compulsory minimum) to approximately 3000 m^3/ha;
- Type of disinfector (UV, heat, ozone, slow sand filtration);
- Substrate and conducts (drip irrigation or ebb-flow, type of substrate, volume of substrate, etc.)

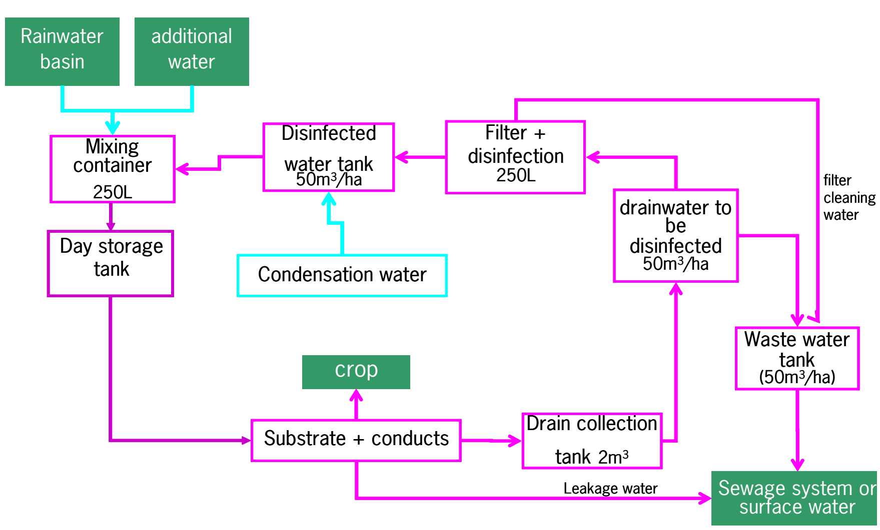


Figure 3.1: Scheme of water fluxes for closed soilless cropping systems.

In the above-mentioned cycle of water and nutrients Plant Protection Products are not mentioned. PPP are introduced for specific reasons at specific places and specific moments in time. A limited number of PPP is directly introduced in the mixing container (Figure 3.2) to treat pathogens in the root zone or for uptake by plant roots (systemic substances). The major part of PPP is introduced by spraying the crop or treating the production room (Figure 3.3).

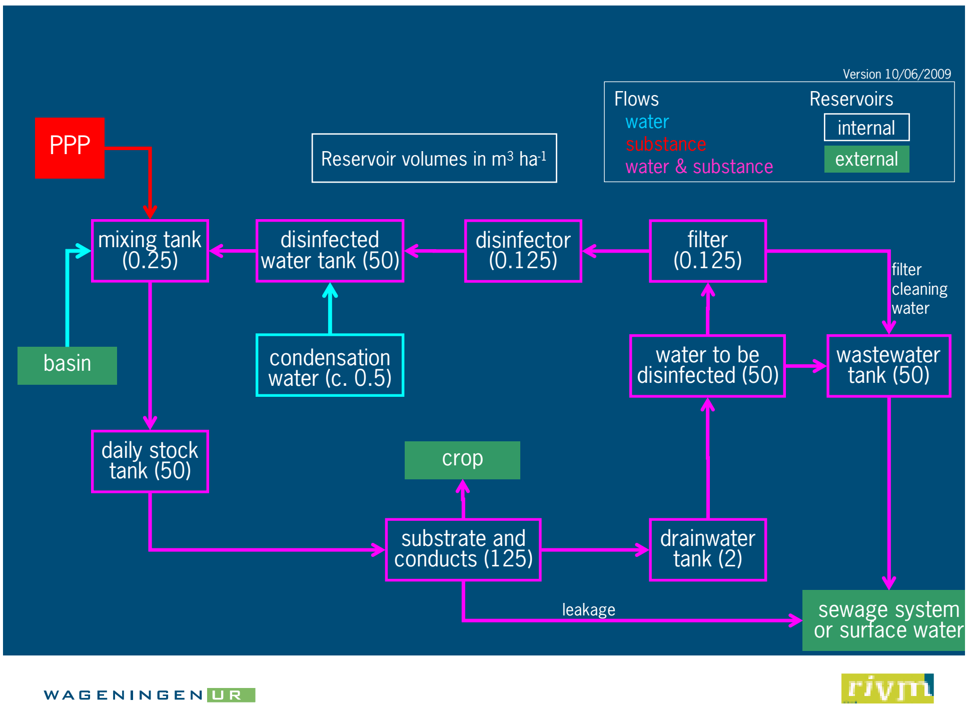


Figure 3.2 Application of PPP to root zones in non-soil based systems (substrate), (between brackets the assumed volumes (m³) per hectare).

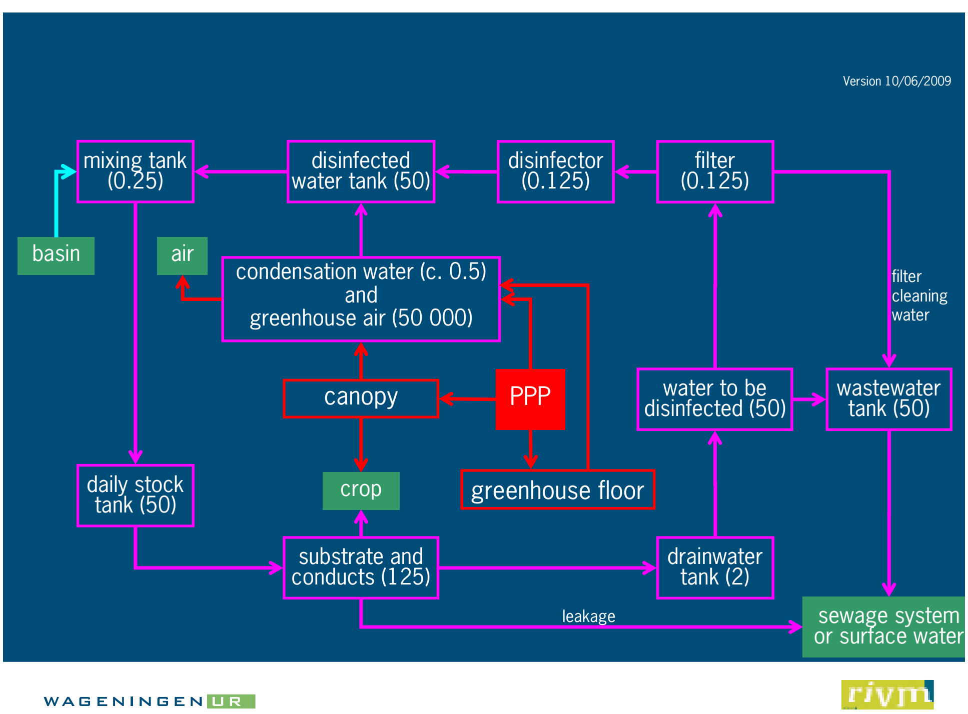


Figure 3.3 Application of PPP to the canopy in non-soil based systems (substrate), (between brackets the assumed volumes (m³) per hectare).

Figure 3.4 Rainwater collection tanks or basins are mainly located outside, but all other storage tanks stand inside the glasshouse. At the right picture at the foreground the disinfection installation (UV radiation) and the blue rapid sand filter. The tanks at the background are for collecting water to be disinfected "dirty water tank" (right) and for waste water to be emitted to the sewage system.

3.2 Flow charts for soil based systems

For the soil grown crop chrysanthemum the scheme as given in Figure 3.5 applies. The nutrient solution for the plants in the production unit is being prepared in the accommodation unit. In this unit different water fluxes (recirculation water, condensation water, fresh water from the basin or other sources) are being collected and prepared for use in the production unit. Plant protection products used as a root treatment may be added to the nutrient solution and applied together with the irrigation water. Plant protection products used as aerial and crop treatments are being applied in the production unit by different application methods. Also soil treatment (injection, incorporation) may occur.

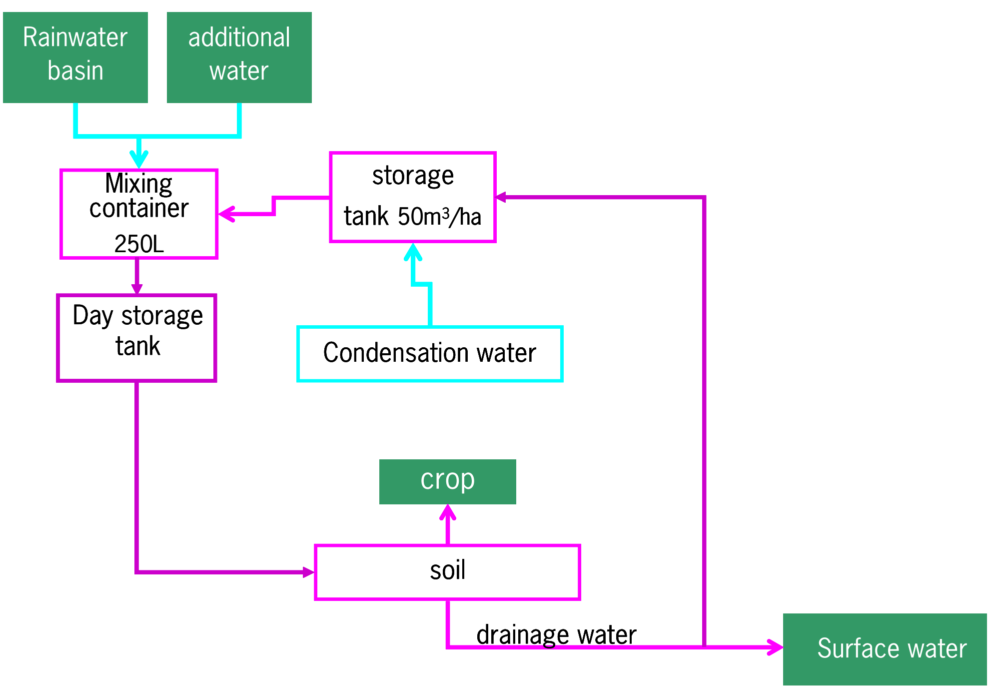


Figure 3.5 Scheme of water fluxes in a soil-bound system. Part of the leaching water may end up in groundwater rather than surface water.

4 Quantifying water fluxes

Water flux calculations were made using the model WATERSTROMEN. Six model crops were selected (see Chapter 4.2) to calculate the water fluxes.

4.1 Model WATERSTROMEN

Based on the water fluxes shown in Figure3.1 and 3.5 the Model WATERSTROMEN (Bezemer & Voogt, 2008, W.Voogt, WUR Greenhouse Horticulture, see frame) was used to quantify the fluxes. The model calculates water fluxes, numbered 1 – 12 in Figure 4.1, on a daily basis. Appendix 5 summarises the water fluxes for a full growing season.

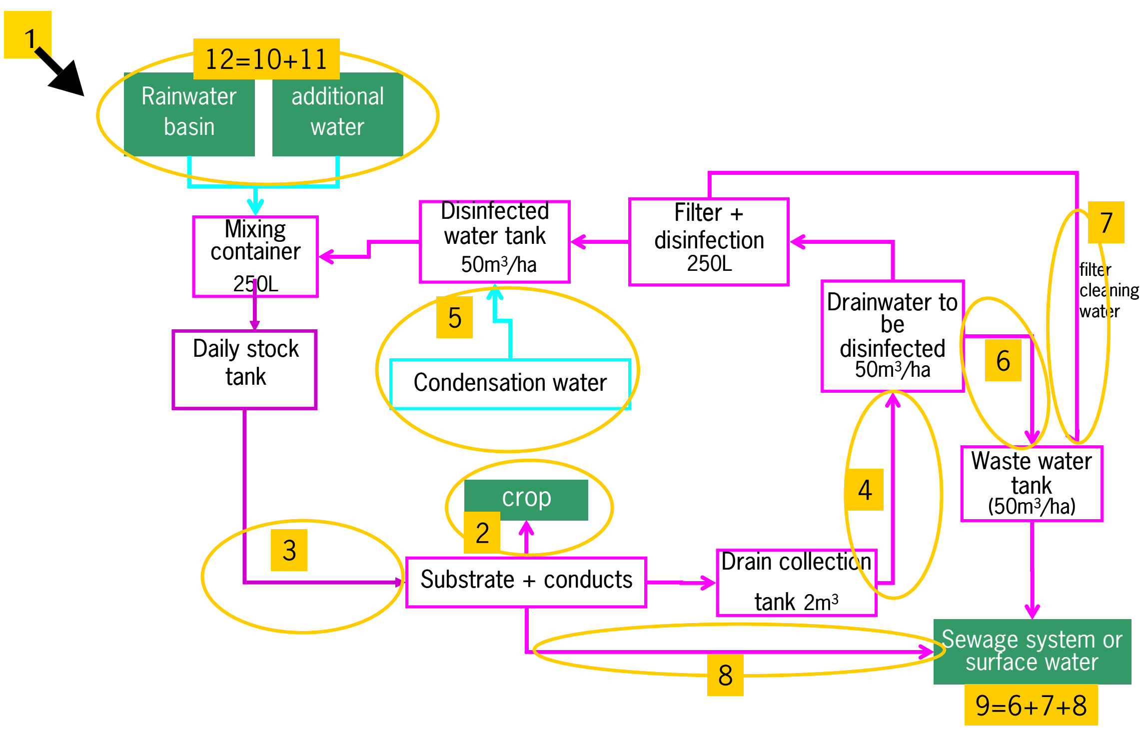


Figure 4.1 Relation between calculated fluxes (Appendix V) and identified fluxes in a closed soilless system.

Ad. 1: Precipitation and filling of the rainwater basin.

Ad. 2: Transpiration of the crop, based on models using the type of crop, plant size, solar radiation, radiation of assimilation lighting and heating energy as main parameters (De Graaf, 1988; Voogt et al., 2000)).

Ad. 3: Water supply to the plants.

Ad. 4: Surplus of water which is not taken up by the plants flows via conducts to a drain collection tank from which it is pumped into a large tank to be disinfected.

Ad. 5: During the year, depending on the outside climate, water vapour condensates at the glass panels of the glass house. This water is collected and reused for irrigation.

Ad. 6: Dependent on the sodium concentration in the nutrient solution it is permitted to discharge a certain amount of solution to a sewage system or surface water. Dependent on the Water Board, a maximum discharge flux to the sewage system is allowed, for which reason a buffer tank (waste water tank) may be installed.

Ad. 7: Filter cleaning is needed after a certain amount of solution has passed the filter. The filter cleaning usually happens automatically, for example based on pressure build-up in the filter system. The cleaning water, (order of magnitude 1% of the total volume through the filter), emits to a sewage system or the surface water.

Ad 8: The leakage water is caused by an imperfect technical system and is estimated as a fixed percentage of the water supply (default 1.5%). The flow disappears as a diffuse emission into the soil.

Ad 9: = 6+7+8

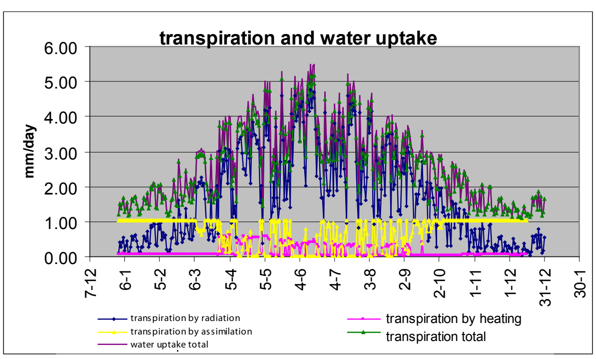
Ad 10: the total amount of rainwater

Ad 11: the total amount of additional water (tap water, reversed osmosis water, surface water or groundwater)

Ad 12: = 10+11: total amount of external water

> Model WATERSTROMEN, version 5.3
> W. Voogt
>
> The model WATERSTROMEN estimates the ingoing and outgoing water flows at a commercial nursery during a year or a growing cycle of a crop. The model uses the crop transpiration model of de Graaf (1988) with some modifications by Voogt *et al.* (2000) and parameters to simulate the water uptake for crop growth. Climate data such as temperature, the sum of radiation and precipitation as well as related greenhouse climate data are used as input.
>
> A number of parameters are used to calculate the various water fluxes on a daily basis. The volume of the rain water collection is a fundamental parameter, because rainwater is used as the primary water source. The chosen year is a variable and can be selected from a database of measured weather data at Naaldwijk (official KNMI weather station). The ten most important greenhouse crops can be selected, amongst them tomato, sweet pepper, cucumber, rose and gerbera. For each crop some crop specific parameter values need to be chosen (day/night temperature, intensity and duration of artificial lighting, sodium threshold value, specific sodium uptake). Other parameter values to be chosen are: sources of additional water with their sodium concentration, the water supply / water uptake ratio, drain fraction, fraction of leakage and filter cleaning water, system values, etc.
>
> As a result of the mentioned input data the model WATERSTROMEN calculates per day the amount of used rainwater, additional water and condensation water. Further the crop uptake, the required amount of discharge of the nutrient solution, resulting from Na^+ accumulation above the threshold value and amounts of leakage and filter cleaning water are calculated.
>
> Besides water fluxes also flows and emissions N, P and other elements can be estimated. As all parameters can be easily changed, the model can be adapted to specific situations.

The following figure gives some insight into the effect of light and temperature on evaporation and condensation (Figure 4.2)



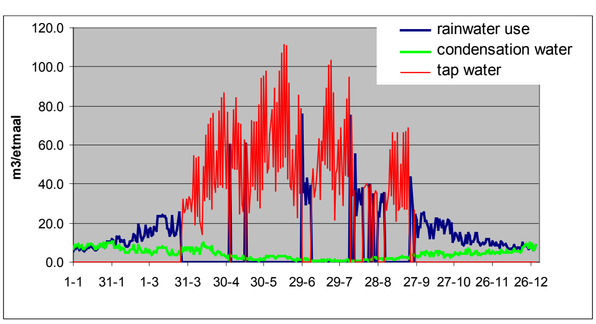


Figure 4.2 Transpiration and water supply.

Explanation: *The same crop (rose) and year is used as in Figure 2.1. Crops in a glasshouse evaporate because of sun radiation (upper figure blue line). Transpiration is caused by solar radiation (upper figure dark blue line), by heating (upper figure pink line) or assimilation lighting (upper figure yellow line); total evaporation is given by the green line. Besides, there is a small quantity of water absorbed for growth (not shown), resulting in a total water uptake by the crop (purple line). The lower figure gives the total water use by the crop divided over the different water sources. In winter condensation water can supply most of the water needed. In spring and fall the rainwater is sufficiently available, while throughout the summer rainwater and tap water is used. In these months there is only limited condensation water. The wide fluctuations in water use are caused by differences in radiation (overcast versus bright sunny days).*

4.2 Calculations for six model crops

For the six model crops the water balance was calculated. We used both fixed and variable parameters to calculate water fluxes in covered cropping systems and the sensitivity of the model to changes in the systems. Fixed parameters are crop-dependent, where variable parameters are system variables.

Fixed parameters per crop:
- area for calculations: 1 ha
- transpiration model: different per crop
- [Na^+] threshold value: crop tolerance for sodium
- Na^+ uptake at maximum sodium level

Variable parameters
- year: wet, dry, warm, cold or average year;
- size of rainwater tank: 500, 1500 and 3000 m^3 ha^{-1};
- Na^+ concentration: rainwater has a standard figure of 0 mmol Na per litre, but additional water has been set at 1.8 mmol dm^{-3} (tap water) or 0.1 mmol dm^{-3} for reversed osmosis;
- presence or level of artificial light;
- heating strategy: level of heating is important for transpiration and growth.

The calculations are summarised in Appendix V. Here tables per crop are presented showing the model results with varying parameters in m^3 per hectare per year. Each line in the table (a varying parameter) is the total amount for the growing season. Daily figures are not presented but used as input for the emission estimations (Chapter 5).

4.2.1 Crop characteristics

Six model crops were selected for each of the water systems (see Table 4.1). The crops were selected for their relevance to Dutch horticulture in terms of hectares.

Table 4.1 Selected model crops for the different water systems

	Watering system	**Selected crop**
soil bound	sprinkler irrigation	chrysanthemum
soilless:		
production on gullies	drip irrigation	cucumber, rose, sweet pepper
production on benches/tables	ebb/flow	kalanchoe
production on a profiled concrete floor	ebb/flow	ficus

As the discharge to the sewage system or surface water is highly dependent on the sodium concentration in the supply water, specific data per crop about the sodium threshold value (Besluit Glastuinbouw, 2002) and the uptake at the maximum sodium level are presented in Table 4.2. The water uptake differs widely between these model crops (Figure 4.3). Kalanchoe and ficus are year round growing crops. Light intensity is highly controlled by screens. Sweet pepper, cucumber and chrysanthemum have a similar water uptake. The uptake of water by rose however, is much higher, which is caused by the year-round use of artificial light and high temperatures and the absence of a period without production. Sweet pepper and cucumber have a crop cycle of about 11 months and in the 12th month the glasshouse is emptied, cleaned and replanted. Use of artificial lighting is at a much lower scale or even absent and consequently, the water need of these crops is less.

Table 4.2: Crop specific sodium threshold values, legal acceptable values and maximum uptake values at the threshold values (Voogt and Sonneveld, 1996; Besluit Glastuinbouw 2002)

crop	threshold value (mmol dm^{-3})	Legal Na levels	uptake at maximum [Na] (mmol dm^{-3})
cucumber	8	6	1
sweet pepper	6	6	0.5 – 0.1[1]
rose	4	4	< 0.1
kalanchoe	1	4	0.1
ficus	5	4	0.1
chrysanthemum	8	*	< 0.1

[1] apparent difference between vegetative and generative crop development stage

* not defined for soil grown crops

4.2.2 Climate

The water uptake does not vary much with changes in the outside climates (Figure 4.3), since the inside climate is highly regulated and, consequently, the variations per day are highly compensated during the overall year. Characteristics of the climate in that specific year are described in Appendix III.

