Interpretation of three pumping tests

Predicting the influence of the drainage of a building pit located in Amsterdam, the Netherlands, to reconstruct the A9 Gaasperdammerweg.

Vera de Jong, BSc.

March 2016

Front cover: photograph of a building pit at the A9, taken during a field visit on the 19th of January, 2016.

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Summary

Introduction

The Schiphol Amsterdam Almere project (SAA-project) is a ten-year project by Rijkswaterstaat to improve the accessibility of Amsterdam and the surrounding areas. South of Amsterdam two tunnels will be constructed at the location of the A9 Gaasperdammerweg. During construction of these tunnels the building pits will be drained by pumps. To predict the discharge and the spatial effects three pumping tests were executed at the site of the A9 highway from Amstelveen to the intersection Diemen Zuid.

Pumping tests

The Huntumdreef pumping test, executed in December 2012, was carried out near the overpass Gaasperdammerweg and Huntumdreef. The observation wells were installed in a southwest to northeast direction alongside the Gaasperdammerweg and at distances between 5 and 830 m from the pumping well. These observation wells were installed in the pumped aquifer and in the first aquitard layer. The pumping test lasted for seven days, and during the test an average of 1680 m^3/d was extracted.

The Nellesteinpad pumping test, executed in March 2013 was carried out near the overpass Gaasperdammerweg and Nellesteinpad. The observation wells were installed in a southwest direction from the pumping well alongside the Gaasperdammerweg and at distances of between five to 1000 m from the pumping well. The eight observation wells were all installed in the pumped aquifer. The pumping test lasted seven days and an average extraction rate of 1255 m^3/d was obtained.

The Amstelveen pumping test was executed near the Keizer Karelweg. The observation wells where installed in a northwest to southeast direction, alongside the Burgemeester van Sonweg at a distance of zero to 915 m from the pumping well. Observation wells were present in the pumped aquifer and in the first aquitard layer for the pumping test. The pumping test lasted six days and an average extraction rate of 1195 m^3/d was obtained.

In this research these pumping tests are subsequently analysed with the programs Multi-Layer Unsteady state or MLU (all three pumping tests) and Triwaco (one pumping test) to better estimate the transmissivity of the first aquifer and vertical resistivity of the top aquitard. Triwaco is an integrated environment for modelling 3D groundwater flow used by Waternet.

Prediction

A tunnel will be constructed at the A9 Gaasperdammerweg between intersection Holendrecht and Diemen Zuid. This tunnel will be built in several phases and the groundwater level needs to be lowered for construction to take place. The planned abstraction rate will be calculated in the best fit models of the Nellesteinpad pumping test in both MLU and Triwaco. Furthermore, the sphere of influence of the drainage during construction of the tunnel will be calculated and compared with the planned values.

Methods

Hydraulic heave calculations are also done for all pumping test locations, to check if hydraulic heave is present at the location of the ditches. Semi-logarithmic graphs are used, with time-drawdown to see what type of aquifers are present and time-distance graphs are used to determine the sphere of influence of the pumping tests.

All three pumping tests are modelled both with steady state and transient models in MLU, which is an analytical model with automatic optimisation. Only the Nellesteinpad pumping tests is modelled with steady state and transient models in Triwaco, which is a full 3D finite element model. Triwaco is also the groundwater model for the entire Amstel, Gooi, and Vecht area of Waternet, and to shorten calculation times a smaller model is also prepared. To optimise from simple to complex according to the principle of parsimony, MLU is used as a relatively simple semi 3D model, to gain insight into the order of magnitude of the parameter values. Then Triwaco is subsequently used to better estimate influences such as surface water infiltration. During modelling only the observation well screens in the pumped aquifer are used.

In MLU, during steady state optimisation only the furthest observation wells are used at a distance of around 1.5 times the thickness of the aquifer. This is done to correct for the partially penetrating pumping wells. During the transient optimisation, first only the furthest observation wells are used and in further runs all observation wells. Then the storativity of the aquifers is optimised, and finally the parameters from layers surrounding the pumped aquifer.

In Triwaco, during steady-state optimisation first the model with the original parameter values is used. Secondly, the fit of the best fit model of the Nellesteinpad pumping test in MLU is tested in Triwaco. Thirdly, the most important parameters, such as the hydraulic conductivity of the pumped aquifer, are optimised to achieve the best fit. In the transient model only the storativity of the aquifers is optimised. The modelled hydraulic head is converted to drawdown manually in Excel for all the runs. Parameters are optimised manually with the residual sum of squares (RSS).

Conclusions

The pumped aquifer has an average combined hydraulic conductivity of between 15 to 25 m/d for all three pumping tests.

The pumped aquifer at both the Huntumdreef and Nellesteinpad pumping test locations are a combination of the Boxtel, Sterksel, Peize and Waalre Formations and the glacially reworked layer. The aquifer is underlain by the Sterksel clay layer at a depth of NAP -70 m. At the Huntumdreef location the pump well screen is adjusted to rest on a thin and locally present clay layer of 0.50 m in the glacially reworked layer. The hydraulic conductivity of the Boxtel Formation is optimised to a combined value of 2 m/d (1.0 to 2.6 m/d). While the vertical resistivity of the first aquitard layer at the location of the Huntumdreef pumping test is optimised to a value of 733 days (682 to 784 days). In MLU the vertical resistivity of the Nellesteinpad pumping test is optimised to a value of 117 days (111 to 123 days), while in Triwaco this value is split into a value of 10.000 days for the first aquitard layer, and an optimised value of 25 days for the infiltration resistance of the ditches.

The pumped aquifer at the Amstelveen pumping test location is a combination of Boxtel, Kreftenheye, Drente, Urk and Sterksel Formations and the glacially reworked layer. The aquifer is probably underlain by the Sterksel clay layer at a depth of NAP -50 m, but for sure by the Waalre clay layer at a depth of NAP -72 m. Hydraulic heave is not present at this location and therefore a value of at least 1000 days for the first aquitard layer is used.

The planned extraction rate of 16 m^3/h with an injection percentage of 60 %, appears to be an adequate estimate for the extraction rate needed for a drawdown of 1.60 m in the building pit. However, planned sheet pilings are not taken into account in this calculation. Furthermore, due to time constraints the Triwaco sum was only calculated with one extraction well and no injection wells.

Recommendations

For further research it is recommended to also use besides the pumping test, the information available of the stopping tests. Furthermore, for pumping test executed in the future it is recommended to put observation well screens above and below aquitards. Lastly, the extractions for the construction of the tunnel taking place in this moment in time can be used for further optimisation of the model, as these extractions are being monitored extensively.

