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TNO report

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Groundwater dynamics in the aquifers of the Netherlands

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Summary

The dynamics of the groundwater in the Netherlands have been analysed using the groundwater head data from the national database at DINOloket and the timeseries modelling software of the grondwatertools website. The latter website presents time series models of the last 8 years of data, long enough for a good success rate and short enough to avoid large system changes.
The analysis resulted in maps of various aspects of the groundwater dynamics at multiple depths: yearly fluctuation, total response and response time of the precipitation response of the groundwater head. Also, the evaporation factor and the noise decay parameter in the stochastic part of the time series models have been mapped. The maps of the precipitation response and the noise parameter show strong resemblance with the pattern of surfacewater intensity, of surface elevation and thickness of the unsaturated zone. Vertical differences in the response time seem to correlate with hydraulic resistance of aquitards in between the piezometers. These relations are statistical and further research is needed for physical quantification.
In addition, a selection of time series with a length of more than 40 years has been analysed. Consistent with previous analyses, downward trends have been found, but the success rate of the time series modelling is limited. To improve this, it is recommended to determine changes in the groundwater system for each time series and to apply non-linear time series modelling.

Contents

1 Introduction

TNO Geological Survey of the Netherlands (TNO-GSN) provides information on the subsurface for the Netherlands at the websites https://www.DINOloket.nl/en/ and https://www.nlog.nl/en/ for the shallow and deep subsurface respectively. The Geological Survey is part of TNO (https://www.tno.nl/en/focus-areas/ecn-part-of-tno/roadmaps/geological-survey-of-the-netherlands/). Background information on the work of TNO-GSN can be found at the site https://www.grondwatertools.nl.
Among the data at DINOloket, TNO-GSN provides the national database with groundwater heads, which can be accessed through https://www.dinoloket.nl/en/subsurface-data. In addition to the measured heads, TNO-GSN provides time series models. These models show the relation with precipitation and potential evapotranspiration and the normal range of the groundwater variation (regime curves). This information is available at: https://www.grondwatertools.nl/grondwatertools-viewer.
The time series models link the variation of the groundwater heads to precipitation and potential evapotranspiration. The models provide more information than the head time series by themselves, because precipitation and potential evapotranspiration represent the main natural influence and because the groundwater response to precipitation is a signature of the dynamics of the groundwater system. In addition, the part of the groundwater fluctuations not influenced by precipitation and potential evapotranspiration may provide information on local, non-natural influences on the groundwater system.

In this report, we focus on the groundwater heads in the aquifers. Mapping the groundwater dynamics of the phreatic groundwater table is the focus area of Wageningen Environmental Research (http://maps.bodemdata.nl). It is a separate item for the National Key Register (BRO). However, multi-piezometer wells with the upper piezometer at a shallow depth are considered in the analysis of changes with depth.
Various aspects of the groundwater dynamics will be shown:

- Average yearly fluctuation;
- Precipitation response and vertical variation in this response.

These aspects have been analysed for all suitable piezometers in the DINO database.

2 Method and data

The Geological Survey of the Netherlands (TNO-GSN) maintains the public national database of groundwater head observations (available at https://www.dinoloket.nl/en/subsurface-data). All groundwater head time series have been simulated using transfer-noise modelling with precipitation and potential evapotranspiration as explanatory variables (Zaadnoordijk et al., 2019). Each night, the models are updated for piezometers in the database for which new data has been received. The precipitation and potential evapotranspiration data are retrieved from a webservice of the Royal Dutch Meteorologic Institute (https://www.knmi.nl). The latter was calculated according to Makkink (Hiemstra & Sluiter, 2011). The individual time series models are available online with interactive graphics (https://www.grondwatertools.nl/grondwatertools-viewer).

The software Metran (Berendrecht & van Geer, 2016) is used for the time series modelling (Zaadnoordijk et al., 2019). The groundwater level time series is split into a deterministic part and a stochastic part (Figure 1). The deterministic part represents the variation due to the specified explanatory variables. For the models on the grondwatertools website, these are precipitation and potential evapotranspiration. It is possible to include additional influences, like surface water levels or a general trend. The difference between the deterministic part and the measurements is called the model residual.

A noise model is used for the stochastic part. The purpose is to remove the autocorrelation in the residuals. The smaller the time steps between the measurements, the larger the autocorrelation. The existence of autocorrelation decreases the reliability of the model. We use a noise model with an exponential decay. The inverse of the noise model is applied to the residuals to obtain so-called “innovations”.

The explanatory variables are convoluted with an impulse response function (see e.g. Kreyszig, 2012): the value of each day is multiplied by the response function and the results are summed. An incomplete gamma distribution is used for the impulse response function (Berendrecht & Van Geer, 2016). It has three parameters, a multiplication factor A* and two shape parameters *a* and *n* (Besbes & de Marsily, 1984). For the grondwatertools website, the same function is used for precipitation and potential evapotranspiration except for a factor. This leads to five parameters to be optimized: three of the precipitation response, one evaporation factor, and one noise model parameter. The parameters are determined by a minimization procedure for the innovations.

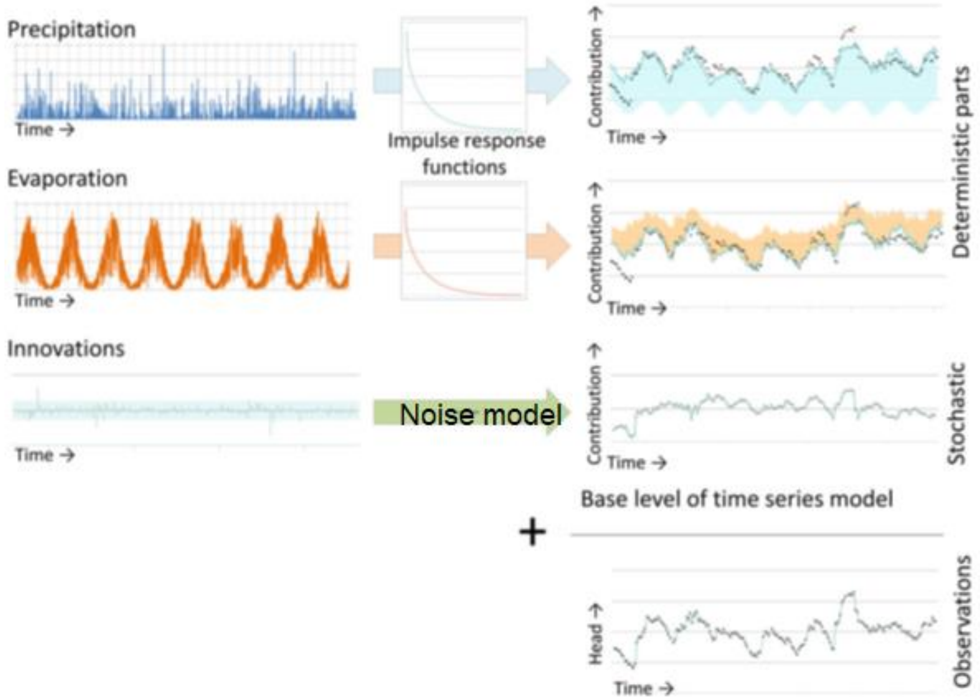

Figure 1 Setup of transfer function-noise model used for modelling head time series in Metran

The resulting time series models are evaluated using model evaluation criteria among which the explained fraction of the groundwater variation (Zaadnoordijk et al., 2019). Three classes are distinguished: bad models, reasonable models, and good models. The bad models are not shown on the website and discarded for the analysis in this report.
We used the selection to create maps showing various aspects:

1. Yearly fluctuation;
2. Precipitation response;
3. Long term trends.

2.1 Yearly fluctuation

The yearly fluctuation of the groundwater head in the aquifers has practical implications for e.g. seepage and groundwater pumping. This fluctuation can be visualized for a piezometer using the regime curve, showing the average fluctuation over the year (Figure 2). Stochastic simulations using the time series models provide reliability bands around the regime curve, so that it can be put into perspective together with the deviations that may be expected.

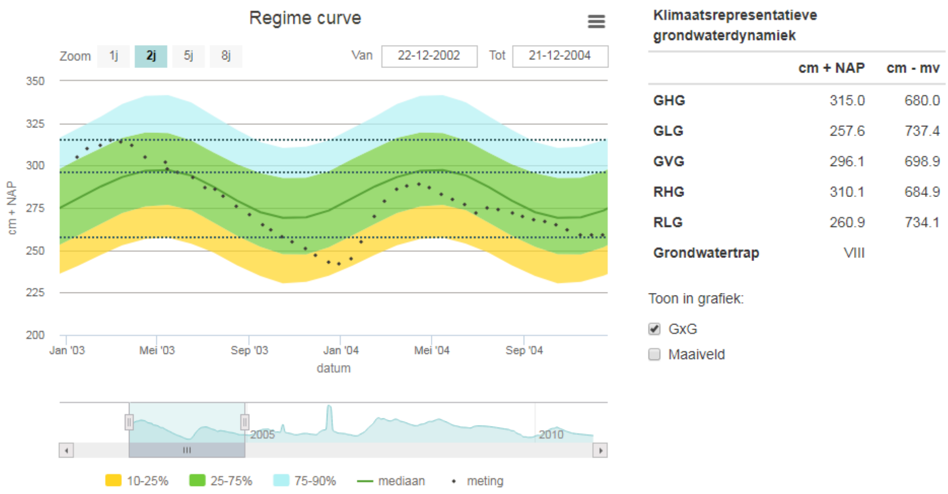

Figure 2 Visualization of normal yearly fluctuation together with measurements

The yearly fluctuation was mapped per major aquifer as distinguished in the Dutch national hydrological model (LHM) of the National Hydrological Instrument (http://www.nhi.nu). This is a simplified subsurface schematisation based on the hydrogeological model REGIS II of TNO Geological Survey of the Netherlands (https://www.dinoloket.nl/en/subsurface-models).

2.2 Response characteristics

The precipitation impulse response function (IRF) is a signature of the groundwater system. It provides insight in the boundary conditions and hydrogeological situation. We characterize it by the total response M_0 and the response time t_{50}. The total response M_0 is equal to the unit step response, which corresponds to the area underneath the curve of the impulse response function. The response time t_{50} is the median time in this curve, the time that 50% of the response has passed.
The relevance of the precipitation impulse response function is illustrated below using data from two piezometers to the Southeast of the city of Utrecht. Also, the response time is important for monitoring and management activities.

Figure 3 shows two time series of the piezometric head together with precipitation response functions for the same measuring points. The different character of the head variation is reflected in the shape of the response functions:

- Timing of the response: an immediate high peak or a more gradual rise and decline;
- Total amount of the response, which is the area underneath the curve.

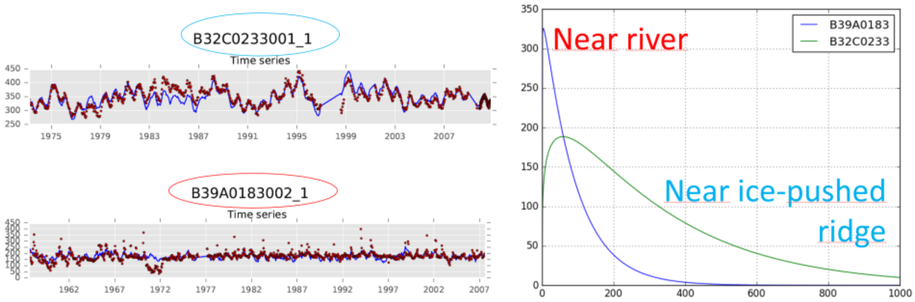

Figure 3 Groundwater head time series (left) and corresponding precipitation impulse response functions (right, with time on the horizontal axis [days] and response [cm per m/d]).

The piezometers are located to the Southeast of the city of Utrecht in two different geohydrological settings (Figure 4). B32C0233 is located at the foot of the ice pushed ridge of the Utrechtse Heuvelrug, which is an area with a mostly sandy subsurface and little drainage. B39A0183 lies near the River Lek (a branch of the River Rhine) and here the aquifer consisting of sand is overlain by a clayey confining layer with an intensive drainage system. The former gives a slower and larger response, which results in stronger seasonal variations and a larger total (step) response. The latter results in faster smaller fluctuations which give the time series a more spiky appearance.

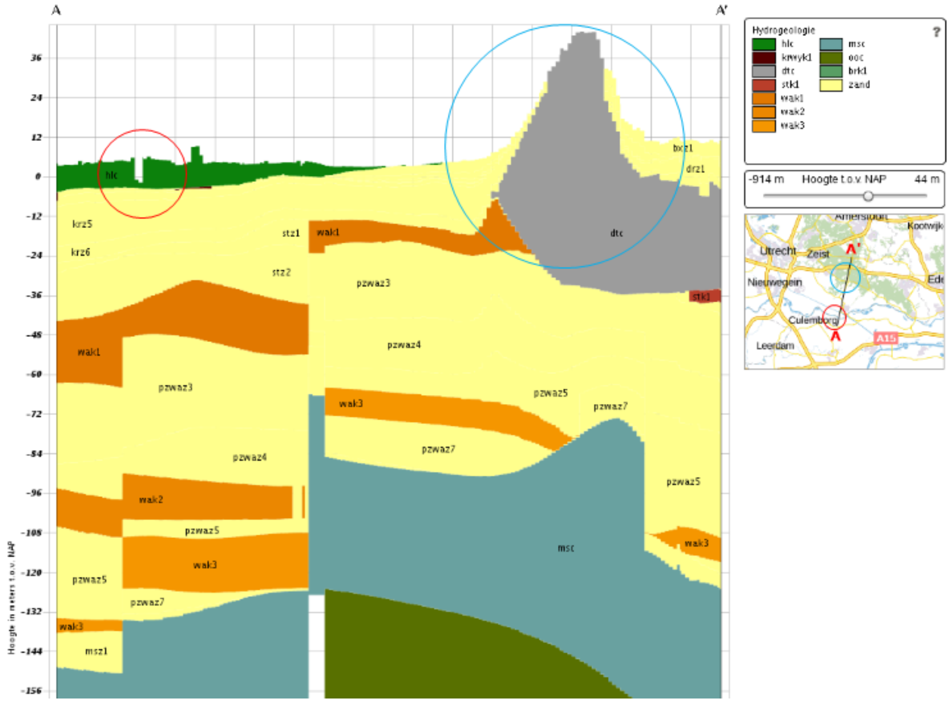

Figure 4 REGIS II cross section along the piezometers of Figure 3 showing the hydrogeological setting. Every unit (aquifer or aquitard) in this figure is annotated. The annotations consist of a formation code (e.g. wa, pzwa), a lithology code (k =clay, z =sand, c =complex) and an order number of the unit.

3 Results

3.1 Yearly fluctuation

We used the difference between the mean high (GHG) and mean low (GLG) groundwater head as a measure of the yearly fluctuation. Figure 5 shows the differences for the upper regional aquifer. The fluctuation is small in the polder areas of the Western part of the Netherlands and to a lesser extent in the North. Values of more than a meter occur in the more elevated areas of South, East and Northeast Netherlands. In central Limburg around the River Meuse river, and in areas of intermediate elevation like Salland and Gelderse Vallei, the fluctuations have intermediate values. There are few points in the Holocene part of the Netherlands (polders in Western and Northern part) and in the highest Pleistocene regions (Veluwe in the Central part, and Zuid Limburg, the Southernmost part of the Netherlands) due to a lower density of piezometers and a larger percentage of bad time series models.

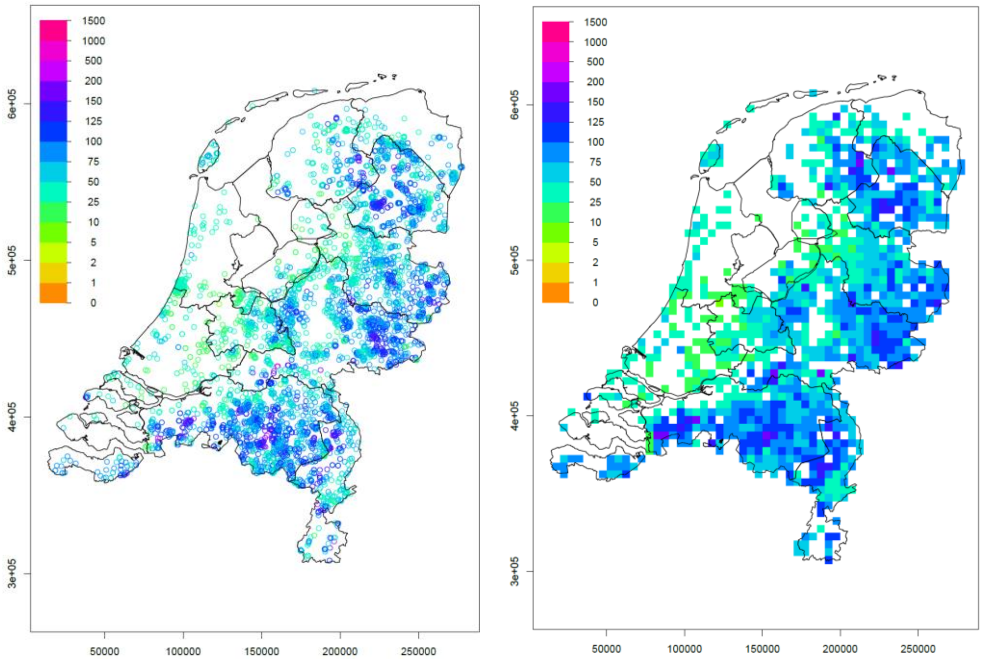

Figure 5 Difference between mean high and mean low groundwater head in the first regional aquifer (NHI-LHM code: WVP2) per piezometer (left) and averaged for 5 km x 5 km cells of a regular grid.

Appendix A shows the differences between GHG and GLG for all aquifers from the NHI-LHM model. The patterns are similar.

3.2 Response characteristics

Figure 6 shows the total response to precipitation (M_0 or step response) for the piezometers in the upper regional aquifer (NHI-LHM code: WVP2). The colours show a clear regional pattern with high values in the higher sandy areas and lower values in the polders and along the major surfaces waters.