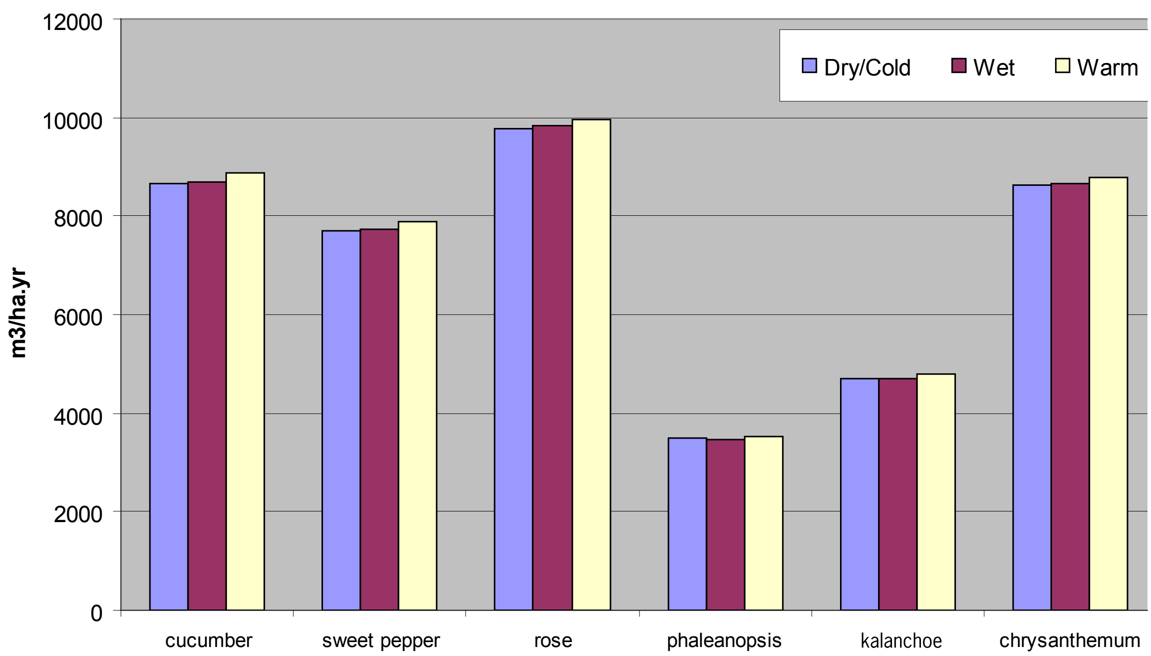


Figure 4.3: Water uptake by the crop in relation to outside climate conditions. Dry/cold, wet and warm are specifications of a specific climatic year (Appendix III). Additional conditions: rainwater basis 1500 m^3 ha^{-1}, [Na$^+$] in rainwater 0 mmol dm^{-3} and in additional water 1.8 mmol dm^{-3}.

Calculation of the amounts of discharge in the same specified years shows another view (Figure 4.4). First there is a clear distinction between soilless crops and the soil-bound crop chrysanthemum. The latter does not have any recirculation and, consequently, the differences between the climatic years are similar to crop uptake (Figure 4.3). Differences between specified years are mainly influenced by the availability of rainwater. In a dry year there is less precipitation (496 mm, Appendix IV) than in a wet year (1091 mm) and, consequently, more supply water (of less quality ([Na$^+$] = 1.8 mmol dm^{-3})) needs to be used. The absolute level of discharge highly depends on the sodium threshold level as given in Table 4.2.

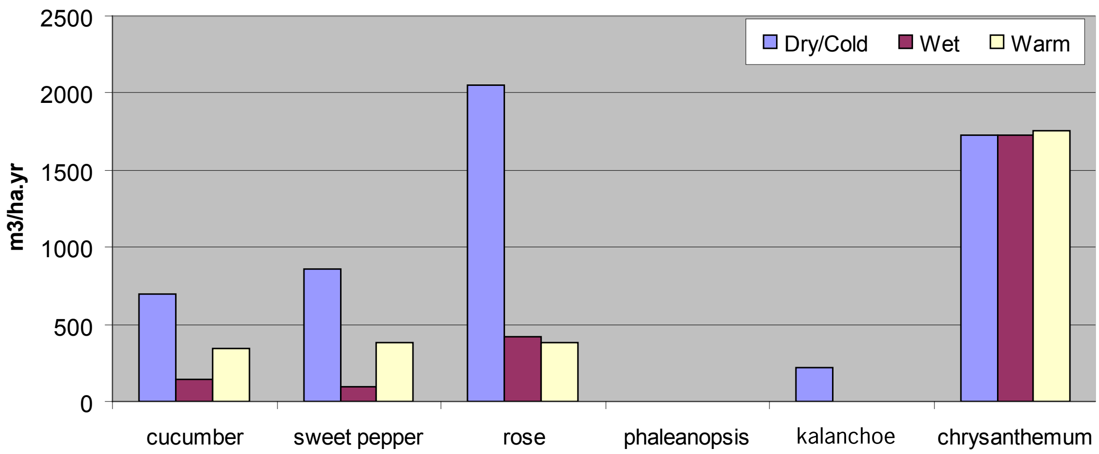


Figure 4.4: Discharge of water in relation to outside climate conditions. Dry/cold, wet and warm are specifications of a specific climatic year (Appendix III). Additional conditions: rainwater basin 1500 m^3 ha^{-1}, [Na^+] in rainwater 0 mmol dm^{-3} and in additional water 1.8 mmol dm^{-3}.

Values shown in Table 4.3 give an indication of the reduced water discharge if a grower differs from the standard starting points. In principle it can be said that if a crop is grown either with less light or with less heat there will be a reduction in the water discharged to sewage system or surface water.

Table 4.3: Relation between water discharge (m^3) and lower heat or light levels.*

	standard	less heat	less light
cucumber	700	660	480
sweet pepper	860	--	--
rose	2052	1936	1705
kalanchoe	0	0	--
ficus	220	140	--
chrysanthemum	1726	--	--

** Additional conditions: rainwater basin 1500 m^3 ha^{-1}, [Na^+] in rainwater 0 mmol dm^{-3} and in additional water 1.8 mmol dm^{-3}, – means that calculation has not been performed.*

4.2.3 Size of rainwater basin and type of supply water

Rainwater is in most cases the best quality supply water available. Following legislation (Besluit Glastuinbouw, 2002) a minimum basin size of 500 m^3 ha^{-1} is compulsory if a better quality source is not available. Growers are most interested to have a larger basin, but for a number of reasons this is not always possible (space, ground price). If the size is not sufficient to cover the water need of a crop additional supply water is needed. The worst case is to use tap water with a Na^+ contents varying between 1.5 and 2.5 mmol dm^{-3}. As a number of drinking water companies in the horticultural area deliver tap water with a [Na^+] of 1.8 mmol dm^{-3} this concentration has been chosen for the calculations. In Table 4.4 an overview is given of the amounts of discharge in relation to the size of the rainwater basin, in wet and dry years.

Table 4.4: Relation between amount of discharge in different climatic years and the size of the rainwater basin.*

	year	500	1500	3000
cucumber	dry	940	860	300
	wet	400	140	0
sweet pepper	dry	1260	860	300
	wet	500	100	0
rose	dry	2619	2052	1166
	wet	963	417	0
kalanchoe	dry	4516	0	0
	wet	0	0	0
ficus	dry	780	220	0
	wet	40	0	0
chrysanthemum	dry	1726	1726	1726
	wet	1732	1732	1732

**Additional conditions: [Na^+] in rainwater 0 mmol dm^{-3} and in additional water 1.8 mmol dm^{-3}.*

In general it can be seen that a larger basin reduces the amount of discharge. In a few cases a size of 1500 m^3 ha^{-1} is sufficient to reduce the discharge to zero, but for some crops a basin of 3000 m^3 ha^{-1} is not yet sufficient to come to a zero discharge throughout the years. As high sodium levels may also reduce product quantity and/or quality growers tend to use 'cleaner' water sources. In the last few years the use of reversed osmosis; [Na^+] varying between 0 and 0.3 mmol dm^{-3} has become popular as an additional source of good quality water.

4.3 Summarising

Parameters with greatest impact on total discharge are (order without regard to importance): 1) crop characteristics for water uptake and Na^+-sensitivity, 2) rainfall, 3) temperature and light settings in the glasshouse, and 4) the size of rain water basin in combination with the source of supply water.

5 Substance Fate Modelling

As described earlier (Chapter 2) the major part of covered cropping systems in the Netherlands is substrate cultivation. Application of plant protection products in such systems may be according to one of three possibilities, 1) application with the nutrient solution, 2 plant or crop treatment (spraying), and 3) treatment of the glasshouse air compartment (fogging or fumigation). The last two possibilities can be combined into one scenario, but with two variants dependent on the possible direct exposure of the root compartment. The first possibility also needs two variants, one for inert substrate and one for substrates interacting with the PPP. It is however assumed that application of PPP at the nutrient solution is of minor importance in ebb/flow systems, so interaction with the substrate is neglected. About 25% of the area is however still soil bound and obviously an additional scenario is necessary for soil bound cultivations. This chapter describes the concepts of the approach adopted for each of the scenarios.

5.1 Application with the nutrient solution

Figure 3.2 gives a schematic representation of a substrate cultivation system. In practice several variants of the system occur and also volumes may be different. For the development of the substance fate model it was assumed that the Daily Stock Tank is not installed and water, nutrients and PPP directly flow from the mixing tank to the substrate compartment. This assumption was done for practical reasons, to circumvent incorporating time delays in the computer code.

5.1.1 Model concepts

water flows

The water requirements of the system are described in Chapter 4.

The following results of the water model WATERSTROMEN, on a daily basis, are used as input to the substance model:

- the water uptake by the crop;
- the amount of condensation;
- the discharge of the water to be disinfected to the waste water tank.

All other water flows are derived from these three water flows on the basis of:

- a water balance for each tank;
- a fixed relation with one of the three given water flows;
- a constant flow rate to a sewage treatment plant according to permit stipulations, when applicable;
- constant volumes of cultivation tank (cult), drain water tank (dwt), filter (fi), disinfection tank (dinf) and mixing tank (mt); and
- maximum volumes of water-to-be-disinfected tank (used water tank, uwt) and clean water tank (cwt).

In case uwt and cwt are not fully loaded, the water flow out of the tank is zero unless according to the input file water is discharged.

The disposal of water to a sewage system is usually limited to a maximum rate as laid down in permits or prescribed by district water boards. The maximum disposal rate is based on the capacity of the sewage system. Values of 12 - 24 m^3 d^{-1} for the discharge are quite common. The discharge to surface water is often not limited.

Temperature

The model allows input of the temperature from a file. For the moment, glasshouse temperature is assumed constant over the growing season, with a daily fluctuation of a few degrees Celsius according to a sine function. Minimum temperature is at 6 o'clock in the morning. It is assumed that the temperature in the cultivation compartment (cult + dwt) is 2 degrees above the temperature in the storage room (mt, uwt, wwt, fi, dinf, cwt).

Application of substance

A substance is applied to the mixing tank and transported to the cultivation system along with the water flow. The application scheme is given via an input file which allows applications on a daily basis.

Uptake of substance by the crop

A plant protection product reaches the crop via uptake by the roots, along with the nutrients and water. It is assumed that the uptake is passive and that there is some barrier (it is more difficult for the plant to take up the substance than to take up water). This assumption is equal to the assumption in the models for the estimation of leaching, for example the PEARL model (Tiktak et al., 2000; Leistra et al., 2001). This is modelled via a factor, the transpiration stream concentration factor (TSCF), which describes the fraction of the concentration which is taken up. The TSCF is input to the calculations. The parameter may be derived from the octanol water partition coefficient Kow (Briggs et al., 1982):

$$TSCF = 0.784 \exp\left\{ \frac{-\left(\log(Kow) - 1.78\right)^2}{2.44} \right\}$$

Transformation

Transformation in each of the tanks is modelled according to first order degradation kinetics:

$$\frac{dC}{dt} = k\ f_T\ C$$

in which

C the concentration of the substance in the tank

t time

k the first order transformation rate coefficient

f_T factor denoting the influence of temperature

The factor denoting the influence of temperature is given by the Arrhenius equation:

$$f_T = \exp\left(\frac{-\Delta H_T}{R} \left(\frac{1}{T_{tank}} - \frac{1}{T_{ref}} \right) \right)$$

in which:

f_T factor denoting the influence of temperature, (-)

ΔH_T molar enthalpy of transformation, (J mol^{-1}), (default value 65400 J mol^{-1} (EFSA, 2008))

R molar gas constant, (J mol^{-1} K^{-1}), (value 8.314 J mol^{-1} K^{-1})

T_{tank} temperature of the tank, (K)

T_{ref} reference temperature, (K), (value 293.15 K ≡ 20 °C)

It is assumed that there are no other factors influencing / limiting the transformation. In principle, salt stress could influence the transformation. However, as plants will suffer from salt stress much earlier than micro-organisms, management of the system will be such that salt stress on the transformation rate will not occur in practice.

As the transformation rate is independent of the concentration, the concentration in the first order equation can be substituted by the total mass in the tank.

For the moment it is assumed that the half-life under reference conditions is equal for all tanks, except for the disinfection tank. The model therefore allows for the definition of two degradation half-lives, one for the disinfection tank and one for all other tanks. The degradation in the disinfection tank is determined by both the half-life in water and the half-life due to the disinfection. If information on the disinfection process is lacking, it is assumed that the half-life in all tanks is equal under reference conditions. On beforehand it is unknown how disinfection takes place. UV-irradiation and heat treatment are two common practices. It is unknown whether a first order process is acceptable for approximating disinfection for these treatment methods.

Substance flows

For each of the tanks, balance equations determine the substance content of the tank. Each tank is assumed to be a perfectly mixed reservoir, so the substance is distributed evenly over the total tank. Inflows are determined by the flows to the tank and the concentrations in the tank from which the flows origin. Outflows are determined by the flows from the tank and the concentration in the tank. Interaction of the substance with the substrate is assumed to be negligible.

5.2 Application to the crop

5.2.1 Variant 1, root compartment covered to prevent direct exposure

Figure 3.3 gives a schematic representation of the system for situations in which the PPP is applied to the crop by spraying the crop or fogging / fumigation of the glasshouse, with the root compartment shielded against direct exposure to the PPP. Spray droplets or droplets from the fogging or substance applied by fumigation can not directly enter the root compartment because a (plastic) shield covers this compartment and prevents it from being directly exposed. This variant is, for example, applicable to the cultivation of cucumbers and tomatoes in hydroponic systems.

The basis of the model for this variant is identical to the model described in the former paragraph, but as the application method is different, some additional processes and other factors have to be taken into account.

5.2.2 Model concepts and assumptions

Glasshouse dimensions

In the case of crop applications it is necessary to define the dimensions of the glasshouse. It is assumed that the volume of a glasshouse is 50000 m^3 for a production area of 1 ha (height on average 5 m). The glass surface area, sidewalls and roof, is 13300 m^2.

Water flows

The water flows are not different from the water flows described in the previous paragraph, but in order to account for exchange of substance between glasshouse air and condensation, a (constant) volume of water is assumed to reside on the glasshouse glass surface. The volume of this water is equal to the glasshouse glass surface times the thickness of the condensation layer (0.04 mm, Hemming et al., 2006). From this volume, water is flowing to the clean water tank, but at the same time an equal amount is condensating on the glass surface. This concept is a highly simplified approximation as in reality the condensation layer will not exist continuously and will vary in thickness.

Air flow

Glasshouse air exchanges with the air outside the glasshouse at a rate of 50 volumes a day. The exchange rate is highly dependent on the construction of the glasshouse and on climate control in the glasshouse. A value of 50 is a first approximation and a rather central value in the range observed.

Temperature

The model allows input of the temperature from a file. For the moment, temperature is assumed constant over the growing season, with a daily fluctuation of a few degrees Celcius according to a sine function. Minimum temperature is at 6 o'clock in the morning. It is assumed that the temperature in the cultivation compartment (cult + dwt) is 2 degrees above the temperature in the storage room (mt, uwt, wwt, fi, dinf, cwt). It is assumed that the amplitude of the temperature fluctuation in the glasshouse air and the water condensated on the glass surface is twice the fluctuation in the water reservoirs in the cultivation area.

Application of substance

A substance is applied to the crop (spraying) or to the glasshouse air (fogging / fumigation). It is assumed that the applied amount is distributed initially over the crop, the glasshouse air and the glasshouse floor. The distribution is dependent on application type and growth stage of the crop and introduced manually by stating the fraction intercepted (P_{int}) and the fraction airborne (P_{air}). The amount deposited on the floor is then calculated as $(1 – P_{int} – P_{air})$. The application scheme is given via an input file which allows applications on a daily basis.

Dissipation from the crop canopy

A plant protection product reaches the crop canopy as the result of the interception process. Dissipation of a substance from the crop canopy is the result of several processes, ao uptake by the crop, volatilisation to the glasshouse air and transformation on the leaf surfaces. Wash-off is not considered here, because water supply to the plants is via the roots.

FOCUS (2002) and EFSA (2009) use a first order concept for describing the dissipation from the canopy. Doing this, the various processes occurring at the canopy surface are lumped into a single parameter. A default value for half-life of this dissipation process is 10 days, based on several hundred measurements (EFSA, 2009). For the purpose of modelling the emissions from a glasshouse to air and surface water, it is not convenient to lump processes into a single dissipation constant. At least volatilisation has to be distinguished from processes like uptake and transformation. Volatilisation is described below. Dissipation as a result of uptake via the leaves and transformation on the leaf surfaces is assumed to follow first order kinetics (cf van den Berg and Leistra, 2004, Chapter 4) with a default rate constant of 0.0693 d^{-1} (equivalent to a half-life of 10 days).

Crop uptake via the roots

Furthermore, uptake by the roots along with the water is possible after the substance has reached the water system via condensation. It is assumed that the uptake is passive and that there is some barrier (it is more difficult for the plant to take up the substance than to take up water). This is modelled via a factor, the transpiration stream concentration factor, which describes the fraction of the concentration which is taken up. The TSCF is input to the calculations. The parameter may be derived from the octanol water partition coefficient (Briggs et al., 1982). It is assumed that other entry routes into the water system are absent.

Volatilisation from crop and floor

After deposition on the crop or on the floor, the substance may volatilise. The type of floor is a plastic sheet. As further information is usually lacking, the volatilisation flux is assumed to be dependent on the difference in concentration at the floor / leaf surface and the concentration in the glasshouse air:

$$J_{canopy2air} = f_{canopy} \frac{\left(C_{g,canopy} - C_{air}\right)}{r}$$

$$J_{floor2air} = f_{floor} \frac{\left(C_{g,floor} - C_{air}\right)}{r}$$

with

$$f_{canopy} = \frac{M_{canopy}}{M_{canopy,ref}}$$

$$f_{floor} = \frac{M_{floor}}{M_{floor,ref}}$$

in which

J flux from canopy / floor to glasshouse air, (kg m^{-2} d^{-1})

f factor accounting for the relative abundance of the substance, (-)

M mass of substance, (kg m^{-2}), the reference is 1e-4 kg m^{-2} (van den Berg and Leistra, 2004)

C_g concentration of substance in the gas phase at the surface of the canopy or the floor, (kg m^{-3})

C_{air} concentration of substance in glasshouse air, (kg m^{-3})

r overall gas phase resistance to transport, (d m^{-1})

The concentration in the gas phase, c_g, is taken to be the saturated vapour pressure as long as there is substance on the surface. The volatilisation is dependent on the temperature as the saturated vapour pressure is dependent on temperature. The saturated vapour pressure and the solubility in water at reference temperature are input to the model.

The dependency of the saturated vapour pressure is described as in the PEARL model (Tiktak et al., 2000; Leistra et al., 2001) according to an Arrhenius equation with a default value of 96 kJ mol^{-1} for the molar enthalpy of vaporisation. The overall gas phase resistance is set equal to 1.16e^{-3} d m^{-1}, a common value for this resistance under field conditions (Jacobs et al., 2007). This parameter needs more attention in order to represent the situation in the glasshouse better.

Deposition on the glasshouse floor or the surface of the leaves may occur in case the concentration in the glasshouse air is above the concentration at the surface. The distribution over the two surface areas is assumed to be dependent on the leaf area index.

Transformation

Transformation is assumed to take place in all water (tanks), in air, on the soil surface and on the surface of the leaves. All transformation processes are assumed to follow first order kinetics and the half-lives in the different compartments are input to the model (see previous paragraph for equations). Transformation in the various water tanks is not different from the situation in which the substance is applied to the nutrient solution. Transformation rates in glasshouse air and on the floor surface will usually be unavailable and therefore conservative default half-lives of 100 d are assumed. Transformation at the surface of leaves is lumped with crop uptake by the leaves (see above). Transformation in the glasshouse air may be different from transformation in open air because of the glass cover, which may filter (part of) the irradiation. The conditions on the glasshouse floor will be not equivalent to soil conditions, so the usual concepts of transformation in soil (see for example Tiktak et al., 2000, Leistra et al., 2001) will not apply.

Substance flows

Substance flows to and from the water tanks are modelled in the same way as described in the previous paragraph with an exception for the substance flow with the condensation. This flow is assumed absent in case of application with the nutrient solution, but is an important pathway in case of spraying, fogging or fumigation. The flow with the condensation is modelled as follows.

The glasshouse air compartment is assumed to consist of the glasshouse air and the thin water film on the inside of the

$$M_{ghair} = V_{gh}\, C_{ghair} + V_{cond}\, C_{cond} = C_{ghair}\left(V_{gh} + \frac{V_{cond}}{k_{aw}}\right)$$

glass cover:

with

M_{ghair}	mass in the glasshouse air compartment (kg)
V_{gh}	volume of the glasshouse air compartment (m^3)
C_{ghair}	concentration in the air phase of the glasshouse (kg m^{-3})
V_{cond}	volume of the water on the inside of the glasshouse cover (m^3)
C_{cond}	concentration in the water on the inside of the glasshouse cover (kg m^{-3})
k_{aw}	the gas/liquid partition coefficient (-)

It is assumed that constant equilibrium exists between the concentration of the substance in the glasshouse air and the concentration in the condensation water.

Substance flow from the glasshouse air compartment is by gas exchange with the air outside the glasshouse and by condensation flow to the clean water tank. It is assumed that the concentration in the outside air is zero so that no PPP is enters the glasshouse by air exchange.

5.2.3 Variant 2 Root compartment possibly directly exposed

Figure 5.1 gives the schematic representation of this variant. The scheme is only different from the scheme in Figure 3.3 in the exposure of the root compartment of the cultivation. This scheme is, for example, applicable to the cultivation of pot plants where the individual pots are not covered by plastic. The surface layer of the root compartment is possibly exposed at the moment of application. A part of the dose may reach the substrate surface of the pots or the flowing water. At the moment of application, the dosed amount is divided over four fractions: 1) fraction which remains in the air compartment of the glasshouse, 2) fraction intercepted by the crop, 3) fraction deposited on the substrate surface, 4) fraction deposited on the water flowing over the tables.

