Validation of the National Hydrologic Model (LHM) for the Fresh Water Demand in the Western Netherlands

Master thesis
Water Science and Management

H.H. van den Berg
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Hoogheemraadschap van Rijnland

Universiteit Utrecht

Pictures on front page (Clockwise, starting top left)

- Agriculture in the Haarlemmermeer polder (WUR.nl, nd)
- Drought in the Netherlands (Deltacommissaris.nl, nd)
- Spraying of peat dykes during drought to prevent oxidation (weer-online.nl, 2015)
- Greenhouses in the Westland (vvddenhaag.nl, nd)
- Loosdrechtse Plassen (vvvstichtesevecht.nl, nd)

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Preface

This thesis is the final product of the master Water Science and Management at Utrecht University, for the degree of Master of Science at the Department of Earth Sciences, Faculty of Geosciences, the Netherlands.

This study is the end product of almost 6 years of study, starting with a three year bachelor of Earth Sciences at Utrecht University, followed by the Master Water Science and Management at Utrecht University. This thesis has been performed in commission of the Hoogheemraadschap van Rijnland. The Hoogheemraadschap van Rijnland is one of the water authorities is the western Netherlands, study area of this research. During this study I have implemented a lot of knowledge that I have gained during my study, and have become really enthusiastic about the connection between theory and practise regarding water management in the Netherlands.

This study would not have been possible without the assistance of numerous people. I would like to thank Mark Kramer and all the other people of Rijnland for their support and involvement during my research. I really enjoyed my stay at the Hoogheemraadschap. I would like to thank Dr. M.R. Hendriks for his assistance at Utrecht University. Additionally, numerous people from the water authorities in the region and Deltares have spent a lot of time and effort to gather data for this research and without their contribution this research would not have been possible. Finally I would like to thank Meike Coonen and the other people of Hydrologic for their assistance. I have also had a great time at Hydrologic.

Abstract

During dry conditions in the western Netherlands external fresh water needs to be supplied for surface water level maintenance, prevention of subsidence and peat oxidation and agriculture. The last decades already some serious dry years occurred (2003 and 2011) during which the fresh water demand was under pressure. Within the Deltaprogramma Zoetwater measures will be taken to secure a sustainable and sufficient fresh water supply. To determine the fresh water demand for the western Netherlands the LHM (Landelijk Hydrologisch Model) will be used. Based on the outcome of this model possible policy measures will be taken. This thesis validates the LHM to determine to what extent the LHM is usable and reliable to determine the fresh water demand for the western Netherlands during dry conditions. The base of this study is the setup of water balances, in which the inlet and outlet of water are the most important terms. Other parameters as precipitation deficit and seepage/infiltration are used to clarify possible deviations of the model. Differences in the amount of flush water between measurements and the LHM is corrected for by comparing the net drainage. It appears that the LHM calculates an almost correct water demand for the boezem of Rijnland and Delfland, with a sinusoidal deviation in water use throughout the year and an overuse of approximately 20-40mm during the growing season. The cause for the sinusoidal deviation could be a storage term in the model. In combination with conclusions from the ground water level validation, a possible location for this storage is the unsaturated zone. Most of the overuse in water during the growing season is depicted on the outlet of water; on average the deviation in inlet is smaller than the deviation in outlet. Additionally, not all of the over demand is concentrated on dry periods; during dry periods no extreme deviations in water demand are observed. However, imposed amounts of flush water in the LHM are not always correct, leading to large deviations in the inlet, especially for individual polders. Allocated agricultural surface water seems to be calculated on the low side, although the total water use for Rijnland and Delfland does apparently not show the same order of magnitude in deviation. For other regions in the western Netherlands measurement data was not detailed enough to make hard conclusions, but results showed the same trends as for Rijnland and Delfland. Except for the Amstel, Gooi and Vecht area and other regions with high seepage/infiltration rates. It appears that the LHM does not capture these extreme seepage/infiltration rates. The conclusion is that the HLM is usable for to determine the water demand for the western Netherlands, with exception of regions with high seepage/infiltration (>0.75mm/d). Additionally, one must be careful when selection small regions or short timescales, and the LHM results must be manually corrected to correct amounts of flush water.

Index

List of abbreviations

AGV	Waterschap Amstel, Gooi en Vecht
AHGW	Average High Ground Water Level
ALGW	Average Low Ground Water Level
ARK	Amsterdam-Rijn Kanaal
CDND	Cummulative Deviation Net Drainage (See section 3.2.3.2)
DM	Distribution Model
DPZW	Deltaprogramma Zoetwater
GHIJ	Gekanaliseerde Hollandse IJssel
HDSR	Hoogheemraadschap De Stichtse Rijnlanden
HHD	Hoogheemraadschap van Delfand
HHR	Hoogheemraadschap van Rijnland
HHSK	Hoogheemraadschap van Schieland en de Krimpenerwaard
HLM	Haarlemmermeer Polder
KWA	Kleinschalige Water Aanvoer
LHM	Landelijk Hydrologisch Model
LSW	Local Surface Water
NAP	Normaal Amsterdams Peil, sea level
ND	Net Drainage (See section 3.2.3.2)
NHI	Nationaal Hydrologisch Instrumentarium
NZK	Noordzee Kanaal
WHD	Waterschap Hollandse Delta

1 Introduction

1.1 Background and problem description

From January 2012 onwards the Dutch Delta Law Water Safety and Fresh Water Supply (Deltawet Waterveiligheid en Zoetwatervoorziening) has been implemented. With this law the Delta program, with as goal to obtain a safe and sustainable water system in the Netherlands by the year 2050, started. As part of the Delta program, the subprogram Fresh Water (Deelprogramma Zoetwater) (DPZW) is introduced. Within this subprogram the policies to limit fresh water shortages and to make optimal use of the available fresh water supplies during dry periods are developed (Deltacommissaris.nl). Recently, some seriously dry summers have been experienced (2003 and 2011), and due to climate change it is expected that dry conditions and fresh water stress will increase the coming decades. Sufficient fresh water supply for the West Netherlands is primarily required to maintain surface water levels to maintain the strength of (peat) dikes, and to prevent peaty soils from oxidising and subsiding. Additionally, areas with (capital intensive) agriculture require fresh water. Other objectives for a sufficient water supply are nature, drinking- and industrial water use, and to maintain the biochemical quality of the surface water (Antea 2011). As part of the DPZW an overview of the main bottlenecks for the fresh water management in the West Netherlands is composed and summarized in figure 1.1. The main bottlenecks include salt water intrusion, low water levels due to low river discharge, over demand of the fresh water supply (from the IJsselmeer), and drought due to the impossibility to let fresh water flow into the system. The aim of the DPZW is to tackle these bottlenecks.

Current state of the DPZW is to aid the decision making for the period 2022-2028. To determine the DPZW policy for the period 2022-2028, first a further elaboration and prioritizing within the fresh water bottlenecks need to be formed. Additionally, the effects of potential measures to reduce the impacts on these bottlenecks will be surveyed. In the last few months a working group has been composed that will tackle this issue for the West Netherlands. This working group is a corporation between the water authorities shown in figure 1.2: Hoogheemraadschap van Schieland en de Krimpenerwaard (HHSK), Waterschap Amstel, Gooi en Vecht (AGV), Waterschap Hollandse Delta (WHD), Hoogheemraadschap van Delfland (HHD), Hoogheemraadschap De Stichtse Rijnlanden (HDSR) and Hoogheemraadschap van Rijnland (HHR).

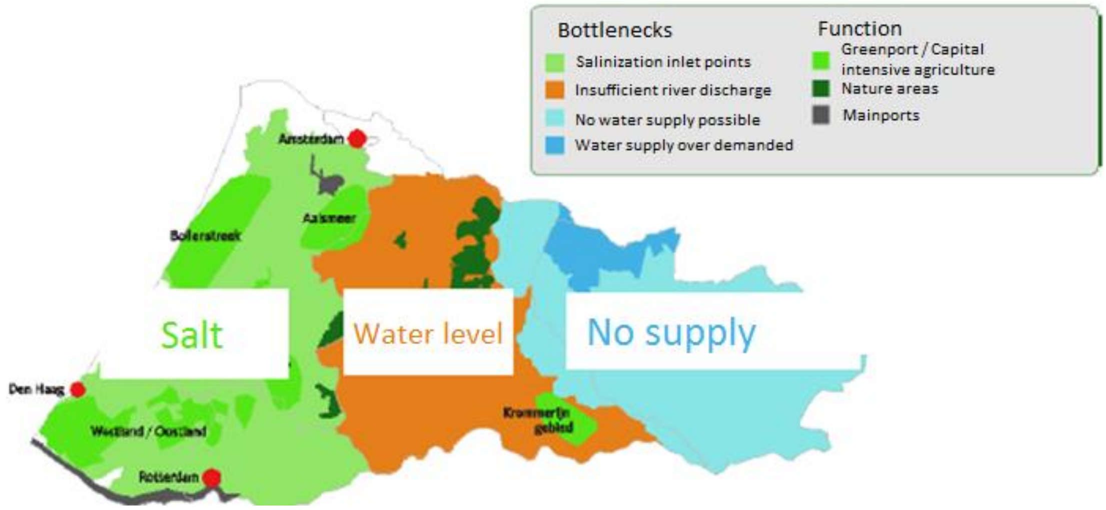


Figure 1.2. Overview of the fresh water bottlenecks in the western Netherlands (After Arcadis 2012)

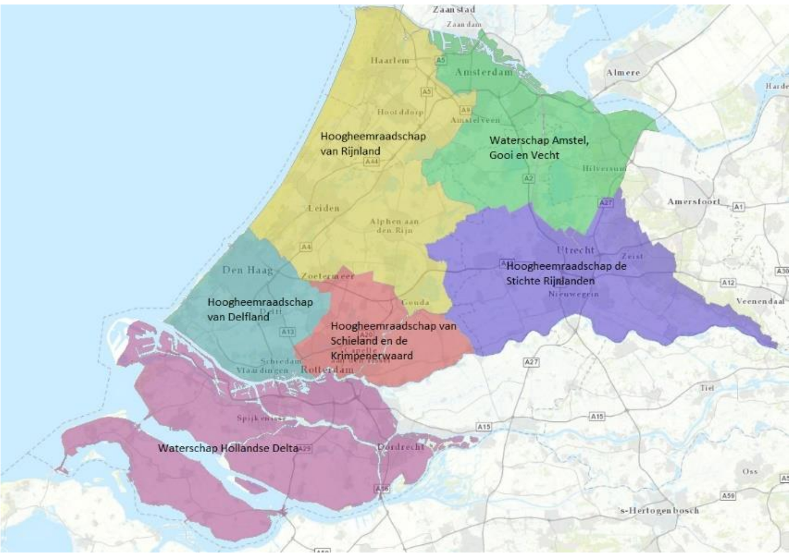


Figure 1.1. Water authorities in the western Netherlands

Use of numerical models

For water management policies, the Dutch government bases her information for a large part on the output of numerical models, of which the National Hydrologic Instrument (NHI) is its base (NHI.nu). The NHI consists of a collection of data and software for the modelling of the Dutch water system. The goal of the NHI is to offer a reliable, well-arranged and consistent database on which, for example, future water policies can be based on and tested against. With the use of this NHI database, models and schematizations can be built, both on a regional or a national scale. One of the applications of the NHI in figure 1.3 is the National Hydrologic Model (Landelijk Hydrologisch Model or LHM), developed by the research institutes Deltares and Alterra. From 2010 onwards multiple versions of the LHM have been published, of which the latest version, version 3.2.0, has been published in November 2016. The LHM is an integrated model that models the complete Dutch water system based on input scenarios. In this way the impact of climate change or the effect of policy measures can be analysed.

Also for determining policy measures within the DPZW the LHM will be used. The DPZW aims at achieving a sustainable and sufficient fresh water supply for the coming decades. To determine the required fresh water amount for the future, future climate change projections will be put into the LHM. When it turns out that the current water system is not capable of providing the calculated amount of fresh water, measures can be taken to increase the fresh water supply. This means that the LHM is at the base of the DPZW and it is therefore important to know to what extent the LHM gives reliable and usable results. For this reason, before further execution of the DPZW, a validation of the LHM results for the western part of the Netherlands will be carried out.

Focus of the validation

The main focus of this validation will be on the fresh water demand for the western Netherlands during the growing season, April to September. This validation is performed in commission of the Hoogheemraadschap van Rijnland. However, since the DPZW for Rijnland is incorporated in the DPZW for the entire western Netherlands, this validation will focus on this entire region.

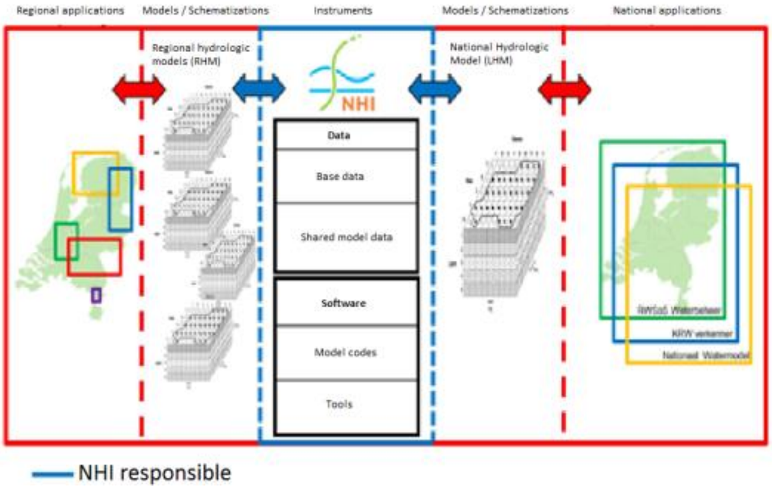


Figure 1.3. Schematization of the NHI and its applications (after NHI.nu).

1.2 Technical details of the NHI / LHM

The LHM consists of 4 different models codes which each comprise a different part of the water system.

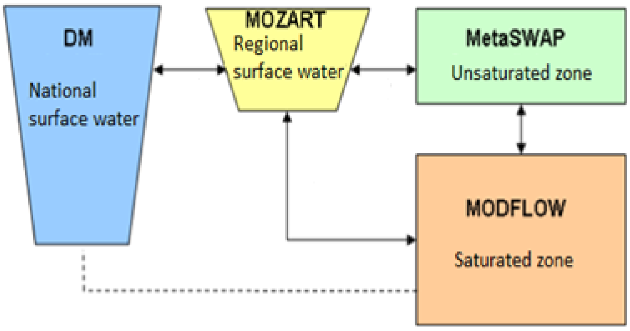


Figure 1.4. Schematic depiction of the submodels and model couplings of the NHI in which the LHM is built (after NHI.nu).

(1) The first model code is Metaswap. Metaswap models the unsaturated zone and interaction of the unsaturated zone with the atmosphere, ground water and vegetation. Precipitation, reference evaporation and other meteorological parameters are imposed on this submodel. Water uptake (root zone), transpiration and irrigation are all included within Metaswap. Spatial schematisation is 250x250m and temporal schematisation is 1 day. See Appendix A for all Metaswap output parameters;

(2) Modflow subsequently models the ground water: potential head, deep infiltration and –seepage and lateral fluxes. Modflow has a spatial schematisation of 250x250m and consists of 7 aquifers with less permeable layers in between, up to a depth of several 100m for the hydrological base. Temporal schematisation is 1 day. Subsurface parameters as surface elevation, drainage resistance and composition are all included within the Modflow part of the LHM. See appendix B for all Modflow output parameters;

(3) Regional surface water is, aggregated to Local Surface Waters (LSWs), modelled by Mozart. Local surface water can generally be seen as the polder ditches. LSWs are the smallest surface

water unit within the LHM. The 1368 LSWs for the western Netherlands are shown in figure 1.5. The LSWs tend to be smaller than individual polders, but larger than individual water level sections (HKV, 2006). As shown in figure 1.6, based on information from Metaswap and Modflow, Mozart calculates infiltration, drainage and surface water levels for each LSW. A LSW acts as a box: a surplus of water will be discharged and a shortage of water will be recharged. Discharge/recharge of surface water occurs via the district water. Districts are clusters of LSWs and the corresponding district waters do not have a physical representation but they are implemented for better calculation procedure. Spatial schematisation of Mozart is 250x250m (aggregated to LSWs), temporal schematisation is 10 days. See HKV 2006 for more elaboration of the Mozart sub model and appendix C for the Mozart output parameters;

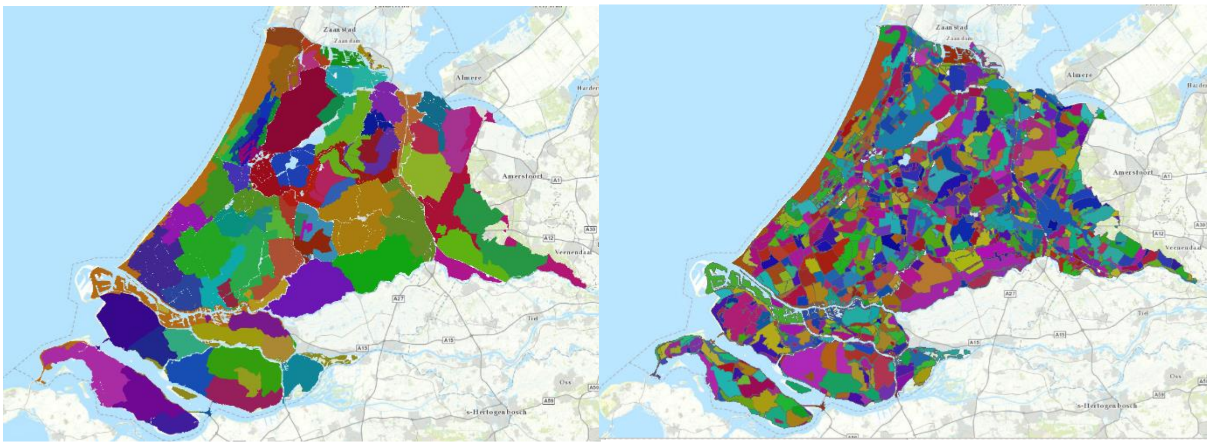


Figure 1.5. Mozart districts (left) and LSWs (right) for the western Netherlands

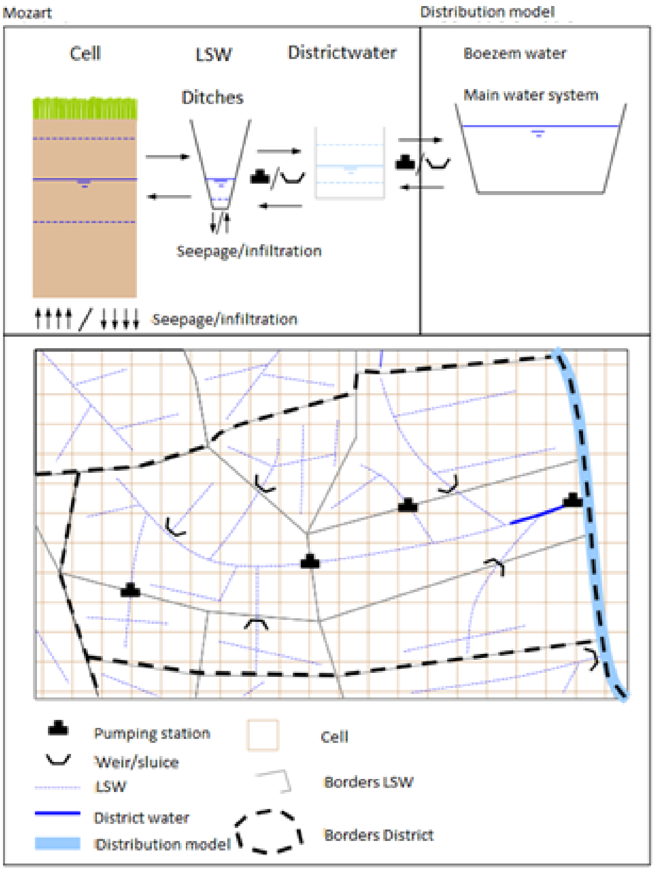


Figure 1.6. Schematisation within Mozart (After HKV 2006)

(4) National surface waters, boezem water and the main water system are represented by the Distribution Model (DM). The DM model is a Sobek like model with nodes and branches. Figure 1.7 (left) depicts the DM for the western part of the HDSR region. Each node or branch represents an engineering structure (weir, sluice, pumping station, inlet point) or a surface water channel;

At each node in the DM model extractions, water treatment plant discharges, rainfall, evaporation, seepage rates, and the Mozart discharges and -extractions are imposed; and subsequently passed on to the neighbouring nodes via the connecting branches. Figure 1.7 (right) depicts the relation of District 44 (LSWs of the Lopikerwaard) with the DM model. In the DM model, district 44 extracts all its water from node 4095 (Gekanaliseerde Hollandse IJssel) without capacity limitations. Water from District 44 is discharged on node 4095 and node 6033 (Lek) with a distribution key: for discharges below 1.5m^3/s 55% is discharged on node 4095 and 45% is discharged on node 6033, for higher discharges this is respectively 25% and 75%. Distribution keys occur throughout the DM and are based on measurements of the actual situation. The DM model has a temporal schematisation of 10 days. See NHI2008DR6 for more elaboration about the DM.

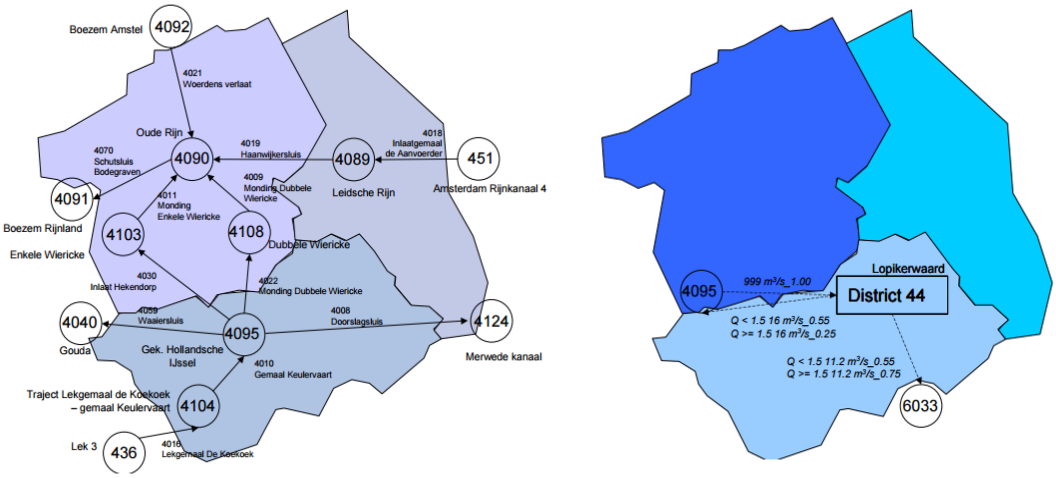


Figure 1.7. DM schematisation of the western part of HDSR (HKV 2009).

(5) The latest versions of the LHM contains chloride concentration calculations of the DM water, which are calculated with the model code Transol. This submodel will not be considered in this report.

1.3 Previous work done

For LHM version 2.0, Ogink performed a validation in 2011 (Ogink 2011). The conclusion was that the LHM results were not yet complete enough to use for the DPZW. Main findings of the validation were: (1) The imposed rainfall was based on data from only a few measurement stations and was subsequently interpolated for the areas in between these measurement stations. Comparison of this interpolated rainfall data with data from additional measurement stations showed that the LHM did not give a realistic representation of the actual rainfall distribution; (2) the calculated actual evaporation gave a rough accurate estimate of the actual evaporation, however it remained questionable to what extent the results were usable and correct; (3) surface water flows were seriously over- or underestimated for several areas. The cause for this was that not all surface water routes were correctly implemented in the model and that chloride concentration calculations were incorrect, leading to incorrect opening or closing of fresh water inlet points; (4) water discharges also showed some major deviations, although for some areas and periods the model outcomes were reasonably correct. Reasons for these discrepancies were the unmodeled surface water routes, wrong seepage rates and the incorrect precipitation and evaporation rates; and (5) the range and dynamicss in the ground water level, as response to precipitation, evaporation and seepage, were not simulated correctly. Reason for this was first due to incorrect input data, but could also be found in incorrect calculation procedures.

For version 3.0, STOWA performed a validation of the groundwater levels in 2013 (STOWA 2013). For this validation around 1200 groundwater level measurement points were selected and the corresponding AHGW (Average High Groundwater level) and ALGW (Average Low Groundwater level) were calculated, and compared with the LHM. The following validation criteria were composed for areas with controlled surface water levels (applicable for the western Netherlands).

Parameter	Validation criteria	Validation result
ALGW	Less than 30cm deviation for 80% of the measurement points	43% complies
	Median of deviation <15cm	-7 cm
AHGW	Less than 20cm deviation for 80% of the measurement points	60% complies
	Median of deviation <15cm	-7 cm
Dynamics (ALGW-AHGW)	Less than 25% deviation for 80% of the measurement points	39% complies
	Median of deviation <15cm	2 cm

Table 1.1. Previous ground water level validation results

The results of this validation in table 1.1 shows that for the 80% criteria none of the parameters sufficed. However, the median of the deviations complied to the validation criteria.

Additionally, for LHM version 3.0, Deltares performed a validation (Deltares 2013A) and an assessment of the applicability for the DPZW (Deltares 2013B). This version of the LHM performed considerably better than the 2.0 version. However still some remarks could be made: (1) The ground water levels, ALGW, AHGW and dynamicss, did still not meet the validation criteria (see table 1.1 for citeria). In some cases, the 2.0 version produced better and in other cases the 3.0 version did. Reasons for this were that the LHM results were on a scale of 250x250m while the measurements represented a much smaller area. Additionally, the precision of the measurements was not known while the validation criteria were quite strict; (2) evaporation results passed the validation, even during dry periods the LHM results were in line with the measurements (see Deltares 2013A for validation criteria). Evaporation data based on satellite measurements (ETLook) showed more variance with the LHM results and deviations showed no clear relation with parameters as land use and soil type, especially during dry summers; (3) irrigation data, for as far as it was possible to gather reliable field data, complied to the validation norms; (4) the in- and outflow of surface water was calculated with sufficient detail on both the national as the regional scale. However, the individual inlet or outlet points performed much less than in comparison to the total water basins. The overall conclusion of Deltares 2013A was that this version of the LHM is detailed enough to perform general calculations for the DPZW. However, recommendation is to perform more detailed validations for specific regions, to determine to what exact extent the LHM is applicable. Validation based on water balances turned out to be an effective way to integrally test the LHM and should be expanded.

1.4 Aim and research questions

The aim of this study is to make a validation of the most recent LHM version to determine whether this model accurately reproduces the fresh water demand for the western Netherlands. The period over which the LHM will be validated is 1996-2015 since for this period LHM results are available. The validation will comprise two main research questions. The first one will be: "To what extent are the results of the LHM, concerning the fresh water demand in the western part of the Netherlands during 1996-2015, in line with the measured results?" It is expected that the LHM results and the field data will not be one on one comparable and that multiple discrepancies will be found. To assess the usability and reliability of the LHM, it needs to be determined to what extent these discrepancies are significant. Therefore, the second research question is: "To what extent are the found differences between the LHM results and the measured results significant for the usability of the LHM concerning the DPZW?" Significant is not strictly defined and depends both on the absolute deviation, but also the trends in measured and modelled water demand. By answering the second research question, it is expected that the conclusion is that for certain analysed areas/periods the LHM performs better than for other areas/periods, this will be integrated in the answer to the research questions.

2 Material and methods

2.1 General approach / setup

General approach for the validation is the setup of water balances. Water balances will be composed for regions by use of LHM output. The LHM water balances will be compared by measurement data. Water balances will be composed of measurement data as far as possible, of which the discharges of pumping stations and the inlet through inlet points are the most important parameters. Other relevant terms in the water balance are precipitation/evaporation and seepage/infiltration rates.

Additionally, ground water levels will be analysed by validation of AHGW and ALGW levels. These values will give a general first impression of the ground water level reconstruction by the LHM. Additionally, time series of individual measurement locations will be analysed. The reason ground water levels are included in the validation is to check whether there are large scale deviations in the ground water level reproduction that could influence the water demand.

The focus of the validation will be on the growing season (April to September). The growing season is the period over which there generally is a net water demand for the western Netherlands. Outside the growing season conditions are sufficiently wet and the fresh water demand is irrelevant.

During the validation and discussion, also the conclusions of previous validations, already generally discussed in the introduction, will be taken into consideration. This will be done to determine whether this version of the LHM (3.2.0) performs better than the previous versions.

2.2 Data collection and analysis

2.2.1 Collection of data

Collection and analysis of LHM data

Data will consist of two major types of data of which the first one is the LHM output. LHM output is provided by Deltares. Analysis of the surface water output is possible using water balance tools. These tools construct water balances based on the Mozart/DM output for selected regions and periods. Ground water level and other Modflow and Metaswap parameters are available on 250x250m resolution. Information about the LHM itself is available via NHI.nu. Analysis of the LHM schematisation is important to connect the surface water schematisation in Mozart/DM to the measurement data.

2.2.2 Collection and analysis of measurement data

The second type of data is measurement data. To gather measurement data a visit to the relevant water boards in the West-Netherlands, mentioned in the introduction, is made. Here, a general overview of the water system is asked for to better understand crucial points in the water system and to connect the physical reality with the schematisation in the LHM. Ground water time series from Dinloket (Dinoloket.nl) and meteorological data from the Dutch meteorological institute (KNMI) (KNMI.nl) are used as well. The final collection of data varies per region and will be discussed in more detail in the validation part below.

First step in the analysis of measurement data is to compose water balances for the regions for which data was available. When possible the temporal resolution is set to ten days, as this is the temporal resolution of the LHM. Additionally, the locations of the measurement data are coupled to the schematisation within the LHM. This means that the locations of water balances were coupled to the specific LSWs in Mozart, and that discharge rates of major surface waters ware coupled to the nodes and braches in the DM. For ground water level measurements, the ALGW and AGHW were calculated.

To answer the research questions, the data from the LHM output will be compared to the measurement data. Focus of this validation is the fresh water demand, and therefore the most important fluxes in the water balance are the supply of external water from inlet points during the growing season. If possible, extra attention will be given to extreme dry periods, as for example summer 2003 and spring 2011. If deviations are found between the modelled water inlet and the measured water inlet, the temporal/seasonal variations and significance of these variations will be discussed. Additionally, it will be tried to find possible explanations for these deviations by use of the other water fluxes within the water balances.

3 Results

3.1 Ground water levels

Main conclusions

Although individual deviations in ground water level can be large, no large systematic errors are found. The observed deviations showed a broad range, and not all the observed deviations can directly be attributed to errors in the LHM. Although it seemed that ground water levels were slightly too low, they performed on average quite well. Because individual deviations can be large, it is recommended that the LHM is not used for ground water level reproduction on small scales.

The dynamics, and especially the small-scale fluctuations in ground water level, appeared to be too large. This could mean that ground water levels react too strong on precipitation/evaporation events, and can be an indication that the buffering of the unsaturated zone is too small. The too small storage in the unsaturated zone could also influence the external fresh water demand during dry periods, as there is less internal storage for the after-delivery of water. The direct effect of this too small storage on the external water demand is not determined

LHM groundwater levels are validated for the period 1996-2006. Initial criteria for the selection of ground water measurements from Dinoloket (Dinoloket.nl) are that the period of measurement is within 1996-2006, with a filter depth above 10m below surface level. The statistical program Menyanthes (KWR 2008) subsequently selected the time series which had a measurement interval and period that was suitable to calculate ALGW and AHGW. This resulted into 897 values distributed across the research area. The LHM appeared not calculate ground water levels for urban areas, and measurements for these locations are not taken further into consideration, resulting into 785 usable measurement locations.

Parameter	Criteria	All 785 measurements	Refinement to filter depth of <2.5m below surface level. (464 measurments)	Filter depth >2.5m below surface level and within polder (256 measurements*)
ALGW	>80% of measurements less than 30cm deviation	49.60%	55.60%	61%
	Median of deviation < 15cm	-0.08m	-0.12m	-0.08m
AHGW	>80% of measurements less than 20cm deviation	40.50%	47.00%	54%
	Median of deviation < 15cm	0.007m	-0.03m	-0.004m
Dynamic	>80% of measurements less than 25% deviation	28.20%	32.50%	30.50%
	Median of deviation < 15cm	0.13m	0.08m	0.07m

Table 3.1.1. Initial ground water level validation results for the western Netherlands

The results in table 3.1.1 show that none of the parameters comply to the 80% norm. The ALGW performs better than the AHGW, but this is also due to the less strict validation criteria. The dynamics (ALGW-AHGW) performs even worse, but this is mainly due to the criteria that is relative: Within surface water level controlled areas ground water levels have minor fluctuations, leading to a small dynamics. A minor deviation in dynamics leads to a large relative error. December 2016 an independent ground water level validation gave roughly the same results (M. Knotters 2016).

The median of the deviations does comply to the validation norms. The median error of the dynamics is in line with the error in ALGW and AHGW, and confirms that the bad score of the 80% dynamics-norm is mainly due to the small absolute dynamics in the region.

The refinement in selection to locations with a filter depth above 2.5m below surface level performs better. Probably some of the deeper measurements are not within the phreatic ground water. For this reason, the rest of the ground water level analyses will be performed on the measurements above 2.5m below surface level.

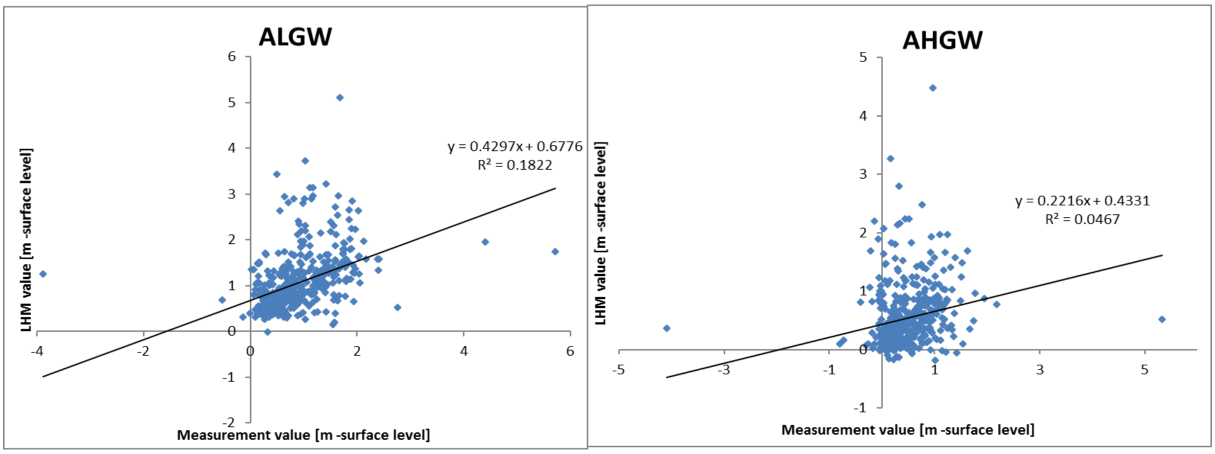


Figure 3.1.1a (left) and 3.1.1b (right). Measured and modelled ALGW and AGHW values.

Figures 3.1.1ab show that, although the spread is large, the measured and modelled ground water level values are generally in line. The trend lines show that, on average, the ALGW and AGHW are modelled too low, respectively 68cm and 47cm. When the intersection of both trend lines is set to 0,0 the gradient for the ALGW and AGHW become 0.94 and 0.63 respectively.

Both the ALGW and the AHGW are calculated too low by the LHM, where the ALGW shows the largest deviation. However, the ALGW shows a more linear relation than the AHGW. The small AHGW gradient indicates that deeper AHGW is calculated too shallow. Additionally, in figure 3.1.1b a lot of spreading is visible above the trendline between 0-1, indicating that the LHM calculates shallow AHGW too deep.

The dataset does contain measurements close to the Utrechtse Heuvelrug and the dunes and ground water levels are generally hard to reproduce for these areas. The third column of table 3.1.1 supports this hypothesis: The ALGW and AHGW perform better for polder-only areas, whereas the relative-dynamics performs worse for polder-only areas. Since the dunes and Utrechtse Heuvelrug are not in the scope of this validation, figures 3.1.2ab show a better representation of ground water levels for the validation area. The 256 polder-only measurements are a random selection and do not represent all the polder measurements.

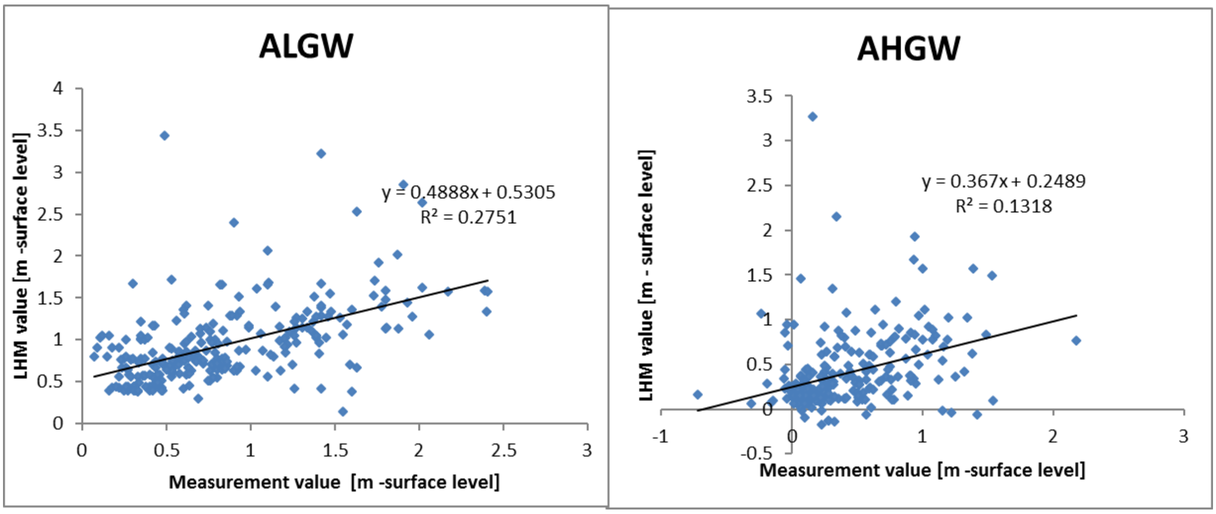


Figure 3.1.2a (left) and 3.1.2b (right). ALGW and AGHW for polder-only areas

figures 3.1.2ab show that ground water levels are modelled better for polder-only areas. Although ALGW and AHGW are, on average, still too low, 53cm and 25cm respectively. When adjusting the intersection of the trend line to 0,0 the gradient of the ALGW and AHGW become 0.95 and 0.68 respectively. This is slightly better than for the whole selection, but still indicates that deeper AHGW is calculated too shallow.

Table 3.1.2 shows that deviations in ground water level are generally the same for different selections. ALGW is calculated too low, and dynamics is too large. Only the ALGW in the Krimpenerwaard meets the validation criteria of 80%. However, the error in dynamics for the Krimpenerwaard, both absolute and relative, is very large. For deep polders, the standard deviation in ALGW and AHGW is large, while the mean error is small. For deep polders, the AHGW performs very poorly, only 8% of the measurements has a deviation less than 20cm, while the ALGW performs in line with the other selections. For selections of measurement locations with 15-30m distance to surface water, the reproduction of the ground water dynamicss shows some improvement. This can be explained by the fact that surface water levels influence ground water levels. Because surface water levels are generally kept constant, the natural dynamics of the nearby ground water levels are dampened.

Parameter		Polders Rijnland (#51)	Krimpener waard (#30)	Peatmeadow (#49)	Low lying areas (<5m –NAP) (#24)	Locations without deviation in surface level between Dinoloket and LHM (#327)	Minimum of 15m distance to surface water (#188)	Minimum of 30m to surface water (#89)
ALGW	% <30cm deviation	49%	83%	65%	60%	60%	52%	47%
	Mean error	-0.17m	-0.05m	-0.05m	-0.05m	-0.19m	-0.19m	-0.24m
	Std error	0.85m	0.29m	0.37m	1.13m	0.56m	0.78m	0.91m
AHGW	% <20cm deviation	51%	50%	55%	8%	54%	43%	42%
	Mean error	-0.05m	0.23m	0.005m	0.04m	-0.10m	-0.15m	-0.17m
	Std error	0.74m	0.25m	0.27m	1.08m	0.53m	0.79m	0.92m
Dynamic	% <25% deviation	25%	10%	27%	33%	34%	37%	39%
	Mean error	0.11m	0.28m	0.06m	0.09m	0.09m	0.04m	0.07m
	Std error	0.39m	0.31m	0.32m	0.38m	0.31m	0.32m	0.34m

Table 3.1.2, Ground water level validation for several selections.