1 Introduction

1.1 Background

1.1.1 A global problem

Historically, people have preferred to live within 100 km of coasts and major rivers despite risks such as flooding, subsidence, and seawater intrusion (Small & Nicholls, 2003). A Low Elevation Coastal Zone (LECZ) is defined as a contiguous coastal area which is less than 10 metres above sea level. In the year 2000, two per cent of land fell into this category, with ten per cent of the total population living in LECZ and thus near the coast in potentially hazardous areas (McGranahan et al., 2007). Furthermore, as many as 11 of the world's 15 largest cities are situated in estuaries or near a coast (Gornitz, 2000) (Cohen & Small, 1998).

Coastal delta areas are often geologically young, with unconsolidated fluvial sediments making up a large part of the foundation for the cities build there. Fresh water is an essential commodity and when water is extracted in large quantities and for long periods of time from unconsolidated aquifers, subsidence and salt-water intrusion can become a problem as has happened *e.g.* in Osaka, Japan. Subsidence has been successfully stopped in Osaka due to improved water management but large areas still remain beneath the high water zone and would be flooded if not for flood defence systems (Klein et al., 2003). However subsidence is not only a coastal problem. As is clear in Mexico City where groundwater extraction has also caused subsidence issues (Osmanoglu et al., 2011).

In the Netherlands, 75 % of the total land area can be classified as a LECZ and 26 % of the Netherlands lies below sea level *e.g.* in the form of polders with high near surface groundwater levels (McGranahan et al., 2007) and (Planbureau voor de Leefomgeving, 2007). If not for flood defences and controlled surface water levels, a large part of the Netherlands would be again returned to the sea from whence it came.

Subsidence, and salt water intrusion are just two parts in a myriad of problems faced by inhabitants in low-lying delta areas such as in the Netherlands. Measures such as groundwater pumping lowering the groundwater level are often essential for building in Dutch polders. But these measures can create their own problems *e.g.* when the groundwater is lowered for too long and historic foundations are damaged and they in turn create a need for mitigating measures.

1.1.2 The project

The Schiphol Amsterdam Almere project (SAA-project) is a ten-year project by Rijkswaterstaat to improve the accessibility of Amsterdam and the surrounding areas. The project comprehends: additional lanes to 63 km of highway, a bridge across the Amsterdam-Rijnkanaal and the renovation of several intersections. Specifically at highway A9 between intersections Holendrecht & Diemen Zuid, the highway will be upgraded from four lanes and two hard shoulders to ten lanes. A three kilometre stretch of road will be underground to improve quality of life for the surrounding residential area and the accessibility of Amsterdam and the surrounding area (Overbeek-te Vaarwerk et al., 2013). However, the work is complicated by several types of pipeline running either alongside or across the highway, such as gas, electricity, water, telephone-lines, and city-heating. Therefore in 2014 and the first half of 2015 all pipelines that formed an obstacle for the building work were relocated

(Rijkswaterstaat, 2015). Furthermore at the A9 between intersection Badhoevedorp and Holendrecht the highway will also be upgraded to a total of eight lanes with new noise barriers. Work is planned to begin in 2019 and will be finished in the years 2024 to 2026 for this part of the highway.

This thesis is part of the master's study Hydrology at the Vrije University in Amsterdam, the Netherlands. The thesis was done as an internship at Waternet.

1.2 Problem outline

The primary project location is located in the polders Bijlmer and Zuid-Bijlmer, which have a relatively high groundwater level. This makes it necessary for the groundwater level to be lowered before work can commence. The amount of water that needs to be extracted is primarily controlled by parameters such as groundwater level, hydraulic head, lithology, geohydrological parameters, and the amount of drawdown needed. Groundwater level, hydraulic head and surface elevation are parameters that are all relatively easily monitored and measured, but determining geohydrological parameters such as transmissivity and hydraulic resistivity is a more complicated process.

Furthermore, calculated drawdown does not always coincide with measured drawdown. Therefore, calculated effects of groundwater extraction such as subsidence of the soil could dramatically deviate from values estimated beforehand. In the Bijlmer several site-specific effects of groundwater extraction also need to be taken into account, such as: possible up-coning of salt water, quality issues with the Gaasperplas, and damage to the top aquitard due to water pressure in the first aquifer (Beemster, 2014). Thus if parameters have a higher precision, plans can be executed with a higher degree of certainty, and more tailor-made design and equipment, probably resulting in less problems during construction.

The secondary project location is located in Amstelveen, which also has a relatively high groundwater level. Several of the same issues present at the location Gaasperdammerweg are also present in Amstelveen, such as potential subsidence of the subsoil, and a nearby lake 'De Poel.'

1.2.1 Objective

The primary objective of this research is to improve the local groundwater model by better determining the transmissivity of the first confined aquifer and the hydraulic resistance of the top aquitard at the location of the polders Bijlmer and Zuid-Bijlmer. A second objective is to determine the transmissivity of the first confined aquifer and the vertical resistance of the top aquitard at a location in Amstelveen also to improve the local groundwater model. Furthermore, the calibrated local groundwater model will then be used to calculate drawdown and compare the plans for construction of part of the A9 highway tunnel.

1.2.2 Method

In 2012 and 2013 two pumping tests were executed at the site of the highway A9 Gaasperdammerweg, while in 2014 a third pumping test was executed in Amstelveen along the A9 Burgemeester van Sonweg. These pumping tests are subsequently analysed with the programs Multi-Layer Unsteady state or MLU (all three pumping tests) and Triwaco (one pumping test) to better estimate the transmissivity of the first aquifer and vertical resistivity of the top aquitard. Triwaco is an integrated environment for modelling 3D groundwater flow used by Waternet. Finally, the optimised models from both MLU and Triwaco will be used to analyse the estimated extraction and injection rates of part of the A9 highway tunnel.

To work according to the principle of parsimony, MLU is used as a relatively simple semi 3D model to gain insight into the order of magnitude of the parameter values. While Triwaco is subsequently used to better estimate influences such as surface water infiltration and other local variations.

1.3 Reading guide

In chapter two, general information such as location, hydrogeology, meteorology, and hydrology is explained. Chapter three describes methods and materials, including software and general information regarding the pumping tests. Chapter four covers the results of the calibration in both MLU and Triwaco. In chapter five predictions are made for part of the tunnel plans in both MLU and Triwaco. Finally, discussion takes place in chapter six, chapter seven ends with conclusions, and recommendations are in chapter eight.

2 General Information

2.1 Location

Two pumping test sites are located near the A9 Gaasperdammerweg in the Bijlmer: one near the underpass Huntumdreef, and the other near the underpass Nellesteinpad. A third pumping test site is located near the A9 Burgemeester van Sonweg, at the underpass Keizer Karelweg in Amstelveen (Figure 2.1). Coordinates of the three pumping test sites can be found in Appendix B for the Huntumdreef pumping test, in Appendix C for the Nellesteinpad pumping test and in Appendix D for the Amstelveen pumping test.