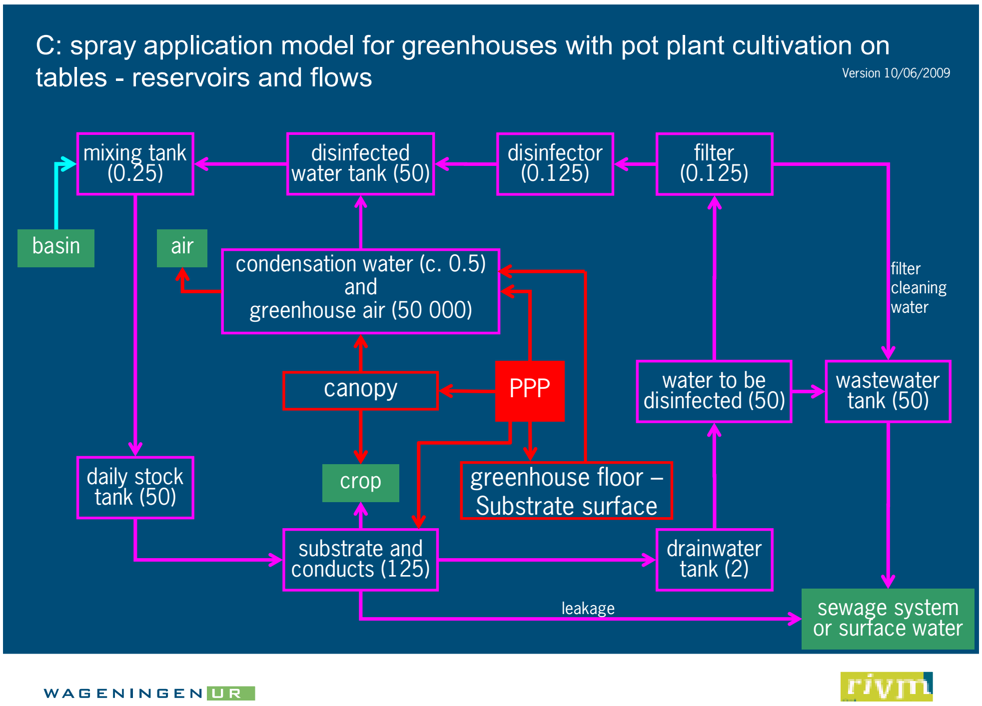


Figure 5.1 Schematic representation of the system for crop application. Variant in which the root compartment may be directly exposed.

5.2.4 Additional concepts and assumptions for the ebb/flow system

Substrate

The substrate is not covered so direct exposure of the substrate to spraying droplets and exchange with the glasshouse air compartment is possible. The total effective (wetted) amount of substrate is 900000 kg ha^{-1} (substrate in pots covering 90% of the area, with an effective height of 10 cm) dry bulk density is assumed to be 1000 kg m^{-3} and the volumetric water content is 0.6. Air-filled porosity is assumed zero in the wetted parts of the pots. Part of the substrate is not wetted, which causes absence of transport between the surface layer of the substrate and the deeper layer. Exchange of substance between the glasshouse air and the surface layer of the substance is possible.

The substrate is not assumed to be inert and sorption to the substrate is possible. Sorption is assumed to be linear with the concentration and is dependent on the organic matter content of the substrate. The fraction organic matter is input to the calculation; the default value used is 0.1.

Application of substance

A substance is applied to the crop (spraying) or to the glasshouse air (fogging / fumigation). It is assumed that the applied amount is distributed initially over the crop, the glasshouse air, the surface of the substrate and the water flowing over the tables. The distribution is dependent on application type, growth stage of the crop and the relative area of the substrate and introduced manually by stating the fraction intercepted (P_{int}), the fraction airborne (P_{air}) and the relative substrate area (P_{pot}). The amount deposited on the substrate is then calculated as $(1 - P_{int} - P_{air}) * P_{pot}$ and the amount deposited on the flowing water as $(1 - P_{int} - P_{air}) * (1 - P_{pot})$ in which P_{pot} indicates the fraction of the surface area occupied by the substrate. For the example calculations a value of 0.9 is taken for P_{pot}. The value of P_{pot} is dependent on the crop and its growth stage. A list of representative values needs to be established. The application scheme is given via an input file which allows applications on a daily basis.

For the simulation of this variant, it is assumed that the total water requirement of the crop is supplied via the tables on which the plants stand. No artificial rain is given. After deposition on the surface of the substrate in the pots, the PPP is assumed to stay on the surface and is not transported further into the substrate. This is because there is no water flow from the surface layer down into the pots. Transport by diffusion is assumed to be negligible. After deposition, the PPP may volatilise from the surface into the glasshouse air.

Volatilisation and deposition
Volatilisation and deposition from / on the surface of the leaves is described identical to the description in section 5.2.2. Volatilisation and deposition on the substrate surface is different as there is interaction with the substrate. It is assumed that the upper 1 cm of the substrate is influencing the concentration in the gas phase at the surface of the substrate and equilibrium partitioning between the phases is assumed. Thus, concentration at the surface may be lower than the saturated gas concentration.

Recirculation concentrations
The part deposited on the tables is dissolved in the water stream over the tables and may distribute in that way over all water tanks. However, as the substrate may interact with the substance and the substance may be distributed over the water phase and the substrate, concentrations in the liquid may be lower, which influences the transfer velocity to other water reservoirs and the uptake by the crop. It is assumed that the pore space of the wetted substrate is completely filled with water. Also here linear equilibrium sorption is assumed. The concentration in the liquid phase in the 'cultivation tank' is calculated according to:
in which

$$C_{cult} = \frac{M_{cult}}{\left(V_{cult} + f_{OM}\ K_{OM}\ S_{cult}\right)}$$

C_{cult}	concentration in the liquid phase of the cultivation tank, (kg m^{-3})
M_{cult}	total mass in the cultivation tank, (kg)
V_{cult}	water volume (content) of the cultivation tank, (m^3)
f_{OM}	fraction organic matter in the substrate in the cultivation tank, (-)
K_{OM}	equilibrium organic matter sorption constant of the substance, (m^3 kg^{-1})
S_{cult}	mass of substrate in the cultivation tank, (kg)

It is assumed that the half-life for the substance in the cultivation tank is not influenced by the sorption process.
The listing of this model is given in Appendix VIII.

5.3 Soil-bound cultivation

Leaching models used in the authorisation procedure of PPP, used in the open field, can in principle also be used to calculate leaching from soil-bound cultivations under cover, possibly with exceptions for highly volatile substances for which the concentration in the glasshouse air may not be neglected. For the time being, it is assumed that the PEARL model (Tiktak et al., 2000; Leistra et al., 2001) can be used for soil-bound covered crops in glasshouses, provided proper soil and climate scenarios are available.

Soil scenario
An overview of soils used in soil-bound cultivation is lacking. As long as there is no good overview and there is no indication that soils used in soil-bound cultivation are more vulnerable than field soils in general, there is no reason to deviate from the scenario used for leaching assessments in the first tier for field applications. Therefore, the FOCUS Kremsmünster soil scenario was used to perform an example calculation. It is recommended that an inventory is performed on the soil types occurring in soil bound covered crop cultivation.

Glasshouse climate

In contrast to the soil scenario, the climate in glasshouses is expected to be quite different from the climate used for field applications. The climate in Dutch glasshouses is highly controlled and climatic conditions differ with respect to temperature, (artificial) precipitation, irradiation and wind conditions and therefore potential evaporation will be different. In principle, the models used for generating the water flows in the previous sections can be used to generate the climate input file for the leaching model.

A pilot run was performed, demonstrating the possible use of the combination of the different models. Time however was lacking to evaluate whether the pilot run can be considered indicative of potential leaching from soil-bound glasshouse cultivations. The evaluation requires more efforts

5.4 Results

This paragraph gives results of simulations for various cases. Appendixes VII and VIII give detailed results of selected cases. The simulations were aimed at testing the models and performing preliminary sensitivity analysis. The results therefore give insight in the order of magnitude of emissions, but cannot be seen as scenarios for evaluation purposes.

5.4.1 Application with the nutrient solution

Tables 5.2 - 5.4 give results for a number of simulations in which the PPP was applied to the nutrient solution. The tables give results for the crops cucumber, pepper and rose. Results for ficus and kalanchoe are comparable. Together these crops are representative of all crops grown in hydroponic systems with the PPP applied to the nutrient solution. Each of the tables gives cumulative amounts (as percentage of the total amount applied) of the substance taken up by the crop, degraded and emitted to surface water. The amounts emitted to surface water are the result of water discharges out of the cultivation system as well as filter rinsing. The percentages in Tables 5.2 and 5.3 do not add up to 100% as leakage is not included in the table. Calculated emission as a result of leakage is in the order of 1 – 2 % of the amount applied (see Table 5.4). Leakage of substance is expected to be close to 1% as it is assumed that 1% of the water supply is lost by leakage. Smaller leakage losses may occur in situations where discharge to the waste water tank is relatively high and recirculation is relatively low.

Table 5.2 Results for cucumber, application to the nutrient solution
(for description of headings see text below Table 5.2)

run	year	basin	ratio	salt 1	salt 2	light	heat	%2crop	%2deg	%2sw
1	wet	500	1.33	0	1.8	10000	VH	57.24	36.30	4.97
2	wet	1500	1.33	0	1.8	10000	VH	57.53	39.70	1.27
3	wet	3000	1.33	0	1.8	10000	VH	58.29	40.16	0.03
4	dry	500	1.33	0	1.8	10000	VH	48.83	38.94	10.97
5	dry	1500	1.33	0	1.8	10000	VH	50.50	40.91	7.27
6	dry	3000	1.33	0	1.8	10000	VH	53.35	43.46	1.80
7	warm	1500	1.33	0	1.8	10000	VH	54.46	37.74	6.39
8	normal	1500	1.33	0	1.8	10000	VH	54.03	39.38	5.19
9	wet	1500	1.33	0.25	1.8	10000	VH	56.71	38.95	2.87
10	dry	1500	1.33	0.25	1.8	10000	VH	49.56	40.04	9.12
11	wet	1500	1.33	0	0.1	10000	VH	58.29	40.16	0.03
12	dry	1500	1.33	0	0.1	10000	VH	54.48	44.07	0.03
13	normal	1500	1.33	0	0.1	10000	VH	56.84	41.65	0.03
14	dry	500	1.33	0	0.1	10000	VH	54.48	44.07	0.03
15#	dry	500	1.33	0	4.5	15000	VH	-	-	-
16	cold	1500	1.33	0	1.8	10000	VH	50.50	40.91	7.27
17	dry	1500	1.33	0	1.8	no	VH	50.28	44.75	3.66
18	dry	1500	2	0	1.8	10000	VH	57.25	39.38	1.88
19	wet	1500	2	0	1.8	10000	VH	57.25	39.38	1.88
20	dry	1500	1.33	0	1.8	10000	N	50.42	41.81	6.46

 # model error for this run, therefore no output

Columns 2 – 8 in all tables characterise grossly the conditions of individual runs. Year gives an indication of weather conditions (outside the glasshouse) during the simulation period. Except for the year 'normal', climate data of a selected real year have been taken; the 'normal' year data are averaged data over years and thus are not real climate data. The column 'basin' indicates the volume ($m^3\ ha^{-1}$) of the basin (per ha). A minimum basin of 500 $m^3\ ha^{-1}$ is compulsory in the Netherlands. Larger basins offer the farmer a larger water supply of water with a low Na concentration; then less water is needed from a secondary water supply with possibly lower quality. The column 'ratio' indicates the ratio between the water supply (m^3) to the crop and the water (m^3) taken up by the crop. The surplus water is recirculated, when possible. The columns 'salt1' and 'salt2' indicate the Na concentration (mmol dm^{-3}) in the water in the basin and the secondary water source respectively. A value of 1.8 mmol dm^{-3} is an indicative value of the Na concentration in drinking water. The column 'light' (lux m^{-2}) indicates the artificial light intensity applied to the crop. The column 'heath' indicates the level of energy used to heat the glasshouse (VH very high, H high, N normal).

The columns %2deg, %2crop and %2sw indicate results of each run as a result of the used application scheme. %2deg gives the cumulative amount of substance degraded in the system as percentage of the total amount supplied. %2crop gives the amounts taken up by the crop (in the case of application with the nutrient solution taken up via the roots). %2sw gives the amounts emitted to surface water or sewage system. This column includes both the amounts rinsed from the filter and the amounts discharged from the cultivation system. The results may vary depending on the application scheme. Emission to surface water will become lower when the substance is applied in the period when enough water of good quality is available, so when there is no need for discharge. In contrast, emission to surface water will become higher when the application is in the period of water discharge. The results therefore should be considered as indicative for possible emissions.

Table 5.3 Results for pepper, application with the nutrient solution (for description of headings see text below Table 5.2).

run	year	basin	ratio	salt 1	salt 2	light	heat	%2crop	%deg	%2sw
1	wet	500	1.33	0	1.8	10000	H	53.87	38.28	6.45
2	wet	1500	1.33	0	1.8	10000	H	57.11	41.15	0.25
3	wet	3000	1.33	0	1.8	10000	H	57.24	41.25	0.02
4	dry	500	1.33	0	1.8	10000	H	60.27	28.03	10.13
5	dry	1500	1.33	0	1.8	10000	H	57.78	37.72	3.00
6	dry	3000	1.33	0	1.8	10000	H	53.03	45.04	0.55
7	warm	1500	1.33	0	1.8	10000	H	54.65	40.38	3.56
8	normal	1500	1.33	0	1.8	10000	H	55.49	42.80	0.27
9	wet	1500	1.33	0.25	1.8	10000	H	56.21	40.51	0.27
10	dry	1500	1.33	0.25	1.8	10000	H	58.09	35.06	5.35
11	wet	1500	1.33	0	0.1	10000	H	57.24	41.25	0.02
12	dry	1500	1.33	0	0.1	10000	H	53.35	45.24	0.02
13	normal	1500	1.33	0	0.1	10000	H	55.65	42.88	0.02
14	dry	500	1.33	0	0.1	10000	H	53.35	45.24	0.02
15[#]	dry	500	1.33	0	3	10000	H	-	-	-
16	cold	1500	1.33	0	1.8	10000	H	57.78	37.72	3.00

[#] *model error for this run, therefore no output*

Table 5.4: Results for rose, application with the nutrient solution (for description of headings see text below Table 5.2).

rose	year	basin	ratio	salt 1	salt 2	light	heat	%2crop	%2deg	%2sw	%leak
1	wet	500	1.5	0	1.8	15000	VH	51.54	37.08	9.83	1.55
2	wet	1500	1.5	0	1.8	15000	VH	54.01	36.61	7.76	1.62
3	wet	3000	1.5	0	1.8	15000	VH	58.54	39.58	0.13	1.76
4	dry	500	1.5	0	1.8	15000	VH	42.72	44.36	11.64	1.28
5	dry	1500	1.5	0	1.8	15000	VH	42.93	40.34	15.44	1.29
6	dry	3000	1.5	0	1.8	15000	VH	49.31	39.42	9.79	1.48
7	warm	1500	1.5	0	1.8	15000	VH	50.03	37.58	10.89	1.50
8	normal	1500	1.6	0	1.8	15000	VH	47.35	40.15	10.99	1.52
9	wet	1500	1.5	0.25	1.8	15000	VH	52.74	36.22	9.46	1.58
10	dry	1500	1.5	0.25	1.8	15000	VH	42.54	40.41	15.77	1.28
11	wet	1500	1.5	0	0.1	15000	VH	58.54	39.58	0.13	1.76
12	dry	1500	1.5	0	0.1	15000	VH	55.17	43.07	0.11	1.66
13	normal	1500	1.5	0	0.1	15000	VH	56.89	41.28	0.11	1.71
14	dry	500	1.5	0	0.1	15000	VH	55.17	43.07	0.11	1.66
15	dry	500	1.7	0	3	15000	VH	38.28	50.57	9.85	1.30
16	cold	1500	1.5	0	1.8	15000	VH	42.93	40.34	15.44	1.29
17	dry	1500	1.5	0	1.8	10000	VH	45.12	40.83	12.70	1.35
18	dry	1500	2	0	1.8	15000	VH	41.77	42.99	13.57	1.67
19	wet	1500	2	0	1.8	15000	VH	51.92	37.81	8.20	2.08
20	dry	1500	1.5	0	1.8	15000	N	44.89	37.55	16.21	1.35
21	dry	500	1.7	0	1.8	15000	VH	40.29	47.82	10.54	1.34

From Tables 5.2 – 5.4 it becomes clear that emission to surface water is highly variable and, as a result, also plant uptake and degradation vary highly. Emission to surface water is calculated to be high when application of the substance is in the period in which the water supply is from a secondary water source with lower quality, ie a higher sodium content. Such situations occur more frequently when the storage capacity for rain water is low and tap water is the second water supply.

If the quality of the secondary water source is high, i.e. low sodium content as in the case of reverse osmosis water, the emission to surface water becomes low. In those cases only rinsing of the filter contributes to the emission as discharge of the nutrient solution from the cultivation system is not necessary. If the quality of the secondary water source is very poor, the necessary discharge is no longer compatible with the other system settings and erroneous results are obtained. For rose, the ratio for supply water / crop uptake is 1.5, while sometimes higher ratios are needed to meet the discharge requirements.

5.4.2 Crop application by spraying

This paragraph gives the results of calculations for cucumber with various growth conditions with respect to water supply, heating and light supply. In all variant a hypothetical substance is sprayed onto cucumber in full leaf stage, with an assumed crop interception of 90%. A general assumption is that 3% of the applied dose stays airborne, so 7% is deposited on the floor surface.

For the calculations the following dossier assumptions were used: The substance is applied 6 times in quantities of 0.165 kg ha^{-1} on days 93, 100, 107, 156, 163 and 170, so the first application is on April 3rd. The substance is assumed to have the default fate properties as described earlier, the most important being: a $DegT_{50}$ in water of 10 days, a DT_{50} for crop uptake of 10 days, a molar mass of 300 g mol^{-1}, a water solubility of 100 mg dm^{-3} and a saturated vapour pressure under reference conditions of 1e-5 Pa.

Table 5.5 gives the results of 20 runs. Run specifications are given in columns 2 – 8. The columns indicate:

year	the overall weather condition in a year
basin	the volume of the basin for storage of rainfall
ratio	the fraction of the total water supply to the crop flowing to the used water tank
salt 1	the sodium concentration (mmol dm^{-3}) in the primary water source (= basin)
salt 2	the sodium concentration (mmol dm^{-3}) in the secondary water source (= for example drinking water, reversed osmosis water of groundwater)
light	the artificial light intensity
heath	the heating conditions (VH = high energy consumption, N = normal energy consumption)

The columns 9 through 13 give the amounts degraded and taken up by the crop as well as the emissions to air and surface water and the amount lost as a result of leakage. The data indicate the results as percentage of the cumulative dose at the end of the simulation period, so the results are the cumulative amounts degraded, taken up or emitted.

Table 5.5 Results for cucumber, crop application. (DegT_{50} of 10 days, molar mass of 300 g mol^{-1}, water solubility of 100 mg dm^{-3} and vapour pressure of 1e-5 Pa).

run	year	basin	ratio	salt 1	salt 2	light	heath	%2deg	%2crop	%2sw	%2air	%leak
1	wet	500	1.33	0	1.8	10000	VH	7.52	90.43	0.16	0.30	0.08
2	wet	1500	1.33	0	1.8	10000	VH	7.58	90.48	0.05	0.30	0.09
3	wet	3000	1.33	0	1.8	10000	VH	7.61	90.48	0.01	0.30	0.09
4	dry	500	1.33	0	1.8	10000	VH	7.34	90.33	0.45	0.32	0.06
5	dry	1500	1.33	0	1.8	10000	VH	7.50	90.38	0.22	0.32	0.07
6	dry	3000	1.33	0	1.8	10000	VH	7.50	90.38	0.22	0.32	0.07
7	warm	1500	1.33	0	1.8	10000	VH	7.51	90.46	0.14	0.30	0.09
8	normal	1500	1.33	0	1.8	10000	VH	7.53	90.43	0.11	0.34	0.08
9	wet	1500	1.33	0.25	1.8	10000	VH	7.55	90.47	0.09	0.30	0.09
10	dry	1500	1.33	0.25	1.8	10000	VH	7.49	90.38	0.24	0.32	0.07
11	wet	1500	1.33	0	0.1	10000	VH	7.61	90.48	0.01	0.30	0.09
12	dry	1500	1.33	0	0.1	10000	VH	7.59	90.48	0.01	0.32	0.09
13	normal	1500	1.33	0	0.1	10000	VH	7.60	90.46	0.01	0.34	0.09
14	dry	500	1.33	0	0.1	10000	VH	7.59	90.48	0.01	0.32	0.09
15#	dry	500	1.33	0	4.5	15000	VH	-	-	-	-	-
16	cold	1500	1.33	0	1.8	10000	VH	7.50	90.38	0.22	0.32	0.07
17	dry	1500	1.33	0	1.8	no	VH	7.53	90.36	0.19	0.35	0.07
18	dry	1500	2.00	0	1.8	10000	VH	7.50	90.39	0.21	0.32	0.08
19	wet	1500	2.00	0	1.8	10000	VH	7.57	90.47	0.06	0.30	0.09
20	dry	1500	1.33	0	1.8	10000	N	7.52	90.37	0.21	0.32	0.07

 # run not successful

%2crop is a combination of crop uptake via the leaves and via the roots and transformation on the leaf surfaces. For crop uptake via the leaf surface and transformation on the leaf surface a combined dissipation half-life of 10 days is assumed.

The emission percentages do not add-up to 100% of the applied amount. At the end of the growing season still some substance is left on the floor of the glasshouse.

The major driving force for the emission to surface water is the discharge of water from the used water tank to the waste water tank and subsequently the discharge from the waste water tank to surface water. If there is little demand for the secondary water supply or the secondary water supply has a low sodium concentration, then the discharge to the waste water tank is low and so is the discharge to surface water. Wet years have lower emissions to surface water than comparable dry years and a higher basin volume per ha goes along with a lower emission. It seems however that even a basin volume of 3000 m^3 ha^{-1} is not large enough to prevent emissions due to discharge. The more recirculation takes place, the more degradation and plant uptake may occur.

The minimum value of 0.02% emission to surface water is due to regeneration of the filter. This amount of emission can be lowered if the amount of water used for the regeneration is lowered or if the residence time of the filter cleaning water in the waste water tank is becoming larger, giving the substance more time to be degraded in the waste water tank.

