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Plagen en ziekten in fruitbomen en laanbomen worden regelmatig behandeld met gewasbeschermingsmiddelen door middel van zijwaartse en opwaartse bespuitingen. Voor het bepalen van de risico's van deze gewasbeschermingsmiddelen voor aquatische organismen in kavelsloten naast fruitbomen wordt gebruik gemaakt van zogenaamde blootstellingscenario's die onderdeel vormen van een getrapte risicobeoordeling. Deze risicobeoordeling vormt onderdeel van de toelating van gewasbeschermingsmiddelen. Dit rapport beschrijft de hydrologische parameterisatie van het model van de kavelsloot naast fruitboomgaarden, onderdeel van blootstelling-scenario's voor fruitbomen in Nederland. Het is de bedoeling dat deze scenarios onderdeel gaan vormen van de toelatingsprocedure van gewasbeschermingsmiddelen in Nederland.

Pests and diseases in fruit-orchards and lane tree-nurseries are frequently treated with pesticides, that are applied by sideways or upward spraying. To assess the risk to aquatic organisms associated with the application of these pesticides, specific scenarios are required as part of a tiered assessment scheme. This report describes the hydrological parameterisation of the edge-of-field ditch model next to fruit-orchards. This parameterised model is part of the Dutch exposure assessment scenarios for fruit-orchards.

Keywords: exposure assessment, risk assessment, pesticides, sideways and upward spraying, surface-water, fruit-orchards

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# Preface

Pests and diseases in fruit-orchards and lane tree-nurseries are frequently treated by sideways or upward spraying of pesticides. To assess the risk to aquatic organisms associated with the application of these pesticides, specific scenarios are required as part of a tiered assessment scheme. The risk assessment is part of the authorization procedure of plant protection products in the Netherlands.

This report is produced within the framework of a Dutch Working Group appointed to develop exposure scenarios specific for sideways and upward spraying of pesticides by the Dutch Ministry of Economic Affairs. The report describes the hydrological parameterisation of the evaluation ditch model, which is part of the developed exposure scenarios for sideways and upward spraying. These scenarios are intended to be used in the registration procedures in the Netherlands.

In a subsequent step, the parameterised evaluation ditch model is coupled to parameterised drift- and drainage models. The coupled models enable the calculation of the Predicted Environmental Concentration. All models will become part of the exposure assessment tool DRAINBOW, which is to be used in the environmental risk assessment process of pesticides used in arable crops, as well as in fruit orchards in the Netherlands.

We would like to thank the following (former) members of the Working Group for their input and discussions:

| | |
|---|---|
| Jos Boesten | Wageningen Environmental Research |
| Jan van der Zande, Henk-Jan Holterman | Wageningen Plant Research |
| Ton van der Linden | National Institute for Public Health and the Environment |
| Aaldrik Tiktak | Netherlands Environmental Assessment Agency |
| Paulien Adriaanse | Wageningen Environmental Research |

We are also indebted to Roel Velner and Hella Pomarius of the Rivierenland Water Board for providing the hydrological models and for the lively discussions.

# Summary


This report describes the hydrological parameterisation of the evaluation ditch as part of the Dutch exposure assessment procedure for sideways and upward spraying. The parameterised evaluation ditch model, which is to be coupled to corresponding parameterised drift and drainage models, enables the calculation of Predicted Environmental Concentrations in surface water for complex application schemes. The concentration averaged over 100 m of ditch is considered as the Predicted Environmental Concentration. Parameterisation was carried out for the pesticide fate model, TOXSWA. Hydrology was simulated with the SWQN model, from which the simulated discharges and water depths provided input for the TOXSWA model.

The parameterisation is part of and builds further on the general scenario selection procedure which are followed by the Working Group. Hence, the ditch parameterisation is a further elaboration based on initial assumptions by the Working Group, with the final aim of including all (complex) pesticide fate processes in the pesticide fate simulations. The scenario selection procedure resulted in the selection of (the geometry and water depth of) one edge-of-field ditch of the hydrotype, 'Betuwe stroomruggronden', for all scenarios. The selected ditch is of the class 'secondary ditch' according to the classifications used by the TOP10 vector-map. Dutch water boards distinguish between summer- and winter water depths. This was accounted for in the scenario selection procedure. The difference between the winter and summer water depths of the selected ditch was less than 5 cm.

As drift deposition was assumed to be the dominant pathway, in 2015, the Working Group decided not to include drainpipe emissions, with the caveat that this approach required checking with the highest Drift Reduction Technique class (DRT99). This presumption was used as the starting point of the parameterisation described in this report. Recent example calculations, however, have indicated that the contribution from the drainpipe to the exposure in fruit crops cannot be ignored. Regarding the inclusion of drainage input in the assessments, the approach that will be followed is still under debate and does not feature in this report.

The management area of the Rivierenland Waterboard is the area in the Netherlands with the highest density of fruit-orchards. Ditches in this area were assumed to be representative for the evaluation ditch. For information on the flow velocity, the Rivierenland Water Board was approached. This Water Board has two high-resolution calibrated model types: one hydrodynamic model (SOBEK) and one high-resolution groundwater model (Moria).

The *hydrodynamic model* (SOBEK) covers a large part of the area of the Rivierenland Water Board. The model was developed to simulate discharges and water depth of the major water courses in the area. The mean velocities calculated by the model are relatively high, because the smaller, local water-courses are not explicitly simulated. Only 20-31% of the total length of ditches next to fruit orchards were covered by the model, hence, 69-80% of the ditches were not considered of relevance to the model, probably because they were too small.

The *groundwater model* of the area (Moria) also covers a large part of the Rivierenland area, but the model only simulates groundwater flow per grid-cell. The model does not provide discharges or water-depths in water courses. The daily flow velocities in water courses were, therefore, approximated by, and derived from, the groundwater surface water exchange fluxes per 'peilgebied' (one water management area with a specific target water level). The resultant water flow velocities show that water flows in two directions in the Rivierenland area, depending upon the situation, if there is water need (mostly in summer) or water discharge (mostly in winter). The calculated flow velocities were by a factor of 3-10 lower in summer and by a factor of 10-100 in winter, and more in line with what would be expected based on local water discharge only.

The flow velocities derived with the groundwater model were used in the further analysis. One hundred and ten pre-selected time series of flow velocities were used to derive further velocities, based on dominant hydrotype and fruit-orchard density in the correspondent ‘peilgebied’. Each time series had a length of nine years. A statistical direct sampling algorithm was used to sample a synthetic signal out of the time series of flow velocities. The constructed time series had a length of 27 years. The flow velocities were not correlated to real weather years.

The flow-velocity time series used in the report was based on one sample of the total data set of flow velocities, whereas each sample gives a new time series. Assessing the difference between cumulative frequency distributions of ten different sample datasets showed a limited difference between individual samples. The technique applied resulted in a limited smoothing of the data. It is recommended to assess the sensitivity of the Predicted Environmental Concentration to the sample used.

Median (absolute) flow velocity of the derived synthetic time series is 177 m/d. In the summer, the median velocity was smaller (77 m/d), and in the winter it was higher (369 m/d). The median summer- and winter velocities were higher than in the current Dutch evaluation ditch and also higher than in the FOCUS surface water ditches.

The evaluation ditch has a length of 300 m, with the evaluated section of the ditch located in the centre (from 100-200 m). Based on GIS analysis of orchard sizes and ditch lengths in the Rivierenland area, the size of the orchard located next to the evaluated section of the ditch was set to 1.4 hectares, with a depth of 140 m perpendicular to the evaluation ditch. The ditch was discretised into segments of 10 m each. For the numerical solution of the mass conservation equation solved by TOXSWA, 10 m was assumed to be the maximum segment size without unacceptable numerical effects. It is recommended that this assumption is verified.

The dynamic hydrological model (SWQN) was used to downscale the daily flow velocities to hourly discharge and to obtain water depth in accordance with the flow velocities. The SWQN was calibrated, such that, given the time-series of flow velocities, the simulated water depths were in line with water depths used in the scenario selection procedure, and consistent with Rivierenland water management practices. The simulations with SWQN were carried out over a period of 27 years. 26 of the 27 simulation years were used. Discharges and water depths per hour and per segment were outputs of the model used as input for the TOXSWA model. The TOXSWA model runs for 26 years, from which of with the first six years were used to establish an initial concentration level in the sediment.

TOXSWA simulates pesticide fate in water- and in sediment. Sediment bulk density, porosity and organic matter content are important properties that impact the calculated water and sediment concentrations. A literature survey resulted in a limited number of possible sediment property sources. Two Dutch sample locations were selected, covering the range of possible sediments and sediment properties. The impact of the selected two types of sediments should be assessed via example calculations, and one sediment should be selected based on this assessment.

The temperature in the ditch water and sediment was calculated from weather data. Hourly weather data from the Herwijnen meteorological station, located in the Rivierenland area, were used.

# Samenvatting

Dit rapport beschrijft de parameterisatie van de evaluatiesloot. De evaluatiesloot vormt onderdeel van de blootstellingscenarios ontwikkeld voor de Nederlandse evaluatieprocedure voor zijwaartse en opwaartse bespuitingen. Het geparameteriseerde evaluatieslootmodel samen met het bijbehorende driftmodel en drainpipe model maakt het mogelijk om de zogenaamde 'Predicted Environmental Concentration' (d.i. de milieuconcentratie) te berekenen voor complexe toedieningsschema's in fruit- en laanbomen. De gemiddelde concentratie over de middelste 100 m is de uiteindelijke 'Predicted Environmental Concentration'. De evaluatiesloot is geparameteriseerd voor het blootstellingsmodel TOXSWA. Onderliggende hydrologie van de sloot is gesimuleerd met het model SWQN. De berekende stroomsnelheden en waterdiepten zijn input voor het blootstellingsmodel TOXSWA.

De slootparameterisatie bouwt voort op de scenario-selectieaanpak die is gevolgd door de verantwoordelijke werkgroep. Deze aanpak leidde tot de selectie van één kavelsloot van het hydrotype 'Betuwe stroomruggronden'. Verder is de geselecteerde sloot een secundaire sloot volgens het classificatiesysteem van de TOP10 vectorkaart. De parameterisatie beschreven in dit rapport is een verder invulling van slooteigenschappen om zo alle relevante (complexe) processen te kunnen simuleren. In Nederland wordt er door watermanagers onderscheid gemaakt in zomer- en winterpeil. Het verschil in de zomer- en winterpeil van de geselecteerde sloot is kleiner dan 5 cm.

Aannemende dat drift depositie voor fruit en laanbomen de dominante emissieroute is naar oppervlaktewater, heeft de werkgroep in 2015 besloten om emissie via de drains niet mee te nemen in de scenarioselectie-benadering. Deze aanname zou dan in de loop van het werk moeten worden gecontroleerd, met name voor de hoogste DRT klasse (DRT99). Ook in dit rapport is de aanname dat emissie uit drains geen rol speelt als uitgangspunt gekozen. Recentelijk is echter geconcludeerd dat de bijdrage vanuit drainpijpen niet kan worden verwaarloosd. Het scenario zal daarom moeten aangepast. De te kiezen aanpak is nog ter discussie. De beschrijving en de parameterisatie van de bijdrage van de drainpijp vormt geen onderdeel van dit rapport.

Voor de stroomsnelheden in de evaluatiesloot is gebruik gemaakt van modeluitkomsten van hydrologische modellen van het waterschap Rivierenland. Rivierenland heeft in haar beheergebied het grootste areaal fruit van alle waterschappen. Het waterschap heeft twee typen hoge resolutie hydrologische modellen in gebruik, een hydrodynamisch model (SOBEK) en een grondwatermodel (Moria).

Het hydrodynamische model SOBEK beslaat een groot deel van het beheergebied van Rivierenland. Het model is ontwikkeld om debieten en waterdiepten van de grotere waterlopen in het gebied te simuleren. De gemiddelde snelheid berekend met SOBEK is relatief hoog. Dit komt omdat de gesimuleerde waterlopen in het model zijn geselecteerd op basis van hun belang voor hoge afvoer. Berekende stroomsnelheden zijn daardoor veel hoger dan puur als gevolg van afvoer van neerslag vanuit aanliggende percelen alleen. Maar 20-31% van alle waterlopen naast boomgaarden zijn gesimuleerd in het SOBEK model. Met andere woorden, 69-80% van de waterlopen wordt niet expliciet meegenomen omdat deze waterlopen van onderschikt belang worden geacht.

Het grondwater model Moria beslaat een vergelijkbaar deel van het gebied als SOBEK. Met het Moria grondwatermodel kunnen stroomsnelheden worden benaderd, ze zijn dus geen uitvoer van het model zelf. Analyse van deze afgeleide snelheden laat zien dat in de meeste peilgebieden water in de zomer wordt ingenomen en in de winter wordt afgevoerd. Dit leidt tot stroming in twee richtingen. De berekende stroomsnelheden zijn lager dan die van SOBEK maar meer in lijn met wat je zou verwachten als je puur naar de afvoer van aanliggende percelen kijkt.

De stroomsnelheden afgeleid van Moria-uitkomsten zijn vervolgens gebruikt voor verdere bewerking. 110 peilgebieden zijn geselecteerd op basis van hydrotype (Betuwe stroomruggronden) en boomgaarddichtheid. Van elk van deze peilgebieden is een tijdserie van 9 jaar afgeleid met uurlijkse stroomsnelheden. Vervolgens is een ‘direct sampling’ techniek toegepast om de benodigde tijdserie van 27 jaar te construeren. De resulterende tijdserie heeft geen relatie tot echte weerjaren. Modelberekeningen moeten in principe onafhankelijk zijn van een trekking met deze ‘direct sampling’ techniek. Met behulp van voorbeeldberekeningen dient dit te worden gecontroleerd.

De resulterende synthetische tijdserie heeft een lengte van 27 jaar. De mediane (absolute) waarde van de resulterende tijdserie is 177 m/d, waarbij in de zomer de mediane waarde 77 m/d is en in de winter 369 m/d. Deze waarden zijn hoger dan die van het huidige Nederlandse oppervlaktewater scenario en ook hoger dan die van het FOCUS oppervlaktewater scenario.

De evaluatiesloot heeft een lengte van 300 m en bestaat uit segmenten van 10 m. Deze segment grootte is de veronderstelde maximale segmentgrootte waarbij nog geen numerieke effecten optreden. Deze aanname moet nog worden geverifieerd. De grootte van de boomgaard dat behandeld wordt met een gewasbeschermingsmiddel is 1.4 ha. Het veld ligt loodrecht op de sloot en heeft een diepte van 140 m. Zowel de grootte van het perceel als de afstand tussen sloten zijn afgeleid van kaarten in het Rivierenland beheergebied.

Het hydrologische model SWQN is zodanig gekalibreerd dat, gegeven de waterstromentijdserie van 27 jaar, de berekende waterdiepte consistent is met eerdere aannames gedaan in de scenario selectie procedure en met gangbare water management praktijken van Rivierenland.

Simulaties met SWQN zijn gedaan over 27 jaar. De verkregen 26 jaar van deze stroomsnelheden en waterdiepten dienen vervolgens als invoer voor het TOXSWA model dat het stofgedrag vervolgens voor de rekening neemt. Met behulp van voorbeeldberekeningen zal moeten worden bepaald of de 26-jaar berekeningen voldoende lang zijn om stabiele resultaten te geven.

Bulkdichtheid, porositeit en organische stofgehalte zijn sedimenteigenschappen die impact kunnen hebben op de berekende concentraties in het slootwater. Uit literatuuronderzoek kwamen een beperkt aantal bruikbare meetlocaties van sedimenteigenschappen naar voren waarvan er twee zijn geselecteerd. Uit voorbeeldberekeningen moet blijken welk van de twee locaties het beste kan worden geselecteerd voor de uiteindelijke evaluatiesloot.

Temperatuur in de sloot wordt berekend met TOXSWA op basis van weercondities. De uurlijkse weergegevens van het meteostation Herwijnen worden gebruikt voor het berekenen van de water- en sedimenttemperatuur.

# 1 Introduction

## 1.1 Background

Ditches and streams are often found at short distances from crop fields in the Netherlands. Pesticide use and correspondingly high concentrations of pesticides in edge-of-field water bodies is a major concern for water quality managers.

Similarly, the aquatic ecosystem in edge-of-field water bodies is an important protection goal in the Dutch pesticides risk assessment. The Dutch Government initiated improvement of the methodology for the risk assessment of aquatic organisms by establishing a Working Group to develop new procedures for pesticide exposure assessment in edge-of-field ditches. Over the last three years, Dutch exposure scenarios were developed as part of a higher tier assessment methodology for upward and sideways sprayed pesticides, which are commonly used techniques in fruit orchards and tree nurseries. The scenarios enable the calculation of a 90$^{th}$ percentile Predicted Environmental Concentration (PEC) for all considered applications and substance-type combinations.

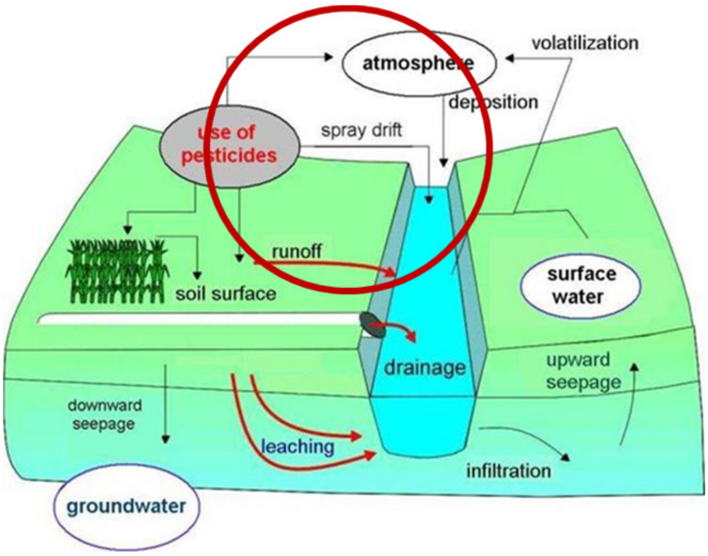


***Figure 1.1*** *Conceptual model of sources and pathways to edge–of-field ditches. Focus of the scenario selection procedure was on spray drift deposition. However, emissions from drainpipes will also become part of the scenario.*

A modelling approach was followed. The entire area of fruit crops in the Netherlands was considered, and scenarios were selected from this. The scenario derivation focused on fruit orchards; avenue trees were considered of less importance. Predicted Environmental Concentrations (PECs) were calculated for all possible combinations of edge-of-field ditches and fruit orchards, while considering the spatial- and temporal variability of meteorological conditions, crop development stages, water-body types, distance to the water bodies and water depths, as well as orchard orientation. One single location was selected that enabled the calculation of the PEC for one application, for three applications, and for multiple applications; only the temporal percentile for each of these scenarios differed. To cover all application schemes, all other (more complex) application schemes were allocated to one- or combinations of these scenarios. A similar procedure was followed for Drift Reducing Technique (DRT) classes, as well as for crop-free buffer zones, both higher tier options in the risk assessment (for detailed description, see Boesten et al.,2018 and Holterman et al., 2016a).

To support this approach, a new and sophisticated drift model was developed to enable the calculation of drift deposition for the entire area of use (Holterman et al., 2016b). Pesticide concentration in surface water was then calculated with a meta model of TOXSWA that assumes dilution of the incoming drift mass over the wetted cross-section of the water body. For the purpose of the scenario selection, pesticide fate in the receiving watercourse was considered to be sufficiently approximated by this model.

Emission via drainpipes needs to be added to the selected scenario. The approach to be taken is still under debate, but the Working Group anticipates following a similar approach to that used by Tiktak et al. (2012).

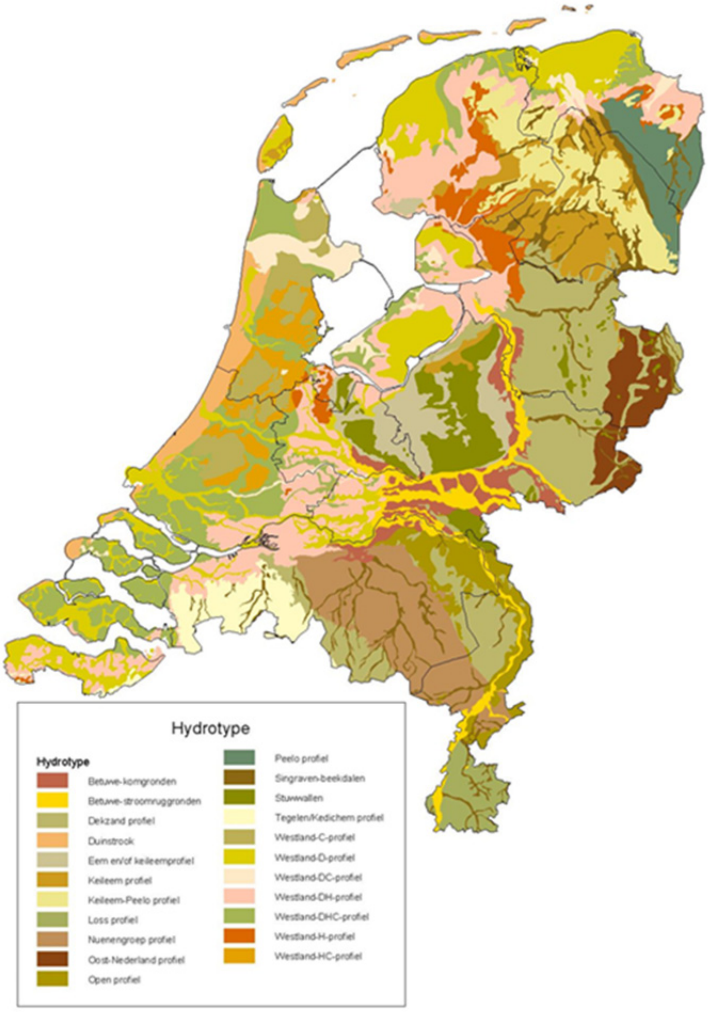


***Figure 1.2*** *Map of hydrotypes in the Netherlands.*

To include information on the spatial variability in watercourse geometries (specifically water depth, width at the bottom and water table) the TOP10 digital vector map of the Netherlands was used (www.kadaster.nl). The map distinguishes between three ditch classes: i.e. small- or temporarily dry watercourses (‘tertiary ditches’); watercourses with a width of less than 3 m (‘secondary ditches’); watercourses with a width of 3-6 m (‘primary watercourses’); and watercourses with a width of 6-12 m. Watercourse geometries are known to be correlated with geo-hydrological characteristics of the subsoil (Massop et al. 2006). Based on field inventories, Massop et al. (2006) provided median values and standard deviations of the ditch-geometry characteristics for all combinations of hydrotype and ditch class. The median values were used in the scenario derivation procedure. The map of hydrotypes is shown in Figure 1.2. Table 1.1 shows frequency of occurrence of specific combinations of hydrotypes and region in fruit orchards. The frequency is expressed with the total area of fruit orchards in the Netherlands as 100%.

***Table 1.1*** *Hydrotype - region combinations as percentage of the total area of fruit orchards. Only the most frequent combinations are shown.*

| Hydrotype | North Holland | South Holland | Rivierenland | Zeeland | Total |
|---|---|---|---|---|---|
| Betuwe komruggronden | 0 | 0 | 6.1 | 0 | 6.1 |
| Betuwe stroomruggronden | 0 | 0 | 9.6 | 0 | 9.6 |
| Westland C | 1.1 | 0.7 | 0.7 | 0 | 2.5 |
| Westland D | 0 | 2.1 | 6.4 | 4.9 | 13.4 |
| Westland DC | 5.7 | 0.5 | 1.1 | 0 | 7.3 |
| Westland DH | 0 | 3.7 | 12.6 | 0.8 | 17.1 |
| Westland DHC | 0.8 | 4.1 | 2.3 | 9.2 | 16.4 |
| Total | 7.6 | 11.1 | 38.1 | 14.9 | 72.4 |

Most water boards allow for additional water storage in the winter, hence, target water levels are usually lower in summer. Managed water levels, however, differ per water board. In the scenario derivation procedure, water board management was included by using one (winter) water depth for the period; 1$^{st}$ April - 30$^{th}$ September, and one (summer) water depth for the period; 1$^{st}$ October – 31$^{st}$ March.

As part of the field inventory, Massop et al. (2006) measured water depth in a wide range of ditches (with a focus on ditches in sandy soils). Measurements were taken in winter times, when the saturation of the soils was highest. In the scenario selection procedure, this value was used for the winter situation and was considered constant over the period; 1$^{st}$ October – 31$^{st}$ March. Hence, the winter water depths in the ditches were based on Massop et al. (2006).

The summer water depths were calculated by adding the difference between the winter and the summer target levels of the water boards to the winter water depths. Winter- and summer water levels were taken from the National Hydrological Instrument (www.nhi.nu). This instrument encompasses data from a target level (‘peilvakken’) map from the water boards. Only the Western part of the Netherlands has managed surface-water levels (‘peilbeheerst’). In the Eastern part, surface water may drain freely and water levels are allowed sink below the target levels. Figure 1.3 shows the frequency distribution of the difference between summer- and winter water depth in areas with fruit orchards for primary- and secondary ditches. Differences may vary between -20 cm (target water level in the summer is lower than in the winter) and +50 cm. The majority of the water level differences lay between -5 cm and + 25 cm.

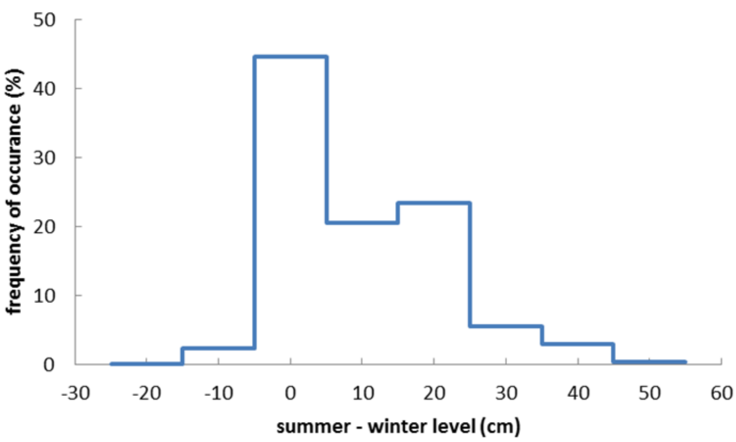


***Figure 1.3*** *Frequency of occurence of differences in target summer and winter water levels (cm) in Dutch edge-of-field ditches next to fruit orchards for primary- and secondary ditches (source NHI).*

## 1.2 Objectives

In the scenario selection procedure applied by the working group, a simplified surface-water model was applied to calculate pesticide concentrations in water. The final parameterised scenarios should enable the calculation of the Predicted Environmental Concentration (PEC) for complex pesticide application schemes, and for an edge-of-field ditch that is situated in the landscape (i.e. connected to other watercourses). The Predicted Environmental Concentration is then the averaged water concentration from 100 m of evaluation ditch. Also, a more elaborate fate model (i.e. TOXSWA) must be applied, that accounts for pesticide fate processes other than dilution only, e.g. transport, sorption and degradation. As a consequence, additional environmental parameters are needed to parameterise the model. The aim of the research described in this report is to parameterise the hydrology of the evaluation ditch as part of the scenarios for sideways and upward spraying, while taking the geometric characteristics of the ditch of the scenario that was selected as the starting point. The sediment compartment was also parameterised.

Example calculations with model pesticides are not included in this report. These will be described in a separate document.

## 1.3 Starting points, approach and reading guidance

Based on the area of use for sideways and upward spraying, one single location was selected with different temporal percentiles per application scheme/drift reduction technique. The selected location consists of a fruit orchard with an edge-of-field ditch of the hydrotype, 'Betuwe stroomruggronden'. The ditch is a secondary ditch, according to the classifications used in the TOP10 map. The difference between the summer- and the winter water levels is zero ± 5 cm.

As drift deposition was assumed to be the dominant pathway, in 2015, the Working Group decided not to include drainpipe emission, with the caveat that this approach required checking for the highest DRT class (DRT99). This presumption was used as the starting point for the work described in this report. Recent example calculations, however, indicate that the contribution from the drainpipe to the exposure in fruit crops cannot be ignored. For drainage input, the approach that will be followed is still under debate and is not included in this report.

Hydrology of the evaluation ditch is simulated with the hydrological model, SWQN (Version 3.03.0; Revision 102). SWQN is a simplified hydraulic model for surface-water systems that simulates water flows and water levels in a schematised network of nodes and sections. Water-flow simulation is based on a simplification of the basic St. Venant Equations. The user can specify a variety of section types, such as open watercourses and weirs, culverts and pumps. Water levels are calculated in the nodes and the differences in water levels between connected nodes are the driving force behind the one-dimensional flow (Smit et al., 2009).

Pesticide fate and behaviour in the evaluation ditch is calculated with TOXSWA (TOXic substances in Surface Waters) (Adriaanse, 1996; Adriaanse and Beltman, 2009). The TOXSWA model has been developed to calculate pesticide concentrations in surface water and sediment. The model was extended with an option to simulate the formation and fate of parents and metabolites (Adriaanse et al., 2014). TOXSWA considers transport, degradation, the formation of transformation products, sorption to sediment and suspended solids and volatilisation. Transformation and volatilisation are assumed to be temperature dependent. Sorption to sediment and suspended solids is described by the Freundlich Equation.

To simulate a realistic hydrological situation, realistic flow velocities are needed for a period of 26 years or more. Flow velocities are discussed in Chapter 2.

The ditch geometry and the position in the landscape are discussed in Chapter 3. Water depth is correlated to the water flow velocities and is set by calibration of the model. The conditions used for the calibration of the hydrological model are also discussed in Chapter 3. Chapter 4 describes the SWQN hydrological model, including its parameterisation and calibration. Results of the calibration and the final water flow velocities and water depth variability over time are shown and discussed in this chapter. The parameterisation of the sediment is discussed in Chapter 5, and the simulated temperature in Chapter 6. Conclusions and recommendations are discussed in Chapter 7.

# 2 Flow velocities

## 2.1 Focus on Rivierenland area

Flow velocity and water depth are considered key parameters for pesticide concentration in watercourses (e.g. Westein et al., 1998). E.g. high pesticide concentrations are exeptected to occur in a ditch with low flow velocities, especially in case of repeated application of persistent substances. Good representation of the flow velocity as part of the scenario is, therefore, important, and should be realistic and representative. Water flow velocities vary as a result of variable weather conditions and water-management decisions. The time-series should, therefore, be long enough to reflect the dynamics of fruit-orchard ditches. It was decided to aim for a flow-velocity dataset of at least 20 years plus six years of warming-up period with a higher temporal resolution, e.g. of hours or days.

Forty-three percent of all Dutch fruit orchards are situated in the managed area of the Rivierenland Water Board (see Figure 2.1). The hydrotype, Betuwe stroomruggronden, selected as part of the scenario (see Section 1.3), is mostly located in this area. Therefore, the Rivierenland area was selected as the focal area for the derivation of a representative time-series of flow velocities.

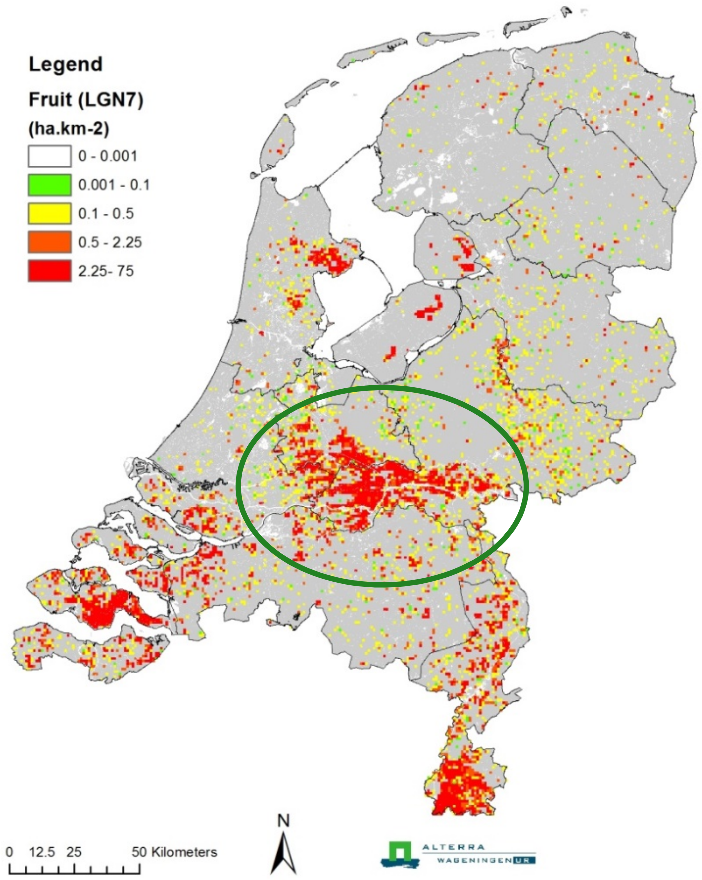


***Figure 2.1*** *Map of density of fruit orchards in the Netherlands based on the LGN7 (Hazeu et al., 2015). The region in the green circle is the Rivierenland area.*

As many areas in the Western part of the Netherlands, water levels are managed in the Rivierenland area; individual water-level regimes are applied per '*peilgebied*', while differentiating between summer- and winter target levels. These levels are referred to as s*treefpeilen* (target water levels) and differ per '*peilgebied*'. In Figure 2.2, an example is given of the summer- and winter (target) water levels for one arbitrary chosen location in the Rivierenland area, each colour refers to one '*peilgebied*', hereafter referred to as '*target level unit*'.

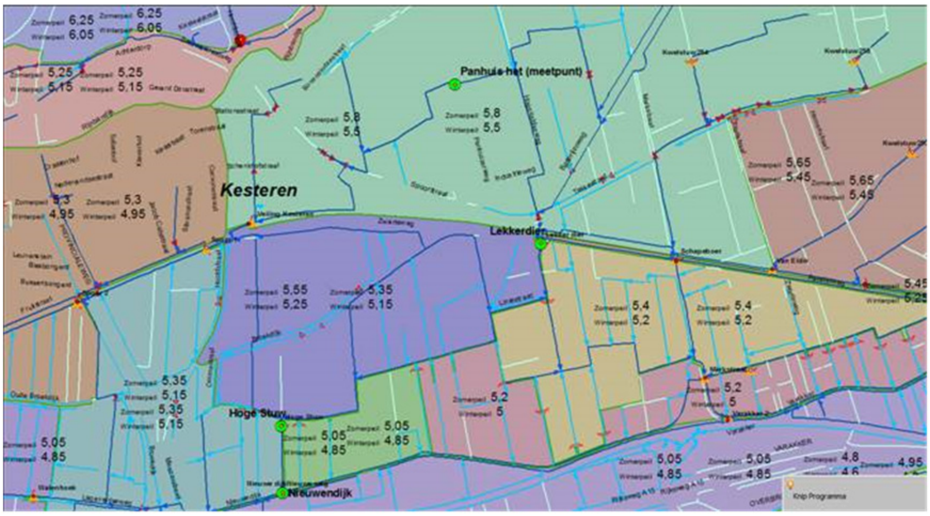


***Figure 2.2*** *Map of an arbitrary example area in the Rivierenland area, indicating the summer- and winter water levels (in m above sea level). Each colour refers to one target level unit (Dutch: peilgebied) with individual target water levels (Dutch: streefpeil).*

## 2.2 Data sources

Flow velocities in edge-of-field ditches are not measured systematically, if at all. Water authorities use regional hydrodynamic models to quantify discharges and flow velocities to support decision making associated with storm flow and droughts. The advantage of these models is that they explicitly quantify flow velocities and water depths of the simulated watercourses. The disadvantage of these models is that edge-of–field ditches that only discharge local water from nearby fields, are simulated as a node in a network of larger water bodies; they are considered as of minor importance for regional quantitative water management. Also, the accuracy for low flow of these models is limited. Low-flow conditions are, however, of special interest for water quality simulations.

Water authorities additionally use groundwater models to assess e.g. the impact of groundwater recharges. These models have a high resolution (e.g. 25x25 m) and are nested in the Dutch National Hydrological Instrument (www.nhi.nu). They simulate per grid-cell discharges to- and from surface water, as part of the groundwater flow simulation. Drainpipe discharges and run-off overflow discharges to surface water, as well as direct exchange between groundwater and surface water, is simulated and each of these discharges are available as daily output of the model. They can be used to estimate daily surface-water flow velocity dynamics. Auxiliary water in- and outflow across grid-cells are not simulated.

Below, the characteristics of the two types of models are described for the Rivierenland area.

### 2.2.1 Rivierenland: hydrodynamic model SOBEK

The Rivierenland Water Board has four hydrological sub-models, which together cover a large part of the managed area, i.e. the sub-models Betuwe & Linge, Bommelerwaard, Lek & Linge and Tielerwaard (Figure 2.3). These models are parameterisations of the hydrological model, SOBEK (www.deltares.nl/en/software/sobek). Watercourses are represented by a network of segments, for which the flow velocity is calculated. The SOBEK sub-models simulate hydrological fluxes in larger water bodies only; smaller water bodies are represented by a node in the network of segments.

Coverage by the model, of ditches next to fruit orchards, was calculated by selecting those ditches that are situated in or next to, a fruit orchard from the TOP10 vector map of the Netherlands, and by making an overlay with SOBEK segments. Table 2.1 gives a summary of the SOBEK sub-models in the Rivierenland area. The last row shows the percentage of coverage, which varies per sub-model between 21% and 31% of the total length of water bodies next to fruit orchards in the simulated areas. Hence, more than 70% of the edge-of-field fruit ditches is not covered by the model, and 69-80% of the ditches were not considered relevant for the model, probably, because they were too small.

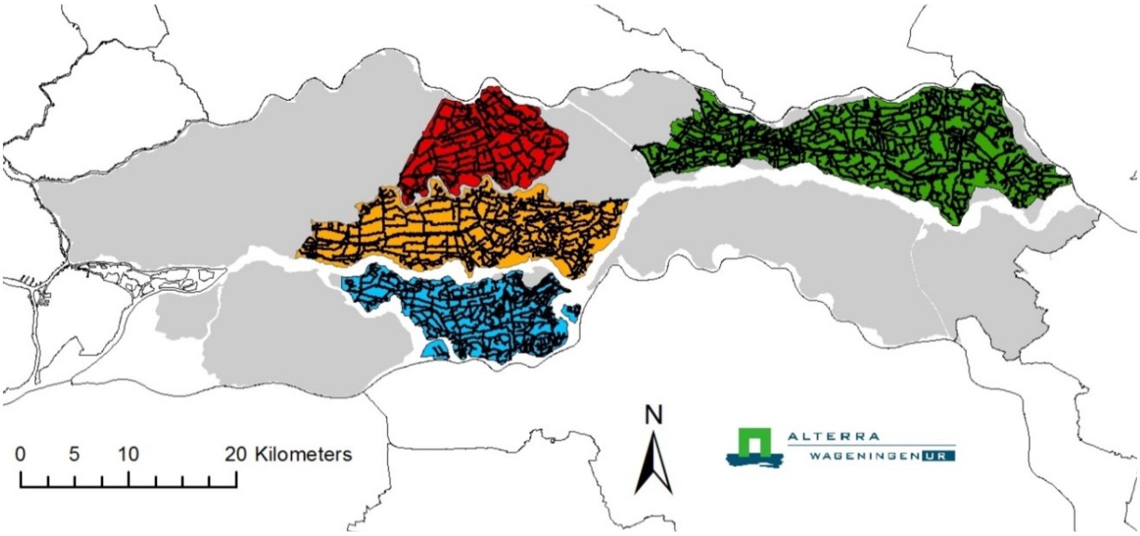


***Figure 2.3*** *Management area of Rivierenland (grey) and the SOBEK sub-models (Betuwe & Linge (green), Bommelerwaard (blue), Lek & Linge (red) en Tielerwaard (orange).*

***Table 2.1*** *Characteristics of the SOBEK sub-models in the Rivierenland area.*

| | Betuwe en Linge | Bommelerwaard | Lek en Linge | Tielerwaard |
|---|---|---|---|---|
| Available simulation period | 1-3-'06 – 1-4-'07 | 1-1-'05-1-4-'06 | 1-3-'04-1-4-'05 | 1-3-'04-1-4-'05 |
| Output frequency | 0.25 d | 1 d | 1 d | 1 d |
| Total length SOBEK segments | 791.4 km | 367.8 km | 259.3 km | 522.4 km |
| Overlap with fruit ditches | 75. 9 km | 34.1 km | 15.3 km | 79.2 km |
| Segments next to fruit orchards (% of ditch lengths next to fruit orchards simulated by SOBEK) | 28% | 31% | 20% | 30% |

### 2.2.2 Rivierenland: groundwater model, Moria 2.2

The Moria 2.2 model (Borren and Hoogewoud, 2014) is a high resolution groundwater model, specially developed and calibrated for the Rivierenland management area. The model has a resolution of 25 x 25 m and solves the water balance per grid cell based on exchange groundwater fluxes with adjacent grid cells, incoming precipitation and outgoing (evapo-) transpiration and also the exchange discharges with surface-water bodies such as ditches or ponds. Note that vertical exchange with surface water is only accounted for and that, hence, surface water that crosses the borders of grid cells horizontally is not considered by the model.