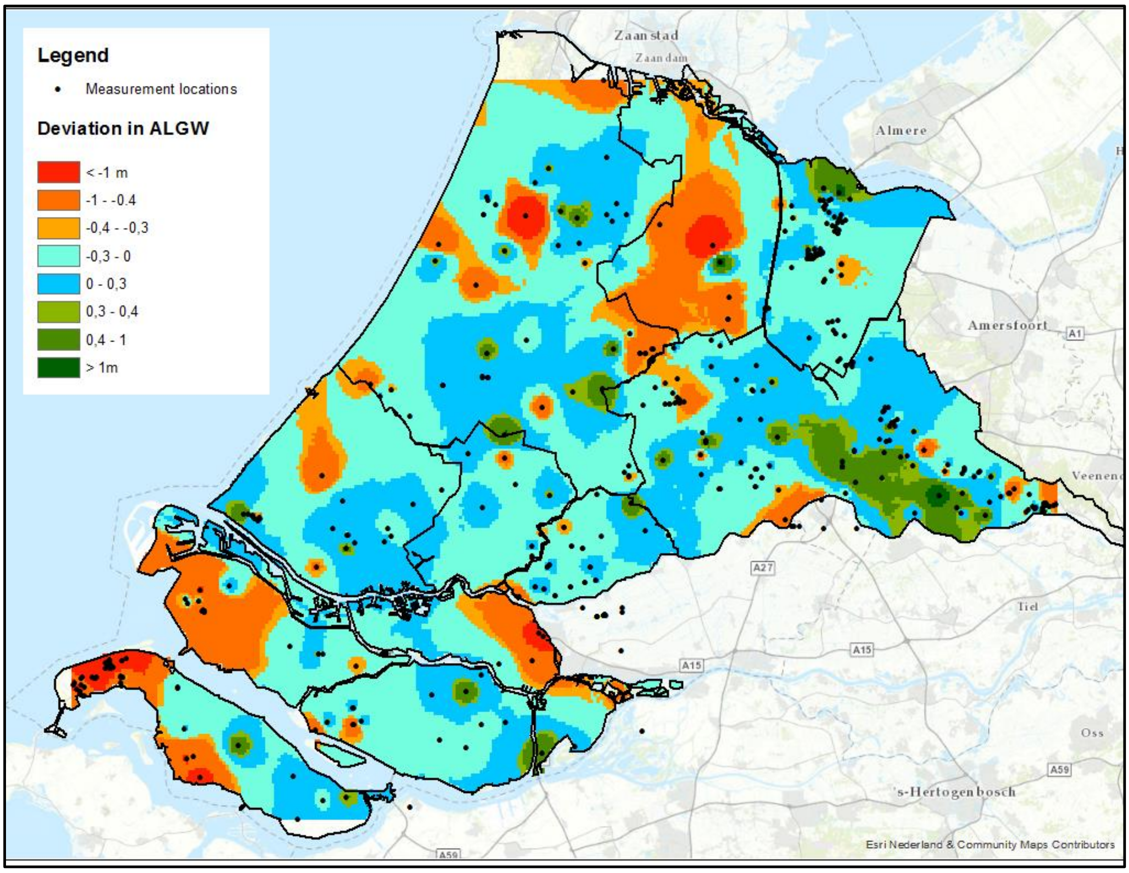


Figure 3.1.3a. Interpolated deviation of ALGW

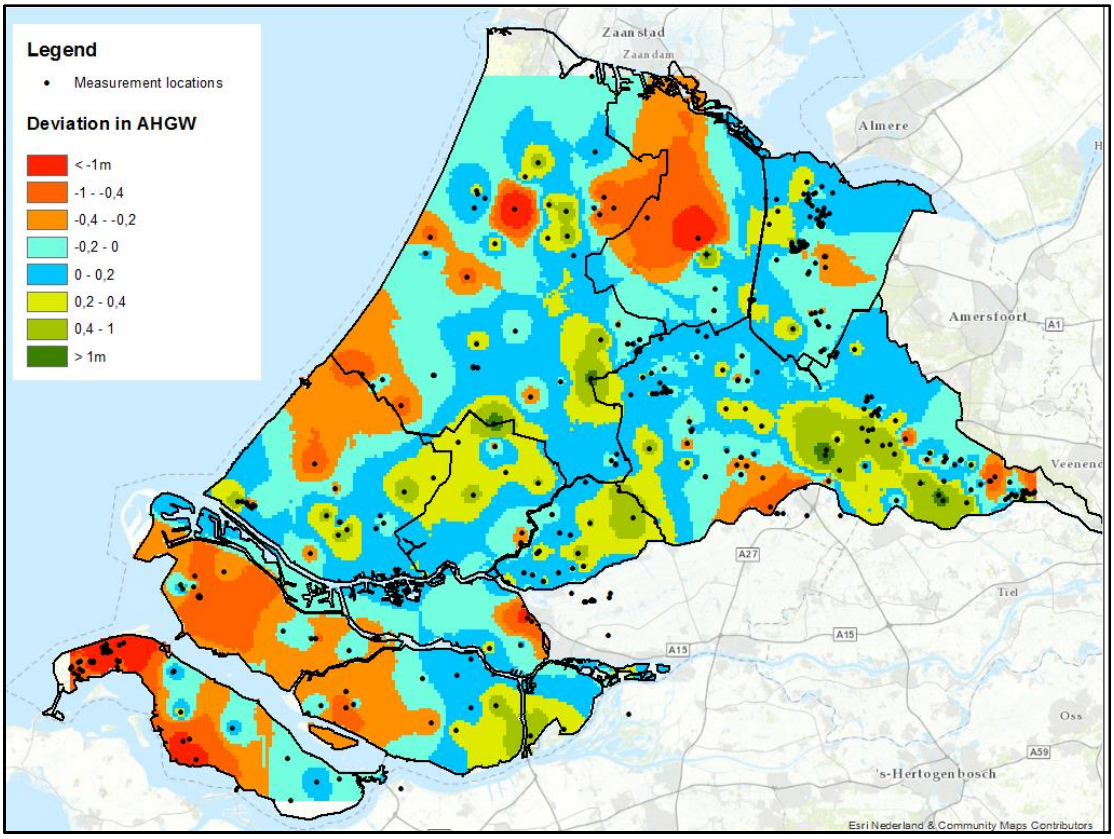


Figure 3.1.3b. Interpolated deviation of AHGW

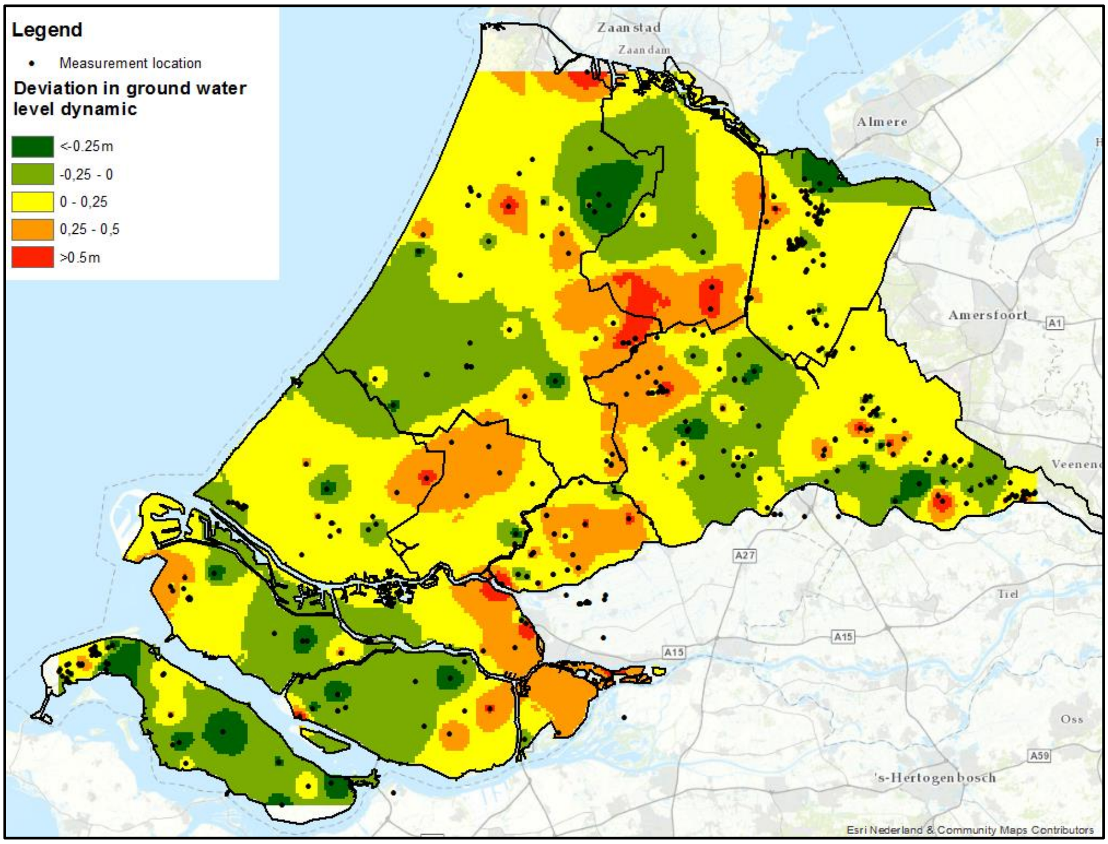


Figure 3.1.3c. Interpolated deviation of ground water level dynamics

Figures 3.1.3ab show that for most areas the interpolated deviation in ALGW and AHGW complies to the 30cm and 20cm deviation norm. This is due to the small median error: During interpolation, the interpolated values will approach the median error. Some of the spots in figures 3.1.3abc are caused by individual measurements; in these cases it is more likely that the measurement value is not correct. For the ALGW in figure 3.1.3a most of the areas indicate an ALGW that is calculated too low, with exception of the Kromme Rijn area. This is in line with the already made observation that ALGW tends to be modelled too low. The AHGW in figure 3.1.3b shows more spatial variation than the ALGW. In general, no clear spatial relationship between the deviation in modelled ground water levels can be observed.

Figure 3.1.3c shows that most areas have an error in absolute dynamics smaller than 25cm. While the relative dynamics scores very poorly, the absolute deviation is not very large. In line with the already made observation, dynamics tends to be too large for most areas.

Concluding, ALGW is calculated quite correct, although slightly too low. AHGW is calculated quite correct as well, but not as good as the ALGW. The median error performs better, indicating that ground water levels are reproduced accurate, but with a low precision. Dynamics is reproduced correct, but slightly too large. The too large dynamics is mainly due to deviations in the AHGW.

3.1.2 Ground water level time series

Table 3.1.3 and figure 3.1.4 give an overview of the selected measurement locations for time series analyses. The selection has been done quite randomly and it is tried to get a representative overview of the physical characteristics of the study area. Some extra selections for the Krimpenerwaard have been made because here large deviations in the surface water validation are observed (see 3.4.3.1).

Location	Measured ALGW	Modelled ALGW	Deviation ALGW	Measured AHGW	Modelled AHGW	Deviation AHGW	Measured dynamic	Modelled dynamic	Deviation dynamic
A	-3,89	1,24	-5,13	-4,09	0,36	-4,45	0,2	0,88	0,68
B	1,48	1,34	0,14	0,75	0,63	0,12	0,73	0,71	-0,02
C	2,4	1,34	1,06	1,54	0,10	1,44	0,86	1,24	0,38
D	0,61	0,96	-0,35	0,19	0,18	0,01	0,42	0,78	0,36
E	0,86	0,96	-0,12	0,08	0,18	-0,10	0,78	0,80	0,03
F	0,94	1,33	-0,39	0,26	0,34	-0,08	0,68	0,99	0,31
G	0,24	0,67	-0,43	0,04	0,16	-0,12	0,2	0,51	0,30
H	1,37	1,22	0,14	0,61	0,86	-0,25	0,76	0,36	-0,39
I	0,54	0,61	-0,07	0,28	0,24	0,04	0,26	0,38	0,12
K	1,87	2,24	-0,36	1,61	1,15	0,46	0,26	1,08	0,83
L	0,69	0,81	-0,11	0,5	0,08	0,42	0,19	0,73	0,54
M	0,77	0,71	0,06	0,51	0,12	0,39	0,26	0,59	0,33
N	1,12	0,83	0,29	0,74	0,44	0,30	0,38	0,39	0,01
O	0,63	0,31	0,31	0,38	0,10	0,28	0,25	0,21	-0,04

Table 3.1.3. Parameters for selected ground water level time series [m-surface level]

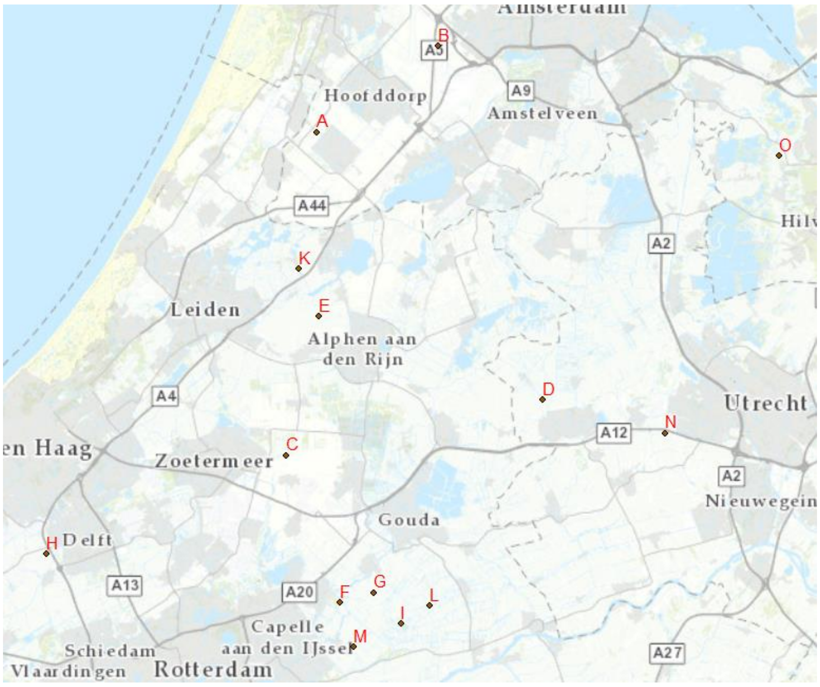


Figure 3.1.4. Location of selected time series

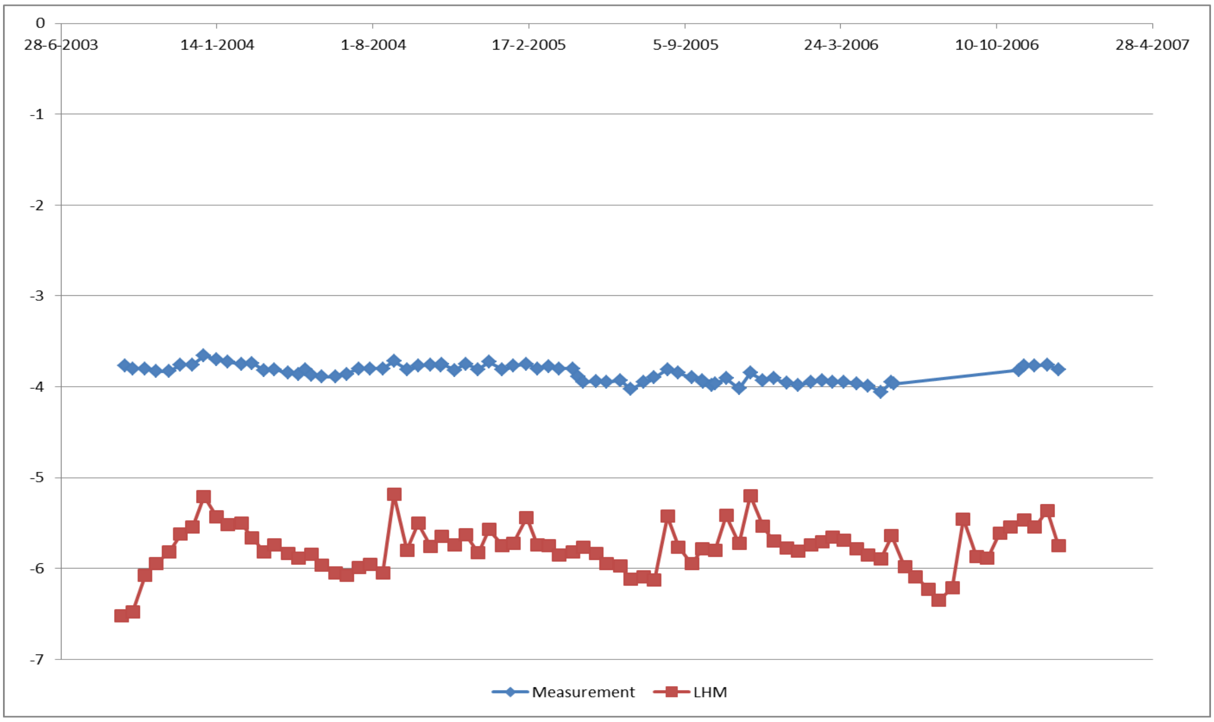


Figure 3.1.5A. Ground water level for location A (Haarlemmermeer Polder) [m –NAP]

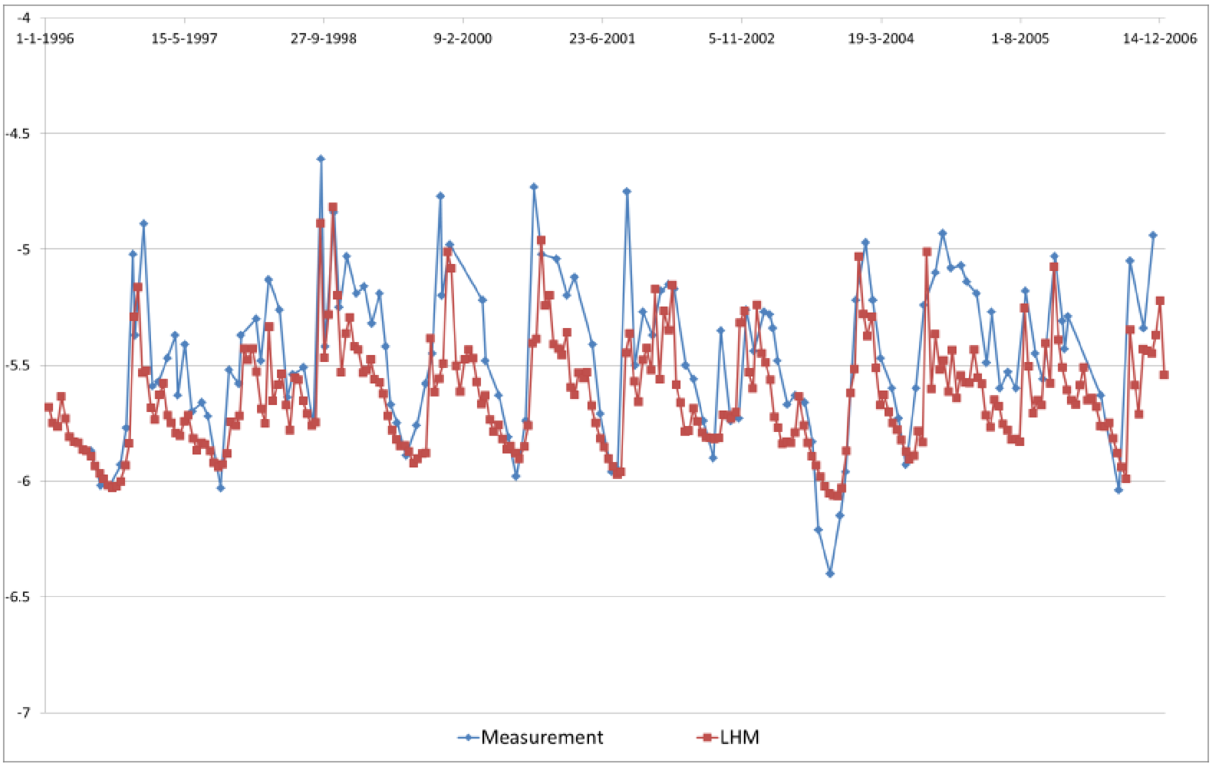


Figure 3.1.5B. Ground water level for location B (Haarlemmermeer Polder) [m –NAP]

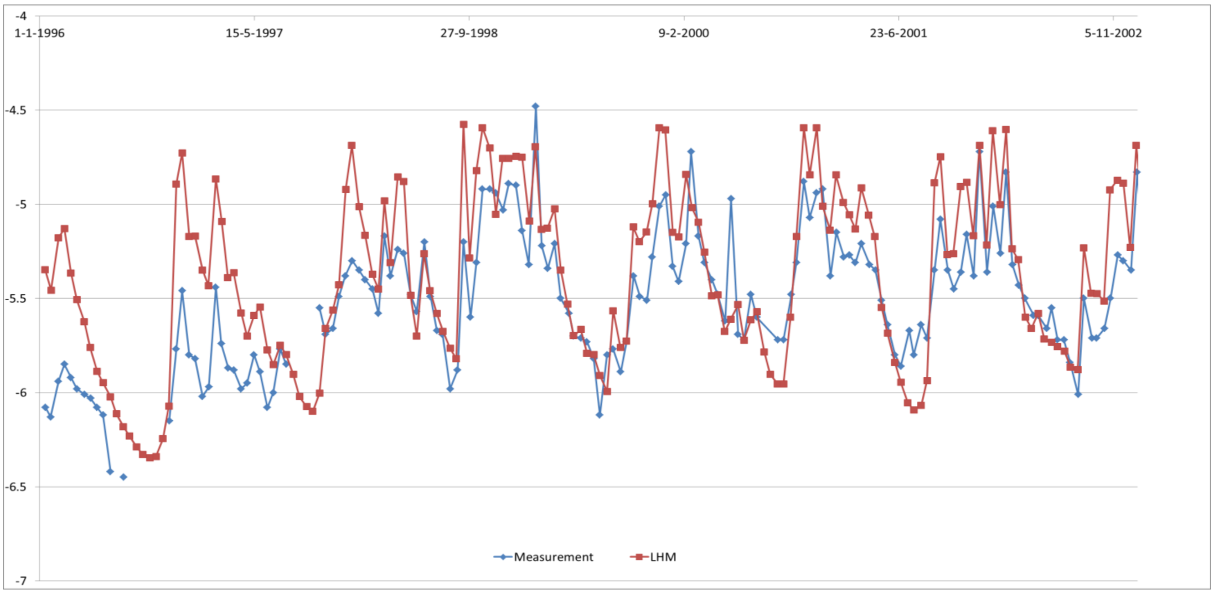


Figure 3.1.5C. Ground water level for location C (Zoetermeer) [m –NAP]

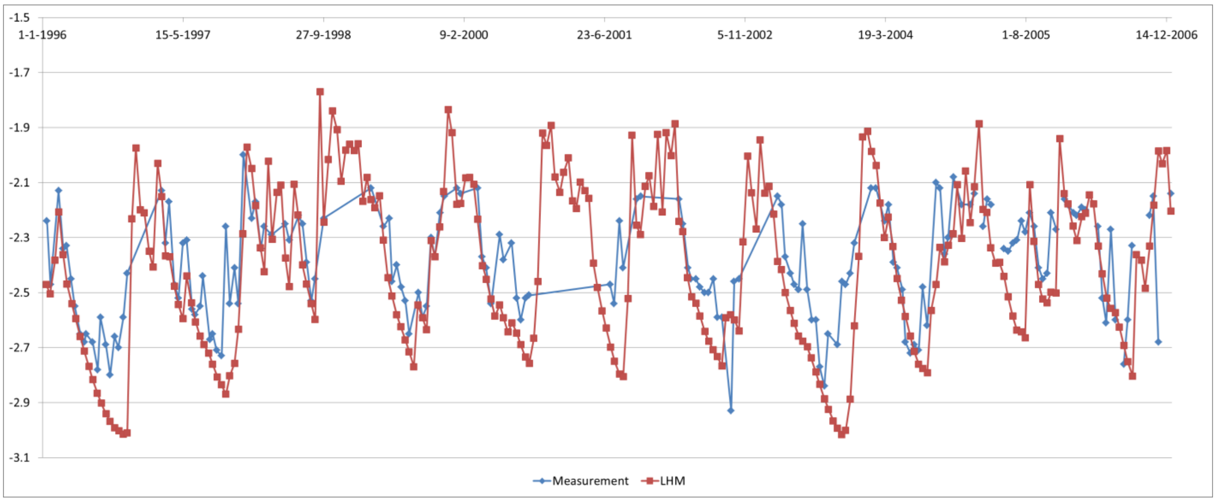


Figure 3.1.5D. Ground water level for location D (Woerden)[m –NAP]

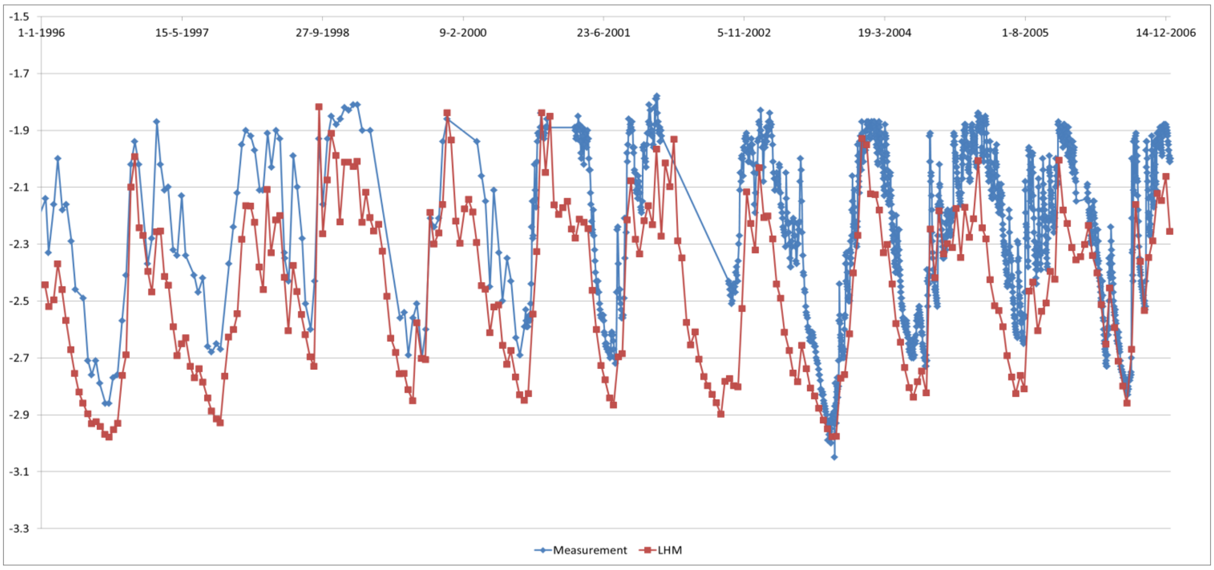


Figure 3.1.5E. Ground water level for location E (Alphen aan den Rijn) [m –NAP]

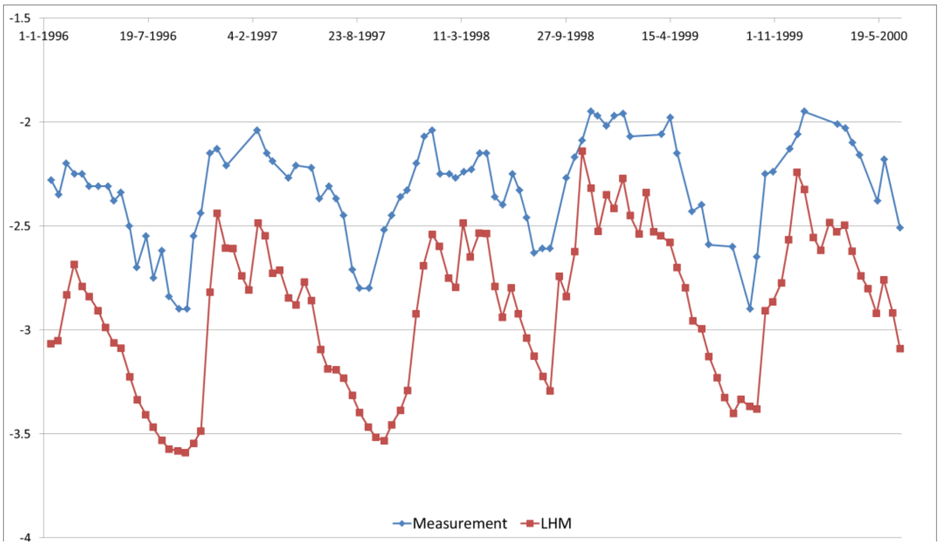


Figure 3.1.5F. Ground water level for location F (Ringvaart HHSK) [m –NAP]

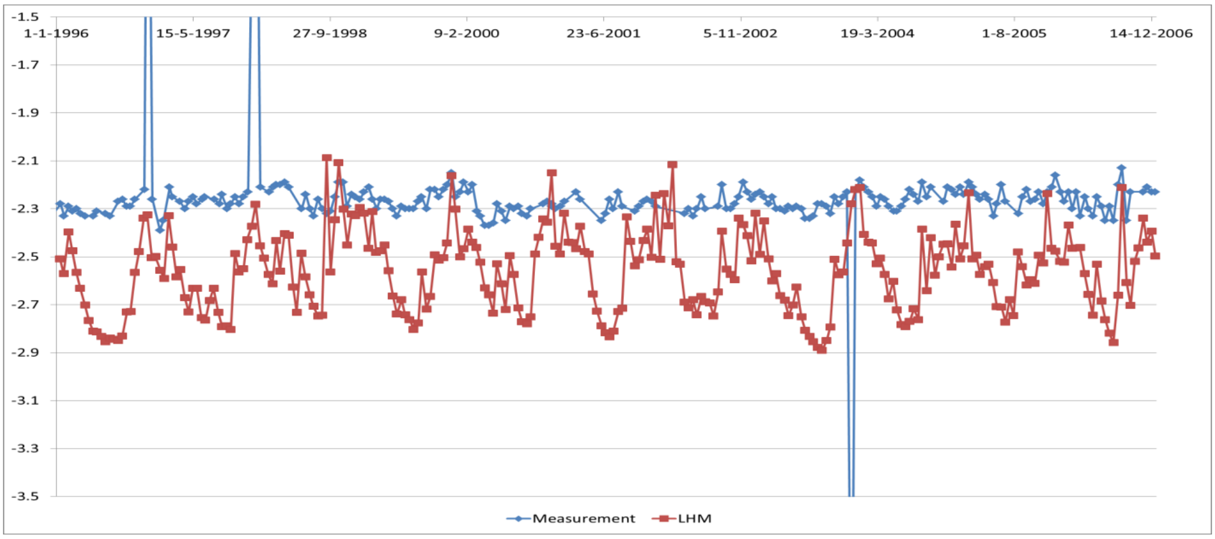


Figure 3.1.5G. Ground water level for location G (Krimpenerwaard) [m –NAP]

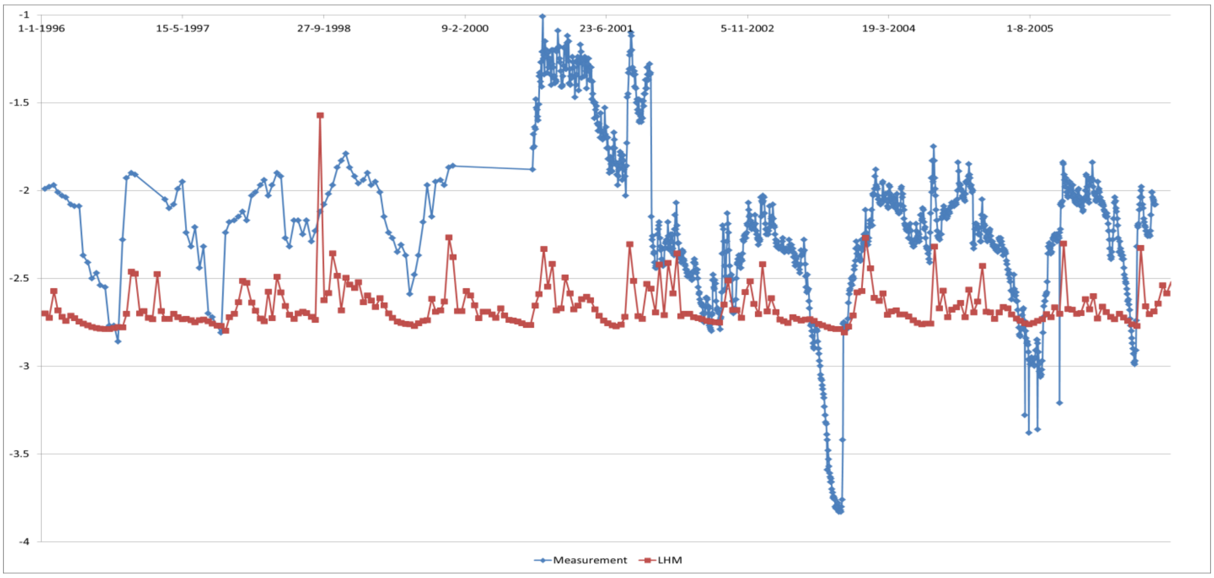


Figure 3.1.5H. Ground water level for location H (Delft)[m –NAP]

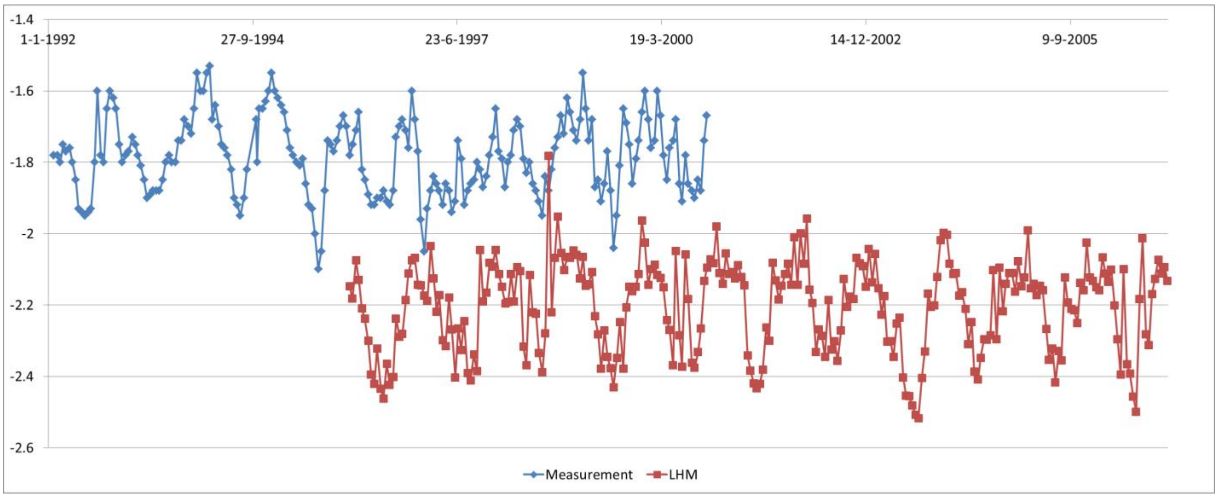


Figure 3.1.5I. Ground water level for location I (Krimpenerwaard) [m –NAP]

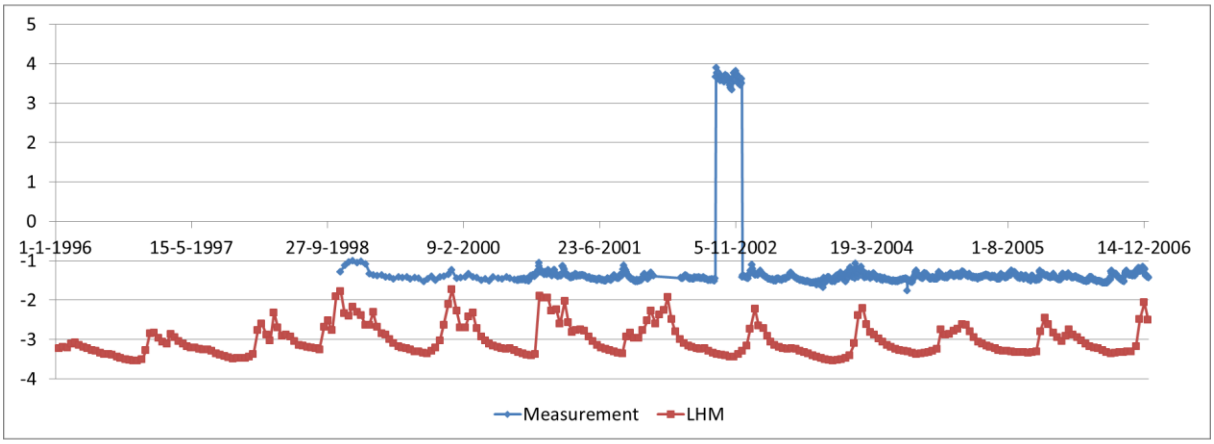


Figure 3.1.5K. Ground water level for location K (Leiden)[m –NAP]

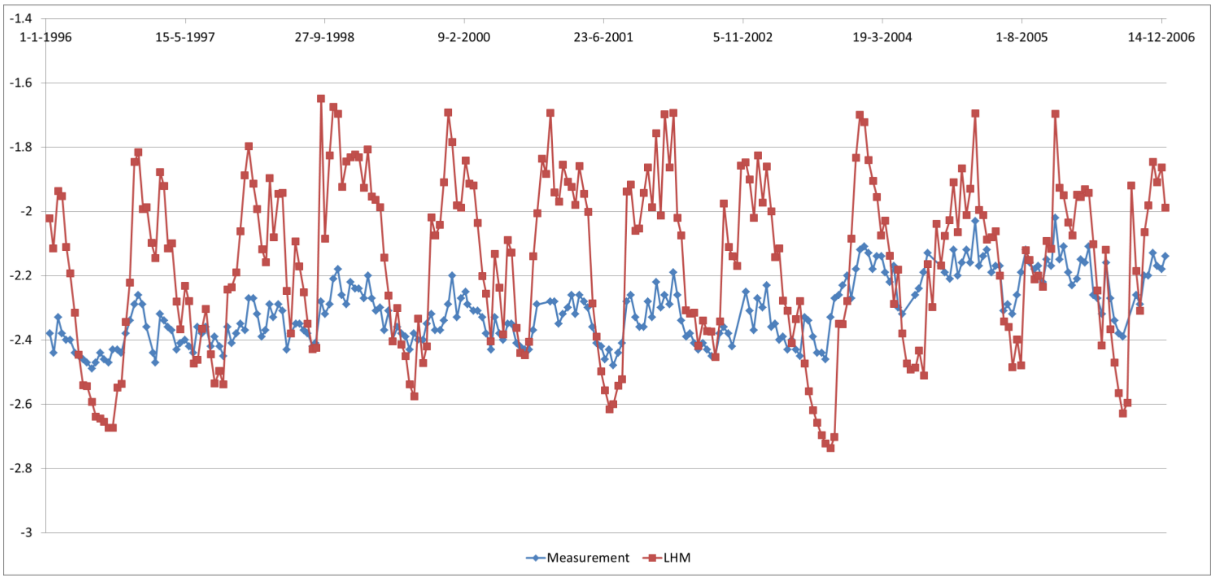


Figure 3.1.5L. *Ground water level for location L (Krimperwaard) [m –NAP]*

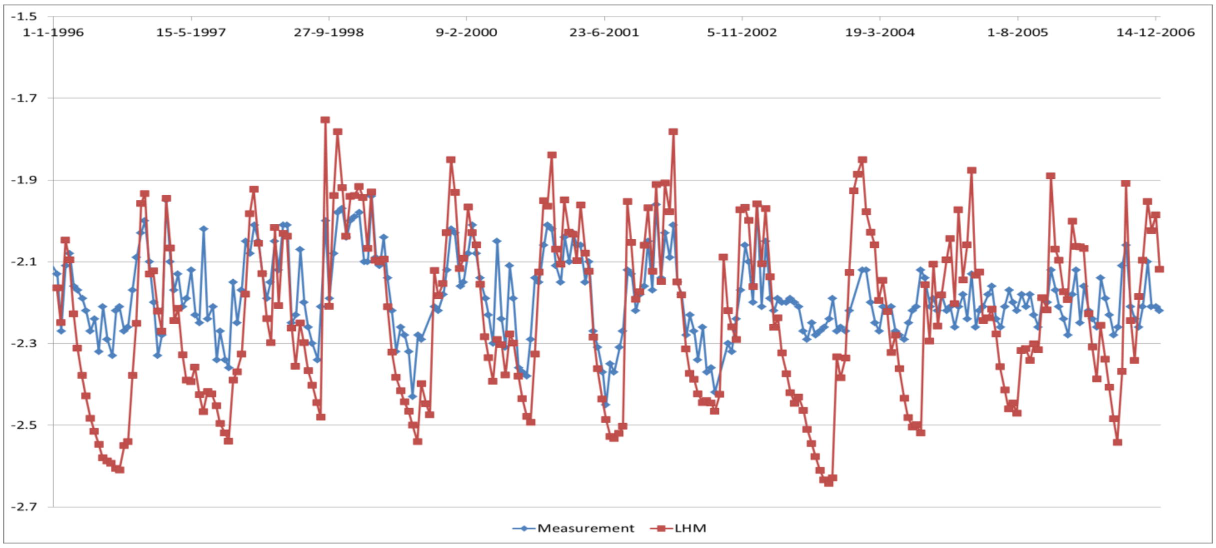


Figure 3.1.5M. Ground water level for location M (Krimpenerwaard) [m –NAP]

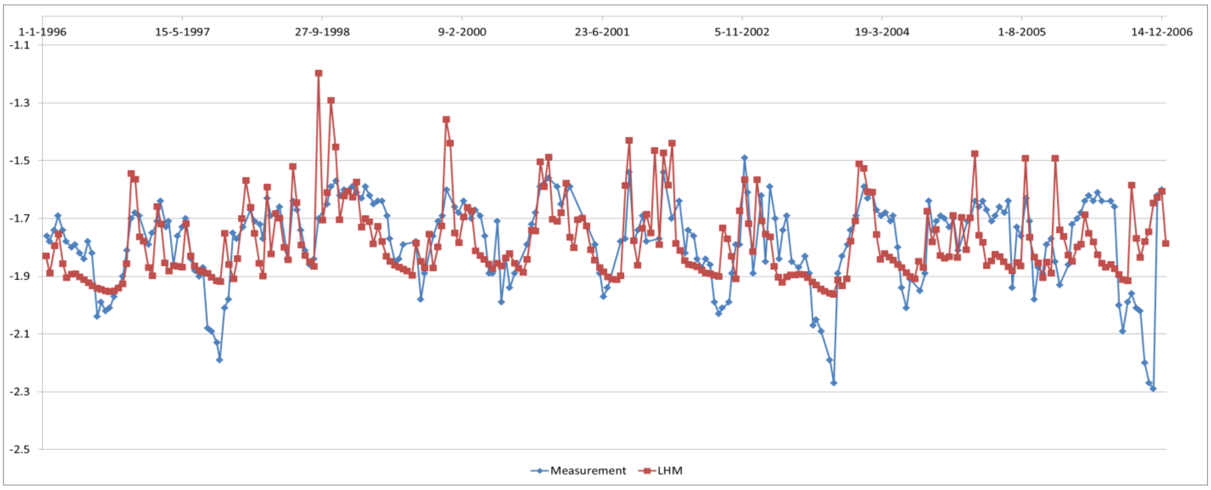


Figure 3.1.5N. Ground water level for location N (Nieuwegein) [m –NAP]

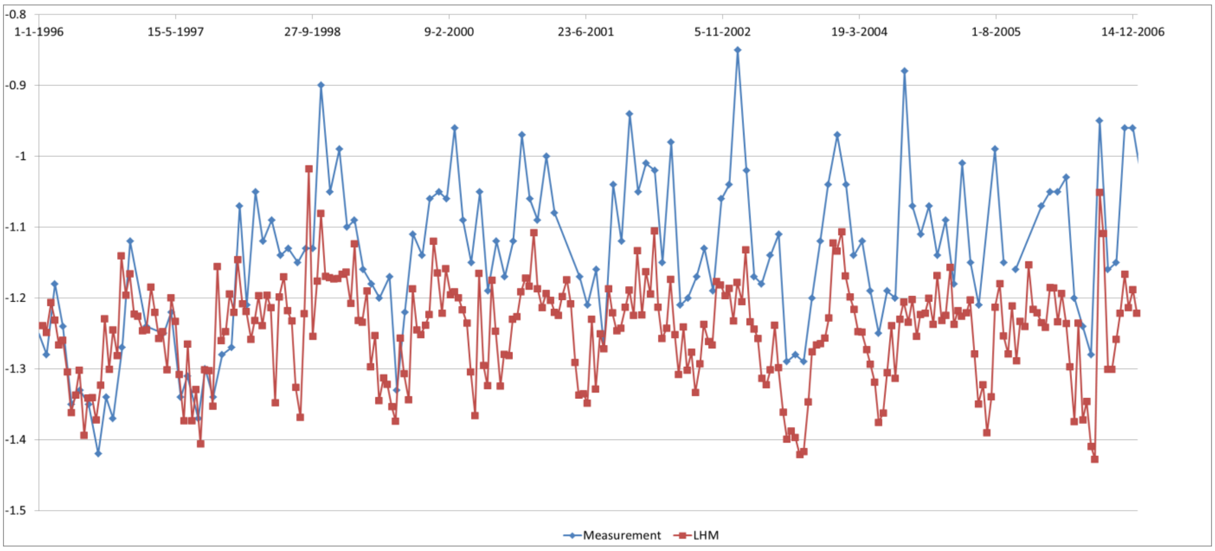


Figure 3.1.5O. Ground water level for location O (Ankeveensche Plassen) [m –NAP]

The time series above show that for most of the locations the temporal fluctuations and average ground water level are accurately reproduced. However, the range in deviations is broad and no clear and consistent error is found. Some of the observed deviations are explained below. Measurement locations are indicated in figure 3.1.4.

Measurement locations A and B are located in the Haarlemmermeer Polder with a surface elevation of approximately 5m –NAP. Figure 3.1.5A shows that the LHM calculates a ground water level which is approximately 2m too deep, dynamics of the modelled ground water level is too large. However, when observing the measurement location in figure 3.1.6, it appears that this measurement is located on top of a dyke. These small scaled surface level fluctuations are not included in the LHM, which has a 250x250m schematisation. The LHM deviation in surface level for location A is 3 meters, which explains for a large part the observed difference. The proximity of surface water could explain the low dynamics within the measurement time series. The deviation at location K can be explained by the same reason. Figure 3.1.5B, although still close to surface water, shows a better reproduction of the ground water levels.