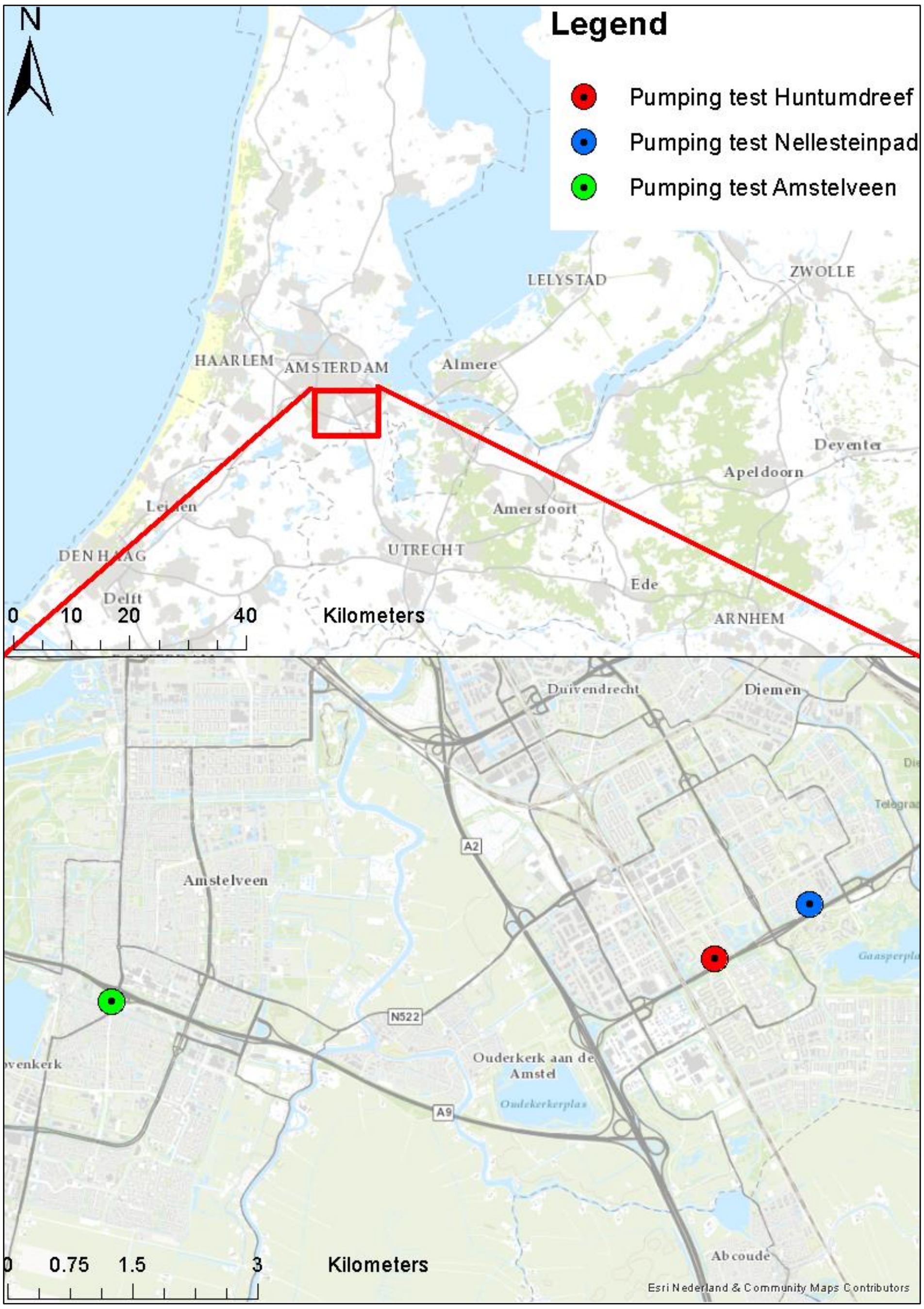

Figure 2.1 Location of the three pumping tests along the A9 in Amstelveen and Amsterdam, the Netherlands.

2.2 Hydrogeology

2.2.1 Cross section

Generally speaking, the geology around the three pumping test is composed of 200 m of sand crossed by several, sometimes discontinuous, clay layers. Figure 2.2 shows a cross section from the location of the pumping test in Amstelveen (A) alongside the A9, towards the Gaasperdammerweg and the pumping test locations in the Bijlmer (A’). The section is 14 km long and shows the Holocene and Pleistocene geology to a depth of 200 m.

2.2.2 Formations

Present beneath the Holocene formations are the sandy Boxtel and Drente Formations (yellow). Below these formations, the Dtc layer is a glacially reworked formation (grey) which is present in the entire cross section. Only in Amstelveen, the sandy Urk layers are present. The Sterksel Formation is present in Amstelveen with both a clay and sandy layer, but only with sandy layers in the Bijlmer. The Waalre clay appears discontinuous, but it should be present in Amstelveen and could be present in the Bijlmer. From there on downwards the Peize and Waalre Formations dominate the geology. Around NAP -190 m the Maassluis Formation appears. ‘Normaal Amsterdams Peil’ (NAP) or Amsterdam Ordnance Datum is a vertical level which is a reference for heights widely used in Western Europa. The Maassluis Formation is considered as the hydrological base of the geohydrological model as it includes several thick marine clay layers with a very low vertical resistivity (Witteveen+Bos, 2014), (Kramer, 2015) and (Vernes & van Doorn, 2005). For more detailed information on the different formations present in the research area, see Appendix A.