The model has been calibrated for the period 01-04-2002 to 01-04-2011; over this period, daily groundwater-surface water exchange discharges are available for five areas within Rivierenland, i.e. the Betuwe-Linge area (BL), the Bommelerwaard (BW), the Lek and Linge area (LL), the Maurikse wetering area (MW) and the Tielerwaard (TW). In Figure 2.4, the modelled areas are indicated. The grey lines in the figure indicate the borders of the individually managed target-level units ('peilgebieden'). Each sub-model contains a number of these units, with a total of 1925. The dominant hydrotypes per unit are shown in Figure 2.5. In the Maurikse Wetering, the Bommelerwaard, the Lek- and Linge area, and the Tiererwaard, the dominant hydrotype is the Westland DH profile. In the Betuwe-Linge area, the dominant hydrotype is Betuwe stroomruggronden.

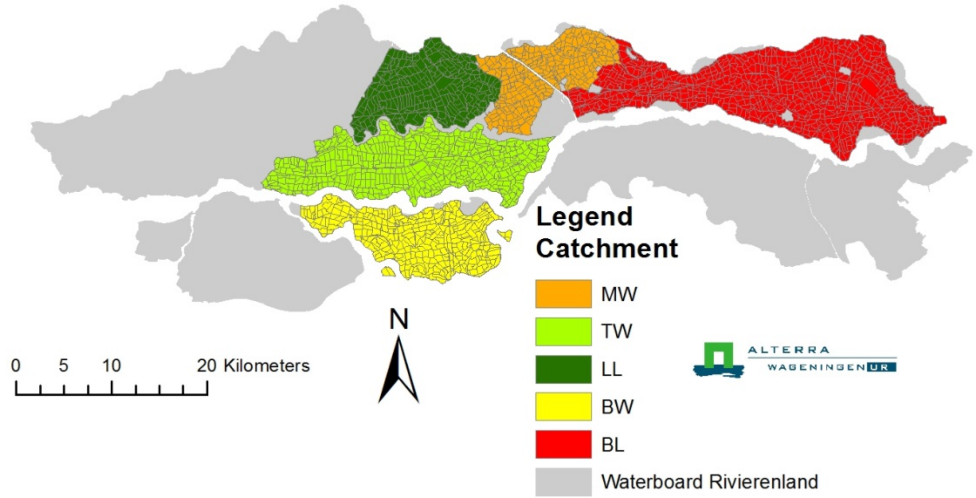


***Figure 2.4*** *Moria sub-models of the Rivierenland Water Board. BL=Betuwe Linge; BW=Bommelerwaard; LL=Lek and Linge; MW=Maurikse Wetering; TW=Tielerwaard.*

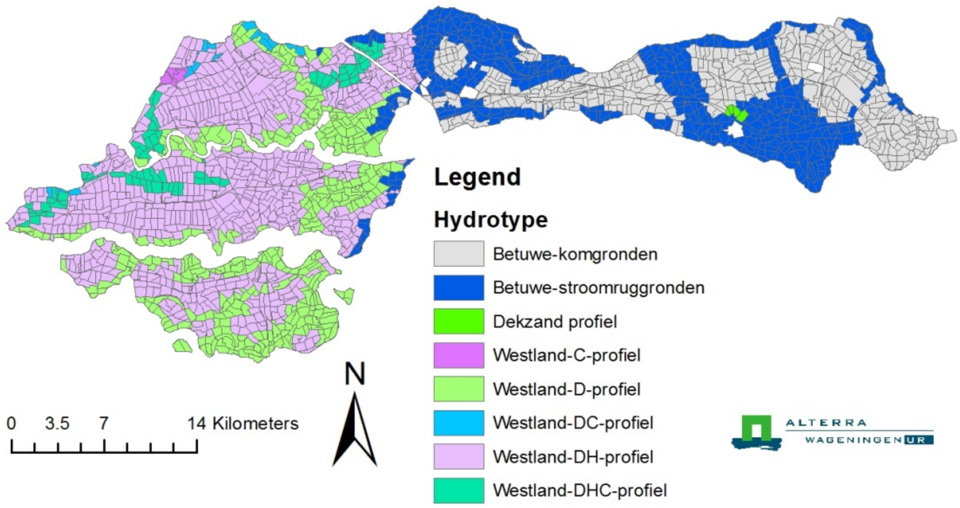


***Figure 2.5*** *Dominant hydrotype in the target level units of the modelled Moria area of Rivierenland.*

Figure 2.6 shows the surface water- groundwater exchange discharges of one example unit for the summer period of 2004. All water that flows towards surface water, e.g. drainpipe discharge or groundwater discharge is represented by negative discharges in the figure. Groundwater recharge (from surface water to groundwater) is considered as positive.

Daily flow velocities averaged per unit can be approximated by:

$$v_t = Q_t / \overline{A} \tag{2.1}$$

with $v_t$ is the average velocity in the unit at time $t$ (m/d), $Q_t$ is the total discharge to the surface water at time $t$ ($m^3$/d), and $\overline{A}$ is the weighted averaged wetted cross section of the ditches in the unit ($m^2$). $Q_t$ is the sum of all exchange discharges ($m^3$/d) at time $t$:

$$Q_t = Q_{t,drpipe} + Q_{t,runoff} + Q_{t,discharge} + Q_{t,recharge} \tag{2.2}$$

where $Q_{t,drpipe}$ is the discharge from the drainpipes and dry falling ditches to surface water ($m^3$/d), $Q_{t,runoff}$ is the discharge to surface water from run-off overflow ($m^3$/d), $Q_{t,discharge}$ is the discharge from groundwater to surface water ($m^3$/d) and $Q_{t,recharge}$ is the recharge from surface water to groundwater ($m^3$/d). $Q_{t,drpipe}$, $Q_{t,runoff}$ and $Q_{t,discharge}$ have negative values and $Q_{t,recharge}$ has positive values in Moria.

$\overline{A}$ is calculated by:

$$\overline{A} = \frac{\sum_{i=1}^{n} L_i A_i}{\sum_{i=1}^{n} L_i} \tag{2.3}$$

Where $L_i$ (m) is the length of the ditches according to the TOP10 vector map for the ditches of primary-, secondary- and tertiary classes, and for the considered hydrotypes, and $A_i$ ($m^2$) is the corresponding wetted cross section for each hydrotype-ditch class combination. Drying out of the shallow trenches in summer was accounted for by taking the wetted cross-section equal to zero in the summer. For larger water bodies, such as large ponds or rivers, a special approach was followed. For these water bodies, the total area covered by the water body was derived directly from the TOP10 vector map.

Note, that the method described above does not distinguish between ditch classes, the velocities derived are average velocities over one unit. Within this unit, ditches of various hydrotypes and of various classes may occur. The finally derived velocity is the weighted averaged velocity over the unit. This derived velocity does not consider (horizontal) exchanged (surface) water volumes between separate units. Also, the discharges $Q_{t,drpipe}$, $Q_{t,runoff}$ and $Q_{t,discharge}$ and $Q_{t,recharge}$ are added, i.e. when both groundwater discharge and groundwater discharge occurs in one day, they will cancel each other out.

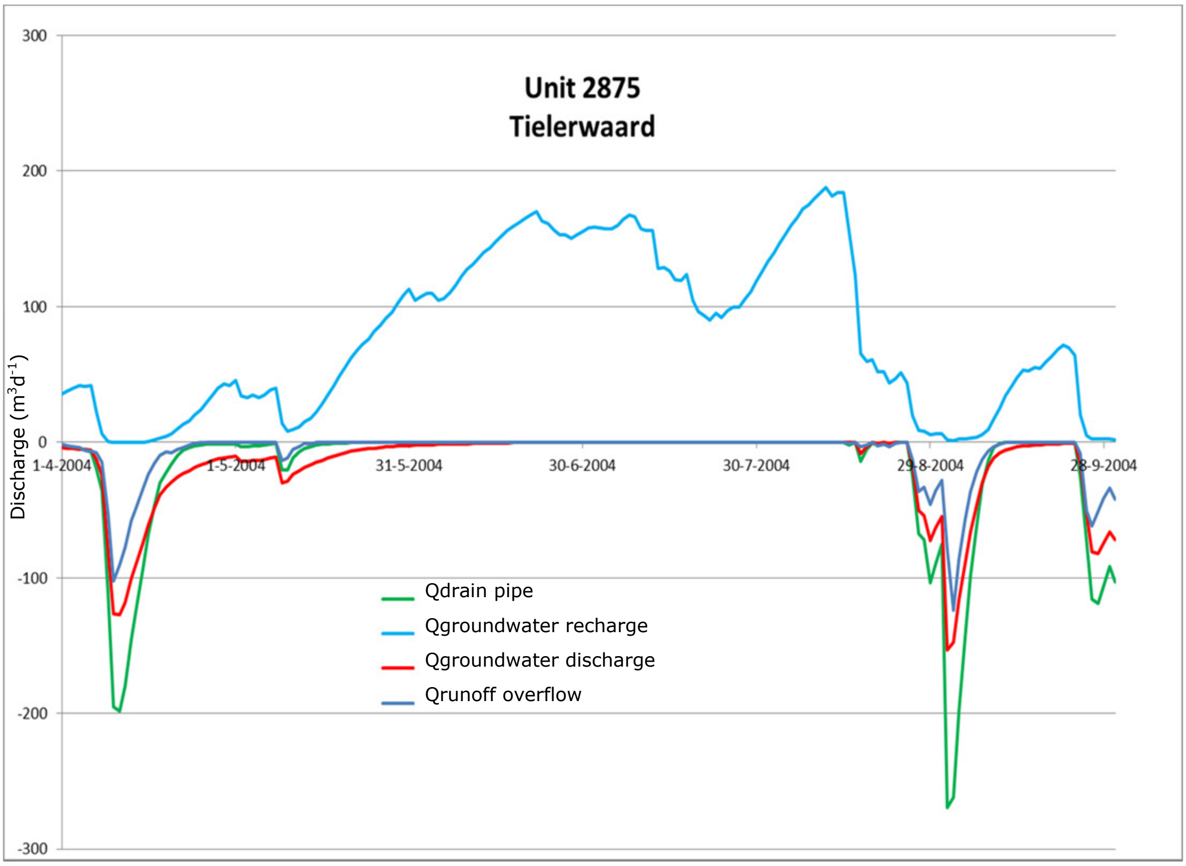


***Figure 2.6*** *Example of exchange discharges for the summer of 2004. The discharges towards surface water are considered negative in Moria and recharge to groundwater as negative.* $Q_{drainpipe}$ *is the discharge from the drainpipes and dry falling ditches to surface water (m³/d),* $Q_{runoff}$ *is the discharge to surface water from run-off overflow (m³/d),* $Q_{discharge}$ *is the discharge from groundwater to surface water (m³/d) and* $Q_{recharge}$ *is the recharge from surface water to groundwater (m³/d). Only recharge occurs in June and July.*

## 2.3 Flow velocities by SOBEK and Moria

### 2.3.1 SOBEK

Flow velocities were analysed over a simulation period of approximately one year, and the output of the different sub-models was compared. In Table 2.2, the mean values of the flow velocities in summer- and winter. Only secondary ditches were considered, as this ditch type corresponds to the ditch class of the selected ditch. The mean model velocities vary between 1200 and 6250 m/d. For Tielerwaard and Betuwe-Linge the mean summer velocity is lower than the mean winter velocity. For the Bommelerwaard and the Lek and Linge sub-models, it is the other way around. We did not investigate the cause of this difference in dynamics between the sub-models, but one might think of the effect of water management practices and differences in local hydrology. In the analyses, summer was defined as the period from 1st April- 30th September and winter was defined as the period from 1st October – 31st March.

The calculated flow velocities are relatively high, as compared to what would be expected based on discharge from nearby fields only. A simple back-of-the-envelope calculation of the velocity due to discharge from nearby fields *v* is (Beltman and Adriaanse, 1999):

$$v = (\gamma PL)/(2A) \quad (2.4)$$

where $\gamma$ is the distance between ditches (m), *P* is the net precipitation (m/d), *A* is the cross-sectional area ($m^2$) and *L* is ditch length (m). For a ditch distance $\gamma$ of 500 m (which is quite large for the Netherlands), a net precipitation *P* of 0.001 m/d, a cross-sectional area *A* of 0.5 $m^2$ and a ditch length *L* of 100 m, the flow velocity would be 50 m/d. This estimated velocity is between a factor of 25 to 50 lower than the simulated mean velocities by the SOBEK sub-models. A plausible explanation for this difference is that the flow velocities calculated with the SOBEK model include auxiliary water from upstream polder areas; next to a local discharge, the simulated watercourses also discharge regional water, and the local (field) discharge is only a small part of the total water budget.

***Table 2.2*** *Mean flow velocities in summer and winter for all segments next to fruit orchards, which are classified as secondary ditches according to the TOP10 vector map (the flow velocities were calculated as the median of velocities per segment in time; then, the mean was taken over all segments).*

| | Betuwe and Linge | Bommelerwaard | Lek and Linge | Tielerwaard |
|---|---|---|---|---|
| Simulation period | 1/3/2006 – 1/4/2007 | 1/1/2005 – 1/4/2006 | 1/3/2004 – 1/4/2005 | 1/3/2004 – 1/4/2005 |
| Number of segments | 1323 | 205 | 101 | 626 |
| Summer velocity (mean) | 1202 m/d | 6234 m/d | 2464 m/d | 1602 m/d |
| Winter velocity (mean) | 2514 m/d | 5968 m/d | 1500 m/d | 2034 m/d |

### 2.3.2 Moria

A pre-selection of the units was made by considering only units with an fraction of area coverage of fruit orchards larger than 0.15, a fraction of water-course lengths of Class 2 (< 3m width), larger than 50%, and with ‘Betuwe stroomruggronden’ as the dominant hydrotype,. The location of the fruit orchards was derived from the LGN map (Hazeu et al., 2014). Next, an additional refinement of the selection was made by ranking the units according to ditch class and select the 110 units with the highest fraction of ditches of Class 3 (smaller ditches) with the rationale that smaller water bodies are considered as more vulnerable. The final set contained 110 flow velocity time series. The selected units are depicted in Figure 2.8. Most of them are located in the Eastern part of the district, predominantly featuring watercourses of hydrotype, Betuwe stroomruggronden. The size of one unit is approximately 40 ha, i.e. 640 gridcells.

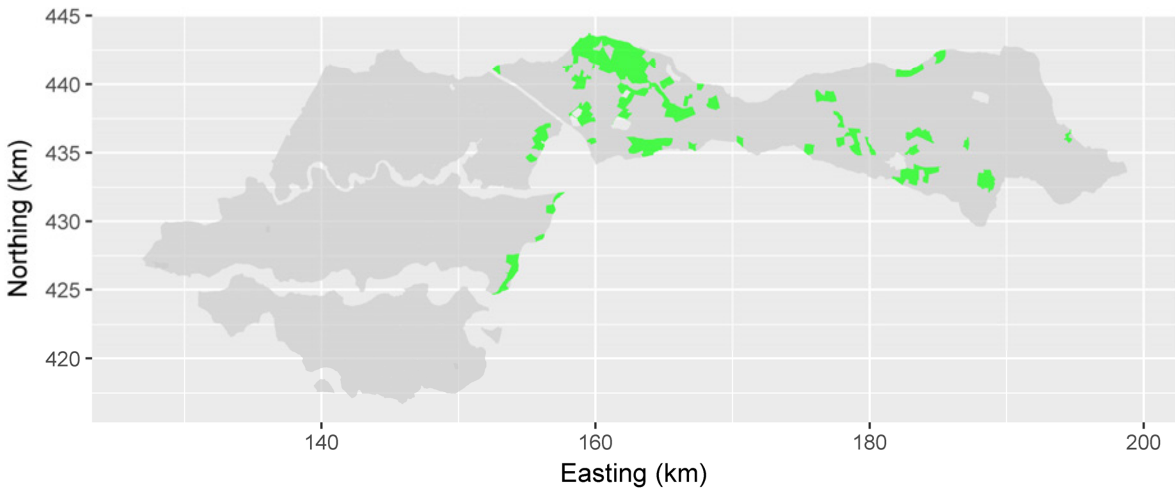


***Figure 2.7*** *Selected units are indicated in green. The selected units have a fraction of area coverage of fruit orchards larger than 0.15, a fraction of watercourses smaller than 3 m of 0.5, and a dominant hydrotype of 'Betuwe stroomruggronden'.*

An example of velocity time-series resulting from the methodology described in Section 2.2.2 is shown in Figure 2.8. The figure shows daily averaged flow velocities with flow in one direction due to discharge in the winter caused by excess precipitation water, whereas, in the summer, the water flows in the opposite direction, as it is let in to support plant uptake and transpiration. In the winter time, the velocities are larger, up to 2.5 km/d.

Figures 2.9, 2.10 and 2.11 illustrate the frequency distribution of these time-series, ranked according to their median daily flow velocity. The median velocity is negative for most of the time-series, which indicates that water is mostly discharged to the watercourses through drainpipes or overland flow (excess of water). Also, most of the time-series show positive, as well as negative water velocities, i.e. the direction of the water flow alternates over the seasons. The median summer- and winter flow velocities, derived with the Moria model are shown in Table 2.3. These flow velocities are much lower than those of the SOBEK model, and more in line with indicative calculations (e.g. Equation 2.4).

An additional comparison between flow velocities of SOBEK and Moria is given in Annex 1 for the area Tielerwaard area. Also, this comparison shows that the velocities derived with Moria are lower.

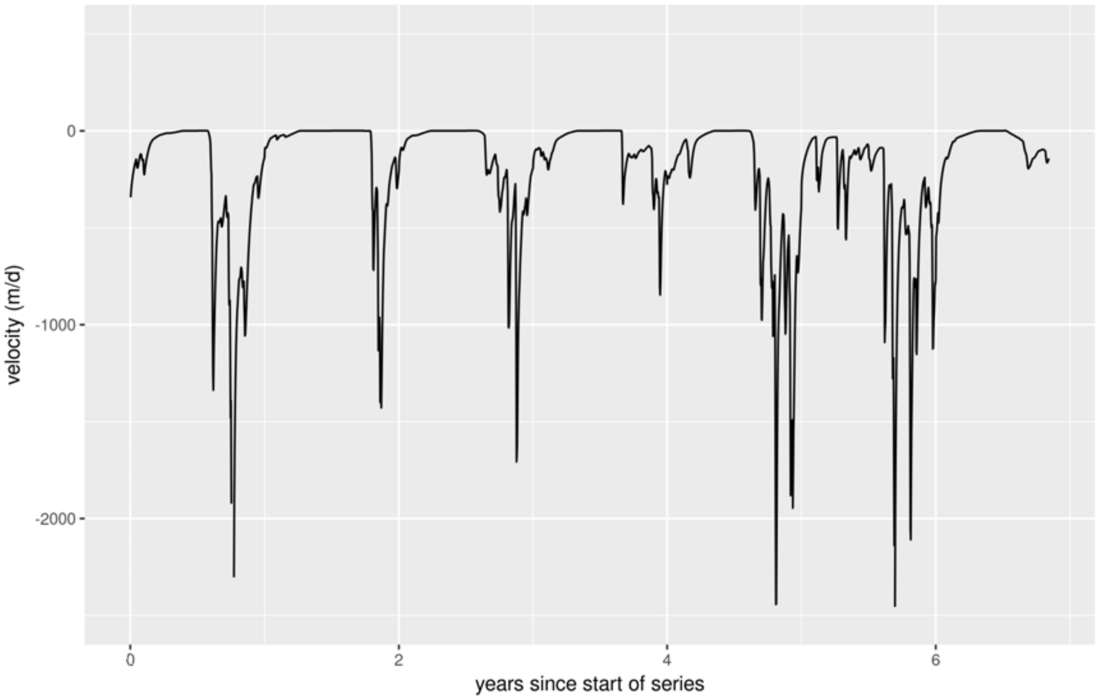


***Figure 2.8*** *Example of the flow velocity time-series over seven years (m/d), i.e. from 1st April 2002 to 1st April 2011, as derived from the Moria model. Velocities show a seasonal trend. Negative flow velocities refer to discharge of excess water in the winter season, positive to inlet of water to support crop irrigation.*

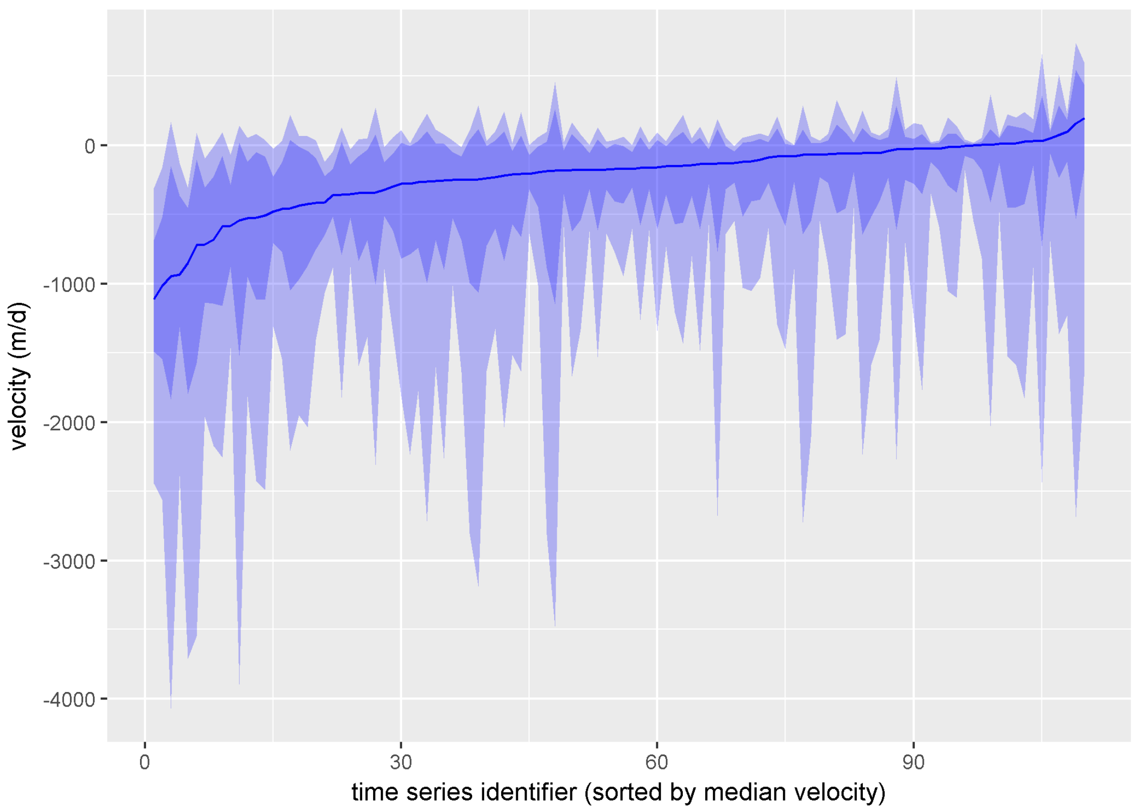


***Figure 2.9*** *Sorted time series of flow velocities (m/d). The time-series ranges from 1-110 on the x-axis according to ranking. Dark blue line: median velocity, the dark blue colour indicates the 25-75th percentiles of the time-series and light blue colour indicates the 10-25th and 75-90th percentiles. Negative flow velocities refer to discharge of excess water in the winter season, positive to inlet of water to support crop irrigation.*

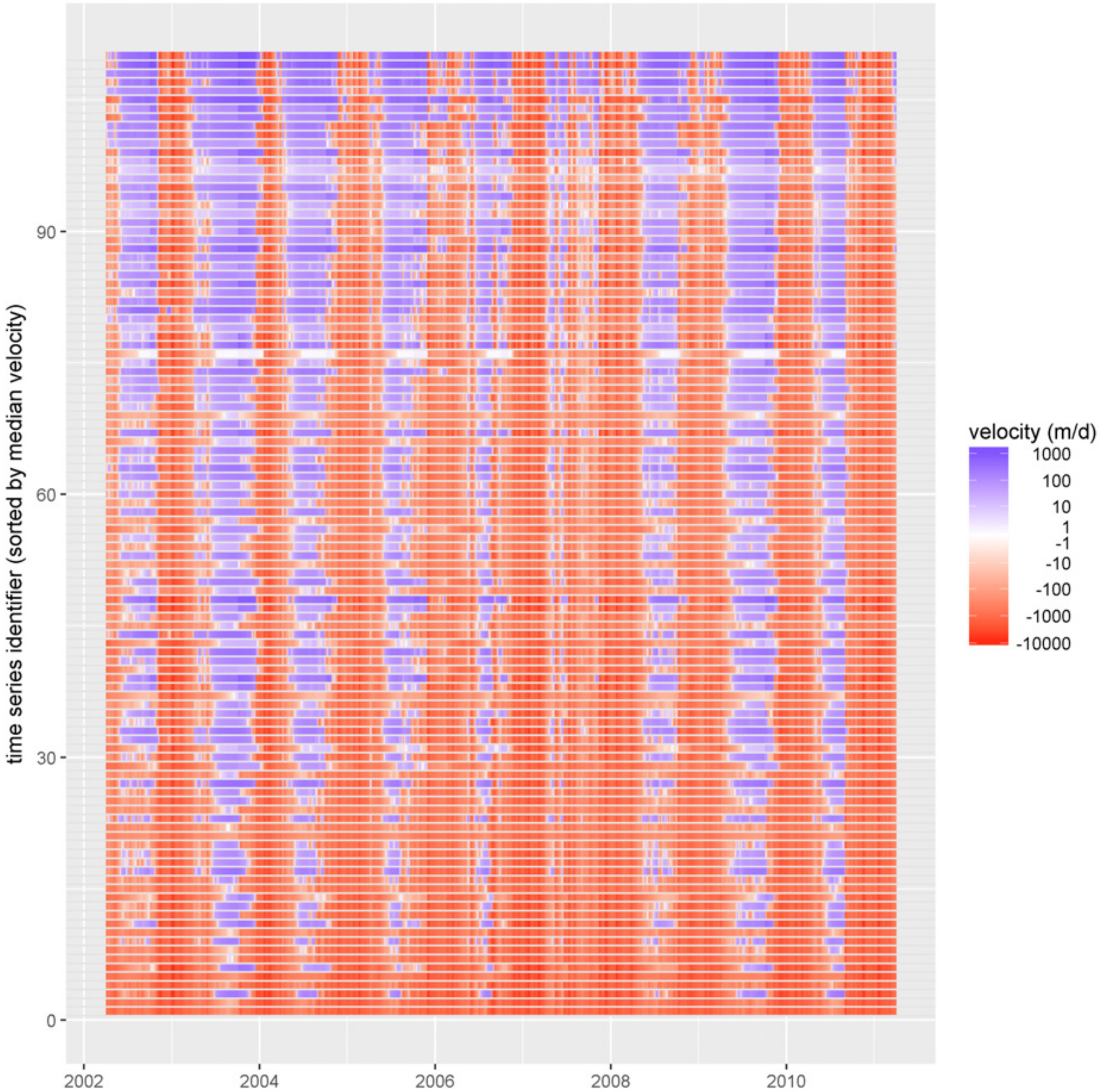


***Figure 2.10*** *Sorted time-series of flow velocities (m/d). The time-series counts from 1-110 on the y-axis according to the median flow velocities. The red colour refers to negative flow velocities and discharge of excess water. The blue colour refers to positive velocities and to the inlet of water to support crop irrigation.*

***Table 2.3*** *Characteristic flow velocities in summer and winter for selected units (based on the Moria model).*

| | |
|---|---|
| Simulation period | 1/4/2002 -1/4/2011 |
| Number of units | 110 |
| Median of the absolute values – 1-Jan to 31-Dec | 209 m/d |
| Median of the absolute values – 1-Apr to 30-Sept (summer) | 89 m/d |
| Median of the absolute values - 1 Oct to 31-Mar (winter) | 515 m/d |

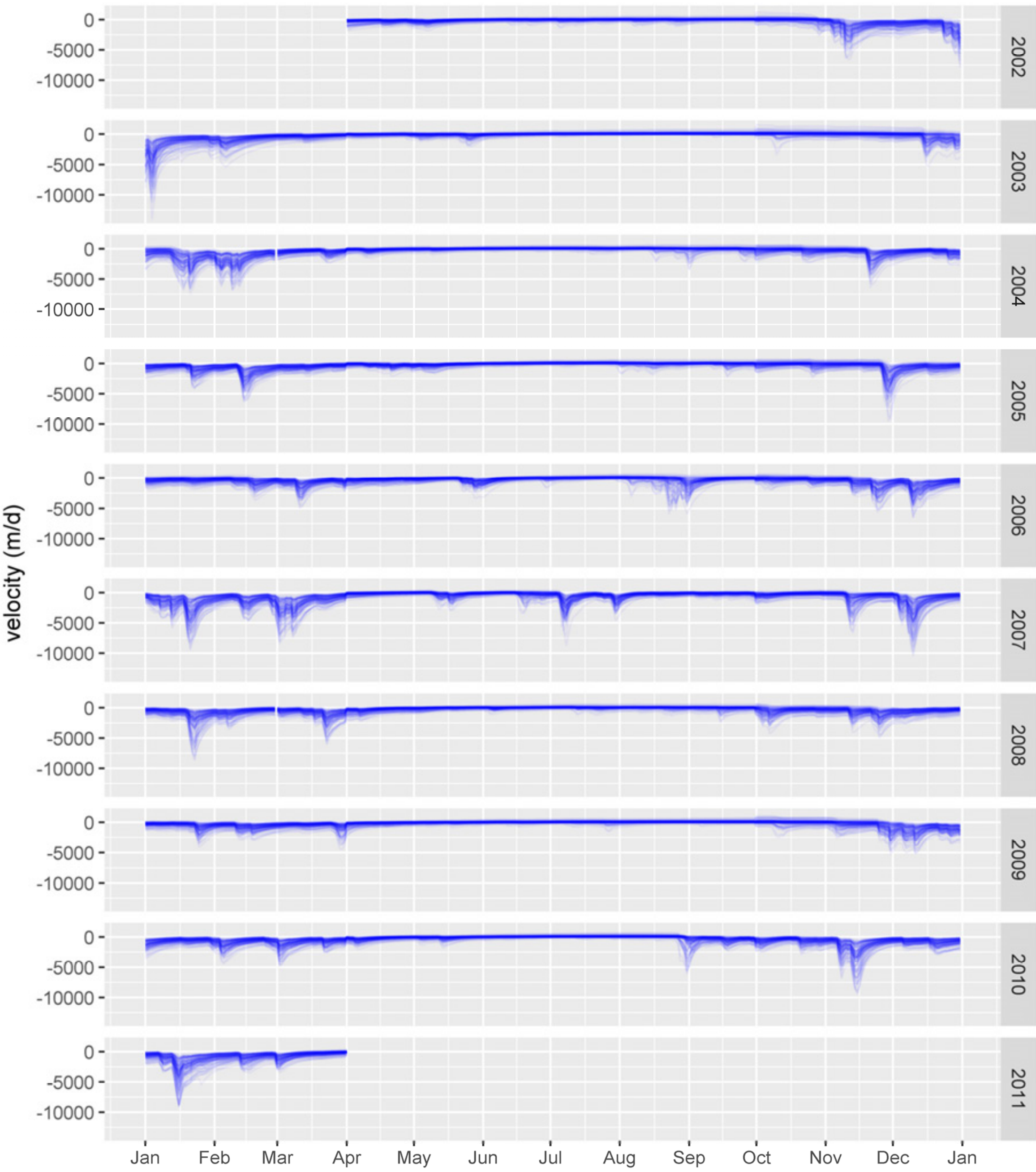


***Figure 2.11*** *Flow velocities (m/d) of all selected time-series plotted per year.*

## 2.4 Flow velocity: extension of time-series

### 2.4.1 Direct sampling

The Working Group decided to proceed with the pre-selected flow velocities derived from Moria. These velocities are expected to be closer to flow velocities of ditches with a local discharge function only. This option is also expected to be more conservative, as a low flow velocity will lead to higher concentrations in the ditch.

The individual time-series derived from Moria have a length of nine hydrological years of daily values (April 2002 – March 2011). This was considered too short for a proper derivation of the target percentiles; it is common in the EU to assess pesticide exposure with at least a simulation run over 20 years with six years of warming-up period.

To generate at least a 26-year-long time series of daily flow velocities, a direct sampling (DS) method was applied. Oriani et al. (2014) recently geared DS to the simulation of synthetic time-series. Their work builds on earlier work carried out in the field of multiple-point geostatistics (Mariethoz et al. 2010, and references therein) during the last decades.

Direct sampling simulates synthetic time series (the so called simulation grid, SG) by iteratively searching for temporal patterns in an existing long time series (the so-called 'training image', TI). Oriani et al. (2014) simulated synthetic time series of rainfall. For a random time $\tau$ in the SG, for which rainfall needs to be simulated, they search for a time $t$ in the TI that has approximately the same temporal pattern as time $\tau$ in the SG. That is, the temporal distribution of rainfall in a time window around time $\tau$ in the SG, is similar to that around t in the TI. The value at time, $t$, in the TI is then assigned to time, $\tau$, in the SG.

Unlike Oriani et al. (2014), we didn't have one long TI (otherwise, we wouldn't have been required to simulate one in the first place). Instead, we had 110 relatively short time series of daily flow velocities. Instead of one long time series, we used these shorter time series as a distributed TI. The time series were offered to the SG as one large time series. We ensured that patterns searched for in the TI only belonged to a single time series to prevent boundary effects.

DS is a relatively simple method that honours higher order statistics in the TI, such as e.g. the shape parameters of skewness or kurtosis. The SG reproduces variation at different temporal scales also found in the TI. The performance of DS can be further improved by adding constraints. As Oriani et al. (2014), we added seasonality constraints. Direct sampling does not rely on an explicit parametric model, like an autocorrelation function. Instead, temporal structure is directly taken from the TI. See Oriani et al. (2014) and Mariethoz et al., (2010) for details.

Figure 2.12 gives a small part of the training image (TI) scaled between 0 and 1. The training image is a concatenation of the 110 smaller time series, each of nine years in length. We sampled this time series (of 9x110 = 990 years) to simulate a new time series of 27 years in length. The first panel gives the time series of the flow velocity (m/d). This is the quantity of interest. The 'target' panel gives a binary time series that is either zero or one. A one means that the value of the flow velocity at this specific date is a candidate for sampling, a zero means that the date is excluded from sampling. The reason for taking this 'target'- timeseries into account, is to prevent edge-effects on the transition between the smaller time series. Indeed, we do not want to compare flow patterns that are part of two different time series. The triangular functions 'tri1` and `tri1' are required to guarantee that seasonality is taken into account. The simulation grid (SG) has the same triangular functions. Samples are only accepted if the values of the triangle wave functions of the training image and simulation grid are approximately equal (see Oriani et al. (2014) for details).

The original time series was transformed, first to a normal distribution using the normal score transformation[1]. After applying the algorithm, the derived time-series was transformed back again. The derived velocities cover 27 years of daily velocities (m/d), and do not refer to a real (weather) year.

[1] For detailed explanation see e.g.: http://pro.arcgis.com/en/pro-app/help/analysis/geostatistical-analyst/normal-score-transformation.htm

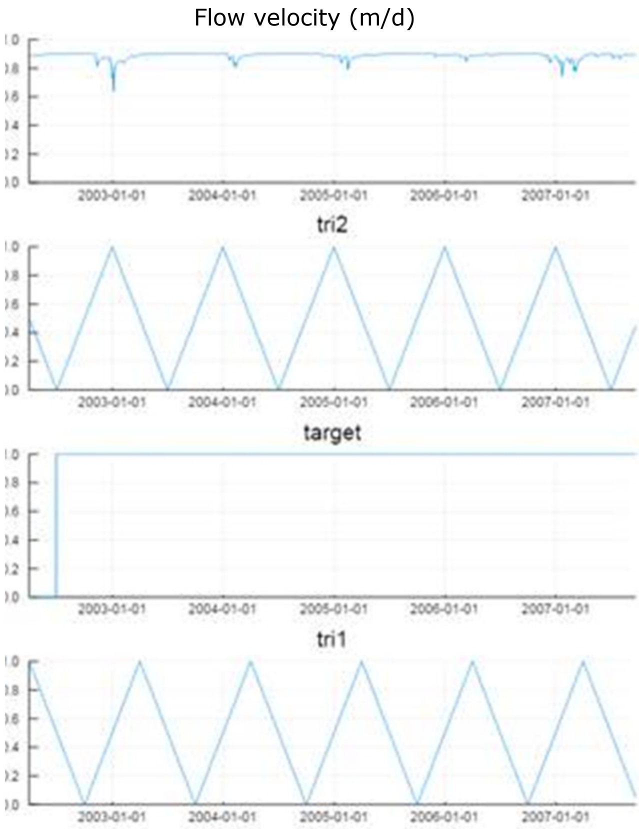


***Figure 2.12*** *Training image and constraints used to sample the so-called 'simulation grid', being a 27-year-long time series of daily flow velocities. The upper panel shows a part of the concatenated time-series of flow velocities from the groundwater model, Moria. Tri1 and tri2 are used as constraints to guarantee the seasonality of the signal. The target 'signal' shown in the target panel is used to overcome the transitions between the nine-year time series. The dates below the panels refer to the dates from the nine-year time series of the training image. The simulation grid has no reference to any real (weather) year.*

### 2.4.2 Results

The direct sampling resulted in the synthetic velocity time series can be found below (Figure 2.13). Note, that an infinite number of synthetic time series may be derived from one training image.

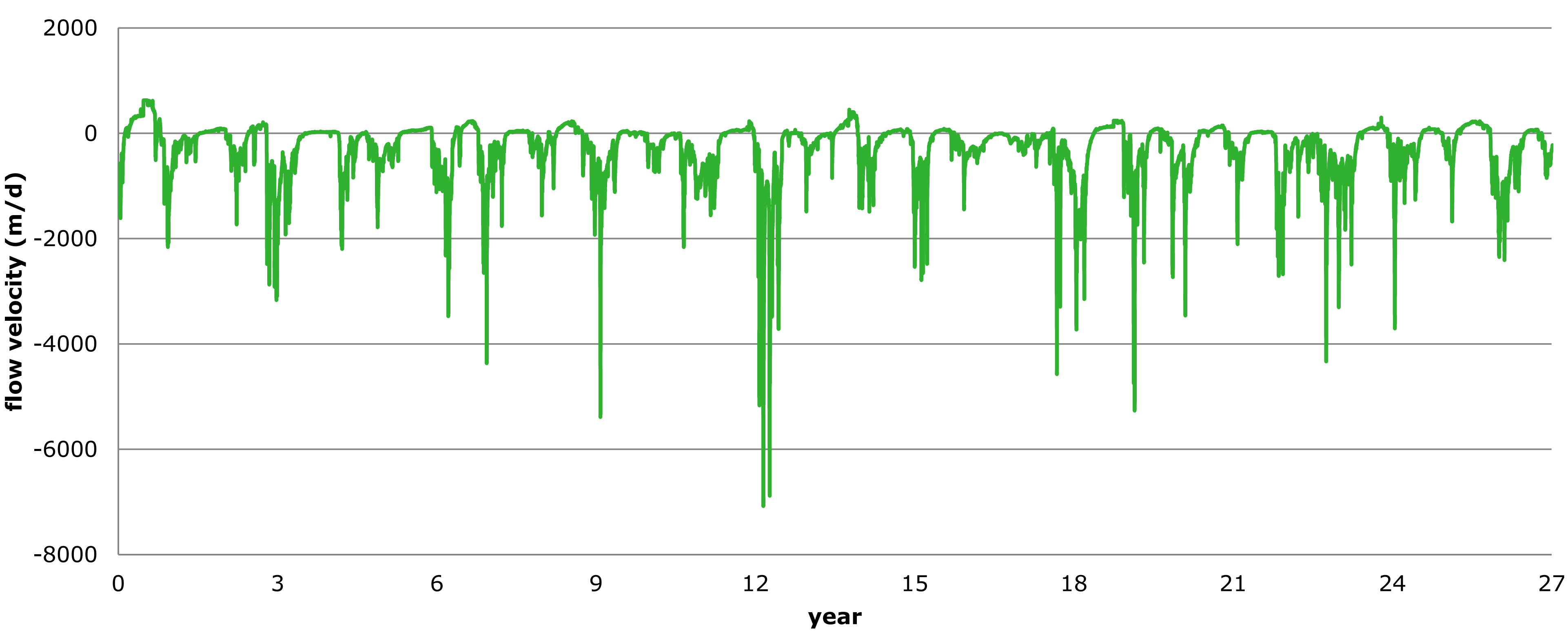


***Figure 2.13*** *One sampled time series of flow velocities as outcome of the applied direct sampling procedure. This time series is further used in the parameterisation.*

To assess the differences in statistical properties of the TI and the SG, we plotted the cumulative probability density functions for both the TI and one or more SGs (Figure 2.14), as well as the autocorrelation functions (Figure 2.15).

Figure 2.14 shows the cumulative probability density functions of the training image in red, and ten separate synthetic time series in blue. The TI function and the synthetic time series functions are very close, but not the same. The applied sampling method lessens the extremes in the dataset, i.e. highest- and the lowest values occur less frequently in the SG as compared to the TI. Also, the median of the synthetic time series is lower than then the training image. E.g. the median of the dataset as presented in Figure 2.13 is -112 m/d, whereas that of the training image is -173 m/d. In the continuation of this report, we use the time-series as presented in Figure 2.13. We expect that the impact of which dataset is finally used in the fate calculations is very limited. This should be verified with example calculations.