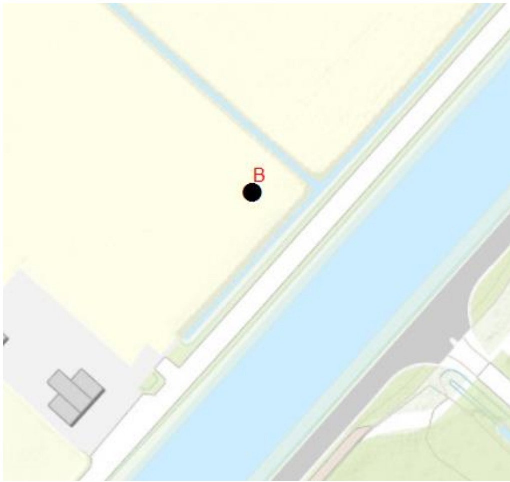


Figure 3.1.6, close-up for measurement locations A and B.

Regarding the reproduced dynamicss, most of the time series show that the LHM calculates too large fluctuations (A, D, G, I, K, L and M). For locations A, G, I and M this can be explained by the proximity of surface water to the measurement locations. However, this is not the case for all the locations. Additionally, some of the other measurements are located close to surface water while the reproduction of the fluctuation in ground water level is performed quite accurately. For some of the time series the magnitude of fluctuations in ground water level are reproduced accurately, but ground water levels drop too early in the season (B and E). Contrary to most of the locations where the LHM calculates too large temporal fluctuations, for location N the calculated ground water levels do not drop far enough during the summer.

Next to the dynamics, which considers the seasonal fluctuations, the time series show fluctuations on a smaller scale. These fluctuations are mainly reactions on precipitation/evaporation events. The results show very consistent that these small scaled fluctuations of the LHM are larger (location E, M and N). It seems that LHM groundwater levels react to strong on precipitation/evaporation events, explanation for this could be that the unsaturated zone has a too small buffering/storage capacity.

Not all the deviations can be explained. So are for locations F, G, and I the calculated ground water levels too low. Location H does not show a very plausible Dinoloket measurement. While it is clear in figure 3.1.5H that the measurement is not very plausible, the calculated AHGW and ALGW values for this location are taken along within the calculations shown in table 3.1.1 and 3.1.2, influencing the validation results. Finally, for location O the ground water level is reproduced accurately for the years 1996 and 1997. While the LHM ground water levels fluctuate within the same regime the following years, the measured ground water levels shift upwards. It could be possible that this shift is due to a human induced change in the water system which is not incorporated into the LHM.

Concluding, for individual locations, deviations can vary strongly in magnitude and nature. For some extent, the deviations in ground water levels cannot directly be assigned to errors in the LHM, but rather to shortcomings of the model. So are spatial fluctuations in surface level and distances to surface water on a scale smaller than 250m impossible to incorporate in a 250x250m schematisation. Additionally, it is not likely that all the 785 ground water time series retrieved from Dinoloket are equally plausible. However, it seems that on average ground water levels are modelled quite correctly. Although, based on figure 3.1.2ab, average ALGW and AHGW are calculated slightly too low, where especially deeper AHGW is calculated too shallow. Based on the time series analyses it seems that the LHM calculates too large temporal fluctuations, especially the small scaled fluctuations.

3.1.3 Ground water level validation HDSR region

Figures 3.1.7abc show the results of the validation of ground water levels based on raster values retrieved from a study by Artesia (Artesia 2011). The AHGW and ALGW data is based on 664 measurement locations across the HDSR region and are interpolated by Kriging.

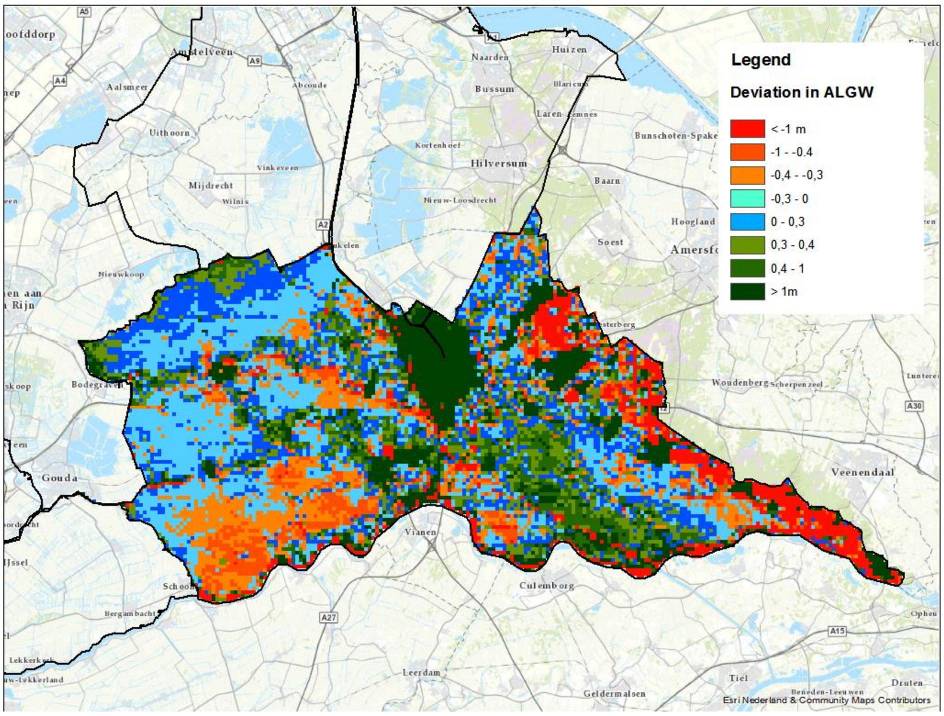


Figure 3.1.7a. Deviation in AHGW for the HDSR region

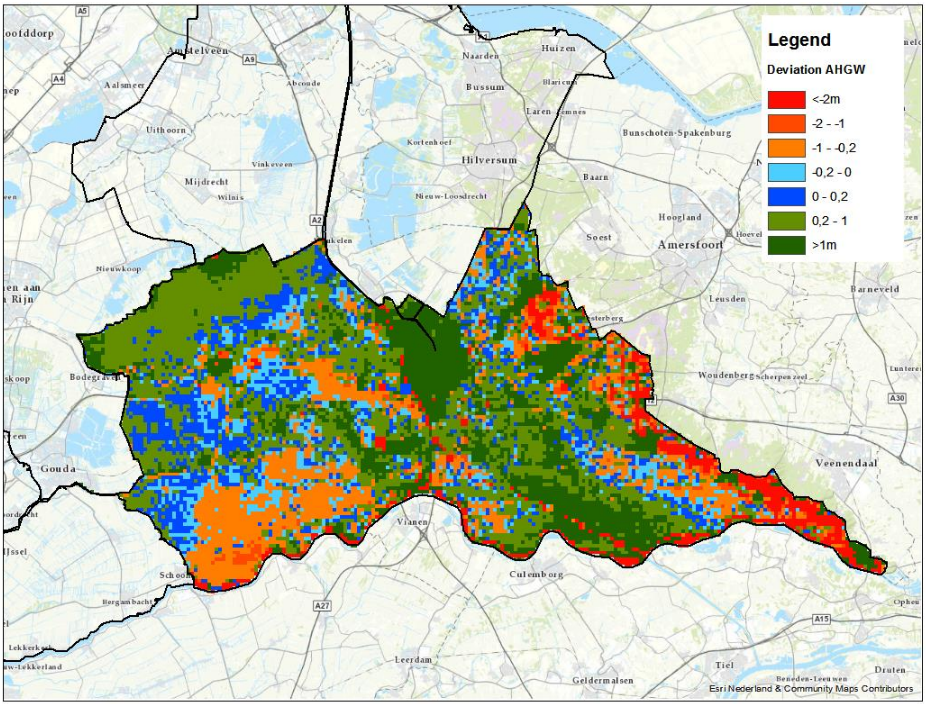


Figure 3.1.7b. Deviation in ALGW for the HDSR region

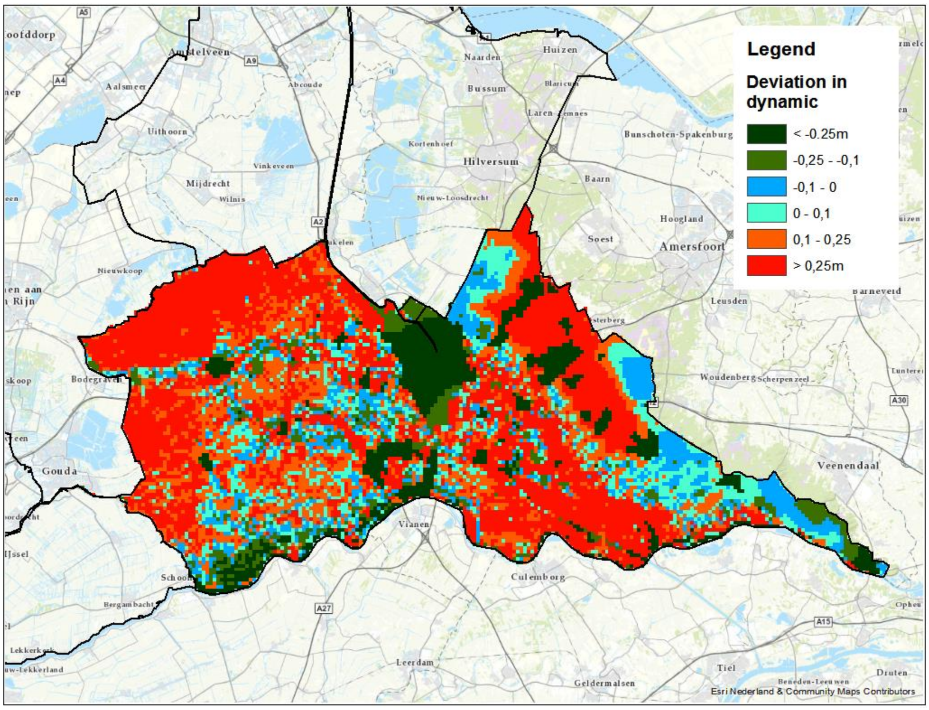


Figure 3.1.7c. Deviation in dynamics for the HDSR region

From the three figures above the following conclusions can be made. Note that urban areas should not be considered as the LHM does not calculate ground water levels for these areas. (1) Within the Utrechtse Heuvelrug area ground water levels are too low; (2) For the Kromme Rijn area calculated ground water levels are too high. This is in line with the validation results from the Dinoloket measurements; (3) The Lopikerwaard has too low ground water levels. An explanation for this could be the evaporation which is thought to be too high for this region (Timo Kroon, 02-13-2017); (4) The AHGW shows the largest deviation and is mostly too high, and the dynamics is too large. This is in line with results from the Dinoloket validation above; (5) With exception of the sub regions mentioned above, the ALGW performs quite well. Better than the Dinoloket validation previously showed.

3.2 Hoogheemraadschap van Rijnland

Main conclusions

For the complete management area, although not all individual peaks in the inlet and outlet are captured by the LHM, the dynamics are reproduced quite well. It appears that the LHM imposes an incorrect amount of flush. The ND, which is corrected for deviations in flush, performs much better. The CDND shows a sinusoidal trend throughout the year, with a linear over-use of water of 20-40mm during the growing season. During extra dry periods, such as 2003 and spring-2011, the deviations do not become significantly larger and it appears that the LHM captures the water demand well during these periods. The calculated net water use during the KWA-2011 for Rijnland was 10-11m^3/s, this is in line with the observations.

The CDND for the HLM Polder is very large, but it seems very plausible that most of the deviation originates from a wrong imposed flush. The validation for all Rijnland polders and the boezem of Rijnland give much better validation results. This is because here the measurement data is based on fluxes in and out the boezem, and therefore by-pass the internal in- and outlet to polders which include the polder flush.

For Polder De Noordplas, seepage is not calculated correctly and the measurement data was not plausible. It seems that the LHM does not calculate higher seepage rates (>0.75mm/d) correctly.

In the LHM most of the over demand is projected on a too small outlet of water, and the inlet shows much a smaller error during the growing season. This means that the 20-40mm over-use does not lead to a 20-40mm extra calculated water inlet. Also, the over-demand is quite linear throughout the growing season and is not projected on individual dry events. This makes the LHM usable to determine future water demand for the DPZW for Rijnland. However, especially for individual polders, correct amounts of flush need to be imposed.

3.2.1 Area description

The Hoogheemraadschap van Rijnland (HHR), shown in figure 3.2.1, is situated in the west of the Netherlands and comprises an area of about 114.000 hectares. Rijnland consists of an extensive polder and drainage system. Almost all the 206 polders, 91.000 hectares in total, drain on the same central drainage system: the boezem. Along the coast high elevated sand dunes are present. Water levels in the polders are maintained at around NAP to 7m –NAP.

Crucial points regarding the fresh water management of Rijnland during dry periods are the maintenance of surface water levels, flushing of brackish seepage and water supply to important agricultural areas.

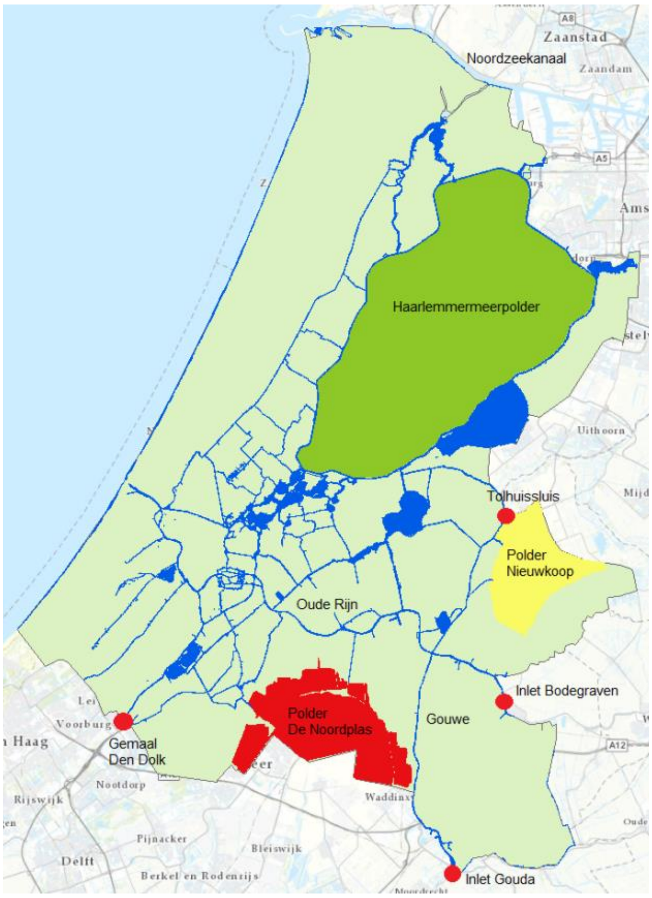


Figure 3.2.1. Boezem of Rijnland and main fresh water supply locations

Supply of water

External supply of fresh water occurs via the inlet locations near Gouda and Bodegraven. Gouda is the main inlet location, however when the chloride concentration in the Hollandse IJssel reaches above 250 mg/l this inlet location must close. In this case the 'KWA' (Small Scalled Water Supply) becomes operative and water from the Oude Rijn will be let in at Bodegraven. The capacity of the KWA has a theoretical limit of a net 4 m^3/s for Rijnland. In reality Bodegraven can transfer up to 11 m^3/s to the Rijnland area. During the summer of 2003 additional water from the Amstel (AGV region) was supplied via the Tolhuissluis.

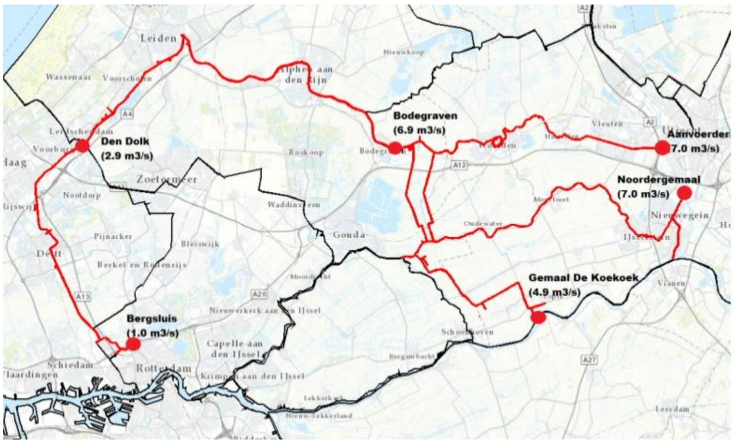


Figure 3.2.2. Kleinschalige Water Aanvoer (KWA) route and major throughput locations (red)

Figure 3.2.2 shows that the KWA-route starts in the HDSR region where water from the Amsterdam-Rijn Kanaal is let into the Gekanaliseerde Hollandse IJssel (GHIJ) and Leidsche Rijn near Utrecht, and water from the Lek is let into the Lopikerwaard. This water will subsequently flow through the HDSR region towards Bodegraven. Here, a theoretical discharge of 7 m^3/s will be transferred towards Rijnland, of which 3 m^3/s will be transferred at pumping station Den Dolk towards Delfland. Delfland subsequently transfers 1m^3/s to Schieland via Bergsluis. The discharge distribution described above is theoretical and varies depending on the actual demand, so received Rijnland a net 11 m^3/s from Bodegraven during spring 2011. One of the current issues of the DPZW is an upgrade of the KWA to 14.5 m^3/s, the KWA+.

3.2.2 LHM results

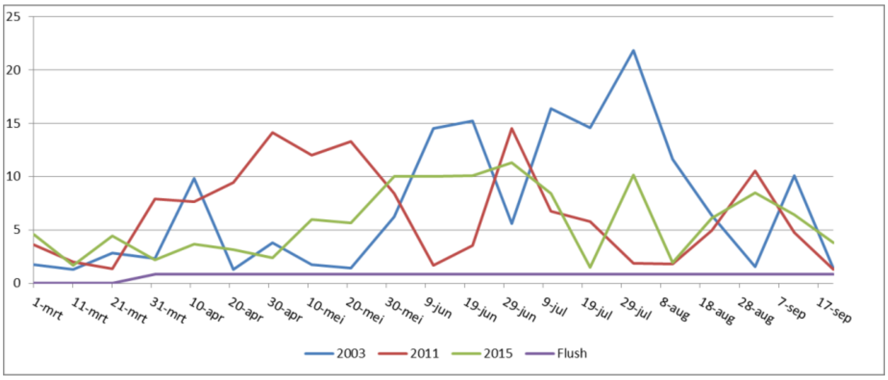


Figure 3.2.3. Modelled water demand for Boezem Rijnland and imposed flush on polders [m^3/s]

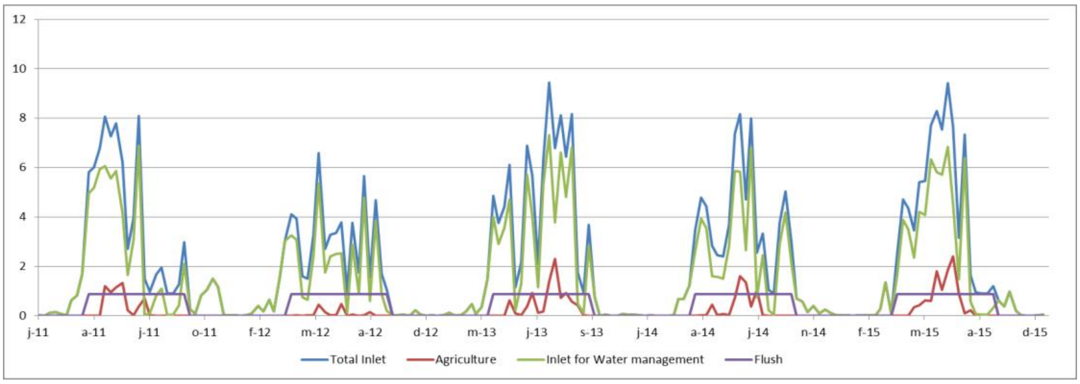


Figure 3.2.4. LHM surface water allocation Rijnland polders 2011-2015 [m^3/s]

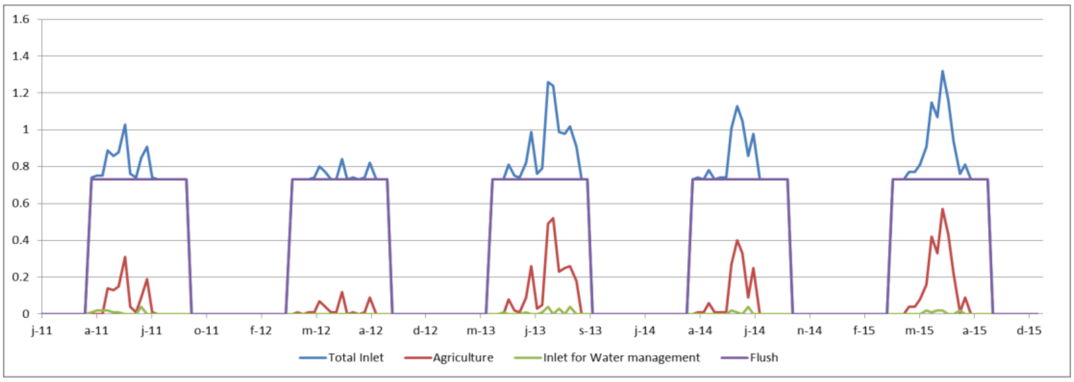


Figure 3.2.5a. LHM surface water allocation Haarlemmermeer polder 2011-2015 [m^3/s]

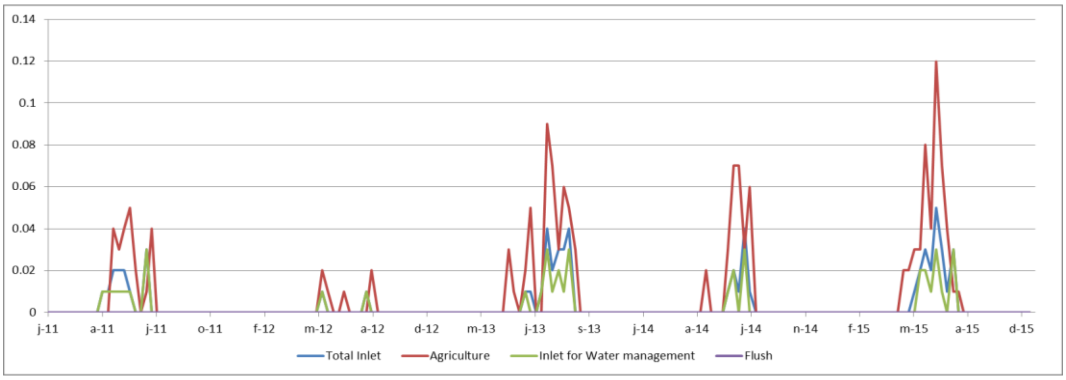


Figure 3.2.5b. LHM surface water allocation Polder De Noordplas 2011-2015 [m^3/s]

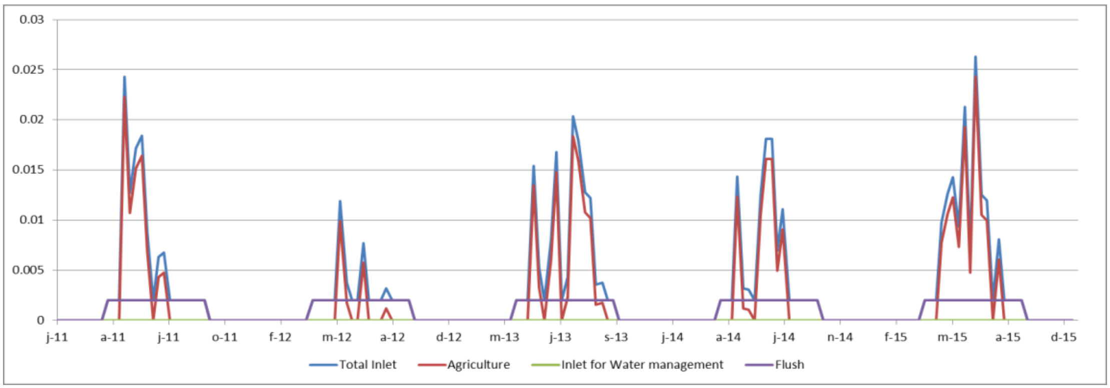


Figure 3.2.5c. LHM surface water allocation Polder Nieuwkoop 2011-2015 [m^3/s]

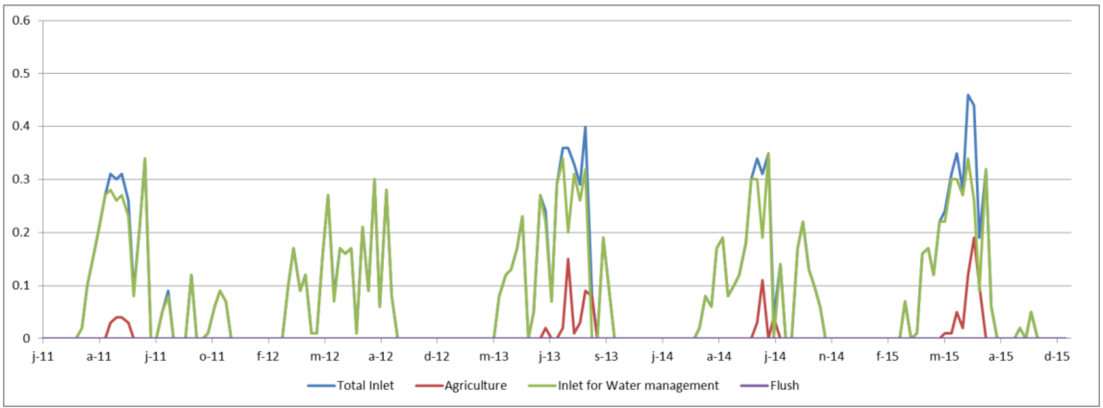


Figure 3.2.6a. LHM surface water allocation Boskoop 2011-2015 [m^3/s]

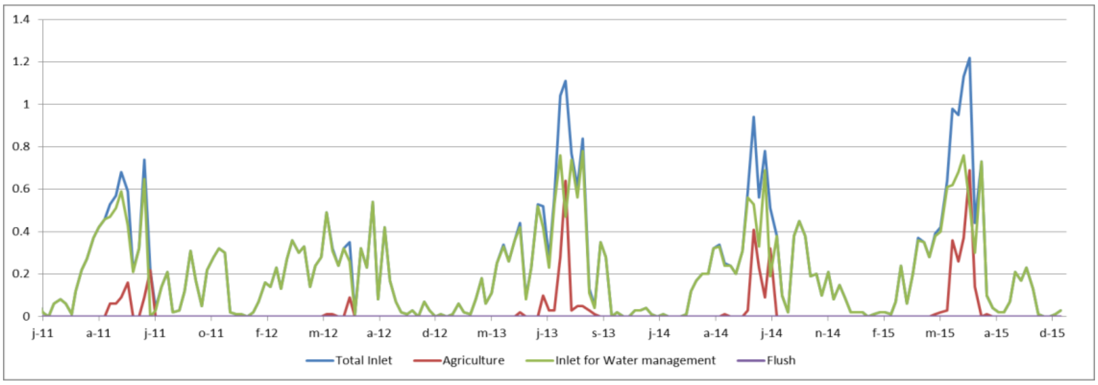


Figure 3.2.6b. LHM surface water allocation Bollenstreek 2011-2015 [m^3/s]

Figure 3.2.3 gives the LHM water demand for the boezem of Rijnland, and flush of the polders. For the complete Rijnland area it is known that 10-15 m^3/s is the minimum amount of fresh water required during dry periods, the LHM calculates this order of magnitude water demand. Notice that some of the water is transferred to Delfland via Den Dolk during dry periods. Figure 3.2.4 shows that most of the inlet water for Rijnland polders is for water management (maintenance of surface water levels). During dry periods, 1-2 m^3/s is allocated to agriculture.

For the three polders in figures 3.2.5abc, indicated in figure 3.2.1, the nature and allocation of surface water inlet differs. For the HLM Polder most of the inlet water is for flushing, seepage water is used for water management. Estimated fresh water demand for the HLM Polder is on average 1.6 m^3/s during the growing season, of which 25% is not directly needed, resulting into a demand of 1.2 m^3/s. Figure 3.2.5a shows that the LHM calculates this amount only during dry periods. The

LHM does not impose flush on Polder De Noordplas while this region experiences brackish seepage, and figure 3.2.5b shows that more water is allocated to agriculture than the total amount of inlet. This indicates that brackish seepage in Polder De Noordplas is allocated to agriculture, which is not realistic. For Polder Nieuwkoop practically no fresh water inlet is required.

Agricultural surface water allocation is calculated as the replenishment of the precipitation deficit after available water in the root zone is used, and after capillary after-delivery of water. It is manually imposed whether agricultural water originates form ground water or surface water (Alterra 2012). The agricultural allocation in the regions Boskoop and Bollenstreek, figures 3.2.6ab, has a relative high share. This makes sense since in these two regions intensive agriculture takes place. However, water demand estimates for Boskoop are in the order of $1m^3/s$, which is much higher than the LHM indicates. Presumably the depicted agricultural surface water allocation is not the complete agricultural water use, but only a supplementation to shortages.

The LHM calculates a seepage of 0.42, 0.48 and 0.47mm/d for HLM-, Noordplas- and Nieuwkoop polder respectively. These values seem to be reasonable, although on the low side. For all Rijnland polders combined the LHM calculates a net infiltration of 0.17mm/d. A net seepage was expected.

3.2.3 Validation results

3.2.3.1 Rainfall and evaporation

One of the recommendations of the validation of LHM2.0 by Ogink 2011 is that rainfall and evaporation data should be better imposed on the LHM. Within version 2.0 rainfall and evaporation were based in measurements from KNMI measurement stations and subsequently interpolated by Thiessen polygons across the region. This method leaded to large deviations and Ogink concluded that a lot of these deviations could be resolved by a better imposing of rainfall and evaporation data.

Currently, rainfall data is imposed on the LHM by Meteobase data (NHI.nu; Meteobase.nl). Meteobase offers rainfall data based on KNMI measurement stations, which is spatially interpolated by support of radar data. Evaporation is still based on KNMI Makink reference evapotranspiration, however the Thiessen polygons have disappeared since NHI2.1 (NHIVR2.1). Largest shortcoming is the open water evaporation which is calculated by use of a “crop” factor of 1.25. This method is generally known not to be a very accurate approximation of open water evaporation, but no better alternatives are available.

Rainfall and evaporation data will not be further validated. Reason for this is that Meteobase is the best available rainfall data. No data to validate the Meteobase rainfall with is available, and it is assumed that the Meteobase data is imposed correctly on the LHM. The largest deviations in evaporation are expected to occur for open water evaporation. Evaporation satellite measurements are available. However, based on observation of these measurements, open water evaporation seemed implausible (forested areas show higher evaporation than open water). Additionally, anticipating on the results of this validation, a lot of deviations in LHM2.0 of which Ogink 2011 concluded that they were caused by wrong precipitation/evaporation data have disappeared in the current LHM version.

3.2.3.2 Polders Rijnland

The surface water of the Mozart model for the Rijnland area is validated by use of a balance for the boezem channel. Within this water balance the amount of surface water that was drained from the polders, or discharged towards the polders is known. The amount of water form/towards the polders from the boezem channel should be equal to the amount of water that flows from/towards the Mozart LSWs in the LHM.

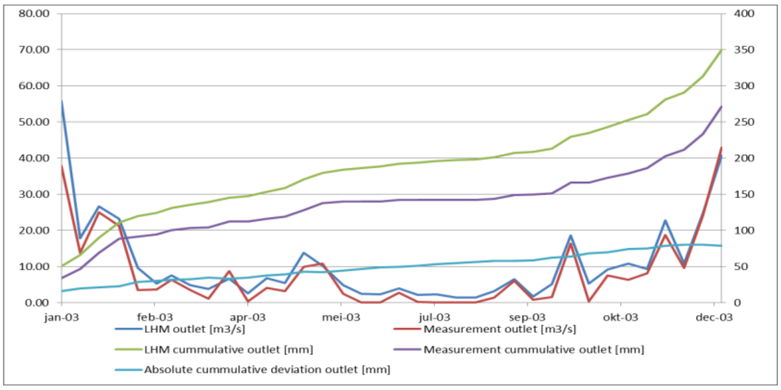


Figure 3.2.7a. Measured and modelled water outlet for Rijnland polders 2003 (left: [m^3/s], right: [mm])

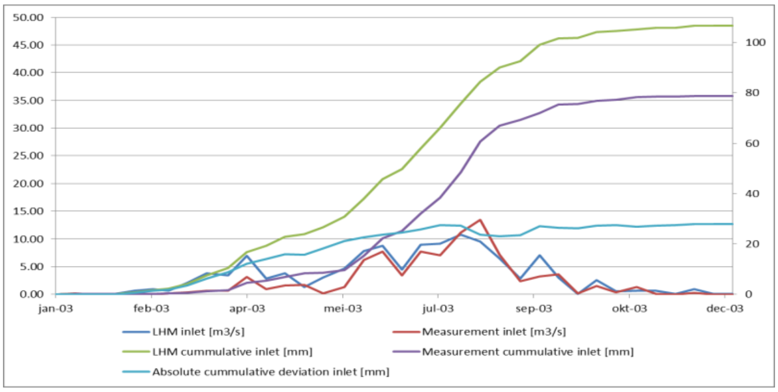


Figure 3.2.7b. Measured and modelled water inlet for Rijnland polders 2003 (left: [m^3/s], right: [mm])

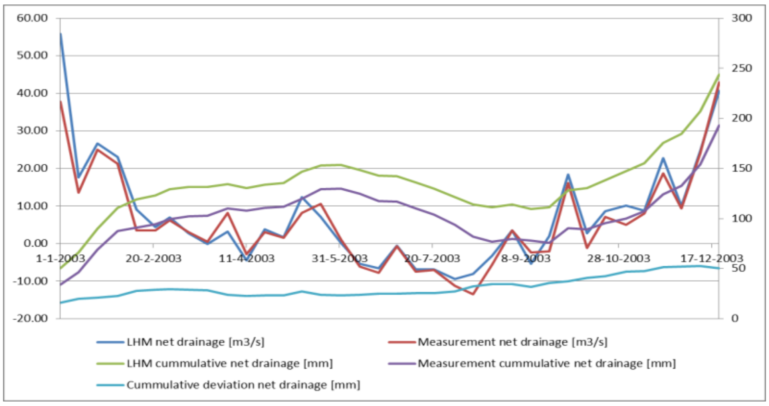


Figure 3.2.7c. Measured and modelled net water discharge for Rijnland polders 2003 (left: [m^3/s], right: [mm])

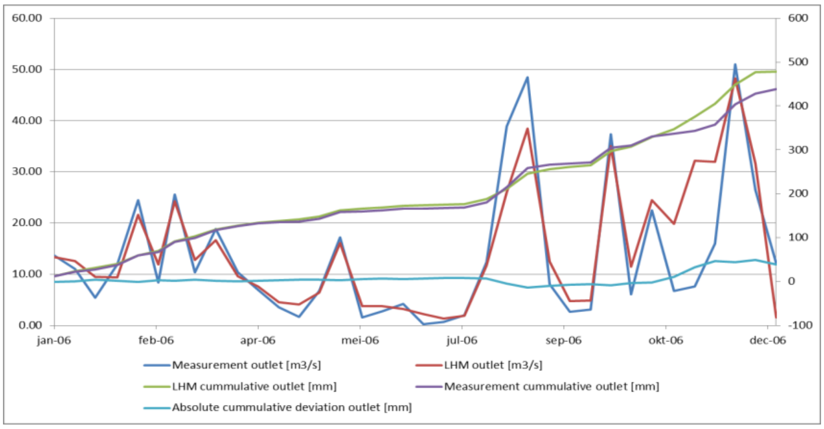


Figure 3.2.8a. Measured and modelled water outlet for Rijnland polders 2006 (left: [m^3/s], right: [mm])

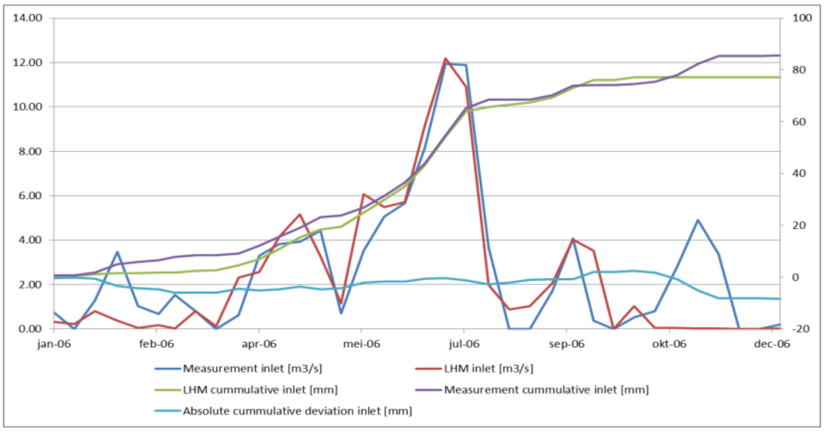


Figure 3.2.8b. Measured and modelled water inlet for Rijnland polders 2006 (left: [m^3/s], right: [mm])

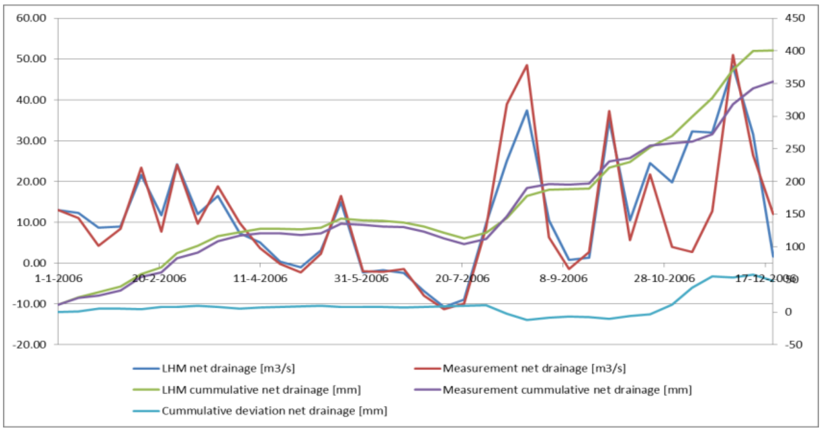


Figure 3.2.8c. Measured and modelled net water discharge for Rijnland polders 2006 (left: m^3/s], right: [mm])

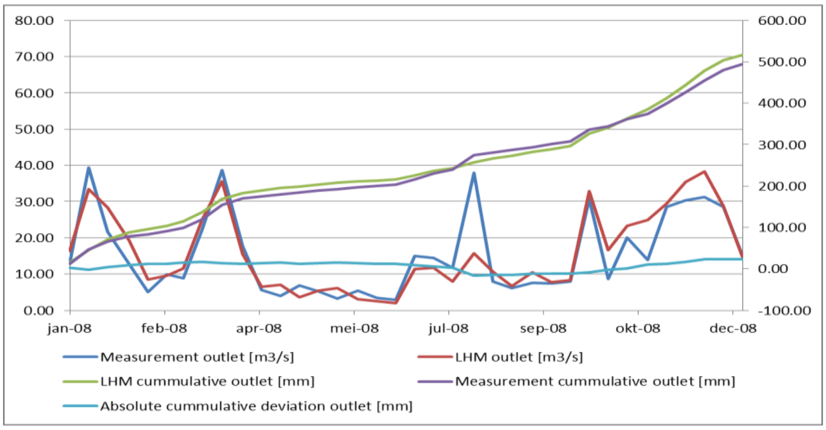


Figure 3.2.9a. Measured and modelled water outlet for Rijnland polders 2008 (left: [m^3/s], right: [mm])

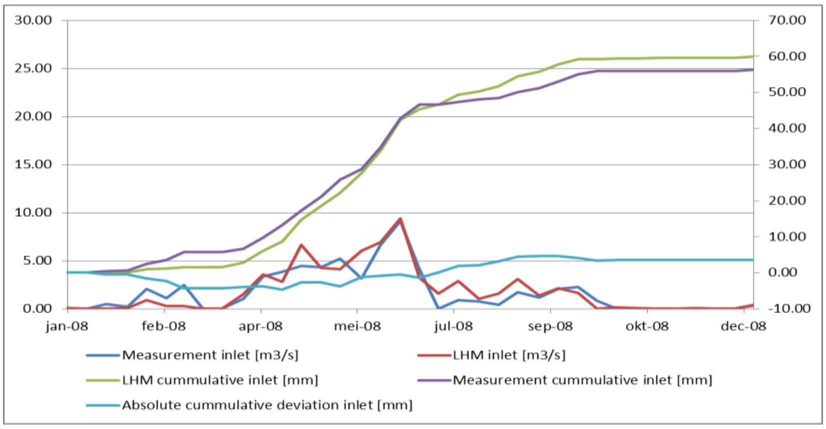


Figure 3.2.9b. Measured and modelled water inlet for Rijnland polders 2008 (left: [m^3/s], right: [mm])

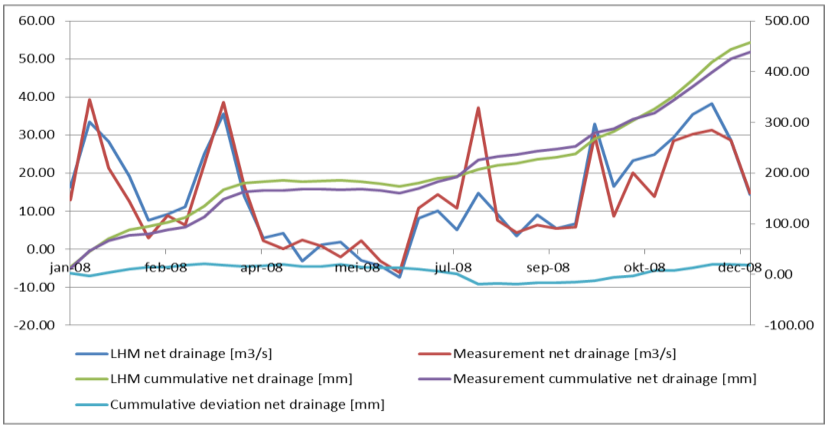


Figure 3.2.9c. Measured and modelled net water discharge for Rijnland polders 2008 (left: [m^3/s], right: [mm])

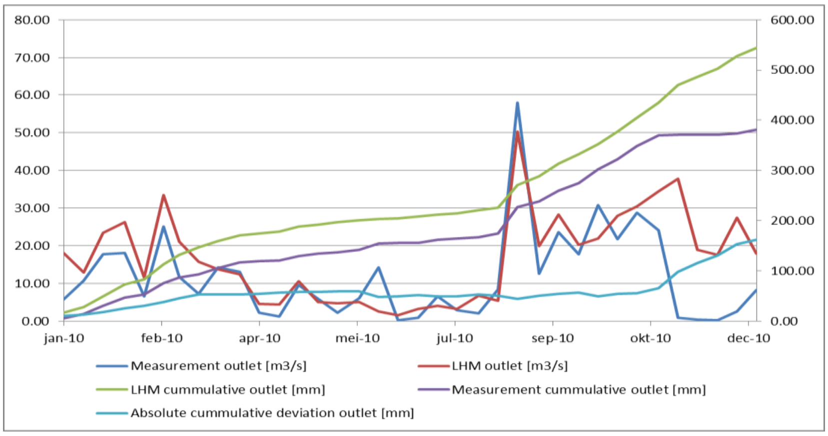


Figure 3.2.10a. Measured and modelled water outlet for Rijnland polders 2010 (left: [m^3/s], right: [mm])