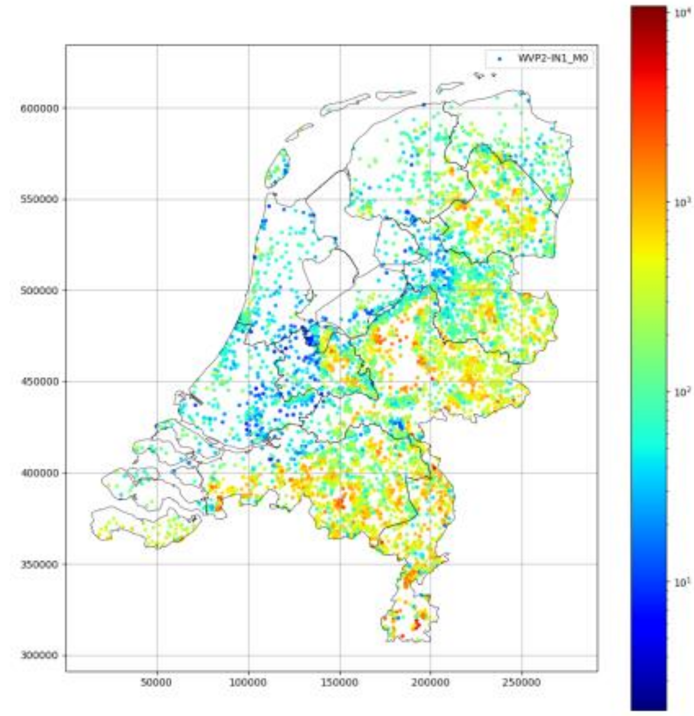

Figure 6 Total precipitation response (M_0, step response, [100 days] groundwater head in centimeters over precipitation in meters per day) in the transfer-noise models for the upper regional aquifer (NHI-LHM code: WVP2)

Appendix B gives the total precipitation response for all aquifers of the national groundwater model of NHI-LHM. The maps differ more in the piezometers present per aquifer than in the distribution over the country.

Figure 7 shows the map of the average precipitation response time for the first regional aquifer.

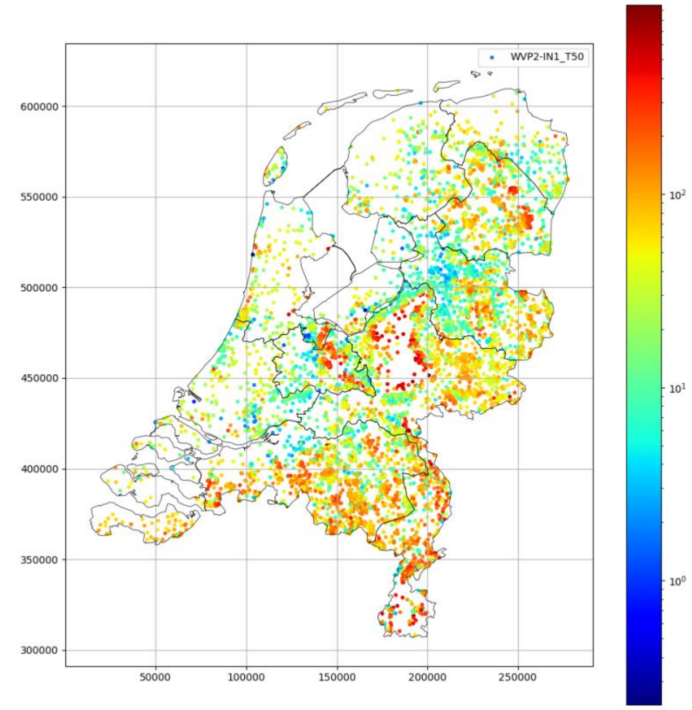

Figure 7 Precipitation response time (t_{50}, [days]) in the transfer-noise models for the upper regional aquifer (NHI-LHM code: WVP2)

The pattern of the response time is similar to the total response (Figure 6). This also holds for the precipitation response time in Appendix C.

The lateral variation in the total response and response time are more striking than the vertical variation. Therefore, the differences between aquifers are hard to be seen from comparing the separate maps for these aquifers. Figure 8 shows the difference in response time between the local phreatic aquifers (WVP1 in NHI-LHM) and the first regional aquifer (WVP2). The differences are calculated for observation wells which have at least one piezometer in each aquifer. The lowest WVP1 piezometer and the highest WVP2 piezometer have been used.
Both positive and negative differences occur, meaning that the response time may decrease or increase with depth.

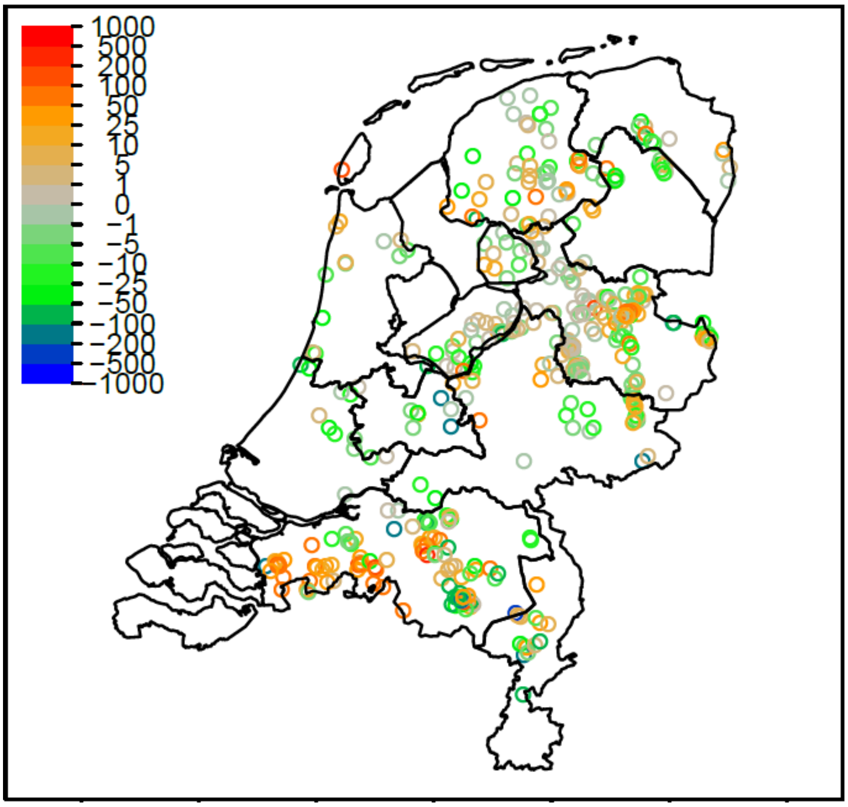

Figure 8 Difference in precipitation response time [days] between local phreatic and first regional aquifer

The time series models do not only contain the response to precipitation, but also the response to potential evapotranspiration and the noise model. The impulse response function for potential evapotranspiration has the same shape as precipitation. The size is determined by an evaporation factor. The noise model has a parameter for exponential decay.

The evaporation factor indicates how strong the groundwater head responds to potential evapotranspiration compared to precipitation. A factor smaller than one suggests that the actual evapotranspiration is less than the potential evapotranspiration of the KNMI. The potential evapotranspiration is representative of a grassland with optimal moisture conditions (Hiemstra & Sluiter, 2011). Reduced evapotranspiration is well possible depending on the type of land cover and the moisture content of the soil.
An evaporation factor greater than one would suggest that the actual evapotranspiration is larger than the potential evapotranspiration. This is only realistic for a few types of land cover (e.g. deciduous trees with enough moisture in a warm period). A more likely explanation is that a significant part of the precipitation does not recharge the groundwater but is diverted to the surface water by pavement or drainage. Figure 9 shows the evaporation factor for the first regional aquifer and Appendix D for all aquifers of the national groundwater model NHI-LHM. There are regional differences, but the maps show a less clear pattern than the precipitation response time (Figure 7).

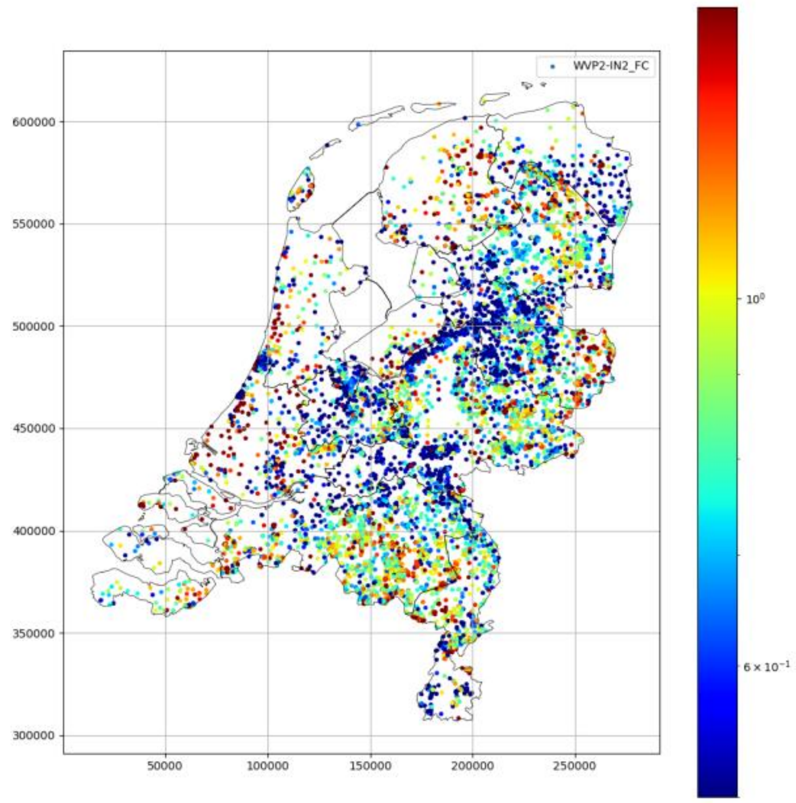

Figure 9 Evaporation factor in the transfer-noise models for the upper regional aquifer (NHI-LHM code: WVP2)

In addition to the parameters of the transfer functions, the time series models contain a parameter of the stochastic part of the model, the decay parameter of the noise model. Figure 10 shows the values of this parameter for the upper regional aquifer. The pattern is similar to that of the total response (Figure 6) and the response time (Figure 7) of the precipitation: lower values in the Holocene polder areas and higher values in the higher sandy Pleistocene areas. The highest values occur at the edges of the Veluwe, the high region in the centre of the Netherlands.

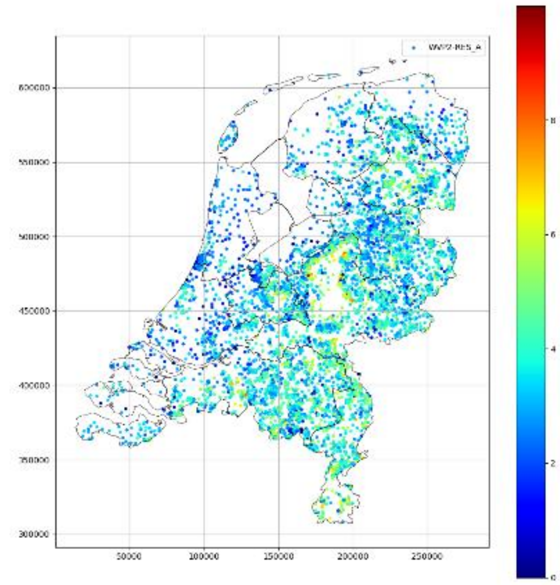

Figure 10 Noise model parameter (*RES_A*, [-], the expression $T = -1 / \ln(1 - \exp(-RES\_A))$ transforms this into a decay time in days) for the upper regional aquifer (NHI-LHM code WVP2)

4 Discussion

4.1 Yearly fluctuation

We limited the analysis of the yearly fluctuation to the difference between the average high and average low groundwater level and did not look at the timing of the maximum and minimum during the year or other aspects of the regime curve. Intuitively, the timing of the minimum and maximum of the regime curve depends on the response time to precipitation. It is recommended to verify this.

We used the common Dutch definitions (van Heesen, 1970) of mean high groundwater level (GHG) and mean low groundwater level (GLG) to calculate the range of the yearly fluctuation. Most piezometers have values less than 1.5 m, with lower values in the West and in the North and higher values in the sandy regions of the South – Central – Eastern part of the Netherlands. There are some isolated places where higher values occur, notably in the province of Noord Brabant. The reason for this is unclear and these piezometers deserve further analysis.

4.2 Response characteristics

The analysis of the precipitation response characteristics is based on the assumption that the response can be determined reliably by fitting transfer-noise models using METRAN. This assumption was validated by Zaadnoordijk (2018).

The lateral pattern of the total response to precipitation (M_0 or step response, Figure 6) and the response time (t_{50}, Figure 7) reflect the boundary conditions and the general properties of the groundwater system.

This is illustrated by Figure 11, which shows the precipitation response time together with the surface water percentage and the surface elevation. These two maps are strongly correlated. The presence of surface water is a strong control on the groundwater so that the extra recharge due to precipitation easily leaves the groundwater system reducing the response time. A thick unsaturated zone between the surface and the groundwater table attenuates the recharge which contributes to longer response times.

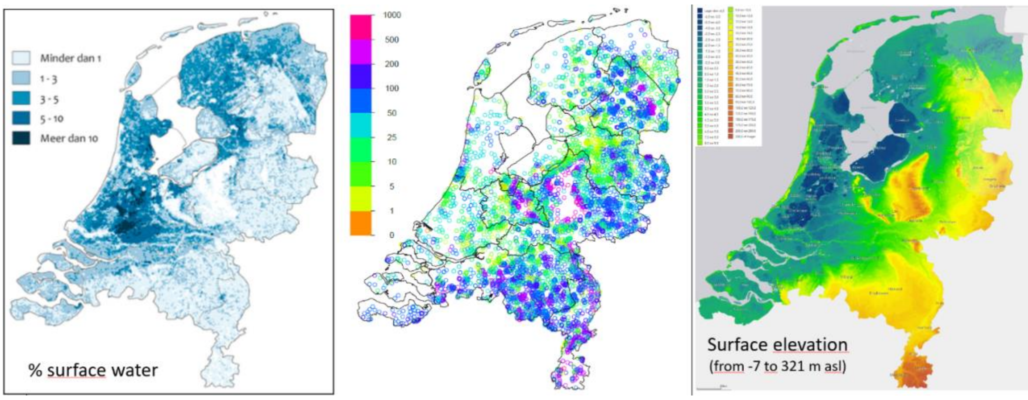

Figure 11 Precipitation response time [days] (centre, Figure 7), surface percentage of surface water (left) and surface elevation (right)

The pattern of the response time also looks similar to that of the total precipitation response (Figure 6) and of the yearly fluctuation (Figure 5). However, the correlation is not very large as the following graphs show (Figure 12, Figure 14, and Figure 15).

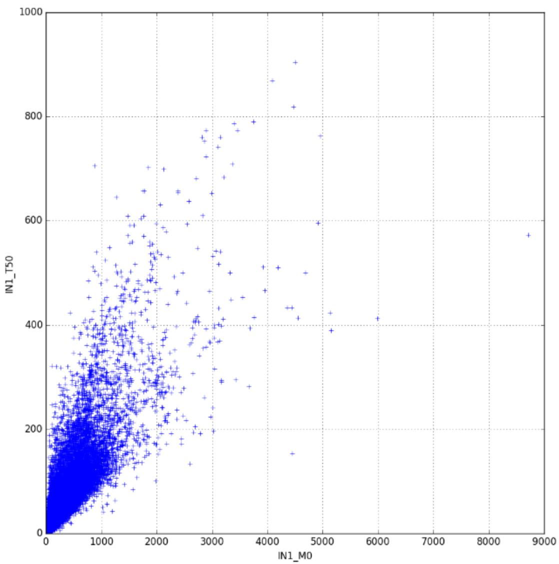

Figure 12 Precipitation response time [days] as function of the total precipitation response [cm per m/d] for all good time series models

The low correlation between the total response and the response time can be explained in part by the fact that fixed head boundary conditions (related to surface water control on the groundwater) have a different influence. Toward the head boundary, the total response reduces rapidly to zero, while the response time shows a more gradual reduction (Figure 13).

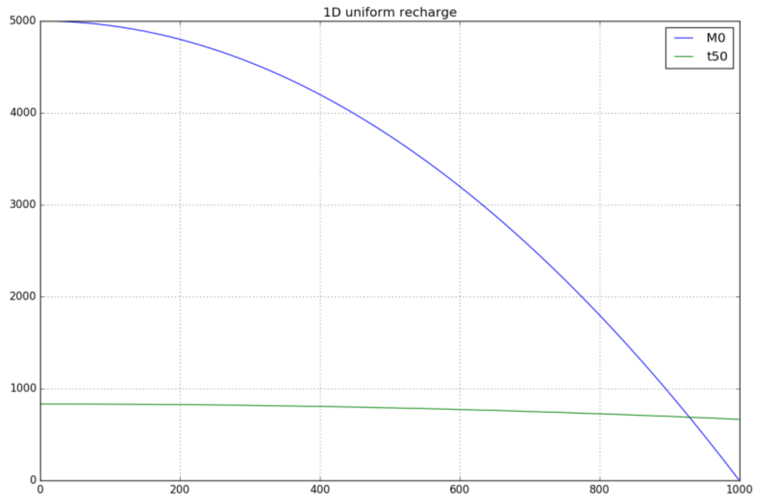

Figure 13 Total response M_0 and response time t_{50} from 1-dimensional analytic solution between impermeable (left) and constant head boundary (right). The vertical axis shows the numerical value of the response [cm per m/d] and the response time [days], the horizontal axis shows the distance from the impermeable boundary [m].

The limited change of the precipitation response time near groundwater head boundaries indicates that this characteristic of the precipitation response reflects more the hydrogeological system than the total response.

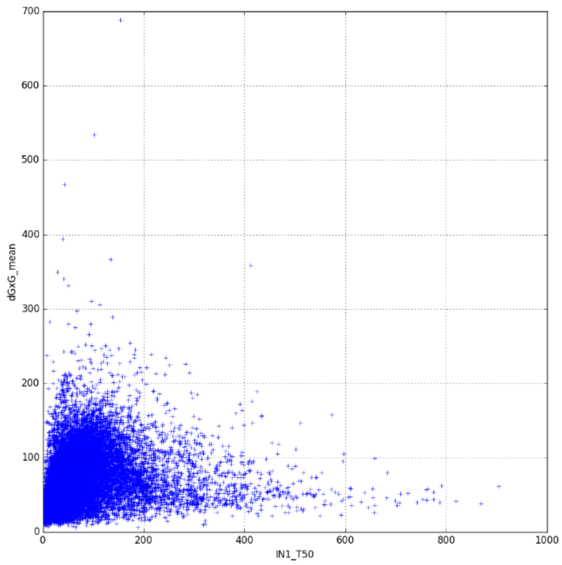

Figure 14 Range of the yearly fluctuation [cm] as function of the precipitation response time [days] for all good time series models

The correlations of the yearly fluctuation with the response time of the precipitation is quite poor (Figure 14), even though the spatial patterns are similar (compare Figure 5 and Figure 7). This suggests that it is not useful to consider the response time for the yearly fluctuation, although it seemed to be preferable over the total response for the analysis of the hydrogeological system.