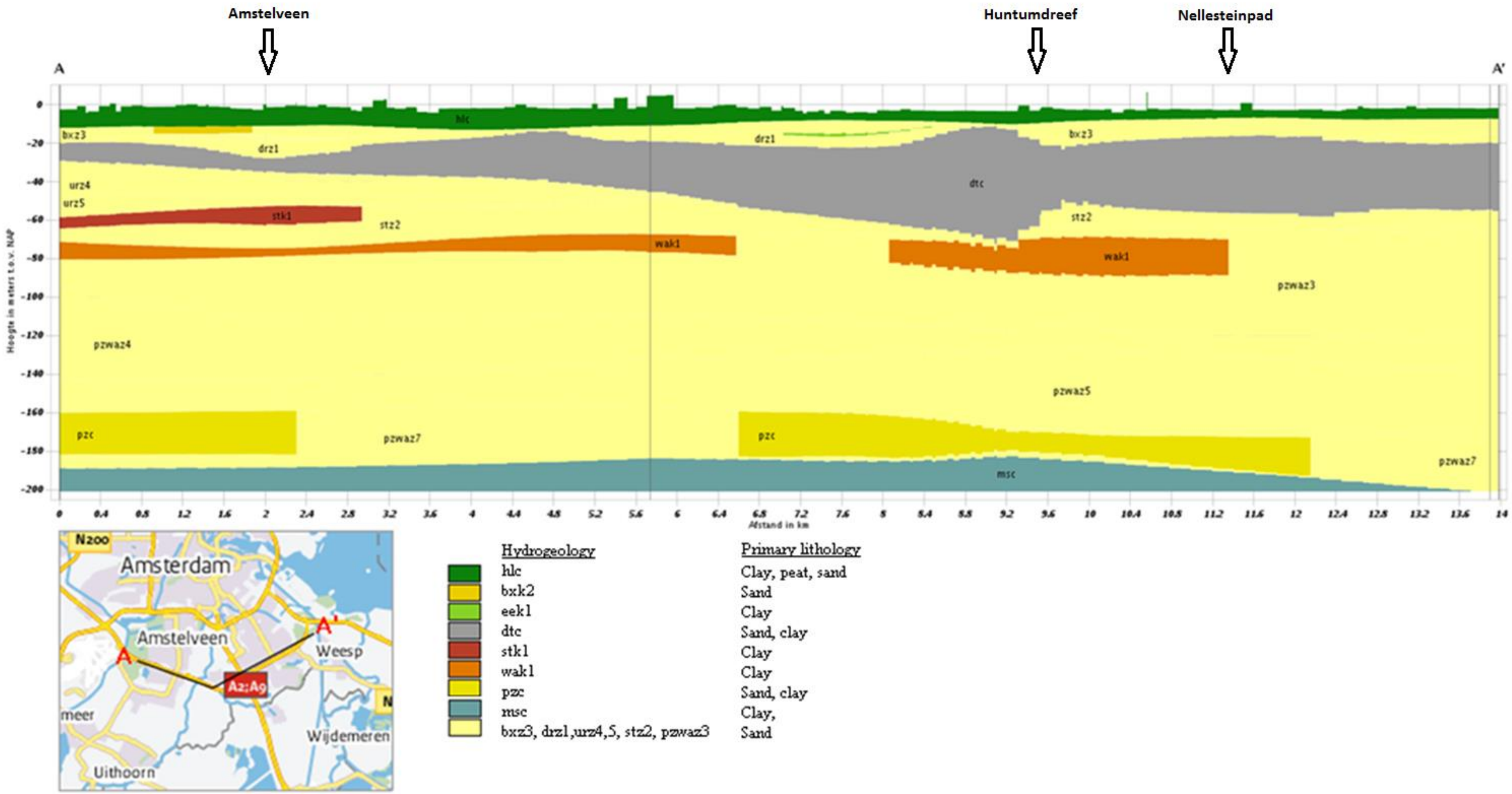

Figure 2.2 Cross section of the lithology of Amstelveen and Amsterdam from surface level to NAP -200 m, with information from the REGIS II v2.1 model (Dinoloket, 2015).

2.2.3 Local geology

The specific geology of the three pumping test locations is notated in Table 2.1. The anthropogenic layer is the phreatic aquifer and the Naaldwijk and Nieuwkoop Formations make up the first aquitard. Below the first aquitard is the first aquifer, including *e.g.* the Boxtel, Kreftenheye, Drente, Urk Formations, which stretches until the second aquitard. The second aquitard is either the Waalre clay layer as is the case for the Huntumdreef and Nellesteinpad or the Sterksel clay layer in Amstelveen. The Peize and Waalre Formation below the Waalre clay layer form the second aquifer, with the Maassluis Formation as the geohydrological base. The main difference between the locations is the presence of Kreftenheye, Drente and Urk Formations in Amstelveen, while part of the Peize and Waalre Formations are not present in Amstelveen.

Table 2.1 Geology of the three pumping test sites (Dinoloket, 2015).

<table>
<tr><th colspan="3" rowspan="2">Chrono-stratigraphy</th><th rowspan="2">Formation</th><th rowspan="2">Abbreviation</th><th colspan="3">Depth of formations [m NAP]</th></tr>
<tr><th>Huntumdreef</th><th>Nellesteinpad</th><th>Amstelveen</th></tr>
<tr><td rowspan="21">Quaternary</td><td colspan="2" rowspan="3">Holocene</td><td>(Anthropogenic)</td><td>AAOP</td><td rowspan="3">-2 to -8</td><td rowspan="3">-2 to -7</td><td rowspan="3">-2 to -9</td></tr>
<tr><td>Naaldwijk (Wormer layer)</td><td>NAWO</td></tr>
<tr><td>Nieuwkoop (basal peat layer)</td><td>NIBA</td></tr>
<tr><td rowspan="18">Pleistocene</td><td rowspan="3">Late</td><td rowspan="2">Boxtel</td><td>Bxz2</td><td rowspan="2">-8 to -20</td><td rowspan="2">-7 to -16</td><td rowspan="2">-9 to -13</td></tr>
<tr><td>Bxz3</td></tr>
<tr><td>Kreftenheye</td><td>Krz5</td><td colspan="2"></td><td>-13 to -17</td></tr>
<tr><td rowspan="8">Mid</td><td rowspan="2">Drente</td><td>Drz1</td><td colspan="2" rowspan="2"></td><td rowspan="2">-17 to -25</td></tr>
<tr><td>Drz2</td></tr>
<tr><td>(glacially reworked)</td><td>Dtc</td><td>-20 to -55</td><td>-16 to -55</td><td>-25 to -32</td></tr>
<tr><td rowspan="3">Urk</td><td>Urz3</td><td colspan="2" rowspan="3"></td><td rowspan="3">-32 to -50</td></tr>
<tr><td>Urz4</td></tr>
<tr><td>Urz5</td></tr>
<tr><td rowspan="2">Sterksel</td><td>Stk1</td><td colspan="2"></td><td>-50 to -72</td></tr>
<tr><td>Stz2</td><td colspan="2">-55 to -64</td><td></td></tr>
<tr><td rowspan="7">Early</td><td>Peize and Waalre</td><td>Pzwaz2</td><td colspan="2">-64 to -70</td><td></td></tr>
<tr><td>Waalre</td><td>Wak1</td><td colspan="2">-70 to -89</td><td>-72 to -77</td></tr>
<tr><td rowspan="4">Peize and Waalre</td><td>Pzwaz3</td><td rowspan="4">-89 to -185</td><td rowspan="4">-89 to -190</td><td rowspan="4">-77 to -186</td></tr>
<tr><td>Pzwaz4</td></tr>
<tr><td>Pzwaz5</td></tr>
<tr><td>Pzc and pzwaz7</td></tr>
<tr><td>Maassluis</td><td>Msc</td><td>below -185</td><td>below - 190</td><td>below -186</td></tr>
</table>

In Table 2.2 hydraulic conductivities (K) and vertical resistivities (c) for all the different formations are compared from different sources. REGIS II values only indicate high, average, or low values, and formations often include more than one lithology. In Appendix A, the primary lithologies are connected to ranges of both hydraulic conductivity and vertical resistivities from values from Bear (1972).