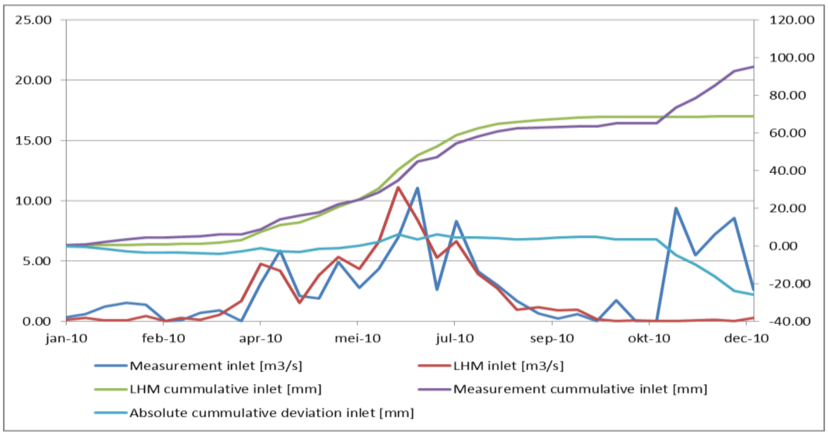


Figure 3.2.10b. Measured and modelled water inlet for Rijnland polders 2010 (left: [m^3/s], right: [mm])

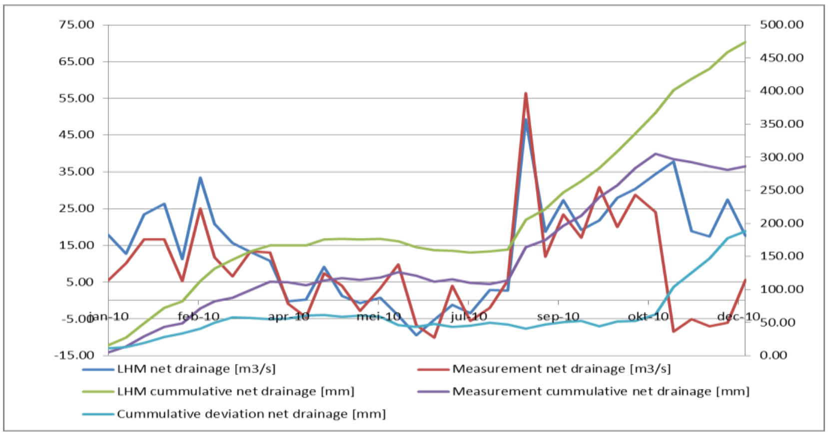


Figure 3.2.10c. Measured and modelled net water discharge for Rijnland polders 2010 (left: [m^3/s], right: [mm])

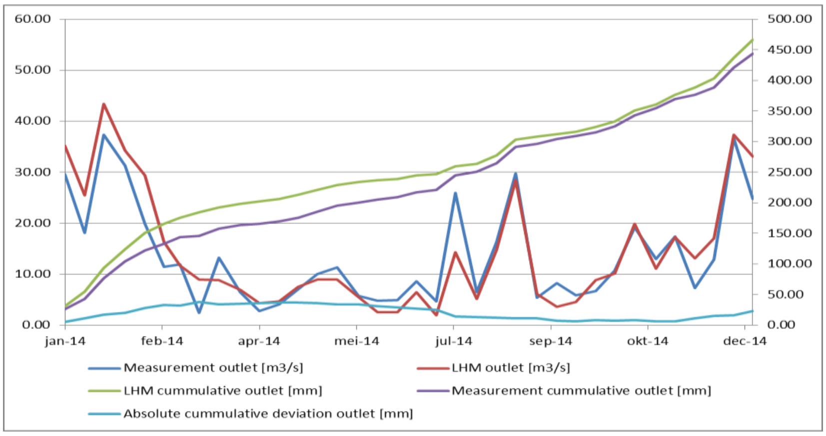


Figure 3.2.11a. Measured and modelled water outlet for Rijnland polders 2014 (left: [m^3/s], right: [mm])

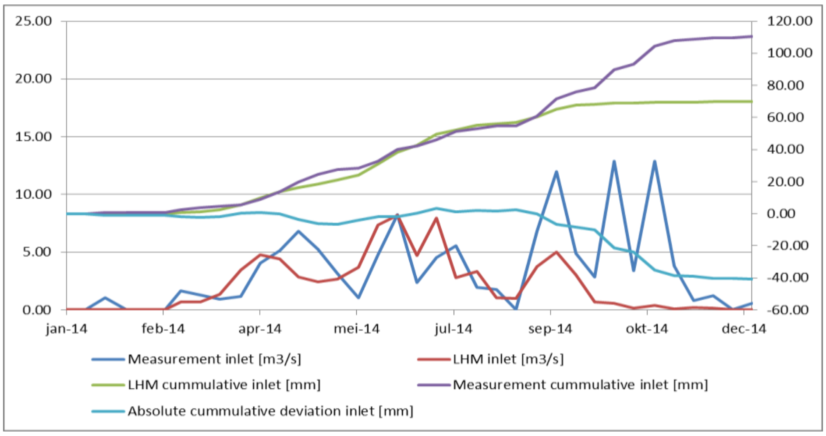


Figure 3.2.11b. Measured and modelled water inlet for Rijnland polders 2014 (left: [m^3/s], right: [mm])

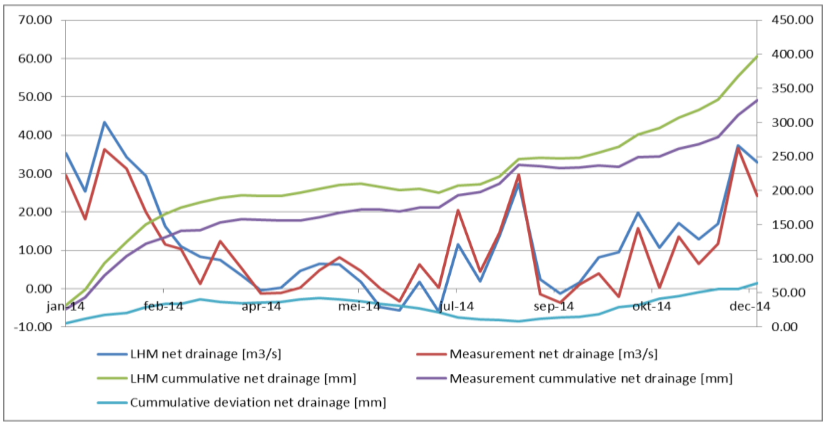


Figure 3.2.11c. Measured and modelled net water discharge for Rijnland polders 2014 (left: [m^3/s], right: [mm])

2003

Figures 3.2.7ab show that the trend in both the water discharge and -inlet is properly reproduced, and that no major peaks are missing. However, the cumulative deviations can become quite significant throughout the year. Figure 3.2.12 shows that 2003 has been a dry year, especially during July and August. The inlet in figure 3.2.7b shows that most of the inlet deviation occurs before July. After July, the modelled inlet fluctuates between high and low values, but the cumulative deviation remains rather constant. The discharge of water from the polders is approximately a constant 2 m^3/s too high.

For the year 2003 the LHM calculates more inlet of water, but also more outlet than measured. These deviations are for some part due to deviations in the amount of applied flush water. To account for these differences the net drainage (ND) is calculated. The ND represents the water discharge minus the water inlet. In general, this means that during the winter the ND is positive, and that during the growing season the ND is negative (a net water demand). The Cumulative Deviation in Net Drainage (CDND) represents the LHM ND minus the measurement ND. An increase in CDND indicates that the LHM net-discharges more water than according to the measurements occurred, and a decrease in CDND indicates that the LHM has a too large water net water use/demand

Figure 3.2.7c shows that for 2003 the dynamicss in ND are properly reproduced. The CDND increases at the start of the year and shows a small decrease at the start of the growing season, while it remains rather constant from April to July. From August onwards, CDND increases again. The water demand for the growing season is calculated rather well with a modelled under-demand of 11.5mm, or an average 0.7 m^3/s.

2006

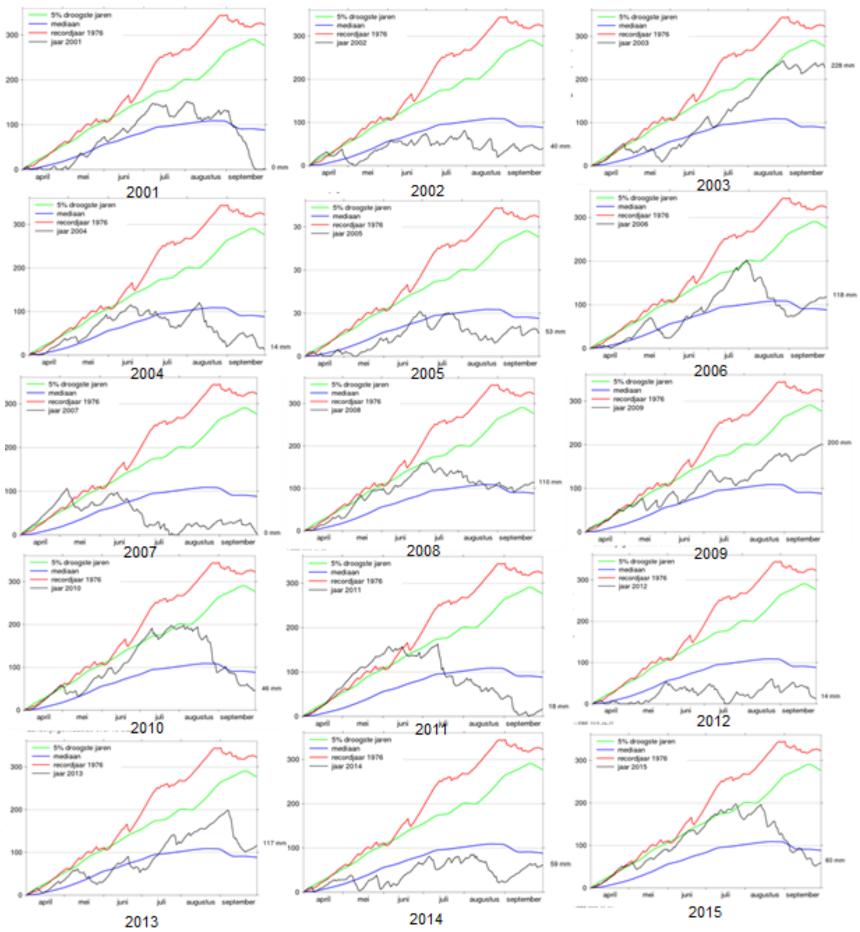
In figure 3.2.8ab the cumulative deviations of inlet and discharge for 2006 are much smaller than for 2003. The ND in figure 3.2.8c performs well, only in august a ND peak is missed by the model and during November the LHM is discharging water that is not found within the measurements. The water demand for the growing season is modelled 13.6 mm, or an average 0.84 m^3/s, too high.

2008

In figure 3.2.9abc the outlet peak during July 2008 is missed. Figure 3.2.9c shows that this error balances the high CDND that is developed since the start of the year. The water use for the growing season is modelled 31.2mm to high, which is mainly due to the missing of the discharge peak in July. Without July the calculated water use is around 6mm to high, or 0.37 m^3/s.

2010

The 2010 water balance is composed in a less detailed way, this probably explains the larger deviation. For the year 2010 in figure 3.2.10abc the same trends apply as for the years described above. However, the CDND becomes very large during the winter season. This could very well be caused by errors in the measurement data, as it shows a net inlet for the months November and December. For the growing season the ND is reproduced much better. The water demand is calculated 3.1mm, or 0.2 m^3/s, to high, fluctuating throughout the season. For June 2010, a major drop in ND demand is visible, this is because the model starts earlier with the inlet of water (See figure 3.2.14 for better scale of CDND).



Red line: recordyear 1976; green line: 5% dryest years; blue line: median; black line: concerning year

Figure 3.2.12. Precipitation deficit for the Netherlands for the years 2001-2015, April to September [mm] (after KNMI.nl)

2014

The year 2014 in figure 3.2.11abc shows that the inlet is not reproduced very nicely, the trends in ND performs quite well this year. The modelled over use of water for the growing season is high compared to other years, 20.2mm or 1.25 m^3/s.

2000-2014

Figures 3.2.13 and 3.2.14 show that, while individual year differ, one major trend in CDND becomes visible. For the winter season the model structurally net drains too much water. The trends reverses for the growing season, here the model structurally has a too low ND, or a too large water demand/use. The height for each yearly sinusoidal CDND differs and no trend is found in this: A few large deviation peaks generally determine the height of the whole graph. It is clear however that the over-ND in winter season does not completely balance the under-ND in the growing season. The average deviation of the years in figure 3.2.13 supports these conclusions. Table 3.2.1 shows that there are large differences in deviation between the validated years. It is noteworthy that the median deviation of inlet and outlet for the growing season show that most of the over-demand during the growing season is due to a too small outlet.

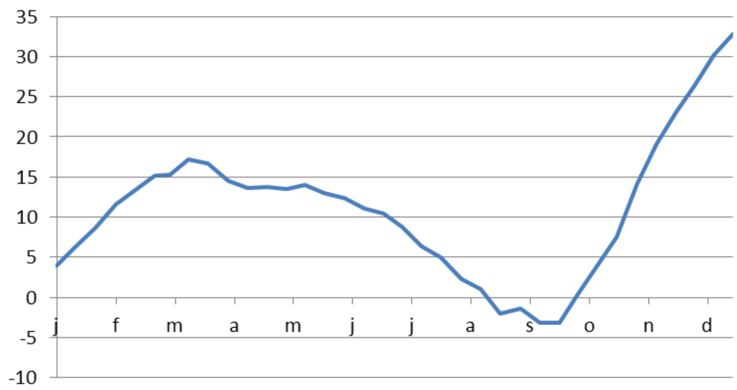


Figure 3.2.13. Average CDND over the years 2000-2014 for the Rijnland polders [mm]

Year	Deviation inlet				Deviation outlet				Deviation net drainage			
	Year		Apr-Sep		Year		Apr-Sep		Year		Apr-Sep	
	Abs [mm]	%	Abs [mm]	%	Abs [mm]	%	Abs [mm]	%	Abs [mm]	%	Abs [mm]	%
2000	3.3	5.5	14.5	32.8	0.3	0.1	-23.3	-19.8	-3.0	-0.5	-37.8	-51.2
2001	-4.1	-6.3	5.3	10.0	-20.4	-3.2	-29.8	-12.5	-16.3	-2.9	-35.1	-18.9
2002	42.8	214.5	36.7	211.5	60.8	13.7	11.4	12.6	18.0	4.3	-25.2	-34.5
2003	27.9	35.0	20.1	27.1	78.5	28.8	28.9	74.0	50.5	26.2	11.4	-32.9
2004	-30.4	-31.4	-15.1	-19.8	21.4	4.4	-14.9	-9.4	51.8	13.2	0.2	0.2
2005	-28.0	-32.4	-10.6	-17.5	-23.7	-5.0	-29.2	-19.1	4.3	1.1	-18.6	-20.2
2006	-8.3	-9.8	6.4	9.8	39.5	9.0	-7.2	-5.0	47.8	13.5	-13.6	-17.0
2007	-35.1	-40.5	-15.9	-27.8	1.2	0.2	-7.6	-3.9	36.4	8.0	8.3	6.1
2008	3.5	6.3	8.0	16.5	22.7	4.6	-23.2	-16.9	19.2	4.4	-31.2	-35.0
2009	4.8	5.7	8.8	12.4	51.8	14.9	-2.0	-2.6	46.9	17.9	-10.8	-392.1
2010	-26.1	-27.5	7.6	13.1	162.2	42.6	4.4	2.8	188.3	65.8	-3.1	-3.1
2011												
2012	-46.2	-44.8	-15.2	-24.4	-9.6	-1.7	-49.0	-26.2	36.6	7.9	-33.7	-27.1
2013	-24.7	-22.6	-16.8	-17.9	47.0	9.9	-39.7	-29.1	71.7	19.5	-22.9	-53.9
2014	-40.6	-36.8	-8.3	-11.7	23.4	5.3	-28.4	-19.5	64.0	19.2	-20.2	-26.7
Average	21.7	34.6	12.6	30.2	37.5	9.5	19.9	16.9	43.7	13.6	18.1	47.9
st. dev.	15.7	50.2	8.2	49.1	40.1	11.5	14	17.5	44.3	16	12.3	93.4
Median	-16.5	-16.2	5.8	9.9	23.1	4.9	-19.1	-10.9	41.8	10.6	-19.4	-26.9

Table 3.2.1. Overview of the Mozart validation for the Rijnland Polders

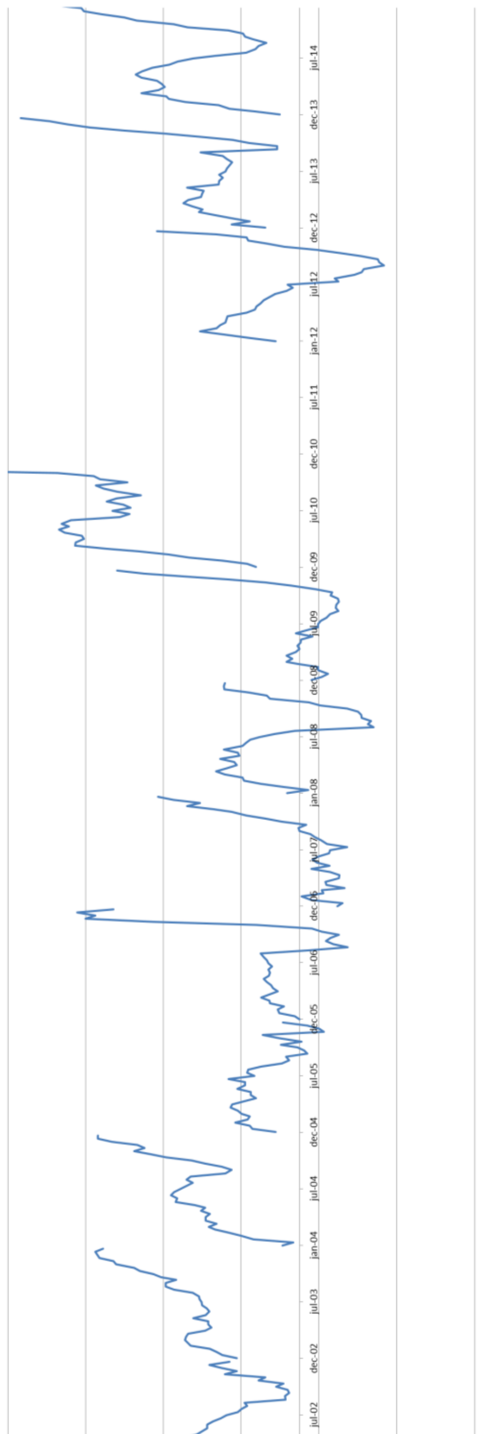


Figure 3.2.14. Yearly CDND for Rijnland polders 2000-2014 (excl 2011) [mm]

3.2.3.3 Boezem Rijnland

Within the DM model for Rijnland the Rijnland boezem is schematised. While the Mozart validation above represents only the polder areas, the DM model gives a more practical understanding of the complete water demand. Validation has been done for the years 1997-2015. Generally, the results for these years show the same patterns, outlined below are the years 2003, 2011 and 2015 as these years have been particularly dry. 2015 showed a constant dryness-progression from April to August, toward substantial dry conditions in August (see figure 3.2.12).

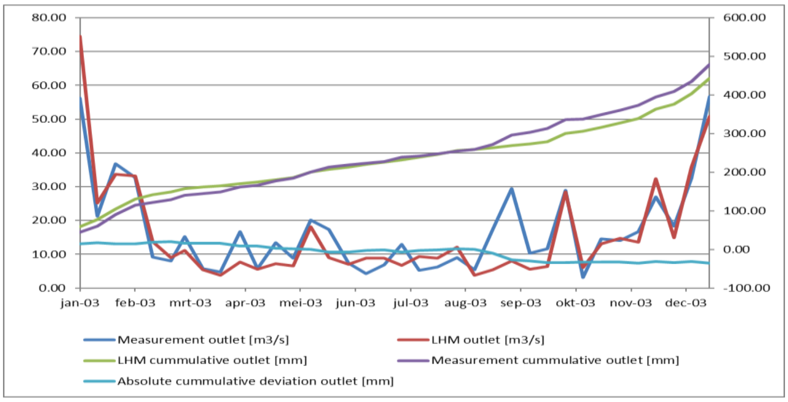


Figure 3.2.15a. Measured and modelled water outlet for Rijnland 2003 (left: [m^3/s], right: [mm])

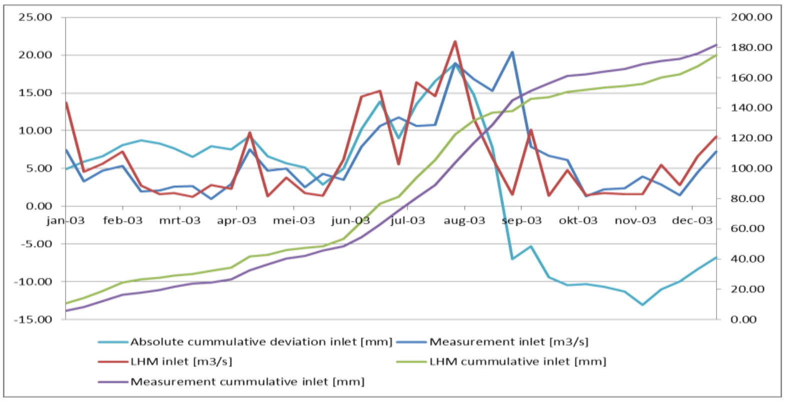


Figure 3.2.15b. Measured and modelled water inlet for Rijnland 2003 (left: [m^3/s], right: [mm])

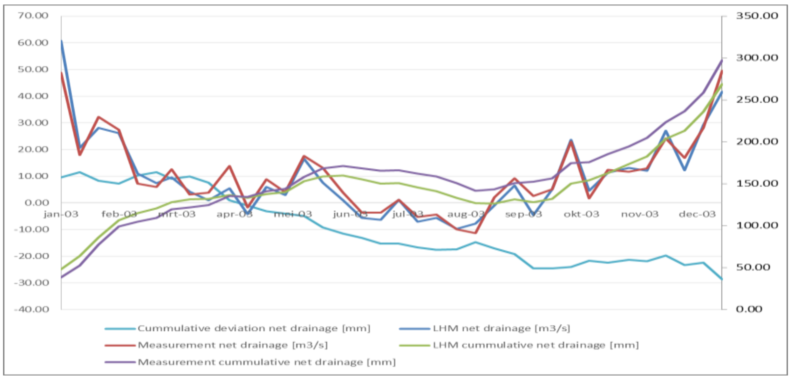


Figure 3.2.15c. Measured and modelled water net drainage for Rijnland 2003 (left: [m^3/s], right: [mm])

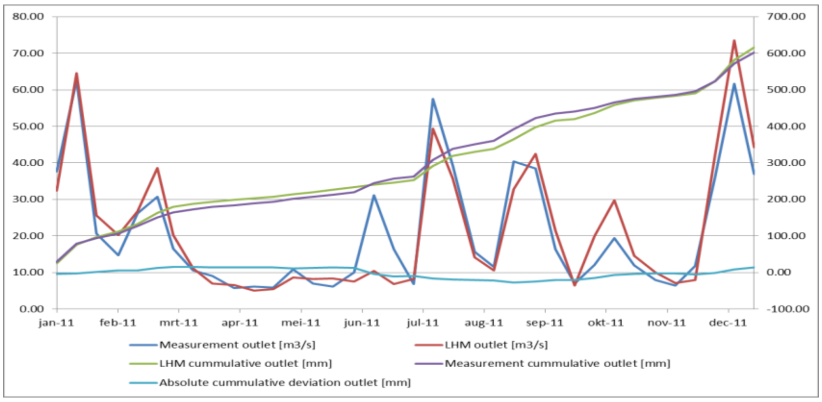


Figure 3.2.16a. Measured and modelled water outlet for Rijnland 2011 (left: [m^3*/s], right: [mm])*

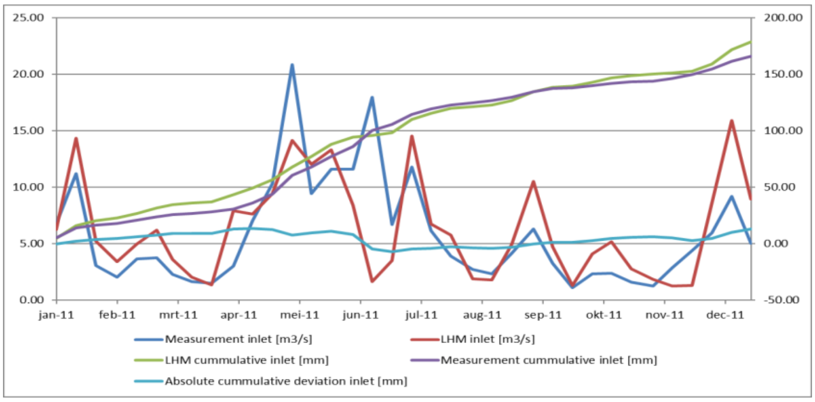


Figure 3.2.16b. Measured and modelled water inlet for Rijnland 2011 (left: [m^3*/s], right: [mm])*

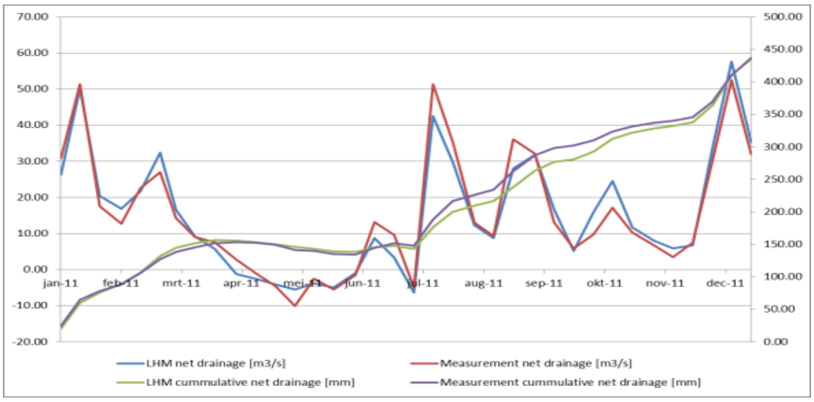


Figure 3.2.16c. Measured and modelled water net drainage for Rijnland 2011 (left: [m^3*/s], right: [mm])*

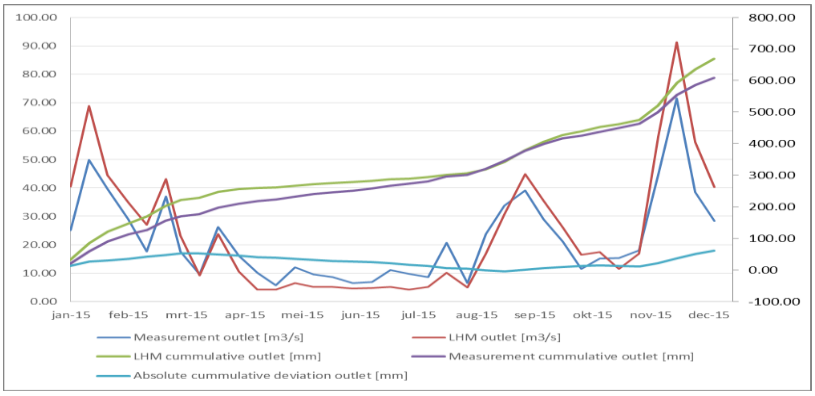


Figure 3.2.17a. Measured and modelled water outlet for Rijnland 2015 (left: [m^3/s], right: [mm])

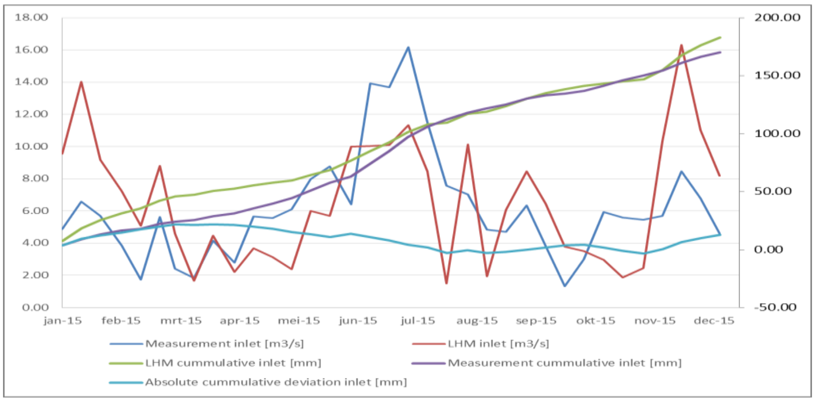


Figure 3.2.17b. Measured and modelled water inlet for Rijnland 2015 (left: [m^3/s], right: [mm])

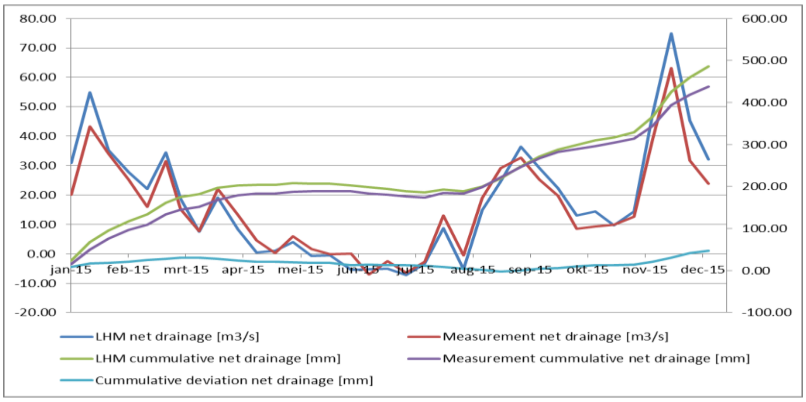


Figure 3.2.17c. Measured and modelled water net drainage for Rijnland 2015 (left: [m^3/s], right: [mm])

2003

In 2003, by the end of August and start of September extra fresh water from the AGV area was supplied to Rijnland via the Tolhuissluis-route, see 3.7.1. This route is not implemented in the model. However, when needed, the LHM should still supply this water via the common supply routes. In figure 3.2.15b the Tolhuissluis peak is clearly visible in the measurements and not included in the LHM, however at the same time an un-modelled outlet peak is visible in figure 3.2.15a. This indicates that most of the water that is supplied via the Tolhuissluis route was used for flushing. This is backed by the facts that figure 3.2.12 shows that precipitation deficit dropped by the end of august, and that the ND for 2003 in figure 3.2.15c does show no deviation at the time the Tolhuissluis was implemented. The dry summer of 2003 does show no deviations that are more extreme than the deviations in other years. For the growing season of 2003 the LHM overestimates the water demand with 25.6mm, or an average 1.8m^3/s.

2011

The year 2011 was particularly dry during spring, during the end of May and June water was supplied at Bodegraven via the KWA-route. In figure 3.2.16abc, during this period the individual outlet and inlet are not exactly reproduced by the LHM, but do show the same trends and order of magnitude. For the beginning of May, the LHM shows an underestimate of the water demand by 5 m^3/s, but this is before the KWA started. The ND during the start of the KWA is remarkably well reproduced by the LHM, with a demand of -5.5 m^3/s. Halfway June the ND starts to deviate again, but at this moment the worst drought is over and there is already a water surplus again. For the growing season of 2011 the LHM overestimates the water demand by 23.8mm, or an average 1.7 m^3/s. While 2011 was dry, the overestimate is in line with the overestimations in other years. KWA 2011 results will be further discussed in the HDSR section.

2015

Figure 3.2.12 shows that the year 2015 experienced a very steady increase of dryness throughout the growing season. The outlet in figure 3.2.17a for 2015 shows that the LHM calculates a too large outlet in winter and a too small outlet during summer. The water inlet in figure 3.2.17b is reproduced quite poorly and the LHM calculates too less inlet of water. However, the cumulative deviation in water outlet and inlet remain small. Figure 3.2.12 shows that the drought in 2015 is at its peak during June and July, here the difference in inlet is the largest as well. The trends in the ND are captured very well by the LHM, as shown by figure 3.2.17c. The ND does not show an exceptional large deviation during June and July.

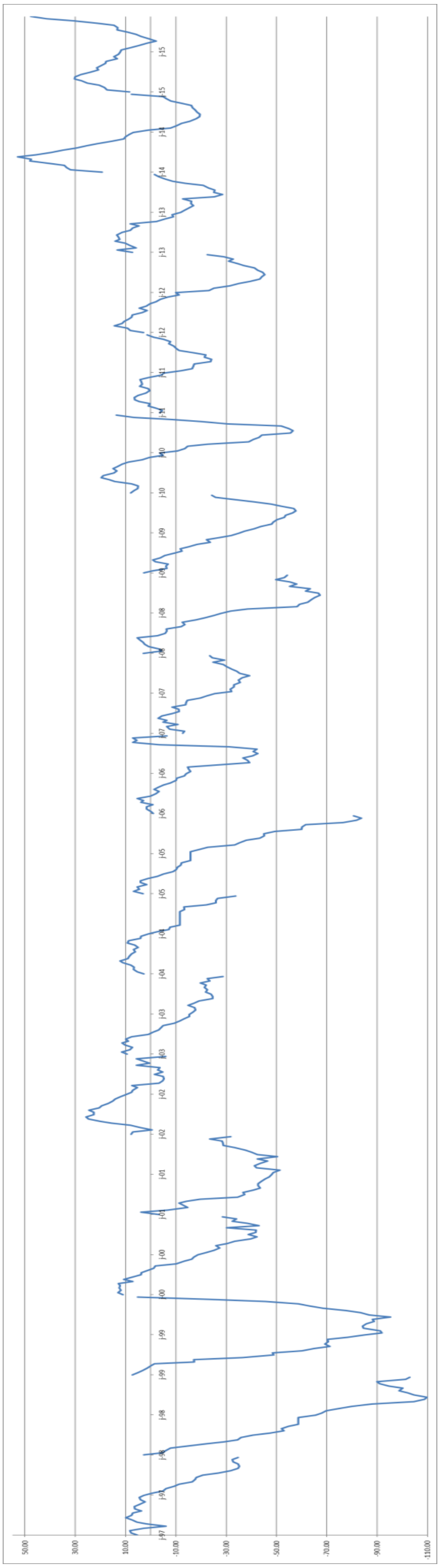


Figure 3.2.18. Yearly CDND for boezem Rijnland [mm]

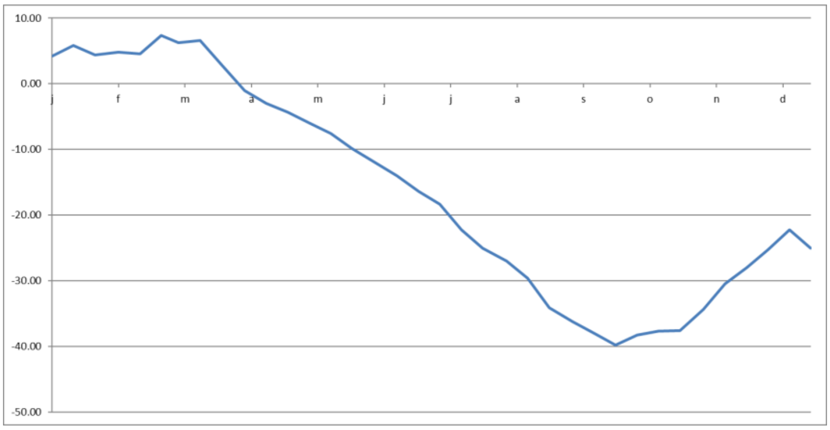


Figure 3.2.19. Average CDND over the years 1997-2015 for the Rijnland boezem [mm]

Year	Deviation inlet				Deviation outlet				Deviation net drainage			
	Year		Apr-Sep		Year		Apr-Sep		Year		Apr-Sep	
	Abs [mm]	%	**Abs [mm]**	%	**Abs [mm]**	%	**Abs [mm]**	%	**Abs [mm]**	%	**Abs [mm]**	%
1997	46.3	51.4	21.5	35.1	11.5	3.3	-4.3	-4.3	-34.8	-13.6	-25.8	-64.9
1998	46.1	34	1.3	2.3	-56.9	-6.6	-67.8	-25.1	-102.9	-14.2	-69.1	-32.6
1999	71.5	66	22	43.6	76.7	12	-24.5	-15	5.1	1	-46.5	-41
2000	67.2	64.2	18.6	44	38.7	5.6	-27.5	-19.4	-28.5	-4.9	-46.1	-46.3
2001	46	32.2	17.1	22.4	14.3	1.9	4	1.6	-31.7	-5.4	-13.2	-7.6
2002	39	32.5	1.1	2.1	33.1	5.7	-26.3	-18.4	-5.9	-1.3	-27.4	-30
2003	-6.8	-3.7	-16.9	-13	-35.4	-7.4	-42.5	-28.2	-28.6	-9.6	-25.6	-122.2
2004	25.2	21.7	-7.7	-10.9	-8.5	-1.7	-26.9	-22.6	-33.7	-8.5	-19.2	-39.3
2005	-5.6	-5	-14.4	-32.6	-86.3	-14.3	-54.5	-31.9	-80.7	-16.4	-40.1	-31.7
2006	20.5	13.5	6.2	6.8	14.1	2.5	-32.3	-15.7	-6.4	-1.5	-38.5	-33.5
2007	28.8	22.2	-5.7	8	5.3	0.8	-36.5	-14.2	-23.5	-4.4	-30.8	-16.7
2008	1.4	1	-24.2	-28.2	-52.9	-7.9	-85.8	-38.8	-54.3	-10.4	-61.6	-45.6
2009	39.8	32.4	21.4	31.3	15.4	3.2	-22.9	-18.6	-24.3	-6.8	-44.3	-81.1
2010	44.2	33.8	11.6	15.5	58	9.6	-47.3	-19.6	13.8	2.9	-58.8	-35.4
2011	13	7.9	-11.6	-10.8	14.5	2.4	-35.4	-13.8	1.5	0.3	-23.8	-16
2012	15.3	13.3	-12.6	-25.3	-7.2	-1.1	-61.4	-29.8	-22.5	-4.2	-48.8	-31.2
2013	6.4	3.6	-30.8	-28.6	5	0.8	-70.6	-37.9	-1.4	-0.3	-39.9	-50.7
2014	41	41.1	2.6	4.9	48.6	9.7	-56.6	-31.6	7.6	1.9	-59.2	-46.8
2015	12.6	7.4	-17.5	-16.9	60.4	9.9	-35.6	-17.3	47.7	10.9	-18.2	-17.6
Average	29.1	24.7	-0.9	1.8	7.8	1.5	-39.7	-21.1	-21.2	-4.5	-38.8	-41.6
st. dev.	22.1	20.7	16.1	23.9	41.4	6.7	22	10.2	33	6.6	15.8	25.4
Median	28.8	22.2	1.1	2.3	14.1	2.4	-35.6	-19.4	-23.5	-4.4	-39.9	-35.4

Table 3.2. Overview of the DM validation for the Rijnland Boezem

1997-2015

Figure 3.2.18 shows that the CDND varies for each year, but for each year the same upward trend during the winter and downward trend during the growing season is visible (figure 3.2.19). This trend was, with the same order of magnitude and different height, also visible for the Rijnland polder validation above. Table 3.2 shows that for each year the ND during the growing season is calculated too small by the LHM, indicating a too large water demand. This is on average 40mm/decade, or 2.9 m^3/s. Table 3.2 also shows that most of this over demand is projected on the outlet. While the average deviation in inlet is -0.9mm/decade, or -0.06 m^3/s, the average deviation in outlet is -39.7mm/decade, or -2.8 m^3/s. The fact that most of the over demand is projected on the outlet is probably due to the combination of calculation procedure and 10-day resolution within the LHM. When water is used within the model, for example for evaporation, this amount of water will first be reduced from the total outlet of water. Only in cases when no internal water is left, external water will be let in. This explanation leads to the hypothesis that during longer periods of drought, the error in water inlet should increase. Because during these periods the model runs out of internal water to use for the over-demand. This trend is not found; and is probably due to the 10-day resolution of the model. Most of the time there will occur some rainfall event during these 10 days, over which the results are averaged.

One of the explanations for the sinusoidal deviation in water demand in figure 3.2.19 could be a storage term. Average error in ND is 40mm/year, which would indicate a storage error of 20mm/yr. While the LHM discharges too much water during the winter season, in reality some of this water is stored within the system. During the growing season, some of this stored water will be used again, however, within the LHM this water must be supplied again. While there is no direct evidence to make this conclusion, the error in storage capacity could be within the unsaturated zone and in line with the findings from the ground water level validation in section 3.1.

3.2.3.4 Haarlemmermeer Polder

	Measurement		**LHM**	
	2014	2015	2014	2015
Inlet	25	25	12.6	13.5
Discharge	121	138	142	164
Seepage	26	26	28	28

Table 3.3. Comparison of estimates and LHM results for the Haarlemmermeer polder [Mm^3/yr]

Table 3.3 shows that for the Haarlemmermeer polder an approximate underestimate of inlet by 8.25Mm^3/yr and overestimate of outlet by 20Mm^3/yr, respectively 44.5mm and 108mm, is calculated. Seepage is calculated almost correct. CDND for 2014 and 2015 is 33.5Mm^3 and 37.5Mm^3, or 181mm/yr and 203mm/yr respectively.

For the HLM polder inlet is not directly measured, outlet however is. During the growing season average low outlet of the HLM polder is approximately 2m^3/s. Seepage is 0.8m^3/s, indicating that the flush inlet is 1.2m^3/s. The LHM imposes a flush of 0.7m^3/s (figure 3.2.5a). Adding the deviation in flush to the LHM inlet results in an inlet of 20-21Mm^3/yr. This is much closer to the measurements and suggests that most of deviation in inlet results from a wrong flush.