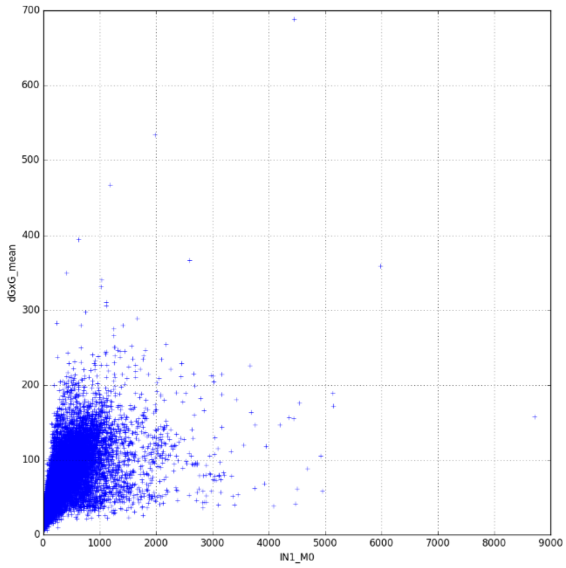

Figure 15 Range of the yearly fluctuation [cm] as function of the total precipitation response [cm per m/d] for all good time series models

The correlation of the yearly fluctuation with the total precipitation response (Figure 15) is larger than with the response time (Figure 14). Still the spread is so large that the total response by itself is not a good predictor of the yearly fluctuation.

The vertical variation of the precipitation response time has been further analysed, because of the suggestion, that the response time relates better to the hydrogeological system properties. Figure 16 shows the precipitation response time differences between the phreatic and upper regional aquifers (as shown in Figure 9) together with the corresponding aquitard resistance. The absolute value of the difference correlates with the resistance of the aquitard.

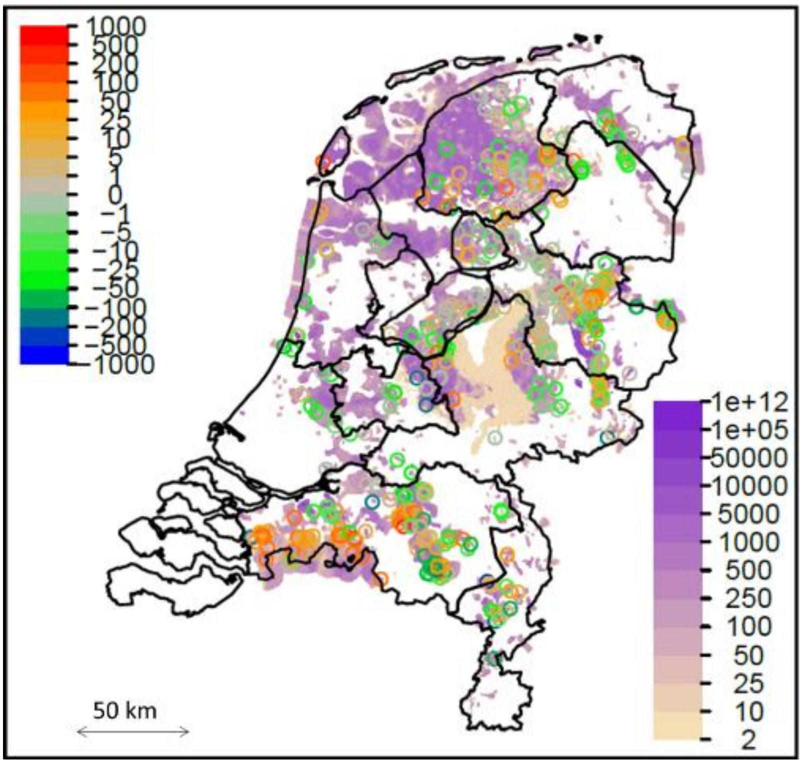

Figure 16 Difference in precipitation response time [days] (Figure 8) together with the resistance of the aquitard [d] separating the two aquifers

The sign of the response time difference indicates whether to response time decreases or increases with depth. This depends on the position in the groundwater system and how the influence of the precipitation propagates. A typical Dutch groundwater flow system connects infiltration in a higher, usually more sandy, area with a polder with artificially maintained lower surface water levels. In the sandy area the influence travels downward. Then the groundwater flows laterally to the polder area, where it goes up toward the surface water.

The evaporation factor does not show a similar striking pattern (Figure 9) as the total response (Figure 6) and the response time (Figure 7) of the precipitation. This is probably due to the strong impact of the land use and vegetation type on the actual evapotranspiration. Also local differences in paved area and drainage intensity influence the evaporation factor.
The question remains whether the evaporation factor can be used to estimate the groundwater recharge. It would be valuable to get an independent estimate from the time series models to use as reference for the top system schematisation of spatially explicit groundwater models such as the national groundwater model (LHM-NHI). It also is a topic of research in the TACTIC project in the GeoERA programme (http://www.geoera.eu) and will be studied within this project next year.
A simple proposal for the quantification of the recharge R is:

$R = P - f_c * E$ for $fc < 1$

$R = P/f_c - E$ for $fc > 1$

In which R is the recharge, P the precipitation, E the potential evapotranspiration and f_c the evaporation factor. These equations may be too simple. Obergfell et al. (2019) report recharge estimates based on similar time models, but they also used data on groundwater extractions and applied an additional constraint for the time series model.

The noise model represents the influences besides precipitation and potential evapotranspiration. It is to be expected that the response time of such influences also is longer when the precipitation response is longer. Thus, it is not surprising that the pattern of the noise model parameter (Figure 10) is similar to that of the precipitation response time (Figure 7). However, further research is required to establish physical grounds for the similarity.

5 Conclusions and recommendations

We provided insight in the natural groundwater dynamics of the Netherlands, by means of maps covering various aspects of groundwater responses on precipitation and evapotranspiration. Our analysis was based on groundwater head measurements from the Dutch national database for the subsurface.

Various aspects have been shown: the yearly fluctuation of the groundwater head, response to precipitation and potential evapotranspiration, the noise decay parameter of the stochastic part of the time series models, and trends in long term time series.
These results are useful information for groundwater management and subsurface planning, some more and some less concrete. The yearly fluctuation is important for the design of excavations such as building pits, assessment of seepage flows, and implementation of groundwater extractions. The response to precipitation has potential for better characterization of the groundwater system and supporting more efficient groundwater modelling, both of which are important for groundwater management as well as policy development and evaluation.
The evaporation factor is related to the recharge of the groundwater system due to precipitation minus actual evapotranspiration. This is the most important input to the groundwater systems in the Netherlands and thus of paramount importance for groundwater management.

The applied linear time series modelling approach, with constant response functions for the entire period, seems less appropriate for time series longer than 40 years, as opposed to the 8 years that is used by default for the time series models on https://www.grondwatertools.nl.

Based on the results the following recommendations are made:
- Further develop evaluation of precipitation response in groundwater piezometers for the characterization of the hydrogeological system;
- Implement non-linear time series modelling in METRAN and apply this to the long time series to better determine trends and detect system changes.

6 Acknowledgements

This work has beeen sponsored by the VP KarDySaG within TNO and the GeoERA project TACTIC, which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731166.

Part has been presented at IAH 2019, the 46th Congress of the International association of Hydrogeologists, held in Málaga, Spain from 22 – 27 September 2019.

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8 Signature

Name of the principal
SMO, GeoERA (European Union's Horizon 2020 research and innovation programme grant agreement No.731166)

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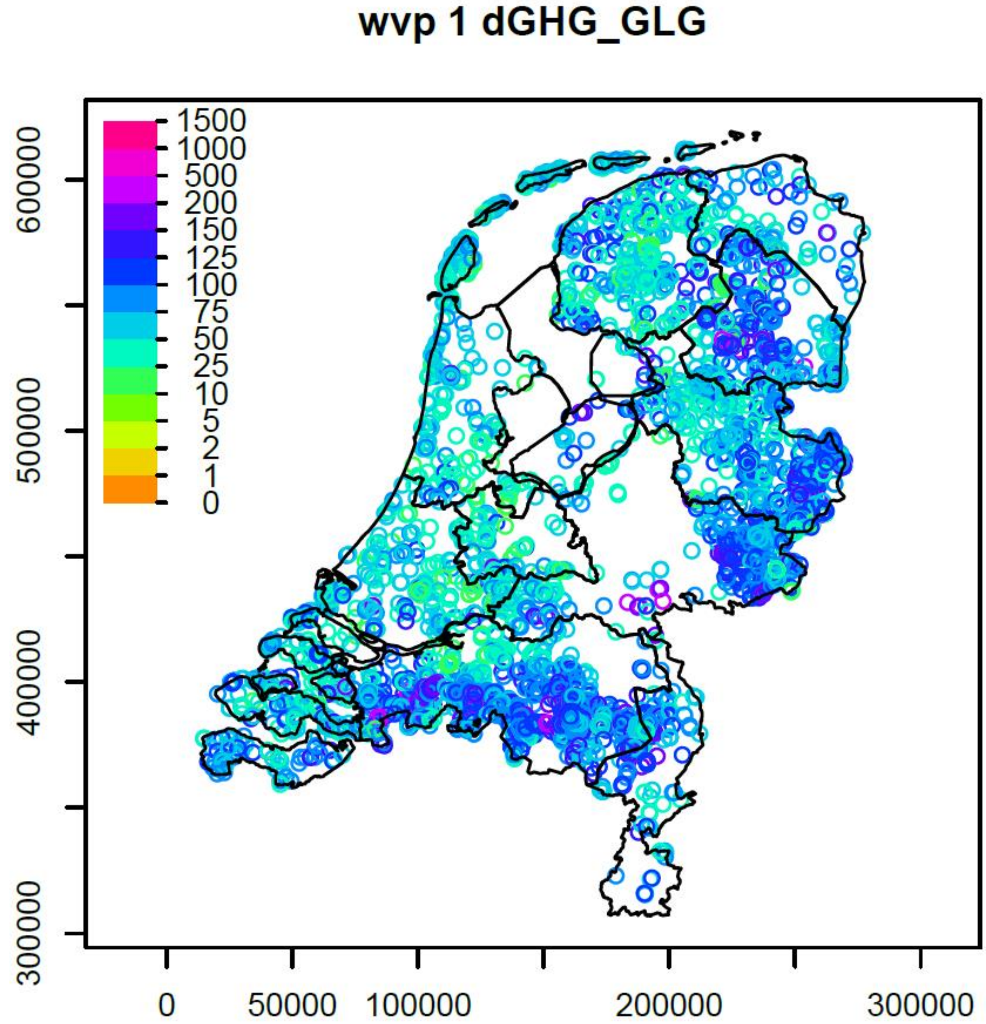
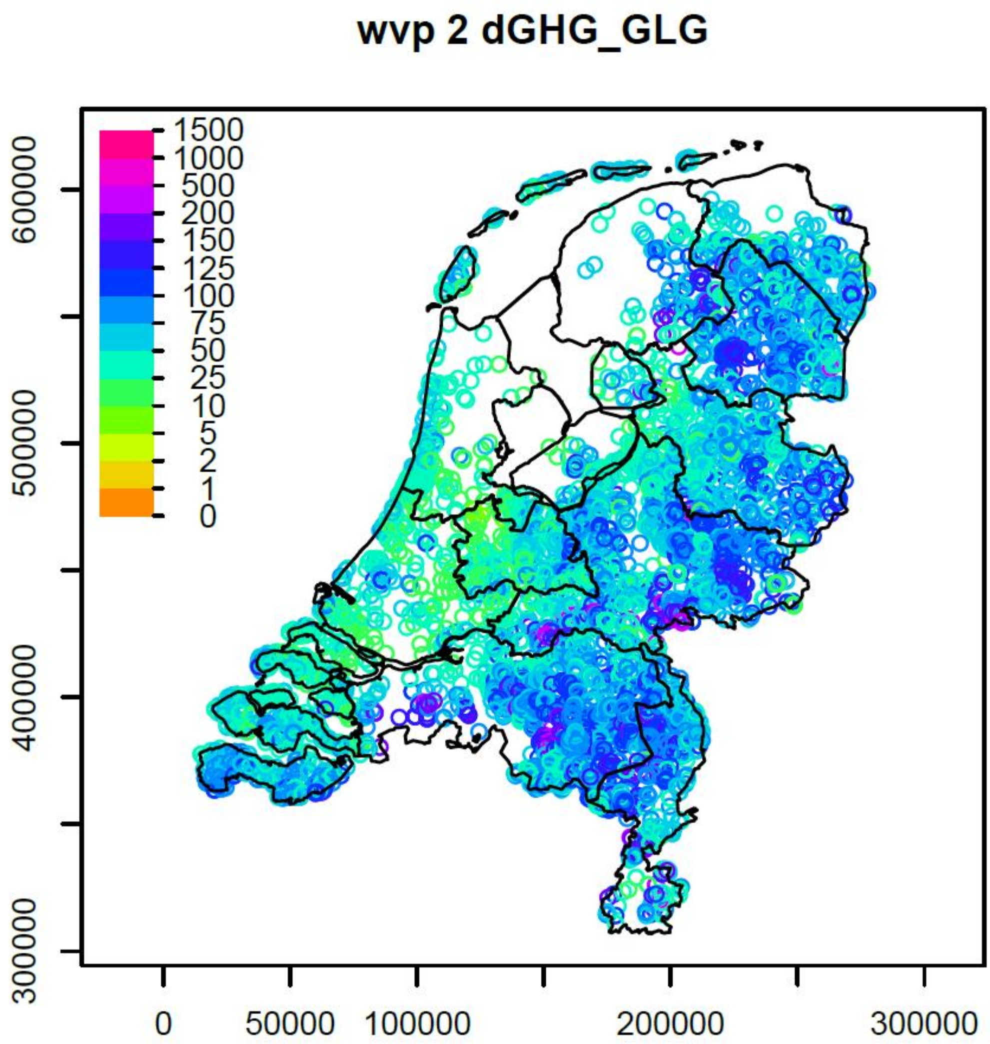
Release:

Dr. M.J. van der Meulen
Research manager

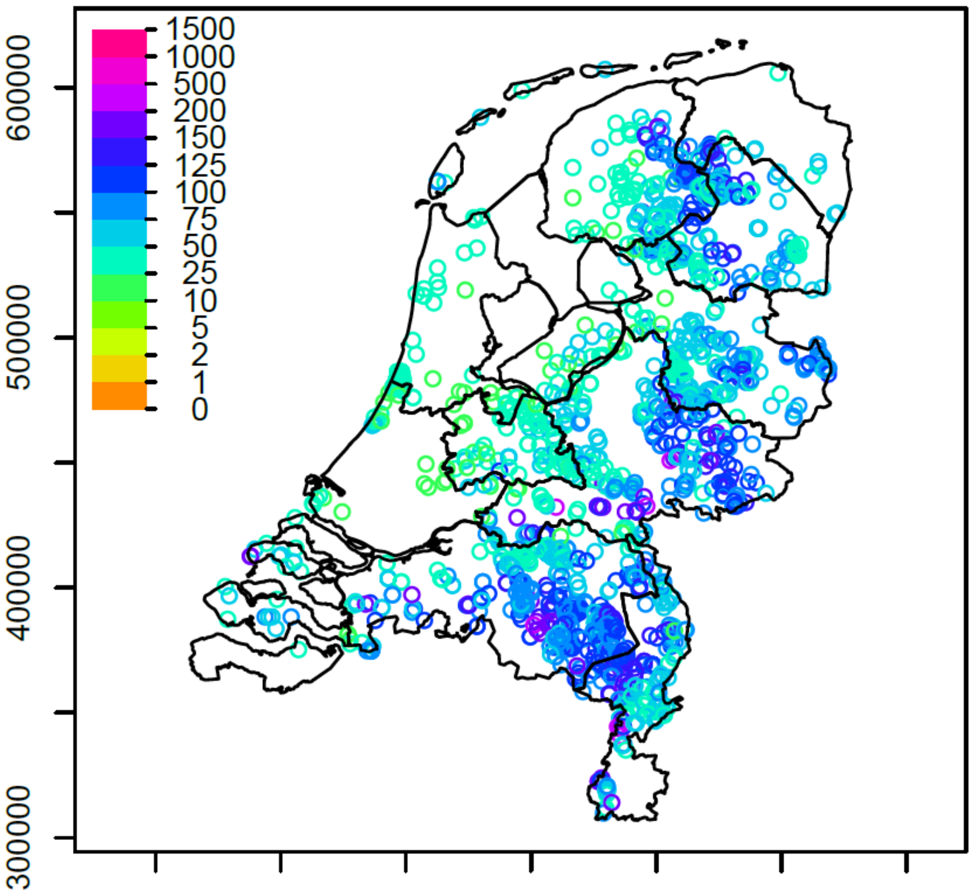
A Maps of yearly fluctuation

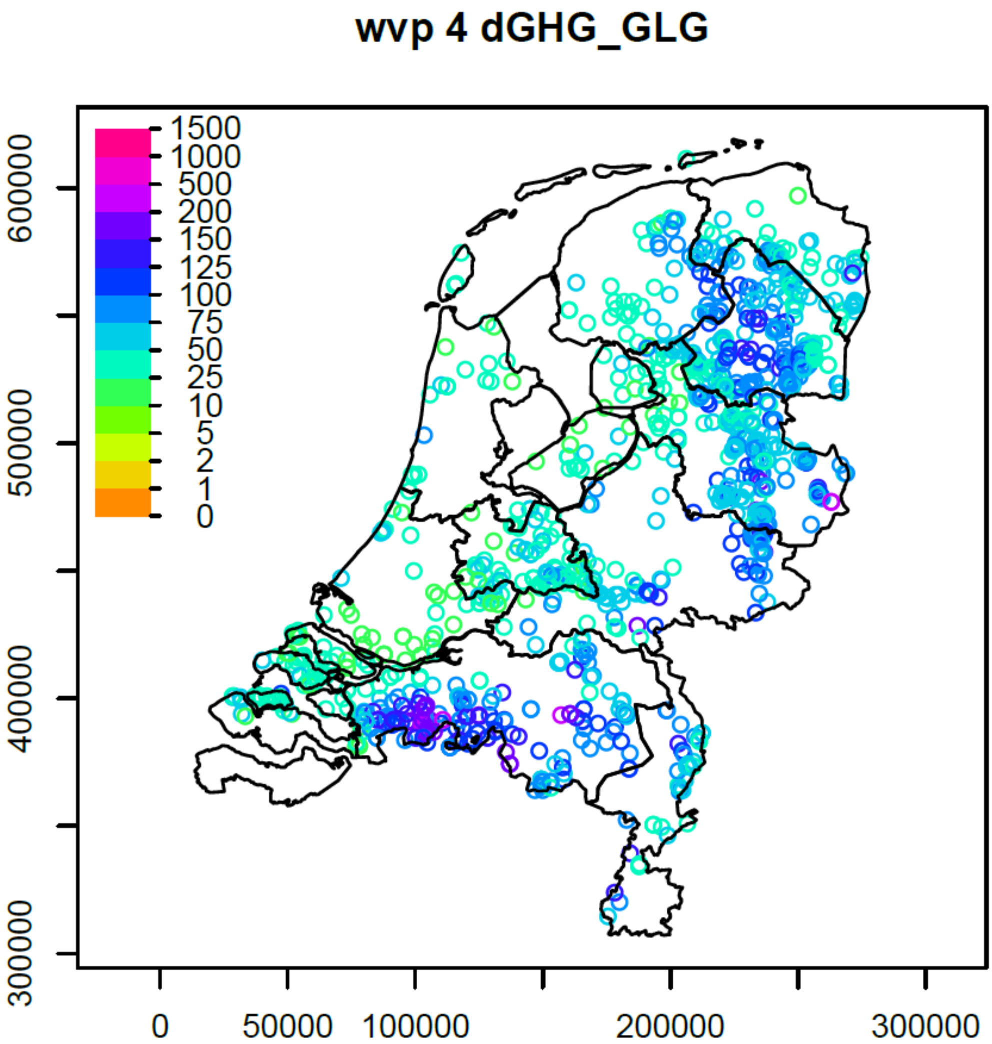
The yearly fluctuation is presented as the difference between the mean high (GHG) and the mean low (GLG) groundwater head. The units are [cm] and the aquifers (WVP) are numbered as in the Dutch national hydrological model (LHM).