Table 2.2 Hydraulic conductivities and vertical resistivities for the present formations and layers.

	Bear (1972)		**RegisII v2.1** (Dinoloket, 2015)		**Triwaco model** (Beemster, 2014)	
Formations and/ or specific layers (REGIS II)	**K [m/d]**	**c [d/m]**	**Kh [m/d]**	**c [days]**	**K [m/d]***	**c [d/m]***
(anthropogenic)	1-30	-	-	-	5	-
Naaldwijk	0.01-10	-	-	-	5	-
Naaldwijk (Wormer layer)	-	-	-	-	-	1500
Nieuwkoop (basal peat layer)	-	10-1000	-	-	-	5000
Boxtel	0.05-10	-	10-100	-	2	-
Kreftenheye	30-200	-	10-100		30	-
Drente	0.01-200	-	10-100		37.5	-
(glacially reworked)	-	-	-	-	37.5	-
Urk	10-500	-	10-100	-	37.5	
Sterksel	30-200	-	10-100	-	37.5	-
Sterksel clay 1		20	-	100-1000		25
Peize and Waalre	1-200	-	10-100	-	37.5	-
Waalre clay 1	-	20	-	1000-10000		6
Peize	-	-	10-100	-	25	-
Maassluis	0.01-30	-	1-10	10000	25*	-

* Top sand layer of the Maassluis Formation has a hydraulic conductivity of 25 m/day, and the clay layers of the Maassluis Formation are seen as the hydrological base of the model and therefore form the bottom boundary.

2.3 Meteorology

The average temperature in Amsterdam is between 7 and 14 ^{o}C, while precipitation is around 900 mm per year. At measuring station Schiphol the average yearly precipitation during the period 1981-2010 is 838 mm with a minimum of 41 mm for July and a maximum of 90 mm in October. Makkink reference evaporation is on average 591 mm per year (KNMI, 2015). All average monthly values for precipitation, Makkink potential evapotranspiration and precipitation minus Makkink potential evapotranspiration can be seen in Figure 2.3. Measuring station Schiphol is the nearest meteorological station with a complete dataset at a distance of around 20 km.

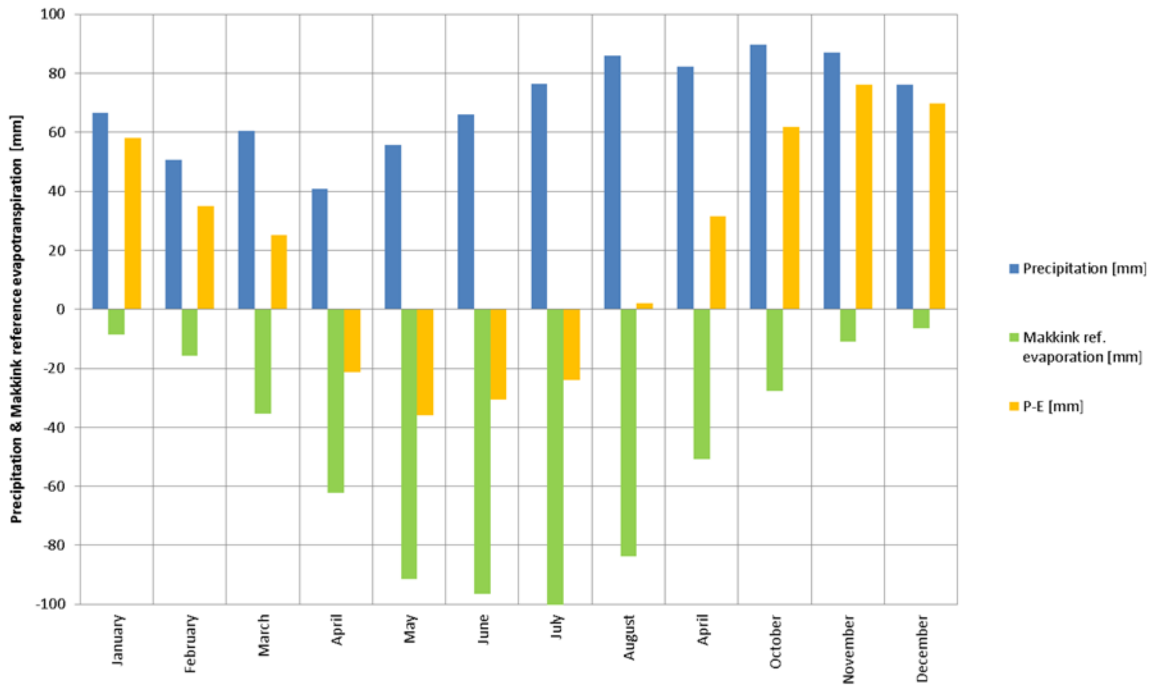

Figure 2.3 Precipitation and Makkink reference evaporation from meteorological station Schiphol (KNMI, 2015).

2.4 Surface water

Figure 2.4 shows a map of the polders with their target surface water levels in m NAP. The abbreviation VP means fixed level all year round, but a variation of *e.g.* 0.05 m can be present. The surface water level near the pumping test Nellesteinpad is NAP -4.20 m, while levels in the polder south of the Gaasperdammerweg are higher at NAP -2.70 m, and the level near the pumping test in Amstelveen is NAP -2.25 m.