3.2.3.5 Polder De Noordplas

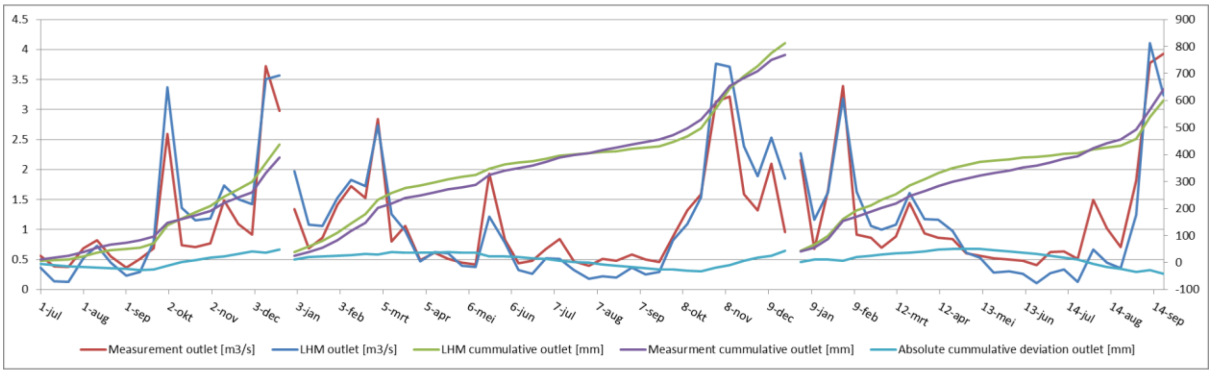


Figure 3.2.20a. Measured and modelled outlet for polder Noordplas 1999-2001 (left: [m^3/s], right: [mm])

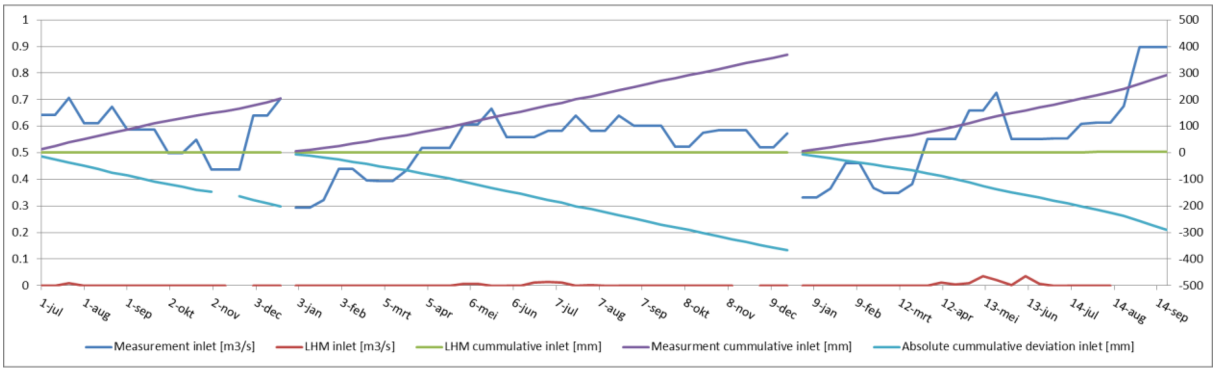


Figure 3.2.20b. Measured and modelled inlet for polder Noordplas 1999-2001 (left: [m^3/s], right: [mm])

Figure 3.2.20ab show that the outlet for Polder De Noordplas is in line with the measurements, with a cumulative deviation in outlet for the year 2000 of 43mm. However, the inlet is not in line. Where the LHM calculates barely any inlet, according to the measurements 400mm of inlet occurred during 2000. In the LHM no flush is imposed on Polder De Noordplas, this is also visible in figure 3.2.4b. This region experiences a lot of brackish seepage and flushing occurs to keep surface waters fresh.

For the year 2000, the deviation in inlet is -367mm. Together with the deviation in outlet this results in a CDND of 411mm. This indicates that, in comparison to the measurement data, the LHM net discharges 411mm more water. Seepage is estimated to be around 299 mm/yr, while the LHM calculates 175mm of seepage. The deviation in seepage increases the CDND to 534mm for the year 2000.

However, the measurement balance should also be approached critically. The measurements show an outlet of 769mm and an inlet of 368mm, resulting in a ND of 401mm for the year 2000. 299mm of the ND originates from seepage, this leaves only 102mm to discharge the precipitation deficit! However, the precipitation deficit was 553mm. So, it seems that the measurement data is not very realistic. When correcting for the precipitation deficit, a CDND of 81mm remains.

It remains unclear why the outlet is modelled so correctly. Before being able to draw further conclusions, it is recommended to compose a more realistic measurement balance, to impose a correct flush term on Polder De Noordplas in the LHM and to correct the seepage in the LHM.

3.3 Hoogheemraadschap van Delfland

Main conclusions

For Delfland the same systematic sinusoidal error in water use is detected as for Rijnland, with a linear over-use of 30-40mm during the growing season. Also for Delfland most of the deviation in over-use is projected on a too small outlet, and no relation with extreme dry events is detected. The amount of surface water allocation to agriculture in the Westland is significantly more than that for other regions, and there is no large-scale deviation in the boezem water use. It seems that greenhouse surface water use is calculated correctly.

Since two independent data sets show the same results this indicates that this deviation is probably very systematic for the LHM. Although it is of course recommended to fix this deviation, the magnitude and nature of the error still allows applications in the DPZW for this region.

3.3.1 Area description

The Hoogheemraadschap van Delfland (HHD), shown in figure 3.3.1, comprises an area of 39.000 hectares, of which 30.000 hectares of polders that all drain on the same boezem channel. Along the coast high elevated sand dunes are present. Crucial aspect in the fresh water management is the presence of greenhouses, mainly in the Westland in the south-west. Although most the greenhouses are largely self-sufficient in their fresh water supply, they still require fresh surface water to some extent.

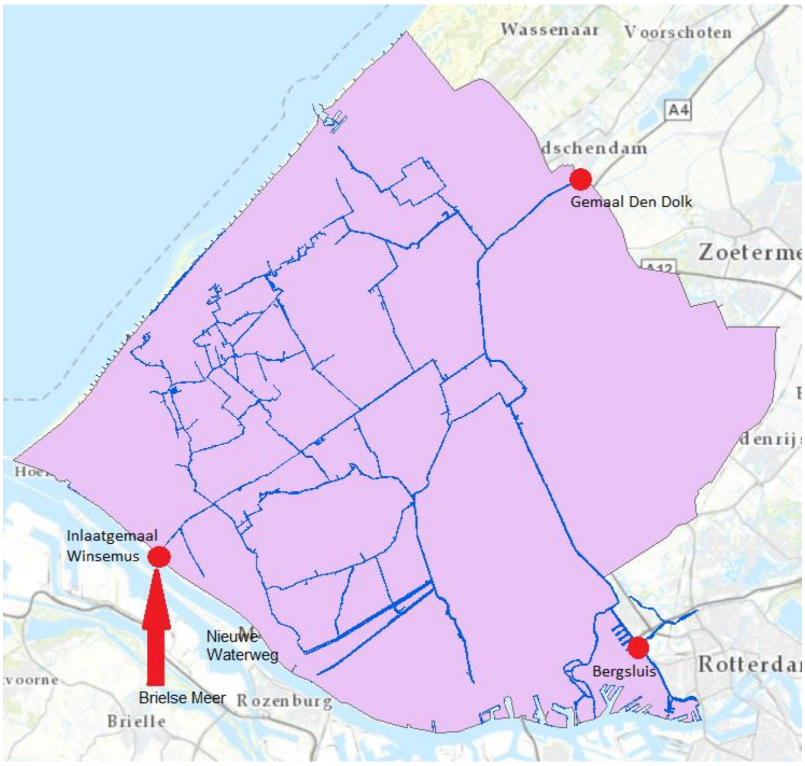


Figure 3.3.1. Boezem of Delfland and main fresh water supply locations

Supply of water

The Nieuwe Waterweg is too saline to use as a source for inlet water. Most fresh water is supplied from the Brielse Meer, via a pipeline underneath the Nieuwe Waterweg fresh water is supplied towards Delfland at pumping station Winsemus. Maximum capacity of this pipeline is $4m^3/s$. Additional water can be let in form the Rijnland area at Den Dolk, with a capacity of $8m^3/s$. In practise, capacity of Den Dolk is mainly depended on the availability of fresh water in Rijnland. Figure 3.2.2 shows that during the KWA Delfland can receive $2.9m^3/s$ via Den Dolk and must transfer $1.0m^3/s$ of this water to Schieland via pumping station Bergsluis. During dry periods, approximately $2m^3/s$ of fresh water is required for flushing to counteract salt water intrusion from the Nieuwe Waterweg at Parksluizen in Rotterdam.

3.3.2 LHM results

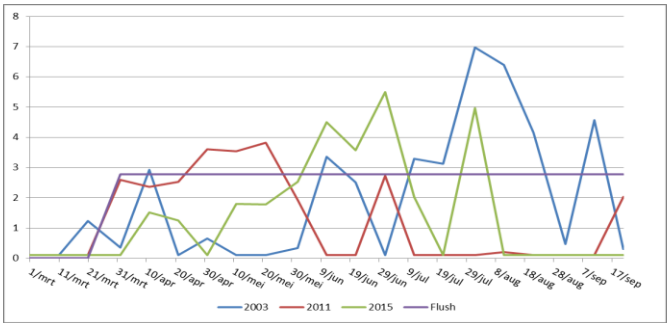


Figure 3.3.2a. Calculated water demand for the boezem of Delfland and flush of polders 2003, 2011 and 2015 [m^3/s]

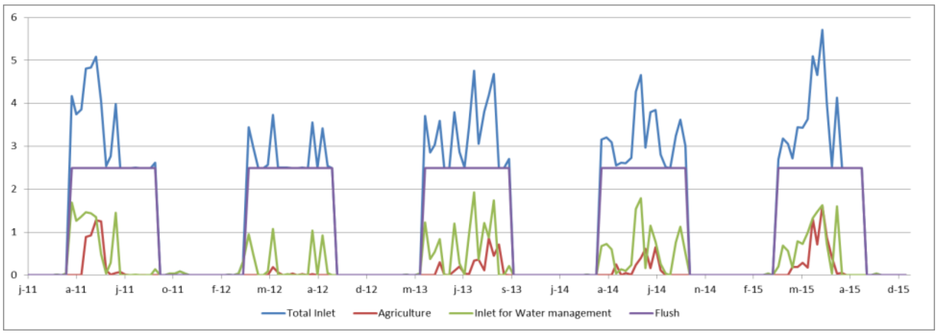


Figure 3.3.2b. LHM surface water allocation for Delfland polders 2011-2015 [m^3/s]

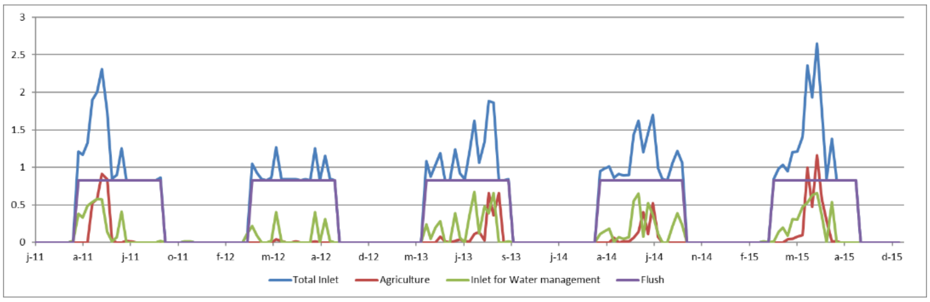


Figure 3.3.2c. LHM surface water allocation for Westland 2011-2015 [m^3/s]

Figure 3.3.2a shows the calculated inlet for the boezem of Delfland. The difference in water inlet during the dry periods in 2003, 2011 and 2015 differs strongly. It seems that when dryness occurs later in the growing season, more water is required. The depicted flush is the flush demand of the polders and is relatively high compared to the total inlet. The figure indicates that water can be used multiple times for flushing, e.g. from polder 1 to boezem to polder 2. Flush of the boezem itself is coupled to calculated chloride concentrations, and therefore fluctuates throughout the season.

Figure 3.3.2b shows that the Delfland polders have a much higher flush than Rijnland. The amount of surface water allocated to agriculture is around 1.0m^3/s for dry periods. Most of the agricultural water is allocated in the Westland. The flush-, agriculture- and water management allocation combined adds up close to the total inlet, and no explicit greenhouse water demand is given. It is therefore assumed that the greenhouse water allocation is included in the agricultural allocation. Estimated surface water extraction for greenhouse irrigation is around 0.5m^3/s during dry periods (0.8mm/d if all for the Westland). The LHM allocates this order of agricultural surface water.

The complete management area, excluding the dunes, experiences a net infiltration of 0.10mm/d.

3.3.3 Validation results

3.3.3.1 Boezem Delfland

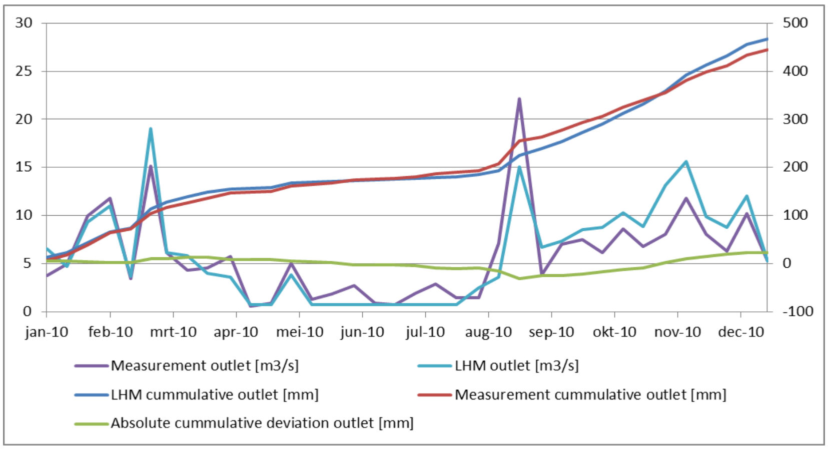


Figure 3.3.3a. Measured and modelled water outlet for Delfland 2010 (left: [m^3/s], right: [mm])

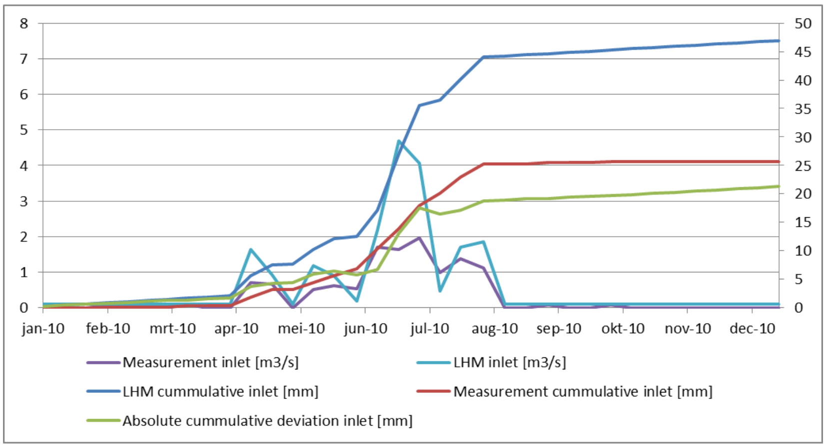


Figure 3.3.3b. Measured and modelled water inlet for Delfland 2010 (left: [m^3/s], right: [mm])

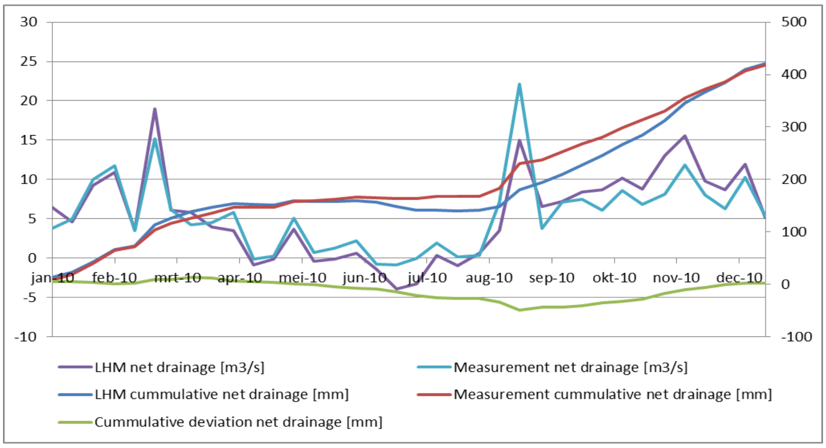


Figure 3.3.3c. Measured and modelled water net drainage for Delfland 2010 (left: [m^3/s], right: [mm])

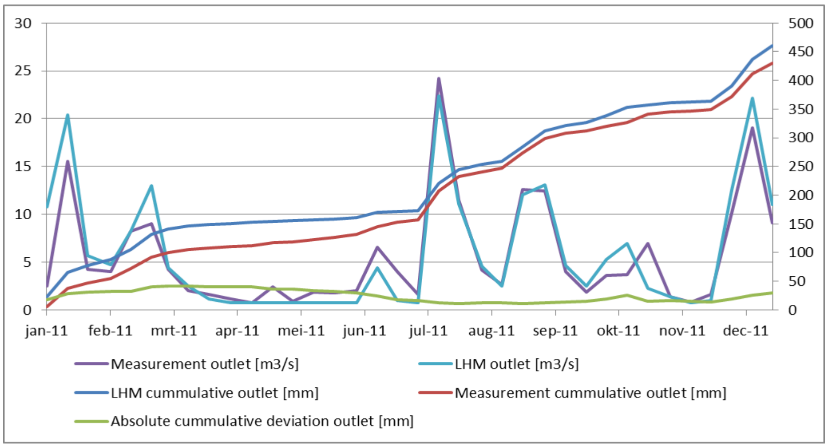


Figure 3.3.4a. Measured and modelled water outlet for Delfland 2011 (left: [m^3/s], right: [mm])

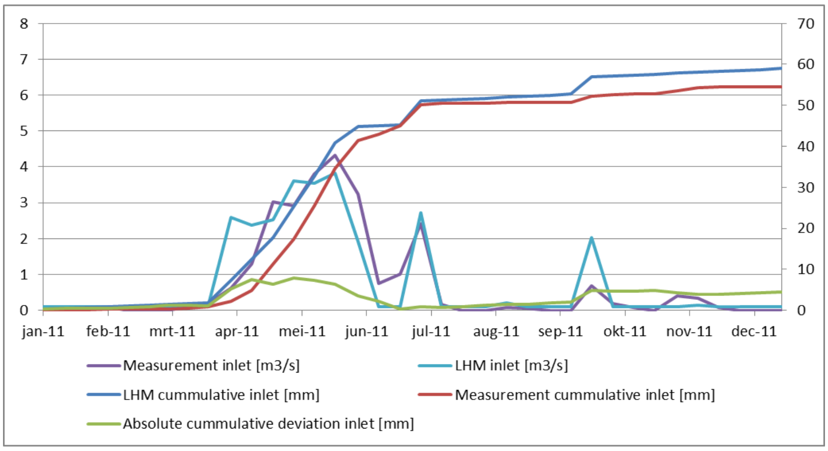


Figure 3.3.4b. Measured and modelled water inlet for Delfland 2011 (left: [m^3/s], right: [mm])

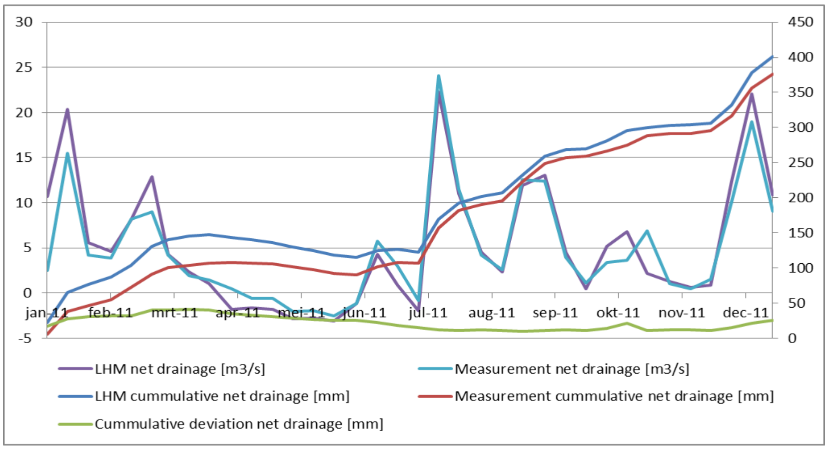


Figure 3.3.4c. Measured and modelled water net drainage for Delfland 2011 (left: m^3/s], right: [mm])

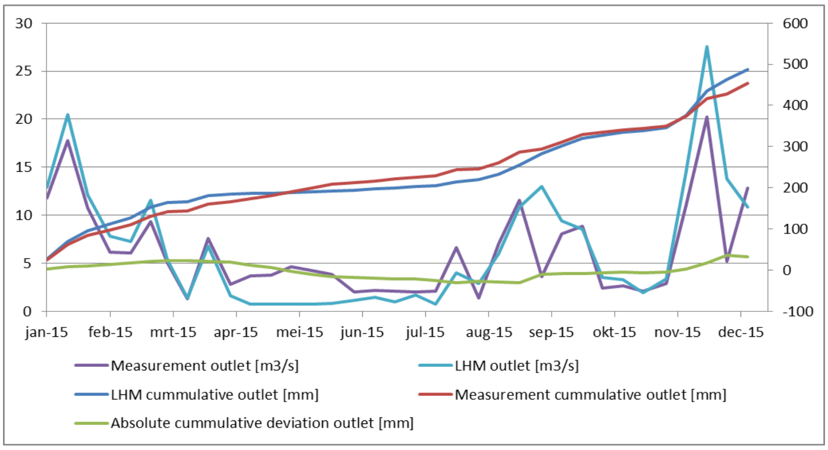


Figure 3.3.5a. Measured and modelled water outlet for Delfland 2015 (left: [m^3/s], right: [mm])

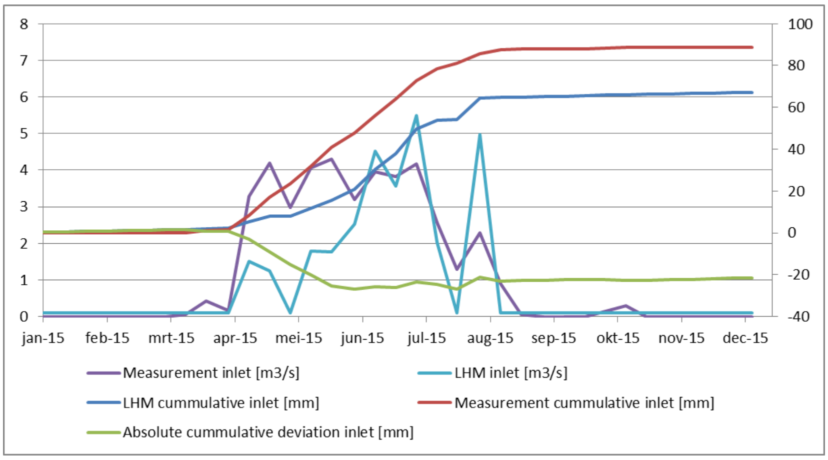


Figure 3.3.5b. Measured and modelled water inlet for Delfland 2015 (left: [m^3/s], right: [mm])

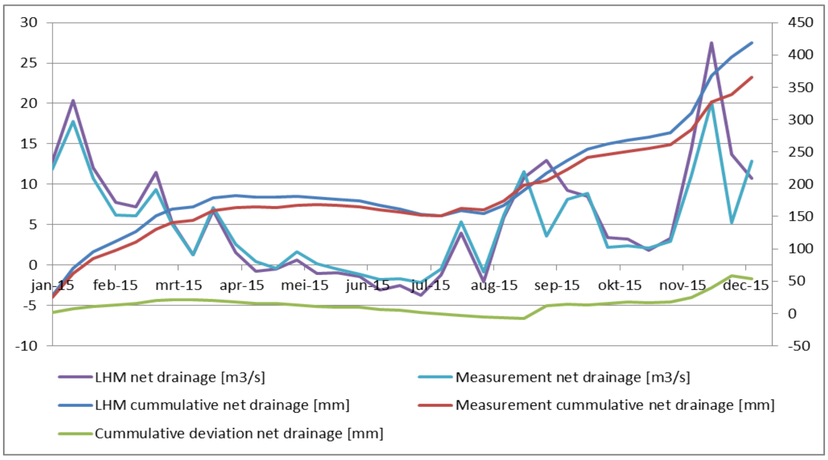


Figure 3.3.5c. Measured and modelled water net drainage for Delfland 2015 (left: [m^3/s], right: [mm])

2010

For 2010, in figure 3.3.3abc, the LHM overestimates the peaks in inlet, leading to a large cumulative deviation. Outlet during the growing season is structurally too low, causing the calculated water demand by the LHM to be too large for the growing season: 47.8mm or 1.26m^3/s. The dynamicss in ND are captured quite well by the LHM.

2011

It is remarkable that the year 2011, in figure 3.3.4abc, performs as one of the best in the Delfland validation, while it was quite dry during spring. However, most of the too large inlet for 2011 occurs during the dry spring and this deviation is partly balanced throughout the rest of the season. Flush seems to be imposed relatively correct for this year. During the driest May-June, net water use is too large but no significant error occurs. Water use during spring 2011 is calculated approximately 1m^3/s too high. This error is completely due to a too small outlet. Inlet is 0.3mm, or 0.008m^3/s, too small during the summer.

2015

During April-May 2015, in figure 3.3.5abc, the model misses a large amount of in- and outlet, but the ND is reproduced well for this period. This indicates that a major amount of flush is missed by the LHM. For the rest of the growing season the extremes in inlet are calculated too extreme. Compared to the other year the LHM scores average for this year, for the growing season inlet is underestimated by 23.0mm, outlet is underestimated by 27.6mm and ND is underestimated by 5.9mm.

2008-2015

Graph 3.3.6 shows that the sinusoidal trend that is visible for the CDND of Rijnland (Figure 3.2.18 and 3.2.19) becomes visible again in the average CDND for Delfland. For Delfland the CDND is more continuous than for Rijnland. The average CNCD in figure 3.3.7 shows an overestimation in ND of about 40mm for the winter, and an underestimation of ND of approximately 40mm for the growing season.

Table 3.3.1 shows that the deviation in inlet during the growing season varies strongly for the validated years, -0.7% to 127%. The average deviation in inlet during the growing season is 4.9mm, or 0.13 m^3/s. In absolute terms this deviation is very small, but still 41% of the measured inlet. Deviations in in- and outlet cannot al be attributed to too low flush rates, as the inlet is only significantly too low for 2014 and 2015, the outlet is too small for every growing season.

Average overdemand is 35.8mm, or 0.94 m^3/s. Most of the deviation in ND during the growing season is projected on the outlet of water, this is in line with the observations from the Rijnland boezem validation. No correlation between the magnitude in deviation and dryness-progression throughout the growing season has been found for the validated years.

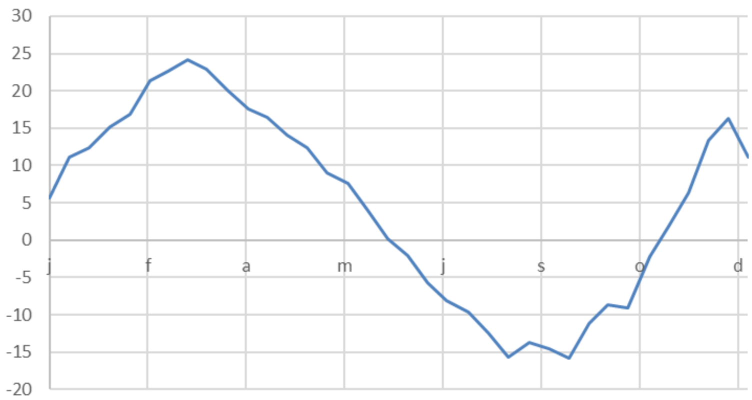


Figure 3.3.7. Average CDND over the years 2008-2015 for the Delfland boezem

Year	Deviation inlet				Deviation outlet				Deviation net drainage			
	Year		Apr-Sep		Year		Apr-Sep		Year		Apr-Sep	
	Abs [mm]	%	Abs [mm]	%	Abs [mm]	%	Abs [mm]	%	Abs [mm]	%	Abs [mm]	%
2008	2.7	10.1	0.2	0.8	77.6	21.9	-11.9	-12.4	74.9	22.9	-12.1	-17.1
2009	35.5	77.0	31.0	71.6	33.3	10.3	-10.6	-14.3	-2.2	-0.8	-41.6	-134.6
2010	21.3	83.2	17.8	70.8	23.3	5.3	-29.9	-20.5	2.0	0.5	-47.8	-39.5
2011	4.5	8.3	-0.3	-0.7	30.1	7.0	-24.9	-12.4	25.6	6.8	-24.6	-16.2
2012	20.5	123.1	16.4	125.8	31.6	6.8	-30.4	-21.1	11.1	2.5	-46.8	-35.6
2013	42.8	135.1	37.5	127.3	22.7	4.9	-24.6	-18.5	-20.1	-4.6	-62.1	-59.9
2014	-52.4	-45.5	-40.3	-40.8	-65.6	-15.0	-87.0	-53.9	-13.2	-4.1	-46.7	-74.7
2015	-21.5	-24.3	-23.0	-26.6	32.2	7.1	-27.6	-16.8	53.8	14.7	-4.6	-5.9
Average	6.7	45.9	4.9	41.0	23.2	6.0	-30.9	-21.2	16.5	4.7	-35.8	-48.0
st. dev.	29.3	63.5	24.8	62.3	37.3	9.5	22.4	12.7	31.0	9.0	18.6	39.2
Median	12.5	43.6	8.3	35.8	30.8	6.9	-26.2	-17.7	6.5	1.5	-44.1	-37.5

Table 3.3.1. Overview of the DM validation for the Delfland Boezem

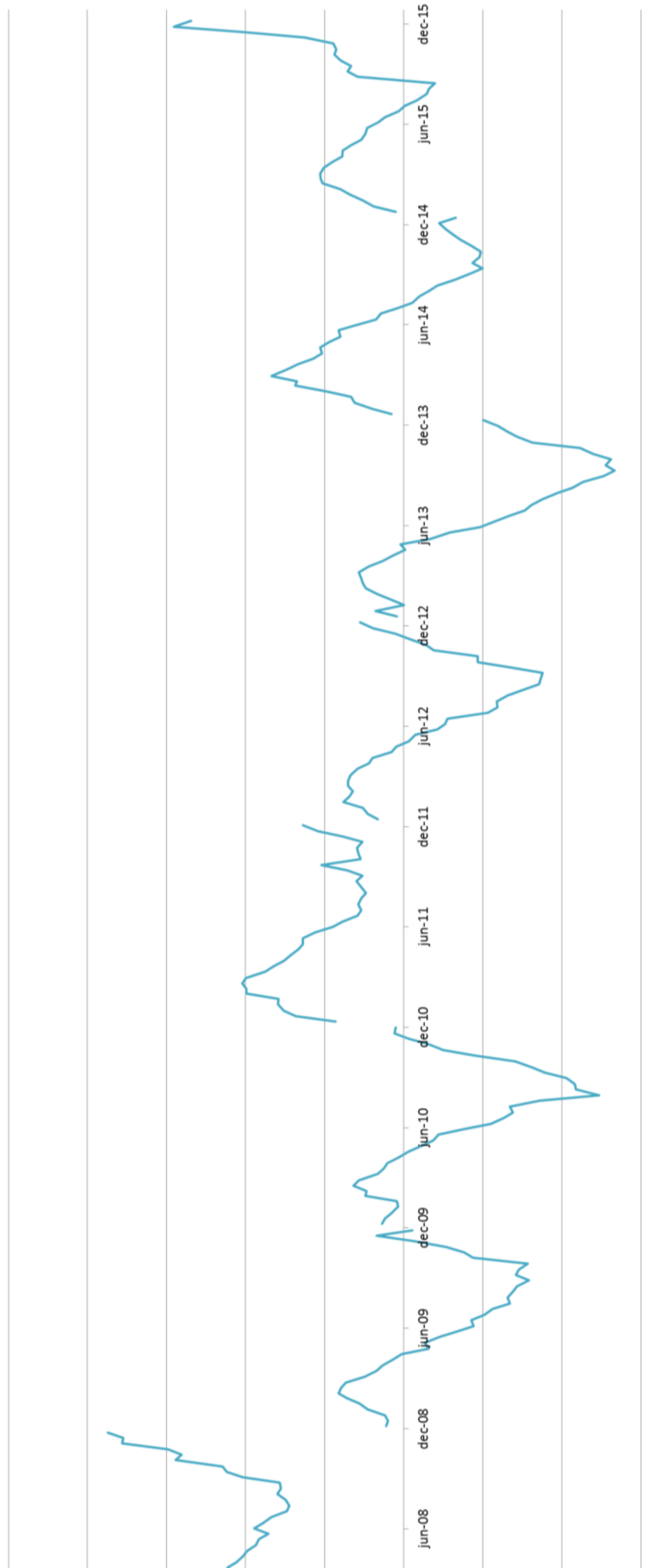


Figure 3.3.6. Yearly CDND for Delfland boezem 2008-2015 [mm]

3.4 Hoogheemraadschap van Schieland en de Krimpenerwaard

Main conclusions

For Schieland en de Krimpenerwaard the calculated water inlet for De Rotte, Ringvaart and Krimpenerwaard during dry conditions are approximately half the estimates given by HHSK. HHSK already expected that their estimates were serious overestimates and this is confirmed by the LHM. For the Krimpenerwaard and Ringvaart infiltration/seepage is calculates correctly, although the largest deviations occur at/near places with the largest infiltration/seepage rate. Seepage for De Rotte is 50% too low.

It is very well possible that the LHM calculates correctly for the Krimpenerwaard, and that the measurement data is wrong. This is supported by the conclusion that the LHM water inlet for the three HHSK regions in figures 3.4.2-3.4.4 all equally deviate from the estimates (slightly higher than half the estimate). Also the infiltration rate for the Krimpenerwaard is calculated correctly.

The measurement data is not detailed enough to make strong conclusions and no further recommendation regarding the usability for the DPZW can therefore be made.

3.4.1 Area description

The Hoogheemraadschap Schieland en de Krimpenerwaard (HHSK), shown in figure 3.4.1, is situated in the centre of the western Netherlands and is, with an area of 36.000 hectares, the smallest water authority in the region. The water system of HHSK can be subdivided into three hydrological regions, Schieland with De Rotte and De Ringvaart in the west, and the Krimpenerwaard in the east. Schieland and the Krimpenerwaard are separated by the Hollandse IJssel.

The Ringvaart district exchanges most of its water with the Hollandse IJssel, at Snelle Sluis. Although the location of Snelle Sluis is more sensitive to salinization than the Rijnland inlet at Gouda, salt tolerance for the Ringvaart is higher (400mg/l vs. 250mg/l). Therefore, in practice almost no limitations in fresh water inlet for the Ringvaart occur.

Within the Rotte district the local river De Rotte functions as boezem channel. Water inlet and outlet mainly occurs at Schilthuis, here water is exchanged with the Nieuwe Maas. The inlet location Schilthuis is very sensitive to salinization. However, land use in the south is mainly urban and saline water is not an issue. In the northern part of De Rotte greenhouses are situated which require fresh water of a higher quality. In case the inlet location Schilthuis must close due to salinization, fresh water from the Ringvaart can be let into the Rotte. This water will be pumped through the Eendragtspolder, indicted by the red arrow in figure 3.4.1. Additionally, Schieland can receive water from Delfland via Bergsluis: 1.4 m^3/s of Delfland water and 1 m^3/s of KWA water. The KWA for Schieland has been implemented in 2003 and 2011, Schieland has received water from Delfland in 2013 and 2014 as well.

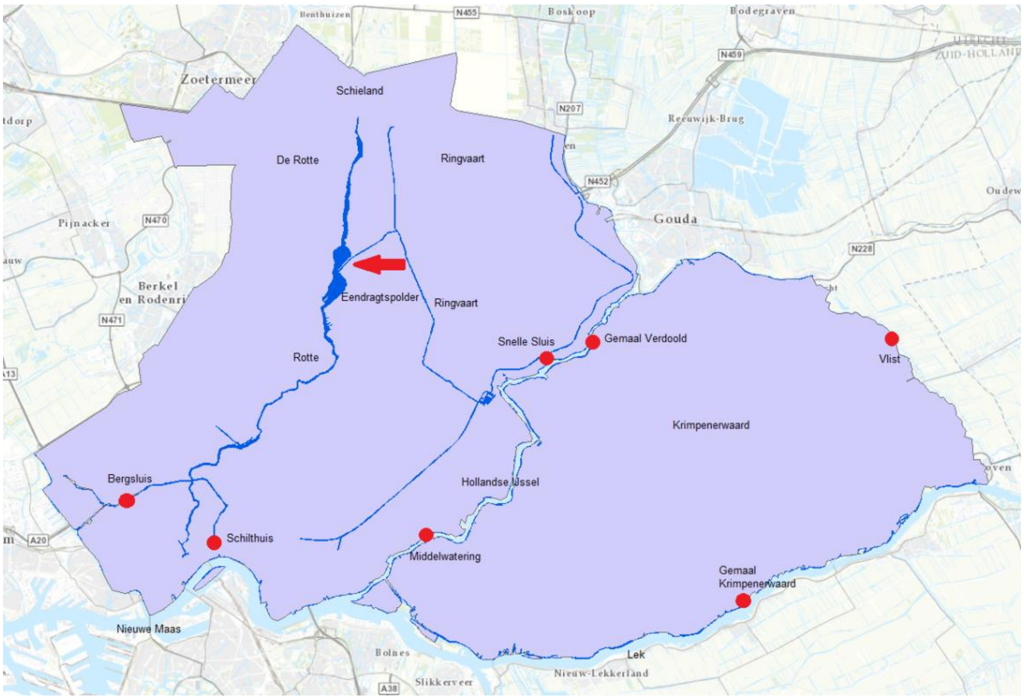


Figure 3.4.1. Boezem of Schieland and main fresh water supply locations for HHSK

The Krimpenerwaard does not have a boezem channel; instead water is exchanged directly with the surrounding rivers. Fresh water is mainly supplied from the Lek at Gemaal Krimpenerwaard, additionally multiple smaller inlet locations are distributed along the Krimpenerwaard. The Lek, at the location of Gemaal Krimpenerwaard, is practically insensitive to salinization and the Krimpenerwaard does not experience fresh water shortages. During spring-2011, when the chloride concentration in the Hollandse IJssel became too high for Rijnland, extra fresh water from the Lek was let in at Gemaal Krimpenerwaard to be subsequently discharged on the Hollandse IJssel by Gemaal Verdoold. This led to a reduction of chloride concentration in the Hollandse IJssel, and made this water more suitable for Rijnland.

3.4.2 LHM results

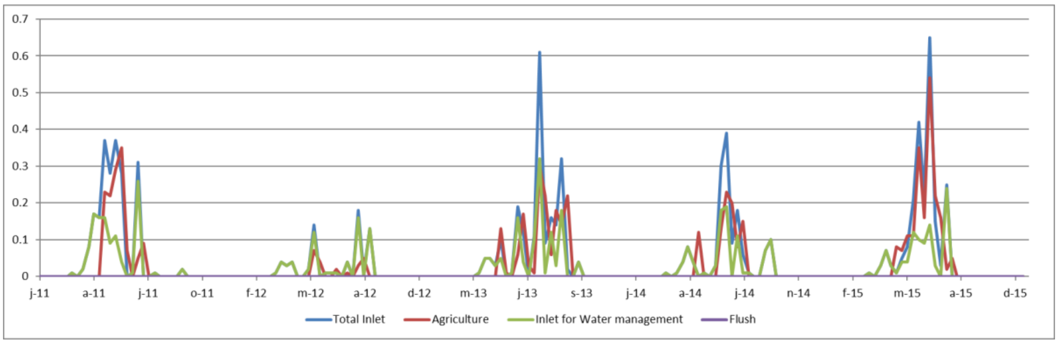


Figure 3.4.2. LHM surface water allocation for Rotte (excl Rotterdam) 2011-2015 [m^3/s]

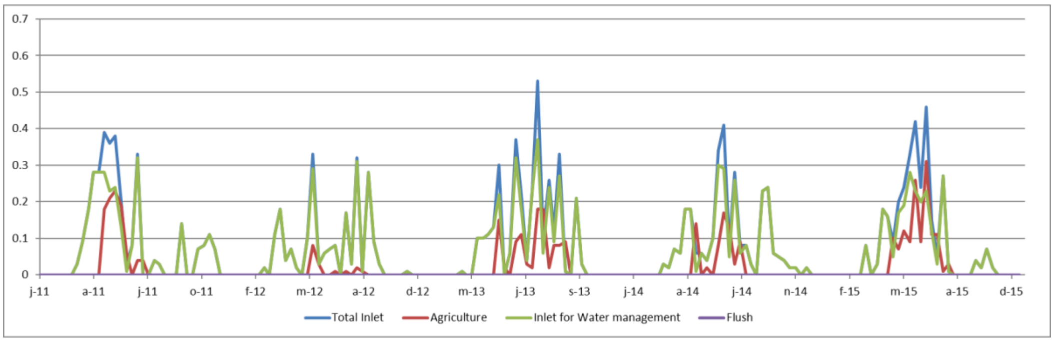


Figure 3.4.3. LHM surface water allocation for Ringvaart 2011-2015 [m^3/s]

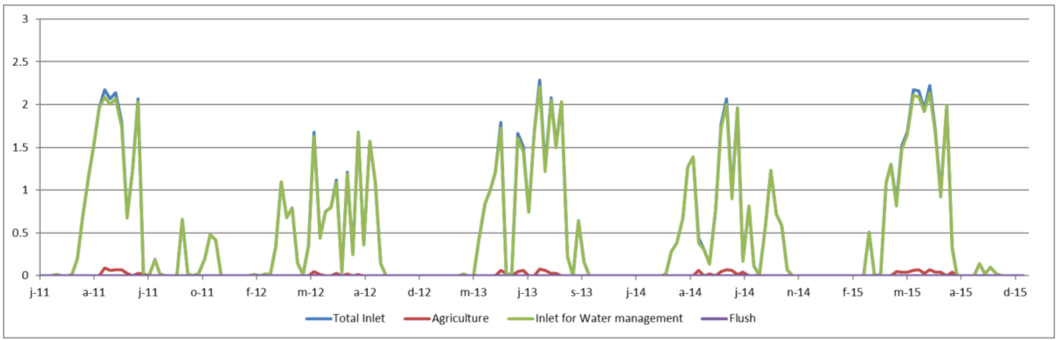


Figure 3.4.4. LHM surface water allocation for Krimpenerwaard 2011-2015 [m^3/s]

As rule of the thumb, HHSK uses a theoretical water demand for De Rotte, Ringvaart and Krimpenerwaard of 1.5 m^3/s, 1.0 m^3/s and 5.6 m^3/s respectively during dry periods. These quantities of water demand are highly theoretical and it is not known where they are exactly based on. It is known however that these theoretical demands are overestimates, and figure 3.4.2-3.4.4 show that the LHM is line with this conclusion. The LHM calculates a water demand for the three regions that, for dry periods, is half of the theoretical demand estimated by HHSK. However, the LHM does not impose flushing on these three regions. This is correct for De Rotte and Krimpenerwaard, but flushing is applied in the Ringvaart. Therefore, the actual water demand for the Ringvaart is higher than the LHM shows.

Surface water allocation to agriculture is relatively high for Ringvaart and De Rotte. In the Krimpenerwaard almost all the inlet is allocated to water management. This is in line with the seepage/infiltration rates. For the Krimpenerwaard external surface water is needed to counteract the infiltration.

	LHM		Measurement		Deviation	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Krimpenerwaard	-0.34	0.45	-0.29	0.37	-0.05	0.43
Ringvaart	0.31	0.75	0.31	0.67	0	0.52
De Rotte (excl Rotterdam)	0.16	0.36	0.33	0.34	0.17	0.36

Table 3.4.1. LHM and measurement seepage rates [mm/d] (seepage is positive)

Table 3.4.1 shows LHM seepage results for the three HHSK regions. The results are in line with the assumption that the Krimpenerwaard experiences high infiltration, and that the Ringvaart experiences high seepage.