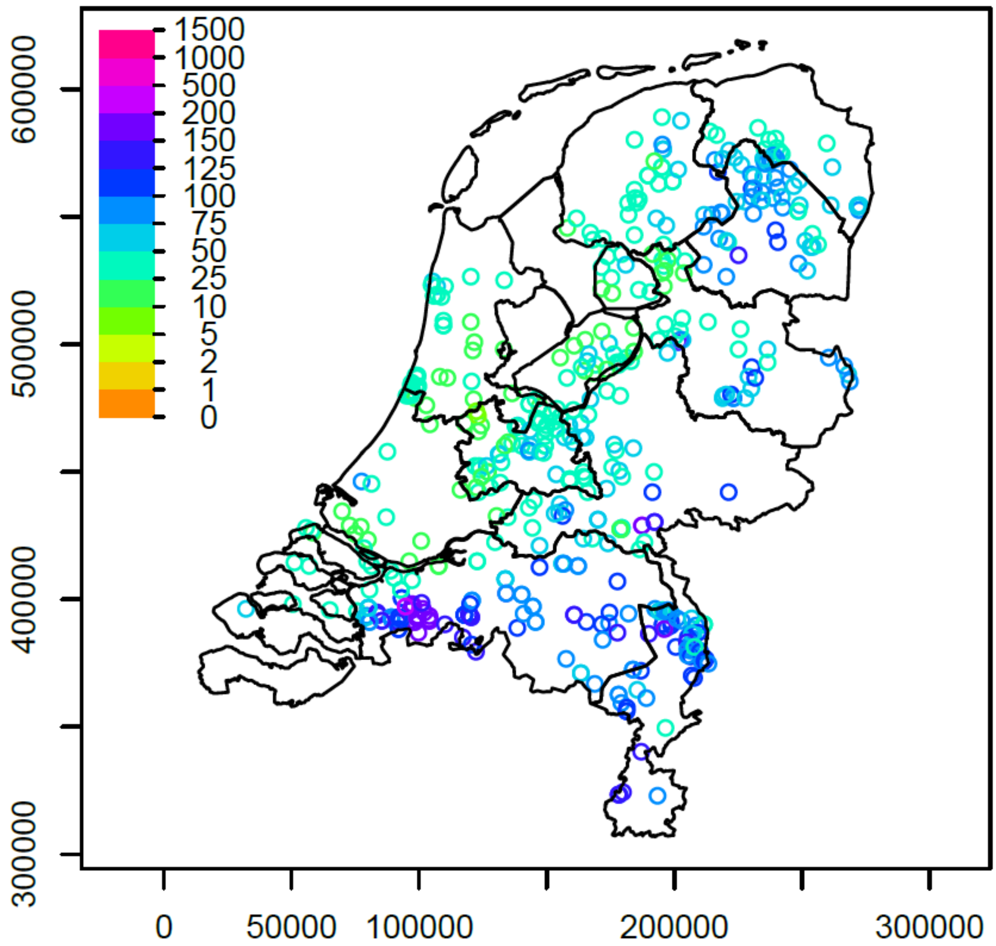

wvp 2 dGHG_GLG
1500
1000
500
200
150
125
100
75
50
25
10
5
2
1
0
600000
500000
400000
300000
0
50000
100000
200000
300000

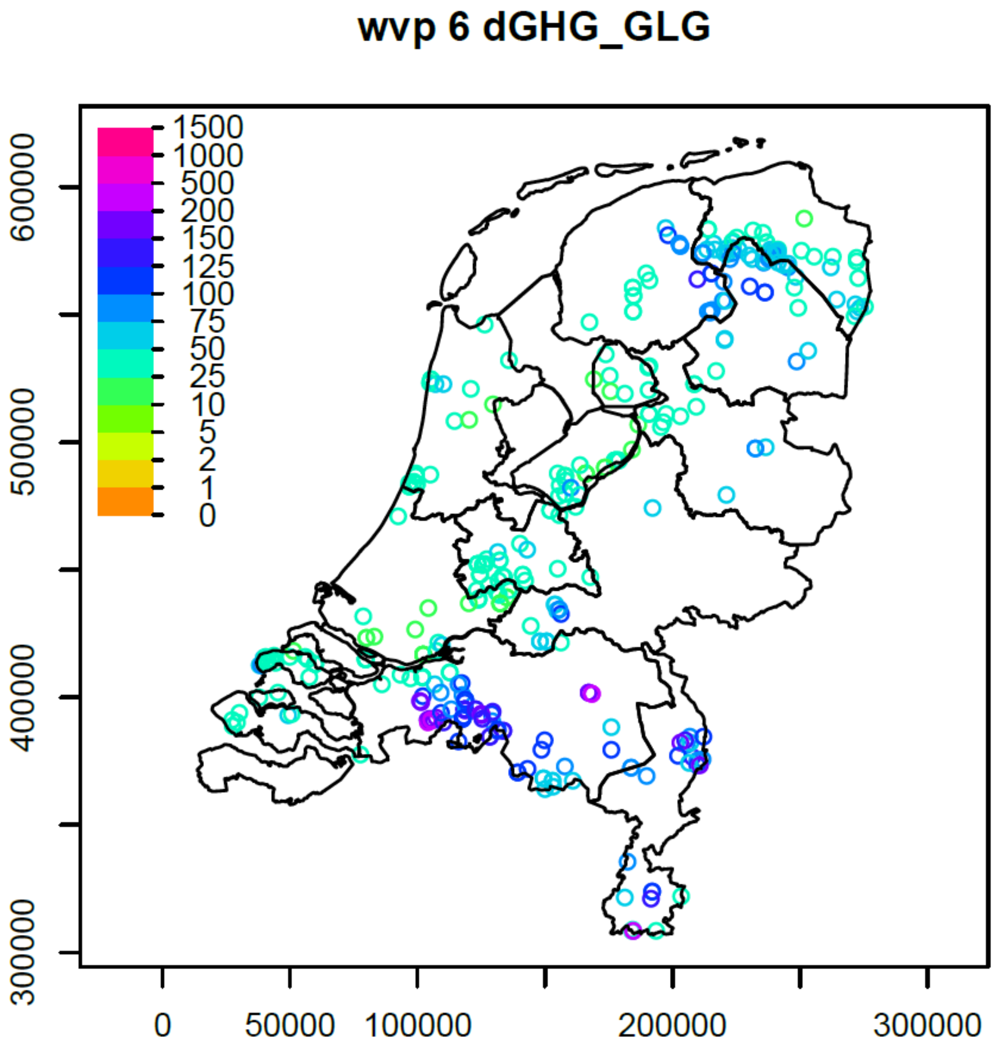
wvp 3 dGHG_GLG

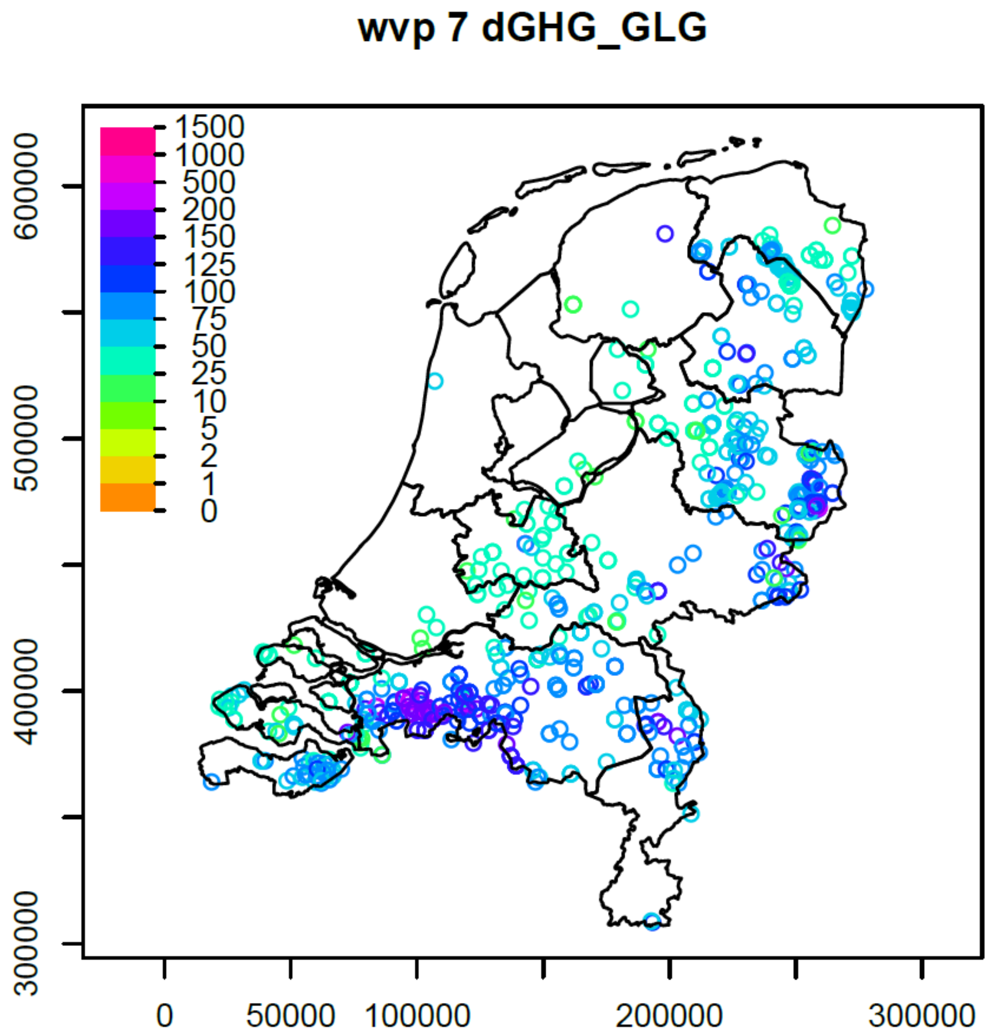



wvp 4 dGHG_GLG
1500
1000
500
200
150
125
100
75
50
25
10
5
2
1
0
600000
500000
400000
300000
0
50000
100000
200000
300000

wvp 5 dGHG_GLG

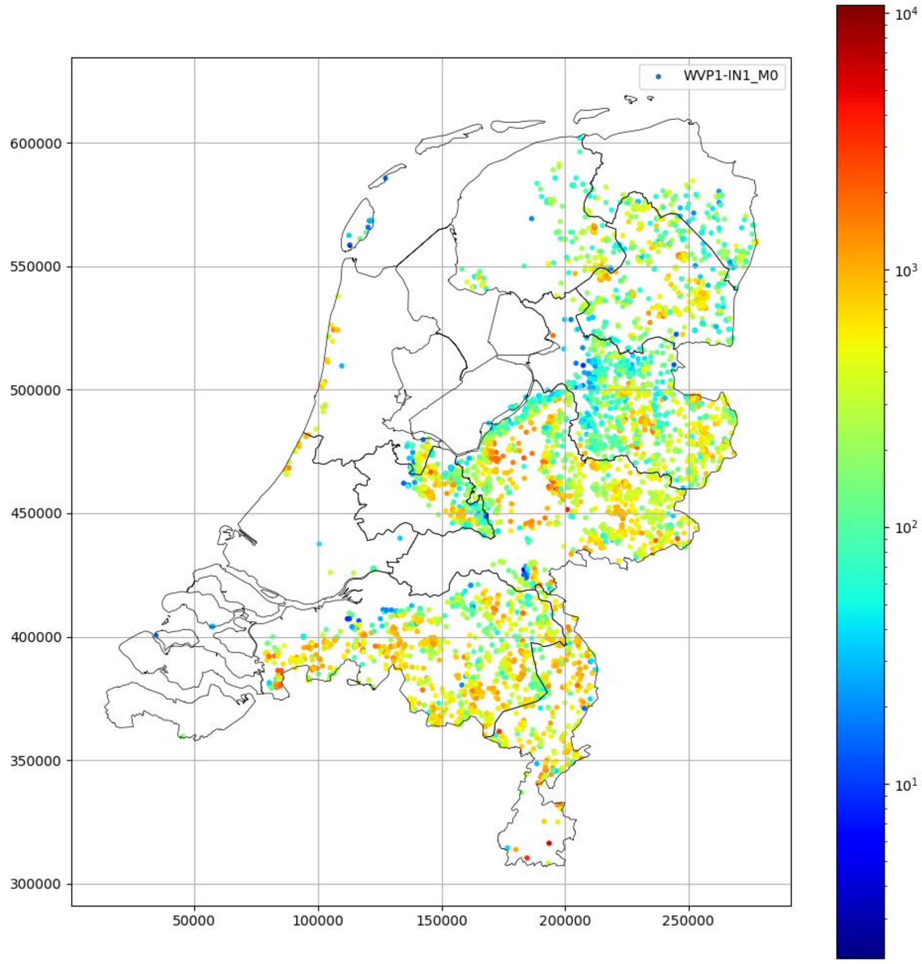


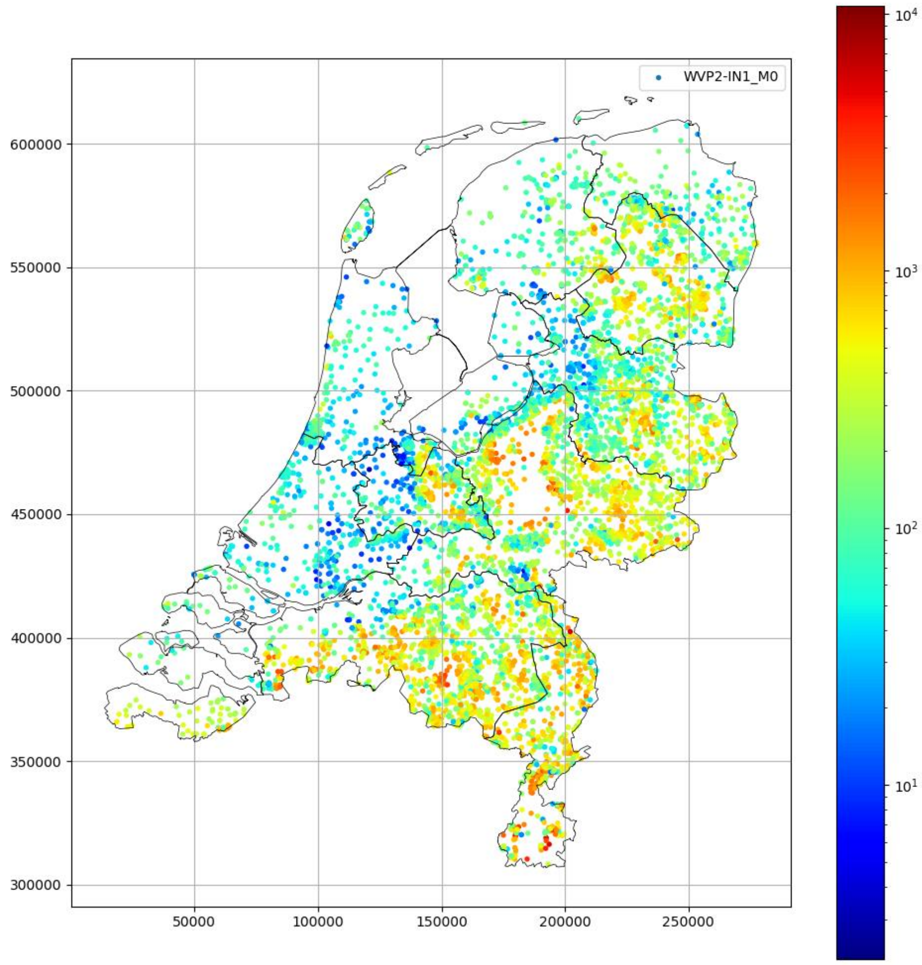

wvp 6 dGHG_GLG
1500
1000
500
200
150
125
100
75
50
25
10
5
2
1
0
600000
500000
400000
300000
0
50000
100000
200000
300000