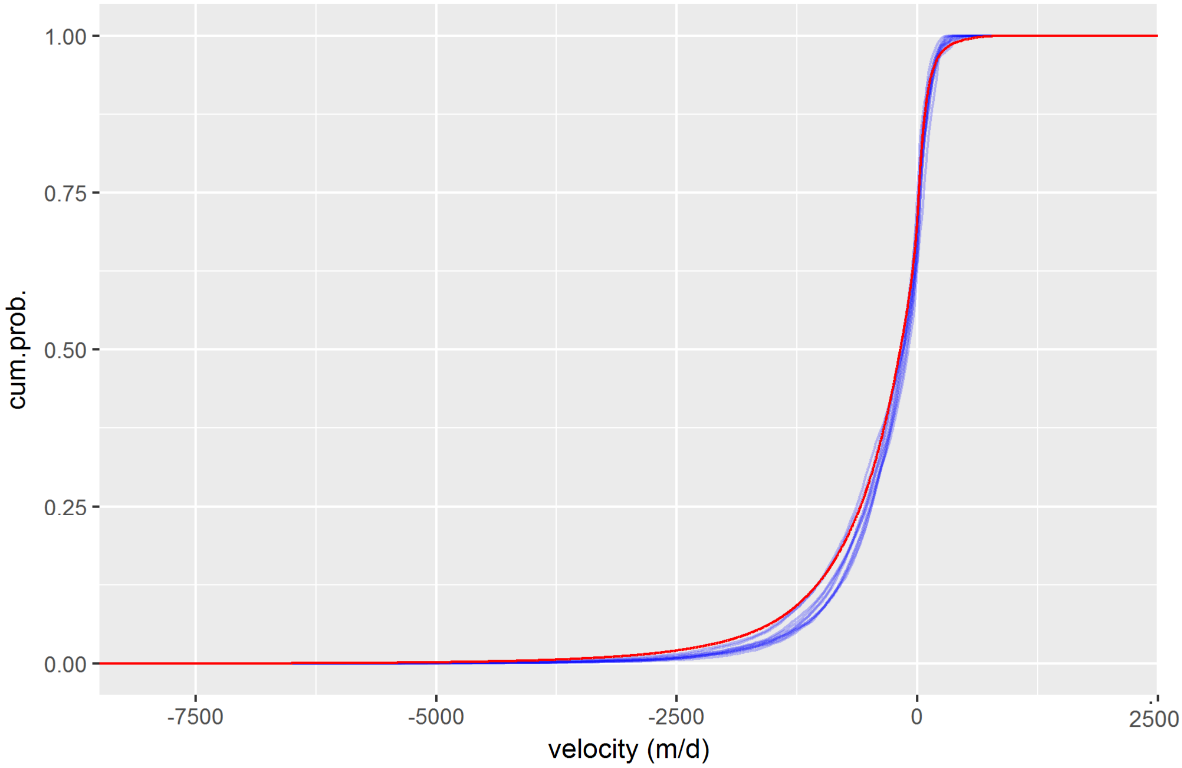


***Figure 2.14*** *Cumulative probability density function of the training image (IT) in red, and ten synthetic time series sampled from the IT in blue (also referred to as simulation grid, SG). Note, that the negative velocities refer to discharge in the winter and the positive to the summer.*

Figure 2.15 shows the autocorrelation function of both the training image and the sampled time series of Figure 2.13. The autocorrelation is the correlation of a signal with a delayed copy of itself as a function of delay. In other words; it is the similarity between observations as a function of the time lag between them. Up until 20 days, both functions have the same autocorrelation. The functions only start to deviate after 20 days, which implies that the method is able to conserve the autocorrelation rather well, up until 20 days.

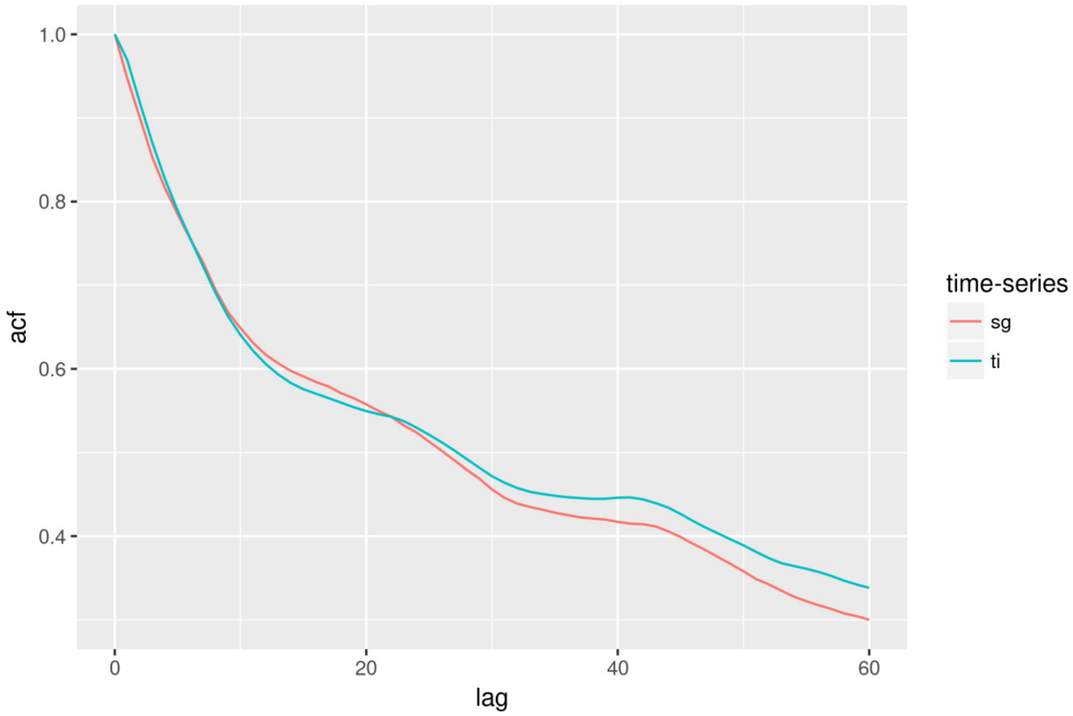


***Figure 2.15*** *Autocorrelation function of the training image (IT) and the synthetic time series (also referred to as simulation grid, SG). The lag is given in days.*

### 2.4.3 Residence times

Given a standard evaluation ditch of 100 m, instantaneous residence times can be calculated. Instantaneous residence times refer to residence times corresponding to each of the (daily) flow velocities in the time-series, in contrast to e.g. monthly (averaged) residence times or seasonal residence times.

Residence times of the derived synthetic time series are summarised in Table 2.4. Typically, the minimum instantaneous residence time is 20 minutes for the summer and the winter, whereas maximum instantaneous residence times are higher in the summer, i.e. 6,377 days, than in winter, i.e. 1,681 days.

Median instantaneous residence time is 13.5 h, which corresponds to a median velocity of 177 m/d for a 100 m ditch. In the summer the median instantaneous residence time is longer, 31 hr and in the winter it is shorter, 6.5 hr, corresponding to respectively a flow velocity of 77 m/d and 369 m/d.

For reference: the mean velocities of the FOCUS surface water scenarios vary between 9.6-84 m/d and the currently used Dutch evaluation ditch has a velocity of 9.6 m/d (summer) and 101 m/d (winter), which is considerably lower. Hence, for these scenarios the residence time would be 1-10 d.

The chance of accumulation of pesticides in the simulation ditch will be smaller than the FOCUS scenarios or the Dutch scenario. This will, of course, depend upon the timing of the application, as well as on the substance characteristics. The impact of the residence time on the accumulation of pesticides in the evaluation ditch is not part of this report.

***Table 2.4*** *Statistical parameters of the time series of the instantaneous residence time corresponding to the final constructed flow velocity time series from Section 2.4.3.*

| | Residence time<br>1-Jan to 31-Dec | 1-Apr to 30-Sept (Summer) | 1-Oct to 31-Mar (Winter) |
|---|---|---|---|
| Minimum | 20 min | 20 min | 20 min |
| $10^{th}$ percentile | 2.5 hr | 5 h | 2 h |
| $50^{th}$ percentile | 13.5 hr | 31 h | 6.5 h |
| $90^{th}$ percentile | 114 hr | 180 h | 49 h |
| $99^{th}$ percentile | 41.8 d | 73.6 d | 16.5 d |
| Maximum | 6377 d | 6377 d | 1681 d |

### 2.4.4 Discussion

Ideally, flow velocities are based on experimental data or alternatively modelled data covering a wide range of edge-of-field ditches. These measured or modelled flow velocities in addition cover a longer time period and have a temporal resolution of at least hours or minutes. However, this data is not available. Calibrated high resolution hydrological models can be used to derive flow velocity dynamics. These are widely available in the Netherlands. Hydrodynamic models, though, have the drawback that only larger water bodies are explicitly simulated by the model, which makes the output of these models less useful. Groundwater models can be used to estimate flow velocities, as well. As a best approximation, we decided to derive flow velocities from the Moria groundwater model.

The method discussed in this chapter aims to derive flow velocities that conserve the dynamic effects of (time-variable) precipitation, farmers' practices (irrigation), as well as water-management practices. A number of interpretation and post-processing steps were taken to come to a dataset of the requested length- and temporal resolution. In how far the applied post-processing steps affect the final data set, and if they can be justified, is not easy to answer. Each of these steps has an effect on the lower- and higher order statistics of the dataset.

In Figure 2.16, an overview is given of the original output by the Moria model and how it was translated into the final dataset of flow velocities, which is used in the further parameterisation described in this report. The first column contains the process steps taken, the last column contains the characteristics of the datasets and the column in the middle contains the interpretation or post-processing steps applied. Also the expected effect is described, qualitatively.

In order to justify all of these steps taken, it should be assessed if the statistics of the final dataset of flow velocities are in line with flow velocities in real ditches next to fruitorchards. To this end, it is recommended to start a survey to measure flow velocities in Dutch edge-of-field ditches. The measures flow velocities will be the basis to justifying the followed approach, but also, to better underpin model parameterisation in general of smaller edge-of-field watercourses used in the exposure assessment of agrochemicals.

In the near future computer power will increase further and high resolution models will be improved. The output of these future models will, therefore, e.g. cover a longer simulation period and have a higher spatial- and temporal resolution. The survey mentioned above may also serve to support calibration and validation of future hydrological models that provide edge-of-field hydrological information used in scenario derivation.

| | Criteria/assumptions and effect | Dataset characteristics |
|---|---|---|
| Output Moria | | • Type: Groundwater-surface water exchange fluxes in Rivierenland area.<br>• Unit: $m^3$/d.<br>• Frequency: daily.<br>• Length of data set: 9 years.<br>• Weather years: 2002-2011.<br>• Spatial unit: grid cell, 25 x 25 m.<br>• Number of spatial units: >> $10^6$. |
| Eq. 2.1-2.3 | • Spatial averaging over water management area, over $10^2$-$10^3$ grid cells. **Effect**: smoothing, lower extremes.<br>• Only local exchange fluxes drive velocities in ditch and these fluxes can be used to approximate the flow velocities. **Effect**: lower flow velocities, lower extremes. | |
| Selection of units | • Target level unit with fraction fruit orchards> 0.15.<br>• Target level unit with fraction of hydrotype, Betuwe Stroomruggronden, Class 2 > 0.5.<br>• Selection of target-level unit with many smaller ditches. **Effect**: unknown. | |
| Velocities | | • Type: flow velocity.<br>• Unit: m/d.<br>• Frequency: daily.<br>• Length of data set: 9 y,<br>• Weather years: 2002-2011.<br>• Spatial unit: target-level unit ('peilgebied', ca 40 ha.<br>• Number of spatial units: 110. |
| Statistical technique, Oriani et al. | **Effect:**<br>• Higher statistical powers of data are maintained, but smoothing of the data occurred for higher flow velocities. Also median flow velocity is higher.<br>• Relation to real weather data is lost and also correlation between weather year, corresponding drift and flow velocities. | |
| Velocities | | • Type: flow velocity.<br>• Unit: m/d.<br>• Frequency: daily.<br>• Length of data set: 27 y.<br>• Weather years: -<br>• Spatial unit: evaluation ditch.<br>• Number of spatial units: 1 |

***Figure 2.16*** *Flow chart with the process steps, criteria/assumptions and expected effect on data set, as well as the characteristics of the resultant datasets for the velocity derivation from the output of the Moria model.*

# 3 Ditch- and landscape geometry

## 3.1 Ditch dimensions

One scenario was selected with an edge-of-field ditch of the hydrotype, Betuwe stroomruggronden, secondary ditch. The corresponding mean ditch geometry was taken from Massop et al. (2006), as listed in Table 3.1 and as depicted in Figure 3.1.

***Table 3.1*** *Dimensions of the selected ditch for the upwards and sideways directed spraying scenario.*

| | Ditch properties |
|---|---|
| Hydrotype | Betuwe stroomruggronden |
| Ditch type | secondary ditch |
| Width top ditch (m) | 3.90 |
| Width bottom ditch (m) | 1.74 |
| Width water (m) | 2.34 |
| Water depth (m) | 0.30 |
| Lineic volume ($m^3$ $m^{-1}$) | 0.612 |
| Slope (horizontal:vertical) | 1 |

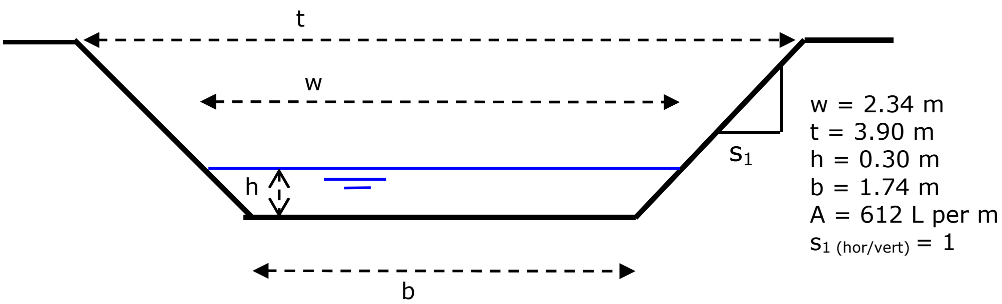


***Figure 3.1*** *Dimensions of the ditch for the selected scenario, where w is the width of the water surface, h is the water depth, b is the width of the bottom of the ditch, t is the width of the top of the ditch, s1 is the side slope (horizontal/vertical), and A is the lineic volume of the water in the ditch.*

In line with preceding exposure assessment methodologies, the length of the evaluation ditch is 100 m, i.e. the calculated Predicted Environmental Concentration (PEC) is the concentration averaged over 100 m of ditch (e.g. Tiktak et al., 2012).

## 3.2 Positioning of the ditch in the polder landscape

Up until now, the water flow velocity in evaluation ditches used for the risk assessment of pesticides in the Netherlands and the EU was in one direction only (FOCUS, 2001). Flow in two directions is typical for polder regions, such as in the Netherlands, as excess water is discharged in the winter and water is let in during the summer to support irrigation and crop growth. The water-flow-velocity time series, as derived in Chapter 2 has two flow directions.

Pesticides entering the ditch may, therefore, be transported over one of the boundaries of the evaluation ditch and then return, due to the alteration of flow direction. Hence, model simulations should be done over the length of a ditch, which is longer than 100 m. In the following, we distinguish between the '*evaluation ditch'*, i.e. the part of the ditch, for which the PEC is calculated, and the '*simulated ditch'*, i.e. the length of the ditch, over which the pesticide fate is simulated.

It was decided to simulate the pesticide fate over a length of 300 m, i.e. the simulated ditch is 300 m. The rationale behind the extension of no more than 100 m is that the ditch will be no longer as it is connected to other water bodies downstream and upstream, as part of a network of watercourses, in which the concentrations are yet unknown, but probably lower than in the evaluation ditch.

### 3.2.1 Distance between ditches

The depth of the orchard has little to no effect on the drift deposition on the evaluation ditch. However, when the drainpipe is included in the scenario, the depth may become important.

If we assume that a fruit orchard is in-between two ditches, then the median distance between ditches may be considered as a proxy for the depth of the fruit orchard situated perpendicular to the ditch. The median distance between ditches was approximated by dividing the total area of one target level unit (*peilvak*) by the total length of all water bodies. This was done for the selected units in the Rivierenland area (see also Figure 2.8, which shows the selected units). The lengths of the ditches were derived from the TOP10 vector map. Some (tertiary) ditches become dry in the summer. In that case, they were only accounted for in the winter.

In Table 3.2, mean- and median distances are given for the selected units (110 units), as well as minimum and maximum values in summer and winter times. The median distance was 137 m in summer and 103 m in winter. The Working Group decided to use the rounded summer value in the parameterisation, i.e. 140 m between the ditches. Tertiary ditches are not part of the exposure assessment goal, therefore, the summer value was considered appropriate.

***Table 3.2*** *Distances between ditches in summer and winter in the Rivierenland, calculated by dividing the total area of a unit by the ditch lengths.*

| Distance between ditches (m) | Summer | Winter |
|---|---|---|
| Mean | 236 | 113 |
| Median | 137 | 103 |
| Minimum | 42 | 42 |
| Maximum | 1218 | 320 |

### 3.2.2 Fruit orchard sizes

The LGN6 map and the BRP map 2012 (Dutch registration of land plots) both contain geographical information of arable and horticultural crops. LGN6 is a grid-map with a resolution of 25 m x 25 m. The BRP map is based on field inventories, for which the grower has indicated the crops per field. In Figure 3.2, an example of an overlay is shown of both maps. The figure shows that orchard sizes and dimensions differ per map. Some fruit orchards that are on the LGN6 map are not on the BRP map and vice versa. Also, the orchards of LGN6 appear to be merged sometimes. Table 3.2 summarises the mean- and median fruit-orchard sizes for both maps. The BRP map, which is based on an annual survey among farmers was considered to be the best source (pers. Comm. Massop). The Working Group decided that the simulated fruit orchard should have a median size derived from the BRP map for the selected units, of 1.39 ha, rounded to 1.4 ha.

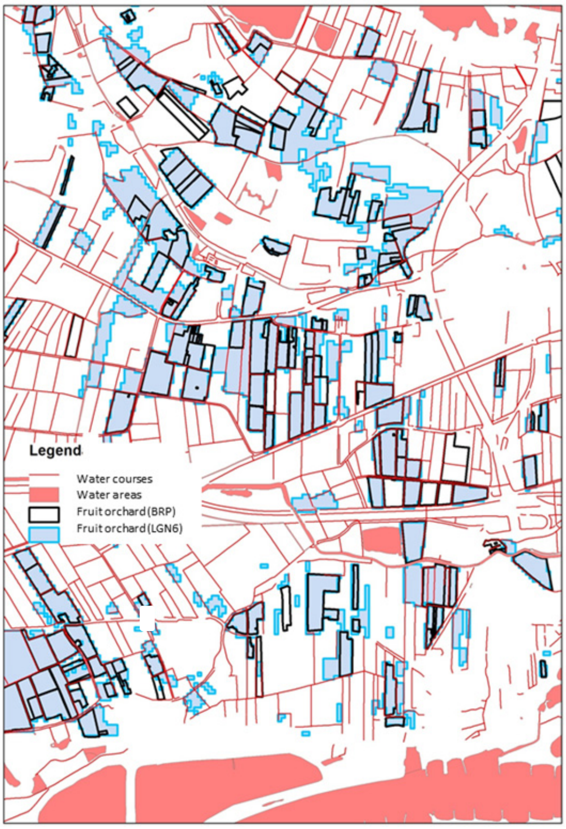


***Figure 3.2*** *Example of an area with fruit orchards as defined by the BRP map (black lines) and the LGN6 map (blue lines). Water area and water courses are indicated in red.*

***Table 3.3*** *Fruit orchard surface areas as derived from the BRP map and the LGN6 map. 'All units' refers to the target level units that were simulated by the groundwater model, Moria, in the Rivierenland area. 'Selected units' refers to the target level units in the Rivierenland area that were selected for the flow velocity derivation.*

| | BRP map | | | LGN6 map | |
|---|---|---|---|---|---|
| | Netherlands | All units | Selected units | All units | Selected units |
| Number of fruit-orchards | 9870 | 2330 | 544 | 2476 | 567 |
| Mean (ha) | 1.98 | 1.78 | 2.00 | 2.41 | 2.46 |
| Median (ha) | 1.31 | 1.28 | 1.39 | 0.44 | 0.27 |

### 3.2.3 Final configuration

Figure 3.3 shows the final configuration of the simulated ditch. For pesticide fate calculations, a ditch length of 300 m was simulated, with the evaluation part of the ditch in the centre (from 100-200 m). This ditch is situated parallel to the tree rows. The size of the fruit orchard is 1.4 ha with a depth perpendicular to the evaluation ditch of 140 m.

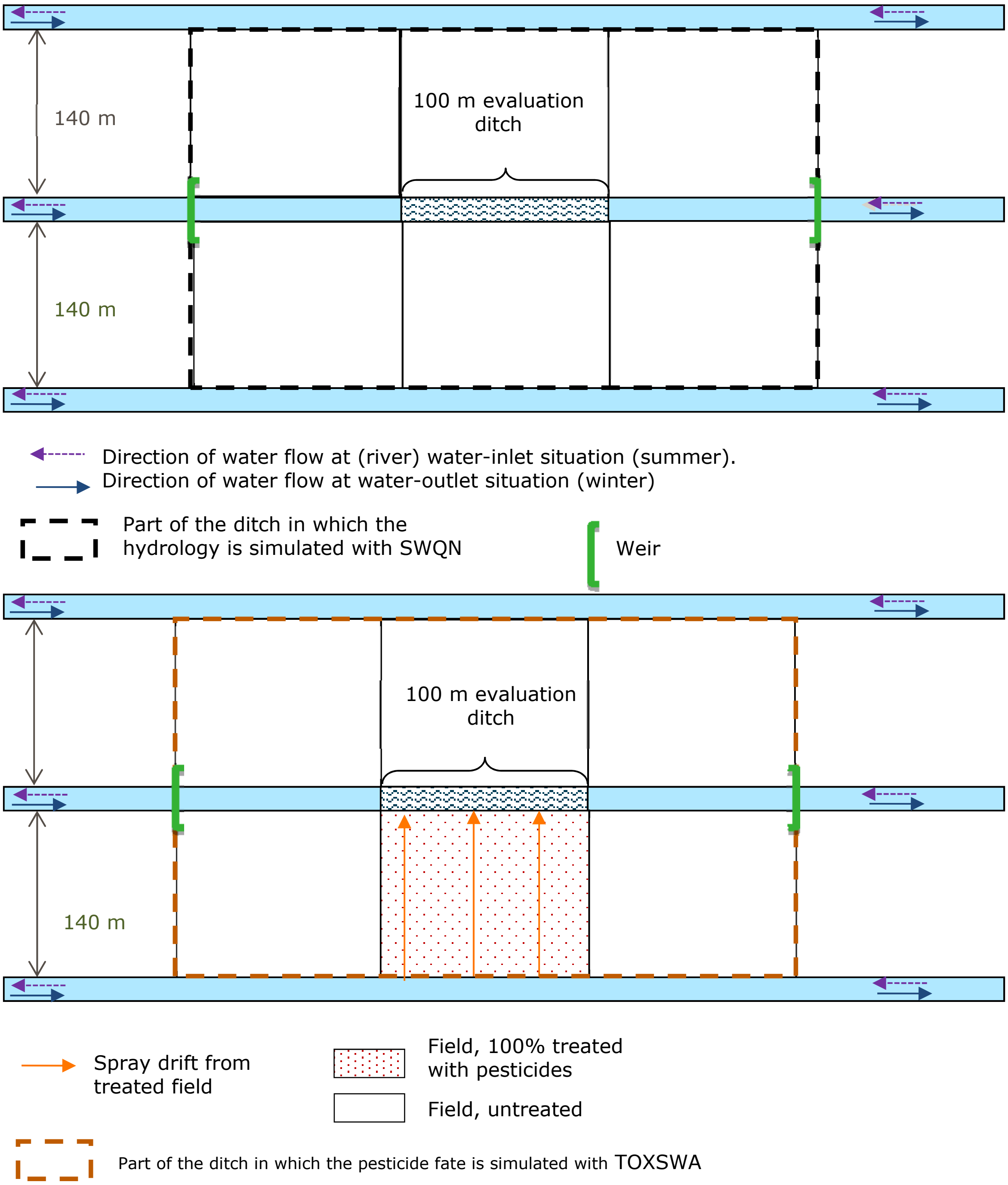


***Figure 3.3*** *Schematic layout of the 100 m evaluation ditch with adjacent field. Upper part: position of the evaluation ditch in landscape and the hydrological situation simulated with SWQN. Lower part: Pesticide entries from the field adjacent in the evaluation ditch simulated with TOXSWA. The model will be extended with drainpipe emission. How this will be described in a separate document.*

Drains are very common in fruit orchards. Since drift was supposed to be the major source, it was decided not to include drain emission in the scenario selection procedure. This approach was also followed for the ditch parameterisation. A new example recently calculated, however, has shown that the contribution of the drainpipe cannot be ignored, especially for drift reduction classes higher than 95%. Hence, the contribution from the drainpipe must be included in the scenario. This is not part of this report, though. Note, that drain discharges are one of the drivers for the flow velocities in the scenario, drainpipe flow is, hence, implicitly considered in the hydrology.

## 3.3 Water depths

The water depth of the evaluation ditch, as given in Table 3.1 refers to an average water depth measured in a wet winter situation. In real-life the water-depth fluctuates driven by excess precipitation and correlates with flow-velocity dynamics; the larger the velocity the higher the water depth in the ditches and vice versa. The hydrodynamic model SWQN is used to derive a consistent and realistic correlation between the time variable water-flow velocities and the water depth. The model is calibrated, such that the simulated water depths are consistent with those assumed in the scenario selection procedure:

(i) The winter water depth had to be equal to the Betuwe Stroomruggronden ditch, i.e. 30 cm.
(ii) Water depths had to be the same in the summer and in the winter, i.e. the maximum summer water depth should be no more than 5 cm, plus or minus the winter water depth.

These two requirements were considered not very specific. Is the winter water depth the median value, the mean value or a 90th percentile in time? And how are the water levels defined?

Ad (i) Winter water depth. The water depth for the winter period is based on Massop et al. (2006). Massop et al. (2006) measured water depth in a wide range of ditches. Measurements were taken in winter times, when the saturation of the soils was highest. The corresponding temporal percentile of these water depths is unknown. The definition of a wet winter period may apply, which is 'exceeding the mean highest groundwater level 30 days a year'. In Tiktak et al. (2012), this definition was used and translated to 'exceeding the mean highest water level 30 days a year'.

Ad (ii). Summer- and winter levels. Water managers of the water boards apply different target polder water levels in summer and winter. The target polder water level in summer is usually higher than the target polder water level in winter. Definitions for summer- and winter target levels are not well established. The target levels refer, however, to fixed levels that are imposed officially over a certain period[2].

The water managers aim to maintain the target polder water levels in the centre of the drainage level area (polder). The Rivierenland Water Board estimates that levels are met for 80 percent of the time. Deviations from the target level may occur mainly due to intensive rain events or intensive water-spraying events to prevent frost damage in fruit orchards (pers. comm. Rivierenland Water Board). These deviations are accepted by the Water Board. Ranges are accepted between -25 cm and +25 cm in the summer and -30 cm and +20 cm in the winter of the target level. Also water depths reaching the soil surface are anticipated to occur once in ten years.
The everyday practice shows that the polder water level is regulated by weirs. Regulation occurs mostly manually, but the most important weirs are controlled automatically. A rule of thumb is that the target level of the weir is about 5 cm lower than the target polder water level in summer and the target level of the weir is about 5-10 cm lower than the target polder water level in winter. In vulnerable areas, the weir height is adapted more frequently than other areas (pers.comm Rivierenland Water Board).

Given the definitions as applied by the Water Board and the definition of the wet winter water depth, and that the parameterisation of the evaluation ditch should be conservative in the sense that underestimation of the water depth gives less dilution and, hence, higher concentrations, the two conditions for the water depths was interpreted, as follows:

(i) The winter water depth, as provided by Massop et al. (2006), is assumed to 'exceed the mean highest water level 30 days a year'. This excess belongs to the winter situation only (six months). Hence, the percentile corresponding to the water depth of 30 cm will be: 100-(100 * 30/180) = $83.33^{th}$ percentile.

[2] The website of the '*Hollandse Delta*' Water Board uses the following definitions (in Dutch):
- *Winterpeil: Een vast peil dat in de winterperiode (meestal september tot april) wordt gehanteerd. De periode wordt in het peilbesluit vastgelegd en mag ook afhangen van de weersgesteldheid.*
- *Zomerpeil: Een vast peil dat in de zomerperiode (meestal april tot september) wordt gehanteerd. De periode wordt in het peilbesluit vastgelegd en mag ook afhangen van de weersgesteldheid.*

(ii) Water levels should be the same in the summer and in the winter is interpreted as: the 50th percentile of the summer level and the 50th percentile of the summer level are equal.

Furthermore, management of the weirs aims to achieve a difference of ca. 5 cm between summer- and winter weir levels. The calibration of the hydrological model based on these conditions is described in Chapter 4.

# 4 Parameterisation of the hydrological model

## 4.1 Schematisation

SWQN is a dynamic model that simulates water flows and water levels in a schematised network of nodes and sections. Water levels are calculated in the nodes, and the differences in water levels between connected nodes are the driving force behind the (one-dimensional) flow (Smit et al., 2009). The water levels depend upon the storage capacity, and are driven by incoming and outgoing flows imposed on the sections and a number of different boundary conditions. A section can represent an open water course, but also a structure, like a weir or a pump. The SWQN model was adapted to enable hourly output of water levels and discharges per section (instead of daily output). Hourly hydrological data are required for TOXSWA.

The simulated ditch comprises of a length of 300 m. The direction of the water flow alternates between incoming and outgoing. SWQN allows for a number of boundary conditions, including; a fixed water level, a fixed sink/source or a fixed discharge-water level (Q-h) relationship. The model does not allow for types of boundary conditions that alternate within one simulation. Also, a section can only be specified as a weir, when it is not connected to a boundary node. To simulate alternating water-flow directions, and to simultaneously maintain a certain minimum water level, these constraints had to be dealt with. The approach followed is explained below.

Firstly, to maintain a certain minimum water level, the parameterised ditch has two weirs located at both sides of the ditch (Figures 4.1 and 4.2). Next, to generate the water flow, a water flux is imposed at the node located at the 'inner-ditch' side of the weir section (i.e. nodes 2 and 35 in Figure 4.2). In case of discharge of water (the blue, solid arrow in Figure 4.1), water is let in on the left-hand side of the ditch, and in case of inlet of water (the purple, dashed arrow in Figure 4.1), this water is let in on the right-hand side of the ditch. Only the downstream weir has a realistic height, i.e. when the water direction is from the weir towards the ditch, the height of the weir is increased, such that it functions as an artificial flow barrier.

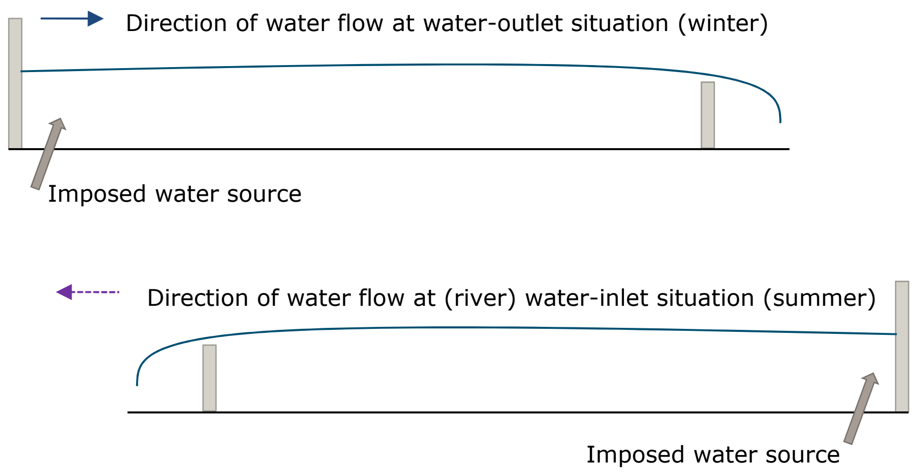


***Figure 4.1*** *Visualisation of the configuration of the weirs in the ditch, as applied in the SWQN parameterisation for simulating alternating water flows in two directions. Only the downstream weir has a realistic height, the upstream weir is used to avoid water flowing in the wrong direction.*

## 4.2 Parameterisation

A 360 m long ditch with 36 sections, each of 10 m, was schematised in SWQN (Figure 4.2). The sections connect all 37 nodes, which are defined by a node ID, an x- and y-coordinate, a bottom level and a minimum- and maximum water level. The SWQN-simulated discharges and water depths for the 10-m-sections from section number 4 upwards to, and including, section number 33, are to be provided as input to TOXSWA model for the pesticide fate calculations, i.e. discharges and water depths over 300 m of ditch (with the 100m evaluation ditch in the centre) are provided as input to TOXSWA. As TOXSWA needs discharges at the boundaries of the segments and the heads in the centre, a conversion is required. Annex 2.2 describes the method for converting the output of SWQN to input for TOXSWA.

The ditch geometry (bottom width etc.) was parameterised, as shown in Figure 3.1. Starting at Node 1 on the left-side and ending at Node 37 and the right-side, incoming water fluxes were imposed via either Node 4 or Node 34, depending on the flow direction. A discharging situation is defined as water flowing from Node 4 to Node 37. A water-inlet situation is defined as water flowing from Node 34 to Node 1. The imposed incoming discharges were calculated by multiplying the derived flow velocities from Section 2.4 with the wetted cross-sectional area corresponding to a water depth of 30 cm (i.e. 0.612 $m^2$; see Figure 3.1). Hence, a constant water depth is assumed here.

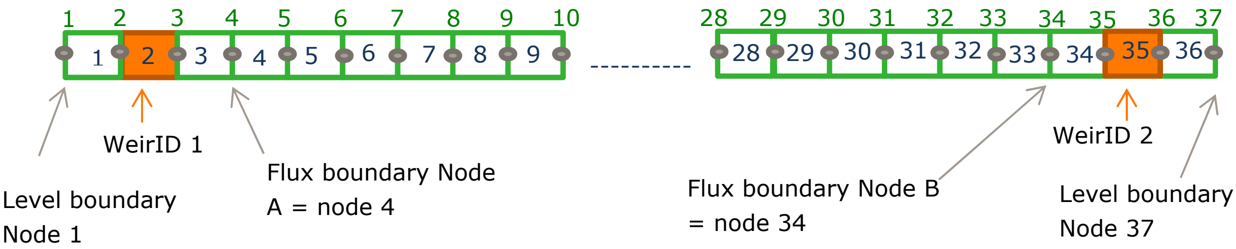


***Figure 4.2*** *Schematisation of the ditch in nodes and sections. The dots represent the nodes (starting with Node ID 1 on the left-hand side and ending with Node ID 37 on the right-hand side). The green boxes represent the sections (starting with Node ID 1 on the left-hand side and ending with Node ID 36 on the right-hand side). The size of one section is 10 m. 'Level boundary node' refers to fixed-level boundary conditions. WeirID 1 and 2 refer to a specific control that corresponds to Figure 4.1 and Eq. 4.1.*

Figure 4.3 shows the daily (imposed) discharge at the 'inner-ditch' side of the weir as function of time for the 27-year simulation period. Discharges during an inlet situation (mainly in summer) have a negative sign and discharges during an outlet situation have a positive sign. Note, that the pattern is similar to the velocities shown in Figure 2.13. The velocities have been multiplied by minus the cross-sectional area (i.e. -0.612 $m^2$).

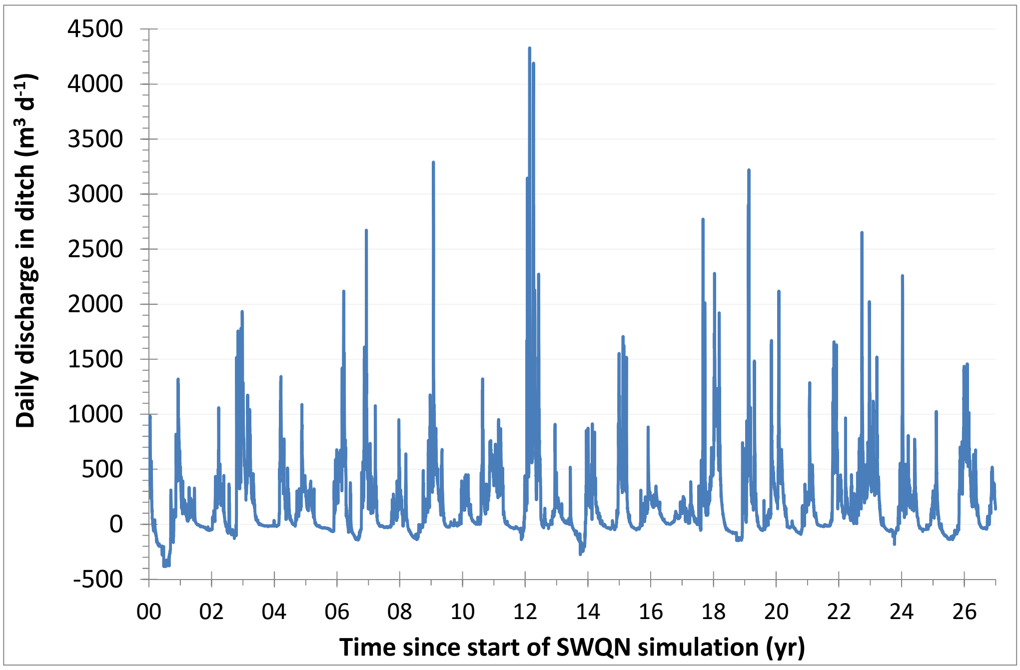


***Figure 4.3*** *Daily discharge in the SWQN ditch as a function of time for a period of 27 years. The daily discharges are imposed to the boundaries of the model, and derived by multiplying the flow velocities of Chapter 2 by minus the cross-sectional area of 0.612 $m^2$.*

Sections 2 and 35 were specified as weirs to control the water depth. The discharge over the weirs was simulated by:

$$Q_{weir,t} = \mu_{weir} W_{crest} \left(h_{up,t} - h_{crest,t}\right)^{1.5} \qquad (4.1)$$

Where $Q_{weir,t}$ is the weir discharge at time t ($m^3\ s^{-1}$), $\mu_{weir}$ is the weir coefficient ($m^{0.5}\ s^{-1}$), $W_{crest}$ is the width of the crest of the weir (m), $h_{up,t}$ is the upstream water level (m) and, $h_{crest,t}$ is the crest level (m).

The main characteristics of the weirs are:
- Weir width: 50 cm
- Weir coefficient ($\mu_{weir}$) = 1.5 $m^{0.5}s^{-1}$

The value for the weir coefficient is experimentally determined for broad-crested weirs and taken from the Cultuur Technisch Vademecum (Cultuurtechnisch Vademecum, 1988). The weir heights in summer and winter were calibrated, such that the management of the Water Board, as well as the pre-assumptions done in the drift scenario derivation procedure were fulfilled (see Section 3.3).

In case a weir functions as a flow barrier, the height of the weir crest in Section 2 is set equal to the soil surface to simulate a flow barrier. The boundary Sections 1 and 36 have fixed-level boundaries which were set to 5 cm above the bottom of the ditch. The fixed-level boundaries are needed to allow the water to leave the ditch at either side, depending on the flow direction. The parameterisation of the weirs in SWQN is described in more detail in Annex 2.1

The simplified St. Venant Equations solved by SWQN (Smit et al., 2009) require either the Manning- or Chézy friction coefficient as input. We decided to use the Manning coefficient with the same value as for the ditch of the EU FOCUS Surface Water scenarios: 25 $m^{1/3}\ s^{-1}$ (FOCUS, 2001).
The simulations with SWQN were done over an artificial period of 27-years, of which the first six years were used to establish a realistic initial concentration in the sediment. The approach differs from that of the FOCUS groundwater scenarios, where only 20 unique years were used and the first six years are identical to the last six years. We improved this procedure by using 26 of the 27 unique years.

Note, that the velocity time-series used to calculate the imposed discharges do not refer to real weather years. SWQN hydrology output from the last 26 of the 27 years simulated with SWQN were then provided to TOXSWA for the pesticide fate simulations. Annex 6 shows the relation between the year numbers used for the SWQN and TOXSWA simulations.

## 4.3 Calibration

In an ideal situation, data of measured water depths would be available and by tweaking the height of the weir crest, the SWQN model could have been calibrated, such that a good fit between the simulated and the measured water depths would be attained. For our case, measurements of water depths were not available, but several related system properties are known, based on previous assumptions made during the scenario derivation or water-management practices of the Rivierenland Water Board. A set of preconditions for the water depth was drafted and discussed in Section 3.3. The SWQN model was calibrated, such that these preconditions were met:

1. The winter water depth, as provided by Massop et al. (2006), is assumed to be equal to the wet winter water level of the type Betuwe stroomruggronden, secondary ditch, which is 30 cm. The level is defined as: 'exceeding the mean highest water level for at least 30 days a year'. The operational definition here is that the 83.3$^{rd}$ percentile of the water depth in a winter situation should be equal to 30 cm.
2. The weir heights will be calibrated such that the 50$^{th}$ percentile of the winter level (1 October – 31 March) and the 50$^{th}$ percentile of the summer level (1 April- 30 September) are equal.