Emission to air is rather low because substance properties are chosen to have rather low emissions to air. Emissions to surface water are low compared to emissions in other paragraphs because of the sorption of the substance to the organic matter in the pots. This causes relatively low concentrations in the cultivation tank and consequently lower concentration in discharge water.

Run 15, with a relatively high sodium content in the secondary water supply, did not end successfully. Given the other conditions, the water discharge to surface water is too high for the set-up of the system. In order to terminate the run successfully conditions have to be changed, for example by increasing the ratio.

5.4.3 Crop application in ebb/flow systems

Table 5.6 gives results of calculations in which a PPP is applied to pot flowers grown in an ebb/flow system.

Table 5.6: Results for ficus grown in pots on floor in an ebb/flow system ($DegT_{50}$ of 10 days, molar mass of 300 g mol^{-1}, water solubility of 100 mg dm^{-3} and vapour pressure of 1e-5 Pa)

ficus	year	basin	ratio	salt 1	salt 2	light	heath	%2crop	%deg	%2air	%leak	%2sw
1	wet	500	1.33	0	1.8	no	VH	90.38	7.73	0.40	0.08	0.06
2	wet	1500	1.30	0	1.8	no	VH	90.40	7.76	0.40	0.08	0.01
3	wet	3000	1.30	0	1.8	no	VH	90.40	7.76	0.40	0.08	0.01
4	dry	500	1.70	0	1.8	no	VH	90.30	2.50	0.43	0.08	0.53
5	dry	1500	1.33	0	1.8	no	VH	90.39	7.64	0.43	0.08	0.11
6	dry	3000	1.33	0	1.8	no	VH	90.40	7.73	0.43	0.08	0.01
7	warm	1500	1.33	0	1.8	no	VH	90.41	7.76	0.39	0.08	0.01
8	normal	1500	1.33	0	1.8	no	VH	90.38	7.72	0.46	0.08	0.01
9	wet	1500	1.33	0.25	1.8	no	VH	90.39	7.77	0.40	0.08	0.01
10	dry	1500	1.40	0.25	1.8	no	VH	90.36	7.54	0.43	0.08	0.24
11	wet	1500	1.30	0	0.1	no	VH	90.40	7.76	0.40	0.08	0.01
12	dry	1500	1.30	0	0.1	no	VH	90.40	7.73	0.43	0.08	0.01
13	normal	1500	1.30	0	0.1	no	VH	90.38	7.72	0.46	0.08	0.01
14	dry	500	1.30	0	0.1	no	VH	90.40	7.73	0.43	0.08	0.01
15	cold	1500	1.30	0	1.8	no	VH	90.39	7.64	0.43	0.08	0.11
16	dry	1500	2.00	0	1.8	no	VH	90.39	7.55	0.43	0.12	0.16
17	wet	1500	2.00	0	1.8	no	VH	90.39	7.55	0.43	0.12	0.16
18	dry	1500	1.30	0	1.8	no	N	90.37	7.71	0.45	0.08	0.04

Emission to air is rather low because substance properties are chosen to have rather low emissions to air. Emissions to surface water are low compared to emissions in other paragraphs because of the sorption of the substance to the organic matter in the pots. This causes relatively low concentrations in the cultivation tank and consequently lower concentration in discharge water.

6 Scenario Development

At the moment insufficient census information on glasshouse cultivation systems is available to derive overall 90th percentile emission scenarios for different crop groups. Necessary information would be on o.a. size of rain basin, secondary water source, discharge strategy, heating strategy and type of filter. As an alternative, it is proposed to derive 90th percentile situations from all calculations as described in this report. It is advisable however to gather information on the systems and derive system weighted 90th percentiles in the near future.

Under normal operating conditions, the sodium concentration determines the discharge of recirculation solution to the waste water tank and eventually to sewage system or surface water. Figure 6.1 – 6.3 give %2sw as a function of total Na supply to the growing system. It appears that there is a rather good correlation between total sodium supply and emission%, as expected.

The 90th percentile emission occurs for the situations:

- total sodium supply of approximately 6000 mol ha^{-1} in case of pepper with application to the nutrient solution;
- total sodium supply of approximately 8000 mol ha^{-1} in case of cucumber with application to the crop;
- total sodium supply of approximately 1700 mol ha^{-1} in case of ficus with application to the crop in an ebb/flow system.

In terms of scenario parameters, this would be: 1500 m^3 ha^{-1} basin in a dry year with tap water as additional water source.

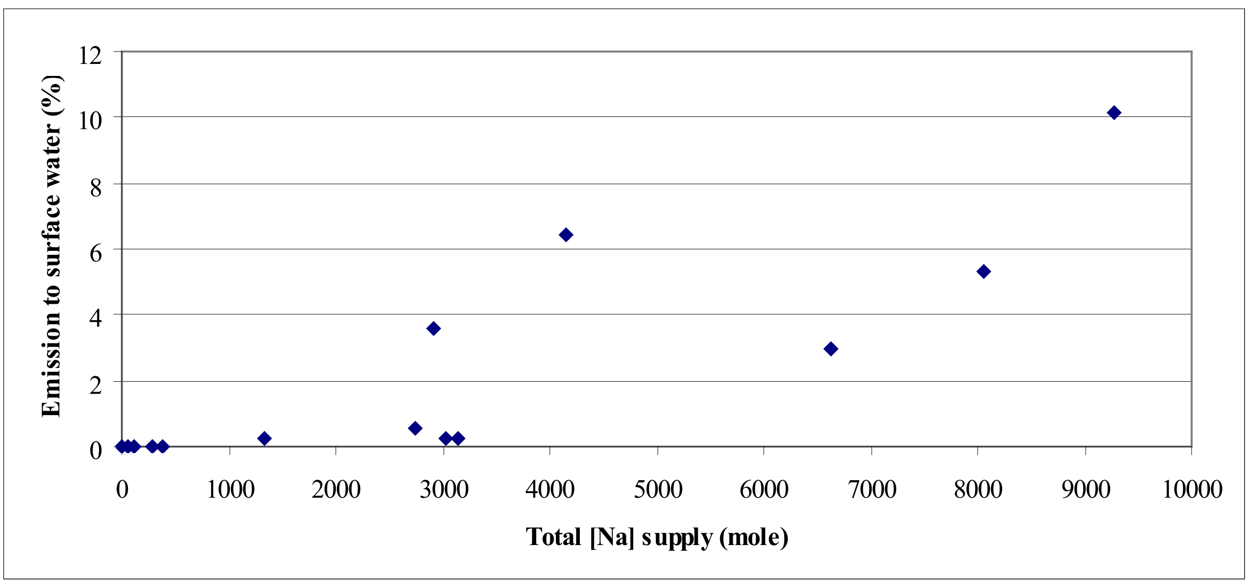


Figure 6.1 Emission to surface water (% of applied amount) as a function of total sodium supply: pepper application to solution

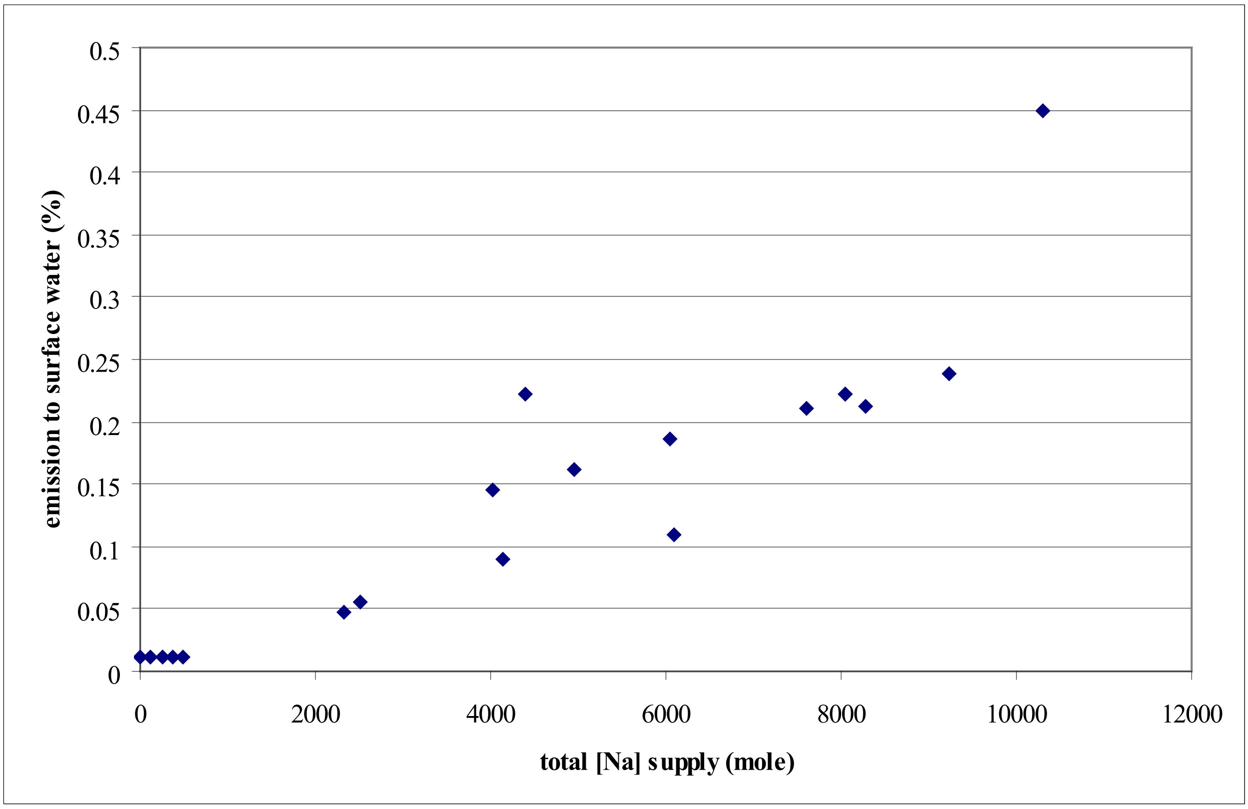


Figure 6.2 Emission to surface water (% of applied amount) as a function of total sodium supply: cucumber crop application

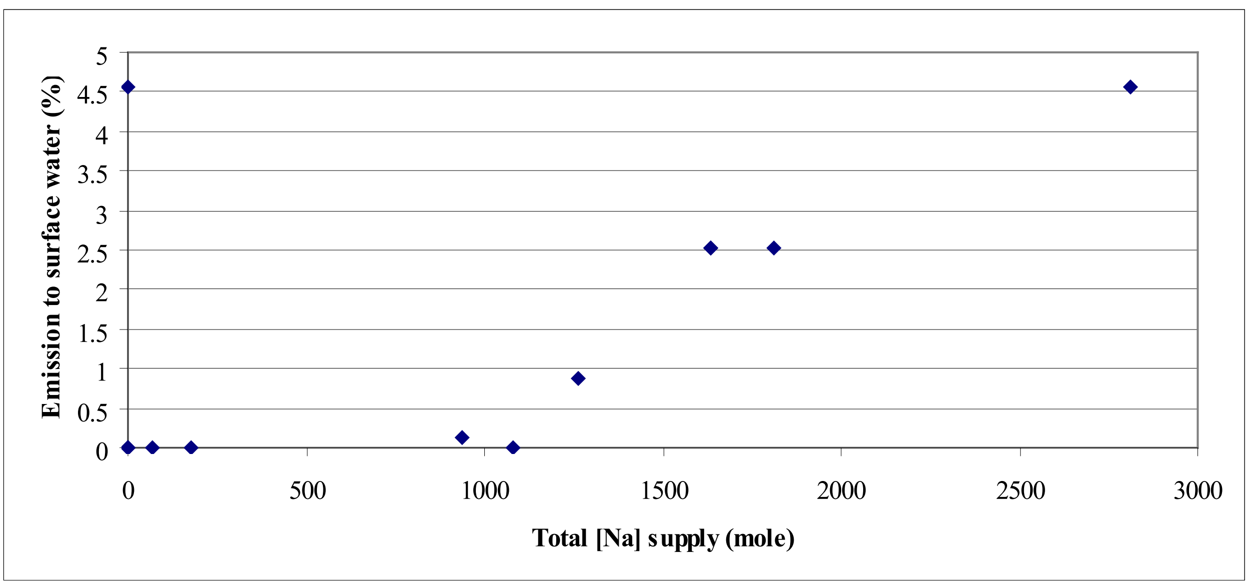


Figure 6.3 Emission to surface water (% of applied amount) as a function of total sodium supply: ficus crop application

7 Conclusions and Recommendation

7.1 Conclusions

Ministries of LNV and VROM asked the Dutch work group on emissions of PPP from glasshouses to surface water whether the fixed percentage of 0.1% emission from glasshouses as used in the authorisation procedure for PPPs in the Netherlands and elsewhere in the EU needs reconsideration. It was concluded that this percentage indeed needs reconsideration because:

- The high variability in cropping systems and developments in these systems in glasshouse horticulture.
- The nature of the emission: the emission is to be considered a point source rather than a diffuse source.
- Calculated emissions for a hypothetical substance applied to different example crops, cultivation systems with different application methods ranging from negligible to over 10% of the applied amount. Although the percentages cannot be directly compared, it is clear that the currently used value is likely to underestimate the emission for realistic worst case conditions.

In Phase I it was concluded that the wide variation in the system dimensions in the sector and the lack of quantitative data required a modelled approach. By stating that emissions of PPPs will always follow water stream, models were developed or adapted to quantify water streams and substance fate.

7.1.1 Modelled approach

The modelled approach required clustering and schematisation to cope with the diversity in watering systems and water management strategies. This was achieved by:

1. Taking into account only glasshouse systems.

2. Clustering / limiting watering systems to:

	Water system
Soil bound	Sprinkler irrigation
Soilless:	
Production on gullies	Drip irrigation
Production on benches/tables	Ebb/flow
Production on profiled concrete floor	Ebb/flow

3. Focusing on main emission routes.
The main emission routes to surface water were found to be: system discharge and filter cleaning.

4. Limiting to discharge strategies based Na^+- accumulation
As system discharge was found to be the main contributor to the total emission, the leading principle for this discharge had to be understood. The Na^+ concentration in recirculation water was found to be the most quantitative and (legally) accepted leading principle for discharge of nutrient solution. Since discharge seems to be the most important emission route in many situations, the variables that determine the Na^+ concentration in the nutrient solution were the main factors

influencing the emissions to surface water. Other main contributors to emissions are filter cleaning and leakage. In our approach we modelled for differences in application method, watering system and in Na^+ sensitivity of the different crops.

5. Selecting of discharge strategy

The model WATERSTROMEN was adapted for the purpose of calculating water flows and timing of discharge based on Na^+ concentration and leakage. Water flows were modelled for six selected model crops: cucumber, sweet pepper, rose, kalanchoe, ficus and chrysanthemum. Series of calculations with the model of WATERSTROMEN lead to the following conclusions regarding discharge quantities:

- The amount of discharge is greatly dependent on (1) the size of the rainwater collection basin, (2) the [Na^+] in the additional water source, (3) rainfall, (4) irradiation, and (5) the crop characteristics with respect to uptake and sensitivity to Na^+.
- The discharge strategy followed can differ widely – from occasional larger volumes to daily smaller volumes. We modelled for occasional discharge of larger volumes.
- Modelled discharge volumes of order of magnitude up to 2000 m^3 ha^{-1} per year correspond with surveys among growers.

6. Selection of PPP applications

Two main application method categories can be distinguished in soilless cultivation systems: 1) PPP application along with the nutrient solution and 2) PPP spraying or fogging the crop. As the entry of a PPP into the systems is quite different and therewith the redistribution routes, different substance fate models are required. In fact, three substance fate models are necessary: 1) one model for application with the nutrient solution, 2) one model for treating the crop canopy in situations where the root compartment is not directly exposed and 3) one model for treating the crop canopy in situations where part of the application solution may directly enter the root compartment. The third model applies to, for example, the treatment of pot plants.

Substance fate modelling provided insight in total PPP emissions. In the calculations extreme emission-prone situations were avoided (such as large system discharges just after PPP-application).

The calculations summarised in Table 7.1 show emissions in substrate systems to have wide ranges in emissions over the differences in rainfall, water source and the dimensions of water basins of 500-3000 m^3 ha^{-1}. These data are based on a substance with transformation time ($DegT_{50}$) of 10 days and 6 applications per year. Furthermore, it is assumed that disinfection of the nutrient solution does not influence the transformation rate.

Table 7.1 Calculated extremes in emissions caused by differences in rainfall, sizes of water basin and [Na^+] in the water source for additional water, based on the chosen application scheme for PPPs for one example substance and one application scheme

Fate model	Calculated for model crop	Low end of emission (% of application)	High end of emission (% of application)
Application via nutrient solution	cucumber	0.03	11
	pepper	0.02	10
	rose	0.11	16
Crop application by spraying	cucumber	0.01	0.5
Crop application in ebb/flow system	ficus	0.01	0.5

The simulations used were aimed at testing the models and performing preliminary sensitivity analysis. The results therefore give insight in the order of magnitude of emissions, but cannot be used as scenario's for evaluation purposes. For example, no calculations were made to analyse emissions as function of the moment of application and of discharge – though most extreme situations were avoided, and only a limited variety of water sources was used.

The higher calculated emissions in cucumber compared to pepper show the impact of the moment between application and discharge. Cucumber is more tolerant of Na^+ and has a higher maximum uptake than pepper. The expected emission would therefore be lower. Consequently, the cucumber simulation may have calculated the application-discharge less fortunate than in the pepper simulations, resulting in higher total emissions.

The use of PEARL for soil bound cropping systems seems to be adequate. At the moment, however, necessary input information for crops grown in glasshouses is lacking, so no definite calculations can be made. For a full analysis, more information on variability of climatic conditions in glasshouses is necessary.

7.1.2 Scenario Development

In authorisation procedures for plant protection products it is nowadays quite common to use realistic worst case environmental scenarios for the assessments. It seems logical to use such scenarios also for glasshouse horticulture in the Netherlands as well. Earlier chapters indicate that emissions of PPP from substrate growing systems to surface water are highly influenced by the following scenario aspects:

- the cultivation system, soil-bound or soilless;
- the application method of the PPP;
- the tolerance and uptake capacity of a crop for Na^+ ions;
- the Na-concentration in the water supplied to the crop (total sodium amount).

Based on these four aspects, the work group proposes to implement the following combinations in the authorisation procedure:

No.	cultivation system	Fate model	Crop type (based on sodium tolerance level)
1	Soil bound	PEARL	-
2	Soilless	Application along with the nutrient solution	Low
3			Medium
4			High
5		Application to the crop canopy; with no direct exposure of the root compartment	Low
6			Medium
7			High
8		Application to the crop canopy; with direct exposure of the root compartment	Low
9			Medium
10			High

Soil-bound cultivation occurs in approximately 25% of the glasshouse horticultural area in the Netherlands. Based on experience with field applications, it seems adequate to implement only one scenario. If condensation is collected and used for crop water supply, then the emission to surface water via the condensation route will be negligible and does not need to be considered. At the moment information on crop water supply patterns is insufficient to define the scenario more precisely. The scenario can be implemented in the PEARL software. In PEARL all current application methods can be dealt with. Further scenario development needs to take place in the following phase of the project.

Soilless cultivation occurs in approximately 75% of the glasshouse horticultural area. Emissions depend highly on the need for discharge of recirculation water (triggered by the sodium concentration) and the application method. The need for discharge of recirculation water depends on the tolerance of the crop for sodium ions, the uptake capacity for sodium and the sodium ion concentration in the supply water. The work group suggests to distinguish levels of sodium tolerance and -uptake. Boundaries will have to be confirmed in the next phase of the project. This would result in a number of water regimes to be implemented in the assessment procedures. For practical purposes, crops can be attributed to one of these categories.

Correlations were found between the total sodium supply to the cropping system and the emission percentage. Almost independent of the sodium tolerance level, the 90th percentile emission percentages of the performed calculations were found for situations in which the rain water basin amounted to 1500 m^3 ha^{-1} and the additional water supply source was tap water. Unfortunately information is lacking to derive 90th percentile emission percentages based on occurrence of situations in the Netherlands, so a weighted procedure cannot be performed. Nevertheless, the work group proposes to implement these situations for authorisation assessments as a Realistic Worst Case and update this procedure as soon as census information on lay-out of cropping systems becomes available.

7.1.3 Consequences for authorisation

The calculated emissions rates are higher than 0.1%, as used in the current procedure. Because emission rates are input for further eco-toxicological evaluation; the increase in estimated emissions can have consequences for the total evaluation of the environmental impact of a PPP.

An evaluation assessment for a soilless cultivation scenario needs a selection of 1 out of 3 crop groups (based on Na^+ tolerance) and a selection of 1 out of 3 fate models (different because of different application methods). In principle, it is possible to distinguish less or more situations in the evaluation. This is a political choice. It is possible to distinguish less or more categories regarding the sodium tolerance of crops and it is possible to limit or expand the number of fate models.

As a consequence of the used approach, the DegT50 of a substance in water is a prerequisite and therefore needs to be available in an authorisation dossier. DegT50s in water may be derived from, amongst other, transformation studies in water / sediment systems and hydrolysis studies. A DegT50 derived from transformation studies of the PPP in water / nutrient solutions, as used in covered cropping systems, would be preferable. However, such studies seem to be lacking at the moment. Likewise uptake of PPP's in the crop and DegT50 in substrates could be further investigated and used in the calculations.

7.2 Recommendations

7.2.1 Recommendations for further development and implementation

- The effort of the working group has been focused on glasshouse production systems. No models have yet been made for the cropping systems for mushrooms, chicory, bulb forcing and (plastic) tunnels.
- The calculations have not been tested with findings on production sites. The order of magnitude of total discharge seems to correspond with reality, but so far data for further evaluation lack. Further testing of the models therefore requires wider surveys on discharge strategies, use of water sources, dimensions of rain water basins (or other means of capturing and storing rain water), different application schemes and monitoring of actual emission. In addition, experimental research with growing systems is necessary to get a higher validation status of the models.
- Interception of spray by the crop and remaining airborne droplets are now assumed and taken as fixed numbers. In reality they will depend on kind of crop, crop growth stage, dose and spray application method. A further investigation of interception by crops and remaining airborne droplets is necessary to better assess crop uptake and deposits on the floor.

- In order to profit from further experimental research, it is highly recommended to perform further sensitivity and un certainty analyses. Such analyses help in focusing experiments on the most important aspects / parameters.