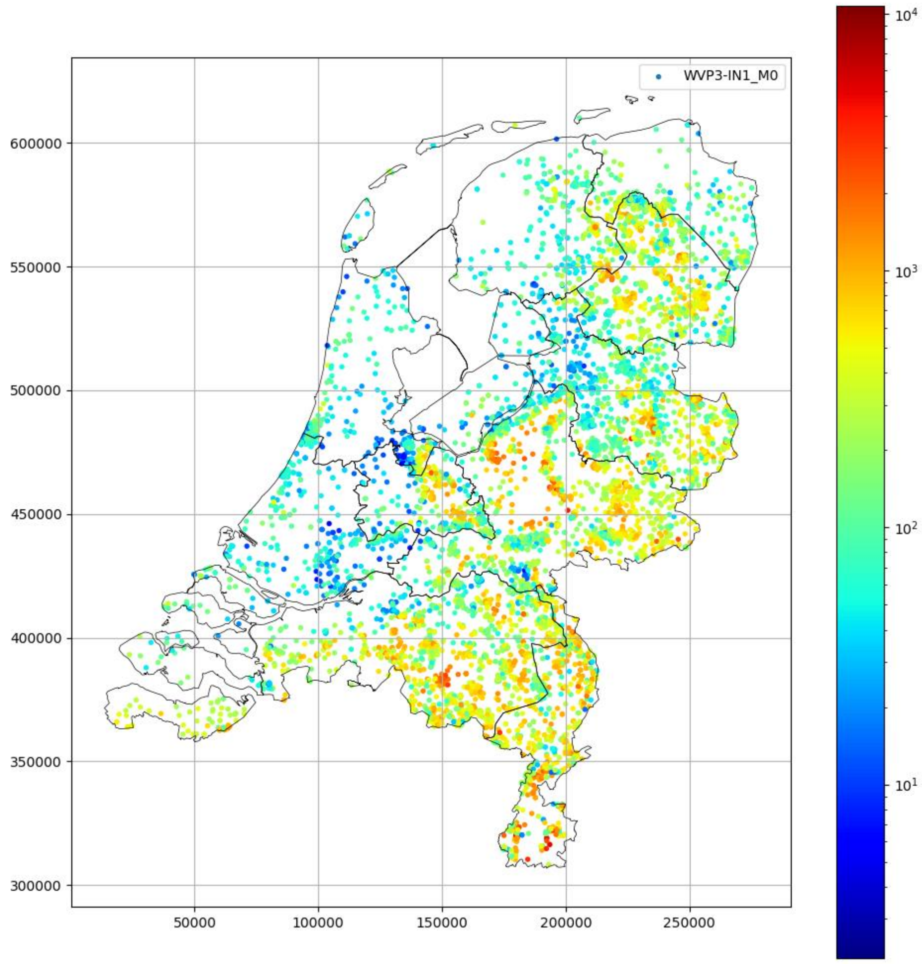

wvp 7 dGHG_GLG
1500
1000
500
200
150
125
100
75
50
25
10
5
2
1
0
600000
500000
400000
300000
0
50000
100000
200000
300000

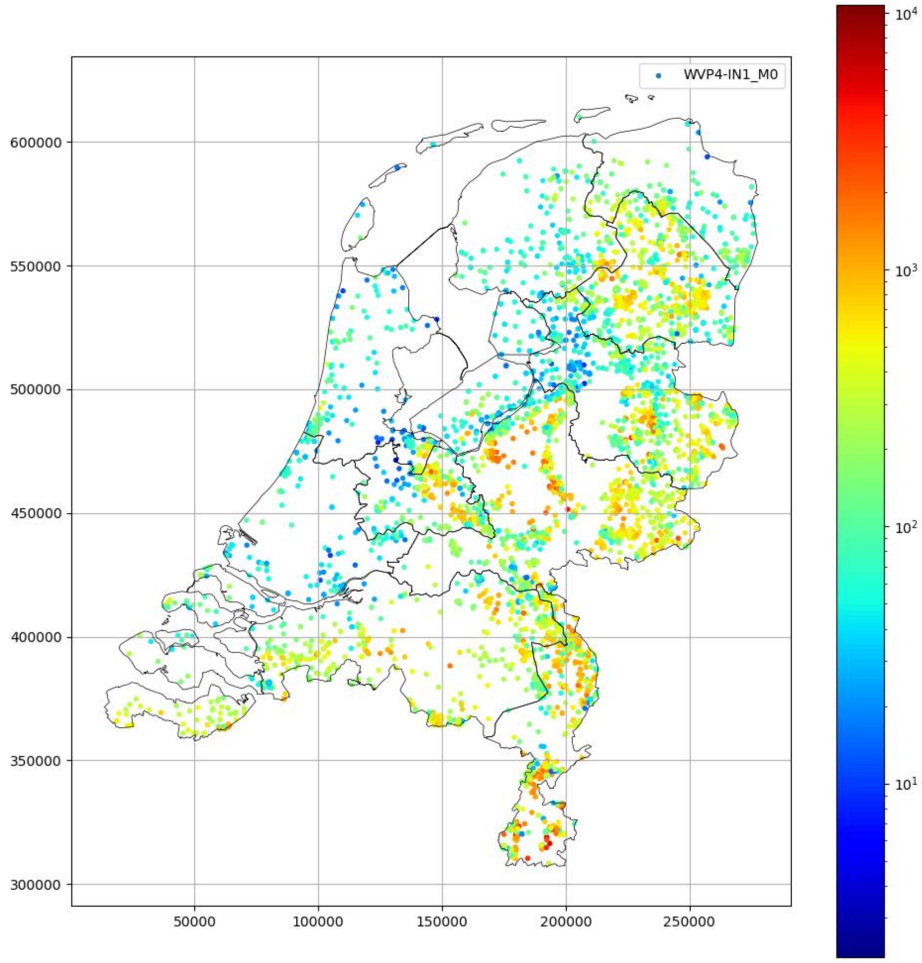
B Maps of precipitation step response

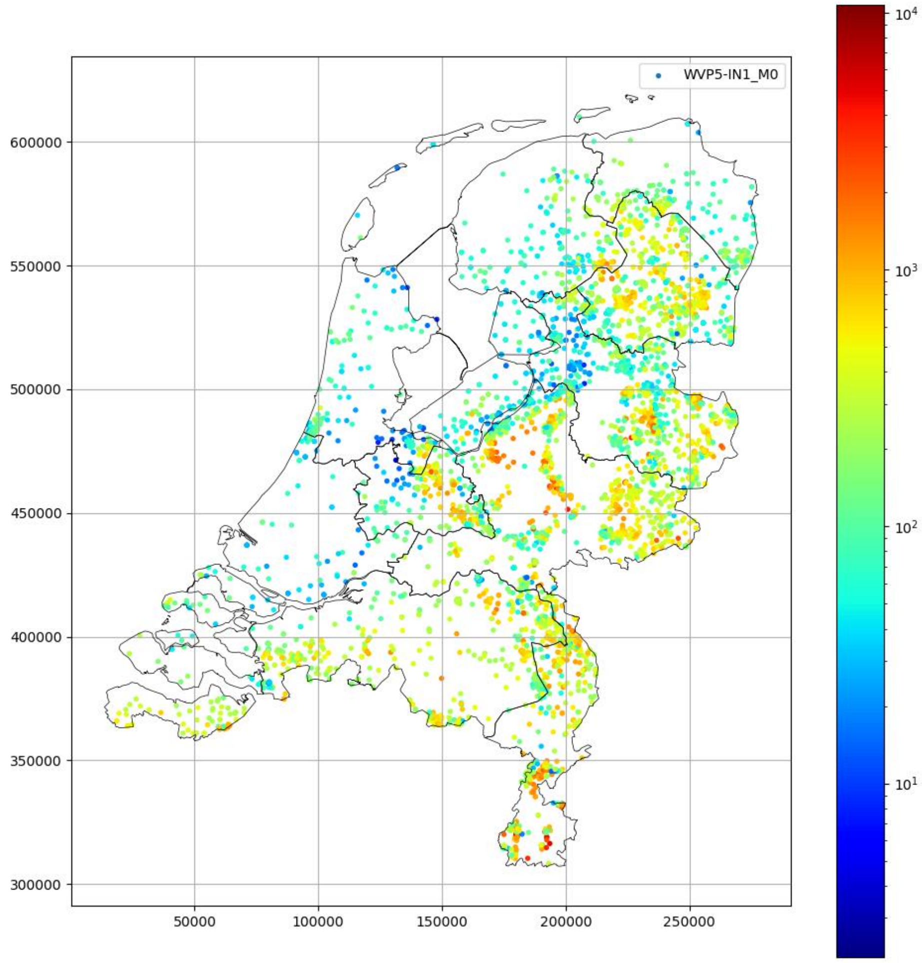
The maps in this appendix show the unit response parameter M_0 [cm per m/d]. The aquifers (WVP) are numbered as in the Dutch national hydrological model (LHM).

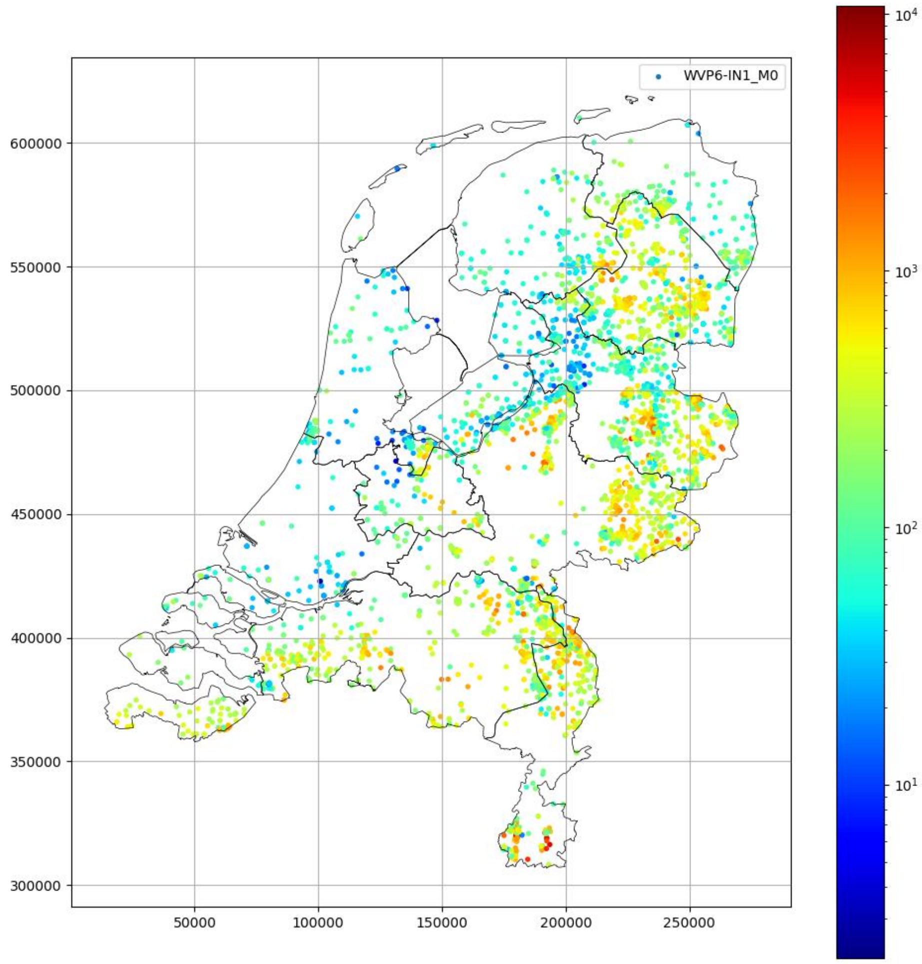


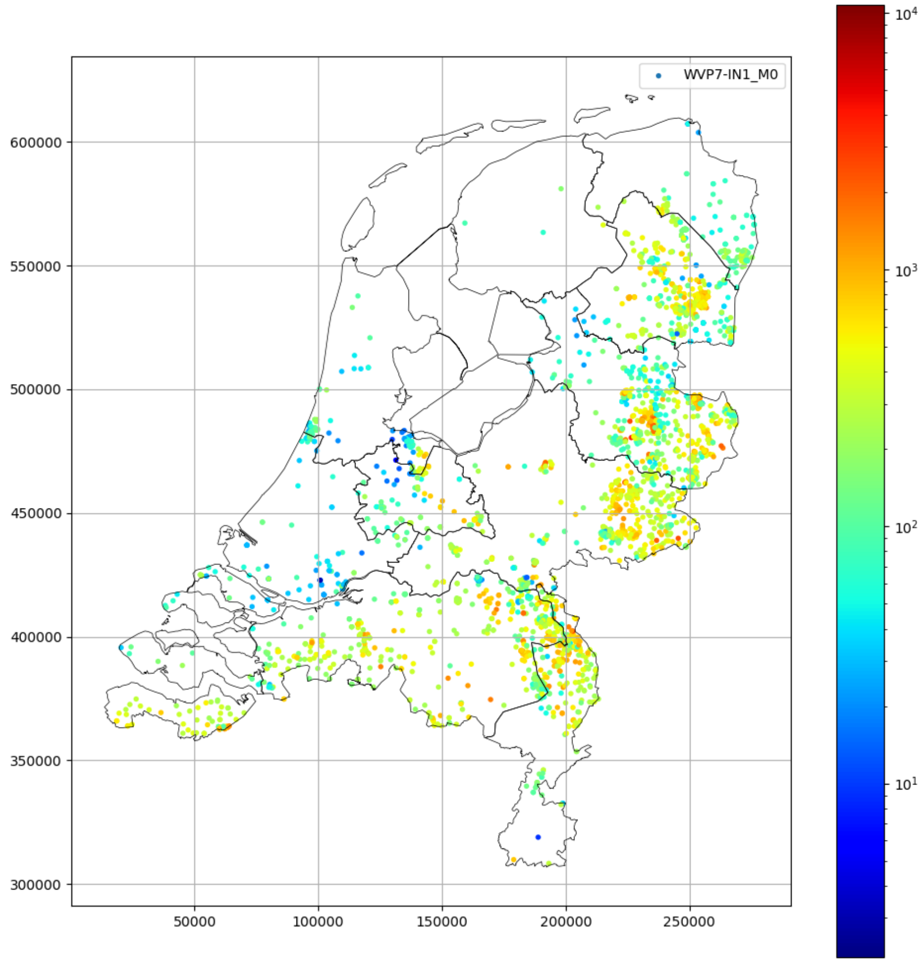

WVP2-IN1_M0
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^4
10^3
10^2
10^1


WVP3-IN1_M0
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^4
10^3
10^2
10^1


WVP4-IN1_M0
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^4
10^3
10^2
10^1

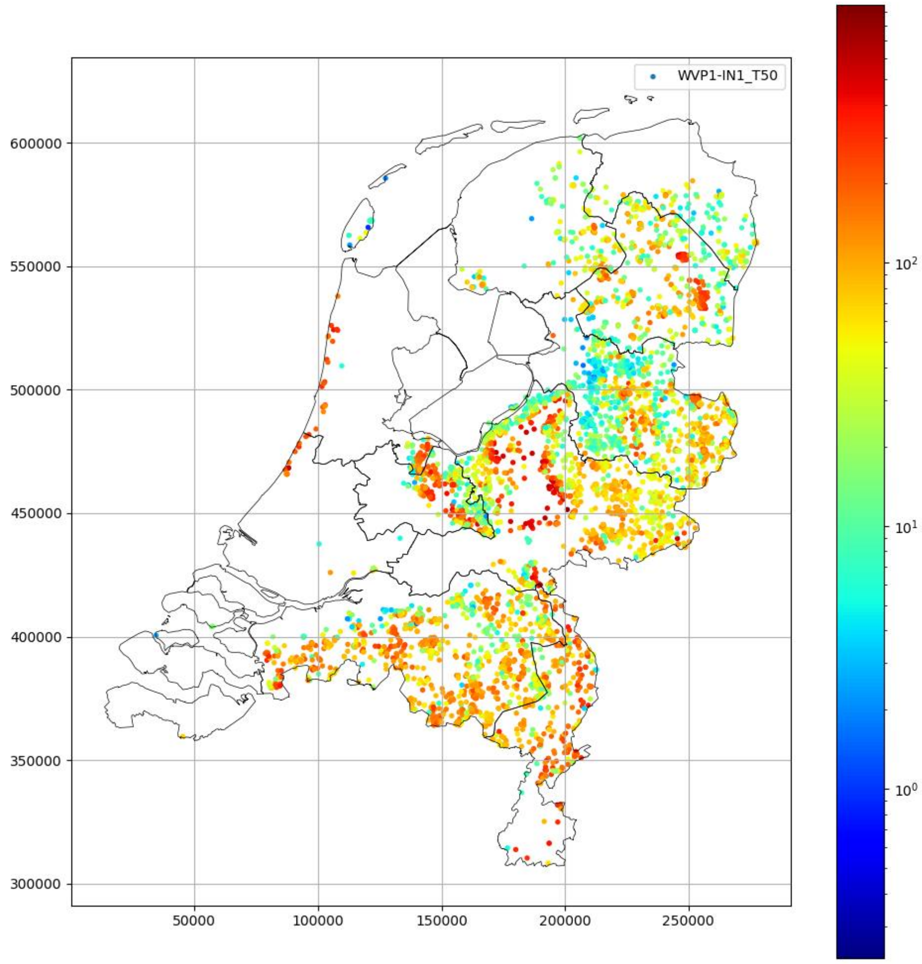

WVP5-IN1_M0
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^4
10^3
10^2
10^1

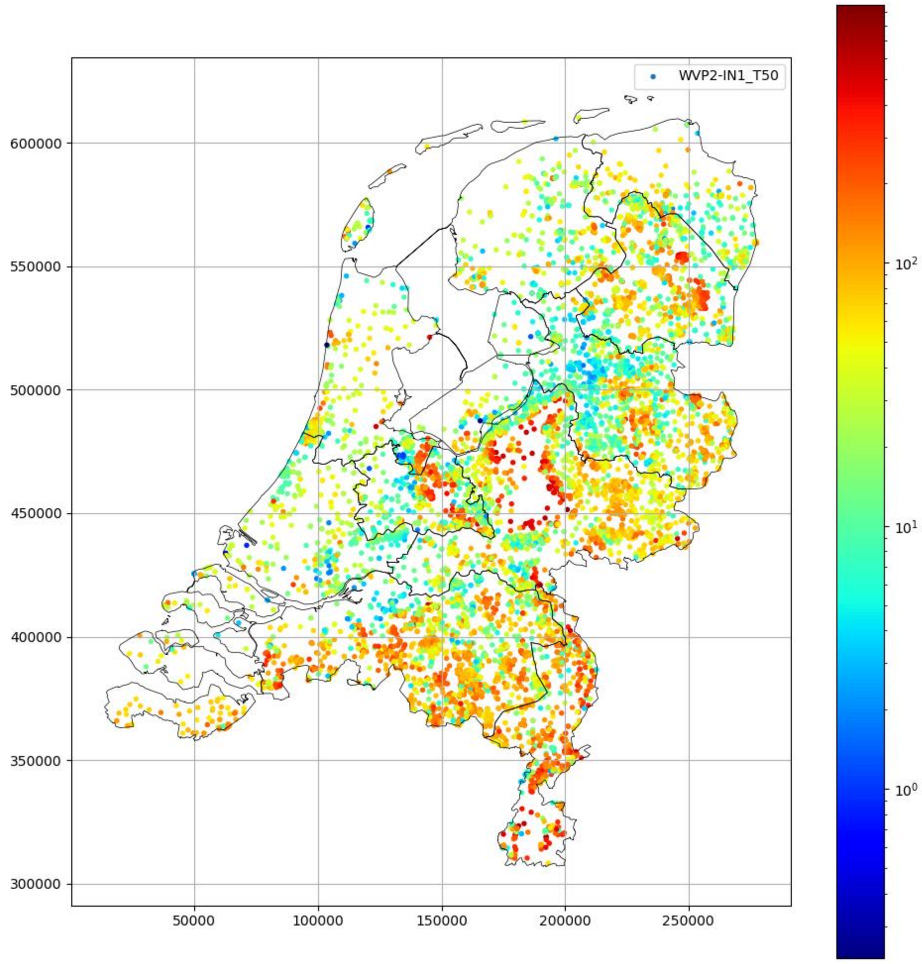

WVP6-IN1_M0
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^4
10^3
10^2
10^1