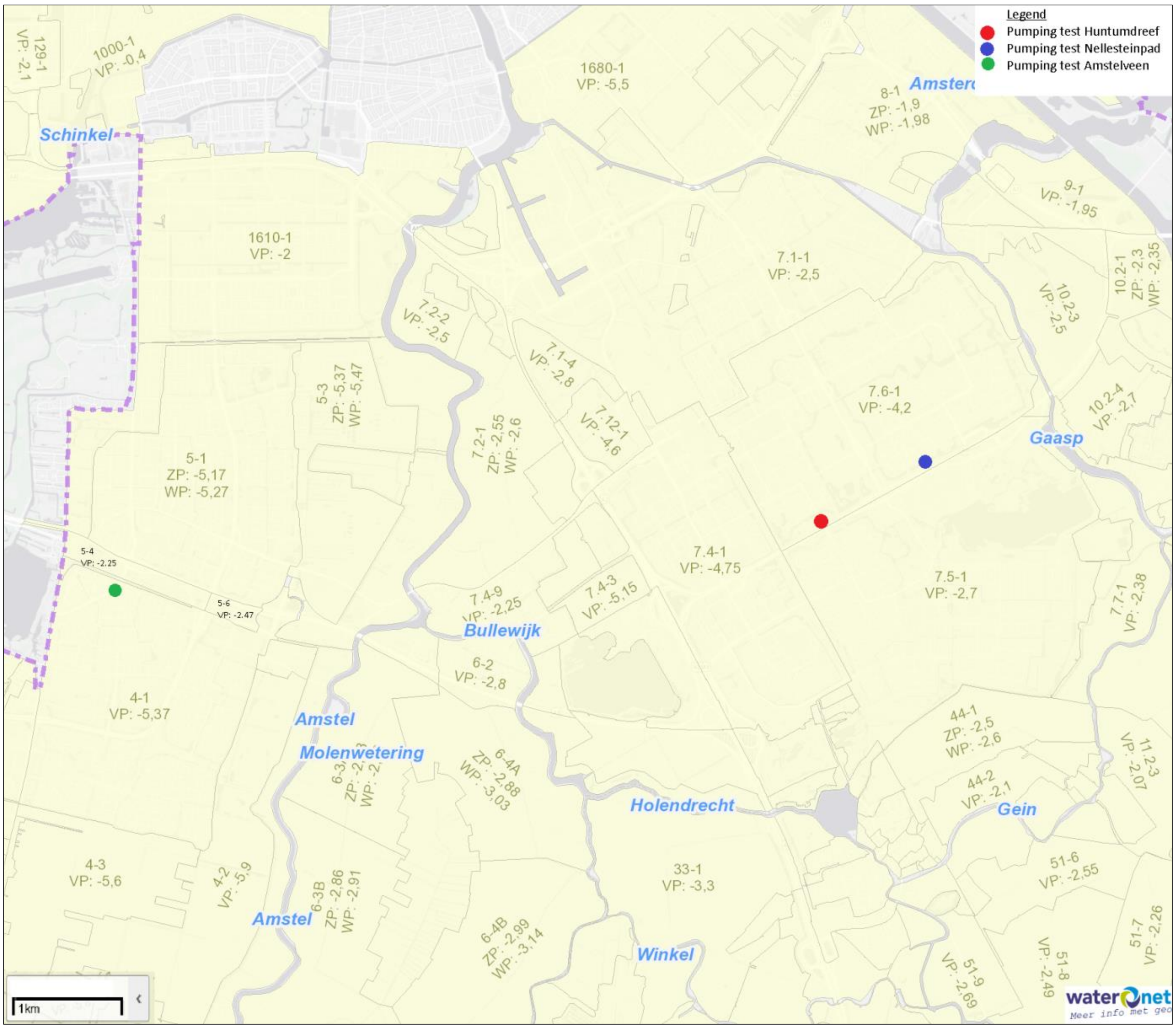

Figure 2.4 Surface water levels in m NAP, with: 7.2.2: codes of the polder areas, VP: fixed surface water level all year round, ZP: surface water level in summer, WP: surface water level in winter *(Geoweb, 2015).*

2.5 Groundwater

In Figure 2.5 a map of the hydraulic head in the first confined aquifer in the area surrounding the three pumping tests is included. The map was made with measurements from 2005 (Waternet & TNO) in ArcGIS using the interpolation technique Inverse Distance (2^{nd} power). It gives an indication of the general flow direction in the first confined aquifer in Amsterdam. In the east near the Gaasperdammerweg the groundwater level has a SE-NW flow direction, while in the west near the Amstelveen pumping test groundwater flow is nearly N-S. All values on the map are in m NAP and observation wells are followed by the depth of the centre of the filter and hydraulic head respectively. Hydraulic head in the area surrounding the Amstelveen pumping test should be around NAP -4.20 m, while in the Huntumdreef area it is around NAP -3.50 m and finally in the Nellesteinpad area it is just NAP -3.20 m.

Based on both Figure 2.4 and the isohypse map in Figure 2.5, water should infiltrate in the area surrounding the Huntumdreef and in Amstelveen, but exfiltrate in the area near Nellesteinpad. This is a generalization and a deviating situation could cause the system to invert, such as e.g. a pumping test. However, exfiltration does occur near the ditches in both areas, because of the lower surface water level.