3.4.3 Validation results

3.4.3.1 Krimpenerwaard

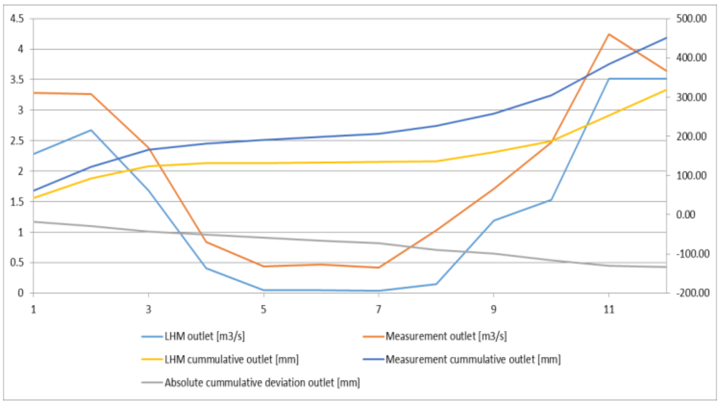


Figure 3.4.5a. Average modelled and measured outlet for the Krimpenerwaard on monthly base for the years 1997-2003 (left: [m^3/s], right: [mm])

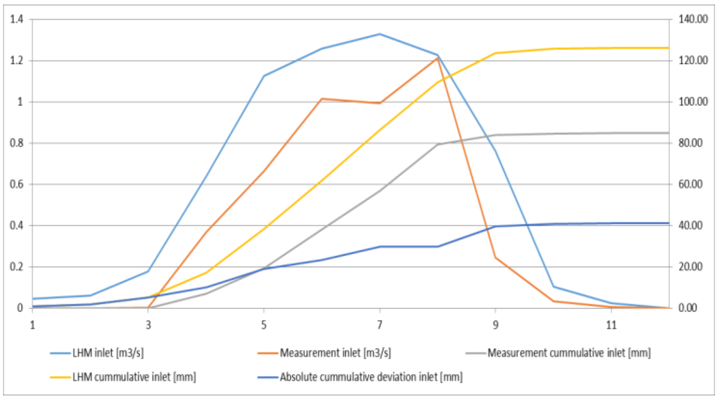


Figure 3.4.5b. Average modelled and measured inlet for the Krimpenerwaard on monthly base for the years 1997-2003 (left: [m^3/s], right: [mm])

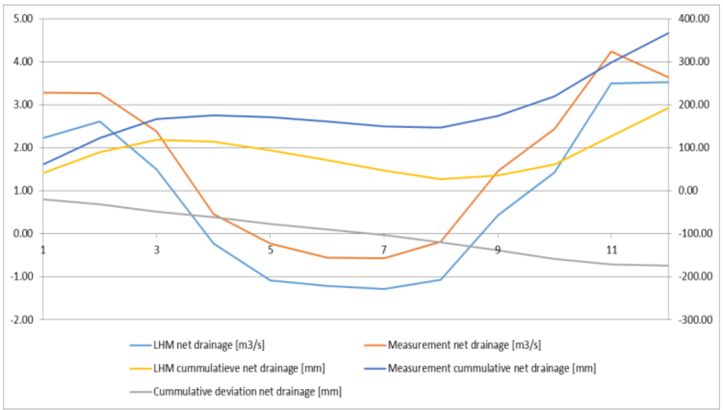


Figure 3.4.5c. Average modelled and measured ND for the Krimpenerwaard on monthly base for the years 1997-2003 (left: [m^3/s], right: [mm])

For the HHSK region only surface water measurements for the Krimpenerwaard are available, for the years 1997-2003 on a monthly base. Figure 3.4.5abc shows the validation results as an average for each month over the validated years. For each year, the outlet is seriously underestimated by the LHM and the inlet seriously overestimated. This results in a too small net drainage by the LHM. Due to the large temporal scale of the measurements and the large systematic deviation, the out- and inlet validation results for individual years did not give more insight and are therefore not shown.

While the deviation in inlet shows some seasonal trend, the deviation in outlet and ND do not have a seasonal trend. The model calculates an overdemand/overuse of approximately 0.50mm/d as shown by the CDND in figure 3.4.5c and 3.4.7. The deviation of the model is very constant throughout the year, indicating that the deviation is not caused by water fluxes that have a large seasonal variation, as precipitation, evaporation, inlet and outlet. However, is it noticeable that the LHM calculates an average yearly net infiltration of 0.33mm/d while the measurement data assumed a net seepage of 0.07mm/d.

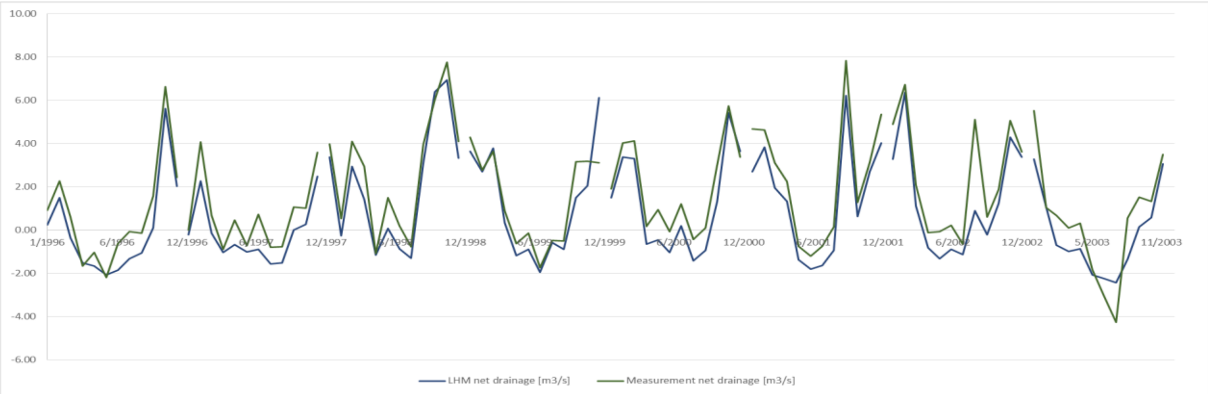


Figure 3.4.6. Modelled and measured ND for the Krimpenerwaard 1997-2003 [m^3/s]

Figure 3.4.7. Modelled and measured cummulative ND and CDND for the Krimpenerwaard 1997-2003 [mm]

The deviation in ND is -0.50mm/d, the deviation in infiltration/seepage is +0.40mm/d. This could indicate that most of the deviation is caused by a wrong infiltration rate. Table 3.4.1 is based on other measurement data, and shows that the LHM calculates a correct seepage rate for the Krimpenerwaard. Also the ground water time series for the Krimpenerwaard (G, I, L, M) do not show major deviations. It is therefore most likely that the measurement water balances on which the in- and outlet are based is not correct. Figure 3.4.8 and 3.4.9 show the ND and CDND after manual correction of the LHM results towards an equal seepage rate.

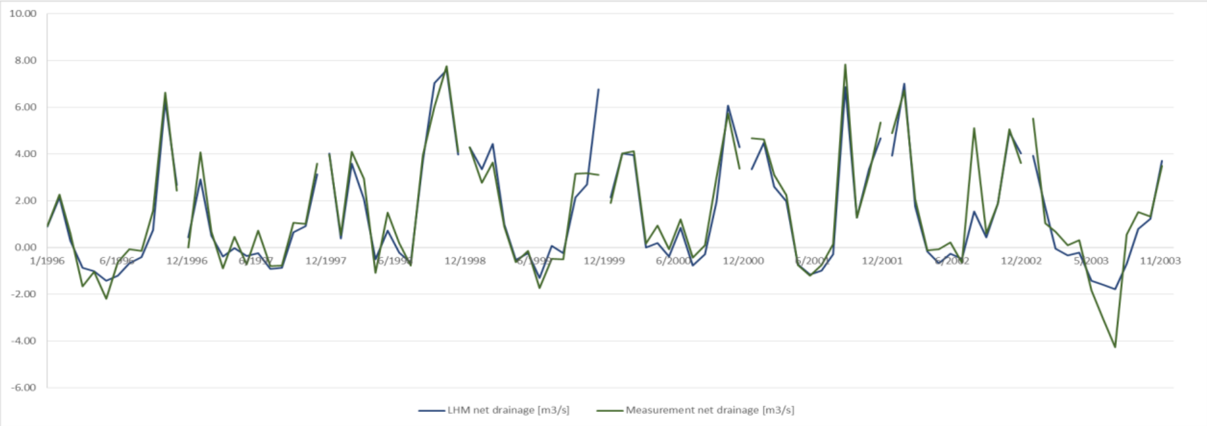


Figure 3.4.8. Measured and corrected LHM ND for the Krimpenerwaard [m^3/s]

Figure 3.4.9. Measured and corrected LHM cummulative ND and CDND for the Krimpenerwaard [mm]

After correction, the deviation of the LHM is still around -50mm/yr, this is the same order of magnitude as the rest term in the measurement balances. It is therefore not possible to make more detailed conclusions about the deviation of the LHM. Additionally, seepage rates still have some seasonality, this is not included in the correction. Due to the large temporal scale and large rest term in the measurement balance, no further conclusions could be drawn from these results.

3.4.3.2 Seepage and infiltration

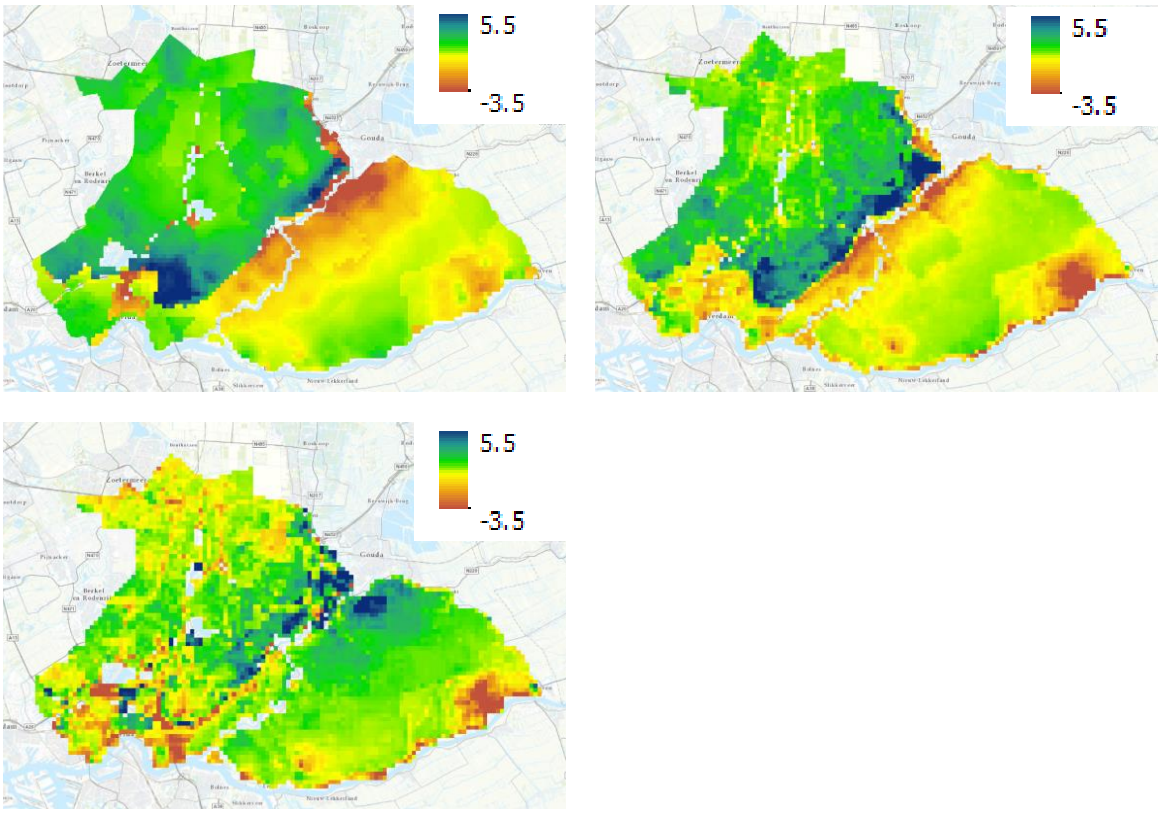


Figure 3.4.10. Measured seepage (top left), LHM seepage (top right), deviation in seepage (bottom) [mm/d] (seepage is positive, and positive deviation indicates too much seepage in LHM)

Figure 3.4.10 shows seepage rates based on TNO measurements and shows that the LHM reproduces the correct spatial patterns in seepage rates. However, the majority of deviations occurs at places with the highest seepage/infiltration rates. These deviations are both in the spatial dimension and quantity of the patches with a large infiltration/seepage rate. Table 3.4.1 shows that for the Krimpenerwaard and Ringvaart seepage is calculated on average correct, but the standard deviation of the deviation is quite large. This is an indication that most deviations occur at the places with the highest rates. The largest deviation in seepage is observed in De Rotte, here the LHM shows a lot of spatial variation that is not present in the measurement data.

3.5 Hoogheemraadschap De Stichtse Rijnlanden

Main conclusions

Measurement data for the HDSR region was not always very detailed and trustworthy. However, from the water balances a slight over demand during growing season is visible, but in-depth analysis was not possible. The KWA-2011 data shows that the LHM calculates a too large water demand during the growing season for the western HDSR. Unfortunately, the LHM did not implement the KWA during spring 2011 and no conclusions regarding the fresh water demand for Rijnland can be made with this data.

Regarding the applicability for the DPZW, measurement data is to crude to make detailed conclusions, but the findings are in line with Rijnland and Delfland.

3.5.1 Area description

The Hoogheemraadschap De Stichtse Rijnlanden (HDSR), shown in figure 3.5.1, is situated in the centre of the Netherlands, comprising an area of approximately 82.000 hectares. At the east side the management area is bordered by the Utrechtse Heuvelrug, composing of high elevated sandy soils. The southern border is formed by the river Lek, which provides most of the fresh water for the area. The western half of the HDSR region consists of low lying Holocene peat and clay soils. The Amsterdam-Rijn Kanaal (ARK) crosses the area from south to north and connects the river Lek with the city of Amsterdam.

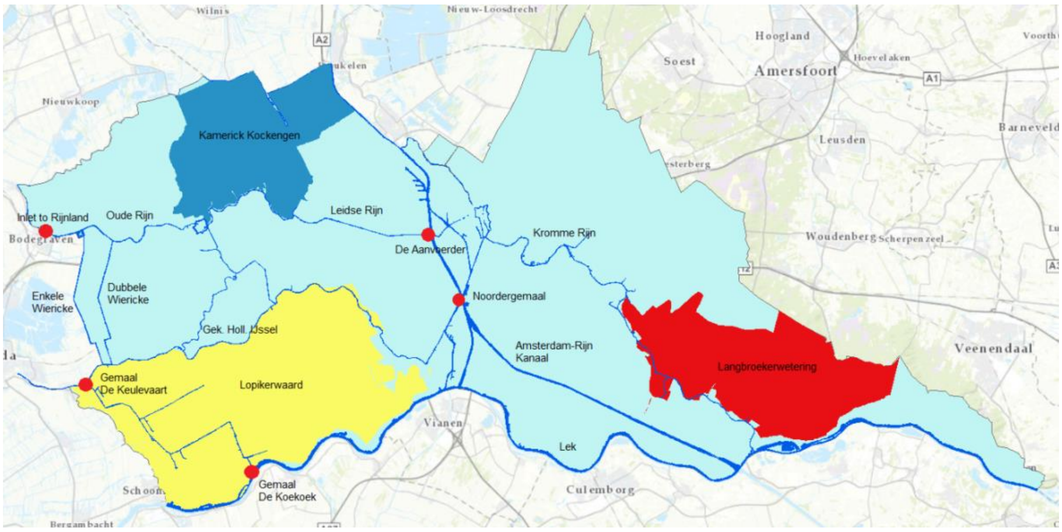


Figure 3.5.1. Main water system of HDSR and main fresh water supply locations.

Supply of fresh water

Main supply of fresh water occurs via the Amsterdam-Rijn Kanaal in the centre and the Lek in the south. Due to the presence of these two main watercourses, in practice no real fresh water shortages occur. Only the high elevated Utrechtse Heuvelrug experiences trouble during droughts because water cannot flow upwards into the region. Land use of the Oude Rijn, Leidse Rijn and Lopikerwaard area in the west are is mainly peat meadow and no bottlenecks regarding fresh water supply are present. In cases of drought extra fresh water is lead through the western part of HDSR as part of the KWA route. See 3.2.1 for further description of the KWA.

3.5.2 LHM results

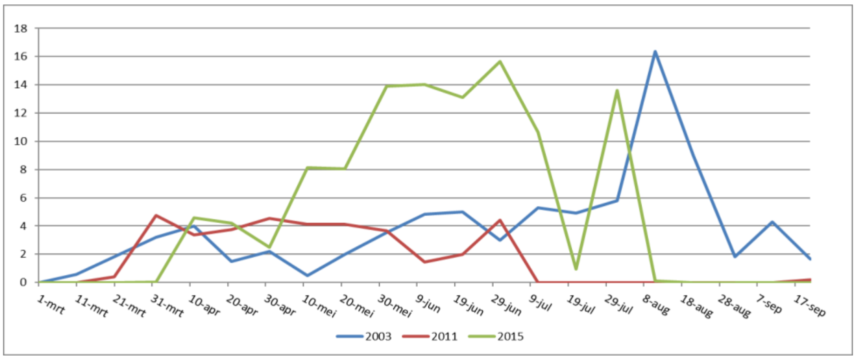


Figure 3.5.2. Modelled water inlet for the western HDSR, KWA route [m^3/s]

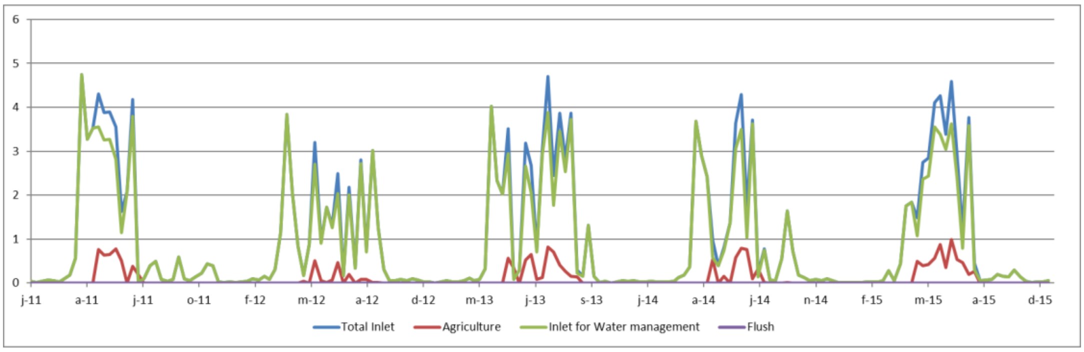


Figure 3.5.3. LHM surface water allocation for the West-HDSR (Lopikerwaard, Leidse Rijn and Oude Rijn) 2011-2015 [m^3/s]

Figure 3.5.2 and 3.5.3 show that the west-HDSR has a base water demand of approximately 4 m^3/s during dry periods. Figure 3.5.2 represents the regional water system (DM), while figure 3.5.3 represents the polders (Mozart). Figure 3.5.2 shows inlet peaks up to 14 m^3/s, which occur during dry periods. The model output showed that subsequently around 10m^3/s of these peaks was discharged again. This is the KWA route, were extra fresh water passes through the region towards Rijnland. Figure 3.5.2 shows that the LHM implements the KWA during 08-2003 and summer 2015, were during 2015 the KWA switches off and on again. During 2011 the KWA is not implemented in the LHM. This is very remarkable since, in reality, the KWA is implemented during august 2003 and spring-2011. So, while the LHM calculates the implementation of the KWA during 2003 right, it misses spring 2011, and implements the KWA in 2015. Next to 2015, the LHM also seems to implement the KWA in 2012, 2013 and 2014.

While the LHM seems not to implement the KWA route at the right moments, this does not need to influence the total calculated water demand. The KWA is implemented when the chloride concentration near Gouda reaches above 250mg/l, and this calculation procedure seems to go wrong in the LHM. When water can still be let in near Gouda, the LHM extracts this water at Bodegraven via the KWA route. For this validation, it is important to determine the total amount of fresh water demand, and this can still be correct, independent of the water supply route. In cases the LHM implements the KWA, up to a net 10-11m^3/s is received by Rijnland.

For the Lopikerwaard, Leidse Rijn area and Oude Rijn area, the LHM calculates infiltration rates of 0.03mm/d, 0.20mm/d and 0.27mm/d respectively. The LHM imposes no flushing on these regions, and water inlet is approximately the same during the dry periods in 2003, 2011 and 2015.

3.5.3 Validation results

3.5.3.1 Lopikerwaard, Langbroekerwetering & Heuvelrug and Kamerick-Kockengen

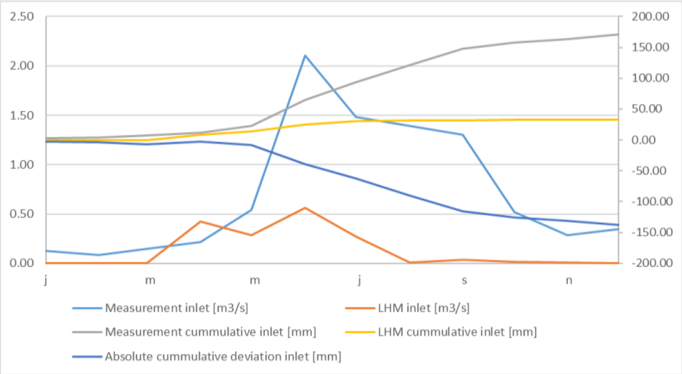


Figure 3.5.6a. Measured and modelled outlet for the Lopikerwaard 2005 (left: [m^3/s], right: [mm])

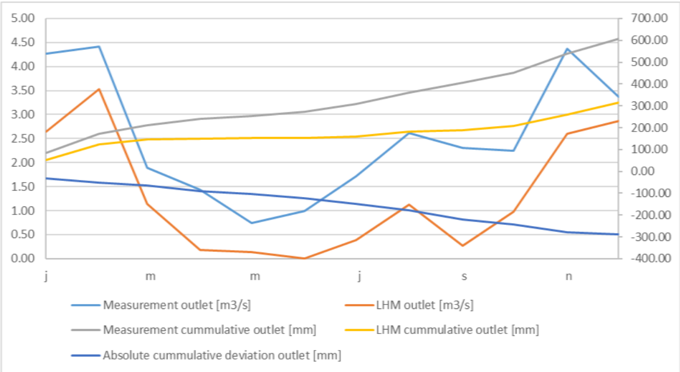


Figure 3.5.6b. Measured and modelled inlet for the Lopikerwaard 2005 (left: [m^3/s], right: [mm])

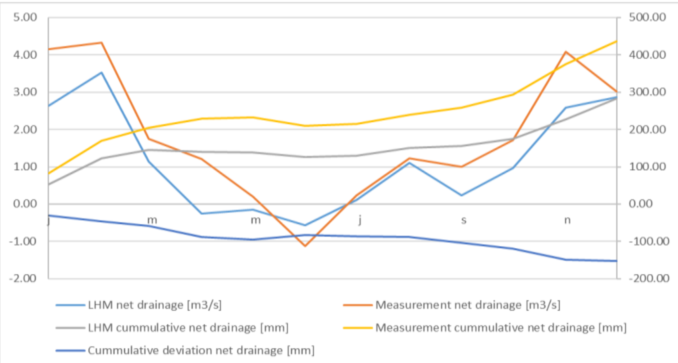


Figure 3.5.6c. Measured and modelled water ND for the Lopikerwaard 2005 (left: [m^3/s], right: [mm])

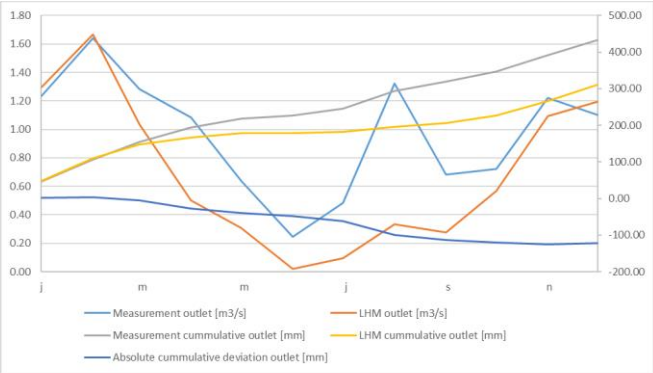


Figure 3.5.7a. Measured and modelled outlet for Langbroekerwetering & Heuvelrug 2005 (left: [m^3/s], right: [mm])

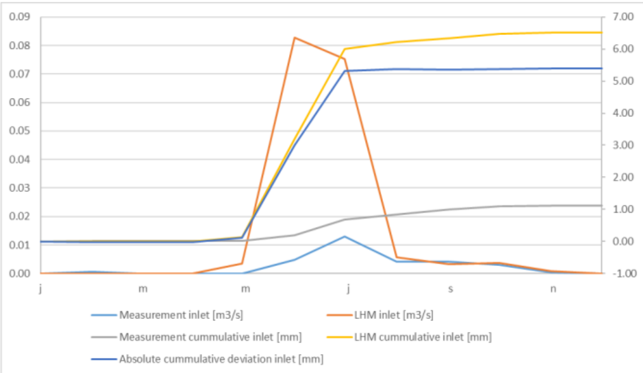


Figure 3.5.7b. Measured and modelled inlet for Langbroekerwetering & Heuvelrug 2005 (left: [m^3/s], right: [mm])

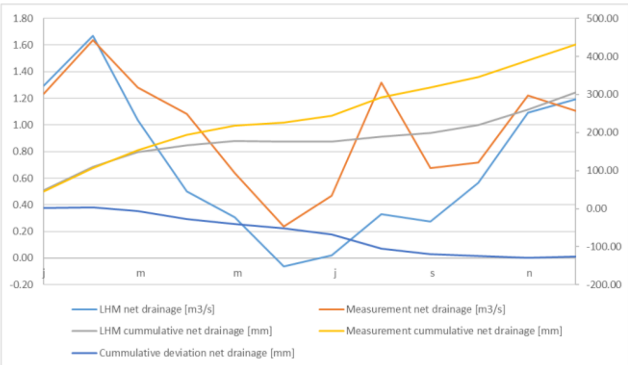


Figure 3.5.7c. Measured and modelled water ND for Langbroekerwetering & Heuvelrug 2005 (left: [m^3/s], right: [mm])

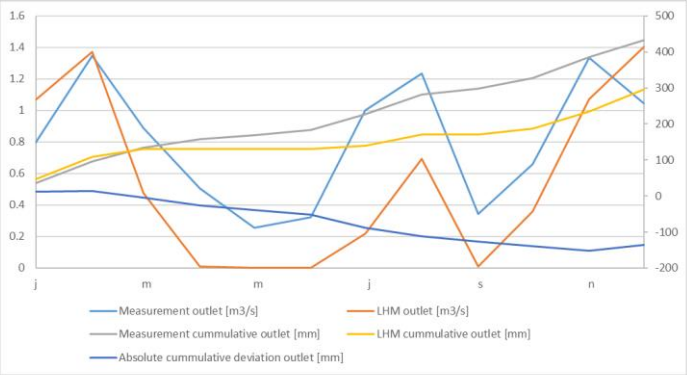


Figure 3.5.8a. Measured and modelled outlet for Kamerick-Kockengen 2005 (left: [m^3/s], right: [mm])

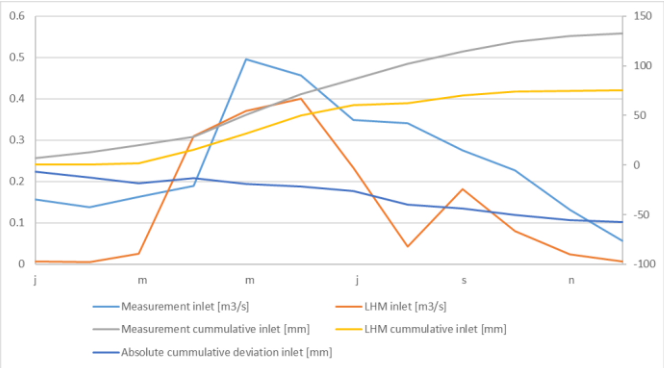


Figure 3.5.8b. Measured and modelled inlet for Kamerick-Kockengen 2005 (left: [m^3/s], right: [mm])

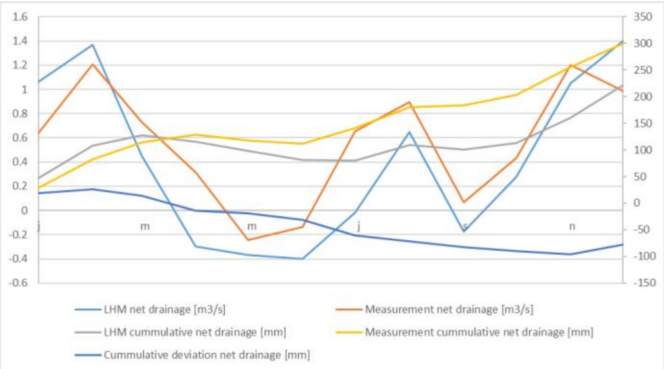


Figure 3.5.8c. Measured and modelled water ND for Kamerick-Kockengen 2005 (left: [m^3/s], right: [mm])

For the HDSR region a water balance for the whole region, subdivided into several subregions, is available on monthly basis for the year 2005. Due to the surface water schematisation in the LHM it was only possible to validate the balance for the subregions. The subregions with the most complete inlet measurements were selected and the results are shown in the figures above.

Figures 3.5.6abc-3.5.8abc show that the in- and outlet are not modelled very well by the LHM. Trends in in- and outlet are visible, although these trends mainly depend on precipitation/evaporation events and it is assumed that these are imposed correctly on the LHM. The ND and CDND perform better for the subregions, indicating that there is a large difference in the amount of flush water. The influence of flush water is very well visible for the Lopikerwaard, here the CDND is almost horizontal during the growing season. This indicates that, although the in- and outlet of water is not correctly reproduced by the LHM, the net water demand for the Lopikerwaard is calculated correctly during the growing season.

The Langbroekerwetering & Heuvelrug balance is very different from the others. This could be because this region is not a polder region. The outlet in figure 3.5.7a is too low, and the inlet in figure 3.5.7b is too high. A possible explanation could be that the gradient in surface level is not completely captured by the LHM.

To conclude, it is difficult to draw further conclusions from these validation results. This is first due to bad quality of the measurement balances, rest terms in the water balances are up to 60%. And the monthly resolution of the measurement data is too large for detailed analyses because extreme events are averaged out.

3.5.3.2 Western HDSR summer-2011

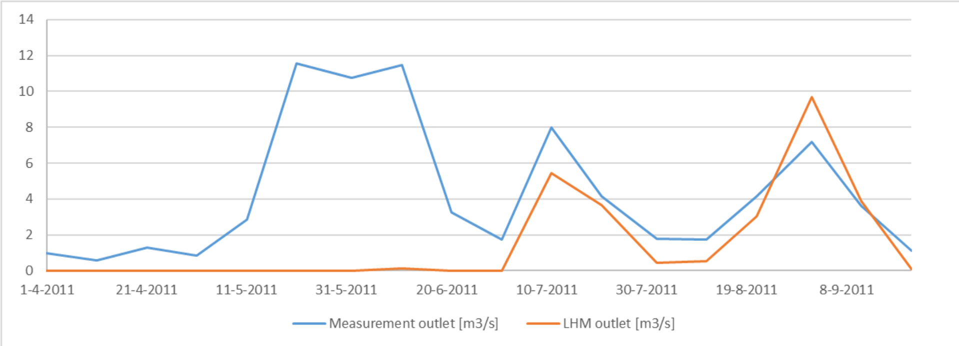


Figure 3.5.9a. Measured and modelled outlet for the west HDSR during summer 2011 [m^3/s]

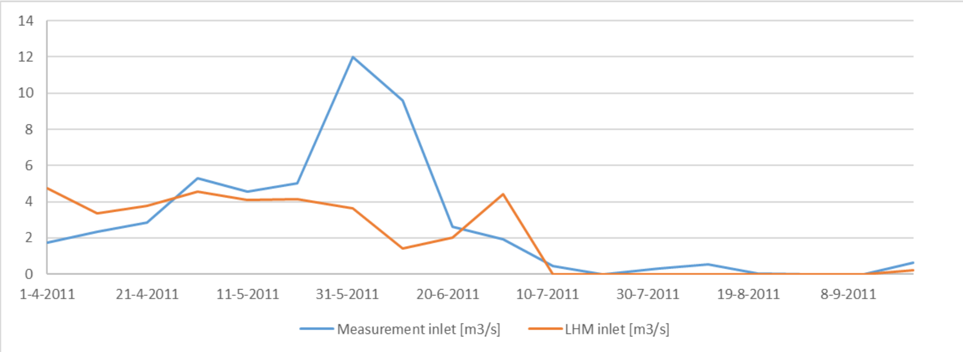


Figure 3.5.9b. Measured and modelled inlet for the west HDSR during summer 2011 [m^3/s]

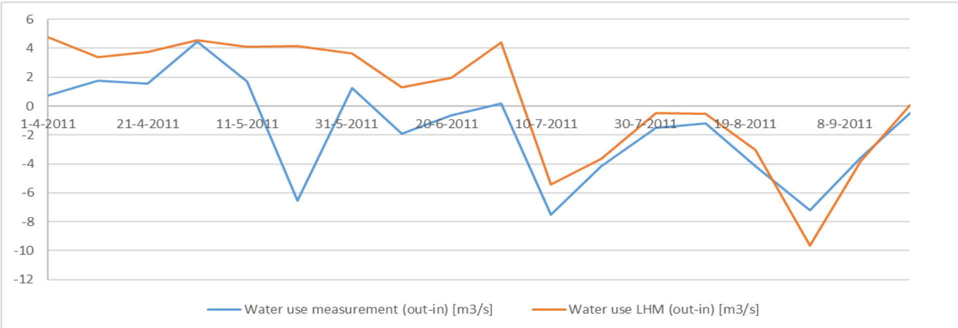


Figure 3.5.9c. Measured and modelled water use for the west HDSR during summer 2011 [m^3/s]

For the figures 3.5.9abc, inlet locations are De Aanvoerder, Noordergemaal and Gemaal De Koekoek; outlet locations are the GHIJ near Gouda and de inlet to Rijnland near Bodegraven. The figures show that during May-June a major peak in the in- and outlet is missed by the LHM. In this period the KWA route was applied and, as already explained above, the LHM does not activate the KWA route. Reason for this is that chloride concentrations near Gouda are not calculated correctly.
However, KWA of no KWA, the total water use in the region should still be modelled correctly. The water use is defined as outflow-inflow. Figure 3.5.9c shows that, although the deviations are largest during the first, dry, half of the season, it generally seems that the LHM over calculates the water use by 2m^3/s, or 2.3mm/decade, this results in an over demand of 60mm for April-September. The dip in water use in figure 3.5.9c, halfway May, is probably an error in the measurement data, as at this time the through flow to Bodegraven already started but De Aanvoerder was not yet in operation. De Aanvoerder, driver of the KWA, was in operation from the end of May till the end of June.

3.6 Waterschap Hollandse Delta

Main conclusions

For Hollandse Delta the findings are in line with conclusions from Rijnland and Delfland. Net water use is linearly over calculated by 20mm during the growing season. Additionally, this dataset showed that the wrongly imposed flush has a large influence on the calculated water inlet.

3.6.1 Area description

Waterschap Hollandse Delta (WHD), shown in figure 3.6.1, is situated in the south-west of the study area and comprises an area of 102.000 hectares. The area composes of five hydrological separated islands: Voorne-Putten, IJsselmonde, Hoekse Waard, Eiland van Dordrecht and Goeree-Overflakkee. WHD is situated in the Rijn-Maas delta with from the east large amounts of fresh water, and from the west brackish (ground)water from the Noordzee. Land use is mainly agricultural, with exception of IJsselmonde and Eiland van Dordrecht, which are predominately urban.

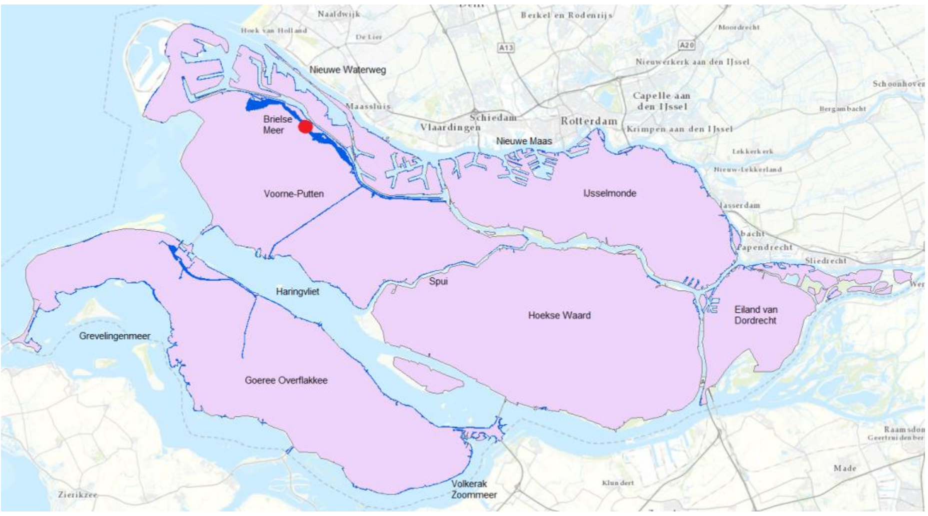


Figure 3.6.1. Main water system of WHD and main fresh water supply locations

Fresh water supply

The area in the west experiences large amounts of brackish seepage, and during winter most of the surface water is brackish. During summer the surface water is maintained fresh for agricultural purposes. Inlet of fresh water occurs from the surrounding fresh water reservoirs. Although the area requires lots of fresh water, due to the presence of large fresh water reservoirs and river discharge, supply of fresh water is not regarded as major bottleneck. The Brielse Meer in Voorne-Putten acts as water reservoir for the harbour of Rotterdam and Delfland. Water in the Brielse Meer originates from the Haringvliet.

3.6.2 LHM results

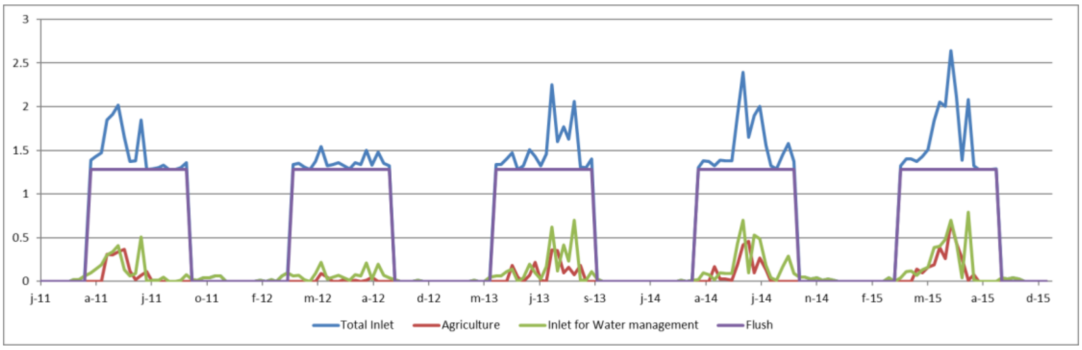


Figure 3.6.2a. LHM surface water allocation for Voorne-Putten 2011-2015 [m^3/s]

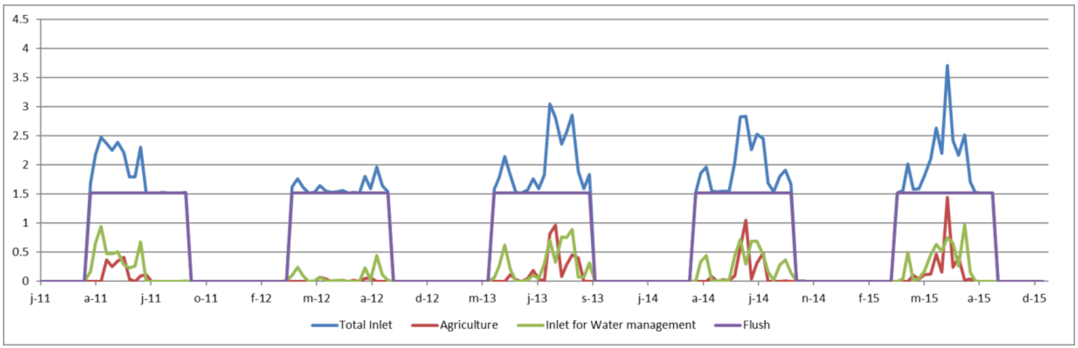


Figure 3.6.2b. LHM surface water allocation for Goeree-Overflakkee 2011-2015 [m^3/s]

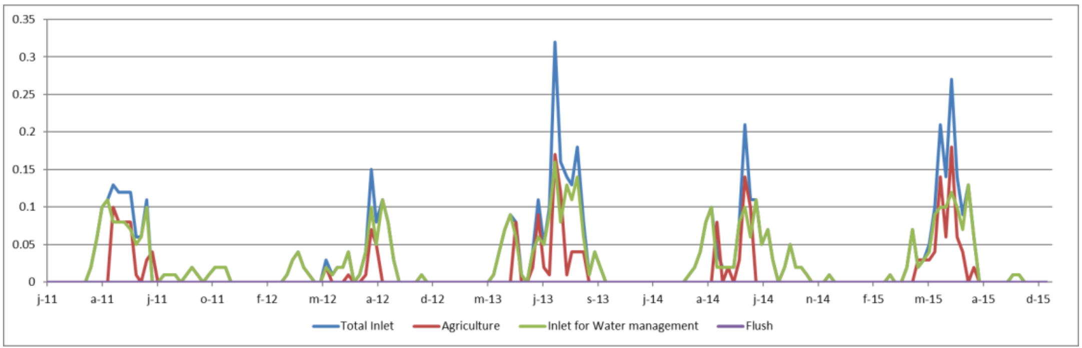


Figure 3.6.2c. LHM surface water allocation for Eiland van Dordrecht 2011-2015 [m^3/s]

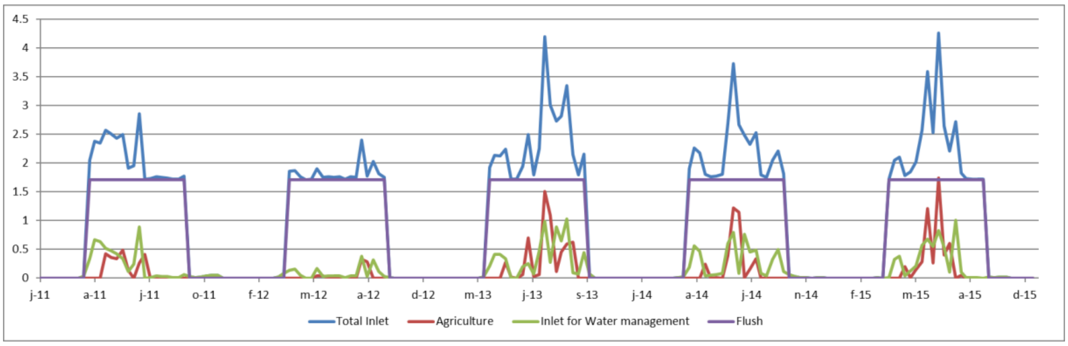


Figure 3.6.2d. LHM surface water allocation for Hoekse Waard 2011-2015 [m^3/s]

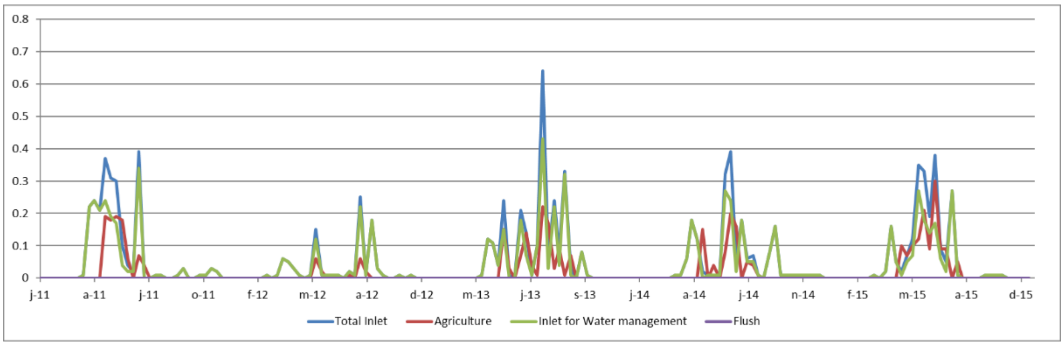


Figure 3.6.2e. LHM surface water allocation for IJsselmonde 2011-2015 [m^3/s]

Figures 3.6.2abcde show that most of the inlet water is, when imposed, allocated to flush. The relative share of allocation to water management and agriculture is approximately the same for the five regions.