- Table 7.4 gives the list of assumptions used by the working group. Based on sensitivity analyses further effort should be focussed on:
    - occurrence of other drivers for system discharge than Na^+ and the discharge strategies;
    - practice of filter cleaning;
    - evaporation models;
    - scenario development for the timing of the PPP application in relation to the moment of discharge;
    - effect of the amount of PPP sprayed and the distribution of PPP on crop, soil and cover
    - watering strategies in soil bound cultivation.
- Further analysis of using PEARL as tool for soil bound cultivation in covered cropping systems is necessary. PEARL can probably not be used if the watering system generates an uneven distribution of water in the system.
- For authorisation purposes a software tool needs to be developed. This was earlier proposed as Phase 3 of the project definition of the Working Group.
- The models should be open for inclusion of strategies of Risk Mitigation, such as end of pipe remediation (UV, H_2O_2-dosage, heating, filters), longer recirculation, delayed discharge and application during specific growing phases.
- Further development of the used models should include:
    - analysis of the impact of addition of pesticide at substrate and conduct-level as opposed to addition with recirculation water
    - Evaluation of recent evaporation studies, including evaporation studies in other climate regions

Table 7.4 Assumptions in the model based approach

WATERSTROMEN model:

1. The models base heavily on Na^+ as the dominant driver for water discharge. This assumption has strong theoretical and practical base. However, experts in the field argue that other drivers are commonly used, such as:
   - observed growth reduction;
   - wish to add a certain quantity of fresh nutrients and water;
   - EC-values in recirculation water;
   - other system parameters, like for example oxygen levels in the substrate; or / and
   - flushing the system as a precautionary measure.
2. Vaporisation (model by De Graaf – 1988)
3. Volume of condensation water – this volume varies depending on the type of ventilation and condensation collection in the glasshouse. The volume contributes to the amount of available Na^+-free water.
4. Filter strategy – the model WATERSTROMEN uses a fixed % of the amount of water draining from the cultivation. The underlying assumption for the filter strategy is a constant quantity of debris in the recirculation water (algae, etc.). In practice, filter cleaning is frequently based on the pressure difference over incoming and outgoing water from the filter. Automatic flushing then occurs when this pressure difference exceeds a preset value
5. % leakage – This is assumed constant over the entire growth period and taken to be approximately 1% of the water that is recirculated. This assumption has little margin of alteration: 0 - 2%.
6. Volumes of reservoirs – due to the assumption of homogenised distribution of plant protection products in the reservoirs, the assumptions on volume of the reservoirs have little impact on the outcome of the calculations.

Pesticide Fate:

1. Filter strategy – this model assumes a % of the volume that passes the filter as filter cleaning water. The chosen percentage has a direct effect on the emission.
2. Moment of application of PPP in relation to system discharge and filter cleaning. The calculations now only account for no system discharge during the first day after PPP application.
3. Reservoirs are assumed perfectly homogenised systems, including the reservoir 'cultivation tank' (the substrate and the pipe systems).
4. Transformation of PPP is assumed to follow a 1st order break down process; no interaction with the substrate is assumed, except for spray applications to pots in ebb/flow systems.
5. A number of assumptions is used for break down in the water film of the condensation stream.
6. The initial distribution of the plant protection product over crop and other parts of the systems is taken as fixed dependent on crop stage and floor occupation. Data on crop stage and floor occupation are however not readily available. Furthermore crop interception and airborne droplets are taken as fixed number, but in reality will depend on crop, crop growth stage, dose and spray application method. They factors were not further investigated.
7. Pesticide in pots filled with soil or peat-mixtures is assumed to degrade and not to diffuse into deeper layers of the pot. This needs more attention / verification.
8. Pesticide fate on leaves and volatilisation from plant and floor are estimated.
9. The discharge strategy of the waste water tank is taken into account. Usually the discharge to a STP is regulated, but the discharge to surface water not. Storage of waste water for some time may reduce emissions to surface water.

Other

- Spray and space application as well as soil applications with volatile substances are considered. Emissions resulting from these applications may be influenced by ventilation of the glasshouses. The ventilation rate is input to the calculations.
- No climate scenarios are available for soil bound cultivation.

7.2.2 Recommendations for reduction of emissions

The main emission routes to surface water were shown to be the discharge of recirculation water and the discharge of filter cleaning water and leaching in soil-bound cultivation.

Reducing discharge of recirculation water

Emissions of recirculation water are currently needed to lower the concentrations of disruptive elements for growth in the recirculation water – be it Na^+ or other growth reducing substances. Based on Na^+ as leading principle for discharge the following recommendations can be drawn:

- optimize the size of rainwater basins and use supply water with low Na^+ levels like reversed osmosis water (~ 0.1 mmol dm^{-3});
- ensure longer recirculation;
- optimizing the size of the waste water tank to allow for longer degradation.

Reducing discharge of filter cleaning water

Emission through the discharge of filter cleaning water can be prevented or lowered by:

- using clean water for cleaning filters instead of the current practice of using recirculation water for cleaning;
- longer retention time in waste water tank to allow for further ongoing degradation.

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Appendix I. Glossary and abbreviations

English Term	Dutch Term	Definition
Brine	Brein	Salt water fraction of the process of reversed osmosis.
Condensation (water)	condens(water)	Condensation at the inside of the cover (glasshouse). Reuse of this water is compulsory.
Container- or pot system	container- of potteelt	Production system for crops in pots, containers, bags, buckets and trays with a fixed shape.
Covered crop	bedekte teelt	crop covered by e.g. net, plastic sheet or glass. At least the roof is covered.
Covered Cropping system	beschermde of bedekte teelt	Production system with crops grown under glass, plastic or other cover for a significant part of the cropping season. This includes cells and climate chambers. Mulching and a plastic film immediately on top of the soil are excluded.
Discharge	Lozing of spui	General term: water which is disposed to surface water or sewage system
Discharge strategy	Lozing strategie	Strategy of discharge – for example: daily discharge versus occasional discharge. The strategy is a result of crop management practices and possibilities for temporary storage of waste water in the watering system.
Drain water	drainwater	Excess water collected after water supply in a substrate system.
Drainage water	drainagewater	Water collected via the pipe drainage system in soil bound cropping systems.
Drift	drift	The spread of fine droplets of PPP outside the area of application caused by wind or thermal transport.
Drip treatment	druppelbehandeling	Application of PPP via the drip irrigation system.
Drip irrigation	Druppelirrigatie	an irrigation method which saves water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters.
Ebb/flow irrigation	Irrigatie met eb- en vloedsysteem	Watering system where plants are watered by a temporary layer of water which goes up and down.
Filter discharge	filterspoelwater	Water used to flush / clean the filters.
First Flush	first Flush	In the Netherlands compulsory collection of the first 2 mm of rain after 48h of dryness and reuse of this water in the recirculation system.
Glasshouse	Glazen kas	A glass building where plants are grown
Greenhouse	Kas	is a structure with a glass or plastic roof and frequently glass, netting or plastic walls where plants are grown
Hydroponic cultivation	substraatteelt	See soilless cultivation
Leakage	lekkage	Unintended flow of water to the environment (leaking pipes or troughs)
Overflow	overstort	surplus water flowing directly from basin to surface water
Cleaning water	spoelwater	Water used to clean/rinse equipment or product
Plant Protection Products (PPP)	gewasbescher-mingsmiddelen	any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest or disease
Protected cultivation	beschermde of bedekte teelt	See: Covered cropping system
Recirculation water	recirculatiewater	Drain water collected from the system and re-used for irrigation.
Scenario	scenario	Set of climatological conditions, lay-out of the growing system, characteristics of the watering system and set management conditions (here, the scenarios are converted to model inputs)
Soil bound production	grondgebonden teelt	Growing system in which plants are grown in soil.
Soilless cultivation	substraatteelt, grondloze teelt	Growing plants in a soilless system
Soilless system	Teeltsysteem voor substraatteelt, grondloze teelt	Growing systems in which plants are grown out of the soil in substrates or directly in a nutrient solution.
Soil treatment	grondbehandeling	Treatment of the soil in order to reduce or eliminate populations of plant pathogens. This may be a biological, chemical, mechanical or thermal treatment.
Spray	bespuiting	The application of PPP often in diluted form, using spray equipment.
Sprinkler irrigation	beregening	water is piped to one or more central locations within the field or greenhouse and distributed by overhead high-pressure sprinklers or guns (overhead irrigation)
Submerge treatment	dompelbehandeling	Submerging plant material (planting material or end product) in a PPP solution
Substrate cultivation	substraatteelt	See soilless cultivation
Supply water	gietwater	Irrigation water supplied to the plants, with rainwater as a basic source
Additional supply water	Aanvullend gietwater (suppletiewater)	Irrigation water from other sources then rain water

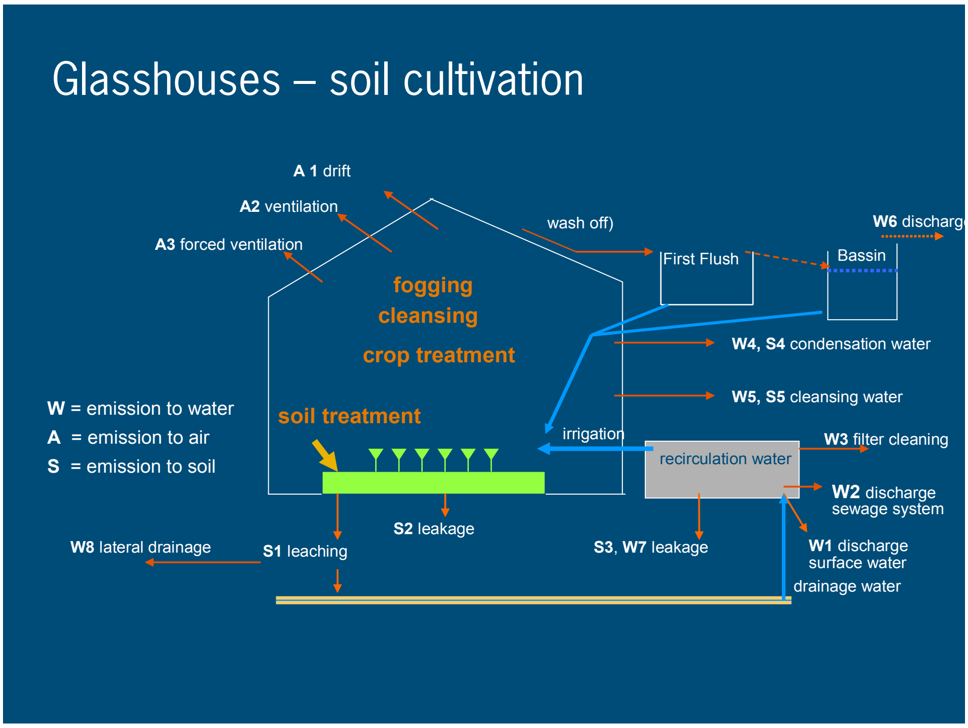
English Term	Dutch Term	Definition
Surface water	oppervlaktewater	Term used as legally determined.
System discharge	spui	Discharge of recirculation water
Ventilation	ventilatie	Exchange of glasshouse air by opening the windows to dehumidify and to decrease temperature in the glasshouse
Waste Water	afvalwater	General term for water that has to be disposed off
Wash off	afspoeling glasdek	PPP being washed off from the glasshouse by rain water
Watering System	watersysteem	System of engineered hydrologic and hydraulic components which provide water supply: collection, supply water, preparation of nutrient solution, irrigation, filtration, re-use and waste water collection.

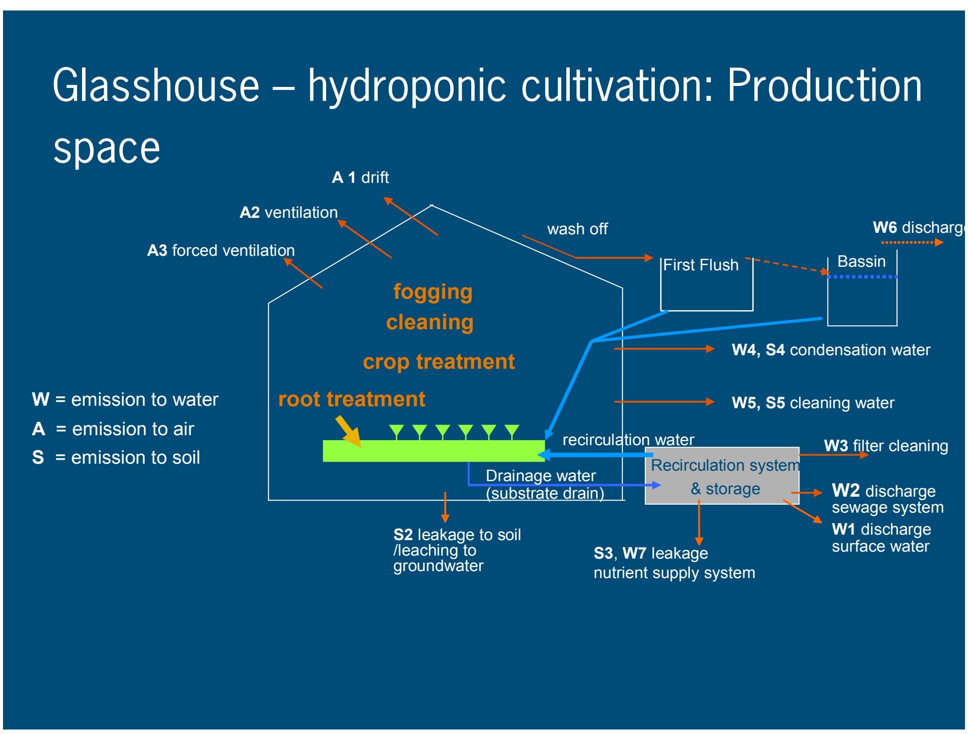
Appendix II. Area of covered crops in hectares

Crop	Area		
	2003	**2004**	**2007**
Vegetables			
Tomato	1257	1352	1478
Cucumber	639	623	557
Sweet Pepper	1213	1205	1074
Aubergine	85	88	92
Vegetables (melon, lettuce, radish, etc)	608	578	444
Berries			57
Plant material			209
Seed production			139
Total vegetables	3802	3846	4.050
Artificial substrate	2987	2925	3.310*
Champignons			77
Chicory			7
Flowers			
Roses	853	848	575
Carnation	46	41	25
Chrysanthemum	702	679	485
Freesia	198	191	131
Gerbera	246	227	162
Lilies	266	273	202
Alstroemeria	98	85	81
Orchids	216	233	205
Anthurium	95	96	93
Eustoma	72	69	37
Other flowers	676	640	567
Total flowers	3468	3382	2563
Artificial substrate	1109	1110	1068
Pot plants			
Flowering	737	767	752
Green	575	573	498
Outdoor plants			805
Plant material			283

* The estimated area of organic production of vegetables is 100 ha. Organic production is soil-based.

Appendix III. Schemes of total emission routes from glasshouse cultivation systems





Appendix IV. Climatic years in WATERSTROMEN

The used climatic years, characterised as dry, wet, warm, cold, average are data from the KNMI weather station Naaldwijk and main characteristics are presented in Table 4.1.The classifications dry, wet, warm, cold are based on one specific parameter. By accident the cold year is the same as the dry year (1996). The average year is an average of 30 years, consequently, it is less dynamic as a single year and hardly any dry, wet or warm periods appear. Therefore this type of year is less useful to use in Model WATERSTROMEN.

Table 4.1: Overview of weather data used in Model WATERSTROMEN

Climate data	weather station Naaldwijk						
year	Average temperature	Average Tmax	Average Tmin	Average Relative Humidity	Annual radiation sum (R)	Sum annual precipitation	characterisation year
	˚C	˚C	˚C	%	kJ/cm^2		
1995	12.0	15.8	8.6	71	396682	663	
1996	9.7	13.7	9.7	72	370930	496	cold, dry
1997	11.7	15.4	8.5	76	374679	582	
1998	12.0	15.6	9.1	79	343274	1013	dark
1999	12.0	15.1	9.1	73	376787	863	
2000	11.5	14.2	9.1	74	352659	696	
2001	11.2	13.9	8.7	74	378932	1091	wet
2002	11.4	14.4	8.8	73	370271	905	
2003	11.2	14.6	8.1	70	416331	619	light
2004	11.1	14.0	8.3	75	383862	894	
2006	11.7	14.6	8.9	64	392258	781	warm
average year	10.6	14.4	8.3		371552	758	1970-1999 30 years average

Appendix V: Results quantifying water fluxes with the water balance model

Numbers refer to water fluxes given in Figure 4.1

CUCUMBER

	artifical lighting lux	heating	size rainwater basin m^3/ha	[Na] in rainwater mmol/l	[Na] in additional water mmol/l	drain percentage %	1 precipitation per year m^3/ha	2 crop uptake m^3/ha	3 total water supply m^3/ha	4 drain m^3/ha	5 condensation water m^3/ha	6 discharge m^3/ha	7 filter cleaning water m^3/ha	8 leakage m^3/ha	9 total waste water m^3/ha	10 basin water m^3/ha	11 additional water m^3/ha	12 total water use m^3/ha
Wet year	10000	very heavy	500	0	1.8	0.25	10905	8693	11591	2898	1113	400	126	174	700	5623	2747	8370
	10000	very heavy	1500	0	1.8	0.25	10905	8693	11591	2898	1113	140	126	174	440	6780	1293	8074
	10000	very heavy	3000	0	1.8	0.25	10905	8693	11591	2898	1113	0	126	174	300	7879	0	7879
	10000	very heavy	1500	0	1.8	0.5	10905	8693	17386	8693	1113	140	189	261	590	6840	1391	8231
	10000	very heavy	1500	0	0.1	0.25	10905	8693	11591	2898	1113	0	126	174	300	6825	1141	7967
Dry year	10000	very heavy	500	0	1.8	0.25	4958	8657	11543	2886	1134	940	125	173	1239	3089	5726	8816
	10000	very heavy	1500	0	1.8	0.25	4958	8657	11543	2886	1134	700	125	173	999	4107	4464	8571
	10000	very heavy	3000	0	1.8	0.25	4958	8657	11543	2886	1134	320	125	173	619	5755	2436	8192
	10000	very heavy	500	0	0.1	0.25	4958	8657	11543	2886	1134	0	125	173	299	3216	4787	8003
	10000	very heavy	1500	0	0.1	0.25	4958	8657	11543	2886	1134	0	125	173	299	4217	3768	7985
	10000	very heavy	1500	0	1.8	0.5	4958	8657	17314	8657	1134	660	188	260	1108	4174	4604	8778
Warm year	10000	very heavy	1500	0	1.8	0.25	7813	8865	11820	2955	1160	340	128	177	646	6193	2231	8424
Cold year	10000	very heavy	1500	0	1.8	0.25	4958	8657	11543	2886	1134	700	125	173	999	4107	4464	8571
Average year	10000	very heavy	1500	0	1.8	0.25	7583	8629	11506	2876	1117	600	125	173	898	5092	3388	8481
	10000	very heavy	1500	0	0.1	0.25	7583	8629	11506	2876	1117	0	125	173	298	5228	2591	7819
Dry year	10000	very heavy	1500	0.25	1.8	0.25	4958	8657	11543	2886	1134	800	125	173	1099	4100	4555	8656
Wet year	10000	very heavy	1500	0.25	1.8	0.25	10905	8693	11591	2898	1113	200	126	174	500	6800	1353	8154
Dry year	no	very heavy	1500	0	1.8	0.25	4958	7129	9506	2376	781	480	103	143	726	3925	3359	7284
	10000	normal	1500	0	1.8	0.25	4958	8441	11255	2814	1107	660	122	169	951	4140	4226	8366

Numbers refer to water fluxes given in Figure 4.1

Sweet Pepper (paprika)

	artifical lighting lux	heating	size rainwater basin m^3/ha	[Na] in rainwater mmol/l	[Na] in additional water mmol/l	drain percentage %	1 precipitation per year m^3/ha	2 crop uptake m^3/ha	3 total water supply m^3/ha	4 drain m^3/ha	5 condensation water m^3/ha	6 discharge m^3/ha	7 filter cleaning water m^3/ha	8 leakage m^3/ha	9 total waste water m^3/ha	10 basin water m^3/ha	11 additional water m^3/ha	12 total water use m^3/ha
wet year	10000	heavy	500	0	1.8	0.25	10905	7739	10319	2580	1012	500	112	155	767	5257	2311	7568
	10000	heavy	1500	0	1.8	0.25	10905	7739	10319	2580	1012	100	112	155	367	6381	742	7123
	10000	heavy	3000	0	1.8	0.25	10905	7739	10319	2580	1012	0	112	155	267	6993	0	6993
	10000	heavy	1500	0	0.1	0.25	10905	7739	10319	2580	1012	0	112	155	267	6361	662	7023
dry year	10000	heavy	500	0	1.8	0.25	4958	7693	10257	2564	1030	1260	111	154	1525	3144	5155	8299
	10000	heavy	1500	0	1.8	0.25	4958	7693	10257	2564	1030	860	111	154	1125	4139	3677	7816
	10000	heavy	3000	0	1.8	0.25	4958	7693	10257	2564	1030	300	111	154	565	5792	1527	7320
	10000	heavy	500	0	0.1	0.25	4958	7693	10257	2564	1030	0	111	154	265	3258	3823	7081
	10000	heavy	1500	0	0.1	0.25	4958	7693	10257	2564	1030	0	111	154	265	4212	2821	7033
warm year	10000	heavy	1500	0	1.8	0.25	7813	7895	10526	2632	1051	380	114	158	652	5894	1620	7514
cold year	10000	heavy	1500	0	1.8	0.25	4958	7693	10257	2564	1030	860	111	154	1125	4139	3677	7816
average year	10000	heavy	1500	0	1.8	0.25	7583	7679	10239	2560	1018	380	111	154	645	5726	1686	7412
	10000	heavy	1500	0	0.1	0.25	7583	7679	10239	2560	1018	0	111	154	265	5781	1149	6930
dry year	10000	heavy	1500	0.25	1.8	0.25	4958	7693	10257	2564	1030	1020	111	154	1285	4065	3912	7976
wet year	10000	heavy	1500	0.25	1.8	0.25	10905	7739	10319	2580	1012	200	112	155	467	6319	864	7183