The height of the weir crest in winter and summer were used as calibration parameters. In addition, the management of the weirs was followed, which implied that the height of the weir crest in summer was taken between 0-5 cm higher than in winter.

The calibration was done manually as follows. SWQN simulations were performed over 27 years using different combinations of height of the weir crest in summer and winter. All other parameters remained constant. Cumulative frequency distributions of the water depth at the centre of the 300 m ditch (i.e. that is also the centre of the 100m evaluation ditch) were made for each simulation. Background for selecting the water depth in the centre of the evaluation ditch was that this value also represents the average water depth in the evaluation ditch.

***Table 4.1*** *83.3$^{rd}$ and 50$^{th}$ percentile water depths as calculated for two combinations of weir crest height in summer and winter. The calculations were performed as part of the manual calibration of SWQN.*

| Case | Height of the weir crest in winter (cm) | Height of the weir crest in summer (cm) | 83.3rd percentile water depth in winter (cm) | 50th percentile water depth in winter (cm) | 50th percentile water depth in summer (cm) |
|---|---|---|---|---|---|
| 1 | 27 | 30 | 31.2 | 28.2 | 30.3 |
| 2 | 27 | 28 | 30.2 | 28.2 | 28.3 |

Result calibration: Table 4.1 show two combinations of winter and summer crest heights for which criteria were assessed. The optimal combination was achieved in Case 2, i.e. using a height of the weir crest in winter of 27 cm and a height of the weir crest in summer of 28 cm, hence, the difference between weir height in summer and winter was 1 cm. Frequency distributions for the summer and winter period based on hourly simulated values are shown in Figure 4.4. The water depths range from 27 cm to 43 cm.
Note that in Figure 4.4, several hourly water depths are below the height of the weir crest of 28 cm in summer (red dots). This is, because after raising the weir from 27 to 28 cm on April 1$^{st}$, it takes a few hours before the water depth at the centre of the ditch reaches 28 cm.

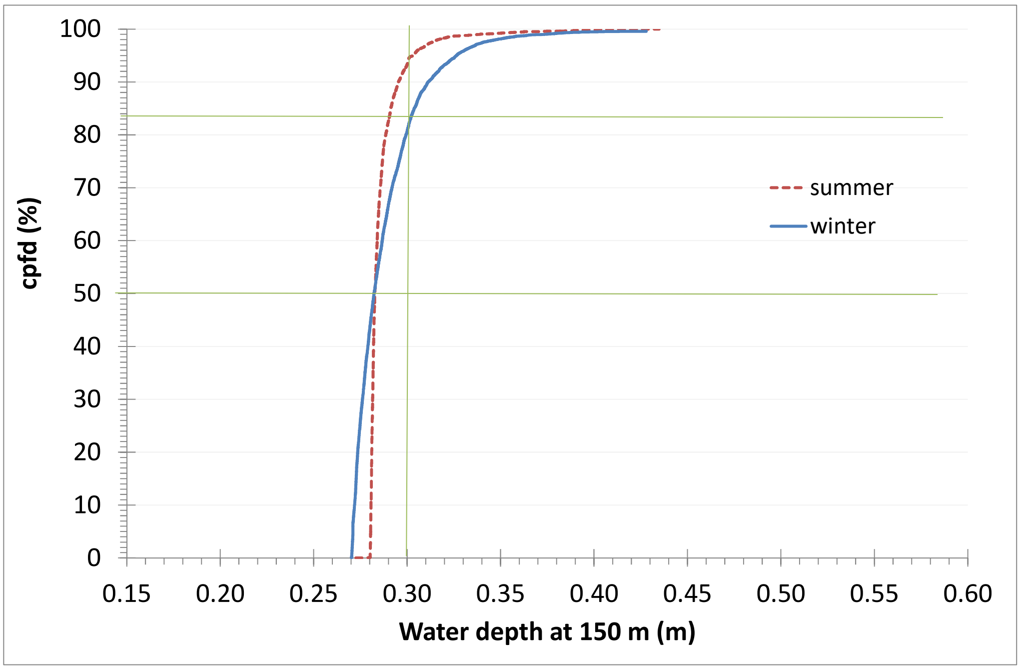


***Figure 4.4*** *Cumulative frequency distribution function (cpdf) of the water depth in the centre of the 100 m evaluation ditch of 27 years of simulations with SWQN for the summer and the winter period for the optimal combination of weir crest heights (Case 2). The horizontal lines indicate the 50$^{th}$ and 83.3$^{rd}$ temporal percentiles and the vertical line indicates the 30 cm water depth.*

## 4.4 Result: Hydrology of the parameterised ditch

### 4.4.1 Water depth and discharge

Figures 4.6 – 4.11 show time courses of the water depth and discharge in the segment in the centre of the evaluation ditch for the optimal case (Case 2 of Table 4.1). Water depth and discharges may slightly differ between segments due to the dynamics of the system. Figure 4.6 gives the water depth for the optimal case. There is no visual difference with Figure 4.3 at this scale (Figure 4.3 plots the discharge at the boundaries of the simulation ditch). Figure 4.6 shows further that the maximum water depth is ca. 43 cm, which is less than half of the total depth of the evaluation ditch, i.e. 1.08 m. The figure shows that the variability of the water depth is limited.

To demonstrate the effect of weather conditions on the system dynamics, a relatively wet year and a relatively dry year were selected and highlighted. Figure 4.7 shows an example of the water depths of a wet year (year 13) with a median instantaneous residence time of 6.1 hours, and Figure 4.8 shows an example of the water depths of a dry year (year 17) with a median instantaneous residence time of 19 hours. The figures show that the water depth may rise and fall within a few days, however, lowering of the water depth occurs more gradually. In year 13, the water depth fluctuates between 27-43 cm, and in year 17, the water depth fluctuates between 27 and 29 cm (note the difference in scale between the vertical axes of Figures 4.7 and 4.8). Figure 4.7 clearly shows the effect of the changes in weir depths from summer to winter and vice versa.

Figure 4.9 shows the discharge for the optimal case. This figure is almost equal to Figure 4.3, with the only difference that it shows the model output of SWQN, and Figure 4.3 shows the discharges as imposed at the boundaries. Figures 4.10 and 4.11 show the discharge dynamics for the selected wet- and dry years, respectively. Both Figures 4.10 and 4.11 show that discharges can be very low for several months. Figure 4.11 shows two remarkable fluctuations in the discharge (around the beginning of April and the beginning of October). These discharge peaks coincide with rising of the weir on April 1$^{st}$ and the lowering of the weir on October 1$^{st}$. In the first case, the discharge sharply decreases, as additional storage is created in the ditch. In the latter case, the discharge sharply increases, because there is suddenly less storage capacity in the ditch due to lowering of the weir. Occasionally, sudden increases or decreases in both the water depth and discharge are found on the day of a switch in the flow direction of the water, or for a few days after this switch. These sudden increases and decreases prolong for one to a few hours. They often occur on the day of a switch in the flow direction of the water or a few days after this switch. We suspect that they are the result of artefacts of the numerical solution. However, analysis showed that they do not provoke water balance errors (Annex 3). Given the limited number of these sudden increases or decreases, their short duration (one to several hours), and limited size (around one order of magnitude for the discharge and several millimetres for the water depth), we expect that the sudden increases or decreases in both the water depth and discharge will have a limited effect on the Predicted Environmental Concentration in the ditch. This should be assessed with example calculations (which do not form part of this report).

For a detailed overview per simulated year, we refer to Annex 5, in which hourly water depth, discharge, flow velocity and residence times per year are given.

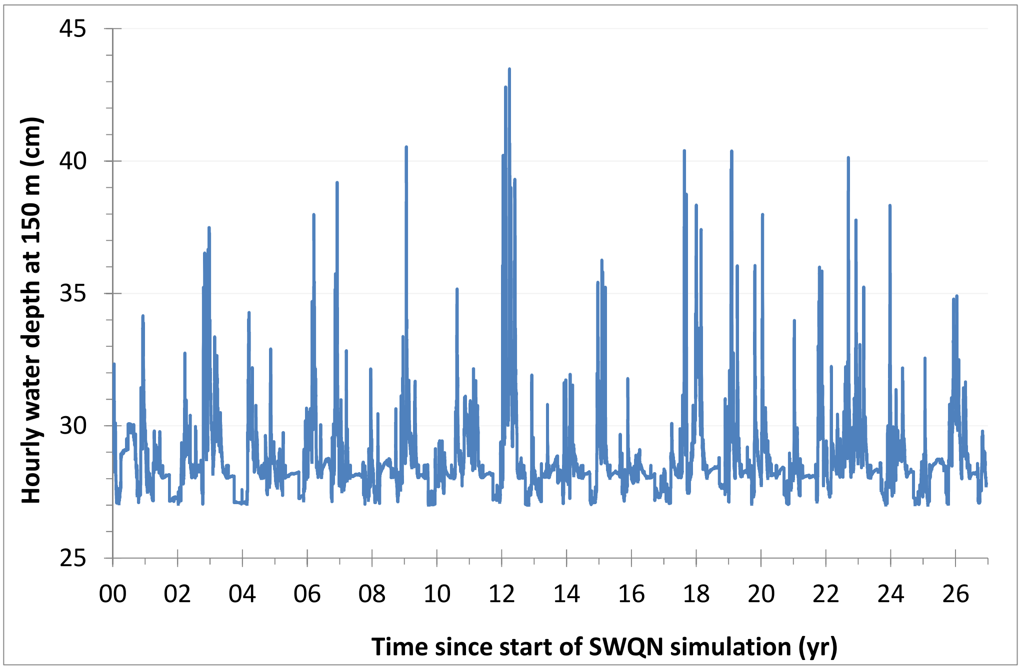


***Figure 4.6*** *Hourly values of water depth in the centre of the 100m evaluation ditch as function of time for a period of 27 years and as a result of the calibration of the model for the selected case (Case 2 in Table 4.1).*

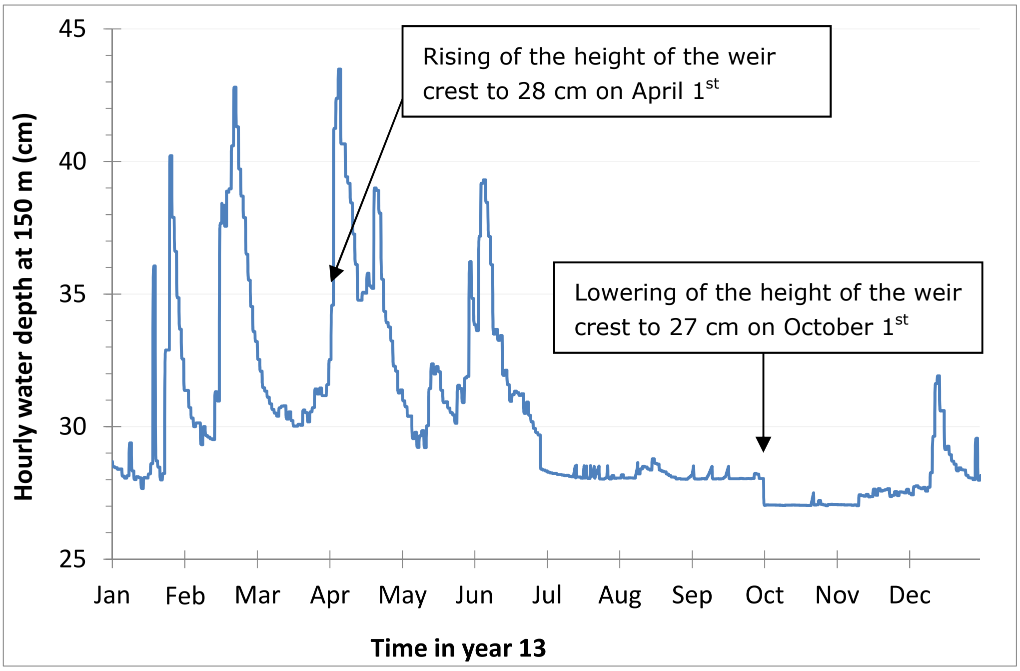


***Figure 4.7*** *Hourly values of water depth in the centre of the 100m evaluation ditch as function of time for year 13 (the year with the highest discharge in the period of 27 years) and as a result of the calibration of the model for the selected case (Case 2 in Table 4.1).*

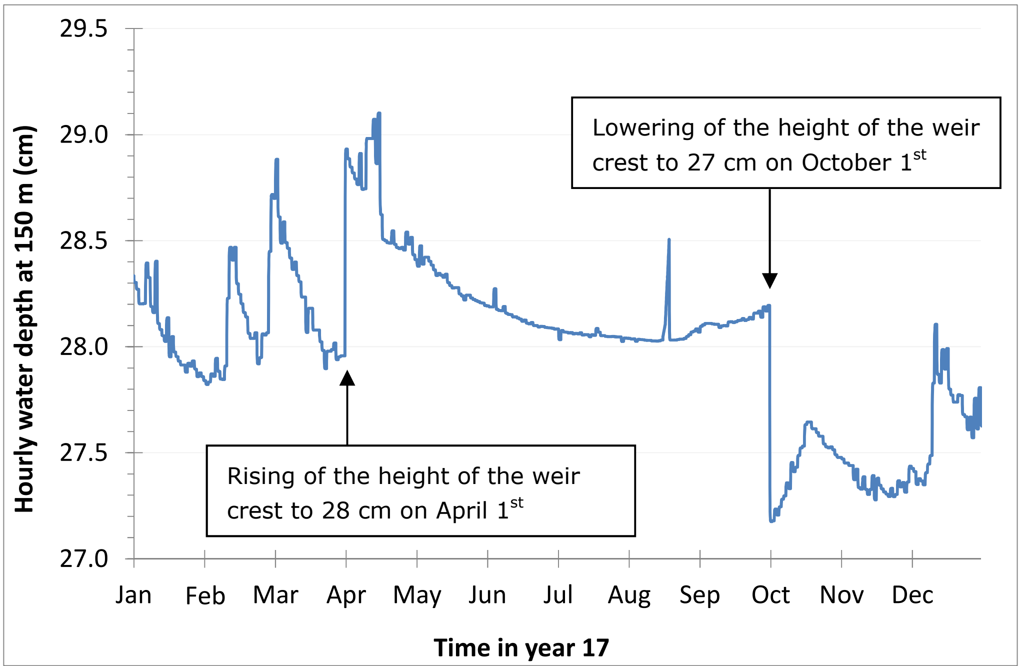


***Figure 4.8*** *Hourly values of water depth in the centre of the 100m evaluation ditch as function of time for the year 17 (a year within the 27-year period with relatively low discharges) and as a result of the calibration of the model for the selected case (Case 2 in Table 4.1).*

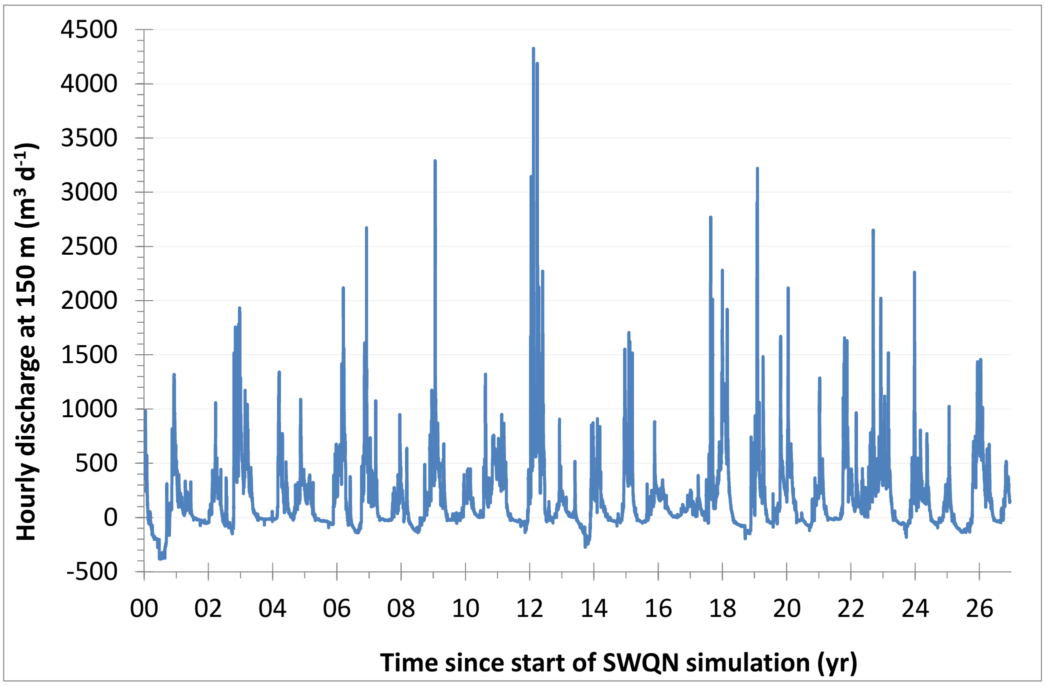


***Figure 4.9*** *Hourly values of discharge in the centre of the 100m evaluation ditch as function of time for a period of 27-years and for Case 2. This figure is almost equal to Figure 4.3. The difference is only that this is the model output of SWQN, and Figure 4.3 shows the discharges, as imposed at the boundaries.*

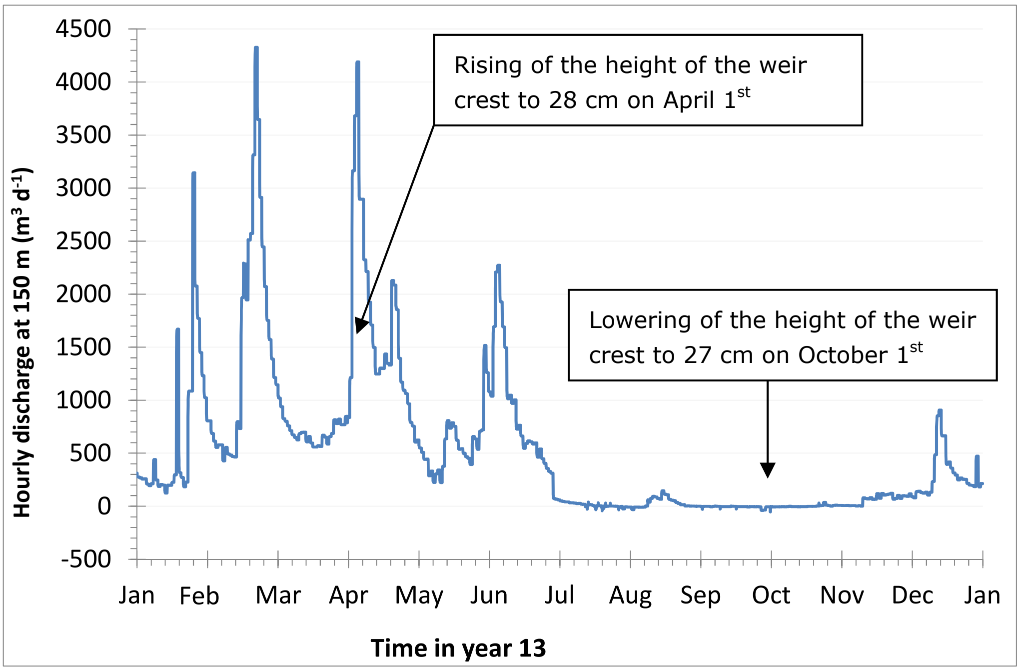


***Figure 4.10*** *Hourly values of discharge in the centre of the 100m evaluation ditch as function of time for year 13 (the year with the highest discharge in the period of 27-years) and as a result of the calibration of the model for the selected case (Case 2 in Table 4.1).*

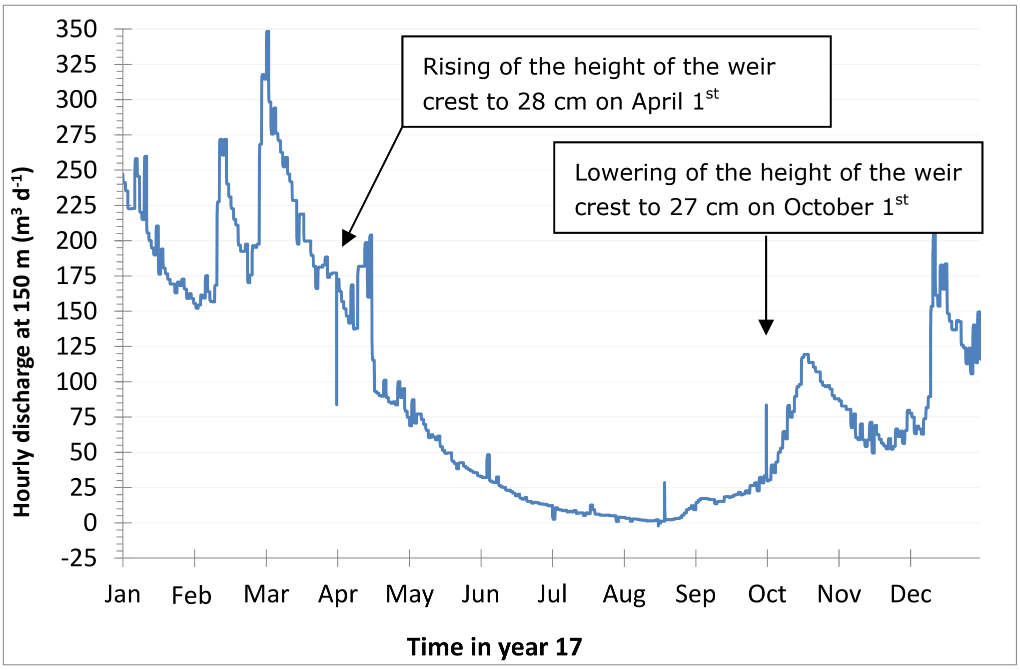


***Figure 4.11*** *Hourly values of discharge in the centre of the 100m evaluation ditch as a function of time for year 17 (a year with relatively low discharges in the 27-year period), and as a result of the calibration of the model for the selected case (Case 2 in Table 4.1).*

### 4.4.2 Water balances

Figure 4.12 gives the annual water balances over the simulated period. The imposed discharges entering the ditch and the outflow of the ditch are the main components of the water balance. The imposed discharges and the outflow are almost equal, which implies that the change in water storage in the ditch is small. The water balance error is calculated as the difference in the annual change in storage minus the sum of the annual inflow (flow boundary discharge) and annual outflow (level boundary discharge). This error is max. 3.2 $10^{-5}$ $m^3$ $yr^{-1}$ (i.e. 0.3 mL $yr^{-1}$), and is considered acceptable for an annual discharge of between $3{\cdot}10^4$ and $2{\cdot}10^5$ $m^3$ $yr^{-1}$. Note that year 13 was the selected wet year and year 17 was the selected dry year.

Figure 4.13 shows the cumulative probability frequency distribution of the hourly water balance errors. A balance error of zero corresponds to the 50$^{th}$ percentile. The errors are more or less evenly distributed around the 50th percentile, indicating there was no bias found in the data. The errors are in the same order of magnitude as the annual water balance error. However, to judge if the errors are low enough, they need to be compared to the total volume in the ditch, which is approximately 183 $m^3$. Figure 4.14 shows that the water balance error relative to the average water volume in the ditch is $4{\cdot}10^{-5}$% at most, which is considered low enough.

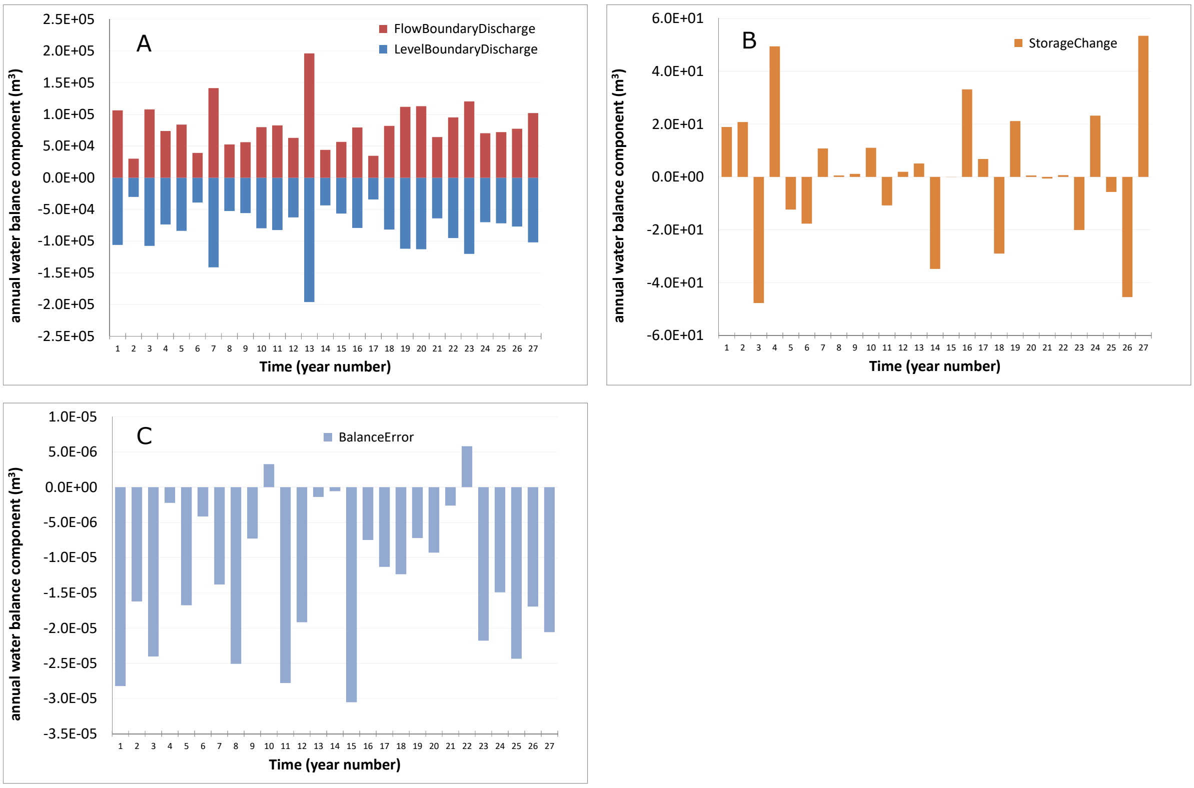


***Figure 4.12*** *Annual water balance for the 27-year simulation period in SWQN. A. Major water balance components: Flow boundary discharge refers to the imposed and incoming discharges. Level boundary discharge refers to discharges leaving the ditch. B. Change in storage in the ditch, as calculated by the model; a positive value indicates an increase in water storage, a negative value indicates a decrease in storage. C. Annual water balance error. Note the different scales at the y-axis.*

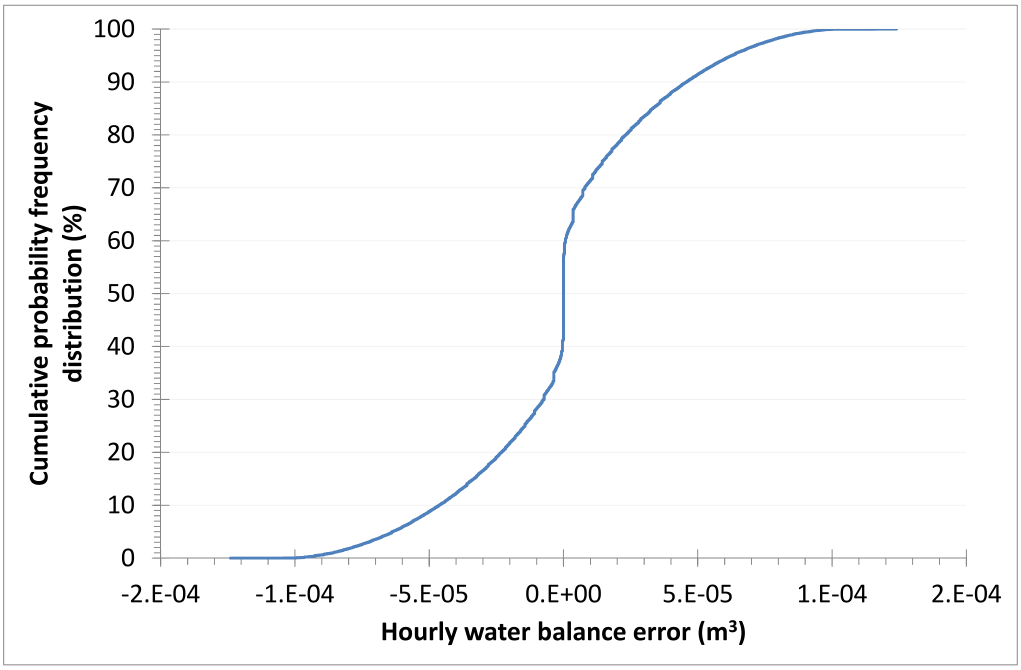


***Figure 4.13*** *Cumulative probability frequency distribution of the hourly water balance errors of 27-years of simulations with SWQN.*

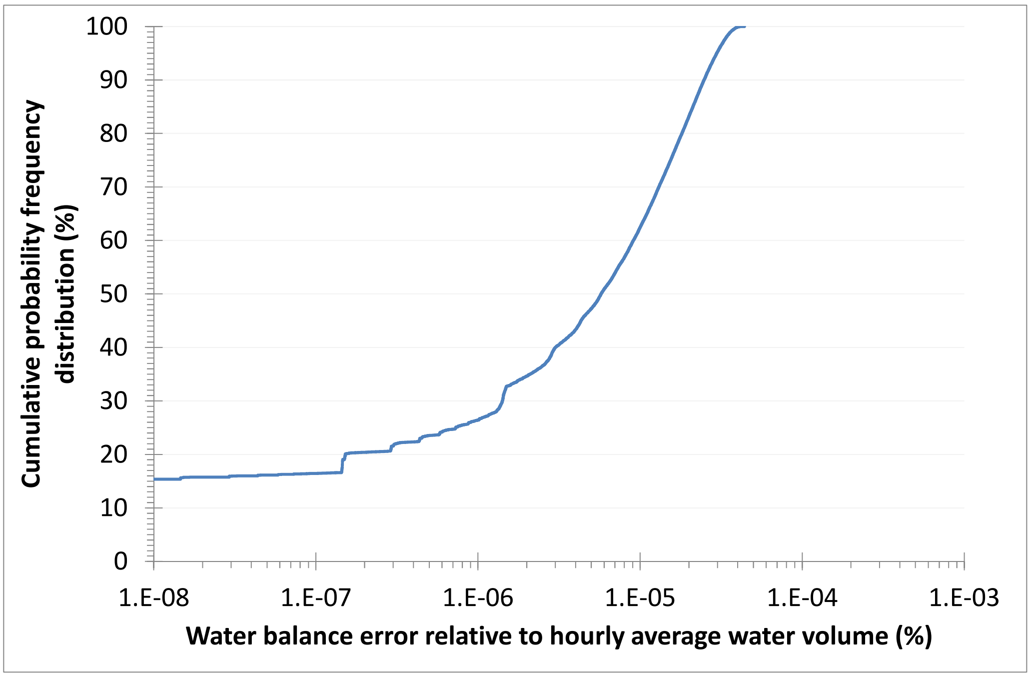


***Figure 4.14*** *Cumulative probability frequency distribution of the water balance error as percentage of the hourly average water volume in the 300 m long ditch. The median relative error is 7 $10^{-6}$% of the volume of water in the ditch.*

## 4.5 Discussion

In this Chapter, the hydrological SWQN model is parameterised. The output of the model, hourly water discharges per segment, as well as hourly water depths is used as input for the TOXSWA model. Flow velocities, as derived in Chapter 2, are used as input for the SWQN model. These flow velocities are subject to a number of process steps before final hourly data for TOXSWA can be derived. In the figure below, these additional process steps are summarised, as well as the corresponding assumptions. In the last column, the characteristics of the datasets are given.

What is the effect of the individual processing steps? And can they be justified? Each of the steps are discussed below following the steps in the figure.

(i) The first interpretation step assumed a fixed water depth and cross-sectional area in the ditch to derive the water discharges in the ditch from the time series of flow velocities. As the water depth and flow velocity are correlated, this may result in lowering the variability of the water discharges and hence a lower variability in the residence times associated with the synthetic dataset and the output of SWQN. A comparison of residence times of both datasets is given in Table 4.2. The median residence time remains more or less the same, although the SWQN calculated residence time is slightly lower, and the variability decreases, i.e. the lower percentiles become a bit higher and the higher percentile, a bit lower. The approach taken is considered to be solid, as the difference is limited, and in view of all other assumptions that have been made.

| Step | Criteria/assumptions | Data characteristics |
| --- | --- | --- |
| Velocities | | • Type: flow velocity<br>• Unit: m/d<br>• Frequency: daily<br>• Length of data set: 27 y<br>• Weather years: -<br>• Spatial unit: evaluation ditch<br>• Number of spatial units: 1 |
| Velocities X cross-sectional area | • Boundary conditions in SWQN are the daily varying discharges given as fixed values at the upper- or lower boundaries. These are calculated from the synthetic dataset of Chapter 2 by multiplying the daily flow velocities by the cross-sectional area of the ditch. Despite the dynamics of the water depth, it is assumed that the cross-sectional area can be approximated with one value, corresponding to a water depth of 30 cm. | |
| SWQN calibration | • Positioning in the landscape according to Section 3.2<br>• Criteria for water depth, as defined in Section 3.3 | |
| Input TOXSWA | | • Type: discharge<br>• Unit: m3/d<br>• Frequency: hourly<br>• Length of data set: 26 y<br>• Weather year: -<br>• Spatial unit: 10-m segments in simulation ditch<br>• Number of spatial units: 36<br><br>• Type: water depth<br>• Unit: cm<br>• Frequency: hourly<br>• Length of data set: 26 y<br>• Weather years: -<br>• Spatial unit: nodes in simulation ditch<br>• Number of spatial units: 37 |

***Figure 4.15*** *Flow chart with steps, criteria and assumptions as made in Chapter 4, as well as the characteristics of the resultant dataset for the flow velocity in the evaluation ditch.*

***Table 4.2*** *Comparison of the statistical parameters of the residence times calculated from the dataset, as discussed in Chapter 2 and used as input for the SWQN simulations and the resulting residence times in the ditch, calculated from the velocities in the centre of the ditch.*

| | Residence time calculated from flow velocities of Chapter 2 | Residence time calculated from SWQN output (this Chapter) |
|---|---|---|
| minimum | 20 min | 30 min |
| $10^{th}$ percentile | 2 h | 2.5 h |
| $50^{th}$ percentile | 13.5 h | 13.2 h |
| $90^{th}$ percentile | 114 h | 108 h |
| maximum | 6377 d | 5658 d |

(ii) The effect on the positioning in the landscape according to Section 3.2 cannot be quantified, there are many options to position the ditch in a catchment.
(iii) Also the effect of the criteria for water depth used for the calibration of SWQN is unknown. The criteria applied to the weir management are in line with the management practices of the Rivierenland Water Board, though. Adjustment twice a year is normal for smaller watercourses. Adjusting a weir only 1 cm in summer and winter is not expected to be common practice for water managers, but it is within the bandwidth indicated by Rivierenland. Furthermore, experts from the Water Board indicated that they expected the water level to reach to the soil surface approximately once in ten years. The evaluation ditch has a ditch depth of 1.08 m. The water depth corresponding to a 1:10 year event of the SWQN output would be the 99.97 percentile[3],which is approximately 45 cm (see Figure 4.4). So, the evaluation ditch will not have a water depth above soil surface once every ten years. This can be explained as daily flow velocities are used: hourly data would have shown higher extremes.

Again, it is recommended to assess the realism of this final dataset against water flow and water depth measurements in ditches next to fruit orchards over a considerable length of time.

[3] 1/(365*10) * 100%

# 5 Sediment characterisation

## 5.1 Introduction

The sediment properties porosity, bulk density and organic matter content play a role in the distribution of pesticides between the pore water and the solid matter (adsorption), as:

$$c_b = \varepsilon c_{lb} + \rho_b X_b \tag{5.1}$$

where (for linear sorption):

$$X_b = m_{om} K_{om} c_{lb} \tag{5.2}$$

With:

| | | |
|---|---|---|
| $c_b$ | = | mass concentration of substance in sediment (M $L^{-3}$) |
| $c_{lb}$ | = | mass concentration of substance in the liquid phase of the sediment (M $L^{-3}$) |
| $X_b$ | = | content of sorbed substance related to the mass of dry sediment material (M $M^{-1}$) |
| $\varepsilon$ | = | porosity of the sediment (-) |
| $\rho_b$ | = | bulk density of dry sediment material (M $L^{-3}$) |
| $m_{om}$ | = | mass fraction of organic matter of the sediment material (M $M^{-1}$) |
| $K_{om}$ | = | sorption coefficient ($L^3$ $M^{-1}$) |

Also, the diffusion flux of the sediment pore water and the diffusion flux that controls the exchange between the water layer and the sediment layer depends upon one of the sediment properties, i.e. the porosity.

As all volume fractions within the sediment add up to one, a relationship between sediment properties can be defined as:

$$\varepsilon + \frac{\rho_{\mathrm{b}}}{\rho_{\mathrm{om}}} m_{\mathrm{om}} + \frac{(1 - m_{\mathrm{om}})\rho_{\mathrm{b}}}{\rho_{\mathrm{min}}} = 1 \tag{5.3}$$

With:

| | | |
|---|---|---|
| $\rho_{om}$ | = | bulk density of the organic matter (M/ $L^{-3}$), approx. with 1.4 g/mL |
| $\rho_{min}$ | = | bulk density of the mineral fraction (M $L^{-3}$), approx. with 2.65 g/mLf |

Ideally, sediment properties should be based on spatially distributed data, measured over a range of ditches. This set would enable the derivation of cumulative probability distribution functions of these properties and corresponding target percentiles. Such an extensive dataset is not available.

A literature survey provided a limited number of field studies. In 1979, de Heer measured sediment properties in ditches nearby fruit orchards at six locations in the management area of the Stichtse Rijnlanden Water Board (de Heer, 1979). Also Arts and Smolders, (2008a & 2008b) measured sediment properties in different types of waters, which were selected on the basis of nature conservation criteria. Evaluation ditches used in the EU and the Netherlands exposure assessments use sediment properties that are largely based on those of the experimental ditches of the experimental site of Wageningen Environmental Research in Renkum, in the Netherlands (FOCUS, 2001). And finally, Adriaanse et al. (2015) measured sediment properties in five ditches alongside Dutch arable crop fields.

The Working Group considered the data obtained by de Heer (1979) and Adriaanse et al. (2015) as the most appropriate and qualified for use in further analyses. The experimental ditches of the experimental site of Alterra were artificially dug in a sandy soil, and are considered less appropriate, as the measured properties are possibly far away from natural ditches situated next to fruit orchards or tree nurseries. Also the properties measured by Arts and Smolders were considered to be less suitable for the selected ditch population, as the ditches were mostly in peaty and sandy areas. Fruit trees grow mostly in well-drained soils with a sandy/loamy texture. The dominant soil texture in the management area of Rivierenland is silty clay and clay and silty loam and loam (see Figure 5.1).

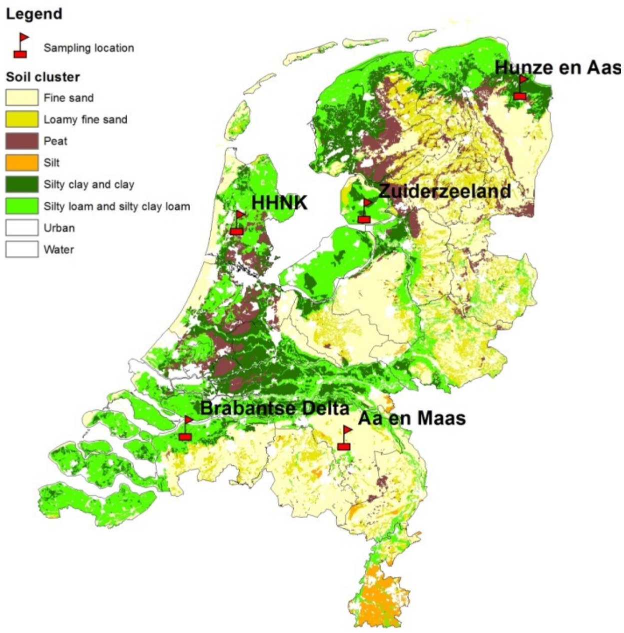


***Figure 5.1*** *Soil texture classes and sample locations of Adriaanse et al. (2015). (source: Adriaanse et al., 2015).*

## 5.2 Sediment properties measured by de Heer (1979) and Adriaanse (2015)

### 5.2.1 Sediment properties measured by de Heer (1979)

De Heer (1979) sampled sediment in the Lopikerwaard Polder at two locations (two ditches in Benschop and one ditch in Jaarsveld), where fruit trees grew just alongside the ditches. The ditches in Benschop had 50-64% clay in the sediment, and the ditch in Jaarsveld had 28-38% clay. The Lopikerwaard is an area with relatively high groundwater levels and with mainly grassland farming.

Mud cores were extracted and frozen to measure the volume fraction of liquid (porosity) and the bulk density and elementary carbon. Cores were taken in triplicate from six sampling sites in three ditches during April 1977: in each ditch, samples were extracted from two sites. Samples were taken from the upper 0-30 cm of the sediment layer with a slice thickness of 2 cm. The organic matter content was measured by 'loss on ignition' corrected for clay and $CaCl_2$ and also by total elementary carbon analysis.

Elementary carbon was translated to organic matter by multiplying by a factor of 1.724.