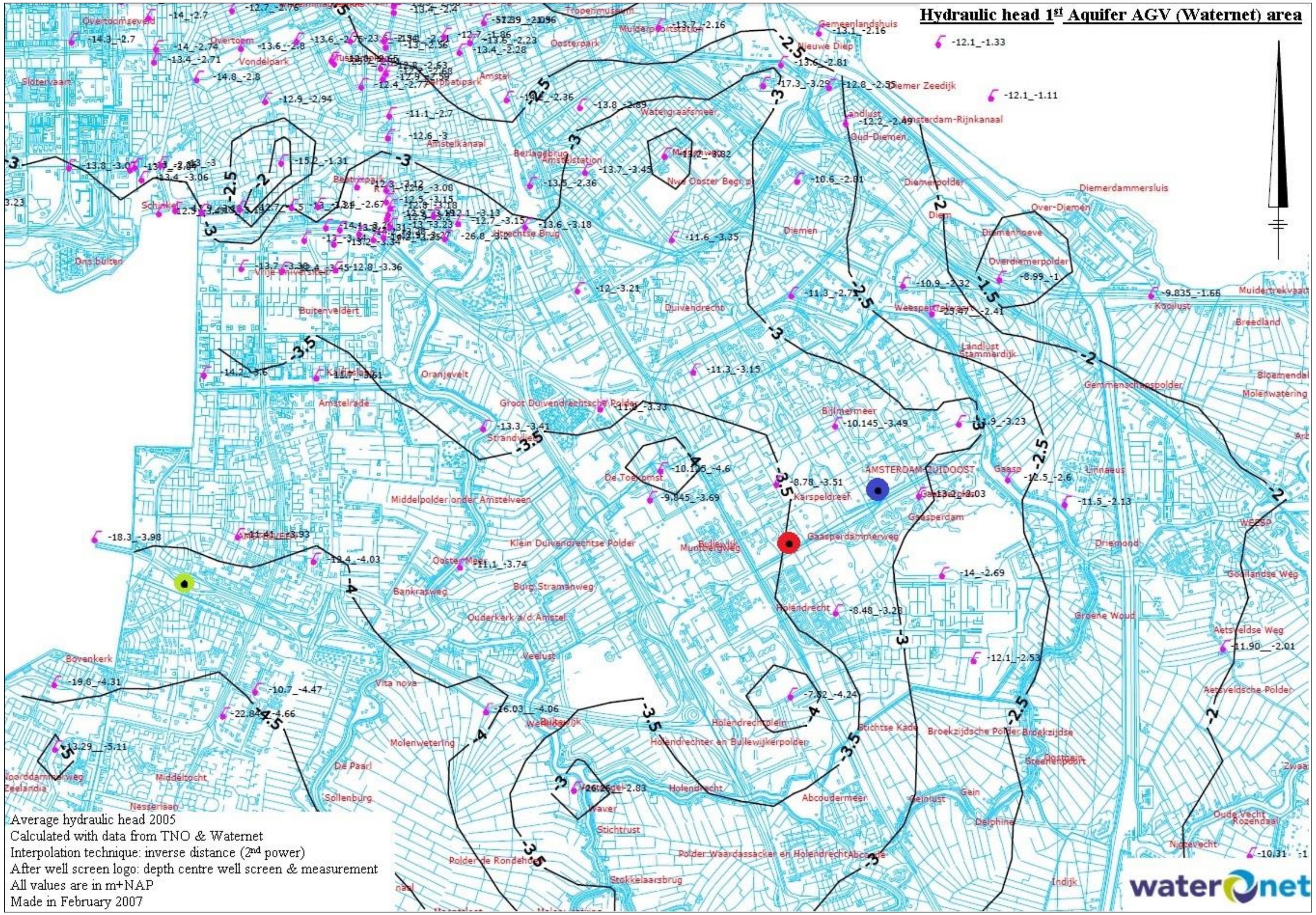

Figure 2.5 Isohypse (black line) map with Huntumdreef pumping test (red dot), Nellesteinpad pumping test (blue dot), and Amstelveen pumping test (green dot) (Waternet, 2007).

3 Methods

3.1 Semi logarithmic graphs

Figure 3.1 shows a picture explaining the difference between the drawdown of confined, unconfined and leaky aquifers when they are plotted in a certain way (Kruseman & de Ridder, 1994). A confined aquifer is enclosed at the top and bottom by an aquiclude, while an unconfined aquifer is only closed off at the bottom by an aquiclude. A leaky aquifer is bounded by an aquitard above and or below. By plotting the drawdown (s) against time (t) in either a log-log or semi log fashion and comparing these graphs with the theoretical relationship as shown in Figure 3.1, a differentiation can be made between these three aquifer types.

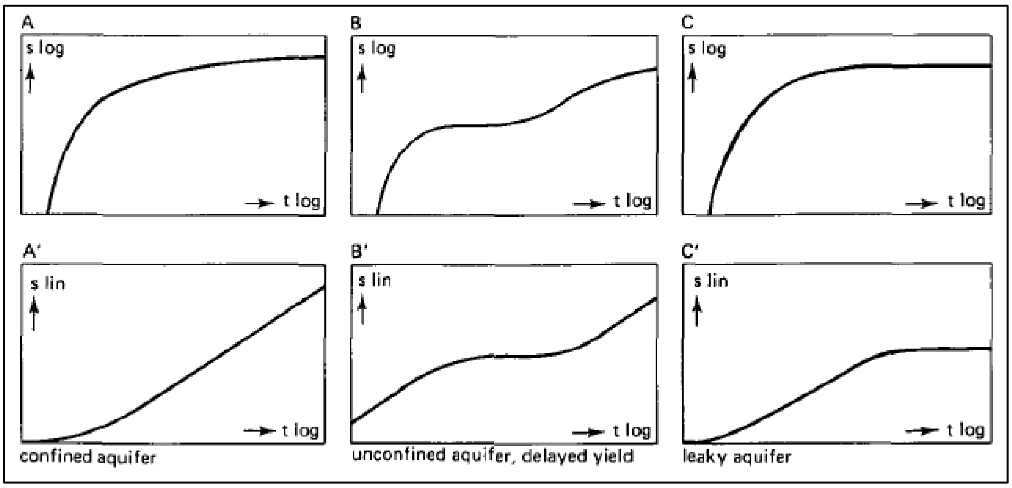

Figure 3.1 *Log-log and semi log plots of the theoretical time-drawdown relationships of unconsolidated aquifers. A and A': confined aquifer, B and B': Unconfined aquifer, and C and C': leaky aquifer (Kruseman & de Ridder, 1994).*

3.2 Hydraulic heave

At the site of the pumping test locations ditches are present that appear to be partially cut through the aquitard layer. Hydraulic heave of the aquitard is the physical bursting of the soil by the seepage force of the hydraulic head. If the combination of surface water column and soil column creates enough downward force to counteract the upward force by the hydraulic head, failure or hydraulic heave of the vertical equilibrium is prevented.

Therefore calculations were made to check if the remaining aquitard layer was enough to retain vertical equilibrium with the water seepage force from below (NEN, 2012). Although a factor of 1.0 indicates an equilibrium between downward and upward pressure, a safety norm of 1.1 is used (Waternet, 2015). Formula 1 is used for the hydraulic heave calculation and in Table 3.1 all the parameters are explained.

$$Sf = \frac{Wd * g + \sum(St_i * \gamma_i)}{(-At + Wg) * g} \tag{1}$$

Table 3.1 Parameters for the hydraulic heave calculation.

Parameters	Parameter explanation [unit]
At	Top of the aquifer [m]
g	Gravitational acceleration [m/s^2]
Sf	Safety factor [-]
St_i	Thickness of different layers of lithology [m]
Wd	Water depth in ditch [m]
Wg	Hydraulic head in aquifer [m NAP]
Ws	Surface water level in ditch [m NAP]
y_i	Specific weight of the different lithologies [kN/m^3]

3.3 Partially penetrating well

> *"Wells, of which the water-entry section is less than the aquifer they penetrate, are called partially penetrating wells. Unlike the flow toward completely penetrating wells where the main flow takes place essentially in planes parallel to the bedding planes of the formation, the flow toward partially penetrating wells is three-dimensional. Consequently, the drawdown observed in partially penetrating wells will depend, among other variables, on the length and space position of the screened portion (water-entry section) of the observation wells, as well as on that of the pumping or flowing well."* (Hantush, 1964)

All of the pumping wells in the three pumping test are partially penetrating wells, which fails one of the assumptions needed for MLU stating that all wells need to be fully penetrating. This is a problem because close to the pump flow lines in the pumped aquifer will defer from horizontal. When this occurs, the vertical hydraulic conductivity also starts to influence groundwater flow besides the horizontal hydraulic conductivity. The distance at which flow lines are horizontal is from 1.5 to 2 times the thickness of the (pumped) aquifer (Hantush, 1964).

Figure 3.2 shows the particulars of a partially penetrating well in a confined aquifer. With *Q* representing the discharge from the well and *H* indicating the thickness of the aquifer. *Du* indicates the distance (1.5 to 2 times the thickness of the aquifer) at which flow is not only under the influence of horizontal hydraulic conductivity, but also influenced by the vertical hydraulic conductivity.