Numbers refer to water fluxes given in Figure 4.1

ROSE

	artifical lighting	heating	size rainwater basin	[Na] in rainwater	[Na] in additional water	drain percentage	1 precipitation per year	2 crop uptake	3 total water supply	4 drain	5 condensation water	6 discharge	7 filter cleaning water	8 leakage	9 total waste water	10 basin water	11 additional water	12 total water use
	lux		m^3/ha	mmol/l	mmol/l	%	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha
Wet year	15000	heavy	500	0	1.8	0.25	10905	9828	13104	3276	1519	963	142	163	1268	6405	3217	9622
	15000	heavy	1500	0	1.8	0.25	10905	9828	13104	3276	1519	417	142	163	722	7437	1609	9046
	15000	heavy	3000	0	1.8	0.25	10905	9828	13104	3276	1519	0	142	163	305	8614	0	8614
	15000	heavy	1500	0	1.8	0.5	10905	9828	19656	9828	1519	421	214	244	879	7523	1670	9194
	15000	heavy	1500	0	0.1	0.25	10905	9828	13104	3276	1519	0	142	163	305	7437	1235	8672
Dry year	15000	heavy	500	0	1.8	0.25	4958	9785	13047	3262	1533	2619	142	162	2923	3348	7922	11271
	15000	heavy	1500	0	1.8	0.25	4958	9785	13047	3262	1533	2052	142	162	2356	4382	6337	10719
	15000	heavy	3000	0	1.8	0.25	4958	9785	13047	3262	1533	1166	142	162	1470	6064	3715	9779
	15000	heavy	500	0	0.1	0.25	4958	9785	13047	3262	1533	0	142	162	304	3576	5098	8674
	15000	heavy	1500	0	0.1	0.25	4958	9785	13047	3262	1533	0	142	162	304	4616	4080	8696
	15000	heavy	500	0	1.8	0.4	4958	9785	16308	6523	1533	2632	177	203	3012	3381	7979	11360
	15000	heavy	1500	0	1.8	0.5	4958	9785	19570	9785	1533	1962	213	243	2418	4572	6132	10704
/arm year	15000	heavy	1500	0	1.8	0.25	7813	9957	13276	3319	1549	841	144	165	1151	6872	2747	9619
Cold	15000	heavy	1500	0	1.8	0.25	4958	9785	13047	3262	1533	2052	142	162	2356	4382	6337	10719
rage year	15000	heavy	1500	0	1.8	0.25	7583	9756	13008	3252	1524	1626	141	162	1929	5462	4775	10237
	15000	heavy	1500	0	0.1	0.25	7583	9756	13008	3252	1524	0	141	162	303	5607	2932	8540
Dry year	15000	heavy	1500	0.25	1.8	0.25	4958	9785	13047	3262	1533	2229	142	162	2533	4498	6441	10940
Wet year	15000	heavy	1500	0.25	1.8	0.25	10905	9828	13104	3276	1519	601	142	163	906	7427	1792	9219
Dry year	10000	heavy	1500	0	1.8	0.25	4958	8900	11867	2967	1299	1705	129	147	1981	4309	5347	9656
	15000	normal	1500	0	1.8	0.25	4958	9552	12736	3184	1501	1936	138	158	2232	4444	5852	10296

Numbers refer to water fluxes given in Figure 4.1

Phalaenopsis on tables

	artifical lighting	heating	size rainwater basin	[Na] in rainwater	[Na] in additional water	drain percentage	1 precipitation per year	2 crop uptake	3 total water supply	4 drain	5 condensation water	6 discharge	7 filter cleaning water	8 leakage	9 total waste water	10 basin water	11 additional water	12 total water use
	lux		m^3/ha	mmol/l	mmol/l	%	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha
Wet year	no	very heavy	500	0	1.8	0.25	10905	3452	4603	1151	393	0	50	69	119	3179	0	3179
	no	very heavy	1500	0	1.8	0.25	10905	3452	4603	1151	393	0	50	69	119	3179	0	3179
	no	very heavy	3000	0	1.8	0.25	10905	3452	4603	1151	393	0	50	69	119	3179	0	3179
	no	very heavy	1500	0	1.8	0.5	10905	3452	6905	3452	393	0	75	104	179	3238	0	3238
	no	very heavy	1500	0	0.1	0.25	10905	3452	4603	1151	393	0	50	69	119	3179	0	3179
Dry year	no	very heavy	500	0	1.8	0.25	4958	3481	4641	1160	412	4516	50	70	4636	2323	5453	7777
	no	very heavy	1500	0	1.8	0.25	4958	3481	4641	1160	412	0	50	70	120	3189	0	3189
	no	very heavy	3000	0	1.8	0.25	4958	3481	4641	1160	412	0	50	70	120	3189	0	3189
	no	very heavy	500	0	0.1	0.25	4958	3481	4641	1160	412	0	50	70	120	2335	931	3266
	no	very heavy	1500	0	0.1	0.25	4958	3481	4641	1160	412	0	50	70	120	3189	0	3189
	no	very heavy	1500	0	1.8	0.5	4958	3481	6962	3481	412	0	76	104	180	3249	0	3249
Warm year	no	very heavy	1500	0	1.8	0.25	7813	3519	4692	1173	416	0	51	70	121	3224	0	3224
Cold year	no	very heavy	1500	0	1.8	0.25	4958	3481	4641	1160	412	0	50	70	120	3189	0	3189
Average year	no	very heavy	1500	0	1.8	0.25	7583	3511	4682	1170	395	0	51	70	121	3237	0	3237
	no	very heavy	1500	0	0.1	0.25	7583	3511	4682	1170	395	0	51	70	121	3237	0	3237
Dry year	no	very heavy	1500	0.25	1.8	0.25	4958	3481	4641	1160	412	3523	50	70	3643	4221	3525	7745
Wet year	no	very heavy	1500	0.25	1.8	0.25	10905	3452	4603	1151	393	1060	50	69	1179	4239	0	4239
Dry year	no	normal	1500	0	1.8	0.25	4958	3248	4331	1083	379	0	47	65	112	2981	0	2981

Numbers refer to water fluxes given in Figure 4.1

Ficus on floor

	artifical lighting lux	heating	size rainwater basin m^3/ha	[Na] in rainwater mmol/l	[Na] in additional water mmol/l	drain percentage %	1 precipitation per year m^3/ha	2 crop uptake m^3/ha	3 total water supply m^3/ha	4 drain m^3/ha	5 condensation water m^3/ha	6 discharge m^3/ha	7 filter cleaning water m^3/ha	8 leakage m^3/ha	9 total waste water m^3/ha	10 basin water m^3/ha	11 additional water m^3/ha	12 tc water u m³/
Wet year	no	very heavy	500	0	1.8	0.25	10905	4695	6261	1565	529	40	68	94	202	3886	520	44
	no	very heavy	1500	0	1.8	0.25	10905	4695	6261	1565	529	0	68	94	162	4328	0	43
	no	very heavy	3000	0	1.8	0.25	10905	4695	6261	1565	529	0	68	94	162	4328	0	43
	no	very heavy	1500	0	1.8	0.5	10905	4695	9391	4695	529	0	102	141	243	4409	0	44
	no	very heavy	1500	0	0.1	0.25	10905	4695	6261	1565	529	0	68	94	162	4328	0	43
Dry year	no	very heavy	500	0	1.8	0.25	4958	4698	6264	1566	551	780	68	94	942	2648	2554	52
	no	very heavy	1500	0	1.8	0.25	4958	4698	6264	1566	551	220	68	94	382	3665	907	45
	no	very heavy	3000	0	1.8	0.25	4958	4698	6264	1566	551	0	68	94	162	4309	0	43
	no	very heavy	500	0	0.1	0.25	4958	4698	6264	1566	551	0	68	94	162	2640	1758	43
	no	very heavy	1500	0	0.1	0.25	4958	4698	6264	1566	551	0	68	94	162	3644	703	43
	no	very heavy	1500	0	1.8	0.5	4958	4698	9396	4698	551	240	102	141	483	3649	1006	46
Warm year	no	very heavy	1500	0	1.8	0.25	7813	4806	6408	1602	561	0	70	96	166	4411	0	44
Cold year	no	very heavy	1500	0	1.8	0.25	4958	4698	6264	1566	551	220	68	94	382	3665	907	45
Average year	no	very heavy	1500	0	1.8	0.25	7583	4730	6306	1577	532	0	69	95	163	4361	0	43
			1500	0	0.1	0.25	7583	4730	6306	1577	532	0	69	95	163	4361	0	43
Dry year	no	very heavy	1500	0.25	1.8	0.25	4958	4698	6264	1566	551	340	68	94	502	3644	1055	46
Wet year	no	very heavy	1500	0.25	1.8	0.25	10905	4695	6261	1565	529	0	68	94	162	4328	0	43
Dry year	no	normal	1500	0	1.8	0.25	4958	4465	5954	1488	518	140	65	89	294	3561	701	42

Chrysanthemum in soil

	artifical lighting lux	heating	size rainwater basin m^3/ha	[Na] in rainwater mmol/l	[Na] in additional water mmol/l	drain percentage %	1 precipitation per year m^3/ha	2 crop uptake m^3/ha	3 total water supply m^3/ha	4 drain m^3/ha	5 condensation water m^3/ha	6 discharge m^3/ha	7 filter cleaning water m^3/ha	8 leakage m^3/ha	9 total waste water m^3/ha	10 basin water m^3/ha	11 additional water m^3/ha	12 tc wa u m³/
Wet year	10000	normal	500	0	1.8	0.25	10905	8658	11545	2886	1342	0	125	1732	1857	7172	1970	105
	10000	normal	1500	0	1.8	0.25	10905	8658	11545	2886	1342	0	125	1732	1857	8002	1140	105
	10000	normal	3000	0	1.8	0.25	10905	8658	11545	2886	1342	0	125	1732	1857	9142	0	105
	10000	normal	1500	0	1.8	0.5	10905	8658	17317	8658	1342	0	188	2598	2786	8531	1534	114
	10000	normal	1500	0	0.1	0.25	10905	8658	11545	2886	1342	0	125	1732	1857	8002	1140	105
Dry year	10000	normal	500	0	1.8	0.25	4958	8628	11504	2876	1368	0	125	1726	1851	4799	4276	104
	10000	normal	1500	0	1.8	0.25	4958	8628	11504	2876	1368	0	125	1726	1851	5676	3399	104
	10000	normal	3000	0	1.8	0.25	4958	8628	11504	2876	1368	0	125	1726	1851	6857	2217	104
	10000	normal	500	0	0.1	0.25	4958	8628	11504	2876	1368	0	125	1726	1851	4799	4276	104
	10000	normal	1500	0	0.1	0.25	4958	8628	11504	2876	1368	0	125	1726	1851	5676	3399	104
	10000	normal	1500	0	1.8	0.5	4958	8628	17256	8628	1368	0	188	2588	2776	5790	4204	114
Warm year	10000	normal	1500	0	1.8	0.25	7813	8781	11708	2927	1370	0	127	1756	1883	7569	1693	106
Cold year	10000	normal	1500	0	1.8	0.25	4958	8628	11504	2876	1368	0	125	1726	1851	5676	3399	104
Average year	10000	normal	1500	0	1.8	0.25	7583	8565	11420	2855	1352	0	124	1713	1837	7774	1243	104
	10000	normal	1500	0	0.1	0.25	7583	8565	11420	2855	1352	0	124	1713	1837	7774	1243	104
Dry year	10000	normal	1500	0.25	1.8	0.25	4958	8628	11504	2876	1368	0	125	1726	1851	5676	3399	104
Wet year	10000	normal	1500	0.25	1.8	0.25	10905	8658	11545	2886	1342	0	125	1732	1857	8002	1140	105

Appendix VI Some sensitivity analyses

This paragraph gives a number of sensitivity analyses for the scenario in which the plant protection product is sprayed onto the crop. The analyses are performed by varying one parameter in each analysis. The basis of this analysis is run 2 in Table 5.5. The target output in all cases is the percentage of the total dose emitted to surface water.

height of the glasshouse

The height of the glasshouse influences the volume of the glasshouse as well as the surface of the glasshouse cover. Therefore it influences the distribution of the substance over the glasshouse air and the condensation. The figure below indicates that the emission to surface water diminishes when the height of the glasshouse becomes larger.

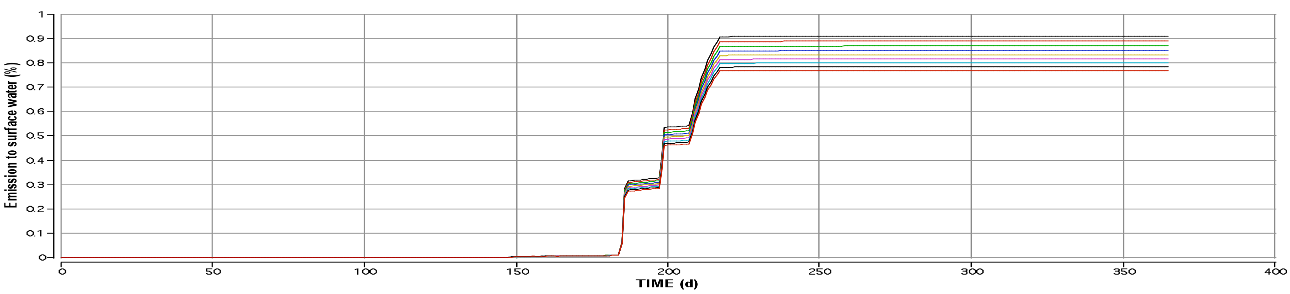


Fig.1 influence of height of glasshouse. Glasshouse height from 3 (top) to 7 (bottom) m

ventilation rate

When the ventilation rate changes from 10 d^{-1} to 100 d^{-1} the emission to surface water diminishes from 1% to 0.7%. The emission might increase when the ventilation rate diminishes to extremely low values, lower than 10 d^{-1}.

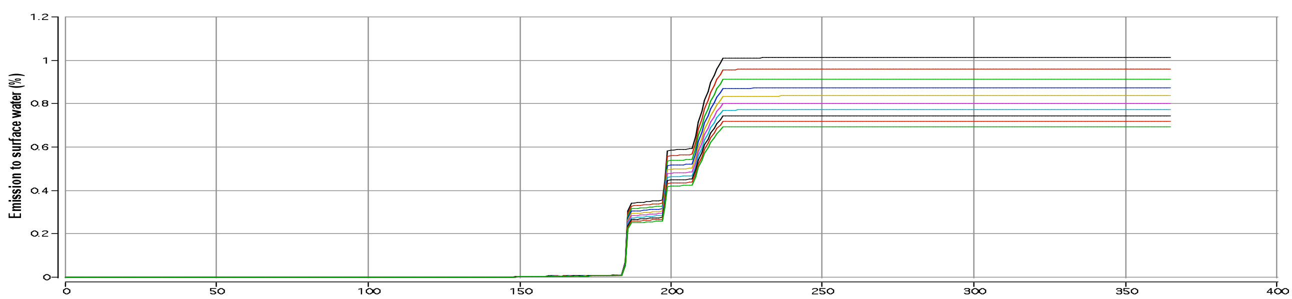


Fig 2 Influences of ventilation rate. Top 10 d^{-1}, bottom 100 d^{-1}.

leakage from cultivation

If substance is leaking from the cultivation, this has a slight influence on the emission to surface water. A leakage fraction of zero leads to an emission to surface water of approximately 1%, a leakage fraction of 0.05 (5%) leads to a lower emission to surface water of approximately 0.7%. The substance leaked from the system might end up in the soil in groundwater or surface water.

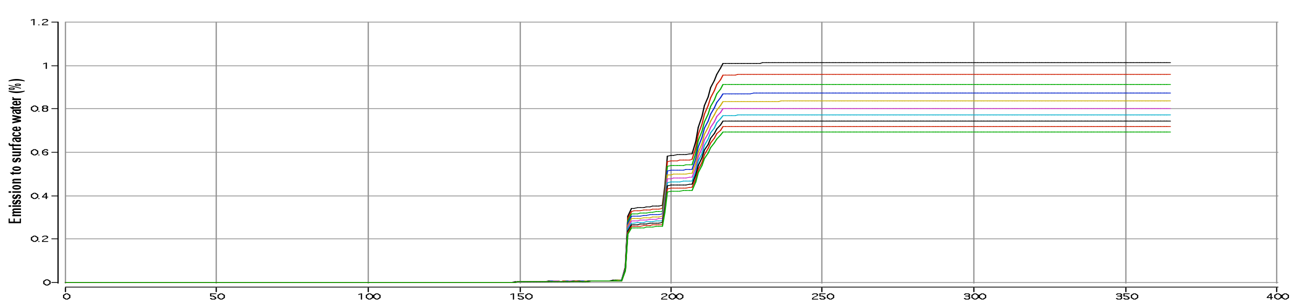


Fig.4 Influence of fraction leakage. Top 0, bottom 5%.

Appendix VII Listing of glasshouse substrate model 1

Table VII.1 Abbreviations

mt	mixing tank
dst	daily stock tank (not used)
cult	substrate and conducts
dwt	drain water tank
uwt	tank containing water to be disinfected (used water tank)
wwt	waste water tank (water to be discharged to surface water or sewage treatment work)
sw	surface water
stw	sewage treatment work (not distinguished from SW)
fi	filter
dinf	disinfection unit
cwt	clean water tank
M	mass
W	water flow
V	volume
J	substance flux
C	concentration
T	temperature
2	(in names) direction
#	indicates input from a file

```
{Glasshouse substrate model with variable water flows PPP applied with the nutrient solution, repeated application possible}

METHOD AUTO

STARTTIME = 1
STOPTIME=350
DTMIN = 1e-6
DTMAX = 0.01
DTOUT = 1

{water part}
{tank volumes}
Vmt = 0.25   ; (m3), mixing tank
Vcult = 125   ; (m3), cultivation, including conducts
Vdwt = 2  ; (m3), drainwater tank
Vuwtmax = 50   ; (m3), water tank to be disinfected (used water tank), max water volume
Vuwtmin = 1.5 ; (m3), water tank to be disinfected, minimum water volume (3% of max)
Vwwt_lim = 10  ; (m3), volume of wwt above which discharge starts
Vfi = 0.125   ; (m3), filter
Vdinf = 0.125  ; (m3), disinfection tank
Vcwtmax = 50 ; (m3), volume clean water tank
```

```
{parameters water flows}
Lcult = 0.01  ; (-), fraction leakage from cultivation
Lfilt = 0.01  ; (-), fraction lost from filter due to regeneration
Wdis = 48   ; (m3/d), (maximum) allowed discharge flow to surface water
Rws_c = 1.7  ; (-), ratio water supply to crop demand

{water flows}
Wmt2cult = Rws_c * #W2crop(TIME)
Wleak = Rws_c * Lcult * #W2crop(TIME)
Wcult2dwt = (Rws_c - Rws_c * Lcult - 1) * #W2crop(TIME)
Wuwt2fi = IF (Vuwt + Wcult2dwt - #Wuwt2wwt(TIME)) > Vuwtmax THEN (Vuwt + Wcult2dwt - #Wuwt2wwt(TIME) - Vuwtmax)
ELSE 0
Wfi2dinf = (1-Lfilt) * Wuwt2fi
Wfi2wwt = Lfilt * Wuwt2fi
Wcwt2mt = IF Vcwt <= Vcwtmax THEN 0 ELSE Wfi2dinf + #Wcond(TIME)
W2sw = IF Vwwt <= Vwwt_lim THEN 0 ELSE Wdis

{variable water volumes}
Init Vwwt = 1  ; (m3), water content waste water tank
   d/dt (Vwwt) = #Wuwt2wwt(TIME) + Wfi2wwt - W2sw
Init Vuwt = Vuwtmin  ; (m3), water content used water tank
   d/dt (Vuwt) = Wcult2dwt - #Wuwt2wwt(TIME) - Wuwt2fi
Init Vcwt = 1  ; (m3), water content clean water tank
   d/dt (Vcwt) = Wfi2dinf - Wcwt2mt + #Wcond(TIME)

{substance input parameters}
DegT50=10  ; (d), half-life for degradation under reference conditions
DegT50dinf = 10   ; (d), half-life in disinfection tank
tscf = 0.5  ; (-), transpiration stream concentration factor, sort of barrier factor
; zero: nothing is taken up by plant, 1: full passive uptake

{Application}
d/dt (Map) = +#application(TIME)
    Init Map = 0   ; (kg), mass applied

{mass in reservoirs}
d/dt (Mmt) = -Jdegmt + Jcwt2mt - Jmt2cult + #application(TIME)
   Init Mmt = 0   ; (kg), mass in mixing tank
d/dt (Mcult) = -Jdegcult + Jmt2cult - Jcult2leak - Jcult2crop - Jcult2dwt
   Init Mcult = 0   ; (kg), mass in substrate
d/dt (Mdwt) = -Jdegdwt + Jcult2dwt - Jdwt2uwt
   Init Mdwt = 0   ; (kg), mass in drainwatertank
d/dt (Muwt) = -Jdeguwt + Jdwt2uwt - Juwt2wwt - Juwt2fi
   Init Muwt = 0   ; (kg), mass in used water tank
d/dt (Mfi) = -Jdegfi + Juwt2fi - Jfi2dinf - Jfi2wwt
   Init Mfi = 0   ; (kg), mass in filter
d/dt (Mdinf) = -Jdegdinf + Jfi2dinf - Jdinf2cwt
   Init Mdinf = 0  ; (kg), mass in disinfection tank
```

```
d/dt (Mcwt) = -Jdegcwt + Jdinf2cwt - Jcwt2mt
   Init Mcwt = 0   ; (kg), mass in clean water tank
d/dt (Mwwt) = -Jdegwwt + Juwt2wwt - Jwwt2sw + Jfi2wwt
   Init Mwwt = 0   ; (kg), mass in waste water tank
d/dt (Mdeg) = Jdegmt + Jdegcult + Jdegdwt + Jdeguwt + Jdegfi + Jdegdinf + Jdegcwt + Jdegwwt
   Init Mdeg = 0   ; (kg), mass transformed
d/dt (M2sw) =  Jwwt2sw
  Init M2sw = 0   ; mass leaking to surface water
d/dt (M2crop) = Jcult2crop
   Init M2crop = 0   ; mass to crop (kg)
d/dt (Mleak) = Jcult2leak
   Init Mleak = 0   ; mass leaked from cultivation

Baltotal = Mmt + Mcult +  Mdwt + Muwt + Mfi + Mdinf + Mcwt + Mwwt + Mdeg + M2sw + M2crop + Mleak   ;balance equation

{concentrations}
Cmt = Mmt / Vmt  ; (kg/m3), concentration in mixing tank
Ccult = Mcult / Vcult   ; (kg/m3), concentration in substrate
Cdwt = Mdwt / Vdwt  ; (kg/m3), concentration in drain water tank
Cuwt = Muwt / Vuwt  ; (kg/m3), concentration in used water tank
Cfi = Mfi / Vfi   ; (kg/m3), concentration in filter unit
Cdinf = Mdinf / Vdinf   ; (kg/m3), concentration in disinfection tank
Ccwt = Mcwt / Vcwt  ; (kg/m3), concentration in clean water tank
Cwwt = Mwwt / Vwwt   ; (kg/m3), concentration in waste water tank

Cout_mt = 10^6 * Cmt  ; (mg/m3), concentration in mixing tank
Cout_cult = 10^6 * Ccult   ; (mg/m3), concentration in substrate
Cout_dwt = 10^6 * Cdwt  ; (mg/m3), concentration in drain water tank
Cout_uwt = 10^6 * Cuwt  ; (mg/m3), concentration in used water tank
Cout_fi = 10^6 * Cfi   ; (mg/m3), concentration in filter unit
Cout_dinf = 10^6 * Cdinf   ; (mg/m3), concentration in disinfection tank
Cout_cwt = 10^6 * Ccwt  ; (mg/m3), concentration in clean water tank
Cout_wwt = 10^6 * Cwwt   ; (mg/m3), concentration in waste water tank

{flows}
Jdegmt = kdegmt * Mmt  ; degradation rate in recirculation tank
Jdegcult =  kdegcult * Mcult   ; degradation rate in cultivation
Jdegdwt = kdegdwt * Mdwt   ; degradation rate in drain water tank
Jdeguwt = kdeguwt * Muwt  ; degradation rate in used water tank
Jdegfi = kdegfi * Mfi   ; degradation rate in filter
Jdegdinf = kdegdinf * Mdinf   ; degradation rate in disinfection tank
Jdegcwt = kdegcwt * Mcwt  ; degradation rate in clean water tank
Jdegwwt = kdegwwt * Mwwt   ; degradation rate in wastewater tank

; water volume flows read from inputfiles
Jmt2cult = Wmt2cult * Cmt  ; substance flow from mixing tank to cultivation
Jcult2dwt = Wcult2dwt * Ccult   ; substance flow from cultivation to drain water tank
Jcult2crop = #W2crop(TIME) * tscf * Ccult   ; substance flow from cultivation to crop
```

```
Jcult2leak = Wleak * Ccult   ; substance leaking from cultivation system
Jdwt2uwt = Wcult2dwt * Cdwt   ; substance flow from drain water tank to used water tank
Juwt2fi = Wuwt2fi * Cuwt  ; substance flow from used water tank to filter
Juwt2wwt = #Wuwt2wwt(TIME) * Cuwt  ; substance flow from used water tank to waste water tank
Jfi2dinf = Wfi2dinf * Cfi  ; substance flow from filter to disinfection tank
Jfi2wwt = Wfi2wwt * Cfi  ; substance flow from filter to waste water tank
Jdinf2cwt = Wfi2dinf * Cdinf  ; substance flow from disinfection tank to clean water tank
Jcwt2mt = Wcwt2mt * Ccwt  ; substance flow from clean water tank to mixing tank
Jwwt2sw = W2sw * Cwwt   ; substance flow from wastewater tank to surface water

{temperatures}
{Temperatures vary daily with a sine function; minimum temperature and 06.00 h. Average daily temperature of cultivation area read from file. Temperature in working / storage room is D degrees Celcius lower (assumption)}
D = 2  ; temperature difference between cultivation room and storage room
Amp = 4  ; difference between max and min temperature
Tmt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tcult = #Temp(TIME) +  Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tdwt = #Temp(TIME) +  Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tuwt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tfi = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tdinf = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tcwt = #Temp(TIME) - D + Amp / 2* sin(-2*pi*MOD(TIME+6/24,1))
Twwt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
fT_mt = exp(-Eact/Rgas*(1/(Tmt+T0)-1/Tref))
fT_cult = exp(-Eact/Rgas*(1/(Tcult+T0)-1/Tref))
fT_dwt = exp(-Eact/Rgas*(1/(Tdwt+T0)-1/Tref))
fT_uwt = exp(-Eact/Rgas*(1/(Tuwt+T0)-1/Tref))
fT_fi = exp(-Eact/Rgas*(1/(Tfi+T0)-1/Tref))
fT_dinf = exp(-Eact/Rgas*(1/(Tdinf+T0)-1/Tref))
fT_cwt = exp(-Eact/Rgas*(1/(Tcwt+T0)-1/Tref))
fT_wwt = exp(-Eact/Rgas*(1/(Twwt+T0)-1/Tref))

kdegmt = fT_mt * logn(2)/DegT50   ; transformation coefficient in mixing tank
kdegcult = fT_cult * logn(2)/DegT50   ; transformation coefficient in substrate
kdegdwt = fT_dwt * logn(2)/DegT50   ; transformation coefficient in drain water tank
kdeguwt = fT_uwt * logn(2)/DegT50   ; transformation coefficient in used water tank
kdegfi = fT_fi * logn(2)/DegT50   ; transformation coefficient in filter
kdegdinf= fT_dinf* logn(2)/DegT50dinf  ; transformation coefficient in disinfection tank
kdegcwt = fT_dwt * logn(2)/DegT50   ; transformation coefficient in clean water tank
kdegwwt = fT_wwt * logn(2)/DegT50   ; transformation coefficient in waste water tank

{summaries}
PercDeg = IF Map > 0 THEN 100 * Mdeg / Map ELSE 0
Perc2sw = IF Map > 0 THEN 100 * M2sw / Map ELSE 0
Perc2crop = IF Map > 0 THEN 100 * M2crop / Map ELSE 0
Perc2leak = IF Map > 0 THEN 100 * Mleak / Map ELSE 0
```