Figure 5.2 shows that in the first 10 cm of the samples, the volume fraction of liquid varies between 0.8 and 0.95, the bulk density varies between 100 and 450 kg m$^{-3}$ and the elementary carbon percentage varies between 6-16%, which corresponds with a % OM content of 10-28%. The bulk density tends to increase with depth and the porosity tends to decrease with depth.

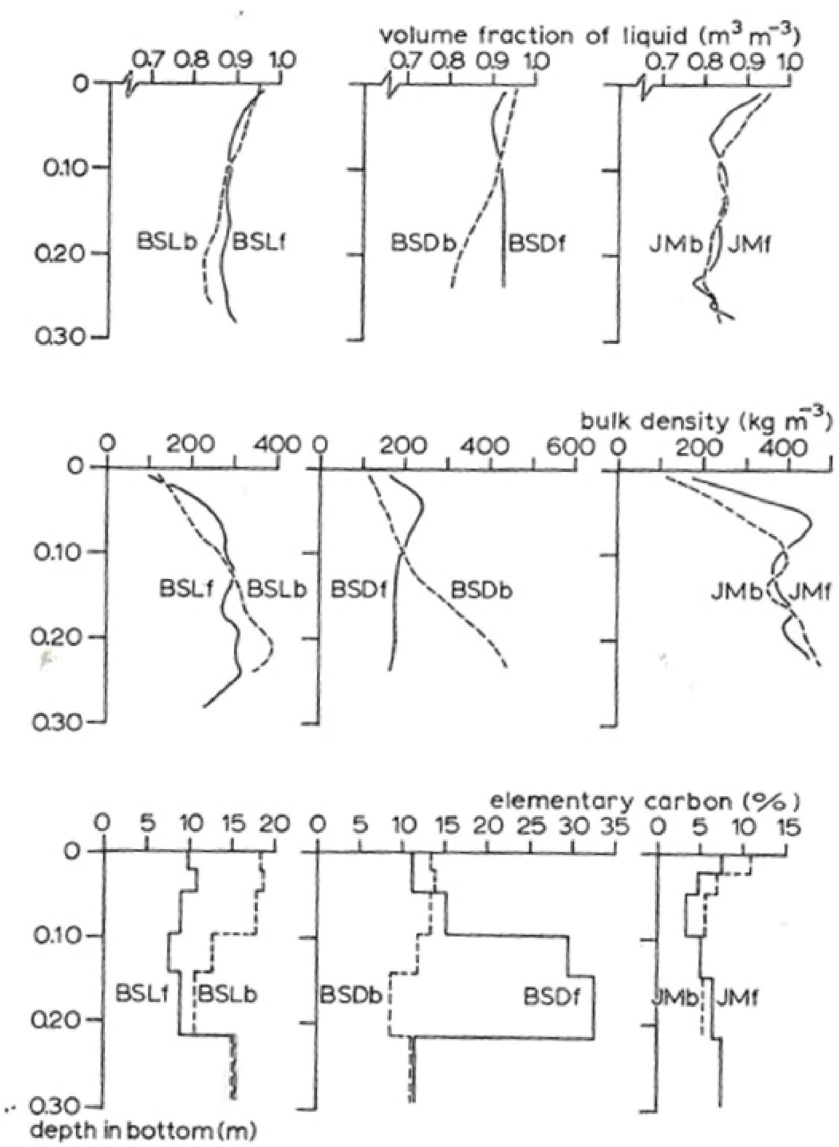


***Figure 5.2*** *The sediment properties of ditch bottoms for six sampling sites in the Lopikerwaard Polder plotted as a function of depth (the lines are averaged values of three samples). Volume fractions of liquid (i.e. porosities), bulk densities and elementary carbon contents. Abbreviations for sampling site: B = Benschop, J= Jaarsveld, SL = siphon-linked ditch, SD= supplementary drained ditch, M= middle ditch, b= back of ditch, f= front of ditch (source: De Heer (1979)).*

## 5.2.2 Sediment properties measured by Adriaanse et al. (2015)

**Sampling strategy and techniques.** Four watercourses were selected that satisfied a set of predefined criteria for sample site selection. The selected watercourses were geographically spread over the Netherlands and corresponded to one of the soil types typical for arable crop farming/horticulture.

Additional criteria for the site selection were:

i. The watercourse should be located adjacent to a field with arable farming or horticulture.
ii. The watercourse should not fall dry during the summer season.
iii. The total set of the selected watercourse should be in line with the watercourses considered by Tiktak et al. (2012), who describes the Dutch scenario for arable farming and horticulture.

Five samples were taken per selected site over a 100 m length of ditch. The samples were taken in June/July 2013, as well as in September 2013. A new sampling technique was applied with relatively wide sampling cores. The sediment cores were frozen without formation of an ice cone on top, and were divided into segments with a belt saw. The measured sample volumes were corrected for expansion due to water freezing. Measurements were taken from the upper 0-10 cm of the sediment layer with a slice thickness of 1 to 5 cm. Sediment properties of the five samples taken from one ditch were averaged per sediment layer. See Adriaanse et al. (2015) for a more detailed description of the sampling strategies and techniques used. The properties of all four selected ditches are provided in Annex 4 for June/July and September 2013 over the entire measured sediment profile (10 cm).

***Table 5.1*** *Main characteristics of the sampling sites (after Table 3.2 of Adriaanse et al., 2015).*

| Municipality | Water Board | Soil type (LGN6) | Watercourse type | Width at water level (m) (June/July) | Water depth (m) (June/July) | Crop observed |
|---|---|---|---|---|---|---|
| Uden | Aa en Maas | Fine sand | Secondary | 1.55 | 0.21 | Maize |
| Emmeloord | Zuider-Zeeland | Silty loam and silty clay loam | Primary | 5.5 | 0.8 | Winter wheat, sugar beets |
| Willemstad | Brabantse Delta | Silty loam and silty clay loam | Secondary | 2.5 | 0.5 | Sugar beets, maize |
| Nieuwolda | Hunze en Aa | Silty clay and clay | primary | 4.2 | 0.55 | Winter wheat, rape |

**General characteristics.** To get a flavour of the values measured, in Table 5.2, the bulk density, the porosity and the OM content measured in June/ July 2013 in the first cm of the sediment are given for the four selected locations. The data suggest a trend from sandy soils with high organic matter content and low bulk densities towards clayey soils, with low organic matter content and high bulk densities.

In Figure 5.2, the profiles over depth are given for the sampling locations, Emmeloord and Willemstad. Both locations are associated with a soil type that corresponds to the dominant soil type for fruitorchards, silty loam and silty clay loam. Sediment properties vary very little in depth, with the exception that the first cm has a lower density and a higher porosity than the deeper layers for all measured profiles in Figure 5.3. Differences between measurements in June and September are small. There is a slight decrease in bulk density in the upper cm of the sediment from June to September and a slight increase of organic matter content. Standard deviations are small between samples in the same ditch.

***Table 5.2*** *Averaged sediment properties in the first upper cm of the sediment layer. Measurements were taken in June/July 2013 in the four sampling locations.*

| | Bulk density (g/mL) | Porosity (-) | OM content (% mass) |
|---|---|---|---|
| Uden | 0.19 | 0.93 | 22.2 |
| Emmeloord | 0.23 | 0.91 | 17.4 |
| Willemstad | 0.31 | 0.81 | 12.4 |
| Nieuwolda | 0.40 | 0.92 | 8.9 |

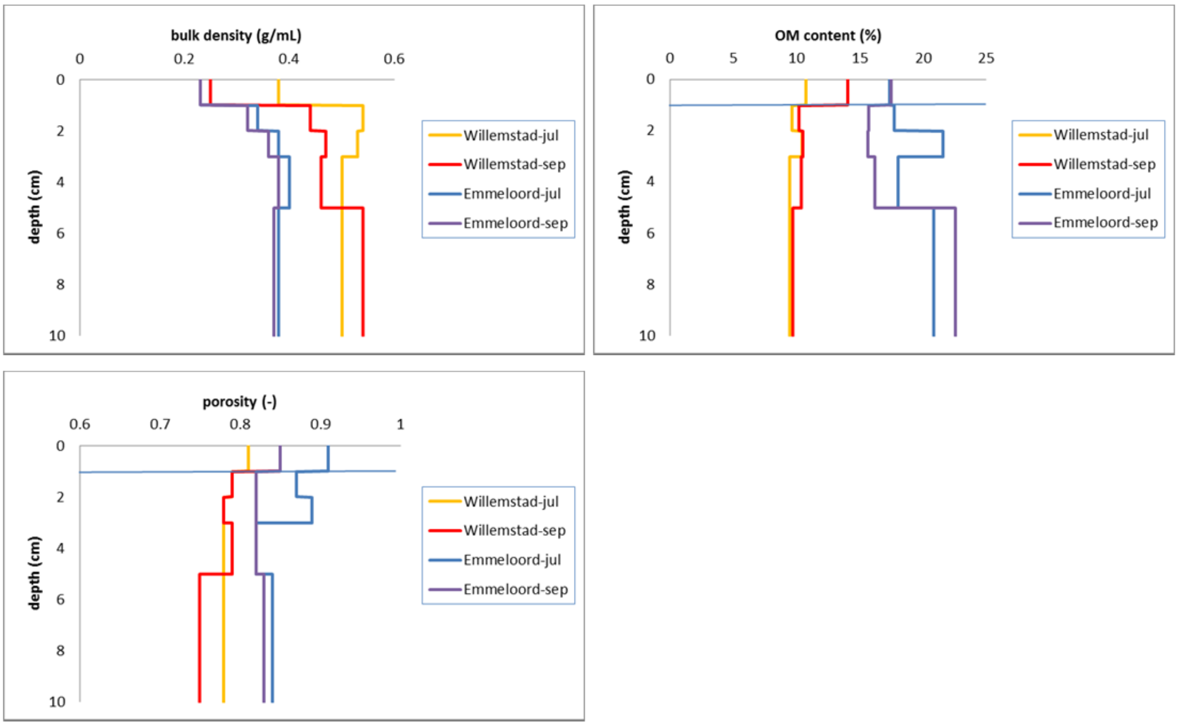


***Figure 5.3*** *Porosity (-), Bulk density (g/mL), and OM content (%) in over depth for the sample locations Willemstad and Emmeloord.*

# 5.3 Considerations

## 5.3.1 Averaging over time and space

Organic matter content, porosity and bulk density are correlated properties; they belong to one sediment profile. Therefore, it is considered most appropriate to select one of the sampling locations and its properties as being representative for fruit-orchard and tree-nursery ditches instead of e.g. averaging over the measurements.

Adriaanse et al. (2015) differentiated between sediment properties in June/July and September, as properties may vary due to e.g. decay of water plants and algae. A closer view on the data, however, showed little variability between both datasets. Also TOXSWA does not allow for variation of sediment properties over time. Therefore, it is considered appropriate to take the average of the sediment properties measured in June/July and September, for each separate location.

The Benschop sampling location contains four sampling sites distributed over two ditches. As the samples were taken in the close surroundings of one fruit orchard, the average value of all samples were considered appropriate for Benschop.

## 5.3.2 Selection

Based on the description, the crop type, soil type and sampling strategies, the sediment properties measured near a fruit orchard (Benschop and Jaarsveld) or in silty loam and silty clay loam (Willemstad and Emmeloord) were preferred above those measured in sandy soil or clayey soil (Uden and Nieuwolda).

In Table 5.3, sediment properties of the first cm of the sediment layer are shown for Benschop, Jaarveld, Willemstad and Emmeloord. For Benschop and Jaarveld, an estimated average of all measurements is given, because the data behind the figures (Figure 5.2) were not available. The values used in FOCUS (2006) have been added for reference.

The measured sediment properties of de Heer (1979) show a higher porosity, a lower bulk density and a higher organic matter content than the properties measured by Adriaanse et al. (2015). Both are very different from FOCUS (2006), with its much higher bulk density and much lower porosity, as compared to the sampling locations properties.

***Tabel 5.3*** *Averaged sediment properties in the upper first cm of the sediment layer, including their source.*

| Source | Sampling location | Bulk density (g/mL) | Porosity (-) | OM content (% mass) |
|---|---|---|---|---|
| De Heer (1979) | Benschop | ~0.12 | ~ 0.94 | 17-31 |
| De Heer (1979) | Jaarsveld | ~ 0.18 | ~ 0.94 | 12-17 |
| Adriaanse et al. (2015) | Emmeloord | 0.23 | 0.88 | 17.4 |
| Adriaanse et al. (2015) | Willemstad | 0.32 | 0.83 | 12.4 |
| FOCUS (2006) | Renkum | 0.80 | 0.68 | 9.0 |

**Further selection**
All measured sediment properties from the sampling locations; Benschop, Jaarsveld, Emmeloord and Willemstad, were considered to be of similar quality. Therefore, it was decided to consider the entire range of properties provided by the four locations. In a next step, the sensitivity of the Predicted Environmental Concentration to the sediment properties must be analysed before selecting one of the sampling locations. As Benschop (high organic matter content and low bulk density) and Willemstad (lower organic matter content and relatively higher bulk density) are the two extremes, with respect to sediment properties, it was decided to use the data of these two locations to assess the impact of the sediment properties on pesticide fate.

### 5.3.3 Sediment profile over the depth

Both Willemstad and Benschop show little variation of properties in depth. The porosity for Willemstad fluctuates around 0.78, whereby the upper 1 cm seems to have a slightly higher porosity than the sediment between 1-10 cm depth. Also the organic matter content in the first cm appears to be higher (10.7-14%) than in the lower layers (9.5-10.5%), especially in September. Although a closer look at the data showed that one sample with a high organic matter content (22%) caused this high value. The bulk density instead is lower in the first 1 cm of the sediment (0.25-0.38 g/ml), as compared to the lower sediment layers (0.44-0.54 g/ml).

A similar pattern can be observed for Benschop (averaged values over two ditches), for which the porosity fluctuates around 0.92. Also in Benschop, the porosity is slightly higher in the upper first 1 cm of the sediment. The bulk density of the sample locations is ca. 0.18 g/ml in the first cm of the sediment layer, which is lower than the 0.38 g/ml in the lower part of the sediment cores: this trend is again similar to Willemstad.

Considering the six available profiles (four from Benschop and two from Willemstad), for five out of six profiles, the upper 1 cm has a lower bulk density and higher porosity than the remainder of the profile. Given these observations, and the sensitivity of the calculated water concentrations to the sediment properties in the upper cm of the sediment (pers. comm. P. Adriaanse), the Working Group decided to differentiate between sediment properties of the first cm of the sediment and then (weighted) average over the sediment between 1- 10 cm or deeper, if the data is available.

## 5.4 Ditch properties to be used in the parameterisation

The final list of ditch properties consists of two sets; one based on data from Willemstad and one based on data from Benschop. The final selection will be based on example calculations with the TOXSWA model.

***Table 5.4*** *Proposed sediment properties based on Willemstad sample location.*

| | Bulk density (g/mL) | Porosity (-) | OM content (% mass) |
|---|---|---|---|
| 0-1 cm | 0.32 | 0.83 | 12.4 |
| 1-10 cm | 0.49 | 0.78 | 10.1 |

***Table 5.5*** *Proposed sediment properties based on Benschop sample location.*

| | Bulk density (g/mL) | Porosity (-) | OM content (% mass) |
|---|---|---|---|
| 0-1 cm | 0.12 | 0.94 | 22 |
| 1-10 cm | 0.2 | 0.92 | 24 |

The consistency of the data was checked by summing the volume fractions for both locations, using Formula 3 (on Page 1), with the values for bulk density of the organic matter, $\rho_{om}$ and bulk density of the mineral fraction, $\rho_{min}$ of 1.4 g/mL and 2.65 g/mL, respectively.
The volume fractions varied between 0.96 and 1.01, which was considered appropriate for use in TOXSWA calculations.

Sum of volume fractions Willemstad:
0-1 cm: 0.96
1-10 cm: 0.98

Sum of volume fractions Benschop:
0-1 cm: 0.99
1-10 cm: 1.01

## 5.5 Tortuosity

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

$$\lambda = \frac{1}{1 - \ln(\varepsilon^2)} \quad (5.4)$$

Consequently the tortuosity (-) will be:

Willemstad:
0-1 cm: 0.73
1-10 cm: 0.67

Benschop:
0-1 cm: 0.89
1-10 cm: 0.86

## 5.6 Suspended solids

Conform FOCUS (2001); the water layer contains suspended solids, but no macrophytes. In the absence of special data on suspended solid characteristics, values for suspended solids from the Dutch downward spraying scenario were used (Tiktak et al., 2012), i.e.: the concentration of suspended solids in the water layer at 11 g $m^{-3}$ and the mass fraction of organic matter in suspended solids at 0.090 kg kg-1.

## 5.7 Sediment discretisation

The sediment layer is discretised into a number of layers for substances with a low sorption coefficient as follows:

| Soil depth below surface (mm) | Thickness layers (mm) |
|---|---|
| 0-4 | 1 |
| 4-10 | 2 |
| 10-20 | 5 |
| 20-50 | 10 |
| 50-70 | 20 |
| 70-100 | 30 |

And for substances with a high sorption coefficient:

| Soil depth below surface (mm) | Thickness layers (mm) |
|---|---|
| 0-0.24 | 0.03 |
| 0.24-0.36 | 0.06 |
| 0.36-0.46 | 0.05 |
| 0.46-0.7 | 0.12 |
| 0.7-1.0 | 0.3 |
| 1.0-2.5 | 0.75 |
| 2.5-6.5 | 2 |
| 6.5-10 | 3.5 |
| 10-20 | 5 |
| 20-50 | 10 |
| 50-70 | 20 |
| 70-100 | 30 |

The value of the sorption coefficient that marks the transition between both discretisation types has yet to be established. This will be done based on the accepted numerical error for the Predicted Environmental Concentration.

# 6 Water temperatures

The temperature of the water in of the water body is simulated on an hourly basis using the TOXSWA model. The TOXSWA model has recently been extended with the functionality to simulate water temperature using hourly meteorological data added (Beltman et al., 2017). The new functionality is based on a 1D-bulk approach, which assumes a well-mixed water layer. Contributions to the energy budget from shortwave radiation, longwave radiation, sensible- and latent heat-exchange between air and water, precipitation, potential heat-exchange between water and sediment and possible external sources, such as incoming drainage water, are taken into account. The temperature of sediment is assumed equal to the water temperature. The main effect of the temperature to the behaviour of pesticide in the water body involves the degradation rate.

To simulate the water temperatures, hourly data from the KNMI Meteostation Herwijnen were used (https://www.knmi.nl/nederland-nu/klimatologie/uurgegevens), Herwijnen is one of the Dutch meteostations used for the drift calculations as part of the scenario derivation procedure (Boesten et al., in prep). The eventual scenario selected calculates drift deposition based on the weather measured at the meteostation Herwijnen over the period 1991-2010. Meteo data of the Herwijnen station were used for the same period. Precipitation data is not available for the period 1$^{st}$ January 1991 – 4$^{th}$ May 1993 and data on vapour pressure is missing for the period 1$^{st}$ January 1991 – 23$^{rd}$ April 2009. Both types of data are needed for the temperature simulations, but not for the drift simulations. Data of nearby meteostation De Bilt were used to fill these gaps. The expected effect of filling the missing data from that of a nearby meteostation is small.

To simulate the temperature in water and in sediment from weather data, TOXSWA requires an input file that specifies hourly meteo data (the so-called *.meth file). Details of the meteorological data needed are given in Annex 7.

**Practical considerations**
The dynamic discharge and the water depths resulting from the SWQN simulation must be coupled to the meteorological data from meteostation Herwijnen. The SWQN simulation covered a period of 27 years. This period does not refer to real weather years because the flow velocities resulted from the statistical direct sampling technique (Section 2.4.2). The meteorological data of meteostation Herwijnen do refer to real weather years and were available for the period 1991-2010. A pragmatic approach was applied of coupling the two different periods, such that leap years coincide. Also, part of the meterological data set is used twice, as the dataset of Herwijnen does not cover the 26 year period needed for the pesticide fate simulations.

This resulted in the following solution:
1. For the period 1985-1990, meteorological data of station Herwijnen from the period 2005-2010 was used.
2. For the period 1991-2010, meteorological data of station Herwijnen from the period 1991-2010 was used.
3. The meteorological data set for the period 1985-2010 constructed in Step 1 and Step 2 was coupled to the SWQN time-series of the period 2021-2046.

# 7 Conclusions and recommendations

In this report, the hydrological parameterisation is described of the evaluation ditch as part of the Dutch exposure assessment procedure for sideways and upward spraying. The parameterised model, which is coupled to corresponding parameterised drift and drainage models, enables the calculation of Predicted Environmental Concentrations in surface water for complex application schemes. The concentration averaged over the 100 m of ditch is the Predicted Environmental Concentration. Parameterisation was done for the pesticide fate model TOXSWA. Hydrology was simulated with the SWQN model of which the simulated water discharges and water depths were input to the TOXSWA model.

The parameterisation is part of, and builds further upon, the scenario selection procedure, which is described in a separate report. The ditch parameterisation is a further elaboration of initial assumptions by the Working Group, with the final aim to allow for all (complex) pesticide fate processes in the pesticide fate simulations. One of the initial assumptions was that drift is the dominant pathway. Recent example calculations, however, indicate that the contribution from drainpipes cannot be ignored. In a follow-up scenario development step, the contribution from drainpipes will be added to the evaluation ditch, as described in this report.

Three aspects were of specific interest for the parameterisation of TOXSWA: the dynamics of the flow velocity in the ditch, the corresponding water-depth dynamics and sediment characteristics.

**Flow velocities**
For scenario derivation, spatially distributed local characteristics in the area of use is one of the major aspects to be considered. GIS information on flow velocities in edge-of-field ditches next to Dutch fruit orchards is, however, not available. Therefore, alternative sources of information, from which flow velocities could be derived were searched for. Also, the focal area was narrowed down from the Netherlands to the high density area of fruit orchards, i.e. the Rivierenland area. Output from a high resolution groundwater model was obtained from the Rivierenland Water Board and used to derive flow velocities. This groundwater model was calibrated over a period of nine years and featured daily output. The spatial resolution of the finally derived flow-velocity data-set was that of a '*target-level unit*' (areas with the same target water level, also referred to as 'peilgebied'). The advantage of the approach followed was that the obtained flow velocities pretty much conserve the dynamic effects of (time-variable) precipitation, farmers' practices (irrigation), as well as water management practices.

As the simulation period of nine years was too short to be able to select a temporal percentile, a statistical direct sampling algorithm was applied. Using this technique we successfully constructed a synthetic time series of daily flow velocities from the 110 series of nine years with a length of 27 years. The applied sampling method maintains the higher order statistics of the original dataset. Also, it includes spatial- and temporal information on flow-velocity dynamics of all selected 'peilgebieden'. Due to the applied method, the link to real weather data was lost, though. Also, some smoothing of extremes occurred.

Each sample results in another pattern of flow velocities. Therefore, we recommend assessing the sensitivity of the Predicted Environmental Concentration to the sampled dataset of flow velocities used with example calculations.

Typical for the flow velocities of this constructed time-series is that water flows in two directions. This behaviour could also be observed from the groundwater model. Actually, it is typical hydrological practice in Dutch polders; in the winter excess precipitation water is discharged, and in the summer water is let in to support crop water demand. It is also consistent with water management practices in the management area of the Rivierenland Water Board. Flow velocities of the dataset are also higher and residence times corresponding to the flow velocities are shorter than currently used in the Dutch risk assessment of pesticides. Based on a calibrated hydrological model, we think that the velocities derived are in line with what can be expected in the Rivierenland area, but in order to better underpin the approach followed, we recommend to assess if the statistics of the final dataset of flow velocities are in line with flow velocities in real ditches next to fruit orchards. To this end, it is recommended to start a survey on flow velocities in Dutch edge-of-field ditches of a sufficient long period and with a high temporal resolution (e.g. hours) for the future.

The flow velocities were used as input for the hydrological model SWQN. The output of SWQN was per hour, hence the model was used to downscale the daily information from the synthetic dataset to hourly information. TOXSWA uses the hourly discharge and the hourly water depth per segment for calculation of the pesticide fate in the ditch.

**Water depths**
A dataset of water depths, corresponding to the synthetic dataset of flow velocities, was derived by calibrating the dynamic hydrological model, SWQN. Criteria for the simulated water depth were formulated, such that they were in line with previous assumptions used in the scenario selection procedure and wit current practices of the Water Board. The variability in the water depth, resulting from the calibration process, was lower than experienced by the Rivierenland Water Board; the Water Board expects the water level to be at soil surface once in every ten years. For the evaluation ditch, the probability is much lower than in every ten years. This can be explained (at least partly) by the averaging of the flow velocities over one '*target level unit*', which diminishes the extremes in individual water courses. Also, the velocity values used were daily averaged values, which smooths the extremes over the day. Also other steps in the flow-velocity derivation may have added to lowering of the extremes. We may conclude that the variability of both the flow velocity and the water depth due to variable weather conditions and water management practices is to a large extent, but not fully maintained. This will have some impact on the calculated Predicted Environmental Concentration, but this is not easy to quantify. However, we expect that this will result in a conservative estimate of pesticide concentrations, as low flows give generally the highest concentrations in a ditch.

We recommend including the measurement of water-depth dynamics in the survey on flow velocities in edge-of-field ditches.

**Sediment characteristics**
A literature survey resulted in two selected beneficial sediment property sources. In total, four locations were considered appropriate. The two finally selected locations represent the extremes in sediment characteristics. One sediment had a bulk density of 0.12-0.2 and a porosity 0.92-0.94 and the other one had a bulk density of 0.32-0.49 and a porosity of 0.78-0.83. Both sediments have a considerable lower degree of compaction than the FOCUS ditch sediment. The FOCUS ditch sediment characteristics are based on water courses in sandy soil, which make it less suitable for fruit orchards. We recommend assessing the impact of the selected two types of sediments. Based on this assessment, one sediment property source can be selected to be used in the evaluation ditch.

# List of Abbreviations

| | |
|---|---|
| CBS | Statistics Netherlands |
| BRP | ‘Basis Registratie Percelen’ (Registration of land plots in the Netherlands) |
| DS | Direct Sampling |
| FOCUS | Forum for Co-ordination of pesticide fate models and their use |
| ID | Identification number |
| LGN | Land Use Database of the Netherlands |
| KNMI | The Royal Netherlands Meteorological Institute |
| NHI | Dutch Hydrological Instrument |
| PEC | Predicted Environmental Concentration |
| SOBEK | Model suite for hydrological quantitative modelling |
| SWQN | Surface Water QuaNtity tool for calculation of water flows in a network of watercourses |
| TI | Training Image |
| TOP10 vector | Digital topographic map of the Netherlands 1:10,000 |
| TOXSWA | Toxic Substances in Water. Model that simulates pesticide fate in surface water |

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# Annex 1 Tielerwaard: Comparison SOBEK- Moria flow velocities

The hydrodynamic model, SOBEK, and the groundwater model Moria 2.2. both simulate flow velocities in the Rivierenland area. In this Annex, simulated velocities are compared for the sub-region Tielerwaard, which is part of the management area of Rivierenland.

The Rivierenland Water Board provided SOBEK daily flow velocities of the Tielerwaard for the period 1/3/2004 to 1/4/2005. Velocities could be positive or negative. The value depends upon the predefined positive direction in the model. Figure A1.1 shows the map of the Tielerwaard, with mean absolute velocities in the simulated watercourses over the period 1 April to 1 October 2004 (summer). For the same region, and the same period, flow velocities were derived with the Moria model, according to the procedure as described in Section 2.2. Absolute mean values are shown in Figure A1.2.

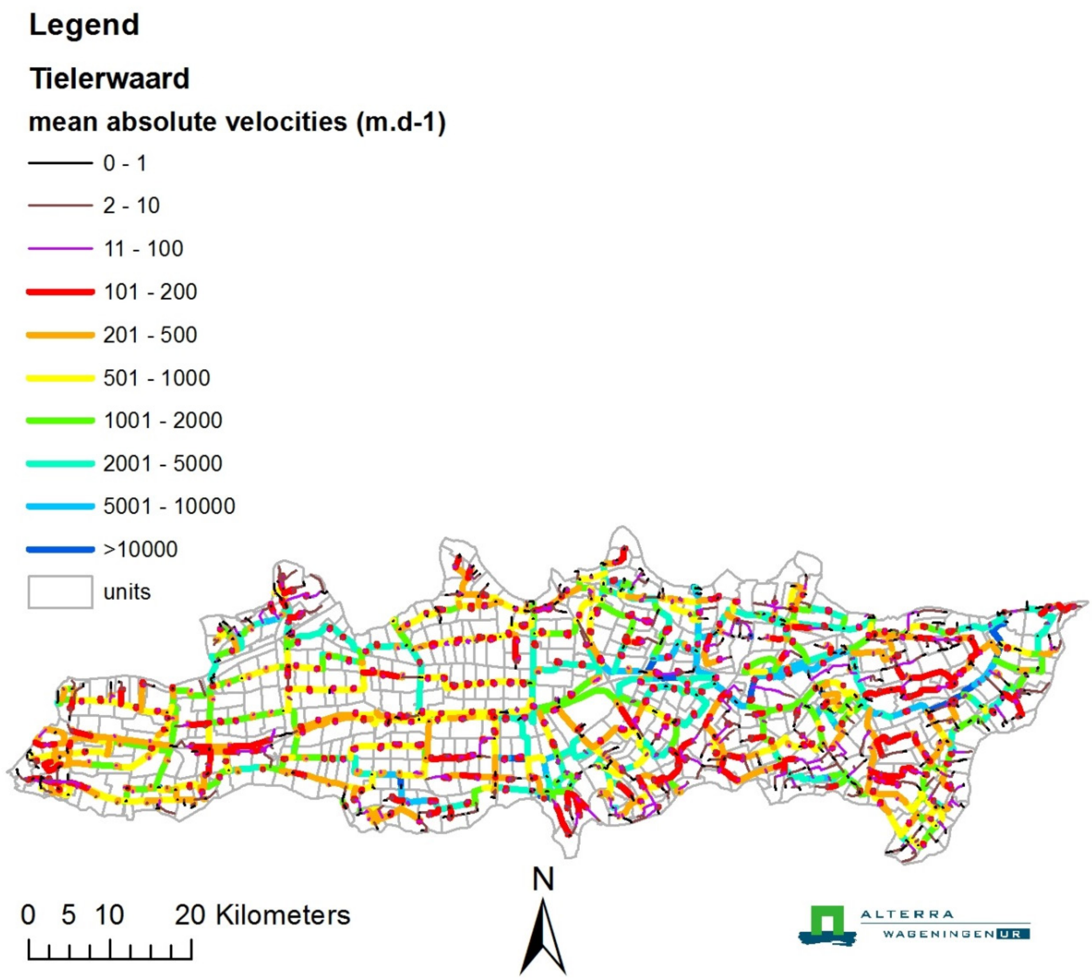


***Figure A1.1*** *Absolute mean summer velocities in the watercourses of the SOBEK model of Tielerwaard.*

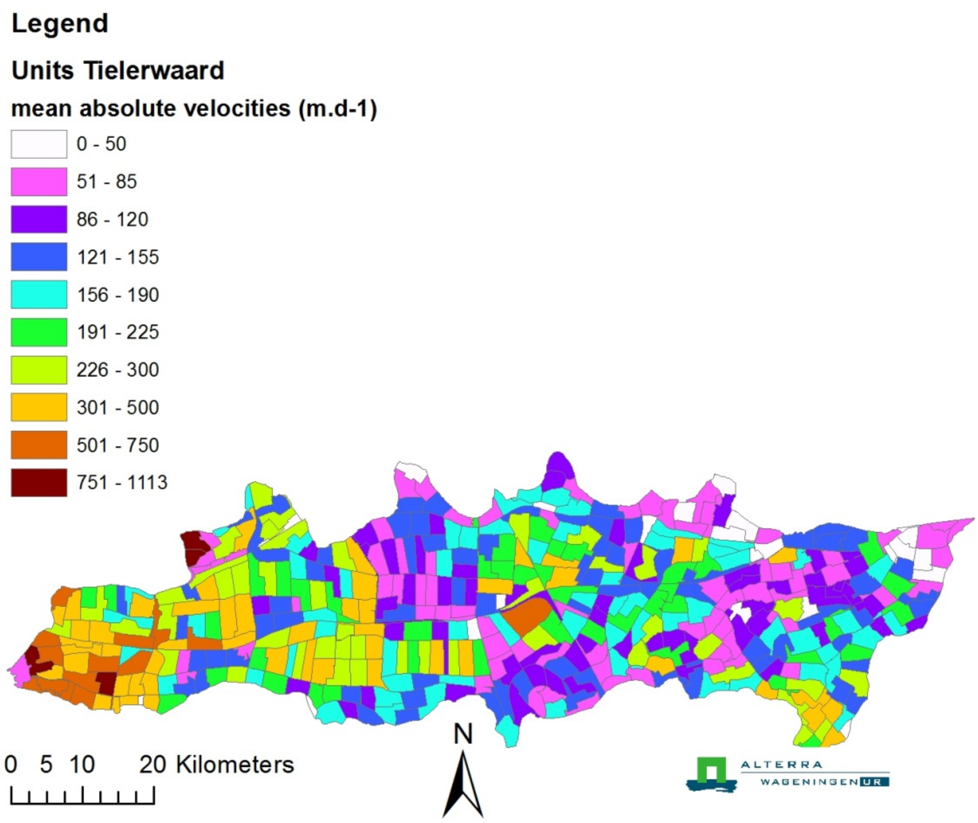


***Figure A1.2*** *Absolute mean summer velocities in the units of the MORIA model simulation of Tielerwaard.*

To enable the comparison of both methods, individual ditch flow velocities from SOBEK were attributed to the units as used by Moria. For each unit, the velocities were averaged (weighted per ditch length). The frequency distributions of both models are provided in Figure A1.3. An overview of the main statistics of both sets over flow velocities is given in Table A1.1. In Figure A1.4, the ratio of velocities calculated by SOBEK and MORIA per unit is plotted.

In general, it may be concluded that SOBEK calculates higher velocities than MORIA. There are some exceptions though, as 89 of the 441 units had lower velocities than MORIA (red- and orange units in Figure A1.4). Also the variability in the velocities calculated by SOBEK is larger than that of MORIA. The higher velocities of the SOBEK model and the larger variability may be explained by the additional discharge of regional water. The cause of the lower velocities calculated by SOBEK is not known.

***Tabel A1.1*** *Mean, median and standard deviation of the flow velocities in summer and winter for the Tielerwaard.*

| Statistics of velocities | SOBEK | MORIA |
|---|---|---|
| Mean | 1382 m/d | 173 m/d |
| Median | 708 m/d | 147 m/d |
| Standard deviation | 2022 m/d | 146 m/d |

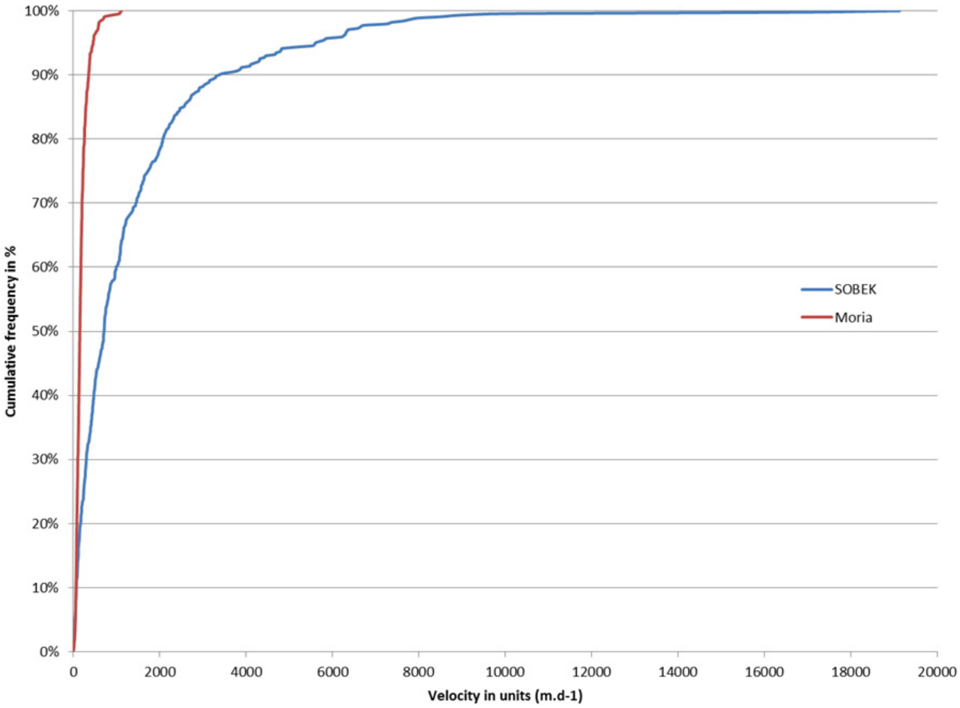


***Figure A1.3*** *Frequency distribution of the simulated velocities per unit for SOBEK and Moria.*

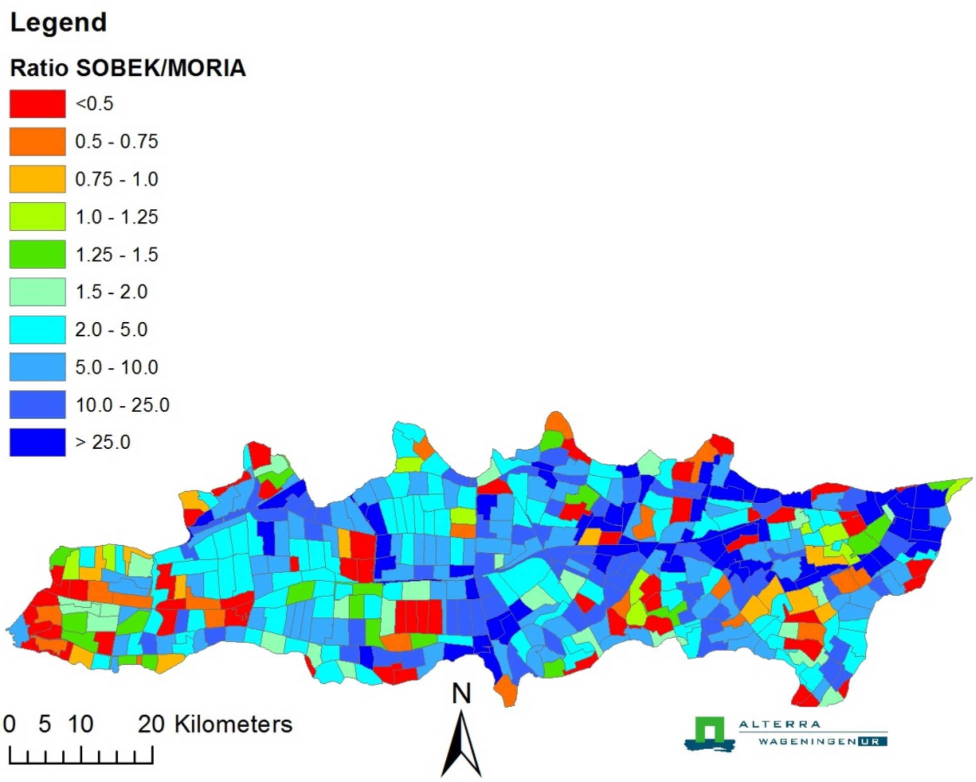


***Figure A1.4*** *Ratio SOBEK / MORIA for the absolute averaged summer velocities in the units (Tielerwaard).*

# Annex 2 Background information SWQN parameterisation

This annex is added as technical description and for reference and transparency. It consists of two parts. Part 1 provides details of the SWQN parameterisation and Part 2 is dedicated to the conversion of water depths and discharges in SWQN output to water depths and discharges in TOXSWA input.

The SWQN version used was SWQN Version 3.03.0 (Revision: 102).

## A2.1 Details SWQN parameterisation

**Reference level**
In SWQN, a reference level needs to be defined at the nodes. We used a reference level of 10 m, which is an arbitrary value (see Table A2.1 – column: *Bottom level*).

**Definition of the nodes for the SWQN simulation**
Table A2.1 gives the definition of the nodes as used for the SWQN simulation of the ditch of the upwards and sideways directed spraying scenario. Precipitation and/or evaporation was not taken into account (PrecEvapID = 0). The maximum water level was 11.08 m (i.e. 11.08 minus 10 m reference level results in 1.08 maximum water depth, which is equal to the soil surface (Figure 3.1). The initial water depth is 30 cm, except for the boundary nodes that have a lower water depth.

**Definition of the sections for the SWQN simulation**
Table A2.2 gives the definition of the sections, as used for the SWQN parameterisation. For each section, the begin- and end nodes are specified, as well as its length (10 m) and bottom width of the begin and end nodes (2.34 m). The simplified St. Venant Equations using in SWQN (Smit et al., 2009) require either the Manning or Chezy friction coefficient as input. We decided to use the Manning coefficient in for all nodes and in all situations (i.e. discharging and inlet situation), and to use the same value as for the ditch of the EU FOCUS Surface Water scenarios: 25 m1/3 s-1 (FOCUS, 2001).