	Seepage [mm/d]	Seepage [m^3/d]
Voorne-Putten	0.22	45482
Hoekse Waard	0.13	37749
IJsselmonde	0.13	16446
Goeree-Overflakkee	0.09	21774
Eiland van Dordrecht	0.16	9814

Table 3.6.1. Calculated seepage rates for WHD

Table 3.6.1 shows the seepage rates that are calculated by the LHM. Although no actual seepage rates are known, these values seem to be reasonable. The western region of WHD does experience seepage. However, the issue of this seepage is not so much the amount of seepage, but rather the chloride concentration of this seepage.

3.6.3 Validation results

3.6.3.1 Voorne Putten

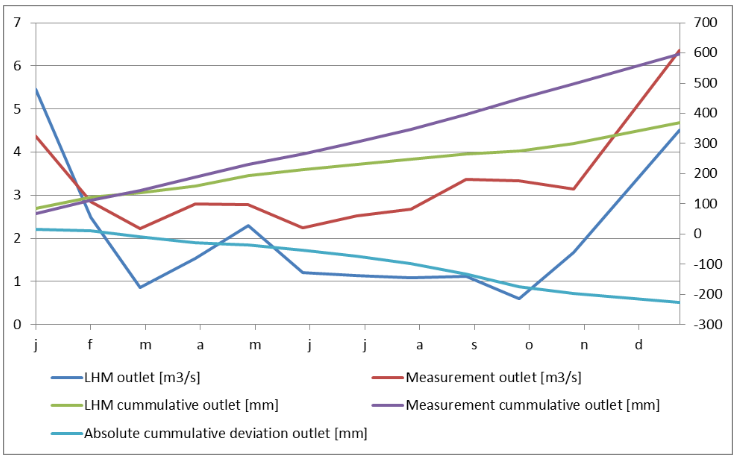


Figure 3.6.3a. Measured and modelled outlet for Voorne-Putten 2003 (left: [m^3/s], right: [mm])

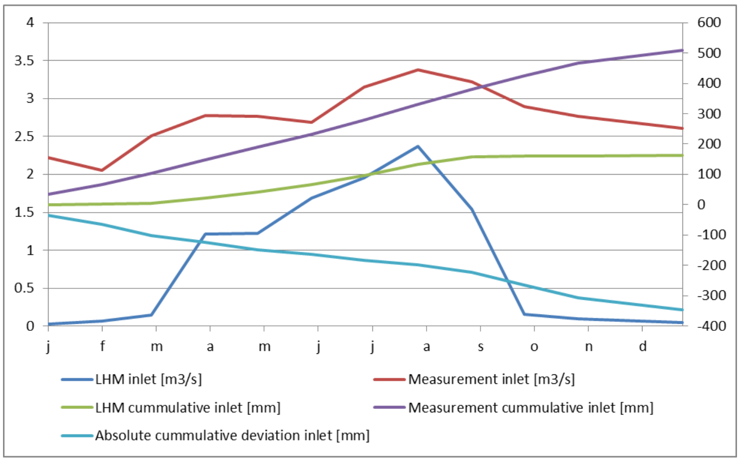


Figure 3.6.3b. Measured and modelled inlet for Voorne-Putten 2003 (left: [m^3/s], right: [mm])

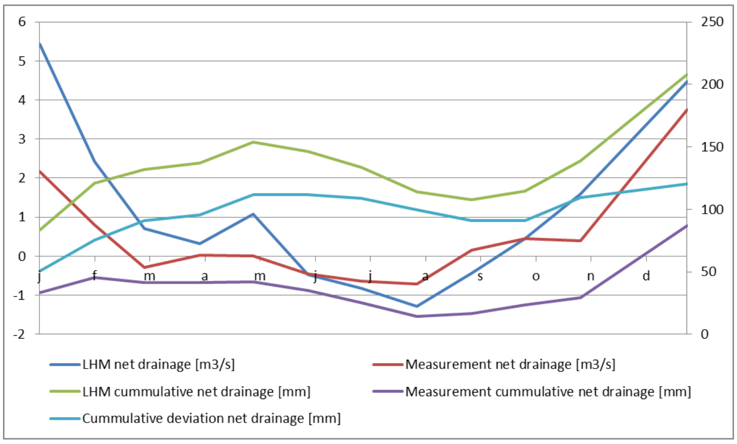


Figure 3.6.3c. Measured and modelled ND for Voorne-Putten 2003 (left: [m^3/s], right: [mm])

For the WHD area only usable surface water measurements were available for Voorne-Putten. Figure 3.6.3abc show that for Voorne-Putten the inlet is structurally too low, and the outlet structurally too high. However, the ND performs much better, especially during the growing season. This indicates that the amount of imposed flush water in the LHM is too low, but the total water use in the area is calculated correctly. The LHM imposes a flush of 1.1m^3/s, while the measurements show that this is around 2.0-2.5m^3/s.

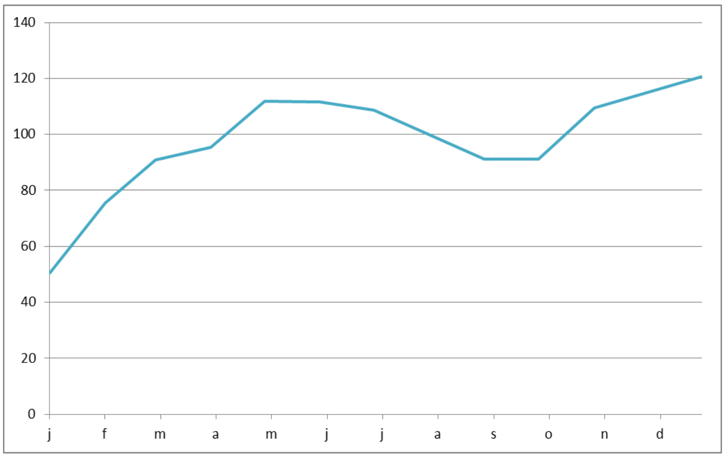


Figure 3.6.4. CDND for Voorne-Putten 2003 [mm]

Figure 3.6.4 shows that, although the base of the graph is very high (42% of the deviation occurs in January) the CDND for Voorne-Putten shows basically the same trend as the CDND for Rijnland and Delfland. For the growing season the CDND is 21mm, or 0.23 m^3/s.

From these results, it can be concluded that the amounts of imposed flush water are not always correct in the LHM, and that this influences the total water demand. However, total calculated net water use is independent of the amount of flush water, and is in this case calculated considerably correct.

3.7 Waterschap Amstel, Gooi en Vecht

Main conclusions

For the AGV region detailed measurement data was available and the results were quite different from those of other regions. It appears that, based on the large linear deviation, extreme seepage/infiltration rates are not captured well by the LHM, having a large influence on the water demand. Correcting the LHM seepage rates with the CDND gives more realistic seepage rates, according to the Water Authority. Additionally, imposed amounts of flush are wrong. Only for Loosdrecht the LHM performs rather well during the growing season. Since this region contains a lot of surface water, it appears that on average open water evaporation is calculated correctly. However, for Loosdrecht, the LHM shows a peak in inlet during April and a peak in outlet during September. This is probably due to a wrong surface water level change and should be corrected. Additionally for Loosdrecht, fluctuations during the growing season are still quite large. Although no direct link to the dryness progression is found, some dry periods do show a larger deviation.

For the AGV region, the LHM is not applicable to determine the fresh water demand. Recommendation is that first the model is adjusted to more extreme seepage rates. The corrected seepage rates were considered by the Water Authority to be more realistic than the original LHM seepage rates. Also, the U-shape for Loosdrecht, in figure 3.7.20, should be corrected. After this a more thoroughly validation can be performed.

3.7.1 Area description

Waterschap Amstel, Gooi en Vecht (AGV), shown in figure 3.7.1, comprises an area of 70.000 hectares and is intersected by the Amsterdam-Rijn Kanaal (ARK). The boezem of AGV is in open connection with the ARK and Noordzeekanaal (NZK). The AGV area can be divided into three regions: Amstelland with the river Amstel west of the ARK; the Vecht region with the river Vecht east of the ARK; and the Gooi region at the eastern border. While the Amstel and Vecht regions are composed of a polder and boezem system, the Gooi region consists of the high elevated Utrechtse Heuvelrug. Within the Amstel and Vecht region some deep polders (<5m –NAP) with high seepage rates are situated. Within the Amstel region seepage is brackish and flushing is required to keep surface water fresh. Reason for the high seepage rates in the deep polders is the relative thin impermeable top layer, and subsequent bursting of this top layer.

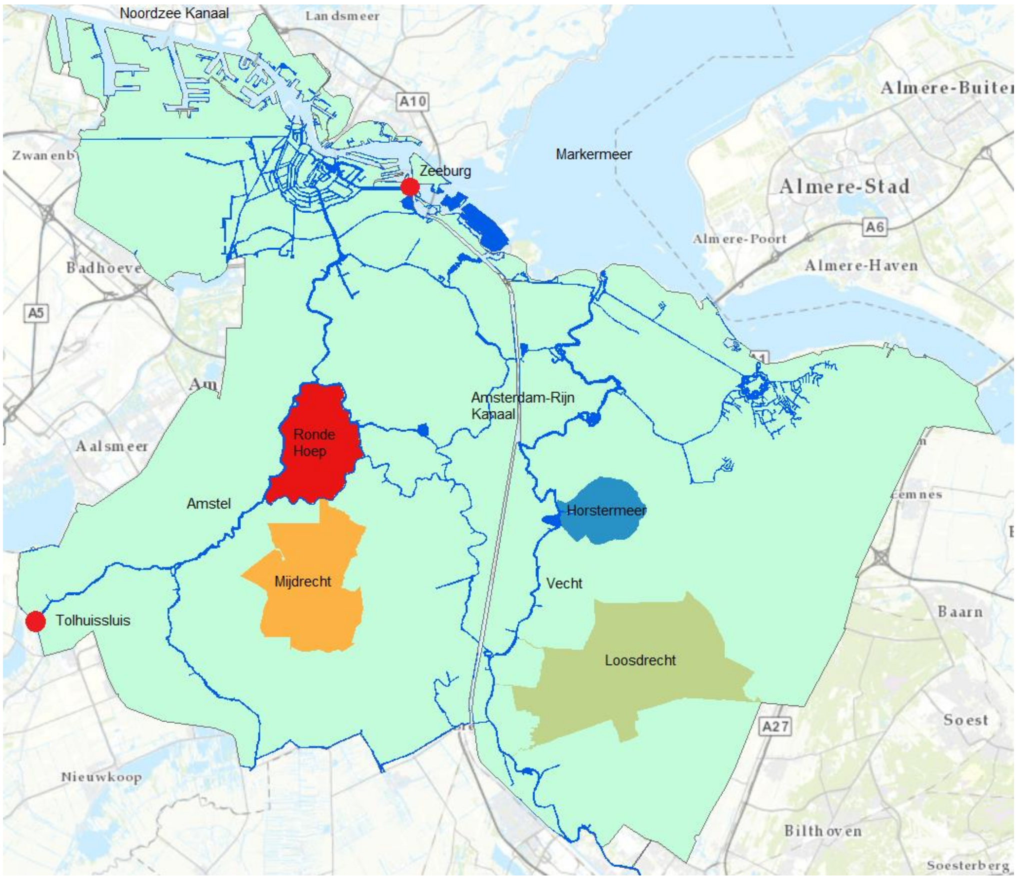


Figure 3.7.1. Boezem of Amstel, Gooi en Vecht and main fresh water supply locations

Fresh water supply

Since the boezem of AGV is in open connection with the ARK, sufficient fresh water supply is not regarded as a major bottleneck. However, large amounts of flush water are required to counteract the brackish seepage. When needed, additional fresh water from the Markermeer, which is separated from the ARK-NZK-boezem, can be let in at Zeeburg. In 2003 fresh water was supplied form Zeeburg, via the river Amstel towards the Tolhuissluis to be subsequently supplied to Rijnland. However, the implementation of the Tolhuissluis route was very elaborate and will not be implemented anymore.

3.7.2 LHM results

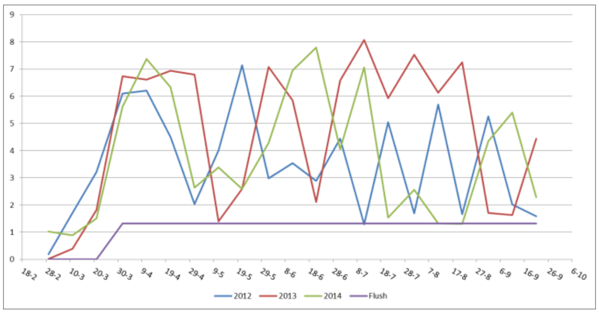


Figure 3.7.2. Calculated water demand and flush for AGV polders (excl city of Amsterdam and Gooi region) [m^3/s]

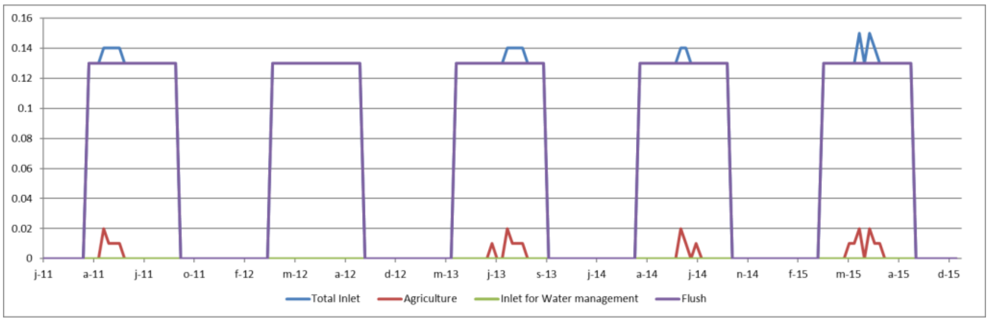


Figure 3.7.3. LHM surface water allocation for Mijdrecht 2011-2015 [m^3/s]

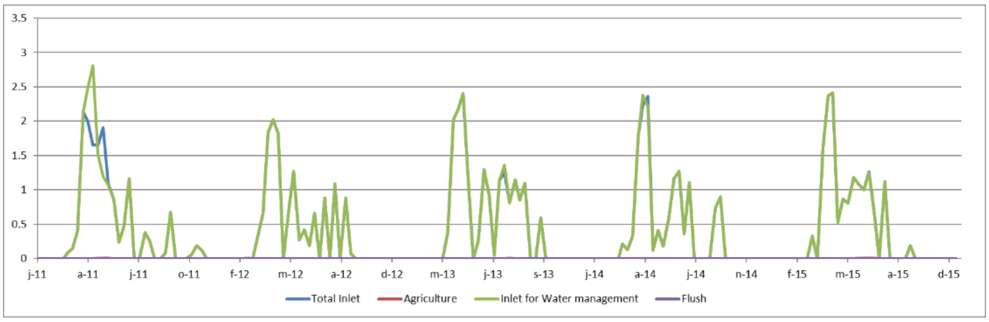


Figure 3.7.4. LHM surface water allocation for Loosdrecht 2011-2015 [m^3/s]

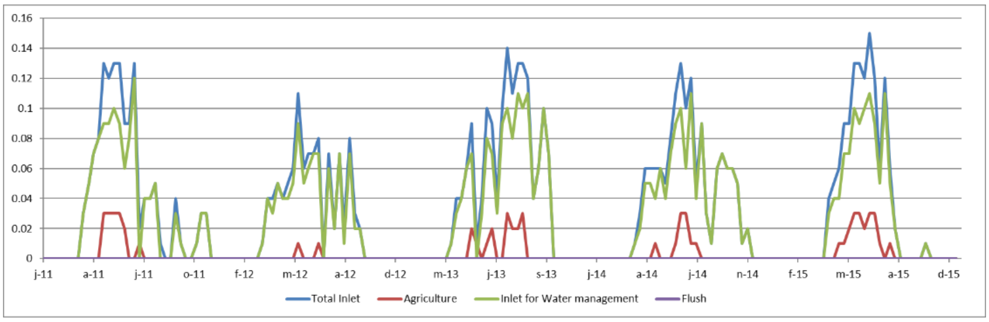


Figure 3.7.5. LHM surface water allocation for Ronde Hoep 2011-2015 [m^3/s]

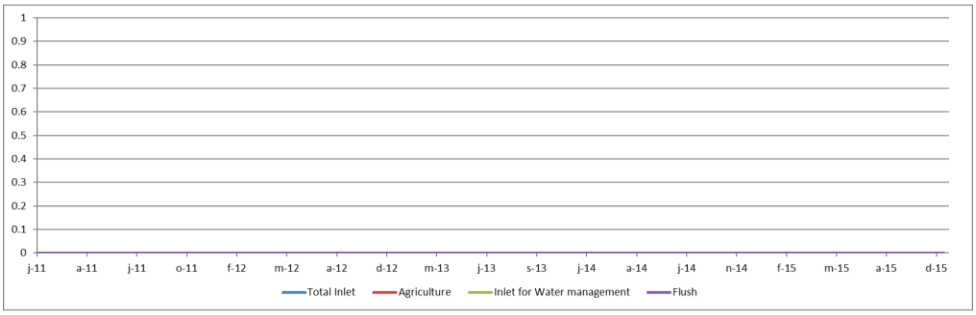


Figure 3.7.6. LHM surface water allocation for Horstermeer 2011-2015 [m^3/s]

Figure 3.7.2 shows that for all the AGV polders combined water demand is 7m^3/s during dry periods, of which 20% is flush demand. Figures 3.7.3-3.7.6 show that the inlet amount and allocation of surface water differs substantially per region highlighted in figure 3.7.1. For regions with high seepage, Mijdrecht and Horstermeer, barely any inlet water is required. This indicates that brackish seepage is allocated to agriculture during dry periods. Contrary, Loosdrecht and Ronde Hoep experience high infiltration rates and inlet water is required mainly for water management. Loosdrecht shows a very unrealistic inlet peak during April. The depicted inlet for water management (surface water level control) is actually the demand and not the allocation. Figure 3.7.4 shows that for Loosdrecht the LHM limits the inlet on surface water level control during spring 2011.

	LHM seepage [mm/d]	LHM seepage [m^3/s]	Measurement seepage [mm/d]
Polder Mijdrecht	1.92	0.45	2-6
Loosdrecht	-0.52	-0.20	-1.8
Ronde Hoep	-0.65	-0.10	-0.5--1.0
Horstermeer	5.76	0.47	?

Table 3.7.1. Seepage/infiltration rates for selected AGV polders

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3.7.3 validation results

3.7.3.1 Polders Amstel, Gooi en Vecht

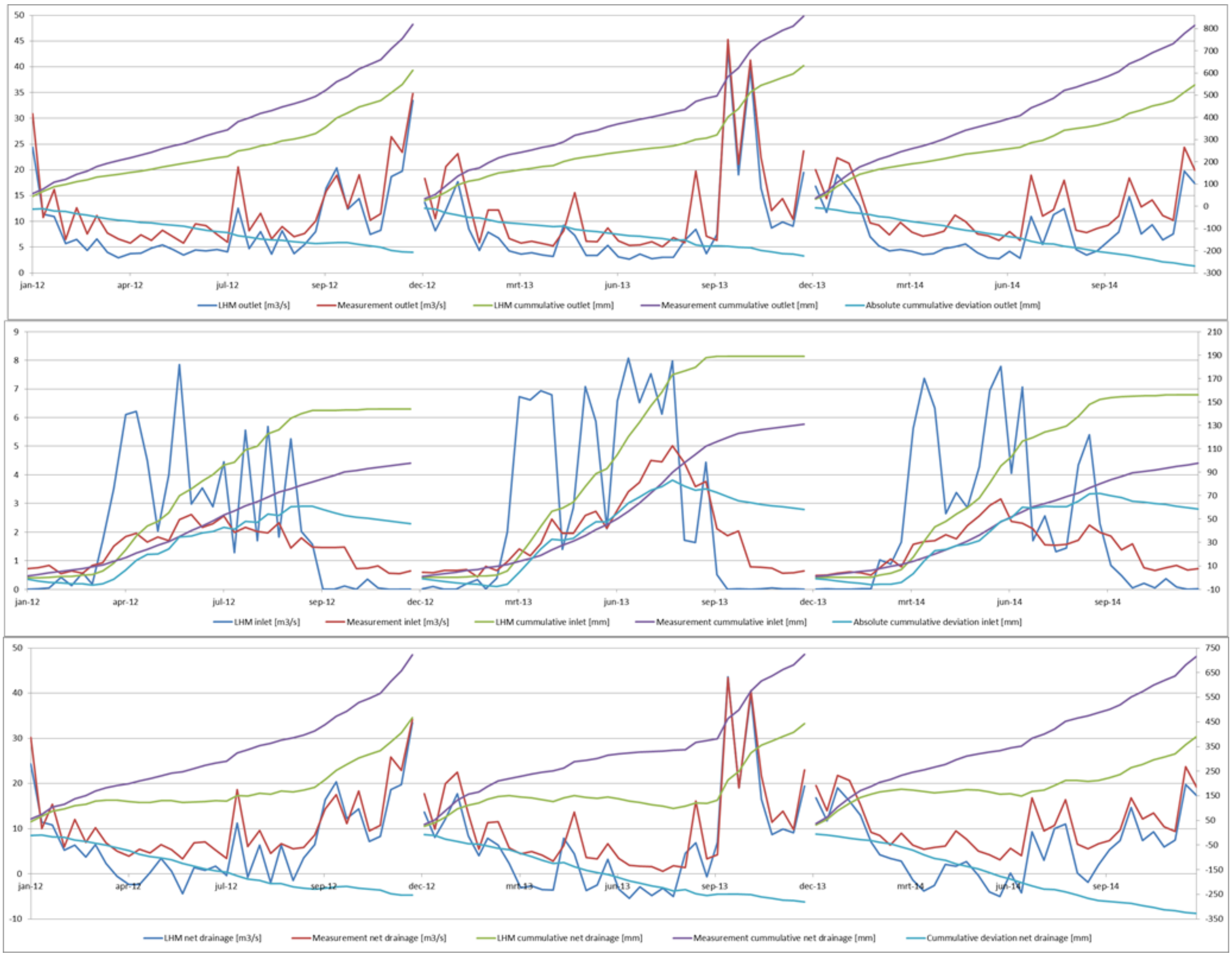

Figure 3.7.7. Surface water results for polders AGV 2012-2014 (left:[m^3/s], right:[mm])

For the AGV area surface water data is obtained from the Sobek/excel model that is built by AGV themselves, this output is further referred to as measurement data. Advantage in using the output of this model is that measurement data with a much finer temporal and spatial resolution can be obtained. Figure 3.7.7 shows the validation results for the AGV polders, enclosing the complete management area with exception of the urban area of Amsterdam and the Gooi region, approximately 45.500 hectares.

The cumulative deviation in outlet in figure 3.7.7 is large, -200--250mm/yr. The dynamicss of the outlet is reproduced quite well, although structurally too low. The inlet is modelled very poorly by the LHM: The inlet fluctuates a lot and is too large. Figure 3.7.2 shows that the imposed LHM flush is 1.3 m^3/s, this is high compared to the measured inlet (~50%) but does not explain the large peaks in LHM inlet. The trend in LHM inlet is strongly correlated to the development of precipitation deficit in figure 3.2.12. The ND is too low in the LHM and the CDND is, with -0.60mm/d, linear throughout the year.

The observed deviations are an order of magnitude larger than for Rijnland and Delfland. This makes it difficult to draw further conclusions. Given the linearity of the deviation and the fluctuations in LHM inlet, it seems very likely that the deviation is caused by a too large LHM infiltration rate. To gain more insight in the deviations, results for individual polders are outlined below.

3.7.3.2 Polder Mijdrecht

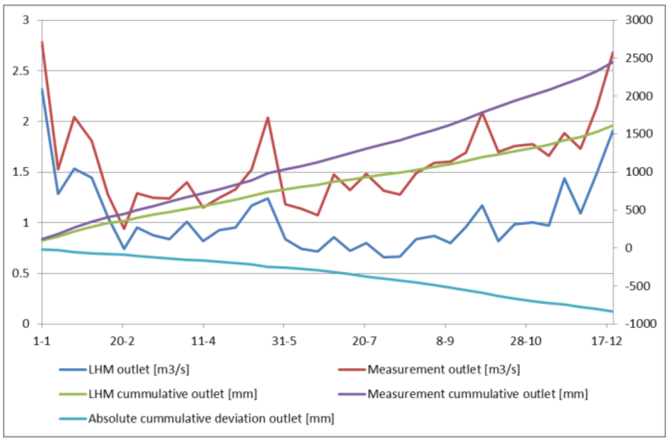

Figure 3.7.8a. Measured and modelled outlet for Mijdrecht 2003 (left: [m³/s], right: [mm])

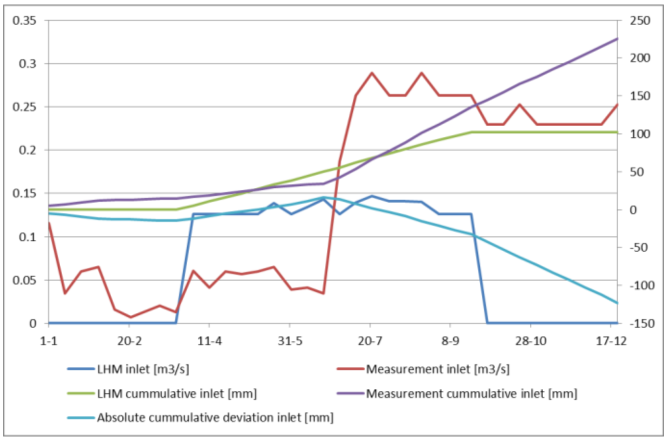

Figure 3.7.8b. Measured and modelled inlet for Mijdrecht 2003 (left: [m³/s], right: [mm])

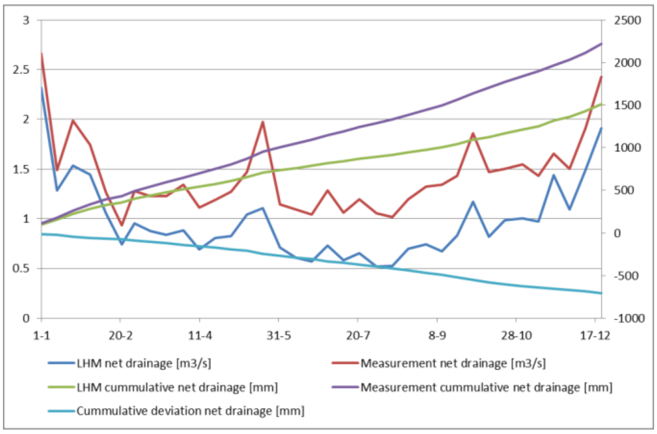

Figure 3.7.8c. Measured and modelled ND for Mijdrecht 2003 (left: [m³/s], right: [mm]

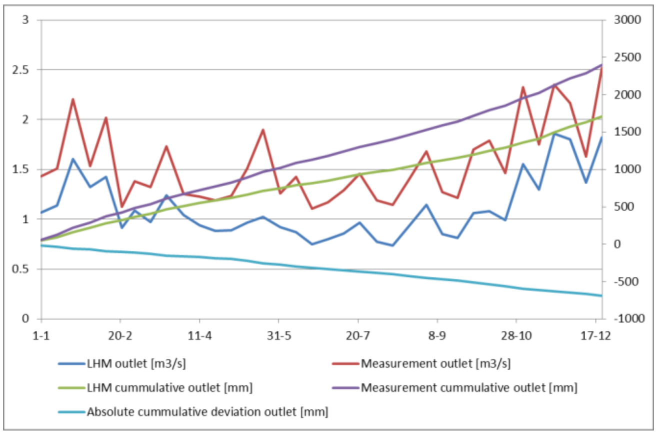

Figure 3.7.9a. Measured and modelled outlet for Mijdrecht 2009 (left: [m^3/s], right: [mm])

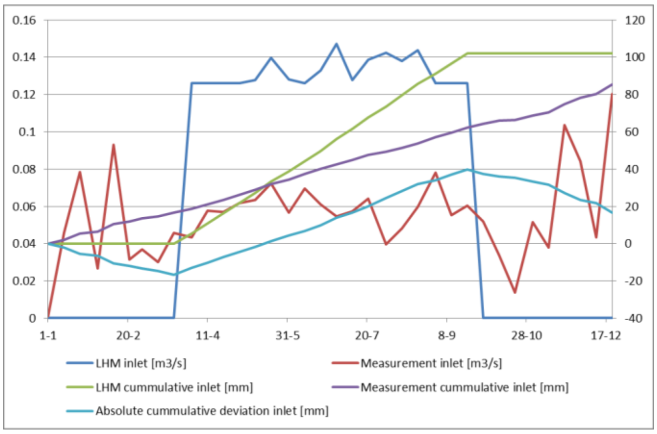

Figure 3.7.9b. Measured and modelled inlet for Mijdrecht 2009 (left: [m^3/s], right: [mm])

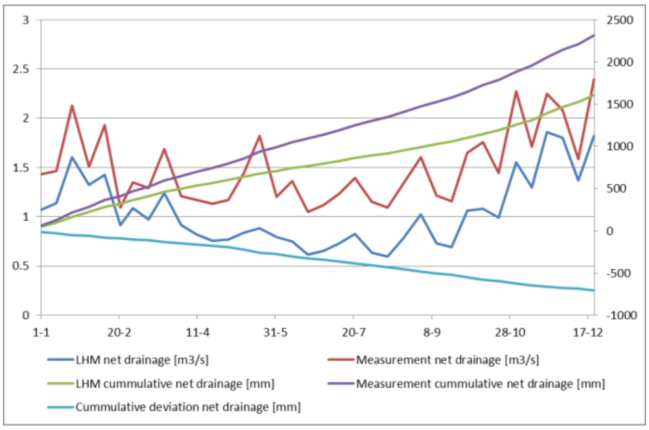

Figure 3.7.9c. Measured and modelled ND for Mijdrecht 2009 (left: [m^3/s], right: [mm])

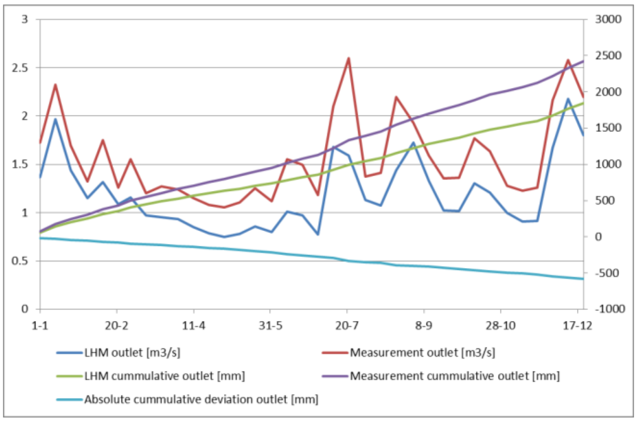

Figure 3.7.10a. Measured and modelled outlet for Mijdrecht 2011 (left: [m^3/s], right: [mm])

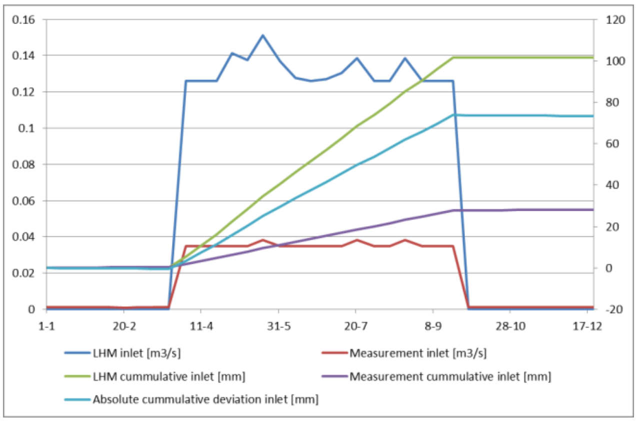

Figure 3.7.10b. Measured and modelled inlet for Mijdrecht 2011 (left: [m^3/s], right: [mm])

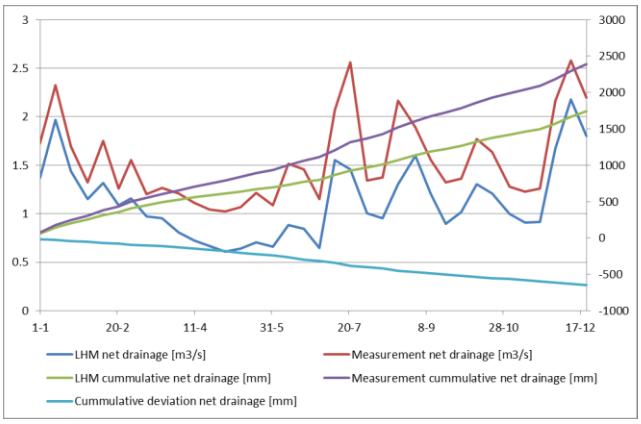

Figure 3.7.10c. Measured and modelled ND for Mijdrecht 2011 (left: [m^3/s], right: [mm])

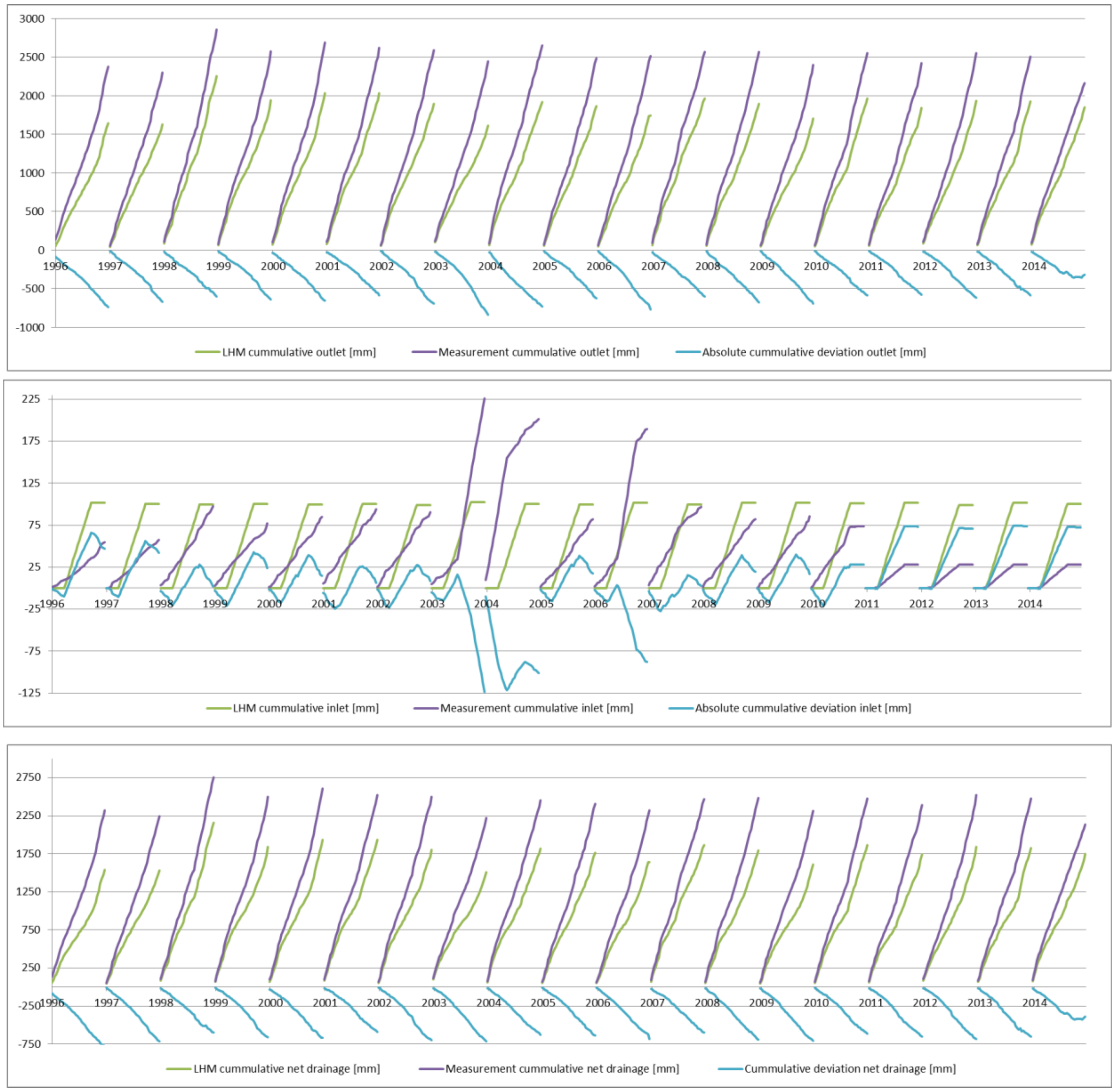

Figure 3.7.11. Total Mijdrecht [mm]

For Polder Mijdrecht, in figure 3.7.8abc-3.7.10abc and 3.7.11, the dynamicss in outlet are modelled well, although structurally too low. Both the measured outlet and the LHM outlet are relatively large, 2000-2500mm/yr. These values are considered to be realistic by the water authority, and are due to high seepage rates.

For the inlet, it appears that the imposed flush in the LHM is too large, leading to a too large inlet. However, the behaviour and amount of measured water inlet differs a lot between the highlighted years as well. So fluctuates the measured inlet around 0.05m^3/s for the year 2009, while for the growing season of 2011 the inlet shows a very strong flushing component. The (deviation in) inlet is small compared to the (deviation in) outlet, and therefore the (deviation in) ND is very like the (deviation in) outlet.

The CDND is approximately -650mm/yr, or -1.8mm/day and linearly throughout the year. Because of the linearity and quantity of the deviation, it is most likely caused by a wrong seepage rate. When the deviation is totally due to a wrong seepage rate in the LHM, actual seepage would be (1.92+1.80=)3.72mm/d. The Water Authority considered this to be a more realistic value.