{general constants}
Eact = 65400 ; (J/mol), Arrhenius activation energy
Rgas = 8.314 ; (J/(mol K), gas constant
Tref = 293.15 ; (K), reference temperature
T0 = 273.15 ; (K), zero degrees Celcius
Appendix VIII Listing of glasshouse substrate model 2
For abbreviations, see Appendix VII
{Glasshouse model for cucumber, tomatoes, ... hydroponic systems, crop application}

METHOD AUTO
; variable integration timestep

STARTTIME = 1
STOPTIME=340
DTMIN = 1e-6
DTMAX = 0.01
TOLERANCE = 0.001
DTOUT = 1

{glasshouse}
Vgh = 50000 ; (m3), volume glasshouse (cultivation part)
Sgh = 13300 ; (m2), glass surface glasshouse
; glasshouse floor surface = 10000 ; (m2), 1 ha
Thcond = 4e-5 ; (m), average thickness condensation layer (Hemmink et al., 2006, WUR)
Nvent = 50 ; (d-1), air exchange rate per day
Vcond = Thcond * Sgh ; (m3), volume condensation

{growth medium}
{substrate, assumed to be inert, fully covered so no exchange with glasshouse air compartment}

{crop parameters}
LAI = 5 ; (-), (effective) leaf area index

{water part}
{tank volumes}
Vmt = 0.25 ; (m3), mixing tank
Vcultmax = 125 ; (m3), cultivation, including conducts
Vdwt = 2 ; (m3), drain water tank
Vuwtmax = 50 ; (m3), water tank to be disinfected (used water tank), max water volume
Vuwtmin = 1 ; (m3), water tank to be disinfected, minimum water volume
Vwwt_lim = 1 ; (m3), volume of wwt above which discharge starts
Vfi = 0.125 ; (m3), filter
Vdinf = 0.125 ; (m3), disinfection tank
Vcwtmax = 50 ; (m3), maximum volume clean water tank

```
{parameters water flows}
Lcult = 0.015  ; (-), fraction leakage from cultivation
Lfilt = 0.015  ; (-), fraction lost from filter due to regeneration
Rws_c = 1.3  ; (-), ratio water supply to crop demand
Wdis = 48   ; (m3/d), (maximum) allowed discharge flow to surface water

{water flows}
Wmt2cult = Rws_c * #W2crop(TIME)
Wleak = Rws_c * Lcult * #W2crop(TIME)
Wcult2dwt = (Rws_c - Rws_c * Lcult - 1) * #W2crop(TIME)
Wuwt2fi = IF (Vuwt + Wcult2dwt - #Wuwt2wwt(TIME)) > Vuwtmax THEN (Vuwt + Wcult2dwt - #Wuwt2wwt(TIME) - Vuwtmax)
ELSE 0
Wfi2dinf = (1-Lfilt) * Wuwt2fi
Wfi2wwt = Lfilt * Wuwt2fi
Wcwt2mt = IF Vcwt <= Vcwtmax THEN 0 ELSE Wfi2dinf + #Wcond(TIME)
W2sw = IF Vwwt <= Vwwt_lim THEN 0 ELSE Wdis

{variable water volumes}
Init Vcult = Vcultmax  ; (m3), water volume culture + conducts
  d/dt (Vcult) = Wmt2cult - #W2crop(TIME) - Wleak - Wcult2dwt
Init Vwwt = 1  ; (m3), water content waste water tank
  d/dt (Vwwt) = #Wuwt2wwt(TIME) + Wfi2wwt - W2sw
Init Vuwt = 1  ; (m3), water content used water tank
  d/dt (Vuwt) = Wcult2dwt - #Wuwt2wwt(TIME) - Wuwt2fi
Init Vcwt = 1  ; (m3), water content clean water tank
  d/dt (Vcwt) = Wfi2dinf - Wcwt2mt + #Wcond(TIME)

{cumulative water flows}
Init TWcrop = 0  ; (m3), total water uptake by crop
  d/dt (TWcrop) = #W2crop(TIME)
Init TWleak = 0  ; (m3), total water loss by leakage
  d/dt (TWleak) = Wleak
Init TWuwt2wwt = 0   ; (m3), total water discharge
  d/dt (TWuwt2wwt) = #Wuwt2wwt(TIME)
Init TWfi2wwt = 0   ; (m3), total water from filter to wwt
  d/dt (TWfi2wwt) = Wfi2wwt
Init TWcond = 0   ; (m3), total volume condensation
  d/dt (TWcond) = #Wcond(TIME)
Init TWS = Vcultmax   ; (m3), total volume water supply
  d/dt (TWS) = Rws_c * #W2crop(TIME) - Wcwt2mt
```

```
{substance input parameters}
MM =0.300  ; (kg/mol), molar mass, note: kg not g
Sref = 1.0e-1 ; (kg/m3), note units, solubility in water at reference conditions (20 C)
Vp_ref=1e-5 ; (Pa), saturated vapour pressure at reference conditions (20 C)
DegT50 = 10  ; (d), half-life for degradation in water under reference conditions
DegT50dinf = 10   ; (d), half-life in disinfection tank under reference conditions
DegT50air = 100  ; (d), half-life for degradation in glasshouse air under reference conditions
; dissipation from floor, all processes lumped except volatilisation
DT50floor = 100 ; (d), half-life for dissipation from floor
; dissipation from foliage, processes uptake and transformation lumped, wash-off does not occur, volatilisation not in-
cluded
DT50fol= 10  ; (d), half-life for dissipation from crop leaves
tscf = 0.1  ; (-), transpiration stream concentration factor, sort of barrier factor
; zero: nothing is taken up by plant, 1: full passive uptake

{Application}
Init Map = 0   ; (kg), mass applied
   d/dt (Map) = +#application(TIME) ; pulse?
Pint = 0.9  ; (-), fraction interception
Pair = 0.03  ; (-), fraction of application initially airborn

{mass in reservoirs}
Init Mghair = 0  ; (kg), mass in glashouse air
   d/dt (Mghair) = Pair * #application(TIME) + Jfol2ghair + Jfloor2ghair - Jdegghair - Jdegcond - Jcond2cwt - Jghair2out
Init Mfol = 0  ; (kg), mass on crop foliage
   d/dt (Mfol) = Pint * #application(TIME) - Jfol2ghair - Jdisfol
Init Mfloor = 0  ; (kg), mass on soil (surface)
   d/dt (Mfloor) = (1 - Pint - Pair) * #application(TIME) - Jdisfloor - Jfloor2ghair
Init M2air = 0  ; (kg), mass emitted to air
   d/dt (M2air) = Jghair2out
Init Mmt = 0   ; (kg), mass in mixing tank
   d/dt (Mmt) = -Jdegmt + Jcwt2mt - Jmt2cult
Init Mcult = 0   ; (kg), mass in substrate
   d/dt (Mcult) = -Jdegcult + Jmt2cult - Jcult2leak - Jcult2crop - Jcult2dwt
Init Mdwt = 0   ; (kg), mass in drainwatertank
   d/dt (Mdwt) = -Jdegdwt + Jcult2dwt - Jdwt2uwt
Init Muwt = 0   ; (kg), mass in used water tank
   d/dt (Muwt) = -Jdeguwt + Jdwt2uwt - Juwt2wwt - Juwt2fi
Init Mfi = 0   ; (kg), mass in filter
   d/dt (Mfi) = -Jdegfi + Juwt2fi - Jfi2dinf - Jfi2wwt
Init Mdinf = 0  ; (kg), mass in disinfection tank
   d/dt (Mdinf) = -Jdegdinf + Jfi2dinf - Jdinf2cwt
Init Mcwt = 0   ; (kg), mass in clean water tank
   d/dt (Mcwt) = -Jdegcwt + Jdinf2cwt - Jcwt2mt + Jcond2cwt
Init Mwwt = 0   ; (kg), mass in waste water tank
   d/dt (Mwwt) = -Jdegwwt + Juwt2wwt - Jwwt2sw + Jfi2wwt
Init Mdeg = 0   ; (kg), mass transformed
   d/dt (Mdeg) = Jdegmt + Jdegcult + Jdegdwt + Jdeguwt + Jdegfi + Jdegdinf + Jdegcwt + Jdegwwt + Jdegghair +
```

```
Jdegcond + Jdisfloor
Init M2sw = 0   ; mass leaking to surface water
   d/dt (M2sw) =  Jwwt2sw
Init M2crop = 0   ; mass to crop (kg)
   d/dt (M2crop) = Jcult2crop + Jdisfol
Init Mleak = 0   ; mass leaked from cultivation
   d/dt (Mleak) = Jcult2leak
Mcond = Ccond * Vcond  ; (kg), mass in condensation

Baltotal = Mmt + Mcult +  Mdwt + Muwt + Mfi + Mdinf + Mcwt + Mwwt + M2sw + M2crop + Mleak + Mghair + Mfol +
Mfloor + M2air + Mcond + Mdeg  ; substance balance equation

{concentrations}
Cmt = Mmt / Vmt  ; (kg/m3), concentration in mixing tank
Ccult = Mcult / Vcult   ; (kg/m3), concentration in substrate
Cdwt = Mdwt / Vdwt  ; (kg/m3), concentration in drain water tank
Cuwt = Muwt / Vuwt  ; (kg/m3), concentration in used water tank
Cfi = Mfi / Vfi   ; (kg/m3), concentration in filter unit
Cdinf = Mdinf / Vdinf   ; (kg/m3), concentration in disinfection tank
Ccwt = Mcwt / Vcwt  ; (kg/m3), concentration in clean water tank
Cwwt = Mwwt / Vwwt   ; (kg/m3), concentration in waste water tank
Cghair = Mghair / (Vgh + Vcond/kaw) ; (kg/m3), concentration in glasshouse air
Ccond = Cghair / kaw  ; (kg/m3) , concentration in condensation

{conversion to usual units}
Cout_mt = 10^6 * Cmt  ; (mg/m3 = ug/l), concentration in mixing tank
Cout_cult = 10^6 * Ccult   ; (mg/m3), concentration in substrate
Cout_dwt = 10^6 * Cdwt   ; (mg/m3), concentration in drain water tank
Cout_uwt = 10^6 * Cuwt   ; (mg/m3), concentration in used water tank
Cout_fi = 10^6 * Cfi  ; (mg/m3), concentration in filter unit
Cout_dinf = 10^6 * Cdinf    ; (mg/m3), concentration in disinfection tank
Cout_cwt = 10^6 * Ccwt   ; (mg/m3), concentration in clean water tank
Cout_wwt = 10^6 * Cwwt  ; (mg/m3), concentration in waste water tank
Cout_cond = 10^6 * Ccond  ; (mg/m3), concentration in condensation

{degradation and dissipation}
Jdegmt = kdegmt * Mmt  ; degradation rate in recirculation tank
Jdegcult =  kdegcult * Mcult   ; degradation rate in cultivation
Jdegdwt = kdegdwt * Mdwt   ; degradation rate in drain water tank
Jdeguwt = kdeguwt * Muwt  ; degradation rate in used water tank
Jdegfi = kdegfi * Mfi   ; degradation rate in filter
Jdegdinf = kdegdinf * Mdinf   ; degradation rate in disinfection tank
Jdegcwt = kdegcwt * Mcwt  ; degradation rate in clean water tank
Jdegwwt = kdegwwt * Mwwt   ; degradation rate in wastewater tank
Jdegghair = kdegghair * Cghair *Vgh ; degradation rate in glasshouse air
Jdisfloor = kdisfloor * Mfloor  ; dissipation from floor
Jdegcond = kdegcond * Mcond  ; degradation in condensation
Jdisfol = kdisfol * Mfol  ; dissipation from crop surface
```

{substance flows, water volume flows read from input files}
Jmt2cult = Wmt2cult * Cmt ; substance flow from mixing tank to cultivation
Jcult2dwt = Wcult2dwt * Ccult ; substance flow from cultivation to drain water tank
Jcult2crop = #W2crop(TIME) * tscf * Ccult ; substance flow from cultivation to crop
Jcult2leak = Wleak * Ccult ; substance leaking from cultivation system
Jdwt2uwt = Wcult2dwt * Cdwt ; substance flow from drain water tank to used water tank
Juwt2fi = Wuwt2fi * Cuwt ; substance flow from used water tank to filter
Juwt2wwt = #Wuwt2wwt(TIME) * Cuwt ; substance flow from used water tank to waste water tank
Jfi2dinf = Wfi2dinf * Cfi ; substance flow from filter to disinfection tank
Jfi2wwt = Wfi2wwt * Cfi ; substance flow from filter to waste water tank
Jdinf2cwt = Wfi2dinf * Cdinf ; substance flow from disinfection tank to clean water tank
Jcwt2mt = Wcwt2mt * Ccwt ; substance flow from clean water tank to mixing tank
Jwwt2sw = W2sw * Cwwt ; substance flow from wastewater tank to surface water
Cgsurffol = IF Mfol > 0 THEN MM * fVT_ghair * Vp_ref / (Rgas * Tref) ELSE 0 ; concentration in gas phase at foliage surface
volfol = IF (Mfol > 0 AND Cgsurffol > Cghair) THEN 10000 * Mfol / Mref * (Cgsurffol - Cghair) / Rair ELSE 0 ; substance volatilisation flux from foliage to ghair, Rair is resistance to transport to air, Mref is reference application rate of 1 kg/ha factor of 10000 for conversion m2 > ha
depfol = IF Cghair > Cgsurffol THEN 10000 * LAI / (LAI +1) * (Cgsurffol - Cghair) / Rair ELSE 0 ; substance deposition on foliage, LAI is leaf area index, factor of 10000 for conversion m2 > ha
Jfol2ghair = volfol + depfol
Cgsurffloor = IF Mfloor > 0 THEN MM * fVT_ghair * Vp_ref / (Rgas * Tref) ELSE 0 ; concentration in gas phase at floor surface
volfloor = IF (Mfloor > 0 AND Cgsurffloor > Cghair) THEN 10000 * Mfloor / Mref * (Cgsurffloor - Cghair) / Rair ELSE 0 ; substance volatilisation flux from foliage to ghair, Rair is resistance to transport to air, Mref is reference application rate of 1 kg/ha
depfloor = IF Cghair > Cgsurffloor THEN 10000 * 1 / (LAI +1) * (Cgsurffloor - Cghair) / Rair ELSE 0 ; substance deposition on foliage, LAI is leaf area index
Jfloor2ghair = volfloor + depfloor
Jcond2cwt = #Wcond(TIME) * Ccond ; substance flow from condensation to clean water tank
Jghair2out = Nvent * Vgh * Cghair ; substance ventilation

{temperatures}
{Temperatures vary daily with a sine function; minimum temperature and 06.00 h. Average daily temperature of cultivation area read from file. Temperature in working / storage room is D degrees Celcius lower (assumption)}
D = 2 ; temperature difference between cultivation room and storage room
Amp = 4 ; difference between max and min temperature
Tmt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tcult = #Temp(TIME) + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tdwt = #Temp(TIME) + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tuwt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tfi = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tdinf = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tcwt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Twwt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tgh = #Temp(TIME) + Amp * sin(-2*pi*MOD(TIME+6/24,1))
Tcond = #Temp(TIME) + Amp * sin(-2*pi*MOD(TIME+6/24,1))

```
; factors denoting influence of temperature on transformation
fDT_mt = exp(-Eact/Rgas*(1/(Tmt+T0)-1/Tref))
fDT_cult = exp(-Eact/Rgas*(1/(Tcult+T0)-1/Tref))
fDT_dwt = exp(-Eact/Rgas*(1/(Tdwt+T0)-1/Tref))
fDT_uwt = exp(-Eact/Rgas*(1/(Tuwt+T0)-1/Tref))
fDT_fi = exp(-Eact/Rgas*(1/(Tfi+T0)-1/Tref))
fDT_dinf = exp(-Eact/Rgas*(1/(Tdinf+T0)-1/Tref))
fDT_cwt = exp(-Eact/Rgas*(1/(Tcwt+T0)-1/Tref))
fDT_wwt = exp(-Eact/Rgas*(1/(Twwt+T0)-1/Tref))
fDT_cond = exp(-Eact/Rgas*(1/(Tcond+T0)-1/Tref))
fDT_ghair = exp(-Eact/Rgas*(1/(Tgh+T0)-1/Tref))

kdegmt = fDT_mt * logn(2)/DegT50   ; transformation coefficient in mixing tank
kdegcult = fDT_cult * logn(2)/DegT50   ; transformation coefficient in substrate
kdegdwt = fDT_dwt * logn(2)/DegT50   ; transformation coefficient in drain water tank
kdeguwt = fDT_uwt * logn(2)/DegT50   ; transformation coefficient in used water tank
kdegfi = fDT_fi * logn(2)/DegT50   ; transformation coefficient in filter
kdegdinf= fDT_dinf * logn(2)/DegT50dinf  ; transformation coefficient in disinfection tank
kdegcwt = fDT_cwt * logn(2)/DegT50   ; transformation coefficient in clean water tank
kdegwwt = fDT_wwt * logn(2)/DegT50   ; transformation coefficient in waste water tank
kdegghair = logn(2)/DegT50air  ; transformation coefficient in glasshouse air
kdisfol = fDT_ghair * logn(2)/DT50fol  ; transformation coefficient on crop foliage
kdisfloor = fDT_ghair * logn(2)/DT50floor  ; transformation coefficient on floor
kdegcond = fDT_cond * logn(2)/DegT50  ; transformation coefficient in condensation

; factor denoting influence of temperature on vaporisation. It is assumed that temperature of canopy and glasshouse floor
are equal to the temperature of glasshouse air. fVT_ghair = exp(-Evap/Rgas*(1/(Tgh+T0)-1/Tref))

; factor denoting influence of temperature on solubility in water.
fST_ghair = exp(-Edis/Rgas*(1/(Tgh+T0)-1/Tref))
kaw = fVT_ghair * Vp_ref * MM / (fST_ghair * Sref * Rgas * Tref)  ; (-), air water partition coefficient

{summaries}
PercDeg = IF Map > 0 THEN 100 * Mdeg / Map ELSE 0
Perc2sw = IF Map > 0 THEN 100 * M2sw / Map ELSE 0
Perc2crop = IF Map > 0 THEN 100 * M2crop / Map ELSE 0
Perc2air = IF Map > 0 THEN 100 * M2air / Map ELSE 0
PercLeak = IF Map > 0 THEN 100 * Mleak / Map ELSE 0
Percbal = IF Map > 0 THEN 100 * Baltotal / Map ELSE 0

{general constants, Eact, Evap and Edis are average values}
Eact = 65400 ; (J/mol), Arrhenius activation energy (EFSA)
Evap = 96000  ; (J/mol), molar enthalpy of vaporisation (default PEARL)
Edis = 27000  ; (J/mol), molar enthalpy of dissolution (default PEARL)
Rgas = 8.314  ; (J/(mol K), gas constant
Tref = 293.15  ; (K), reference temperature, 20 degrees Celcius
T0 = 273.15   ; (K), zero degrees Celcius
Rair = 1.16e-3   ; (d m-1), laminar boundary layer resistance, (Jacobs et al 2006)
```