***Table A2.1*** *The SWQN_NodesDefinition.csv file as used for the SWQN simulation of the ditch of the upwards and sideways directed spraying scenario. The water levels are given in metres. The bottom level is an arbitrary chosen level.*

| Node_ID | PrecEvapID | NodeX | NodeY | Bottomlevel | MaxLevel | Initial Level |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 10 | 11.08 | 10.2[4] |
| 2 | 0 | 0 | 10 | 10 | 11.08 | 10.3 |
| 3 | 0 | 0 | 20 | 10 | 11.08 | 10.3 |
| 4 | 0 | 0 | 30 | 10 | 11.08 | 10.3 |
| 5 | 0 | 0 | 40 | 10 | 11.08 | 10.3 |
| 6 | 0 | 0 | 50 | 10 | 11.08 | 10.3 |
| 7 | 0 | 0 | 60 | 10 | 11.08 | 10.3 |
| 8 | 0 | 0 | 70 | 10 | 11.08 | 10.3 |
| 9 | 0 | 0 | 80 | 10 | 11.08 | 10.3 |
| 10 | 0 | 0 | 90 | 10 | 11.08 | 10.3 |
| 11 | 0 | 0 | 100 | 10 | 11.08 | 10.3 |
| 12 | 0 | 0 | 110 | 10 | 11.08 | 10.3 |
| 13 | 0 | 0 | 120 | 10 | 11.08 | 10.3 |
| 14 | 0 | 0 | 130 | 10 | 11.08 | 10.3 |
| 15 | 0 | 0 | 140 | 10 | 11.08 | 10.3 |
| 16 | 0 | 0 | 150 | 10 | 11.08 | 10.3 |
| 17 | 0 | 0 | 160 | 10 | 11.08 | 10.3 |
| 18 | 0 | 0 | 170 | 10 | 11.08 | 10.3 |
| 19 | 0 | 0 | 180 | 10 | 11.08 | 10.3 |
| 20 | 0 | 0 | 190 | 10 | 11.08 | 10.3 |
| 21 | 0 | 0 | 200 | 10 | 11.08 | 10.3 |
| 22 | 0 | 0 | 210 | 10 | 11.08 | 10.3 |
| 23 | 0 | 0 | 220 | 10 | 11.08 | 10.3 |
| 24 | 0 | 0 | 230 | 10 | 11.08 | 10.3 |
| 25 | 0 | 0 | 240 | 10 | 11.08 | 10.3 |
| 26 | 0 | 0 | 250 | 10 | 11.08 | 10.3 |
| 27 | 0 | 0 | 260 | 10 | 11.08 | 10.3 |
| 28 | 0 | 0 | 270 | 10 | 11.08 | 10.3 |
| 29 | 0 | 0 | 280 | 10 | 11.08 | 10.3 |
| 30 | 0 | 0 | 290 | 10 | 11.08 | 10.3 |
| 31 | 0 | 0 | 300 | 10 | 11.08 | 10.3 |
| 32 | 0 | 0 | 310 | 10 | 11.08 | 10.3 |
| 33 | 0 | 0 | 320 | 10 | 11.08 | 10.3 |
| 34 | 0 | 0 | 330 | 10 | 11.08 | 10.3 |
| 35 | 0 | 0 | 340 | 10 | 11.08 | 10.3 |
| 36 | 0 | 0 | 350 | 10 | 11.08 | 10.3 |
| 37 | 0 | 0 | 360 | 10 | 11.08 | 10.2 |

4 This value was arbitrary chosen and is overruled by the boundary level values as given in Table A2.5.

**Table A2.2** *The SWQN_SectionsDefinition.csv file as used for the SWQN simulation. Water levels and widths are given in metres. Resistance is given in m.s$^{-1}$.*

| Section_ID | BeginNode_ID | EndNode_ID | Length | BottomWidthBegin | BottomWidthEnd | SlopeBegin | SlopeEnd | ResistBeginPos | ResistBeginNeg | ResistEndPos | ResistEndNeg |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 2 | 2 | 3 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 3 | 3 | 4 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 4 | 4 | 5 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 5 | 5 | 6 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 6 | 6 | 7 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 7 | 7 | 8 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 8 | 8 | 9 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 9 | 9 | 10 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 10 | 10 | 11 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 11 | 11 | 12 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 12 | 12 | 13 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 13 | 13 | 14 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 14 | 14 | 15 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 15 | 15 | 16 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 16 | 16 | 17 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 17 | 17 | 18 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 18 | 18 | 19 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 19 | 19 | 20 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 20 | 20 | 21 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 21 | 21 | 22 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 22 | 22 | 23 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 23 | 23 | 24 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 24 | 24 | 25 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 25 | 25 | 26 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 26 | 26 | 27 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 27 | 27 | 28 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 28 | 28 | 29 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 29 | 29 | 30 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 30 | 30 | 31 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 31 | 31 | 32 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 32 | 32 | 33 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 33 | 33 | 34 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 34 | 34 | 35 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 35 | 35 | 36 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |
| 36 | 36 | 37 | 10 | 2.34 | 2.34 | 1 | 1 | 25 | 25 | 25 | 25 |

## Weirs

In SWQN, the weirs are defined by two input files: SWQN_WeirsDefinition.csv (Table A2.3) and SWQN_WeirsControl.csv (Table A2.4). The characteristics of the weir are specified in SWQN_WeirsDefinition.csv.

The sections were the weirs are located are defined, the crest width (50 cm), the initial crest width (note that this value defines the actual crest width in case the option SelectControlWeir is set to 2 in SWQN_WeirsControl.csv), minimal and maximal crest levels and the weir coefficients ($\mu_{weir}$ = 1.5 $m^{0.5}s^{-1}$) are defined.

***Table A2.3*** *The SWQN_WeirsDefinition.csv file as used for the SWQN simulation of the ditch of the upwards and sideways directed spraying scenario.*

| Weir_ID | Section | MaxCrestWidth | InitialCrestWidth | MaxCrestLevel | MinCrestLevel |
|---|---|---|---|---|---|
| 1 | 2 | 3.9 | 0.5 | 11.08 | 10.27 |
| 2 | 35 | 3.9 | 0.5 | 11.08 | 10.27 |

| Weir_ID | Section | InitialCrestLevel | MuPosFree | MuNegFree | MuPosSub | MuPosSub |
|---|---|---|---|---|---|---|
| 1 | 2 | 10.27 | 1.5 | 1.5 | 1.5 | 1.5 |
| 2 | 35 | 11.08 | 1.5 | 1.5 | 1.5 | 1.5 |

The control settings of the weir are specified in SWQN_WeirsControl.csv (Table A2.4). For level control, we used the fixed crest level option (SelectControlWeir = 2). For each weirID and date the level control (CrestLevel in m from reference level) is fixed. In SWQN_WeirsControl.csv crest level values are sustained in time until a new value is given. In case SelectControlWeir is set to 2, the CrestWidth, the Target level of the begin node and the Target level of the end node which are input of SWQN_WeirsControl.csv are dummy values.

***Table A2.4*** *Part of the SWQN_WeirsControl.csv file as used for the SWQN simulation of the ditch of the upwards and sideways directed spraying scenario.*

| Date | WeirID | SelectControl Weir | CrestWidth* | CrestLevel | Targetlevel Begin* | Targetlevel End* |
|---|---|---|---|---|---|---|
| 01/01/2020 | 1 | 2 | 2.34 | 11.08 | | |
| 01/01/2020 | 2 | 2 | 2.34 | 10.27 | | |
| 15/02/2020 | 1 | 2 | 2.34 | 10.27 | | |
| 15/02/2020 | 2 | 2 | 2.34 | 11.08 | | |
| 06/03/2020 | 1 | 2 | 2.34 | 11.08 | | |
| 06/03/2020 | 2 | 2 | 2.34 | 10.27 | | |
| 11/03/2020 | 1 | 2 | 2.34 | 10.27 | | |
| 11/03/2020 | 2 | 2 | 2.34 | 11.08 | | |
| 01/04/2020 | 1 | 2 | 2.34 | 10.28 | | |
| 01/04/2020 | 2 | 2 | 2.34 | 11.08 | | |
| 11/09/2020 | 1 | 2 | 2.34 | 11.08 | | |
| 11/09/2020 | 2 | 2 | 2.34 | 10.28 | | |
| 26/09/2020 | 1 | 2 | 2.34 | 10.28 | | |
| 26/09/2020 | 2 | 2 | 2.34 | 11.08 | | |

On Jan. 1st 2020, Weir 1 in section 2 acts as a barrier forcing flow towards Weir 2 (Section 35), with crest height set to the Winter level of 27 cm.

On Feb. 15th 2020, there is a shift in flow direction. Weir 2 in Section 35 acts as a barrier forcing flow towards Weir 1 (Section 2), with crest height set to the Winter level of 27 cm.

* Dummy values; not used in case SelectControlWeir is set to 2.

**Boundary levels of the begin and end nodes of the 360m long ditch (Node 1 and Node 37)**

Level boundaries are specified in the SWQN input file: SWQN_LevelBoundary.csv (Table A1.5). They were set to 10.05 m (5 cm) on Nodes 1 and 37, and are needed to make sure that the water can leave the ditch. Only the levels on the start date need to be given in SWQN_LevelBoundary.csv as values are sustained in time until a new value is given.

***Table A2.5*** *The SWQN_LevelBoundary.csv file as used for the SWQN simulation of the ditch of the upwards and sideways directed spraying scenario.*

| Date | ExtCompNumber | Level |
|---|---|---|
| 01/01/2020 | 1 | 10.05 |
| 01/01/2020 | 37 | 10.05 |

**Boundary fluxes of the begin- and end nodes of the <u>300</u> m long ditch (Node 4 and Node 34)**
Flow boundaries in Nodes 4 and 34 are specified in the SWQN input file: SWQN_FlowBoundary.csv (Table A2.6). This discharge is given in $m^3$/s.

***Table A2.6*** *Part of the SWQN_FlowBoundary.csv file as used for the SWQN simulation of the ditch of the upwards and sideways directed spraying scenario. Discharge is given in $m^3s^{-1}$. ExtCompNumber referres to nodeID.*

| Date | ExtCompNumber | Discharge |
|---|---|---|
| 01/01/2020 | 4 | 0.010014144 |
| 01/01/2020 | 5 | 0 |
| | | |
| 01/01/2020 | 34 | 0 |
| 02/01/2020 | 4 | 0.007755825 |
| . | . | . |
| 14/02/2020 | 4 | 0.000149082 |
| | | |
| 15/02/2020 | 4 | 0 |
| 15/02/2020 | 34 | 4.87E-05 |
| 16/02/2020 | 34 | 0.000145015 |
| . | . | . |
| 05/03/2020 | 34 | 0.000760901 |
| 06/03/2020 | 4 | 0.000340349 |
| 06/03/2020 | 34 | 0 |
| 07/03/2020 | 4 | 0.000476585 |
| . | . | . |
| 11/03/2020 | 4 | 0 |
| 11/03/2020 | 34 | 0.000231503 |
| 12/03/2020 | 34 | 0.000357686 |

Note: discharge in $m^3$/s
On Jan. 1st 2020, Node 4 receives and incoming discharge, Node 34 for does not. This indicates that there is a discharging situation. On Jan. 1st 2020 for all nodes between Nodes 4 and 34 the incoming discharge is set to zero. The values are sustained in time.

Varying incoming discharge in Node 4 until Feb. 15th. There is a change to an inlet situation. This is indicated by setting the discharge in Node 4 to zero and specifying a discharge > 0 for Node 34.

The dates are artificial. For the relation between year numbers used in the SWQN model and the TOXSWA model, see Annex 6.

**Runtime options**

In the file SWQN_Runtimeoptions.in the calculation period, the numerical and output time steps and the input and output types are given.

Below the content of the SWQN_Runtimeoptions.in file as used for the SWQN simulation of the ditch of the upwards and sideways directed spraying scenario is given.

```
[CalculationSettings]
CalculationID = 601002 ~ Mechteld ter Horst ~ October 2015
StartYear= 2020
StartMonth= 1
StartDay = 1

BottomDepthLocation=1

EndYear= 2046
EndMonth= 12
EndDay = 31

InitiationDays = -1
TimestepNumeric = 1
ResistanceType = 2

SWQNTimestepsPerDay = 24
NuswaLiteTimestepsPerDay = 1
OutputEveryTimeStep = 1
OutBalanceAll = 2

DumpDay=-1
```

Numerical timestep: 1 hour

Use the Manning coefficient

Give output on hourly basis

## A2.2 Method for converting the output of SWQN to input for TOXSWA

In the SWQN output file, SWQN_OutDepths_TStep.csv water depths (in m) are given for each node and each hour. In the SWQN output file, SWQN_OutDischarges_TStep.csv discharges (in m3/s) are given for each section. The discharge is a positive value if flow is from begin node to end node.

In SWQN, a section is found between two nodes as shown in Figure A2.1; n1 is the begin node of Section s1 and n2 is the end node of Section s1. Discharge in section s1 equals the discharge in node n1. This is valid for both flow directions.

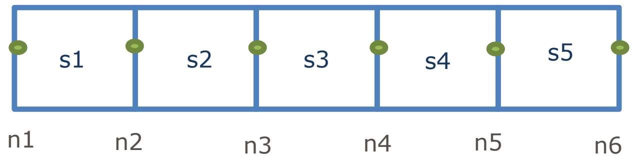


***Figure A2.1*** *System of sections and nodes as used in SWQN.*

TOXSWA uses a system of segments and nodes to describe a watercourse. A node is found in the centre of a segment, as shown in Figure A2.2; Node n1 is found in the centre of Segment s1.

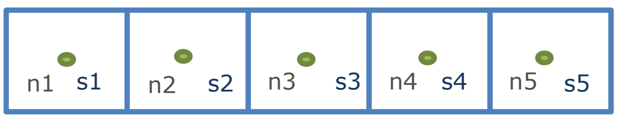


***Figure A2.2*** *System of segments and nodes as used in TOXSWA.*

In TOXSWA, water depths (called DepWat in TOXSWA) are defined in a node, and discharges (called QBou in TOXSWA) are defined on the boundaries of a segment. This implies that, for instance, DepWat(1) gives the water depth in Node 1. QBou(0) gives the discharge over the upper boundary of Segment 1 and QBou(1) gives the discharge on the boundary of Segment 1 and Segment 2.
Note that SWQN sections and TOXSWA segments have matching positions that assume equal lengths of segments and sections. SWQN nodes are, however, found on another location in a section/segment than TOXSWA nodes (Figure A2.3). Water depths in SWQN nodes and discharges in SWQN sections are translated to water depths in TOXSWA nodes and discharges over TOXSWA segment boundaries are as follows:

$$h_{TOXSWAni} = 0.5 * (h_{SWQNni} + h_{SWQNni+1}) \qquad \text{(eq. A2.1)}$$

$$QBou_{si} = Q_{SWQNsi} \qquad \text{(eq. A2.2)}$$

Where $h_{TOXSWAni}$ is the water depth in TOXSWA Node i, $h_{SWQNni}$ is the water depth in SWQN Node i, $QBou_{si1}$ is the discharge over the <u>upper</u> boundary of TOXWA Segment i and $Q_{SWQNsi}$ is the discharge in SWQN Segment i. Equations A2.1 and A2.2 are only valid in case the length of the SWQN sections equals the length of the corresponding TOXSWA segment.


***Figure A2.3*** *Up: System of sections and nodes as used in SWQN; depicting the description of discharge and water depth. Below: System of segments and nodes as used in TOXSWA; depicting the description of discharge and water depth.*

When projecting the 300 m ditch to be simulated with TOXSWA on the 360 m ditch simulated with SWQN, TOXSWA Segment 1 will correspond to SWQN Section 4, and following this system, TOXSWA Segment 30 will correspond to SWQN Section 34. Table A2.1 shows the results of this projection considering the translation of SWQN output of water depths and discharges in to TOXSWA input of water depths and discharges.

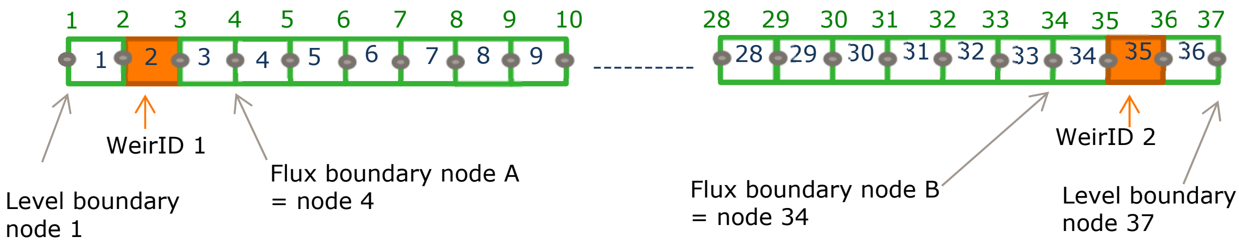


***Figure A2.4*** *Schematisation of the ditch of the upwards and sideways directed spraying scenario in nodes and sections in SWQN (360 m). The grey dots represent the nodes (starting with Node ID 1 on the left-hand side and ending with Node ID 37 on the right-hand side). The green boxes represent the sections (starting with ID 1 on the left-hand side and ending with ID 36 on the right-hand side).*

***Table A2.7*** *Translating discharges in SWQN sections to discharges over the upper boundary of TOXSWA segments and translating water depths in SWQN nodes to water depths in TOXSWA nodes.*

| SWQN section | QBou (TOXSWA) | | h SWQNnodes | | | | $h_{toxswa}$ |
|---|---|---|---|---|---|---|---|
| 4 | 0 | avg ( | 4 | + | 5 | ) | 1 |
| 5 | 1 | avg ( | 5 | + | 6 | ) | 2 |
| 6 | 2 | avg ( | 6 | + | 7 | ) | 3 |
| 7 | 3 | avg ( | 7 | + | 8 | ) | 4 |
| 8 | 4 | avg ( | 8 | + | 9 | ) | 5 |
| 9 | 5 | avg ( | 9 | + | 10 | ) | 6 |
| 10 | 6 | avg ( | 10 | + | 11 | ) | 7 |
| 11 | 7 | avg ( | 11 | + | 12 | ) | 8 |
| 12 | 8 | avg ( | 12 | + | 13 | ) | 9 |
| 13 | 9 | avg ( | 13 | + | 14 | ) | 10 |
| 14 | 10 | avg ( | 14 | + | 15 | ) | 11 |
| 15 | 11 | avg ( | 15 | + | 16 | ) | 12 |
| 16 | 12 | avg ( | 16 | + | 17 | ) | 13 |
| 17 | 13 | avg ( | 17 | + | 18 | ) | 14 |
| 18 | 14 | avg ( | 18 | + | 19 | ) | 15 |
| 19 | 15 | avg ( | 19 | + | 20 | ) | 16 |
| 20 | 16 | avg ( | 20 | + | 21 | ) | 17 |
| 21 | 17 | avg ( | 21 | + | 22 | ) | 18 |
| 22 | 18 | avg ( | 22 | + | 23 | ) | 19 |
| 23 | 19 | avg ( | 23 | + | 24 | ) | 20 |
| 24 | 20 | avg ( | 24 | + | 25 | ) | 21 |
| 25 | 21 | avg ( | 25 | + | 26 | ) | 22 |
| 26 | 22 | avg ( | 26 | + | 27 | ) | 23 |
| 27 | 23 | avg ( | 27 | + | 28 | ) | 24 |
| 28 | 24 | avg ( | 28 | + | 29 | ) | 25 |
| 29 | 25 | avg ( | 29 | + | 30 | ) | 26 |
| 30 | 26 | avg ( | 30 | + | 31 | ) | 27 |
| 31 | 27 | avg ( | 31 | + | 32 | ) | 28 |
| 32 | 28 | avg ( | 32 | + | 33 | ) | 29 |
| 33 | 29 | avg ( | 33 | + | 34 | ) | 30 |
| 34 | 30 | | | | | | |

# Annex 3 Artefacts in discharges and water depths calculated with SWQN

As demonstrated in Figures A3.1 and A3.2, sudden increases or decreases in both the water depth and discharge calculated by the SWQN model were found occasionally. These sudden increases and decreases lasted for one to a few hours. They often occur on the day of a switch in the flow direction of the water or a few days after this switch. We suspect that they are the result of artefacts of the numerical solution. However, analysis showed that they do not provoke water balance errors (Figure A3.3). Given the limited number of these sudden increases or decreases, their short duration (one to several hours) and limited size (around one order of magnitude for the discharge and several millimetres for the water depth), we expect that the sudden increases or decreases in both the water depth and discharge will have a limited effect on the Predicted Environmental Concentration in the ditch. This must be assessed with example calculations (which are not part of this report).

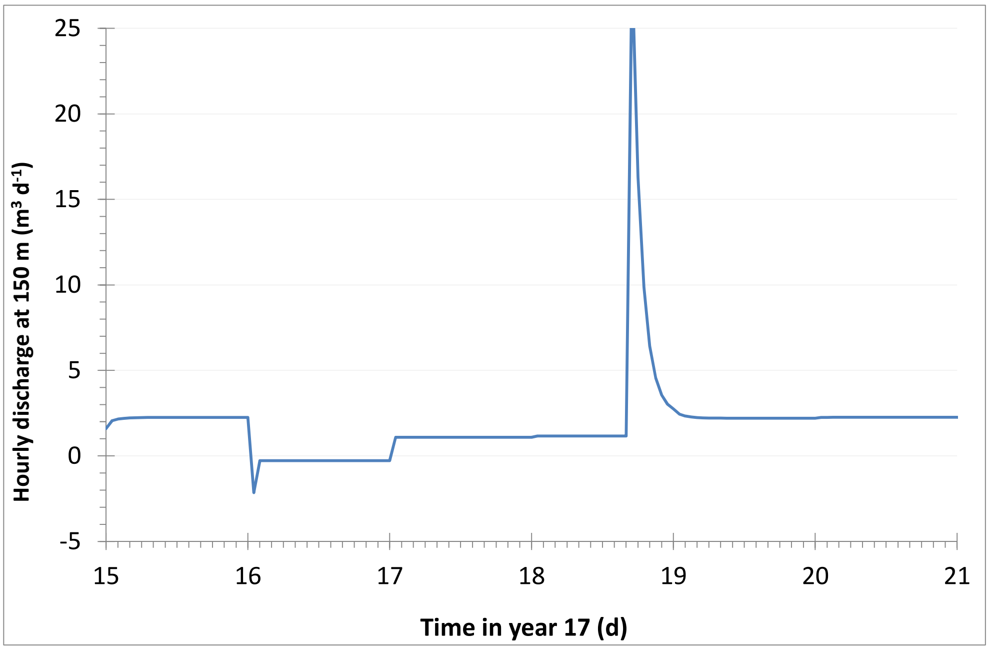


***Figure A3.1*** *Hourly values of discharge in the centre of the 100m evaluation ditch as function of time for a few selected days in year 17 and as result of the calibration of the model for the selected case (Case 2 in Table 4.1). The discharge set as boundary condition changes per day. The simulated discharge at 150 m responds generally within 2 hrs. A peak occurs only after a switch in flow direction (positive to negative and vice versa).*

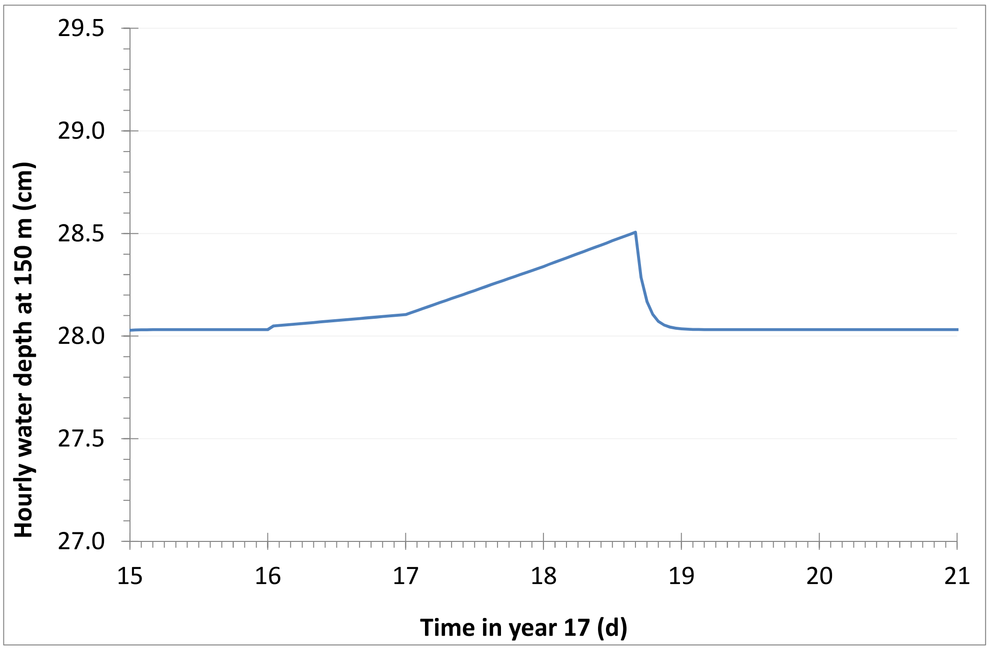


***Figure A3.2*** *Hourly values of water depth in the centre of the 100m evaluation ditch as function of time for year 17 and as result of the calibration of the model for the selected case (Case 2 in Table 4.1). This figure corresponds to the water fluxes in Figure A3.1.*

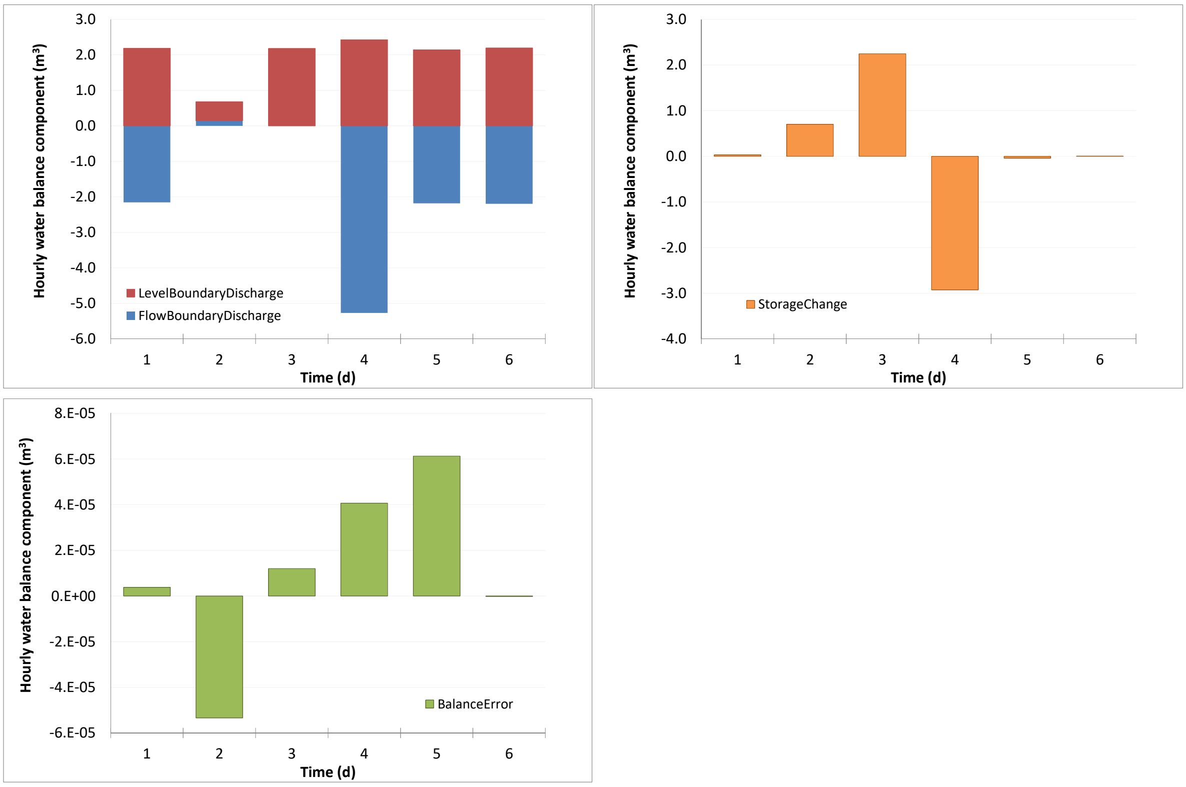


***Figure A3.3*** *Hourly water balance for a six-day period in year 17, corresponding to the period of Figures A3.1 and A3.2 A. Major water balance components: Flow boundary discharge (imposed discharges) and level boundary discharge (discharges leaving the ditch; a positive value indicates incoming flow, a negative value indicates outgoing flow). B. Change in storage in the ditch as calculated by the model; a positive value indicates an increase in water storage. C. Water balance error. Note the different scales of the y-axis.*

The water balance error is calculated as the difference in the hourly change in storage minus the sum of the hourly inflow (flow boundary discharge) and the hourly outflow (level boundary discharge).

The water volume in the 300 m long ditch is about 246 $m^3$ for six-day period in year 17 shown in Figures A3.1 – A3.3. The maximum water balance error for this period is around $6 \cdot 10^{-5}$ $m^3$. The error relative to the water volume in the ditch is around 2.4 $10^{-5}$%.

# Annex 4 Sediment properties of selected ditches measured by Adriaanse et al.

Values are based on five measurements per ditch over 100 m of ditch. Tables are taken from Adriaanse et al. (2015) Chapter 6.

***Table A4.1*** *Sediment properties of the watercourse near Emmeloord in July and September 2013 (Zuiderzeeland Water Board).*

| | Emmeloord 4 July 2013 | | | Emmeloord 25 September 2013 | | |
|---|---|---|---|---|---|---|
| **Averages of bulk density (BD, g/ml), porosity (por, mL/mL) and loss on ignition (om, mass%)** | | | | | | |
| | BD | por | om | BD | Por | om |
| 0-1 cm | 0.23 | 0.91 | 17.36 | 0.23 | 0.85 | 17.50 |
| 1-2 cm | 0.34 | 0.87 | 17.75 | 0.32 | 0.82 | 15.70 |
| 2-3 cm | 0.38 | 0.89 | 21.60 | 0.36 | 0.82 | 15.64 |
| 3-5 cm | 0.40 | 0.82 | 18.06 | 0.38 | 0.82 | 16.21 |
| 5-10 cm | 0.38 | 0.84 | 20.85 | 0.37 | 0.83 | 22.57 |
| | | | | | | |
| **Standard deviation** | | | | | | |
| 0-1 cm | 0.05 | 0.04 | 0.78 | 0.12 | 0.09 | 2.72 |
| 1-2 cm | 0.06 | 0.02 | 2.34 | 0.09 | 0.03 | 1.62 |
| 2-3 cm | 0.10 | 0.08 | 5.31 | 0.09 | 0.06 | 1.71 |
| 3-5 cm | 0.17 | 0.07 | 5.93 | 0.12 | 0.04 | 2.66 |
| 5-10 cm | 0.10 | 0.04 | 13.14 | 0.14 | 0.04 | 17.40 |

***Table A4.2*** *Sediment properties of the watercourse near Nieuwolda in July and September 2013 (Hunze en Aas Water Board).*

| | Nieuwolda 25 July 2013 | | | Nieuwolda 25 September 2013 | | |
|---|---|---|---|---|---|---|
| **Averages of bulk density (BD, g/ml), porosity (por, mL/mL) and loss on ignition (om, mass%)** | | | | | | |
| | BD | Por | om | BD | por | om |
| 0-1 cm | 0.40 | 0.92 | 8.88 | 0.30 | 0.71 | 10.65 |
| 1-2 cm | 0.54 | 0.80 | 8.52 | 0.43 | 0.72 | 9.91 |
| 2-3 cm | 0.58 | 0.80 | 8.36 | 0.45 | 0.68 | 9.77 |
| 3-5 cm | 0.59 | 0.76 | 7.63 | 0.52 | 0.74 | 8.74 |
| 5-10 cm | 0.66 | 0.75 | 6.45 | 0.57 | 0.75 | 8.32 |
| | | | | | | |
| **Standard deviation** | | | | | | |
| 0-1 cm | 0.10 | 0.21 | 0.48 | 0.09 | 0.04 | 1.63 |
| 1-2 cm | 0.10 | 0.04 | 0.60 | 0.10 | 0.05 | 1.29 |
| 2-3 cm | 0.09 | 0.03 | 0.96 | 0.09 | 0.05 | 1.62 |
| 3-5 cm | 0.07 | 0.03 | 0.16 | 0.12 | 0.04 | 1.11 |
| 5-10 cm | 0.07 | 0.02 | 0.54 | 0.12 | 0.04 | 0.70 |

***Table A4.3*** *Sediment properties of the watercourse near Uden, Brabant in June and September 2013 (Aa en Maas Water Board).*

| | Uden 12 June 2013 | | | Uden 24 September 2013 | | |
|---|---|---|---|---|---|---|
| **Averages of bulk density (BD, g/ml), porosity (por, mL/mL) and loss on ignition (om, mass%)** | | | | | | |
| | BD | Por | om | BD | por | om |
| 0-1 cm | 0.19 | 0.93 | 22.18 | 0.09 | 0.84 | 30.23 |
| 1-2 cm | 0.31 | 0.87 | 19.51 | 0.14 | 0.83 | 29.21 |
| 2-3 cm | 0.35 | 0.90 | 18.22 | 0.18 | 0.82 | 25.48 |
| 3-5 cm | 0.44 | 0.85 | 14.82 | 0.34 | 0.87 | 15.10 |
| 5-10 cm | 0.56 | 0.81 | 12.35 | 0.46 | 0.81 | 10.46 |
| | | | | | | |
| **Standard deviation** | | | | | | |
| 0-1 cm | 0.06 | 0.05 | 3.80 | 0.03 | 0.04 | 3.60 |
| 1-2 cm | 0.04 | 0.06 | 1.82 | 0.03 | 0.06 | 4.78 |
| 2-3 cm | 0.07 | 0.06 | 2.25 | 0.04 | 0.06 | 6.22 |
| 3-5 cm | 0.12 | 0.05 | 4.18 | 0.18 | 0.09 | 6.46 |
| 5-10 cm | 0.17 | 0.07 | 4.73 | 0.16 | 0.05 | 2.83 |

***Table A4.4*** *Sediment properties of the watercourse near Willemstad, Noord-Brabant in July and September 2013 (Brabantse Delta Water Board).*

| | Willemstad24 July 2013 | | | Willemstad 24 September 2013 | | |
|---|---|---|---|---|---|---|
| **Averages of bulk density (BD, g/ml), porosity (por, mL/mL) and loss on ignition (om, mass%)** | | | | | | |
| | BD | por | om | BD | por | om |
| 0-1 cm | 0.38 | 0.81 | 10.74 | 0.25 | 0.85 | 14.05 |
| 1-2 cm | 0.54 | 0.79 | 9.66 | 0.44 | 0.79 | 10.19 |
| 2-3 cm | 0.53 | 0.78 | 10.47 | 0.47 | 0.78 | 10.49 |
| 3-5 cm | 0.50 | 0.78 | 9.50 | 0.46 | 0.79 | 10.40 |
| 5-10 cm | 0.50 | 0.78 | 9.49 | 0.54 | 0.75 | 9.73 |
| | | | | | | |
| **Standard deviation** | | | | | | |
| 0-1 cm | 0.08 | 0.04 | 1.08 | 0.11 | 0.08 | 5.10 |
| 1-2 cm | 0.05 | 0.04 | 0.91 | 0.08 | 0.02 | 1.40 |
| 2-3 cm | 0.03 | 0.03 | 0.88 | 0.09 | 0.02 | 1.63 |
| 3-5 cm | 0.04 | 0.02 | 0.72 | 0.08 | 0.03 | 1.06 |
| 5-10 cm | 0.09 | 0.03 | 1.66 | 0.11 | 0.06 | 2.75 |

# Annex 5 Hydrological responses

This annex provides graphical information of several hydrological parameters for each year in the last 20 years of the 26-year-period, for which the hydrology is simulated i.e.

A Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m)
B Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m)
C Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m)
D1 Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m)
D2 Monthly averages of the hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m)

These 20 years are the years over which the Predicted Environmental Concentrations are simulated in the TOXSWA fate model. The numbers of the years refer to the SWQN simulated year numbers 1-27. The monthly averages of the hourly instantaneous residence time are calculated as follows:

$$\tau_m = \frac{l_{ed}\sum_{t=0}^{n}(A_{x=150m})}{\sum_{t=0}^{n}(|Q_{x=150m}|)} \qquad \text{(Eq. A5.1)}$$

where

$\tau_m$ = monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) (d)
$l_{ed}$ = length of the evaluation part of the 300 m long ditch for which the hydrology is simulated, i.e. 100 m (m)
$A_{x=150m}$ = cross-sectional area of flow at x = 150 m (i.e. in the centre of the 100 m evaluation ditch) ($m^2$)
$Q_{x=150m}$ = Discharge at x = 150 m (i.e. in the centre of the 100 m evaluation ditch) ($m^3\ d^{-1}$)
$t$ = time (hour)
$n$ = total number of hours in a month

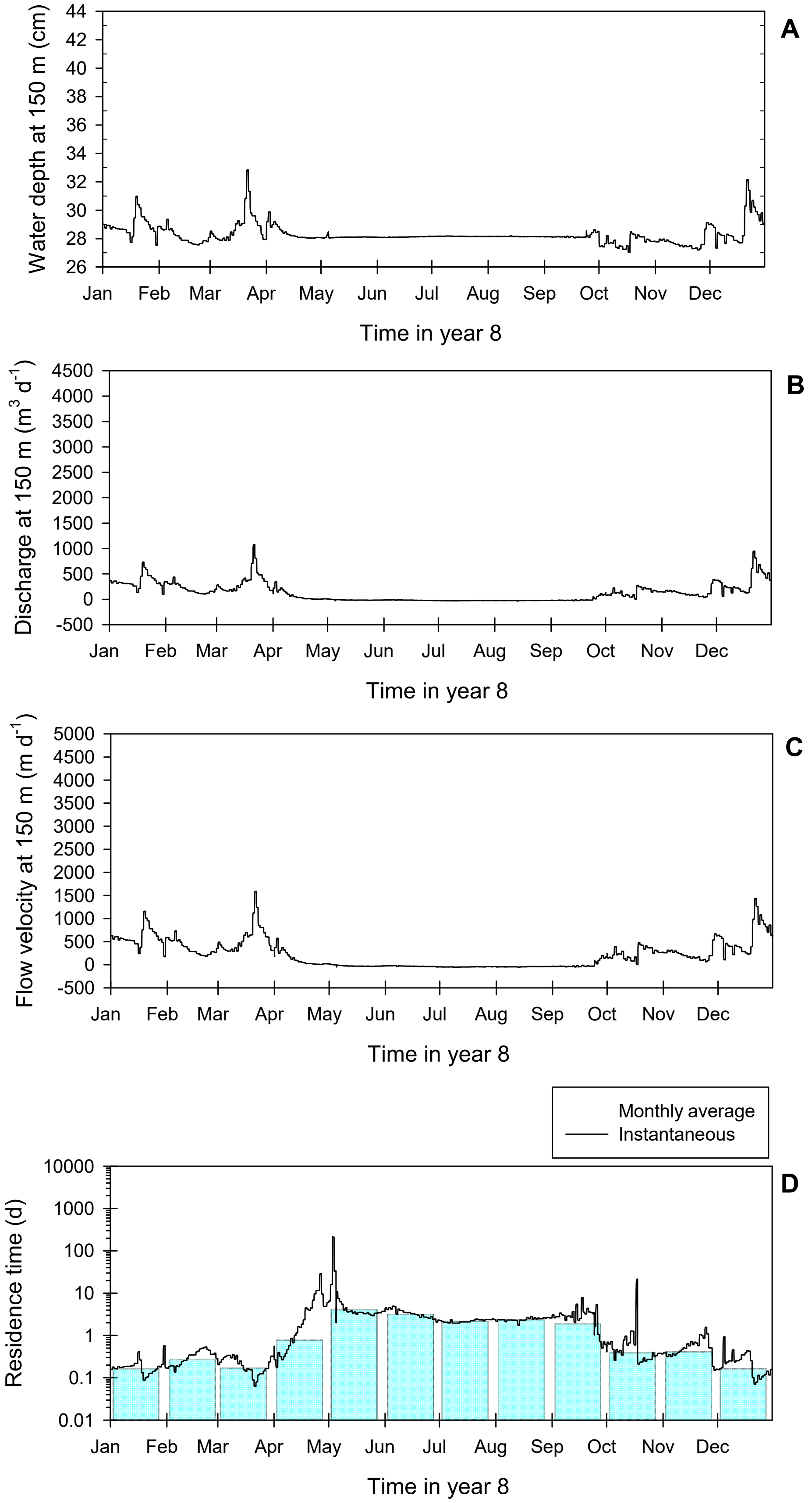


***Figure A5.1*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 8. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 8. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 8. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 8 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 8.*

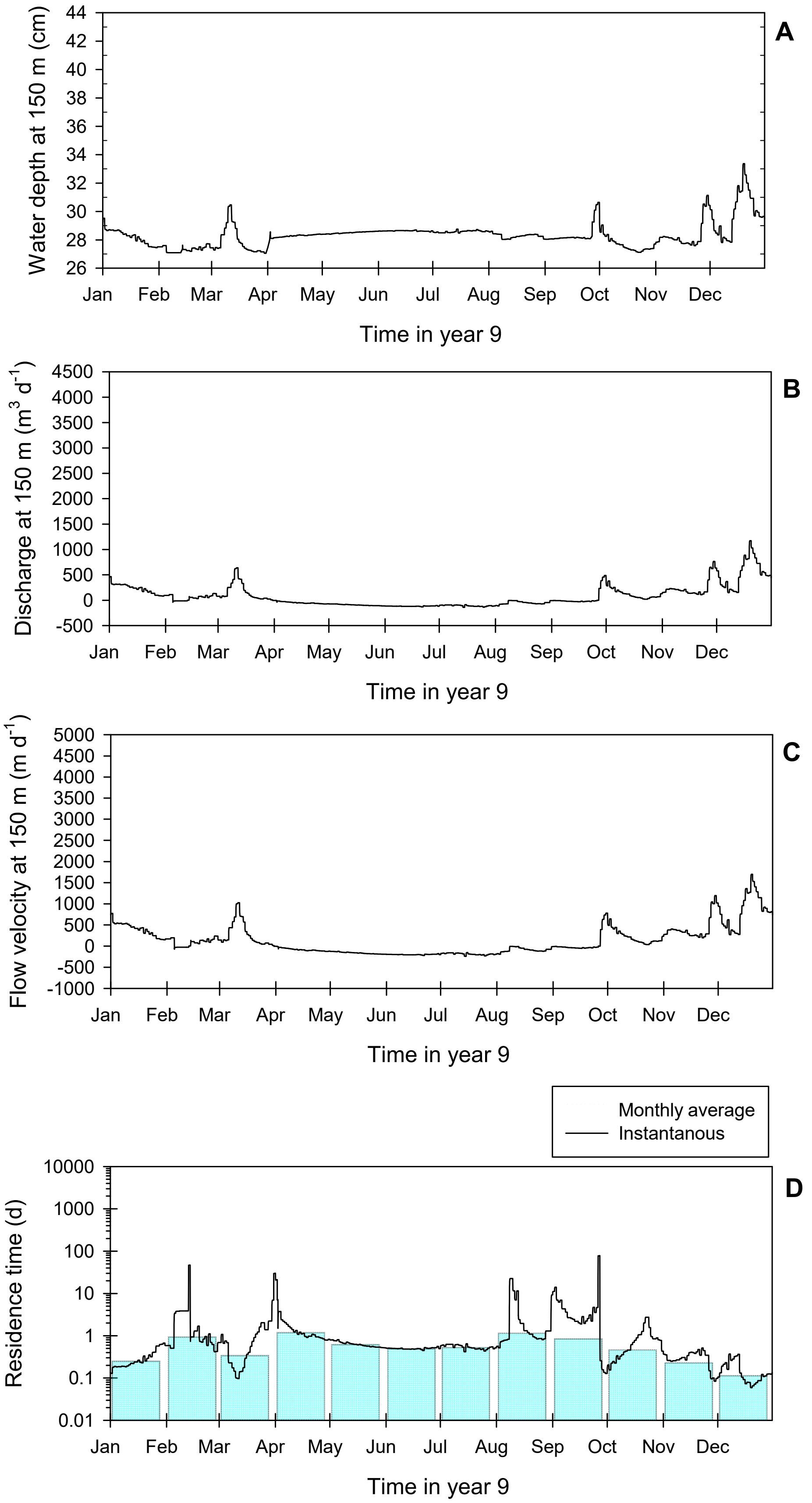


***Figure A5.2*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 9. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 9. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 9. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 9 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 9.*

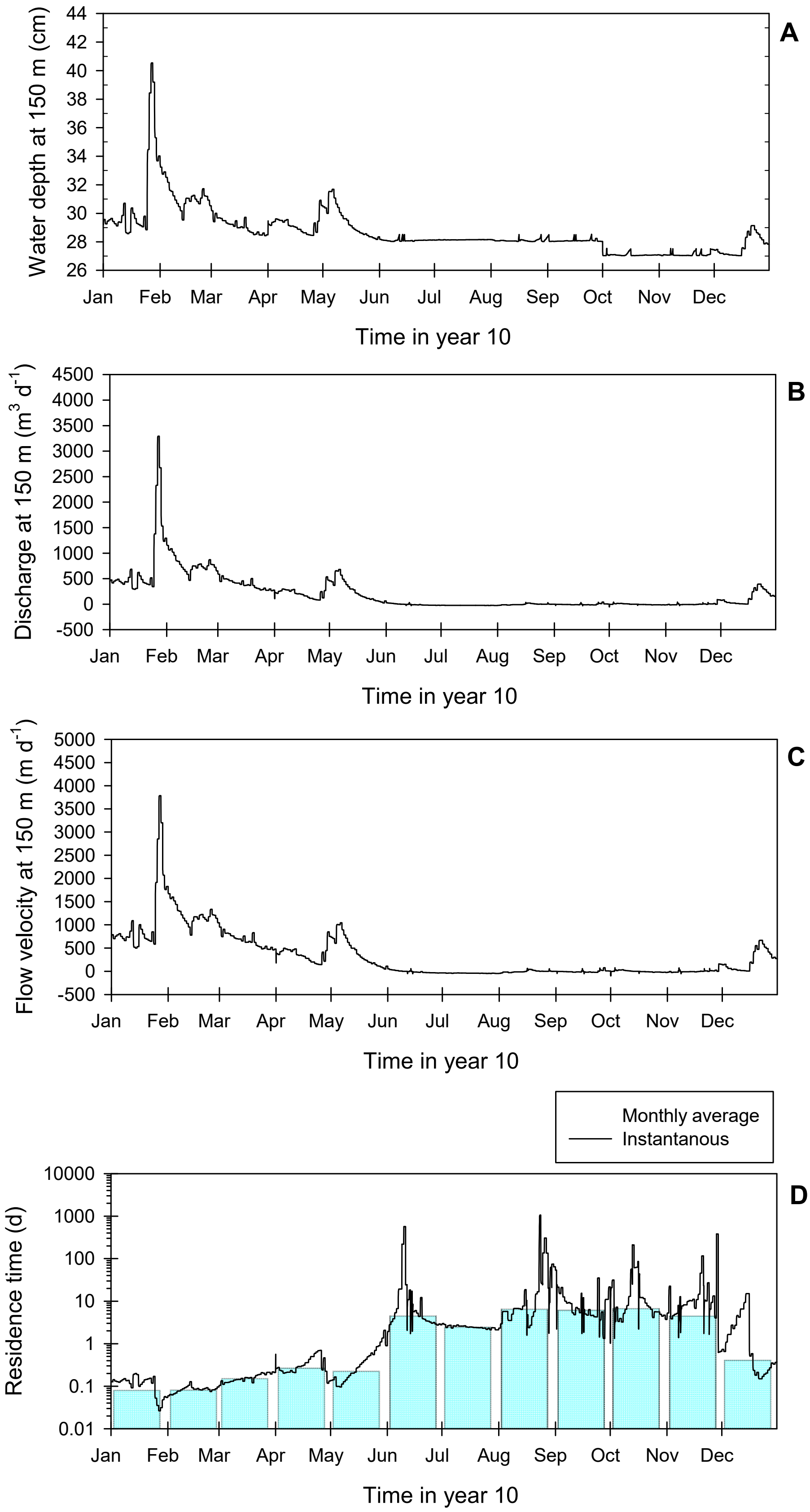


***Figure A5.3*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 10. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 10. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 10. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 10 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 10.*

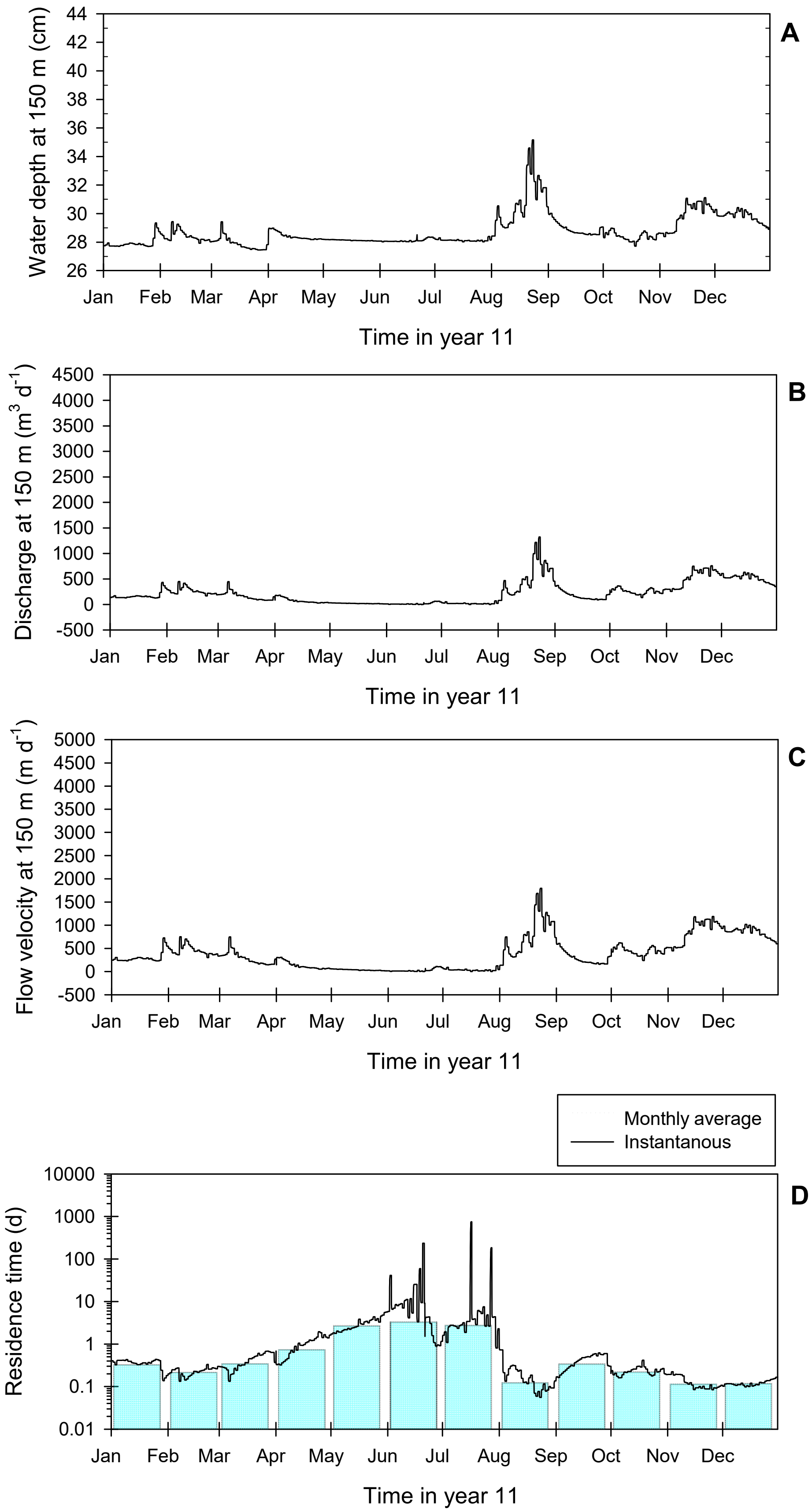


***Figure A5.4*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 11. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 11. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 11. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 11 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 11.*

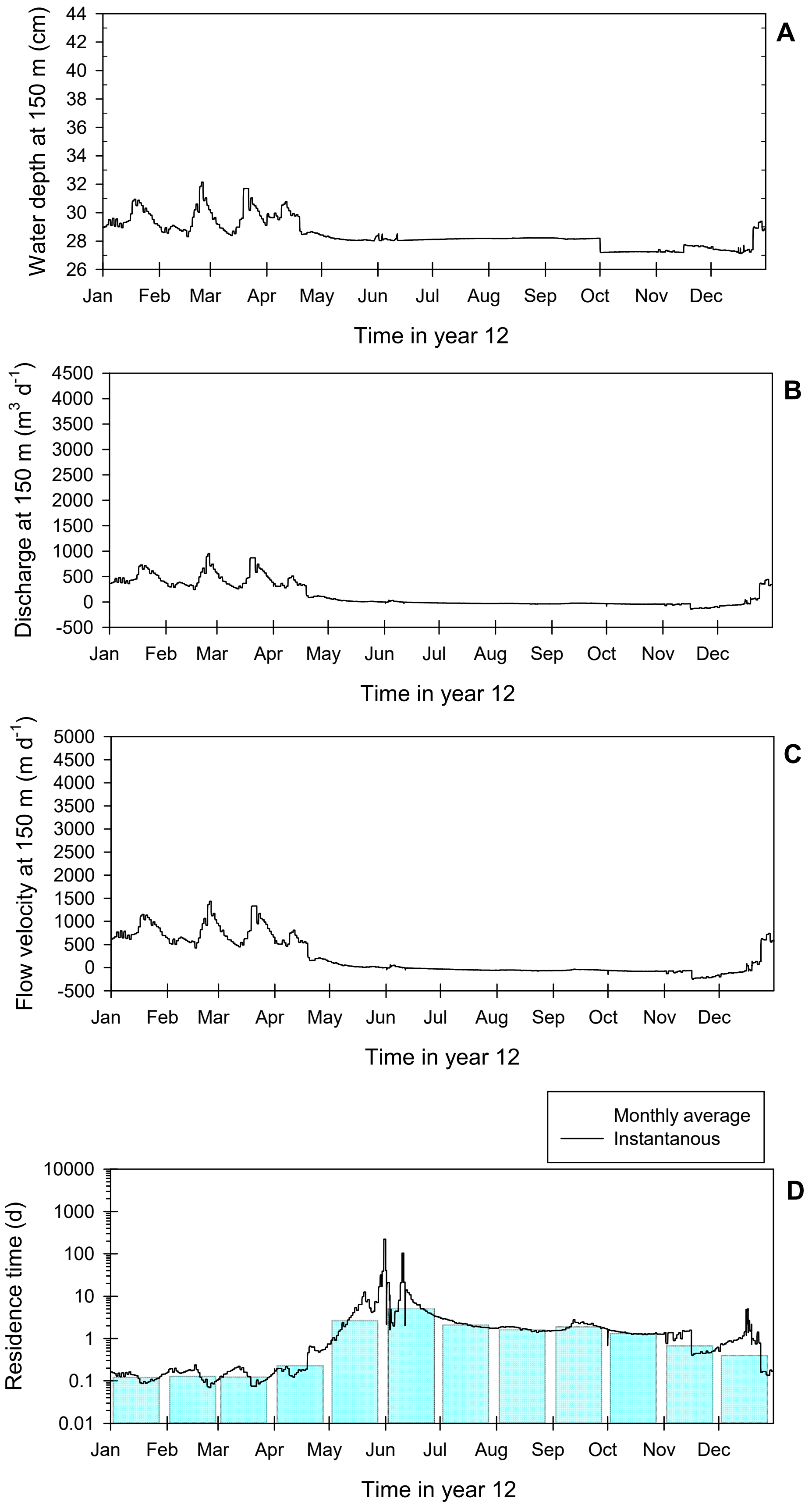


***Figure A5.5*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 12. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 12. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 12. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 12 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 12.*

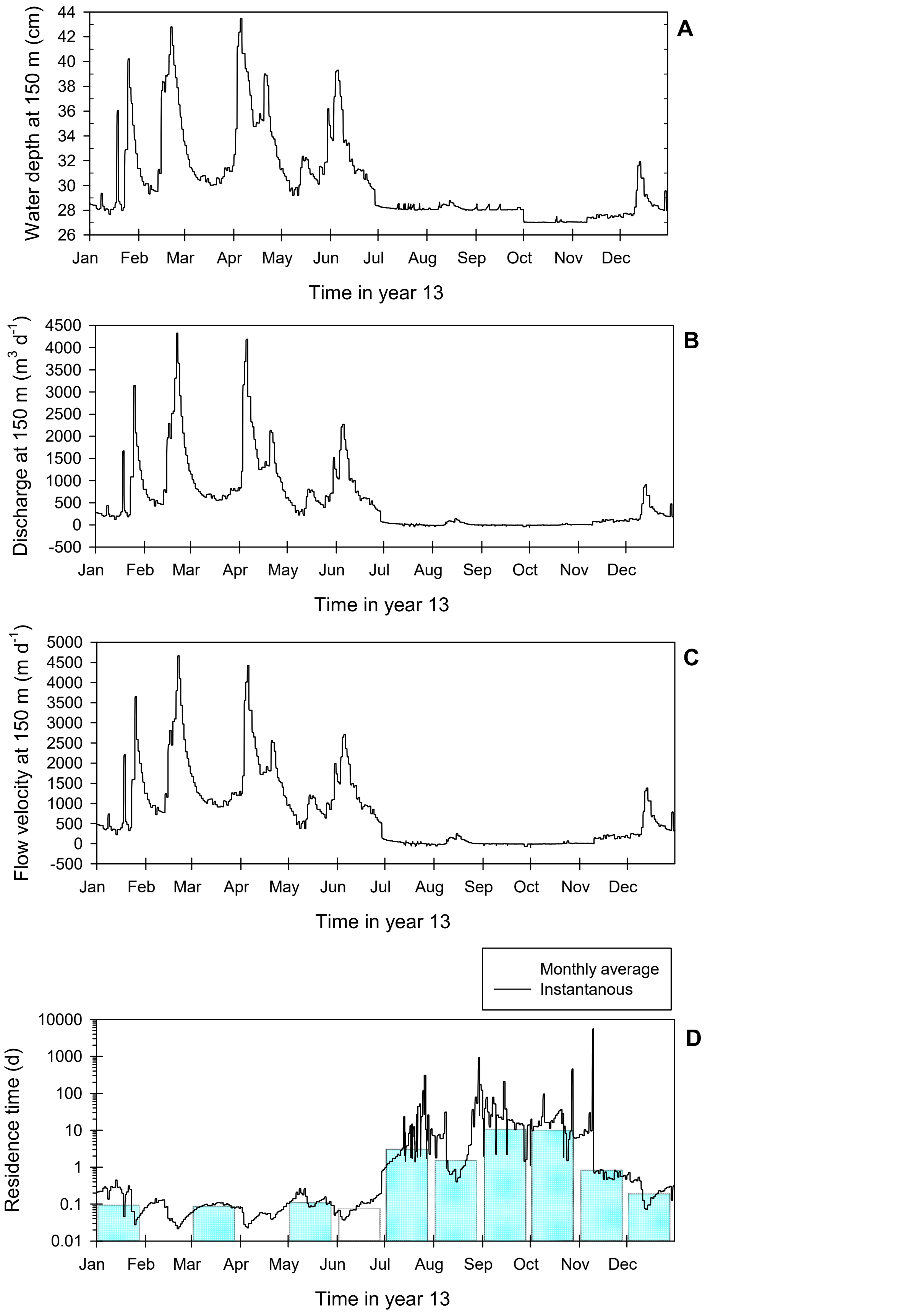


***Figure A5.6*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 13. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 13. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 13. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 13 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 13.*

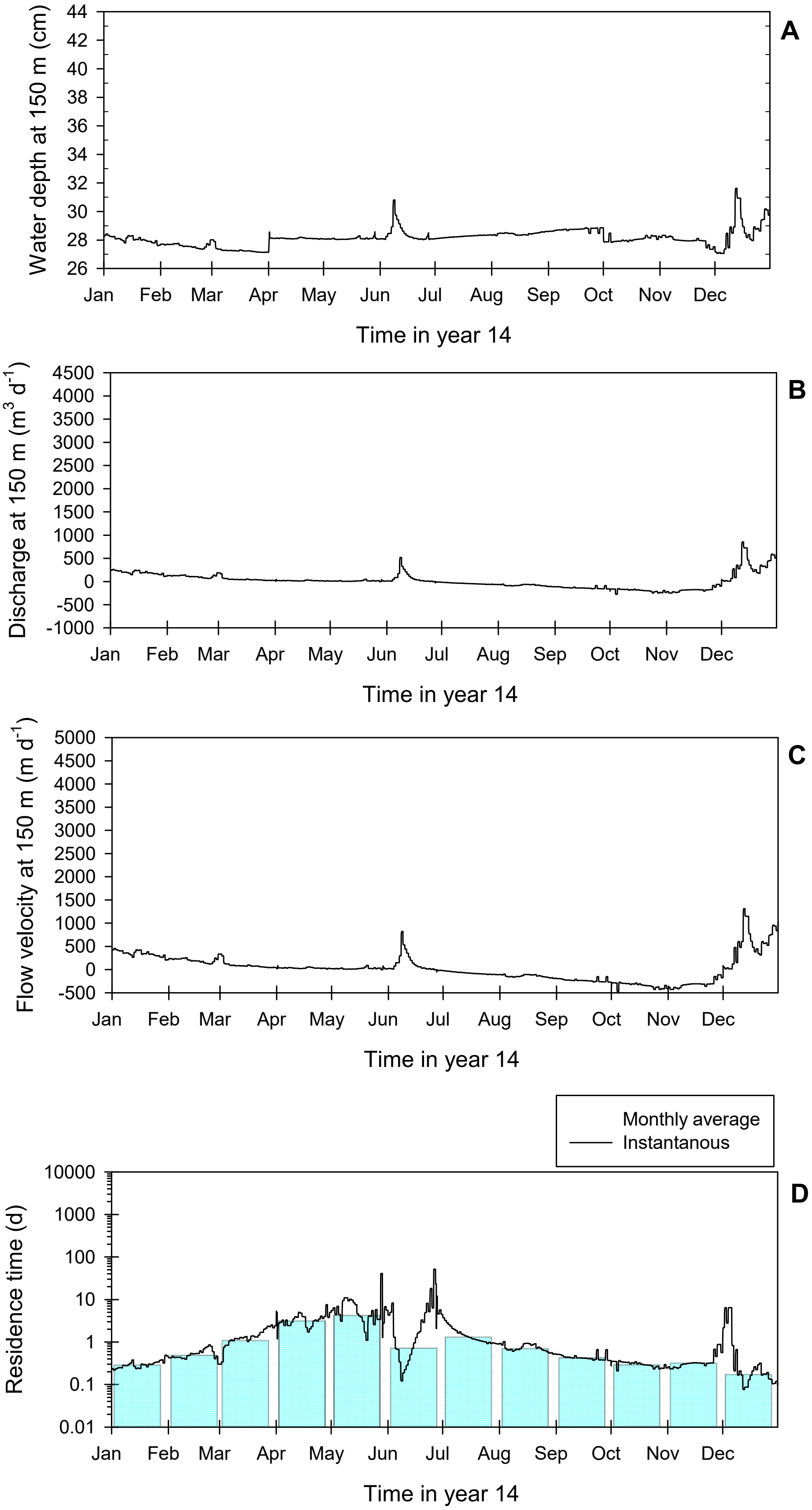


***Figure A5.7*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 14. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 14. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 14. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 14 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 14.*

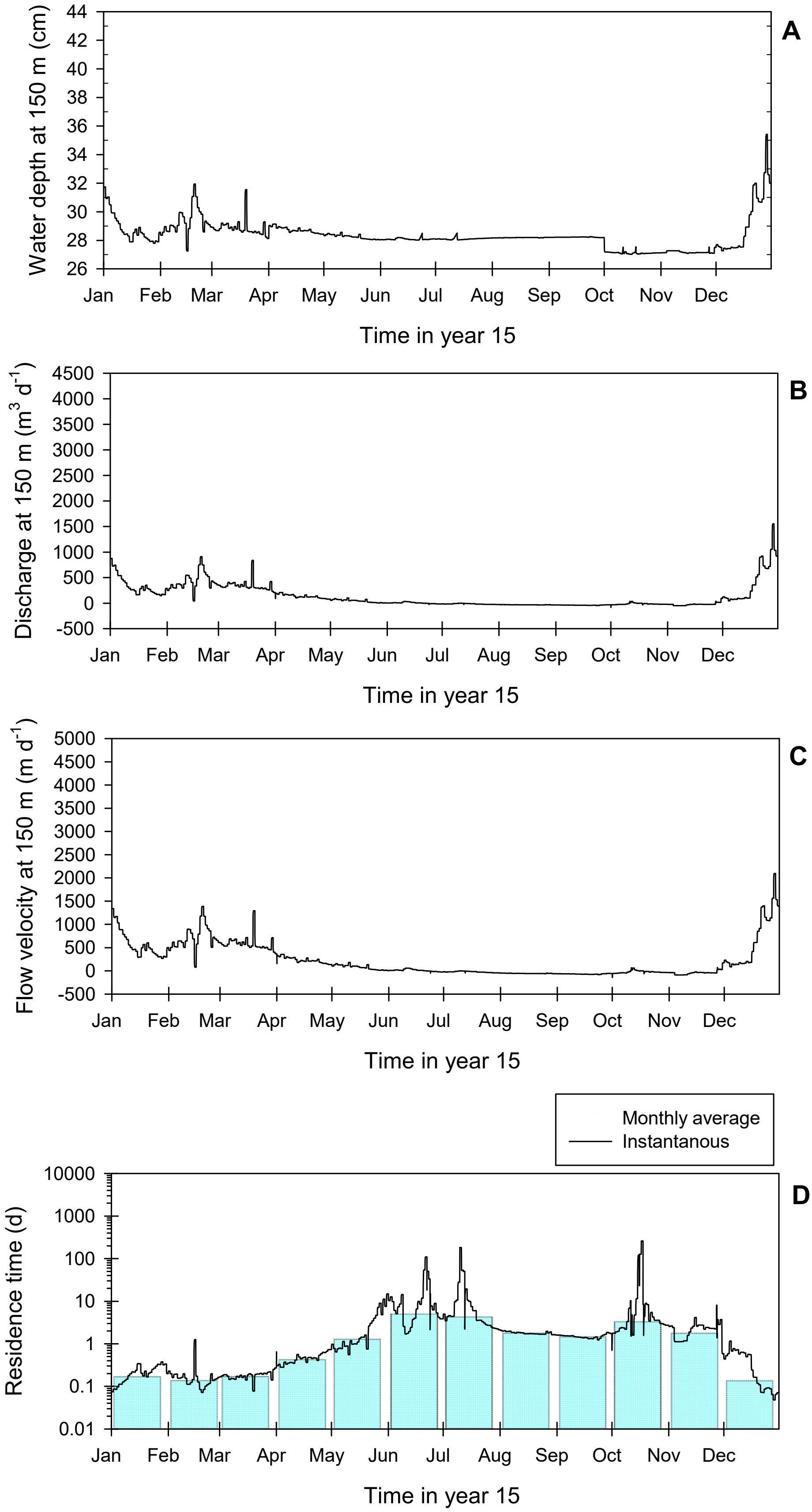


***Figure A5.8*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 15. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 15. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 15. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 15 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 15.*

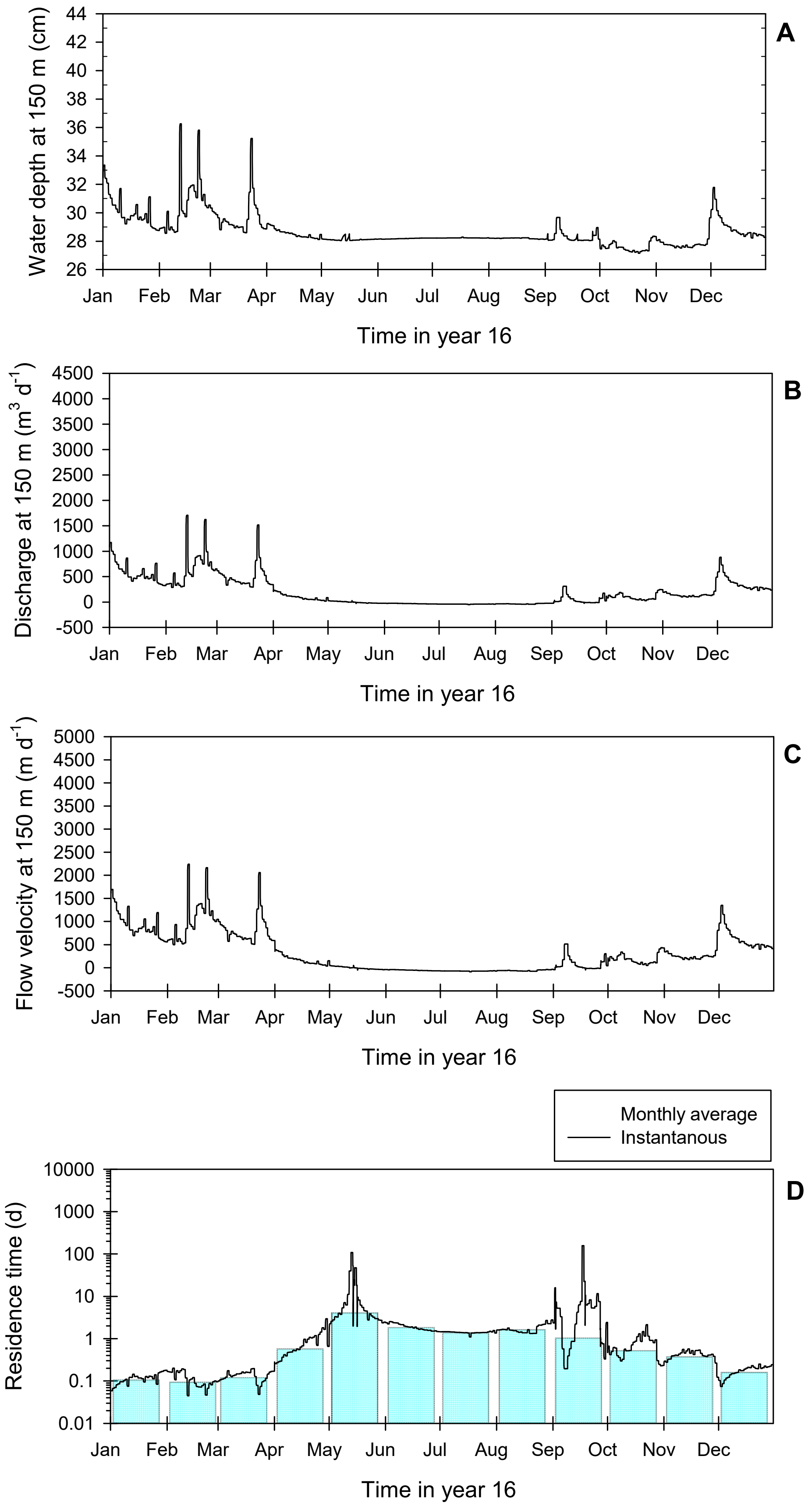


***Figure A5.9*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 16. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 16. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 16. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 16 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 16.*

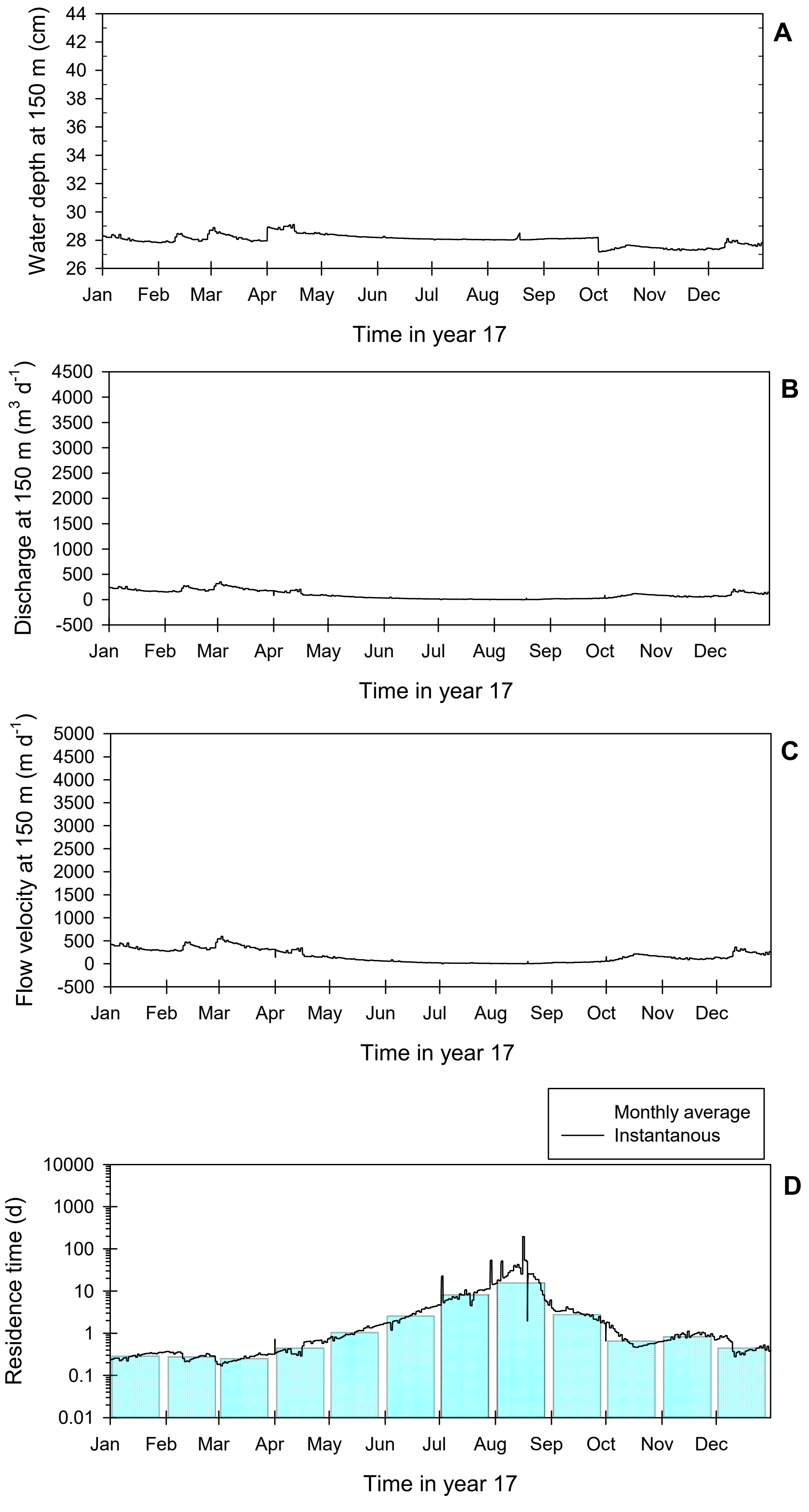


***Figure A5.10*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 17. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 17. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 17. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 17 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 17.*

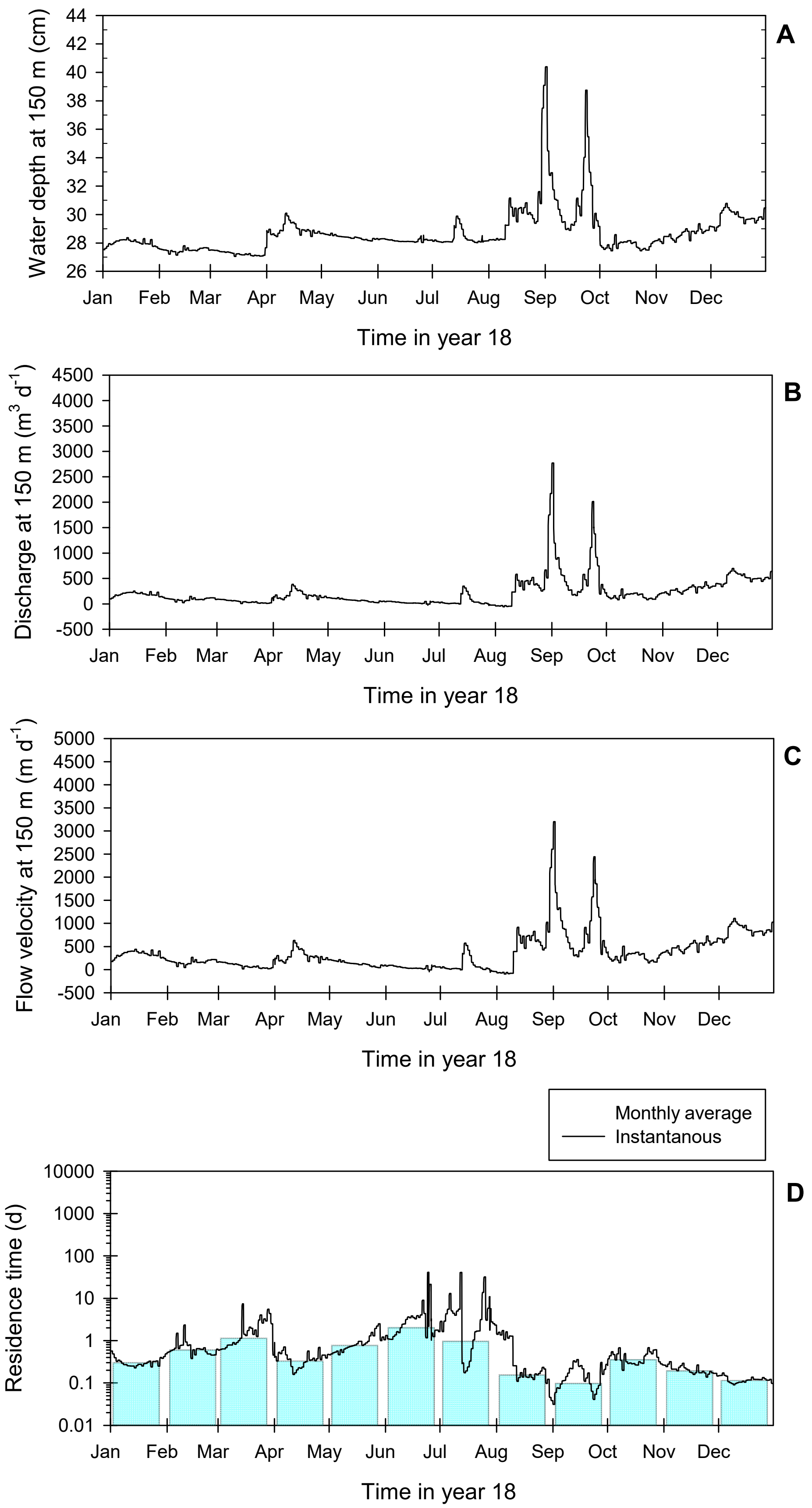


***Figure A5.11*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 18. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 18. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 18. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 18 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 18.*

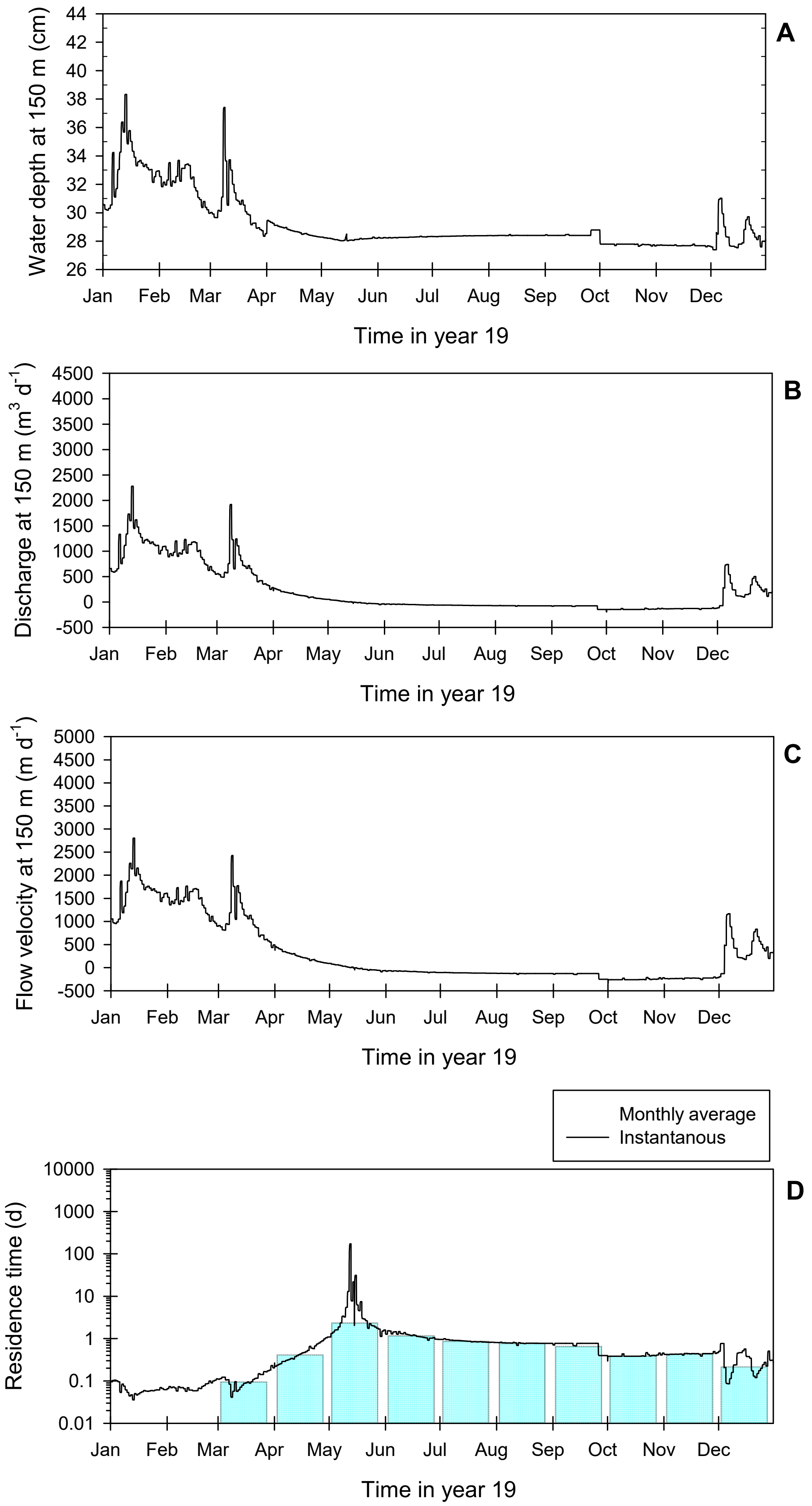


***Figure A5.12*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 19. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 19. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 19. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 19 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 19.*