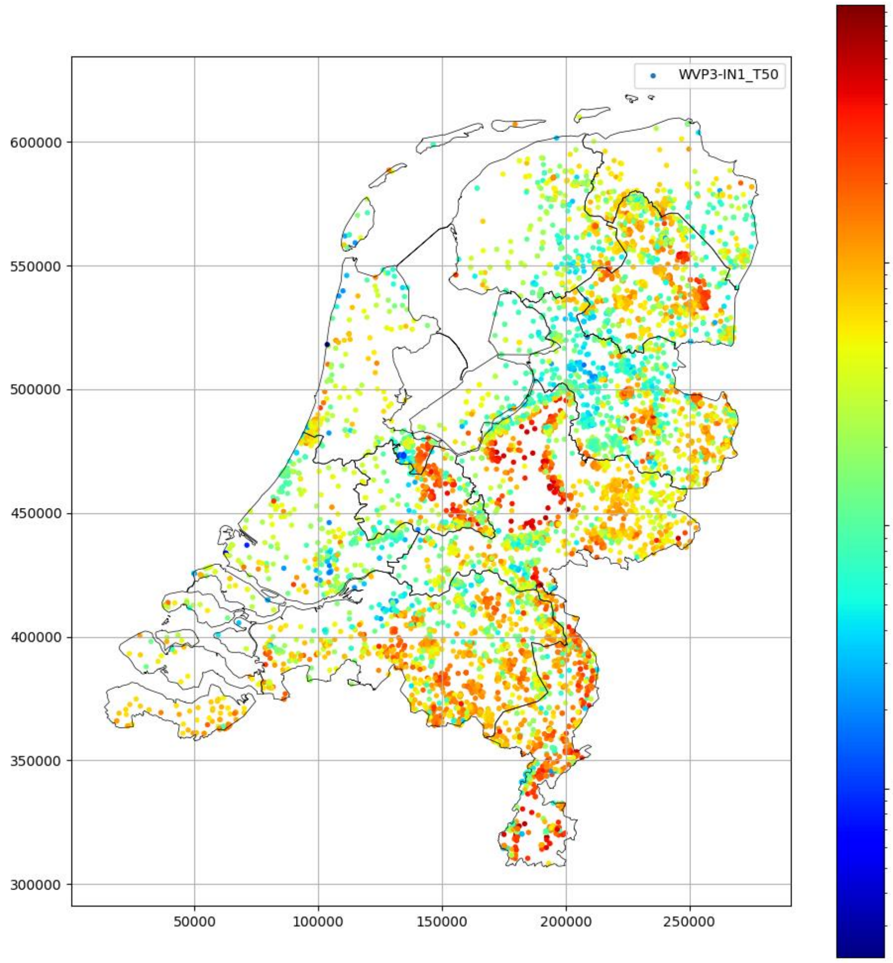

WVP7-IN1_M0
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^4
10^3
10^2
10^1

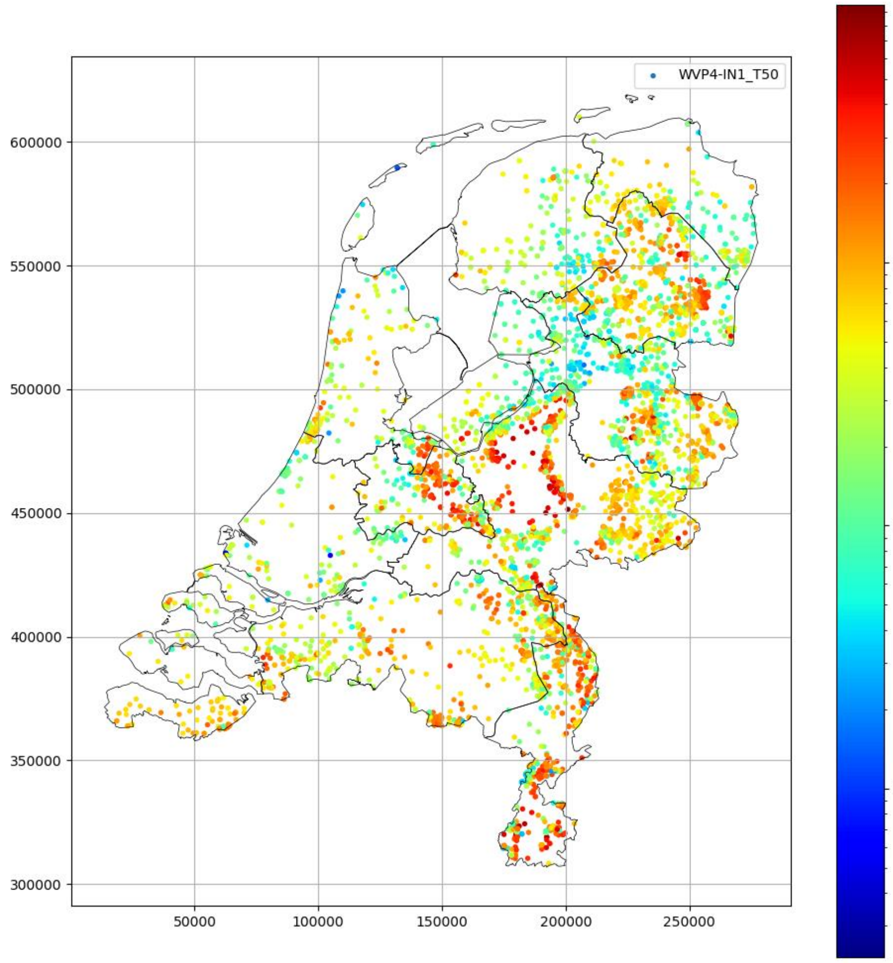
C Maps precipitation response time

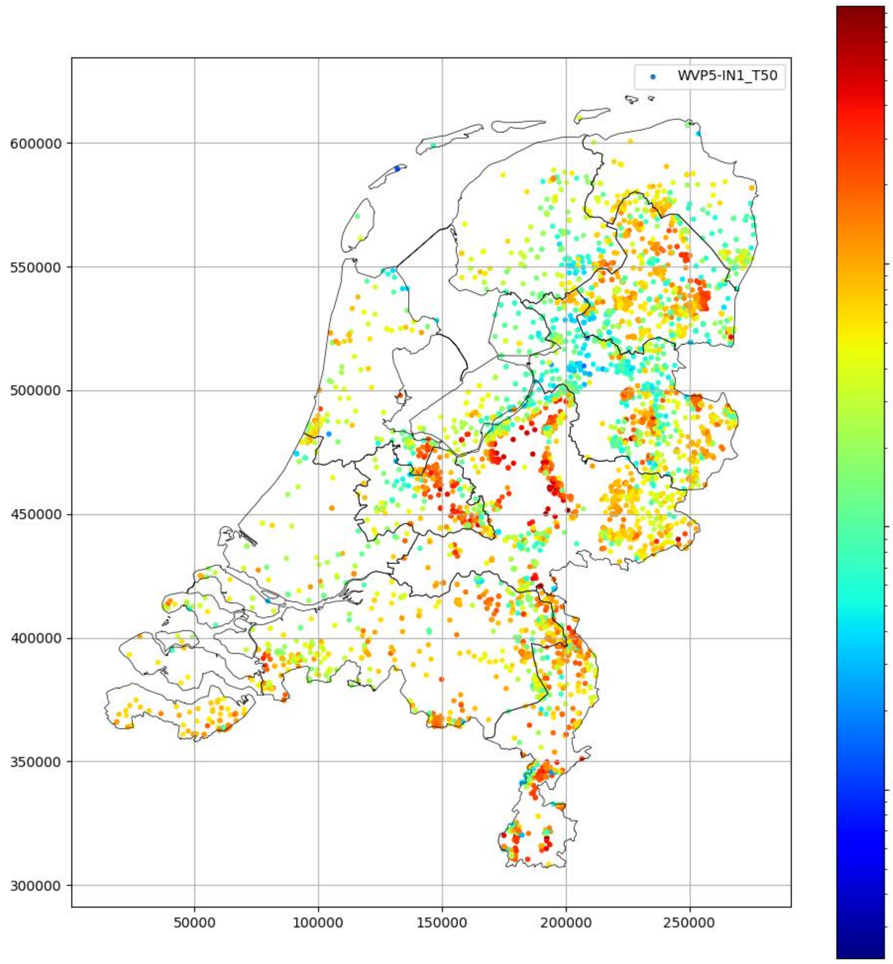
The maps in this appendix show the response time t_{50} [days] of the precipitation time series model. The aquifers (WVP) are numbered as in the Dutch national hydrological model (LHM).