3.7.3.3 Loosdrecht

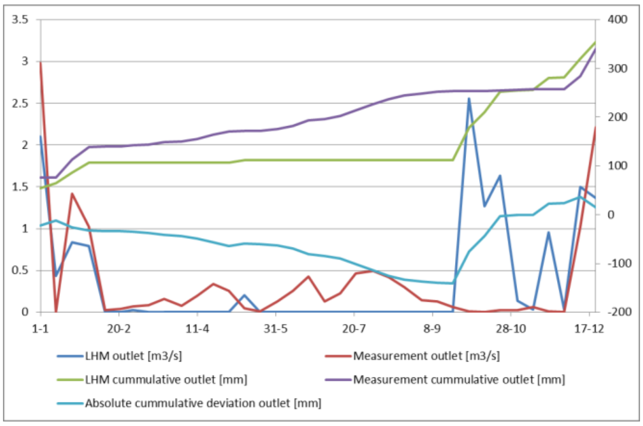

Figure 3.7.12a. Measured and modelled outlet for Loosdrecht 2003 (left: [m^3/s], right: [mm])

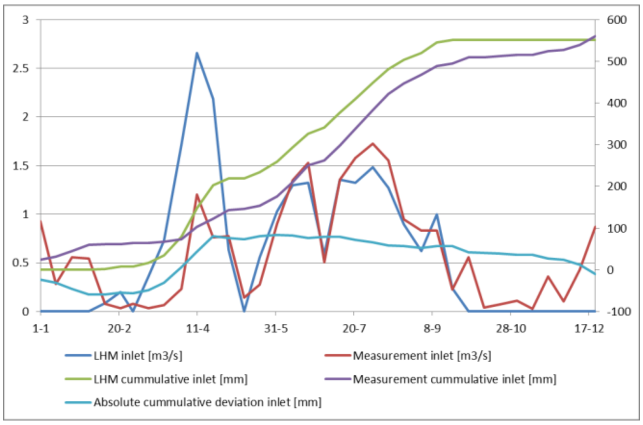

Figure 3.7.12b. Measured and modelled inlet for Loosdrecht 2003 (left: [m^3/s], right: [mm])

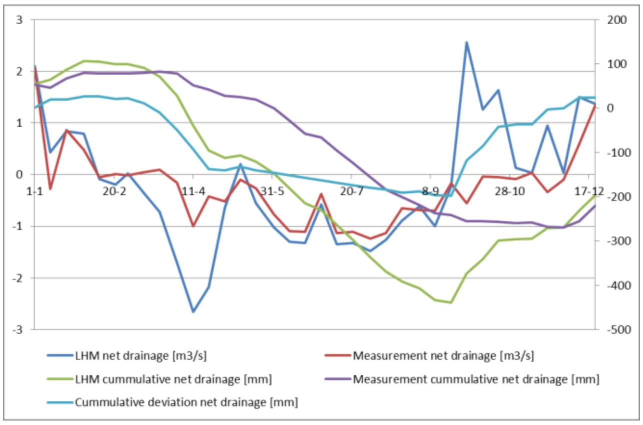

Figure 3.7.12c. Measured and modelled ND for Loosdrecht 2003 (left: [m^3/s], right: [mm])

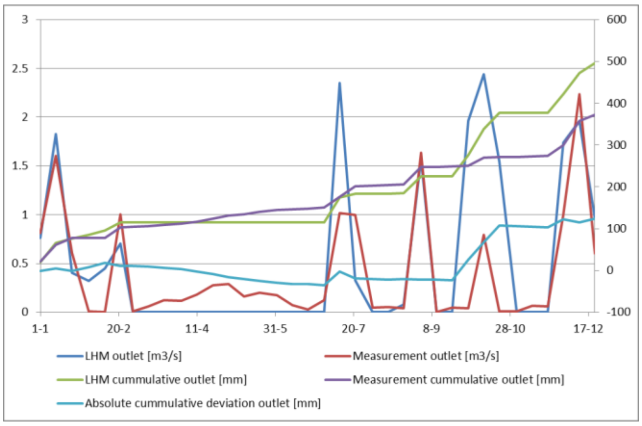

Figure 3.7.13a. Measured and modelled outlet for Loosdrecht 2011 (left: [m^3/s], right: [mm])

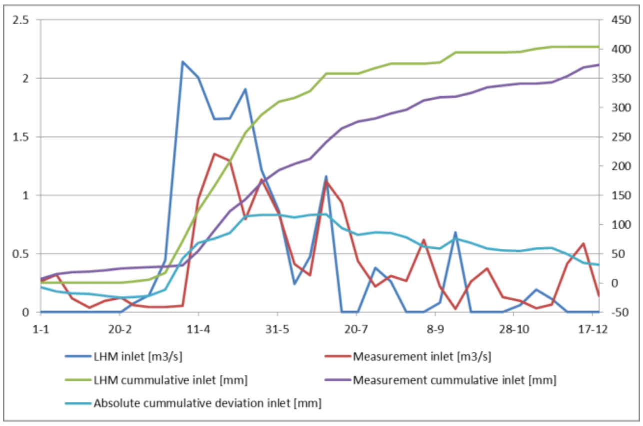

Figure 3.7.13b. Measured and modelled inlet for Loosdrecht 2011 (left: [m^3/s], right: [mm])

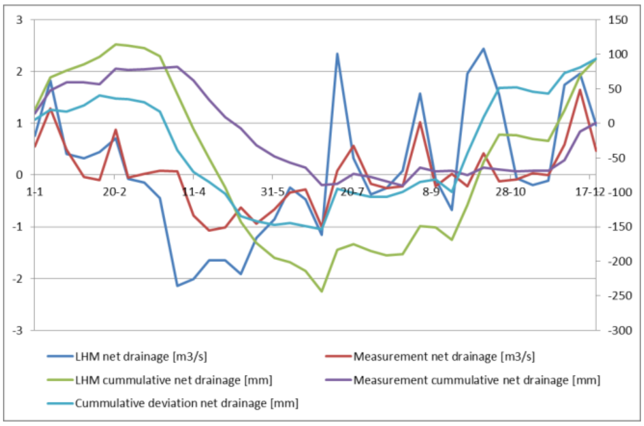

Figure 3.7.13c. Measured and modelled ND for Loosdrecht 2011 (left: [m^3/s], right: [mm])

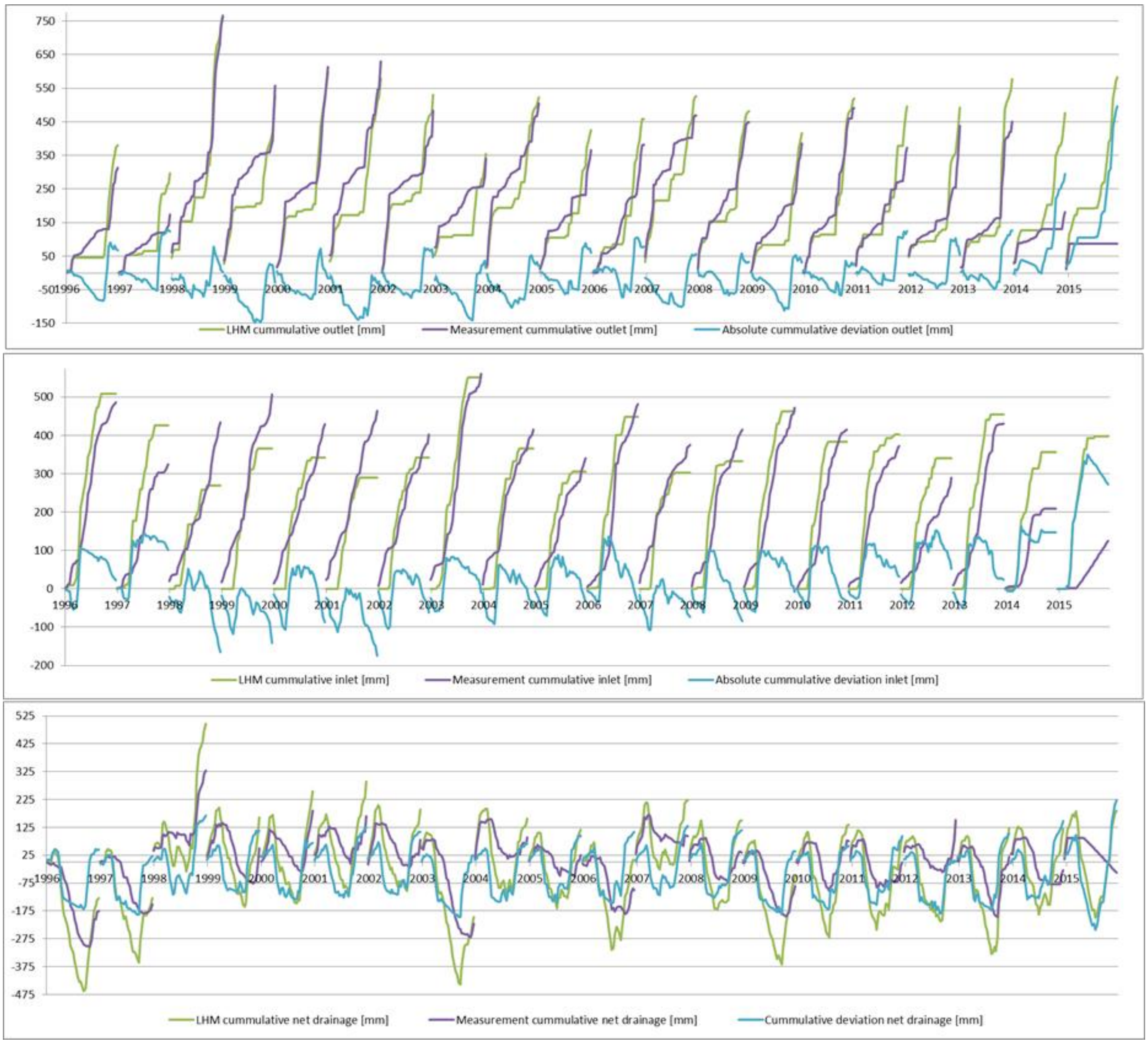

Figure 3.7.14. Total Loosdrecht [mm]

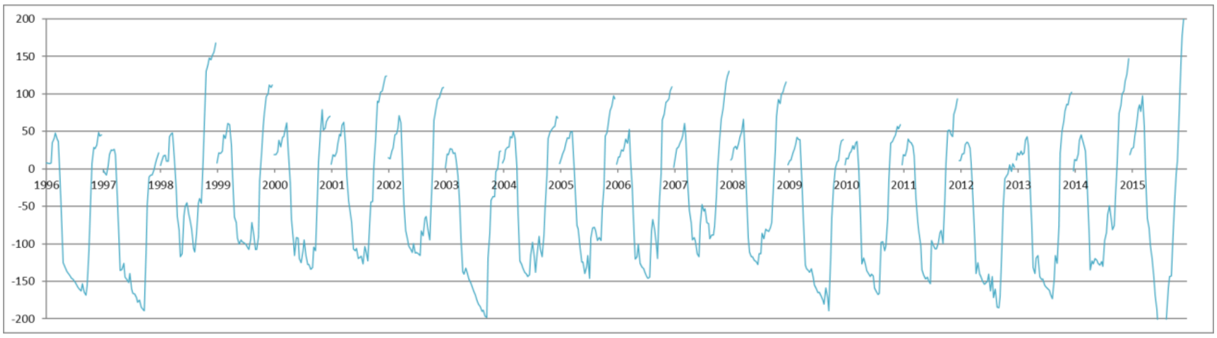

Figure 3.7.15. CDND for Loosdrecht [mm]

For Loosdrecht, figure 3.7.12abc-3.7.13abc and 3.7.14, the LHM is more realistic than the other AGV regions. The cumulative deviation in in-and outlet remains around 100mm/yr. However, each year the LHM produces a strange inlet peak at the start of April, this peak is also present in the outlet at the end of September.

The CDND shows a U-shape each year, with a drop in April and a rise in September, this is related to the observed peaks in inlet and outlet. Figure 3.7.20 shows that, with a deviation of 15mm in three months, the average CDND during the growing season is reproduced very well for Loosdrecht.

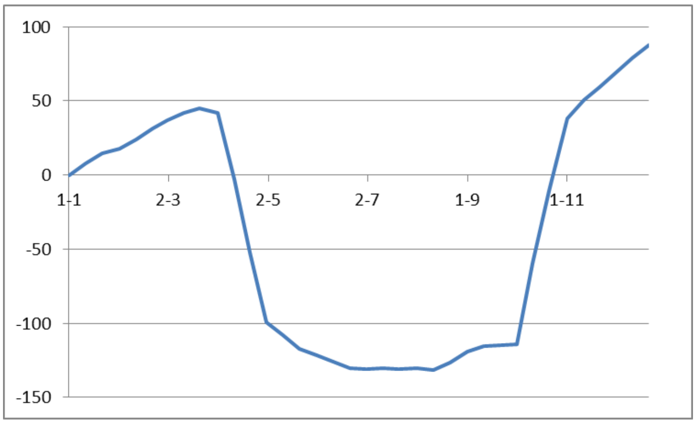

Figure 3.7.20. Average CDND for Loosdrecht (1996-2015) [mm]

The deviation in individual in-and outlet are probably due to differences in flushing. Figure 3.7.4 shows that no flush is imposed in the LHM, while in reality this does occur. The U-shaped CDND could be due to a wrong summer- and winter surface water level (too large fluctuation in the LHM). Summer and winter surface water levels are incorporated in the LHM; however, measurements show that this region does not appear to have seasonally depended surface water levels. Additionally, this region contains a lot of surface water. Since the average CDND in figure 3.7.20 is very small during the growing season, it is credible that no large deviations in surface water evaporation occur.

No clear relation between the CDND in figure 3.7.15 and dryness progression in figure 3.2.12 is found during the growing season. Although, during times the precipitation deficit decreases after a prolonged period of dryness, it seems that the CDND shoots upwards. Also for 2003 and spring-2011 the CDND is larger, but this is not the case for other dry periods. The CDND fluctuates approximately 40mm during the growing season. If this 40mm deviation occurs in 10days, this comes down to 1.6m^3/s.

3.7.3.4 Ronde Hoep

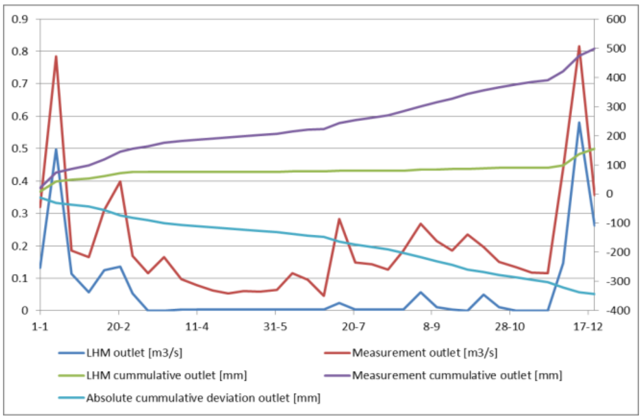

Figure 3.7.16a. Measured and modelled outlet for Ronde Hoep 2011 (left: [m^3/s], right: [mm])

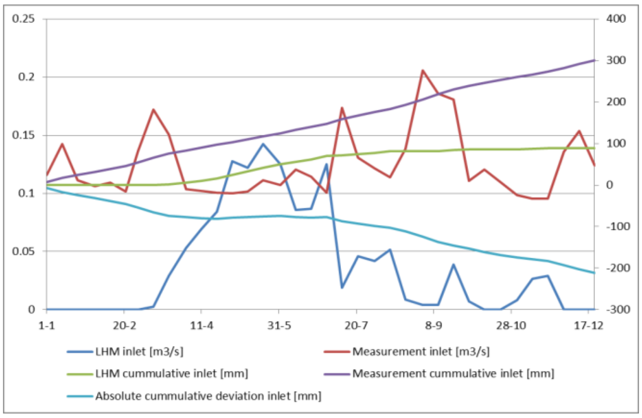

Figure 3.7.16b Measured and modelled inlet for Ronde Hoep 2011 (left: [m^3/s], right: [mm])

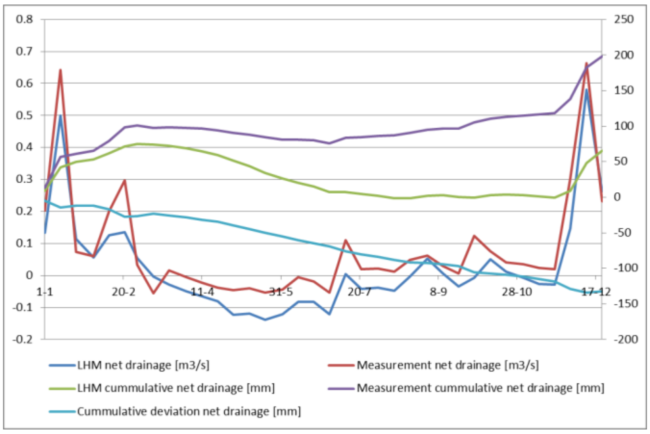

Figure 3.7.16c. Measured and modelled ND for Ronde Hoep 2011 (left: [m^3/s], right: [mm])

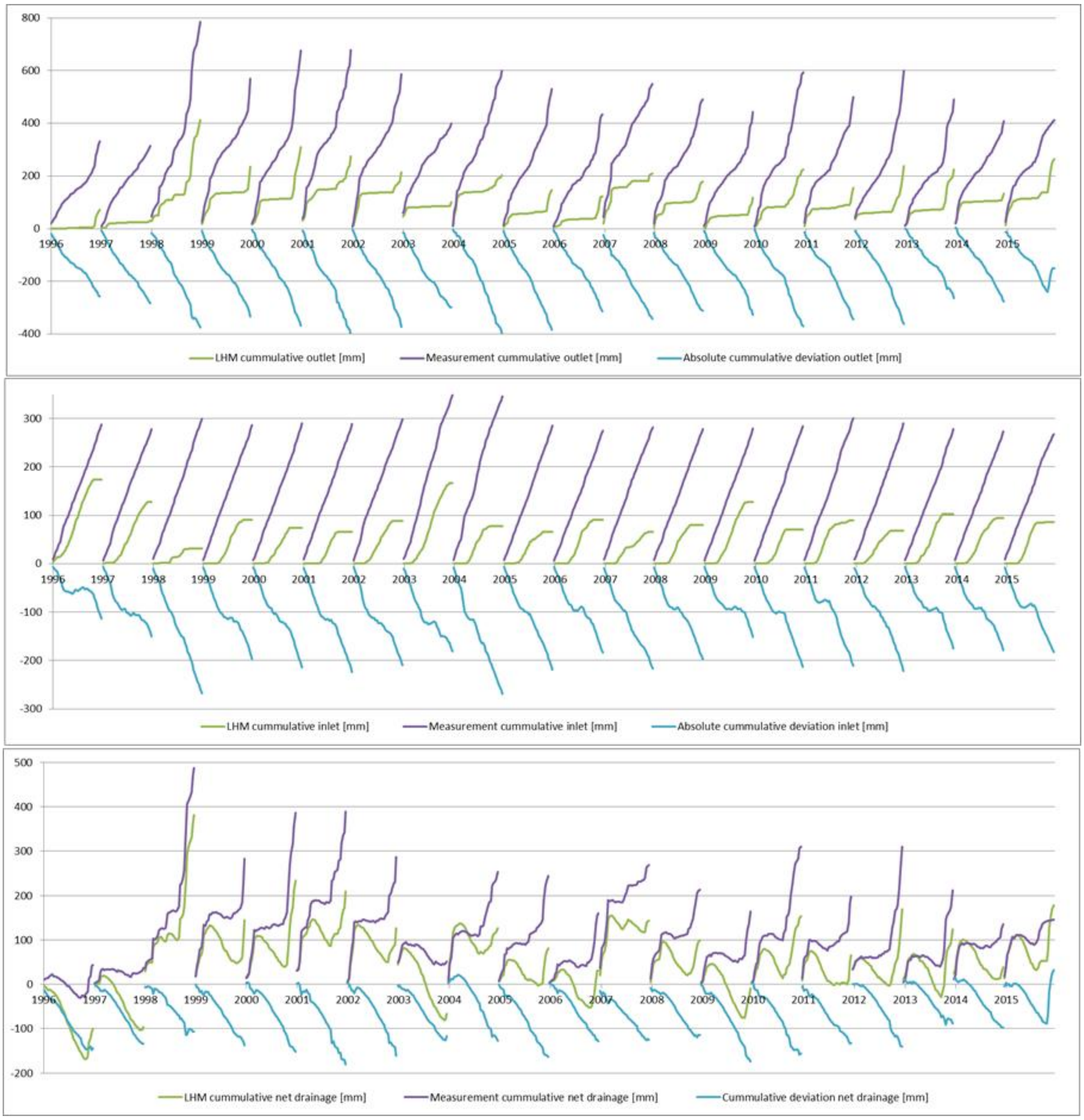

Figure 3.7.17. Ronde Hoep total [mm]

In Polder Ronde Hoep, figure 3.7.16abc and 3.7.17, large amounts of flush water are applied, additionally this polder experiences relative high infiltration rates. Figure 3.7.5 shows that the LHM imposes only 5mm, or 0.004m^3/s, of flush during the whole growing season on Polder Ronde Hoep. From figures 3.7.16abc and 3.7.17 it can be concluded that flushing is much more applied, and that the ND, which corrects for deviations in amount of flush water, is calculated much better. However, the ND still shows a relative linear CDND of about -150mm a year, or -0.41mm/d. When this deviation in CDND is totally due to a wrong infiltration rate in the LHM, actual infiltration would be (0.65-0.41=)0.24mm/d, or 0.04m^3/s. The Water Authority considered this to be a more realistic value.

3.7.3.5 Horstermeer

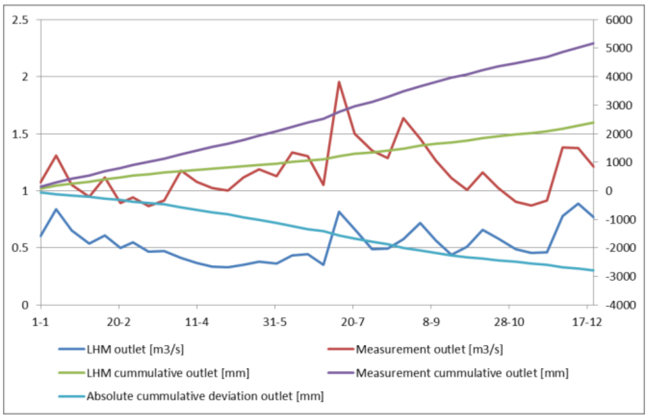

Figure 3.7.18a. Measured and modelled outlet for Horstermeer 2011 (left: [m^3/s], right: [mm])

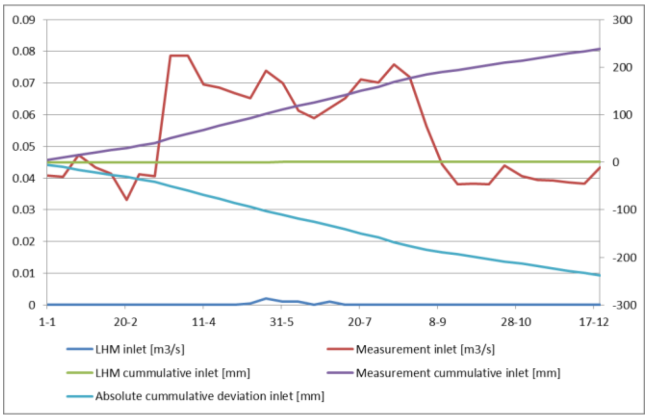

Figure 3.7.18b. Measured and modelled inlet for Horstermeer 2011 (left: [m^3/s], right: [mm])

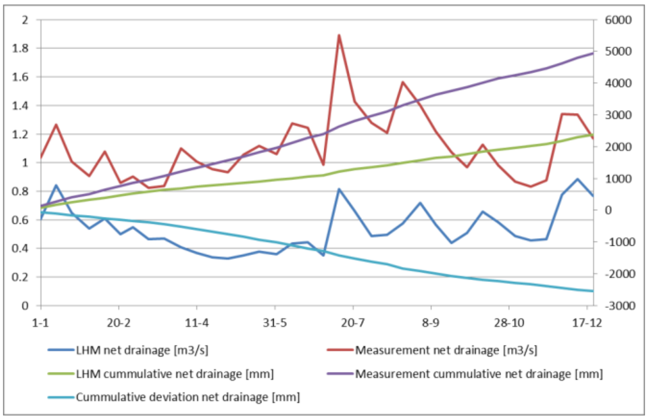

Figure 3.7.18c. Measured and modelled ND for Horstermeer 2011 (left: [m^3/s], right: [mm])

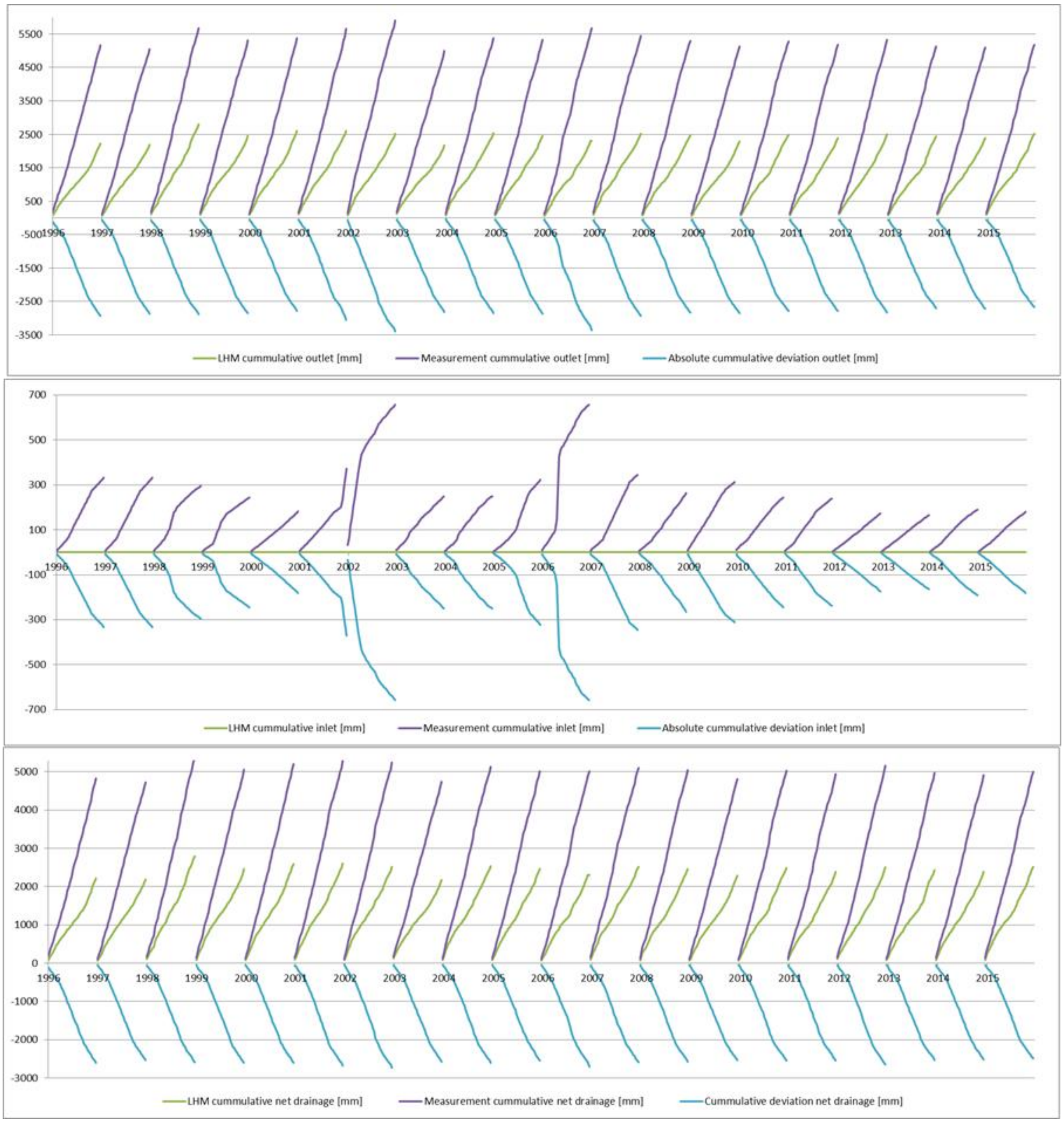

Figure 3.7.19. Horstermeer total [mm]

Horstermeer has a surface elevation that is approximately 2m below that of the neighbouring Vinkeveense Plassen. Additionally, at places, the impermeable top-layer has a thickness of only 1 meter. The combination of these factors leads to very high seepage rates in the polder.

Figure 3.7.18a shows that the LHM outlet is structurally too low. However, both the LHM and measurements show very high amounts of water outlet, 2500mm/yr and 5000mm/yr respectively. 5000mm/yr is considered realistic by the water authority.

Figure 3.7.18b shows that the LHM calculates practically no inlet, while in reality 250mm/yr is let in. From the ND in figure 3.7.18c and 3.7.19 it can be concluded that deviations in amounts of flush water do not explain all the deviation. The CDND is linear throughout the year, to -2700mm/yr. When the CDND is totally due to a wrong seepage rate in the LHM, actual seepage would be (5.76+7.4=)13.2mm/d. This is a very high seepage rate. However, considering the field situation of 5000mm/yr of outlet, realistic.

It should be noted that the LHM ND is already very high, and it seems that the LHM is not capable of calculating seepage rates that are this extreme. The reason for the high seepage rate in Polder Horstermeer is due to cracks in the impermeable top layer, and the bottom of the ditches that penetrate the impermeable layer and reach the sandy aquifer below. At these locations, the most extreme seepage rates occur. Cracks in the top-layer are not incorporated in the LHM.

4 Discussion / Conclusion

"*To what extent are the results of the LHM, concerning the fresh water demand in the western part of the Netherlands during 1996-2015, in line with the measured results?"*

"To what extent are the found differences between the LHM results and the measured results significant for the usability of the LHM concerning the DPZW?"

Ground water

Although individual deviations in ground water level can be large, no large systematic errors are found. The observed deviations showed a broad range, and not all the observed deviations can directly be attributed to errors in the LHM. Although it seemed that ground water levels were slightly too low, they performed on average quite well. Because individual deviations can be large, it is recommended that the LHM is not used for ground water level reproduction on small scales.
The dynamicss, and especially the small-scale fluctuations in ground water level, appeared to be too large. This could mean that ground water levels react too strong on precipitation/evaporation events, and can be an indication that the buffering of the unsaturated zone is too small. The too small storage in the unsaturated zone could also influence the external fresh water demand during dry periods, as there is less internal storage for the after-delivery of water. The direct effect of this too small storage on the external water demand is not determined

Rijnland

For the complete management area, although not all individual peaks in the inlet and outlet are captured by the LHM, the dynamicss are reproduced quite well. It appears that the LHM imposes an incorrect amount of flush. The ND, which is corrected for deviations in flush, performs much better. The CDND shows a sinusoidal trend throughout the year, with a linear over-use of water of 20-40mm during the growing season. During extra dry periods, such as 2003 and spring-2011, the deviations do not become significantly larger and it appears that the LHM captures the water demand well during these periods. The calculated net water use during the KWA-2011 for Rijnland was 10-11m^3/s, this is in line with the observations.

The CDND for the HLM Polder is very large, but it seems very plausible that most of the deviation originates from a wrong imposed flush. The validation for all Rijnland polders and the boezem of Rijnland give much better validation results. This is because here the measurement data is based on fluxes in and out the boezem, and therefore by-pass the internal in- and outlet to polders which include the polder flush.

For Polder De Noordplas, seepage is not calculated correctly and the measurement data was not plausible. It seems that the LHM does not calculate higher seepage rates (>0.75mm/d) correctly.

In the LHM most of the over demand is projected on a too small outlet of water, and the inlet shows much a smaller error during the growing season. This means that the 20-40mm over-use does not lead to a 20-40mm extra calculated water inlet. Also, the over-demand is quite linear throughout the growing season and is not projected on individual dry events. This makes the LHM usable to determine future water demand for the DPZW for Rijnland. However, especially for individual polders, correct amounts of flush need to be imposed.

Delfland

For Delfland the same systematic sinusoidal error in water use is detected as for Rijnland, with a linear over-use of 30-40mm during the growing season. Also for Delfland most of the deviation in over-use is projected on a too small outlet, and no relation with extreme dry events is detected. The amount of surface water allocation to agriculture in the Westland is significantly more than that for other regions, and there is no large-scale deviation in the boezem water use. It seems that greenhouse surface water use is calculated correctly.

Since two independent data sets show the same results this indicates that this deviation is probably very systematic for the LHM. Although it is of course recommended to fix this deviation, the magnitude and nature of the error still allows applications in the DPZW for this region.

Schieland en de Krimpenerwaard

For Schieland en de Krimpenerwaard the calculated water inlet for De Rotte, Ringvaart and Krimpenerwaard during dry conditions are approximately half the estimates given by HHSK. HHSK already expected that their estimates were serious overestimates and this is confirmed by the LHM. For the Krimpenerwaard and Ringvaart infiltration/seepage is calculates correctly, although the largest deviations occur at/near places with the largest infiltration/seepage rate. Seepage for De Rotte is 50% too low.

It is very well possible that the LHM calculates correctly for the Krimpenerwaard, and that the measurement data is wrong. This is supported by the conclusion that the LHM water inlet for the three HHSK regions in figures 3.4.2-3.4.4 all equally deviate from the estimates (slightly higher than half the estimate). Also the infiltration rate for the Krimpenerwaard is calculated correctly.

The measurement data is not detailed enough to make strong conclusions and no further recommendation regarding the usability for the DPZW can therefore be made.

Stichtse Rijnlanden

Measurement data for the HDSR region was not always very detailed and trustworthy. However, from the water balances a slight over demand during growing season is visible, but in-depth analysis was not possible. The KWA-2011 data shows that the LHM calculates a too large water demand during the growing season for the western HDSR. Unfortunately, the LHM did not implement the KWA during spring 2011 and no conclusions regarding the fresh water demand for Rijnland can be made with this data.

Regarding the applicability for the DPZW, measurement data is to crude to make detailed conclusions, but the findings are in line with Rijnland and Delfland.

Hollandse Delta

For Hollandse Delta the findings are in line with conclusions from Rijnland and Delfland. Net water use is linearly over calculated by 20mm during the growing season. Additionally, this dataset showed that the wrongly imposed flush has a large influence on the calculated water inlet.

Amstel, Gooi en Vecht

For the AGV region detailed measurement data was available and the results were quite different from those of other regions. It appears that, based on the large linear deviation, extreme seepage/infiltration rates are not captured well by the LHM, having a large influence on the water demand. Correcting the LHM seepage rates with the CDND gives more realistic seepage rates, according to the Water Authority. Additionally, imposed amounts of flush are wrong. Only for Loosdrecht the LHM performs rather well during the growing season. Since this region contains a lot of surface water, it appears that on average open water evaporation is calculated correctly. However, for Loosdrecht, the LHM shows a peak in inlet during April and a peak in outlet during September. This is probably due to a wrong surface water level change and should be corrected. Additionally for Loosdrecht, fluctuations during the growing season are still quite large. Although no direct link to the dryness progression is found, some dry periods do show a larger deviation.

For the AGV region, the LHM is not applicable to determine the fresh water demand. Recommendation is that first the model is adjusted to more extreme seepage rates. The corrected seepage rates were considered by the Water Authority to be more realistic than the original LHM seepage rates. Also, the U-shape for Loosdrecht, in figure 3.7.20, should be corrected. After this a more thoroughly validation can be performed.

End conclusion

"To what extent are the results of the LHM, concerning the fresh water demand in the western part of the Netherlands during 1996-2015, in line with the measured results?"

The results of the LHM are in line with a deviation in the order of 20-40mm for the growing season. This is clearly shown for the boezem of Rijnland and Delfland. However, the LHM imposes incorrect amounts of flush and this needs to be corrected. For other regions in the study area measurement data was not detailed enough to indisputably make the same conclusion, but results were in line. For the Krimpenerwaard it is not known where the deviation in water demand comes from, it could very well be possible that the measurement data is wrong and the LHM calculates correct.

However, for the AGV region and other regions with high seepage/infiltration rates (>0.75mm/d), here it appears that these seepage/infiltration rates are not calculated correctly. The HLM Polder has a seepage of 0.38mm/d, which is calculated correctly. Polder De Noordplas has a seepage rate of 0.82mm/d, which the LHM calculates to 0.48mm/d. The AGV regions have infiltration/seepage rates that are larger than 2mm/d (except Ronde Hoep). An explanation cloud be the thinness of the impermeable top layer and bursting of this layer.

It seems that there are two orders of deviation. The largest deviation is the extreme seepage that appeared for the AGV region; the second deviation is sinusoidal deviation of 20-30mm amplitude that most clearly appeared for the Rijnland and Delfland region. The hypothesis is that, after correct calculation of extreme seepage/infiltration rates and/or implementation of detailed measurement data, the sinusoidal storage deviation does also appear for the other regions, and that the LHM gives reliable calculations for the fresh water demand.

"To what extent are the found differences between the LHM results and the measured results significant for the usability of the LHM concerning the DPZW?"

For the boezem of Rijnland and Delfland the differences are not significant. For these two regions, the validation is performed on a detailed temporal scale and it showed that deviations remained relative small. Although water use is slightly over estimated, the deviation is small and most if the over demand is projected on a too small outlet, causing the external water demand to be reproduced well. During dry periods, no extreme deviations in water demand are found. The sinusoidal CDND that remained is probably caused by a too small internal storage of approximately 20-30mm. Based on the ground water validation it is plausible that this storage error can be found in the unsaturated zone. For other regions in the study area measurement data was not detailed enough to indisputably conclude the same deviation, but results were in line.

For the AGV region and other regions with high seepage/infiltration rates (>0.75mm/d), here LHM deviations were too large to give a usable water demand for the DPZW.

The validation was not detailed enough to indisputably determine whether the LHM is applicable to determine the water-demand on LSW or polder level. However, results for the HLM Polder were in line with the estimates, but also showed that the LHM imposes incorrect amounts of flush. Although deviations in water use do not concentrate on individual dry events, some peaks in deviation are observed. One must therefore be careful when extracting the water demand for shorter periods (~10s days) from the LHM. Additionally, it is recommended to manually correct the LHM results with the right amount of flush water.

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Hydrologic Amersfoort
Meike Coonen

Appendices

Appendix A

Output parameters Metaswap

Parameter	Unit	Description
sv_Hgw	m+MSL	MetaSWAP groundwater level (+/-)
sv_dHgw	m	MetaSWAP groundwater level change (+=rise)
sv_Hgwmodf	m+MSL	MODFLOW groundwater head (+/-)
sv_dHgwmodf	m+MSL	MODFLOW groundwater head change (+/-)
sv_Hpd	m+MSL	MetaSWAP ponding water level (+/-)
sv_Hsw	m+MSL	surface water level (+/-)
sv_decSic	m3/m2	decrease of interception storage (+/-)
sv_decSpdmac	m3/m2	decrease of ’macro’ ponding storage (+/-)
sv_decSpdmic	m3/m2	decrease of ’micro’ ponding storage (+/-)
sv_decS1	m3/m2	decrease of water storage in rootzone box 1 (+/-)
sv_decS2	m3/m2	decrease of water storage in rootzone box 2 (+/-)
sv_decS3	m3/m2	decrease of water storage in rootzone box 3 (+/-)
sv_Pm	m3/m2	measured precipitation (>=0)
sv_Psgw	m3/m2	sprinkling precipitation from groundwater (>=0)
sv_Pssw	m3/m2	sprinkling precipitation from surface water (>=0)
sv_Esp	m3/m2	evaporation sprinkling water (<=0)
sv_Eic	m3/m2	evaporation interception water (<=0)
sv_Epd	m3/m2	evaporation ponding water (<=0)
sv_Ebs	m3/m2	evaporation bare soil (<=0)
sv_Tact	m3/m2	actual transpiration vegetation (<=0)
sv_qrun	m3/m2	runon (+/-)
sv_qdr	m3/m2	net infltration of surface water SIMGROdrainage (-=dr)
sv_qspgw	m3/m2	groundwater extraction for sprinkling (<=0)
sv_qmodf	m3/m2	sum of all MODFLOW stresses on groundwater (+=in)
sv_vcr	m3/m2	water balance error (water creation) (+/-)
sv_qmodfbot	m3/m2	upward seepage of MODFLOW cell (+=in)
sv_qsim	m3/m2	sum of SIMGRO stresses on groundwater including MODFLOW correction term (+/-)
sv_qsimcorrmf	m3/m2	correction term for realignment of MODFLOW in the case that there was not a full convergence during the last time step(+/-)
sv_dpvgrz	m	root zone depth according to input or veg. model (>0)
sv_dptbrz	m	root zone depth table value of unsa database (>0)
sv_vght	m	height of vegetation (>=0)
sv_lai	m2/m2	leaf area index (>=0)
sv_slcv	m2/m2	soil cover areal fraction (>=0)
sv_Siccap	m3/m2	interception capacity of canopy (>=0)
sv_fT	-	crop factor for transpiration (>=0)
sv_fEic	-	factor for interception evaporation (>=0)
sv_fEbs	-	factor for bare soil evaporation (>=0)
sv_fEpd	-	factor for ponding evaporation below crop (>=0)
sv_Etref	m3/m2	reference crop evapotranspiration (<=0)
sv_Ebspot	m3/m2	potential evaporation bare soil (<=0)
sv_Tpot	m3/m2	potential transpiration vegetation (<=0)
sv_Trel	m3/m3	relative transpiration (=1.0 for Tpot=0.0) (>=0)
sv_Etact	m3/m2	total actual transpiration (<=0)
sv_Psswdem	m3/m2	sprinkling from surface water demand (>=0)
sv_qinf	m3/m2	infiltration on soil surface (total) (+=down)
sv_qmr	m3/m2	flow through bottom of box1 total (+=up)
sv_Sic	m3/m2	interception storage (>=0)
sv_Spdmac	m3/m2	’macro’ ponding storage (>=0)
sv_Spdmic	m3/m2	’micro’ ponding storage (>=0)
sv_S01	m3/m2	soil water storage in rootzone box 1 (>=0)
sv_Ssd01	m3/m2	soil water saturation deficit of box 1 (>=0)
sv_Ssd02	m3/m2	soil water saturation deficit of box 2 (>=0)
sv_Ssd03	m3/m2	soil water saturation deficit of box 3 (>=0)
sv_Ssdtot	m3/m2	total soil water saturation deficit (>=0)
sv_decStot	m3/m2	decrease of total storage (+/-)
sv_Suz	m3/m2	total unsaturated storage above phreatic layer (>=0)
sv_phrz01	m	mean root zone pressure head box 1 (+/-)
sv_phrz02	m	mean root zone pressure head box 2 (+/-)
sv_phrz03	m	mean root zone pressure head box 3 (+/-)
sv_sc1	-	groundwater storage coefficient (0< =1)
sv_TempCmnday	°C	minimum temperature during 24 hrs (+/-)
sv_TempCmxday	°C	maximum temperature during 24 hrs (+/-)
sv_TempC	°C	mean temperature (+/-)
sv_Nrel	-	mean relative sunshine duration (0< <=1)
sv_Rad	kJ/m2/d	mean shortwave radiation (>=0)
sv_Hum	kPa	mean humidity (>=0)
sv_wind	m/s	mean windspeed (>=0)
sv_Rnt	kJ/m2/d	mean net radiation discounting reflection (albedo effect) and long wave emission (+/-)
sv_HG	kJ/m2/d	mean rest term of energy balance available for sensible (H) and ground (G) heat flux (+/-)

Appendix B

Modflow output parameters

Parameter	Unit	Desciption
mf_Head_l1	m+MSL	head of layer 1
...	m+MSL	...
mf_Head_l7	m+MSL	head of layer 7
mf_riv_s1_l1	m3	drainage/infiltration of river system 1 layer 1
...	m3	...
mf_riv_s6_l1	m3	drainage/infiltration of river system 6 layer 1
mf_riv_s1_l2	m3	drainage/infiltration of river system 1 layer 2
...	m3	...
mf_riv_s6_l2	m3	drainage/infiltration of river system 6 layer 2
mf_drn_l1_calc	m3	drainage layer 1
mf_drn_s1_l1	m3	drainage system 1 layer 1
mf_drn_s2_l1	m3	drainage system 2 layer 1
mf_drn_s3_l1	m3	drainage system 3 layer 1
mf_drn_l2_calc	m3	drainage layer 2
mf_drn_s1_l2	m3	drainage system 1 layer 2
mf_drn_s2_l2	m3	drainage system 2 layer 2
mf_drn_s3_l2	m3	drainage system 3 layer 2
mf_riv_l1_calc	m3	drainage/infiltration of river layer 1
mf_drn_riv_l1_calc	m3	drainage of river layer 1
mf_drn_riv_s1_l1_calc	m3	drainage of river system 1 layer 1
...	m3	...
mf_drn_riv_s6_l1_calc	m3	drainage of river system 6 layer 1
mf_inf_riv_l1_calc	m3	infiltration of river layer 1
mf_inf_riv_s1_l1_calc	m3	infiltration of river system 1 layer 1
...	m3	...
mf_inf_riv_s6_l1_calc	m3	infiltration of river system 6 layer 1
mf_riv_l2_calc	m3	drainage/infiltration of river layer 2
mf_drn_riv_l2_calc	m3	drainage of river layer 2
mf_drn_riv_s1_l2_calc	m3	drainage of river system 1 layer 2
...	m3	...
mf_drn_riv_s6_l2_calc	m3	drainage of river system 6 layer 2
mf_inf_riv_l2_calc	m3	infiltration of river layer 2
mf_inf_riv_s1_l2_calc	m3	infiltration of river system 1 layer 2
...	m3	...
mf_inf_riv_s6_l2_calc	m3	infiltration of river system 6 layer 2
mf_ont_calc	m3	total removal of layers 1 and 2
mf_ont_l1_calc	m3	total removal of layer 1
mf_ont_l2_calc	m3	total removal of layer 2
mf_Hflx_l1_calc	m3	lateral flux of layer 1
...	m3	...
mf_Hflx_l7_calc	m3	lateral flux of layer 7
mf_Vflx_l1_calc	m3	vertical flux to layer 1
...	m3	...
mf_Vflx_l6_calc	m3	vertical flux to layer 6
mf_KD_l1	m2.d-1	transmissivity of layer 1
...	m2.d-1	...
mf_KD_l7	m2.d-1	transmissivity of layer 7
mf_C_l1	d	vertical resistance of layer 1
...	d	...
mf_C_l6	d	vertical resistance of layer 6
mf_well_l1	m3	well of layer 1
...	m3	...
mf_well_l7	m3	well of layer 7
mf_well_calc	m3	total well of all layers

Appendix C

Mozart output parameters

Parameter	Unit	Desciption
mz_Precip	m3	Precipitation
mz_Evaporation	m3	Evaporation
mz_Drainage_sh	m3	Drainage (shallow)
mz_Drainage_dp	m3	Drainage (deep)
mz_Infiltration_sh	m3	Infiltration (shallow)
mz_Infiltration_dp	m3	Infiltration (deep)
mz_UrbanRunoff	m3	Urban runoff
mz_Upstream	m3	Upstream
mz_Downstream	m3	Downstream
mz_From_DW	m3	From district-water
mz_To_DW	m3	To district-water
mz_dStorage	m3	Difference in storage
mz_Alloc_Agric	m3	Allocation for agriculture
mz_Alloc_WM	m3	Allocation for water management
mz_Alloc_Flush	m3	Allocation for flush
mz_Alloc_FlushReturn	m3	Allocation for flush return
mz_Alloc_PubWat	m3	Allocation for public water
mz_Alloc_Industry	m3	Allocation for industry
mz_Alloc_GreenHouse	m3	Allocation for greenhouses
mz_Alloc_WM_DW	m3	Allocation for water management from district
mz_Demand_Agric	m3	Demand for agriculture
mz_Demand_WM	m3	Demand for water management
mz_Demand_Flush	m3	Demand for flush
mz_Demand_FlushReturn	m3	Demand for flush return
mz_Demand_PubWat	m3	Demand for public water
mz_Demand_Industry	m3	Demand for industry
mz_Demand_GreenHouse	m3	Demand for greenhouses
mz_Demand_WMtot	m3	Demand for water management total
mz_Demand_WM_ToDW	m3	Demand for water management to district
mz_BalanceCheck	m3	Balancecheck
mz_Drainage_calc	m3	Drainage (total)
mz_Infiltration_calc	m3	Infiltration (total)