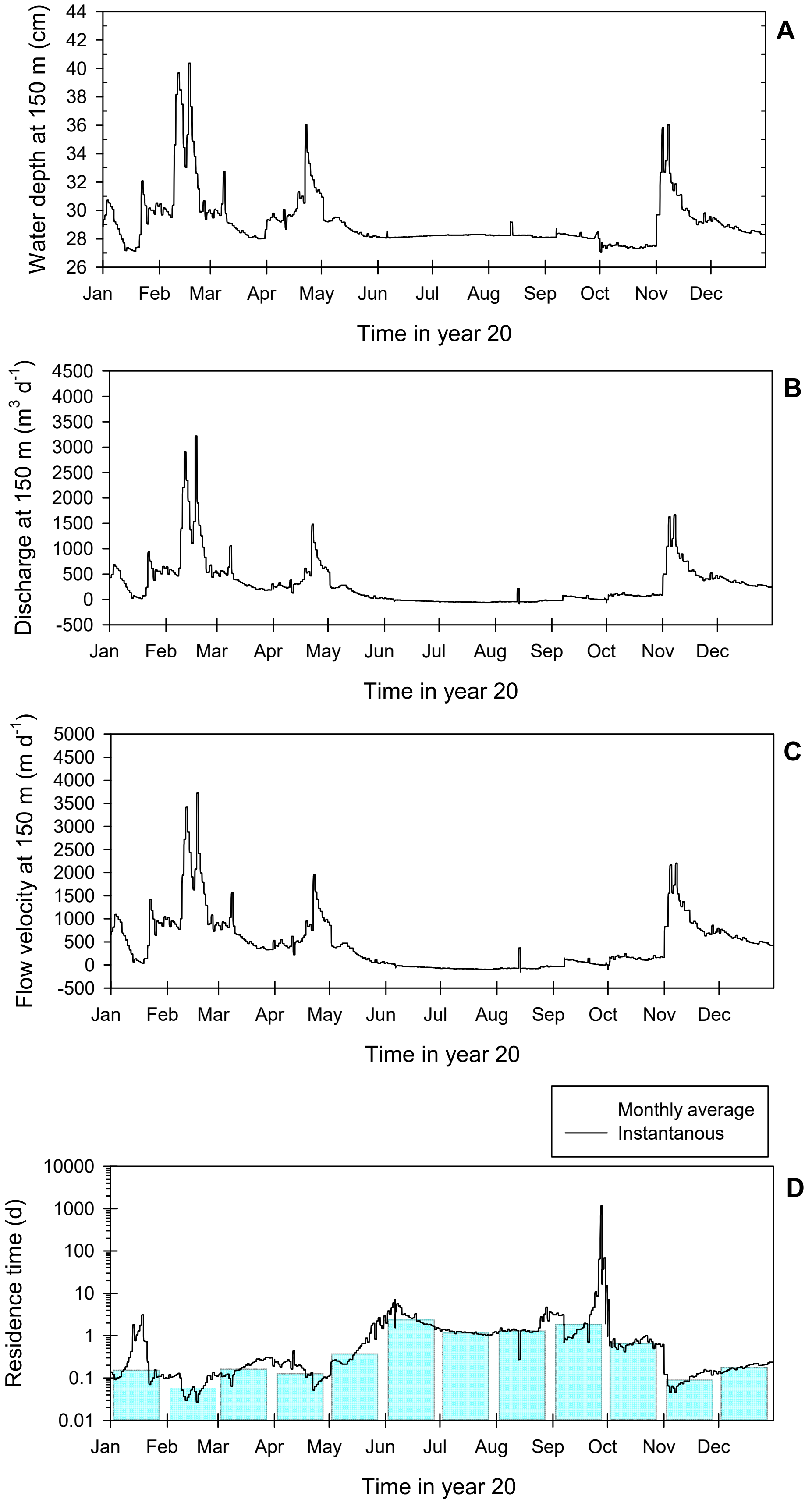


***Figure A5.13*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 20. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 20. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 20. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 20 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 20.*

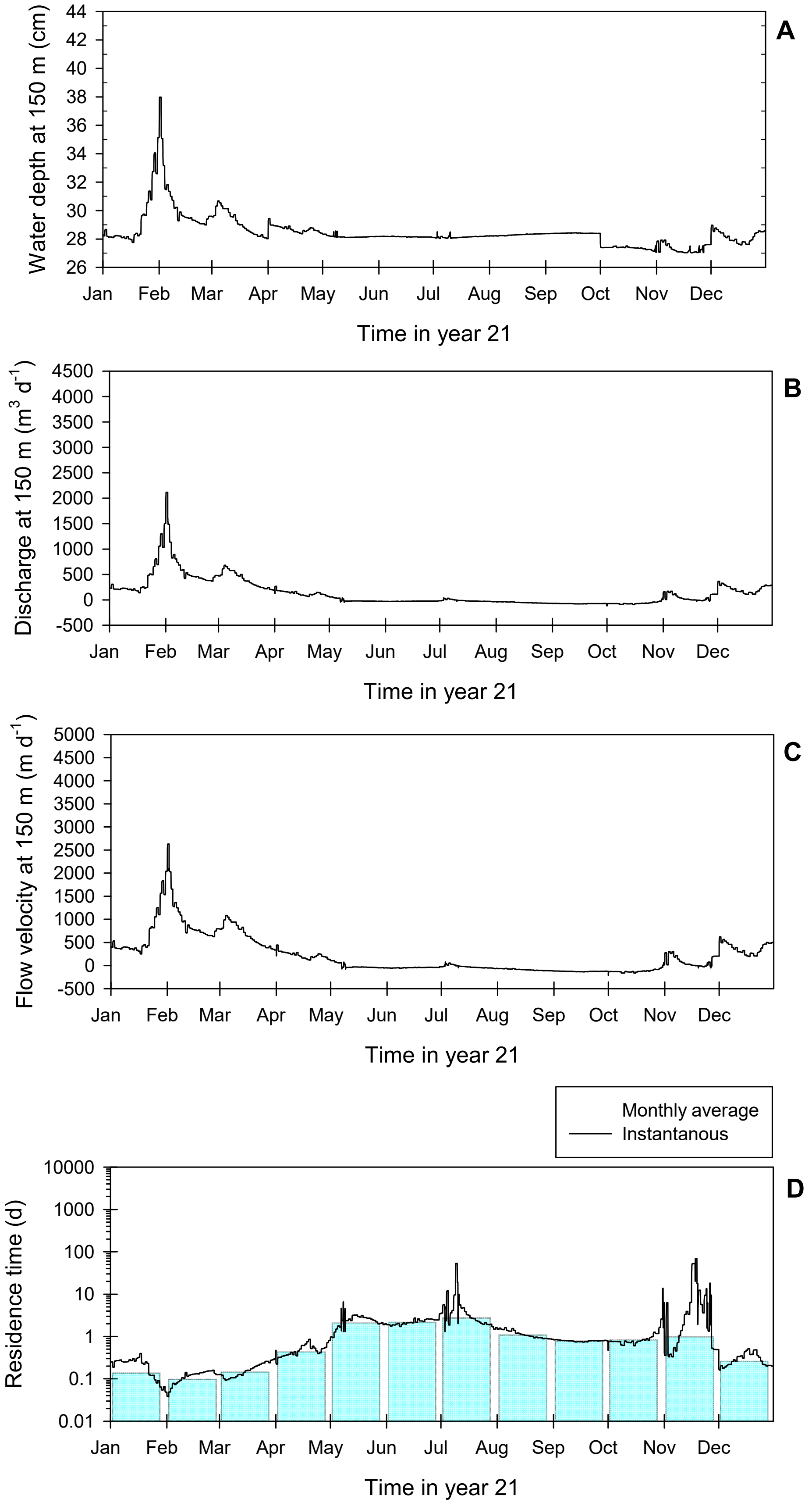


***Figure A5.14*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 21. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 21. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 21. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 21 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 21.*

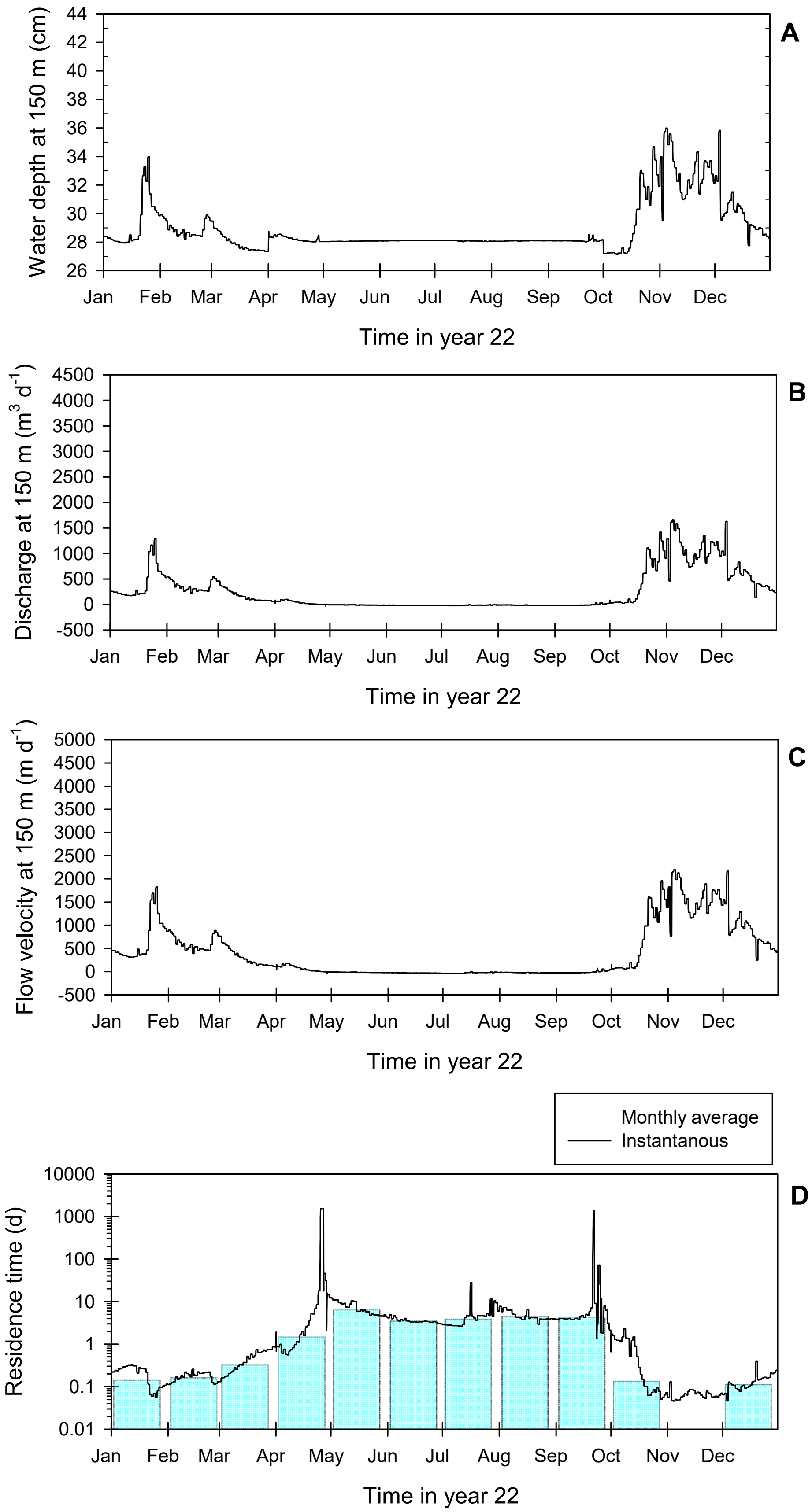


***Figure A5.15*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 22. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 22. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 22. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 22 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 22.*

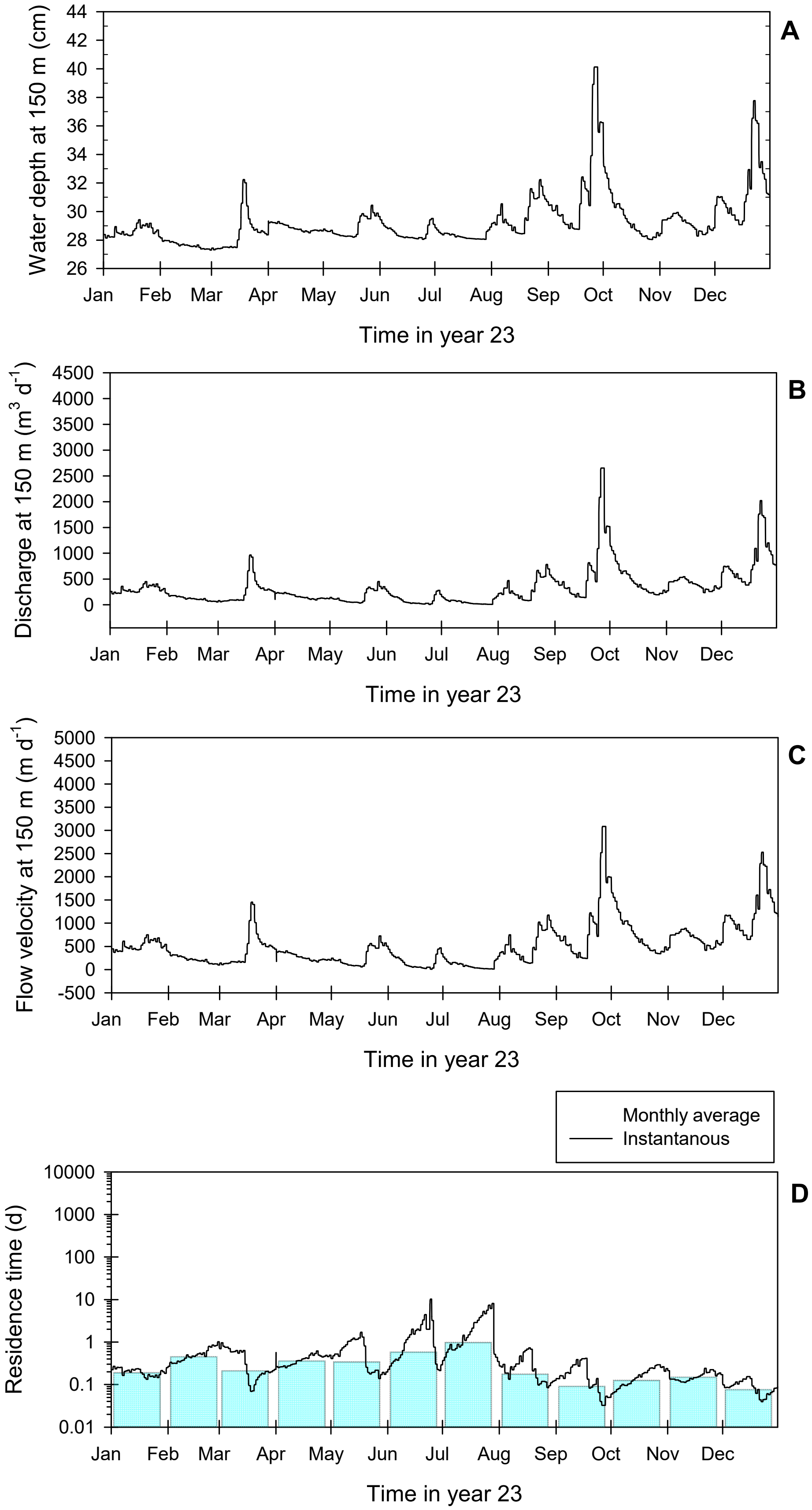


***Figure A5.16*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 23. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 23. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 23. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 23 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 23.*

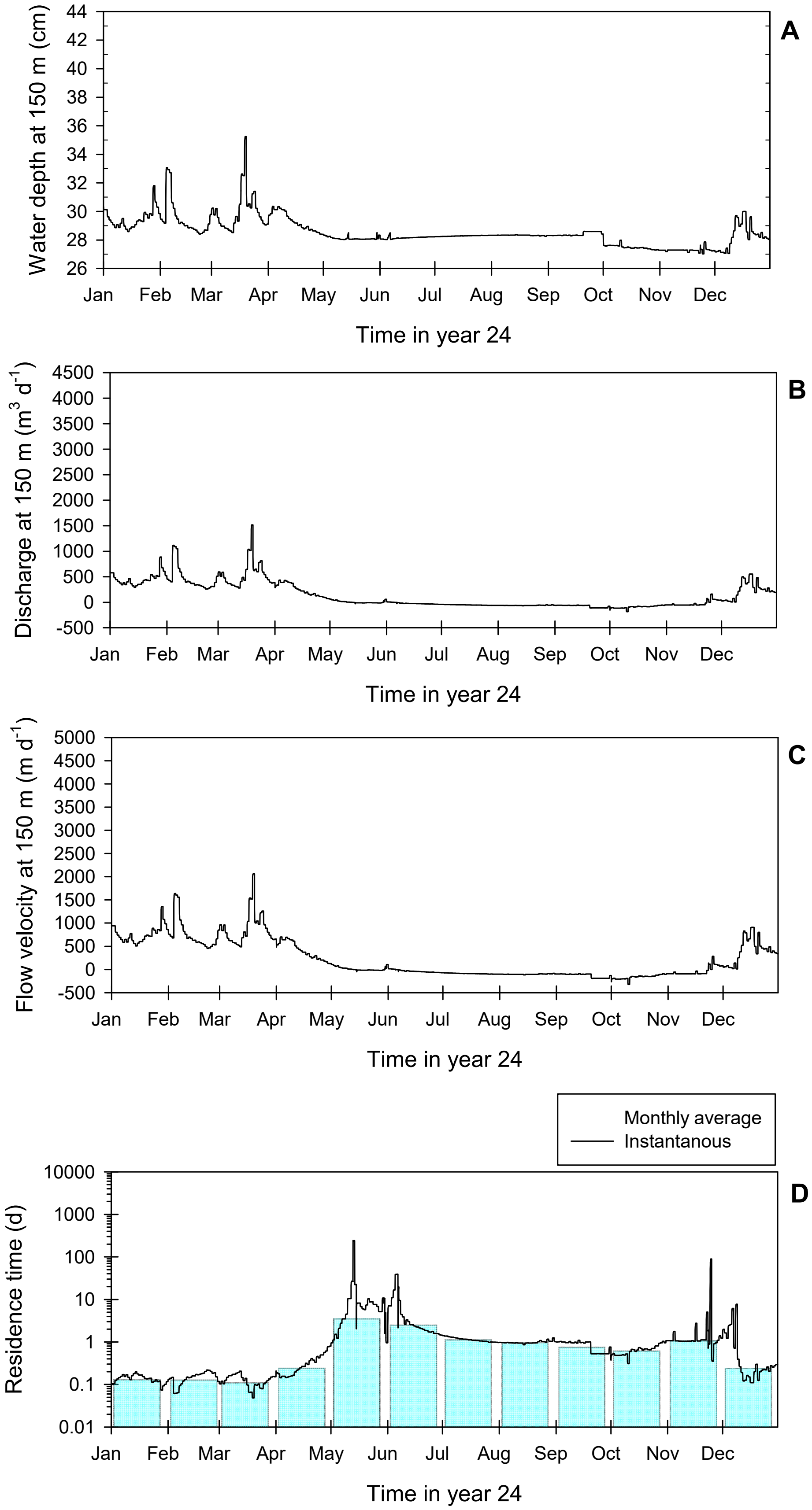


***Figure A5.17*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 24. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 24. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 24. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 24 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 24.*

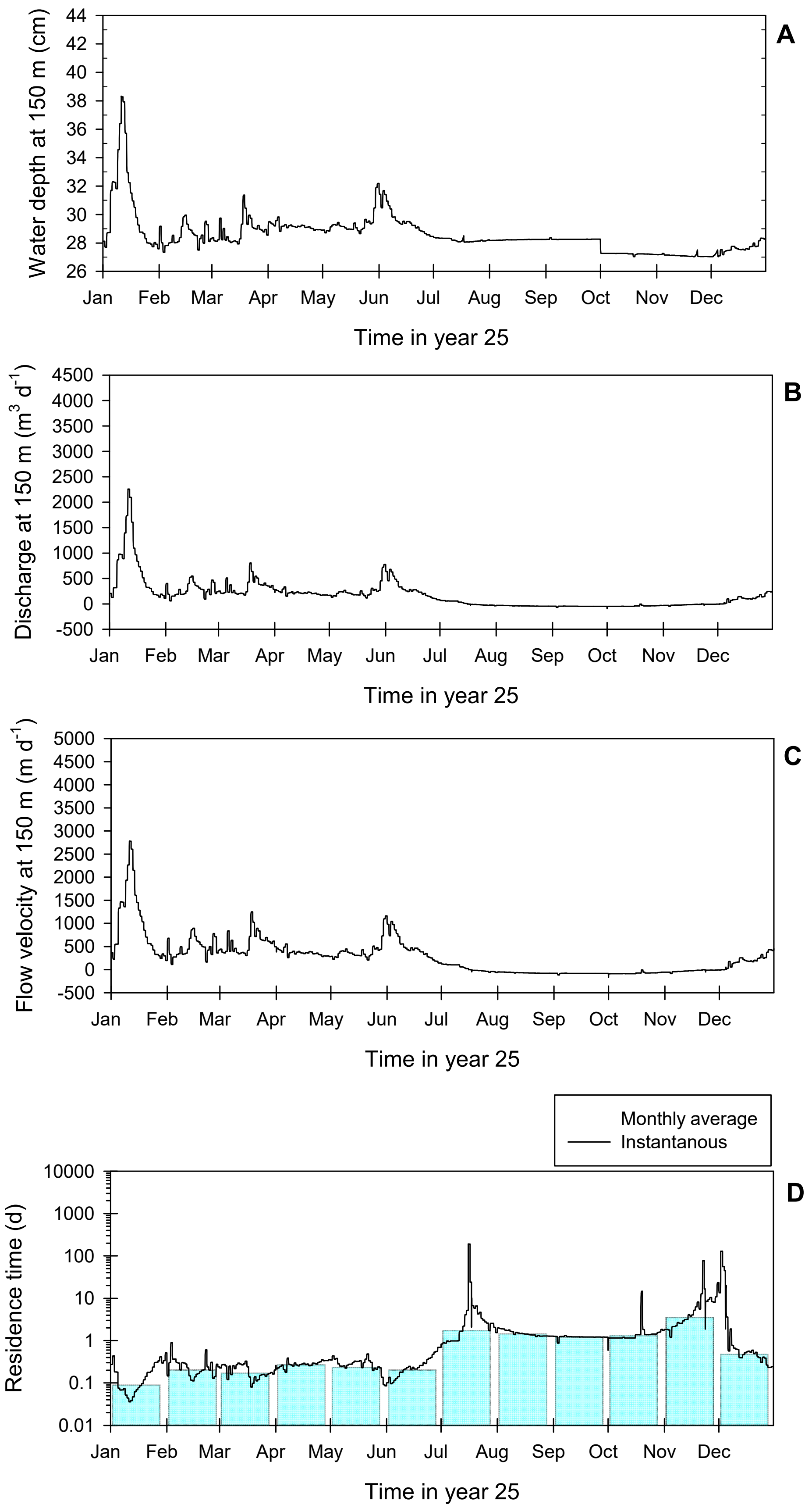


***Figure A5.18*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 25. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 25. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 25. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 25 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 25.*

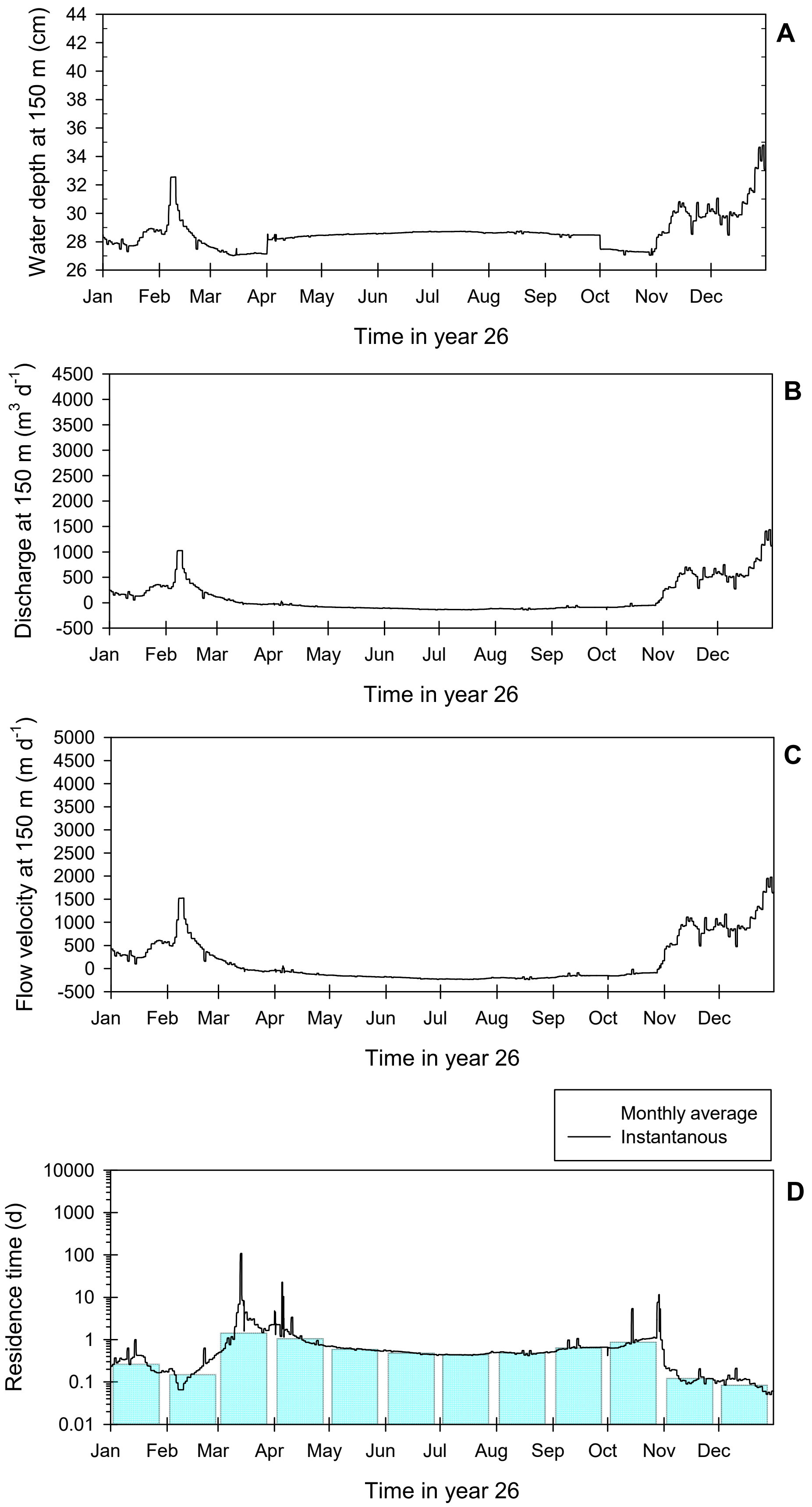


***Figure A5.19*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 26. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 26. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 26. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 26 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 26.*

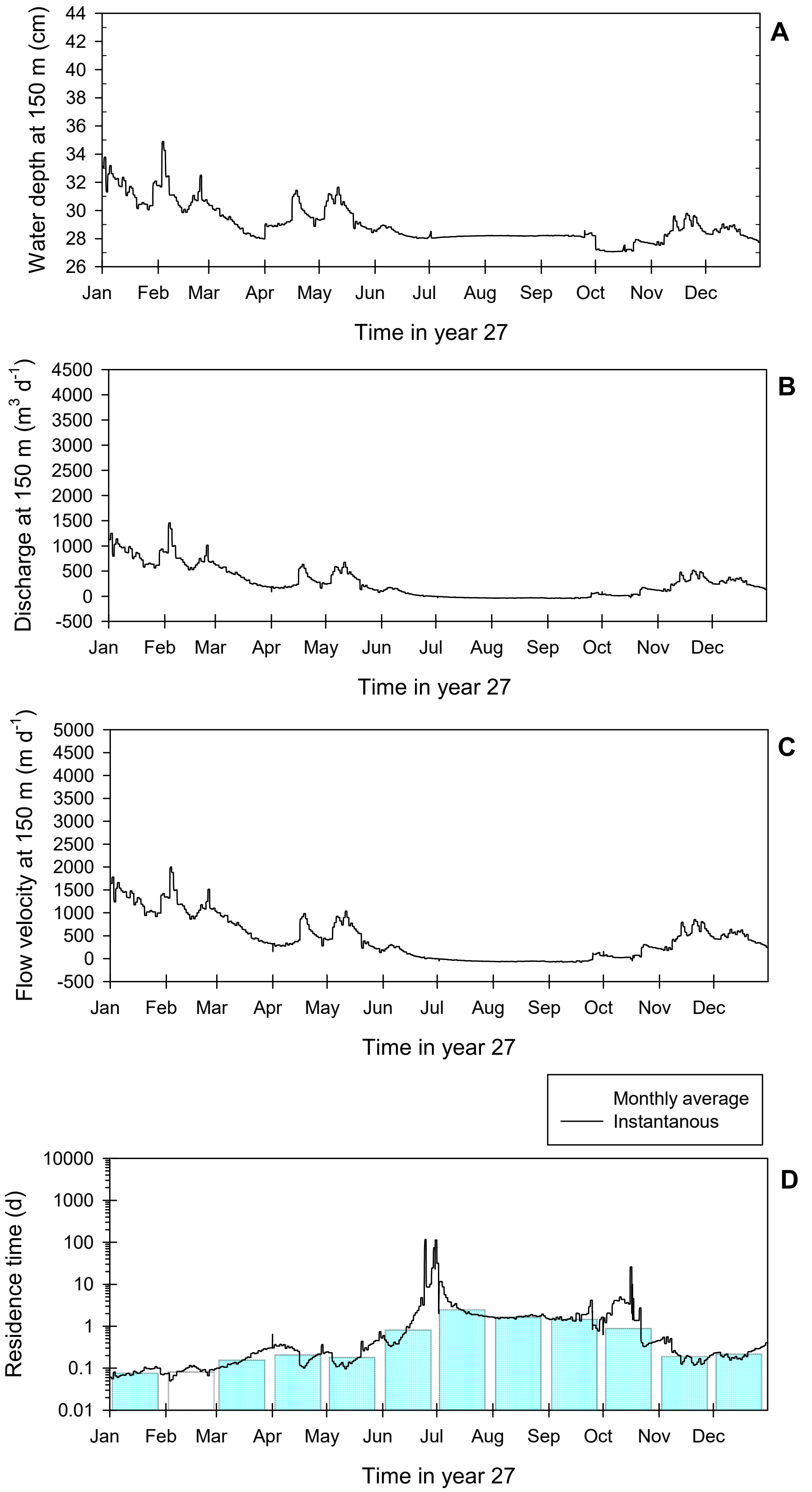


***Figure A5.20*** *(A) Hourly water depth in the centre of the 100 m evaluation ditch (x=150 m) in year 27. (B) Hourly discharge in the centre of the 100 m evaluation ditch (x=150 m) in year 27. (C) Hourly flow velocity in the centre of the 100 m evaluation ditch (x=150 m) in year 27. (D) Hourly instantaneous residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 27 (solid line) and monthly average residence time in the centre of the 100 m evaluation ditch (x=150 m) in year 27.*

***Tabel A5.1*** *Statistical parameters of the instantaneous residence time in the centre of the 100m evaluation ditch (x=150m) specified for each year in the last 20 years of the 26 year simulation period in SWQN.*

| | | Residence time per year | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year no | | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| SWQN year | | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 |
| TOXSWA year | | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| median | hr | 17 | 14 | 55 | 8 | 31 | 6 | 15 | 33 | 14 | 19 | 10 | 11 | 7 | 18.6 | 27 | 6 | 21 | 10 | 12 | 8 |
| mean | hr | 59 | 39 | 306 | 96 | 69 | 495 | 44 | 115 | 56 | 101 | 31 | 30 | 101 | 46.0 | 315 | 14 | 57 | 62 | 24 | 47 |
| 10th percentile | hr | 3.9 | 4.0 | 2.4 | 2.6 | 3.0 | 1 | 5.8 | 3.5 | 2.6 | 6 | 2.9 | 1.6 | 2.3 | 3.1 | 1.7 | 2.3 | 3.0 | 3 | 2.6 | 2.2 |
| 90th percentile | hr | 93 | 64 | 356 | 95 | 105 | 502 | 108 | 166 | 77 | 248 | 68 | 31 | 65 | 70.6 | 156 | 28 | 80 | 70 | 29 | 65 |
| 99th percentile | hr | 494 | 540 | 7316 | 992 | 768 | 4969 | 267 | 2675 | 952 | 1224 | 442 | 295 | 892 | 1160.1 | 1726 | 147 | 643 | 1341 | 184 | 755 |
| min | min | 91 | 85 | 38 | 80 | 100 | 31 | 108 | 69 | 64 | 242 | 45 | 51 | 39 | 54.7 | 66 | 47 | 70 | 52 | 73 | 72 |
| max | d | 213 | 78 | 1059 | 752 | 220 | 5659 | 52 | 260 | 157 | 195 | 41 | 172 | 1186 | 69 | 1555 | 10 | 242 | 191 | 108 | 117 |

***Tabel A5.2*** *Monthly average residence times in the centre of the 100m evaluation ditch (x=150m) specified for each year in the last 20 years of the 26 year simulation period in SWQN.*

| | | Monthly average residence time per year (hour) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year no | | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| SWQN year | | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 |
| TOXSWA year | | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| January | hr | 4.0 | 6.1 | 1.9 | 7.9 | 2.9 | 2.3 | 7.0 | 4.1 | 2.6 | 7.0 | 7.3 | 1.4 | 3.7 | 3.4 | 3.4 | 4.6 | 3.1 | 2.2 | 6.4 | 1.9 |
| February | hr | 6.7 | 22.6 | 2.0 | 5.2 | 3.1 | 1.1 | 11.9 | 3.3 | 2.3 | 6.7 | 14.7 | 1.7 | 1.4 | 2.4 | 3.9 | 11.0 | 3.1 | 5.0 | 3.6 | 2.0 |
| March | hr | 4.1 | 8.2 | 3.6 | 8.3 | 3.0 | 2.1 | 26.2 | 4.1 | 2.9 | 6.1 | 27.6 | 2.3 | 3.9 | 3.6 | 7.9 | 5.1 | 2.7 | 4.1 | 34.8 | 3.8 |
| April | hr | 18.9 | 28.9 | 6.5 | 17.8 | 5.6 | 1.1 | 75.5 | 10.3 | 13.8 | 10.9 | 8.0 | 10.0 | 3.1 | 10.7 | 35.4 | 8.7 | 5.9 | 6.6 | 25.7 | 5.1 |
| May | hr | 99.5 | 14.9 | 5.4 | 65.5 | 64.7 | 2.7 | 102.9 | 31.1 | 98.6 | 25.2 | 18.7 | 56.4 | 9.1 | 50.7 | 156.6 | 8.3 | 85.1 | 5.7 | 14.4 | 4.4 |
| June | hr | 76.4 | 12.0 | 108.4 | 79.5 | 124.9 | 1.9 | 17.5 | 122.2 | 44.2 | 61.9 | 49.0 | 28.1 | 58.3 | 52.7 | 84.0 | 14.0 | 61.0 | 4.9 | 11.7 | 19.8 |
| July | hr | 52.5 | 12.9 | 58.8 | 66.5 | 51.3 | 74.0 | 31.4 | 103.7 | 33.7 | 197.2 | 23.3 | 20.9 | 28.3 | 67.0 | 93.6 | 23.7 | 27.1 | 42.0 | 10.8 | 59.7 |
| August | hr | 57.2 | 27.7 | 156.4 | 3.0 | 39.8 | 36.7 | 16.9 | 43.0 | 39.8 | 381.0 | 3.7 | 18.8 | 31.3 | 26.4 | 107.6 | 4.3 | 23.5 | 35.1 | 11.7 | 40.0 |
| September | hr | 45.7 | 20.6 | 147.3 | 8.2 | 46.2 | 254.0 | 10.3 | 35.7 | 24.9 | 67.4 | 2.4 | 15.9 | 45.1 | 18.9 | 104.4 | 2.2 | 18.2 | 29.1 | 15.5 | 35.6 |
| October | hr | 9.5 | 11.2 | 161.5 | 5.3 | 32.1 | 239.6 | 7.0 | 79.6 | 12.6 | 15.9 | 8.6 | 9.5 | 15.9 | 20.4 | 3.2 | 3.1 | 14.9 | 32.1 | 21.3 | 21.6 |
| November | hr | 10.0 | 5.6 | 108.7 | 2.8 | 16.3 | 20.1 | 7.7 | 43.2 | 9.0 | 20.3 | 4.7 | 10.4 | 2.2 | 23.7 | 1.5 | 3.6 | 26.0 | 86.0 | 3.0 | 4.6 |
| December | hr | 4.0 | 2.8 | 9.9 | 2.9 | 9.8 | 4.6 | 4.2 | 3.3 | 3.9 | 10.9 | 2.8 | 5.2 | 4.3 | 6.3 | 2.7 | 1.8 | 5.8 | 11.5 | 2.1 | 5.3 |

# Annex 6 Relation between the year numbers used in this report and the years used for the SWQN and TOXSWA simulations

| Year number | Years as used in the SWQN simulation | Years as used in the TOXSWA simulation |
|---|---|---|
| 1 | 2020 | NA |
| 2 | 2021 | 1985 |
| 3 | 2022 | 1986 |
| 4 | 2023 | 1987 |
| 5 | 2024 | 1988 |
| 6 | 2025 | 1989 |
| 7 | 2026 | 1990 |
| 8 | 2027 | 1991 |
| 9 | 2028 | 1992 |
| 10 | 2029 | 1993 |
| 11 | 2030 | 1994 |
| 12 | 2031 | 1995 |
| 13 | 2032 | 1996 |
| 14 | 2033 | 1997 |
| 15 | 2034 | 1998 |
| 16 | 2035 | 1999 |
| 17 | 2036 | 2000 |
| 18 | 2037 | 2001 |
| 19 | 2038 | 2002 |
| 20 | 2039 | 2003 |
| 21 | 2040 | 2004 |
| 22 | 2041 | 2005 |
| 23 | 2042 | 2006 |
| 24 | 2043 | 2007 |
| 25 | 2044 | 2008 |
| 26 | 2045 | 2009 |
| 27 | 2046 | 2010 |

# Annex 7 Meteorological data as input in the TOXSWA model

Table A7.1 shows which parameters are needed in this *.meth input file.

***Table A7.1*** *Description of the data in the TOXSWA meteo file, *.meth.*

| Description | Unit | Parameter in "meth" file |
|---|---|---|
| name of meteo station | - | MSTAT |
| year | - | YYYY |
| month | - | MM |
| day | - | DD |
| time | hours | HH |
| shortwave radiation, sum in hour | kJ/m$^2$ | RAD |
| temperature at reference level | °C | T |
| relative atmospheric humidity at reference level (relative to 1(=100%)) | - | HUM |
| cloud cover, (9=sky invisible) | octants | CLD |
| hourly mean wind speed at observation level | m/s | WIND |
| air pressure reduced to mean sea level | kPa | PA |
| hourly precipitation amount (-1 for <0.05 mm) | mm | RAIN |
| evapotranspiration reference (ETref = -99.9 is a dummy value) | mm | ETref |

For use in TOXSWA several parameters in the KNMI meteo files were converted. The conversions required are specified below.

The shortwave radiation (in kJ m$^{-2}$) needed for TOXSWA is derived from the global radiation (in J/cm2) during the hourly division given in the KNMI file by multiplying its values by 10.

At Herwijnen, atmospheric temperature (T) and relative humidity (HUM) are measured at a height of 1.50 m (note that in TOXSWA this is the reference level $z_r$ to be entered in the *.txw file; see Section 3.2.1 in Beltman et al., 2017). Atmospheric temperature is given in 0.1°C in the KNMI file and converted to °C by dividing its values by10. The humidity data is given in percent in the KNMI file and for use in the TOXSWA *.meth converted to a fraction by dividing its values by 100.

The covering of the sky by clouds is determined and is recorded in octants. The values given are the hourly observations in a natural day. 0, 1 and 2 represent blue sky, 3, 4 and 5 partly cloudy, 6, 7 and 8 cloudy and 9 sky invisible. The octant number is translated in the meteo file to values ranging from zero (octant value is 0) with steps of 0.125 to 1 (octant value is 9).

The wind speed (WIND) was measured at a height of 10 m (note that in TOXSWA this is the observation level $z_{obs}$ to be entered in the *.txw file; see Section 3.2.1 of Beltman et al., 2017). Wind speed is given in 0.1m.s$^{-1}$ in the KNMI file and converted to ms$^{-1}$ by dividing its values by10.

The air pressure reduced to mean sea level, at the time of observation values in the KNMI file are given in 0.1 hPa and are for use in TOXSWA converted to kPa by dividing its value by 100.

Rain is given in 0.1mm in the KNMI file and converted to mm by dividing its values by 10.
The so-called reference evaporation (ETref) is not used by TOXSWA at present.

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

To explore the potential of nature to improve the quality of life


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