Mref = 1 ; (kg ha-1), reference application rate

Appendix IX Listing of glasshouse substrate model 3

For abbreviations, see Appendix VII
{Glasshouse model for table and floor systems with ebb/flood, crop application}

METHOD AUTO
; variable integration time step

STARTTIME = 1
STOPTIME=350
DTMIN = 1e-6
DTMAX = 0.01
TOLERANCE = 0.001
DTOUT = 1

{glasshouse}
Vgh = 50000 ; (m3), volume glasshouse (cultivation part)
Sgh = 13300 ; (m2), glass surface glasshouse
; glasshouse floor surface = 10000 ; (m2), 1 ha
Thcond = 4e-5 ; (m), average thickness condensation layer (Hemming et al., 2006, WUR)
Nvent = 50 ; (d-1), air exchange rate per day
Vcond = Thcond * Sgh ; (m3), volume condensation

{growth medium}
{Substrate, not covered so exchange with glasshouse air compartment is possible. Pots are assumed to have an effective height of 10 cm, which is 5 cm less than the actual pot height. I.e. 10 cm of growth medium is assumed to be wetted. The total effective amount of substrate is 900000 kg. Dry bulk density is assumed to be 1000 kg/m3 and theta (volumetric water content) 0.6. Air-filled porosity is assumed zero in the wetted parts of the pots. In the upper layer absence of water and substance transport is assumed, except in the top layer which exchanges with the air. }
Scult = 900000 ; (kg), mass of substrate in cultivation tank
Ppot = 0.9 ; (-), pot density, fraction of production surface area covered with pots
fOM = 0.1 ; (-), fraction organic matter in substrate

{crop parameters}
LAI = 5 ; (-), (effective) leaf area index

```
{water part}
{tank volumes}
Vmt = 0.25   ; (m3), mixing tank
Vcultmax = 125   ; (m3), cultivation, including conducts
Vdwt = 2  ; (m3), drain water tank
Vuwtmax = 50   ; (m3), water tank to be disinfected (used water tank), max water volume
Vuwtmin = 1 ; (m3), water tank to be disinfected, minimum water volume
Vwwt_lim = 1  ; (m3), volume of wwt above which discharge starts
Vfi = 0.125   ; (m3), filter
Vdinf = 0.125  ; (m3), disinfection tank
Vcwtmax = 50 ; (m3), maximum volume clean water tank

{parameters water flows}
Lcult = 0.015  ; (-), fraction leakage from cultivation
Lfilt = 0.015  ; (-), fraction lost from filter due to regeneration
Rws_c = 1.3  ; (-), ratio water supply to crop demand
Wdis = 48   ; (m3/d), (maximum) allowed discharge flow to surface water

{water flows}
Wmt2cult = Rws_c * #W2crop(TIME)
Wleak = Rws_c * Lcult * #W2crop(TIME)
Wcult2dwt = (Rws_c - Rws_c * Lcult - 1) * #W2crop(TIME)
Wuwt2fi = IF (Vuwt + Wcult2dwt - #Wuwt2wwt(TIME)) > Vuwtmax THEN (Vuwt + Wcult2dwt - #Wuwt2wwt(TIME) - Vuwtmax)
ELSE 0
Wfi2dinf = (1-Lfilt) * Wuwt2fi
Wfi2wwt = Lfilt * Wuwt2fi
Wcwt2mt = IF Vcwt <= Vcwtmax THEN 0 ELSE Wfi2dinf + #Wcond(TIME)
W2sw = IF Vwwt <= Vwwt_lim THEN 0 ELSE Wdis

{variable water volumes}
Init Vcult = Vcultmax  ; (m3), water volume culture + conducts
   d/dt (Vcult) = Wmt2cult - #W2crop(TIME) - Wleak - Wcult2dwt
Init Vwwt = 1  ; (m3), water content waste water tank
   d/dt (Vwwt) = #Wuwt2wwt(TIME) + Wfi2wwt - W2sw
Init Vuwt = 1  ; (m3), water content used water tank
   d/dt (Vuwt) = Wcult2dwt - #Wuwt2wwt(TIME) - Wuwt2fi
Init Vcwt = 1  ; (m3), water content clean water tank
   d/dt (Vcwt) = Wfi2dinf - Wcwt2mt + #Wcond(TIME)
```

```
{cumulative water flows}
Init TWcrop = 0  ; (m3), total water uptake by crop
   d/dt (TWcrop) = #W2crop(TIME)
Init TWleak = 0  ; (m3), total water loss by leakage
   d/dt (TWleak) = Wleak
Init TWuwt2wwt = 0   ; (m3), total water discharge
   d/dt (TWuwt2wwt) = #Wuwt2wwt(TIME)
Init TWfi2wwt = 0   ; (m3), total water from filter to wwt
   d/dt (TWfi2wwt) = Wfi2wwt
Init TWcond = 0   ; (m3), total volume condensation
   d/dt (TWcond) = #Wcond(TIME)
Init TWS = Vcultmax   ; (m3), total volume water supply
   d/dt (TWS) = Rws_c * #W2crop(TIME) - Wcwt2mt

{substance input parameters}
MM =0.250  ; (kg/mol), molar mass, note: kg not g
Sref = 1.0e-2 ; (kg/m3), note units, solubility in water at reference conditions (20 C)
Vp_ref=8.9e-2 ; (Pa), saturated vapour pressure at reference conditions (20 C)
Kom = 0.100  ; (m3/kg), sorption constant on organic matter, note units.
DegT50 = 10  ; (d), half-life for degradation in water under reference conditions
DegT50dinf = 10   ; (d), half-life in disinfection tank under reference conditions
DegT50air = 100  ; (d), half-life for degradation in glasshouse air under reference conditions
; dissipation from substrate all processes lumped except volatilisation, leaching does not occur, assumption is that there is no free floor space in the production room
DT50sub = 100 ; (d), half-life for dissipation from substrate
; dissipation from foliage, processes uptake and transformation lumped, wash-off does not occur, volatilisation not included
DT50fol= 10  ; (d), half-life for dissipation from crop leaves
; dissipation from substrate,
tscf = 0.1  ; (-), transpiration stream concentration factor, sort of barrier factor
; zero: nothing is taken up by plant, 1: full passive uptake

{Application}
Init Map = 0   ; (kg), mass applied
   d/dt (Map) = +#application(TIME) ; pulse?
Pint = 0.9  ; (-), fraction interception
Pair = 0.03  ; (-), fraction of application initially airborn

{mass in reservoirs}
Init Mghair = 0  ; (kg), mass in glasshouse air
   d/dt (Mghair) = Pair * #application(TIME) + Jfol2ghair + Jsub2ghair + Jcult2ghair - Jdegghair - Jdegcond - Jcond2cwt - Jghair2out
Init Mfol = 0  ; (kg), mass on crop foliage
   d/dt (Mfol) = Pint * #application(TIME) - Jfol2ghair - Jdisfol
Init Msub = 0  ; (kg), mass on substrate (surface)
   d/dt (Msub) = (1 - Pint - Pair) * Ppot * #application(TIME) - Jdissub - Jsub2ghair
Init M2air = 0  ; (kg), mass emitted to air
   d/dt (M2air) = Jghair2out
```

```
Init Mmt = 0   ; (kg), mass in mixing tank
   d/dt (Mmt) = -Jdegmt + Jcwt2mt - Jmt2cult
Init Mcult = 0   ; (kg), mass in substrate
   d/dt (Mcult) = (1 - Pint - Pair) * (1 - Ppot) * #application(TIME) - Jdegcult + Jmt2cult - Jcult2leak - Jcult2crop - Jcult2dwt
- Jcult2ghair
Init Mdwt = 0   ; (kg), mass in drainwatertank
   d/dt (Mdwt) = -Jdegdwt + Jcult2dwt - Jdwt2uwt
Init Muwt = 0   ; (kg), mass in used water tank
   d/dt (Muwt) = -Jdeguwt + Jdwt2uwt - Juwt2wwt - Juwt2fi
Init Mfi = 0   ; (kg), mass in filter
   d/dt (Mfi) = -Jdegfi + Juwt2fi - Jfi2dinf - Jfi2wwt
Init Mdinf = 0  ; (kg), mass in disinfection tank
   d/dt (Mdinf) = -Jdegdinf + Jfi2dinf - Jdinf2cwt
Init Mcwt = 0   ; (kg), mass in clean water tank
   d/dt (Mcwt) = -Jdegcwt + Jdinf2cwt - Jcwt2mt + Jcond2cwt
Init Mwwt = 0   ; (kg), mass in waste water tank
   d/dt (Mwwt) = -Jdegwwt + Juwt2wwt - Jwwt2sw + Jfi2wwt
Init Mdeg = 0   ; (kg), mass transformed
   d/dt (Mdeg) = Jdegmt + Jdegcult + Jdegdwt + Jdeguwt + Jdegfi + Jdegdinf + Jdegcwt + Jdegwwt + Jdegghair +
Jdegcond + Jdissub
Init M2sw = 0   ; mass leaking to surface water
   d/dt (M2sw) =  Jwwt2sw
Init M2crop = 0   ; mass to crop (kg)
   d/dt (M2crop) = Jcult2crop + Jdisfol
Init Mleak = 0   ; mass leaked from cultivation
   d/dt (Mleak) = Jcult2leak
Mcond = Ccond * Vcond  ; (kg), mass in condensation

Baltotal = Mmt + Mcult +  Mdwt + Muwt + Mfi + Mdinf + Mcwt + Mwwt + M2sw + M2crop + Mleak + Mghair + Mfol +
Msub + M2air + Mcond + Mdeg  ; substance balance equation

{concentrations}
Cmt = Mmt / Vmt  ; (kg/m3), concentration in mixing tank
Ccult = Mcult / (Vcult + fOM * Kom * Scult)  ; (kg/m3), concentration in liquid in cultivation tank, linear sorption isotherm,
equilibrium sorption only
Cdwt = Mdwt / Vdwt  ; (kg/m3), concentration in drainwater tank
Cuwt = Muwt / Vuwt  ; (kg/m3), concentration in used water tank
Cfi = Mfi / Vfi   ; (kg/m3), concentration in filter unit
Cdinf = Mdinf / Vdinf   ; (kg/m3), concentration in disinfection tank
Ccwt = Mcwt / Vcwt  ; (kg/m3), concentration in clean water tank
Cwwt = Mwwt / Vwwt   ; (kg/m3), concentration in waste water tank
Cghair = Mghair / (Vgh + Vcond/kaw) ; (kg/m3), concentration in glasshouse air
Ccond = Cghair / kaw  ; (kg/m3) , concentration in condensation

{conversion to usual units}
Cout_mt = 10^6 * Cmt  ; (mg/m3 = ug/l), concentration in mixing tank
Cout_cult = 10^6 * Ccult   ; (mg/m3), concentration in substrate
Cout_dwt = 10^6 * Cdwt   ; (mg/m3), concentration in drain water tank
Cout_uwt = 10^6 * Cuwt   ; (mg/m3), concentration in used water tank
```

Cout_fi = 10^6 * Cfi ; (mg/m3), concentration in filter unit
Cout_dinf = 10^6 * Cdinf ; (mg/m3), concentration in disinfection tank
Cout_cwt = 10^6 * Ccwt ; (mg/m3), concentration in clean water tank
Cout_wwt = 10^6 * Cwwt ; (mg/m3), concentration in waste water tank
Cout_cond = 10^6 * Ccond ; (mg/m3), concentration in condensation

{degradation and dissipation}
Jdegmt = kdegmt * Mmt ; degradation rate in recirculation tank
Jdegcult = kdegcult * Mcult ; degradation rate in cultivation
Jdegdwt = kdegdwt * Mdwt ; degradation rate in drain water tank
Jdeguwt = kdeguwt * Muwt ; degradation rate in used water tank
Jdegfi = kdegfi * Mfi ; degradation rate in filter
Jdegdinf = kdegdinf * Mdinf ; degradation rate in disinfection tank
Jdegcwt = kdegcwt * Mcwt ; degradation rate in clean water tank
Jdegwwt = kdegwwt * Mwwt ; degradation rate in wastewater tank
Jdegghair = kdegghair * Cghair *Vgh ; degradation rate in glasshouse air
Jdissub = kdissub * Msub ; dissipation from substrate
Jdegcond = kdegcond * Mcond ; degradation in condensation
Jdisfol = kdisfol * Mfol ; dissipation from crop surface

{substance flows, water volume flows read from input files}
Jmt2cult = Wmt2cult * Cmt ; substance flow from mixing tank to cultivation
Jcult2dwt = Wcult2dwt * Ccult ; substance flow from cultivation to drain water tank
Jcult2crop = #W2crop(TIME) * tscf * Ccult ; substance flow from cultivation to crop
Jcult2leak = Wleak * Ccult ; substance leaking from cultivation system
volcult = IF (kaw * Ccult > Cghair) THEN 10000 * (1 - Ppot) * Mcult / Mref * (kaw * Ccult - Cghair) / Rair ELSE 0 ; volatilisation
depcult = IF (Cghair > kaw * Ccult) THEN 10000 * (1 – Ppot) * 1/(LAI + 1) * Mcult / Mref * (Cghair - kaw * Ccult) / Rair ELSE 0 ; deposition
Jcult2ghair = volcult + depcult
Jdwt2uwt = Wcult2dwt * Cdwt ; substance flow from drain water tank to used water tank
Juwt2fi = Wuwt2fi * Cuwt ; substance flow from used water tank to filter
Juwt2wwt = #Wuwt2wwt(TIME) * Cuwt ; substance flow from used water tank to waste water tank
Jfi2dinf = Wfi2dinf * Cfi ; substance flow from filter to disinfection tank
Jfi2wwt = Wfi2wwt * Cfi ; substance flow from filter to waste water tank
Jdinf2cwt = Wfi2dinf * Cdinf ; substance flow from disinfection tank to clean water tank
Jcwt2mt = Wcwt2mt * Ccwt ; substance flow from clean water tank to mixing tank
Jwwt2sw = W2sw * Cwwt ; substance flow from wastewater tank to surface water
Cgsurffol = IF Mfol > 0 THEN MM * fVT_ghair * Vp_ref / (Rgas * Tref) ELSE 0 ; concentration in gas phase at foliage surface
volfol = IF (Mfol > 0 AND Cgsurffol > Cghair) THEN 10000 * Mfol / Mref * (Cgsurffol - Cghair) / Rair ELSE 0 ; substance volatilisation flux from foliage to ghair, Rair is resistance to transport to air, Mref is reference application rate of 1 kg/ha
depfol = IF Cghair > Cgsurffol THEN 10000 * LAI / (LAI +1) * (Cgsurffol - Cghair) / Rair ELSE 0 ; substance deposition on foliage, LAI is leaf area index
Jfol2ghair = volfol + depfol
Cgsurfsub = IF Msub > 0 THEN Msub / (1e5 * fom * Kom / kaw + 4e4 / kaw + 20) ELSE 0 ; concentration in gas phase at substrate surface assuming uniform distribution and equilibrium in substrate top layer
volsub = IF (Msub > 0 AND Cgsurfsub > Cghair) THEN 10000 * Msub / Mref * (Cgsurfsub - Cghair) / Rair ELSE 0 ; substance volatilisation flux from foliage to ghair, Rair is resistance to transport to air, Mref is reference application rate

```
of 1 kg/ha
depsub = IF Cghair > Cgsurfsub THEN 10000 * 1 / (LAI +1) * Ppot *(Cgsurfsub - Cghair) / Rair ELSE 0  ; substance deposition on foliage, LAI is leaf area index
Jsub2ghair = volsub + depsub
Jcond2cwt = #Wcond(TIME) * Ccond  ; substance flow from condensation to clean water tank
Jghair2out = Nvent * Vgh * Cghair  ; substance ventilation

{temperatures}
{Temperatures vary daily with a sine function; minimum temperature and 06.00 h. Average daily temperature of cultivation area read from file. Temperature in working / storage room is D degrees Celcius lower (assumption)}
D = 2   ; temperature difference between cultivation room and storage room
Amp = 4  ; difference between max and min temperature
Tmt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tcult = #Temp(TIME) +  Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tdwt = #Temp(TIME) +  Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tuwt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tfi = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tdinf = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tcwt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Twwt = #Temp(TIME) - D + Amp / 2 * sin(-2*pi*MOD(TIME+6/24,1))
Tgh = #Temp(TIME) +  Amp * sin(-2*pi*MOD(TIME+6/24,1))
Tcond = #Temp(TIME) +  Amp * sin(-2*pi*MOD(TIME+6/24,1))

; factors denoting influence of temperature on transformation
fDT_mt = exp(-Eact/Rgas*(1/(Tmt+T0)-1/Tref))
fDT_cult = exp(-Eact/Rgas*(1/(Tcult+T0)-1/Tref))
fDT_dwt = exp(-Eact/Rgas*(1/(Tdwt+T0)-1/Tref))
fDT_uwt = exp(-Eact/Rgas*(1/(Tuwt+T0)-1/Tref))
fDT_fi = exp(-Eact/Rgas*(1/(Tfi+T0)-1/Tref))
fDT_dinf = exp(-Eact/Rgas*(1/(Tdinf+T0)-1/Tref))
fDT_cwt = exp(-Eact/Rgas*(1/(Tcwt+T0)-1/Tref))
fDT_wwt = exp(-Eact/Rgas*(1/(Twwt+T0)-1/Tref))
fDT_cond = exp(-Eact/Rgas*(1/(Tcond+T0)-1/Tref))
fDT_ghair = exp(-Eact/Rgas*(1/(Tgh+T0)-1/Tref))

kdegmt = fDT_mt * logn(2)/DegT50   ; transformation coefficient in mixing tank
kdegcult = fDT_cult * logn(2)/DegT50   ; transformation coefficient in substrate
kdegdwt = fDT_dwt * logn(2)/DegT50   ; transformation coefficient in drain water tank
kdeguwt = fDT_uwt * logn(2)/DegT50   ; transformation coefficient in used water tank
kdegfi = fDT_fi * logn(2)/DegT50   ; transformation coefficient in filter
kdegdinf= fDT_dinf * logn(2)/DegT50dinf  ; transformation coefficient in disinfection tank
kdegcwt = fDT_cwt * logn(2)/DegT50   ; transformation coefficient in clean water tank
kdegwwt = fDT_wwt * logn(2)/DegT50   ; transformation coefficient in waste water tank
kdegghair = logn(2)/DegT50air  ; transformation coefficient in glasshouse air
kdisfol = fDT_ghair * logn(2)/DT50fol  ; transformation coefficient on crop foliage
kdissub= fDT_ghair * logn(2)/DT50sub ; transformation coefficient on floor
kdegcond = fDT_cond * logn(2)/DegT50  ; transformation coefficient in condensation
```

```
; factor denoting influence of temperature on vaporisation. It is assumed that temperature of canopy and glasshouse floor
are equal to the temperature of glasshouse air.
fVT_ghair = exp(-Evap/Rgas*(1/(Tgh+T0)-1/Tref))

; factor denoting influence of temperature on solubility in water.
fST_ghair = exp(-Edis/Rgas*(1/(Tgh+T0)-1/Tref))
kaw = fVT_ghair * Vp_ref * MM / (fST_ghair * Sref * Rgas * Tref)  ; (-), air water partition coefficient

{summaries}
PercDeg = IF Map > 0 THEN 100 * Mdeg / Map ELSE 0
Perc2sw = IF Map > 0 THEN 100 * M2sw / Map ELSE 0
Perc2crop = IF Map > 0 THEN 100 * M2crop / Map ELSE 0
Perc2air = IF Map > 0 THEN 100 * M2air / Map ELSE 0
PercLeak = IF Map > 0 THEN 100 * Mleak / Map ELSE 0
Percbal = IF Map > 0 THEN 100 * Baltotal / Map ELSE 0

{general constants, Eact, Evap and Edis are average values}
Eact = 65400 ; (J/mol), Arrhenius activation energy (EFSA)
Evap = 96000  ; (J/mol), molar enthalpy of vaporisation (default PEARL)
Edis = 27000  ; (J/mol), molar enthalpy of dissolution (default PEARL)
Rgas = 8.314  ; (J/(mol K), gas constant
Tref = 293.15  ; (K), reference temperature, 20 degrees Celcius
T0 = 273.15   ; (K), zero degrees Celcius
Rair = 1.16e-3   ; (d m-1), laminar boundary layer resistance, (Jacobs et al 2006)
Mref = 1   ; (kg ha-1), reference application rate
```

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