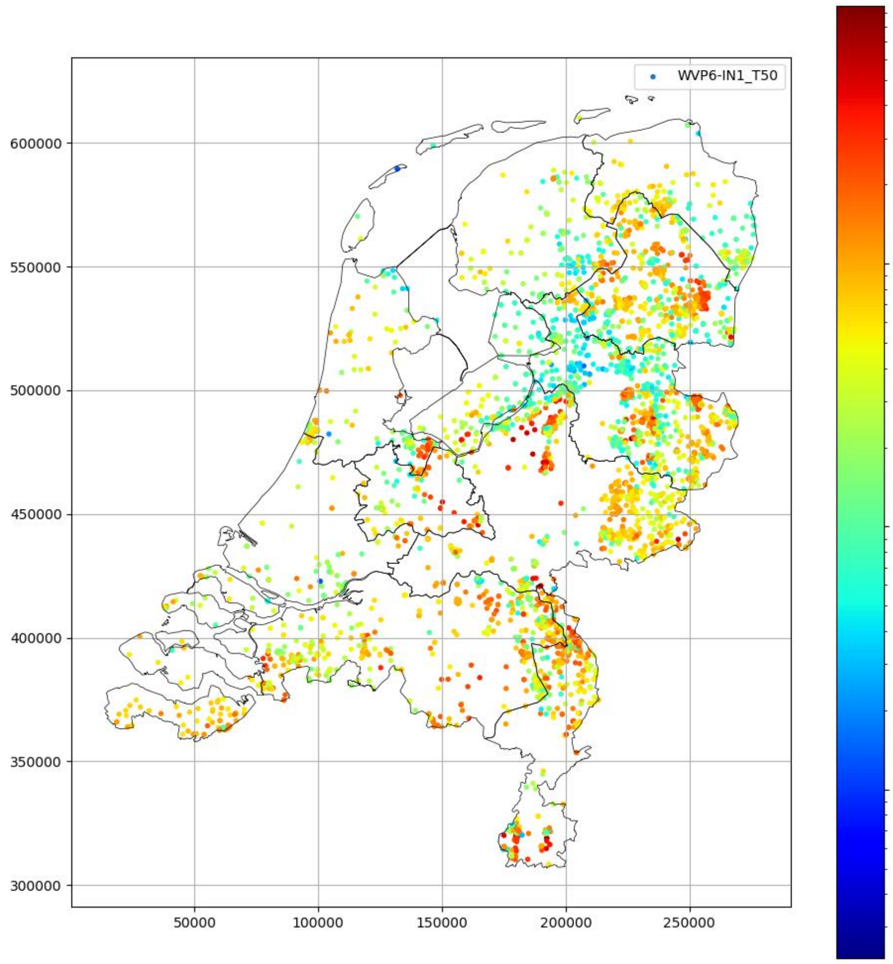


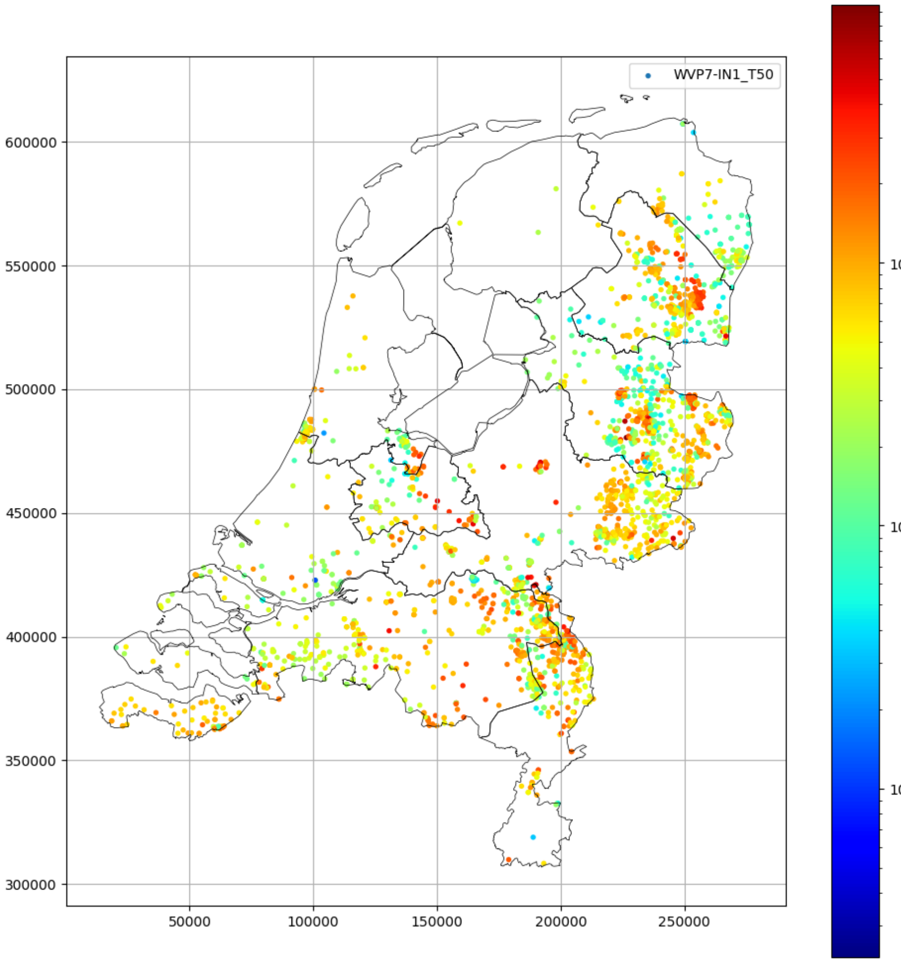

WVP2-IN1_T50
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^2
10^1
10^0


WVP3-IN1_T50
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^2
10^1
10^0


WVP4-IN1_T50
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^2
10^1
10^0

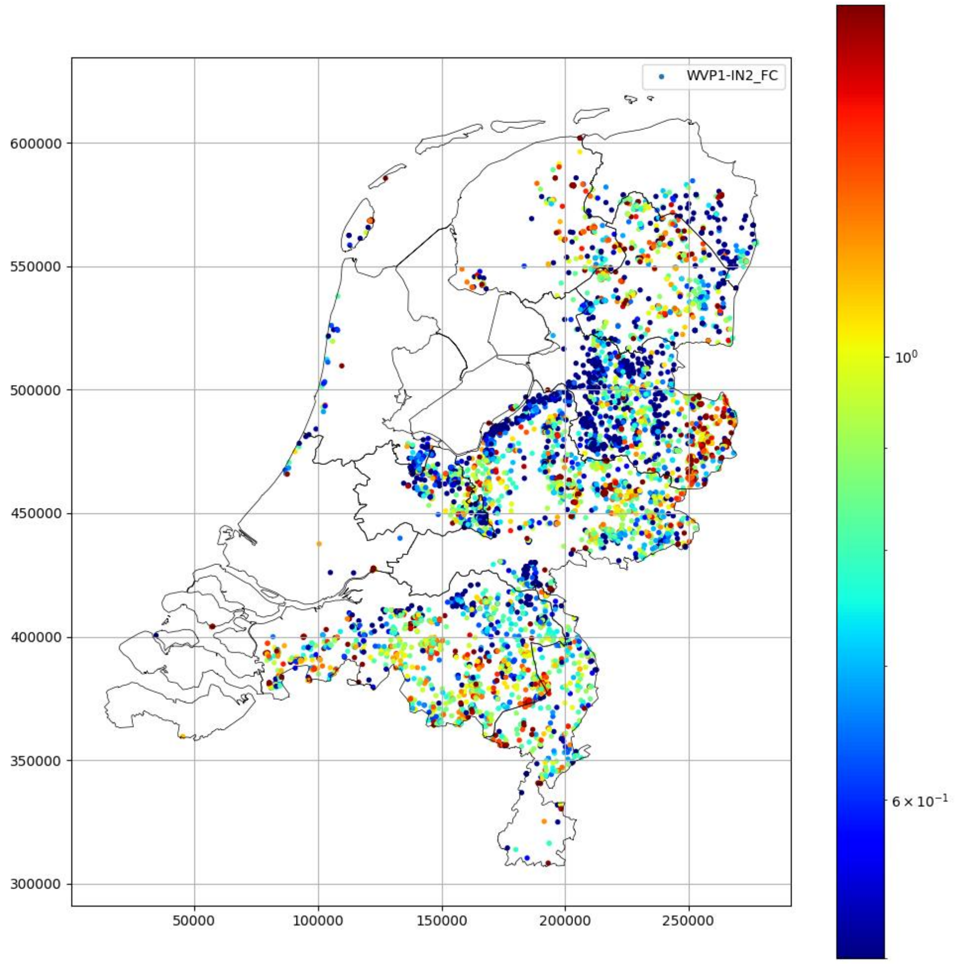

WVP5-IN1_T50
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^2
10^1
10^0

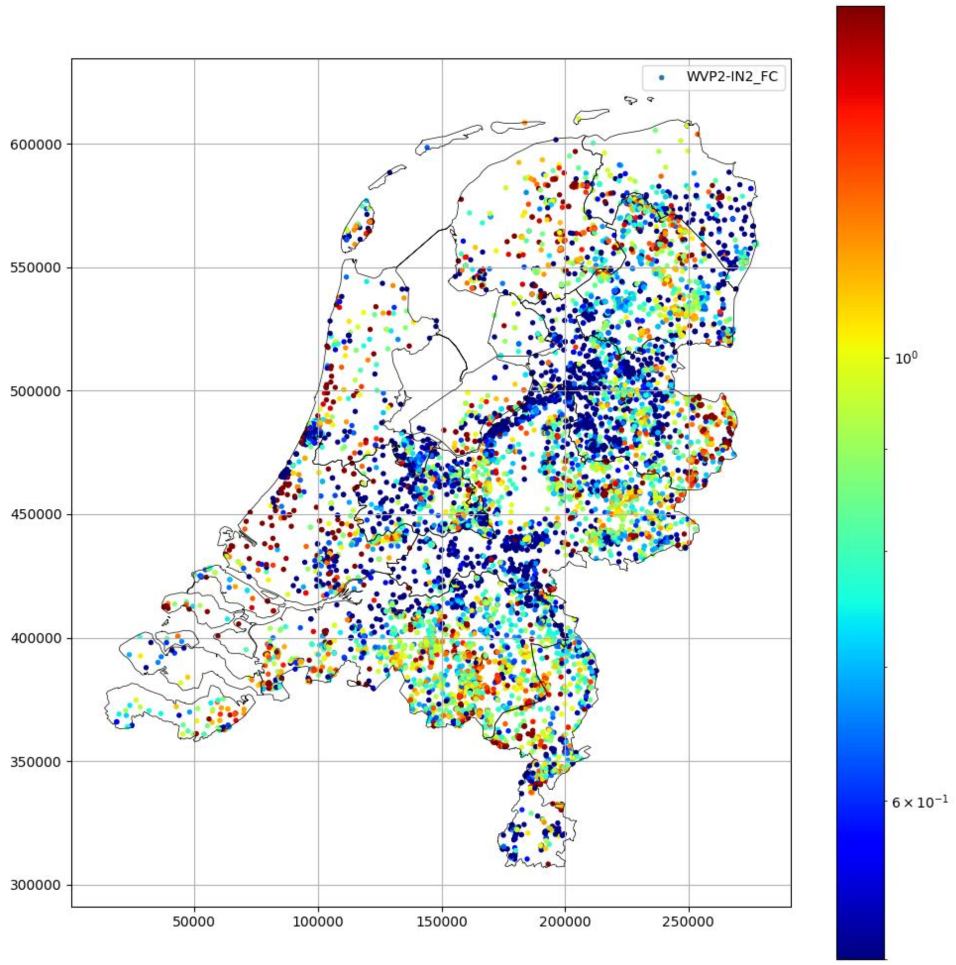

WVP6-IN1_T50
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^2
10^1
10^0

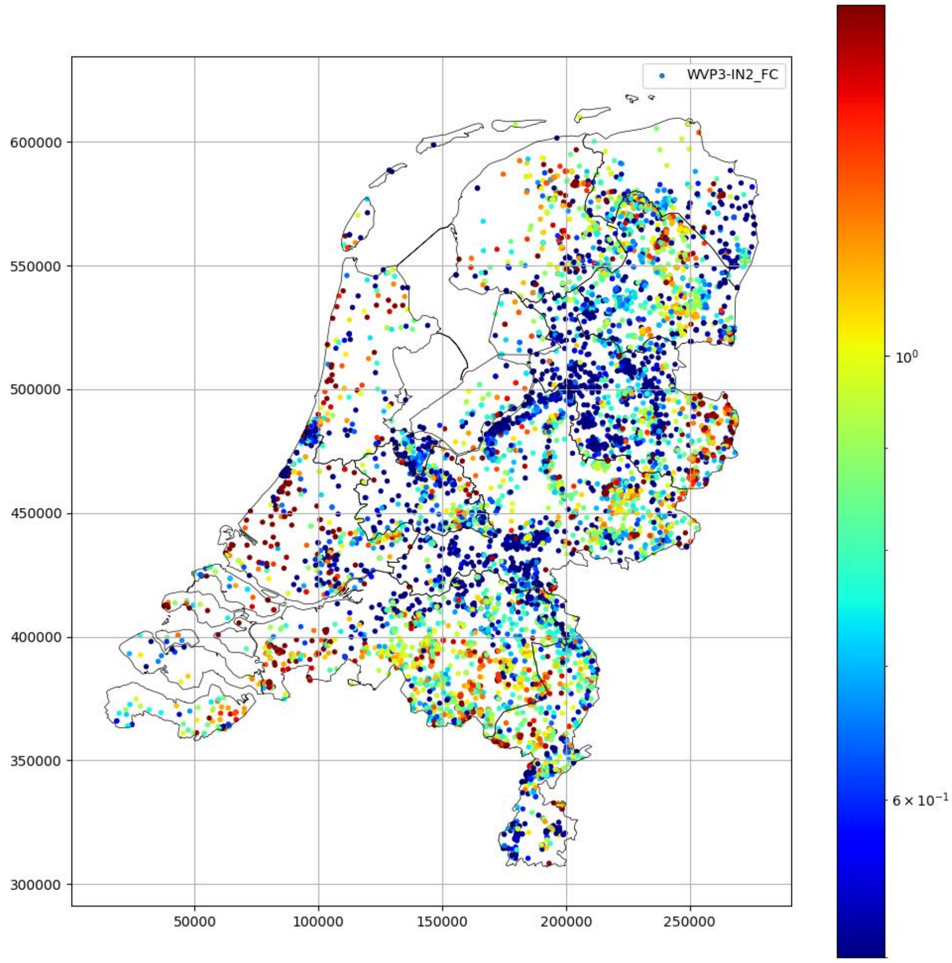

WVP7-IN1_T50
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^2
10^1
10^0

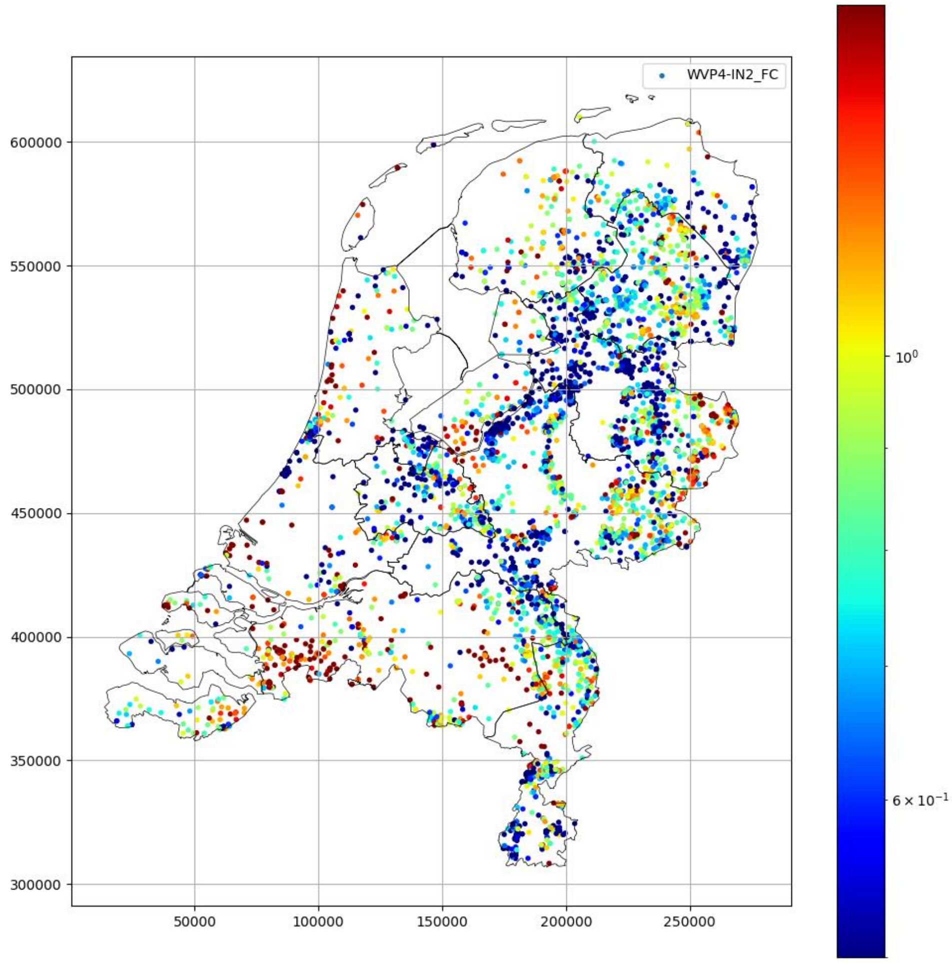
D Maps evaporation factor

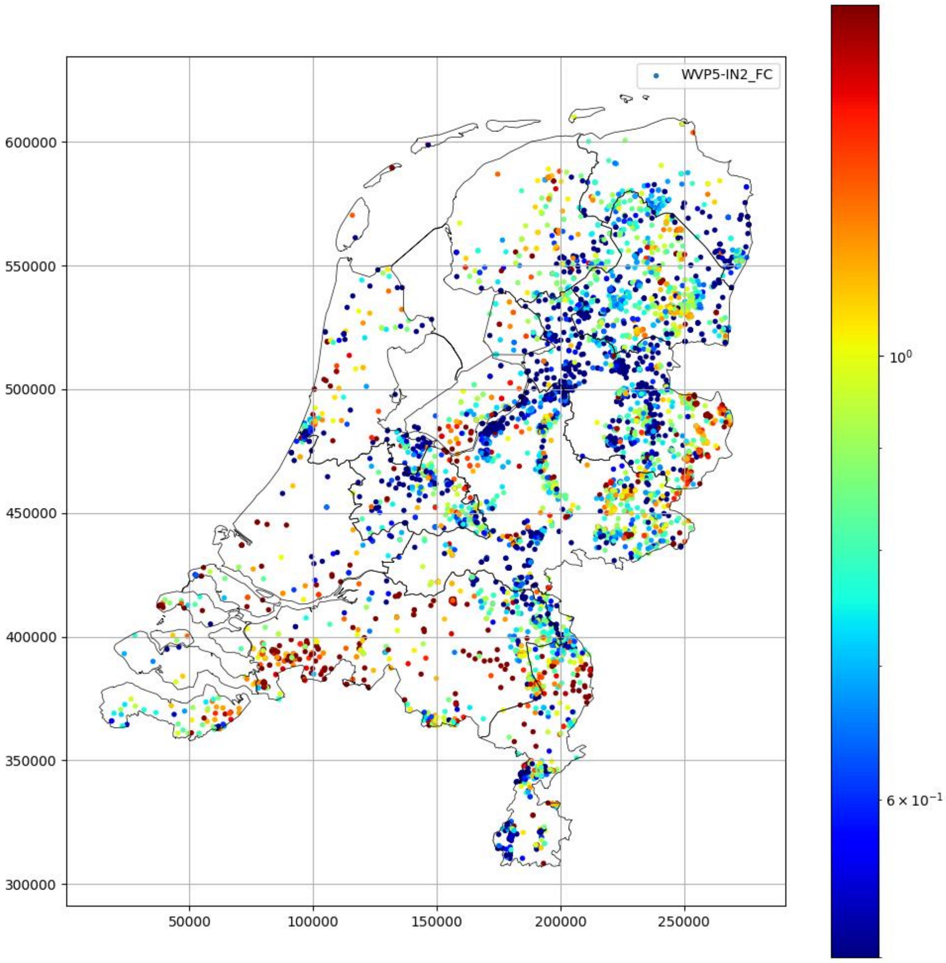
The maps in this appendix show the evaporation factor FC [-]. The aquifers (WVP) are numbered as in the Dutch national hydrological model (LHM).

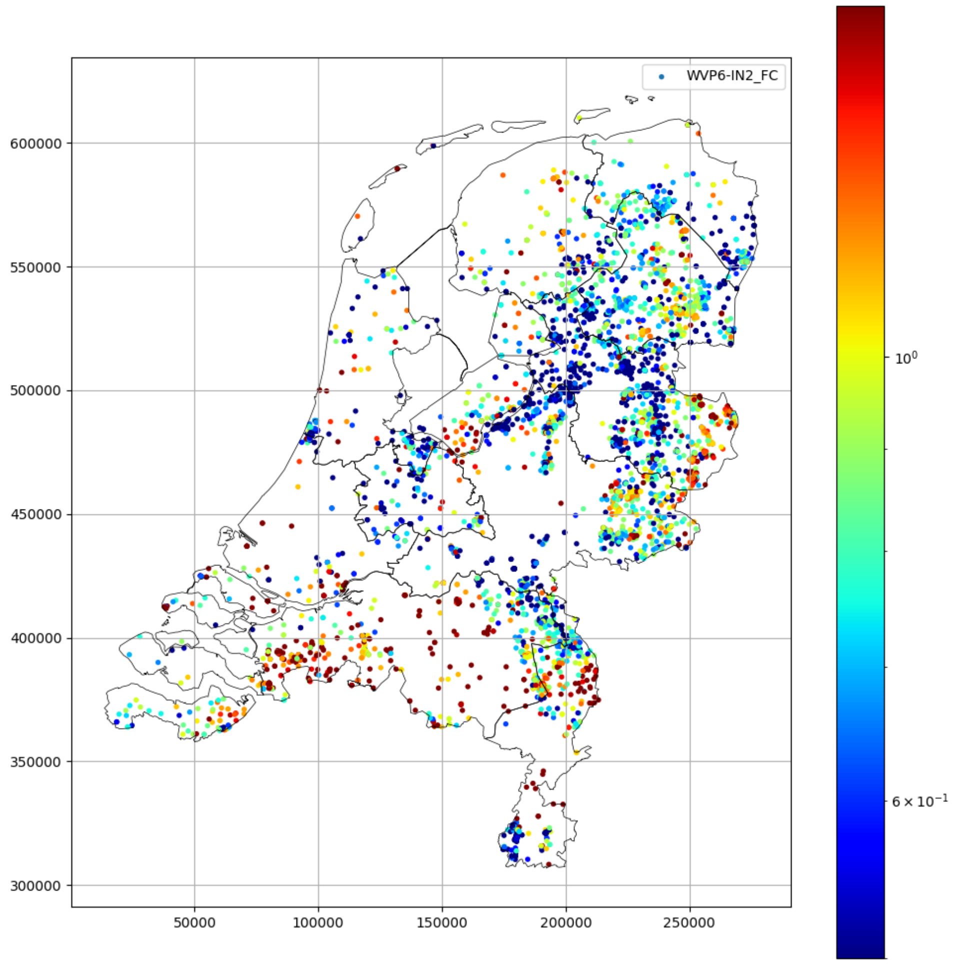


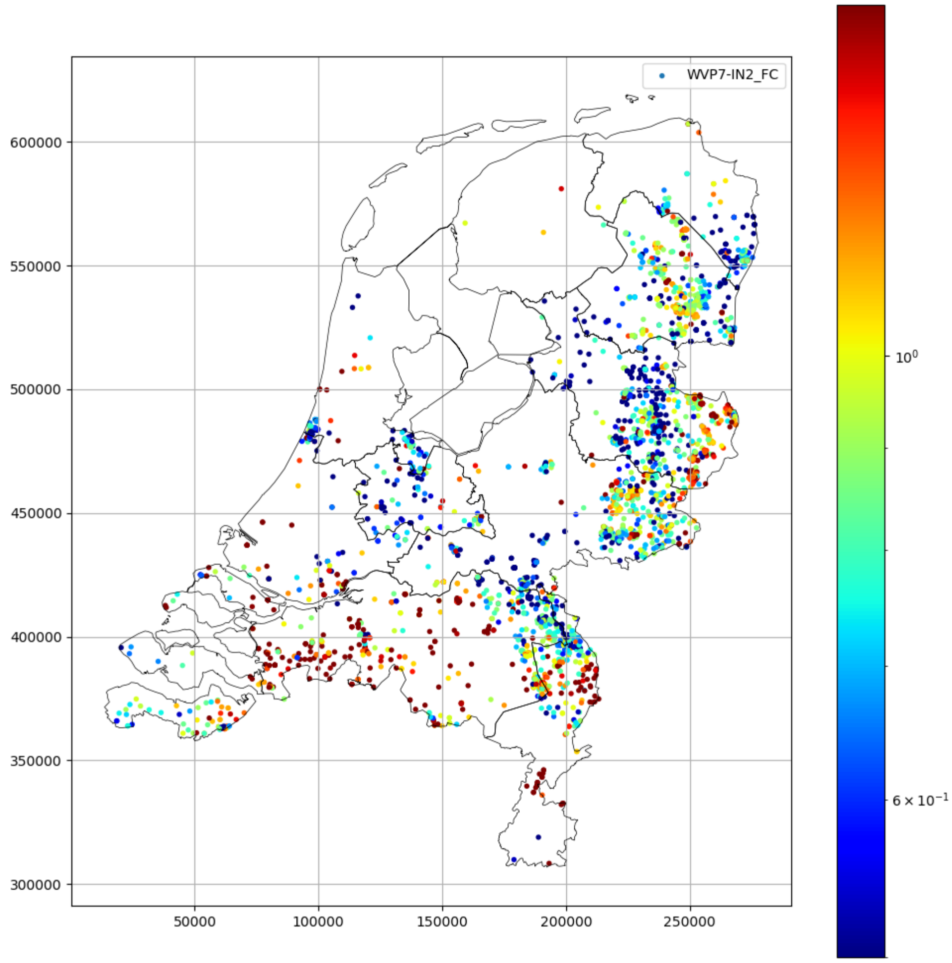

WVP2-IN2_FC
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^0
6×10^{-1}


WVP3-IN2_FC
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^0
6×10^{-1}


WVP4-IN2_FC
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^0
6×10^{-1}

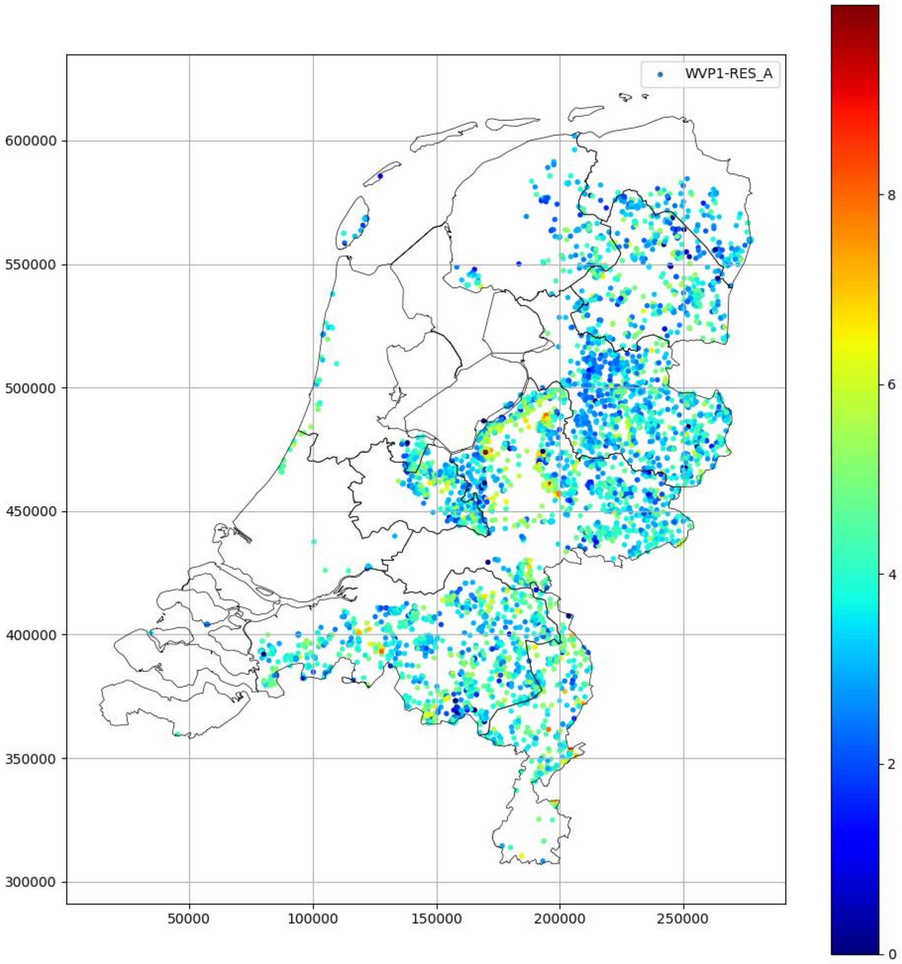

WVP5-IN2_FC
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^0
6×10^{-1}

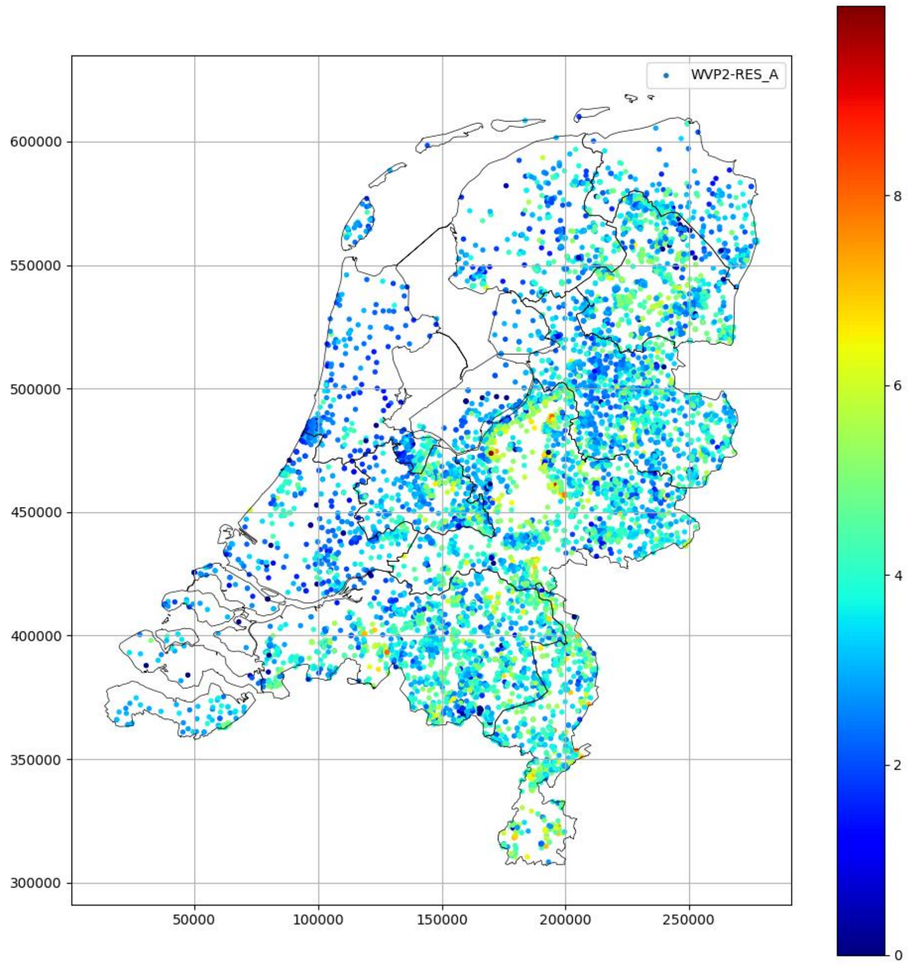

WVP6-IN2_FC
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^0
6×10^{-1}

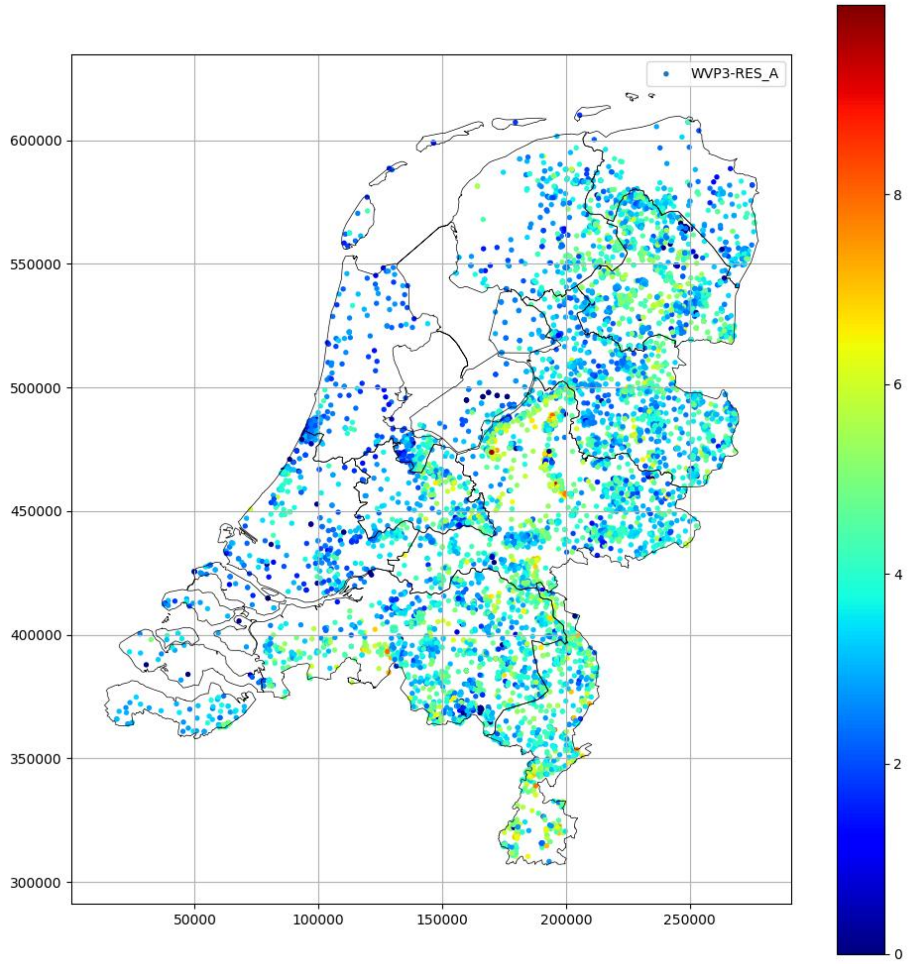

WVP7-IN2_FC
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
10^0
6×10^{-1}

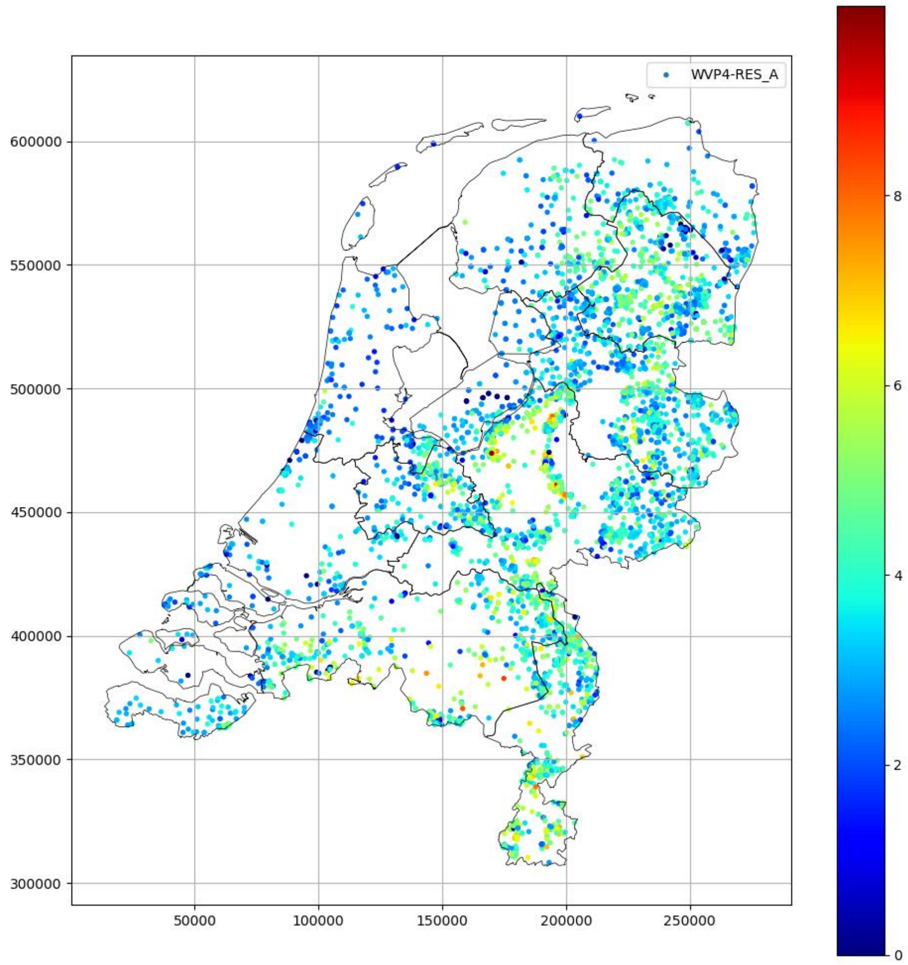
E Maps noise model parameter RES_A

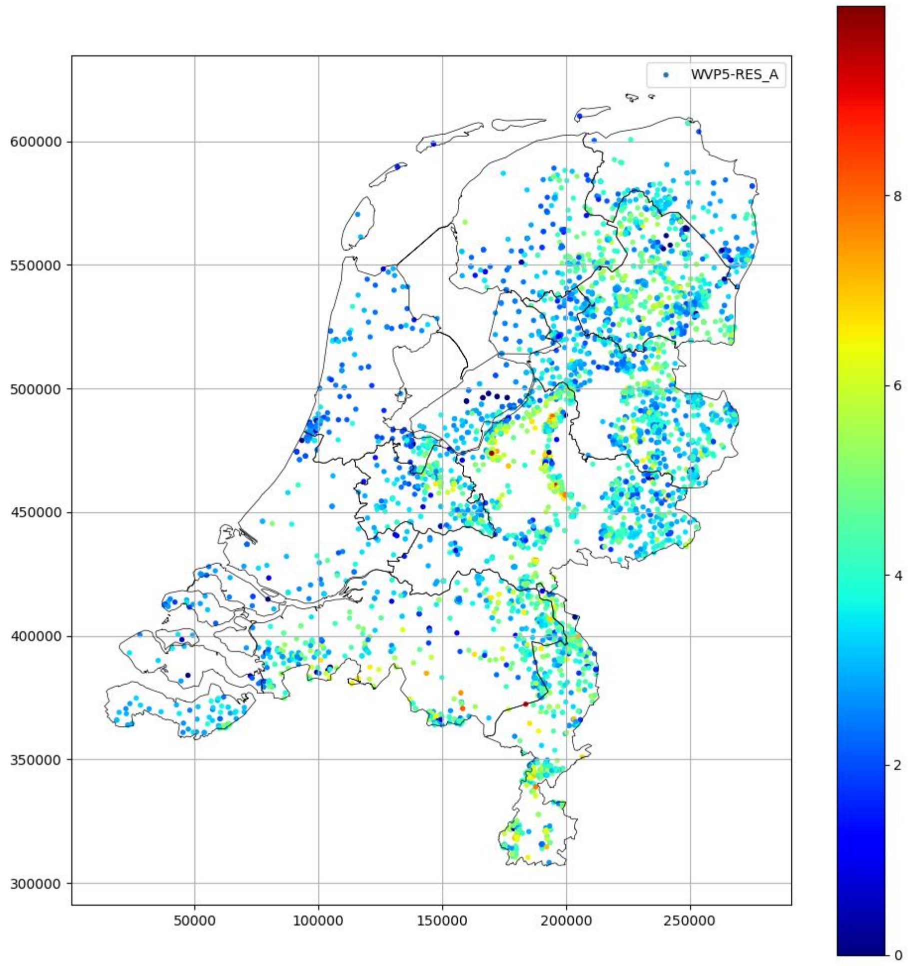
The maps in this appendix show the noise model parameter RES_A [-]. This parameter can be transformed into a decay time of the noise models in days using the expression *T* = - *1 /* ln*(1*-exp(-*RES_A))*. The aquifers (WVP) are numbered as in the Dutch national hydrological model (LHM).

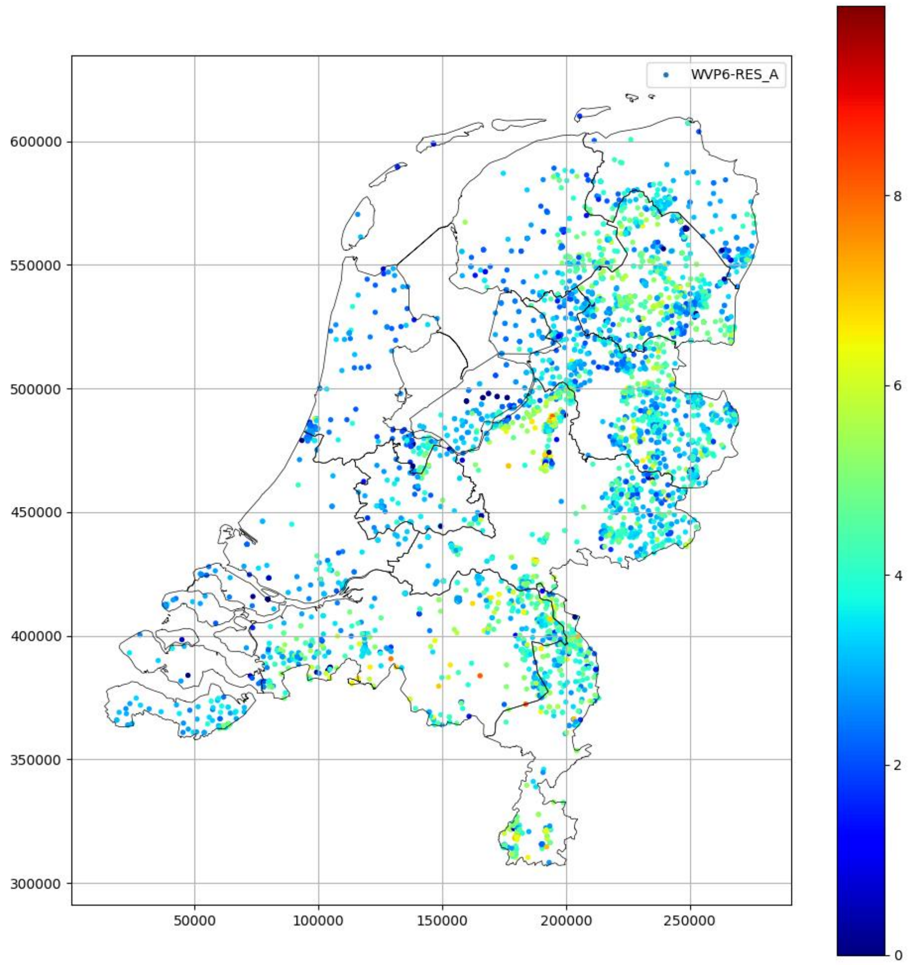


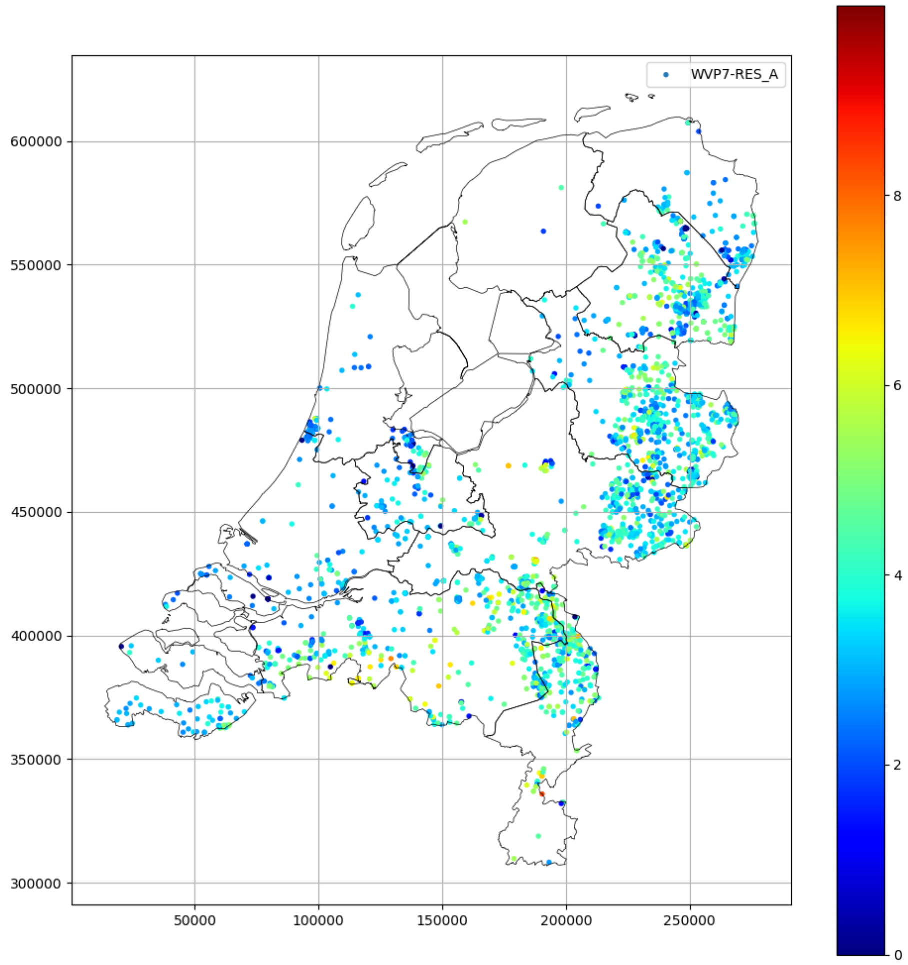

WVP2-RES_A
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
0
2
4
6
8


WVP3-RES_A
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
8
6
4
2
0


WVP4-RES_A
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
8
6
4
2
0


WVP5-RES_A
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
0
2
4
6
8


WVP6-RES_A
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
0
2
4
6
8


WVP7-RES_A
600000
550000
500000
450000
400000
350000
300000
50000
100000
150000
200000
250000
8
6
4
2
0