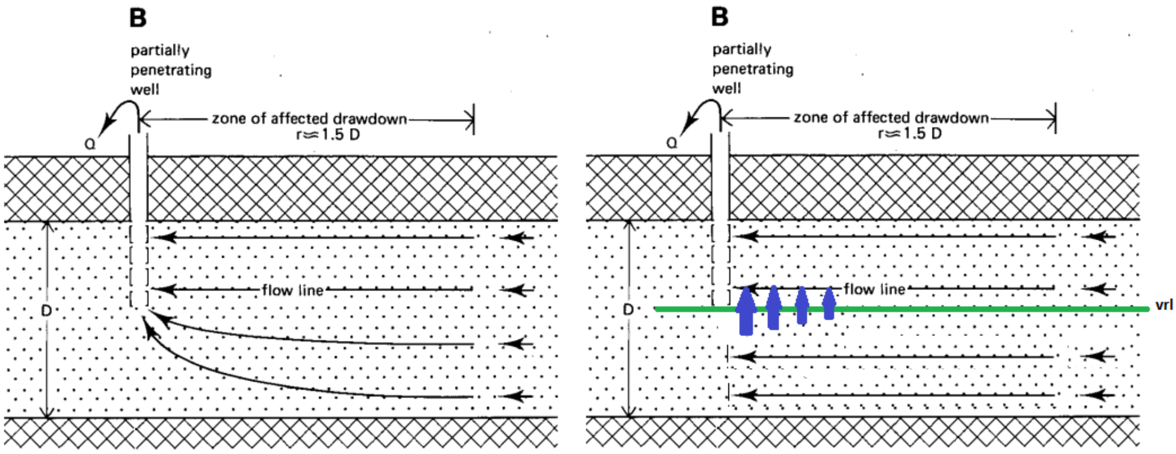

Figure 3.2 *The effect of partial penetration on flowlines to a well, with: D = thickness of the aquifer, Q = discharge, and zone of affected drawdown =1.5 D (Kruseman & de Ridder, 1994).*

Solution

To resolve the issue of a partially penetrating well, different methods where applied in the different models. In MLU the pumping well was modelled as a fully penetrating well by adding a virtual resistivity layer beneath the pumping well and by guidelines as will be mentioned in paragraph 3.4.

In Triwaco (Paragraph 3.5) the model was already build and adding a virtual layer beneath the pumping well was therefore more difficult. But as an empty aquifer was present between aquifer 2 and 4, aquifer 3 was enlarged with one third of aquifer 4 to store the well screen of the pump. This did not change the groundwater level or the size of the other aquifers or the location of the surface level in a significant way. This is further clarified in Appendix E.

3.4 MLU

MLU, which stands for Multi-Layer Unsteady state, is a semi 3-D model for transient well flow in layered aquifer systems. It offers an environment capable of modelling up to 40 aquifer layers with each layer having its own thickness and set of hydraulic parameters. The program uses a multi-layer uniform well-face drawdown solution for all calculations (Hemker, 2014).

Besides Darcy’s law, several assumptions underlie MLU and the most important are:

- Aquifers are for horizontal flow, and aquitards control vertical flow,
- All aquifers have an infinite horizontal extent,
- All aquifers are homogeneous and isotropic for transmissivity,
- All aquifers are homogeneous for storativity and vertical resistance,
- Well screens are fully penetrating,
- Observation wells screen in one aquifer layer,
- Only drawdown from pumping should be considered,
- No mutual effects from other pumping wells,
- Constant or step-wise extraction rate,
- Darcy’s law:
    - Homogeneous, isotropic and uniform layers,
    - No density differences,
    - Laminair and saturated flow.

Optimisation

The principle of parsimony, to keep the model as simple as possible, is important when modelling (Hill et al., 2002). Although it is easy to build a model and to let the software find a good fit, it is difficult to make a reproducible model calibration with meaningful results by using *e.g.* trial and error type method (Olsthoorn T.N., 1993). Therefore by following guidelines a reproducible fit is achieved.

For the modelling process shallow observation wells are only used to give qualitative insight, while the deep observation wells installed beneath the first confined aquifer are used as input for the model. Both steady state model runs and transient model runs are used and the pumping tests were modelled according to the steps in Figure 3.3.

Steady state runs	Transient runs
• 1. Furthest observation wells	• 2. Furthest observation wells • 3. All observation wells • 4. Storativity • 5. Surrounding model layers

Figure 3.3 Types of observations used with the steady state and transient runs.

During the steady state model run, only the furthest observation wells are used to be able to use the Dupuit assumption. The Dupuit assumption entails that groundwater flows horizontally. Flowlines from far observation wells are least influenced by the effects of a partially penetrating well. During transient runs, first only the furthest observation wells are used, although a virtual resistivity layer is present. This resistivity layer is added in the schematisation to correct for the partially penetrating well, but is not present in reality and is therefore mentioned as being ‘virtual.’ After this run all observation wells are used to see if the virtual resistivity layer has enough resistance to counteract the deviation of horizontal groundwater flow near the pumping well. In theory, the difference between run 2 and 3 should be minimal. After storativity is calibrated, the last run focusses on the model layers not including the observation well screens or pumping well screen. Storativity varies in confined aquifers from $5 \cdot 10^{-5}$ to $5 \cdot 10^{-3}$ (Kruseman & de Ridder, 1994)

Figure 3.4 highlights some important differences between steady state and transient modelling. Starting values for hydraulic conductivity and vertical resistivity values were taken from an article by Beemster (2014).

Steady state: General information	Transient: General information
• 1 measurement per observation well • Storativity = 0 • One-layer model • Leaky top aquitard	• Multiple measurements • Storativity = $1 \cdot 10^{-4}$ (standard value in MLU) • Multiple layer model • Non-leaky top aquitard

Figure 3.4 Differences between the steady state and transient models.

With MLU a choice can be made to model either with ‘log drawdown curve fitting’ or with ‘linear drawdown curve fitting.’ While log drawdown curve fitting assumes that small drawdown values also have small measurement errors, linear drawdown curve fitting expects that drawdown measurement errors are independent of their magnitude.

Results

A semi log time-drawdown graph with observed points and calibrated drawdown is available in MLU and gives a quick way to check the fit of the model. The available statistics are Residual sum of Squares (RSS), Condition number (CN), Correlation matrix, and the residuals.

RSS is always in m^2 and is a measure of the discrepancy between observed (y_i) and calibrated (f_i) values. The parameter *n* stands for the amount of observations. The RSS is used to find the best fit. Formula two for calculating RSS is as follows (Zaadnoordijk & Stein, 1997):

$$RSS = \sum_{i=1}^{n} (y_i - f_i)^2 \qquad (2)$$

The condition number is a measure of how difficult it is for the model to find the least accurate parameter, and a number above $1 \cdot 10^6$ indicates that at least one parameter cannot be determined properly (Hemker & Post, 2014).

A correlation matrix is used to check the dependency of individual parameters with respect to other parameters. Values at < -95 % and > 95 % indicate that these parameters should not be optimised together (Hill et al., 2002).

Also during optimisation local minima can occur, which may appear to give a good fit but in reality are at a distance from the actual best fit (Hemker, 1997). If the best fit result is still the same after varying the start-values of the optimised parameter(s) then the chances are higher that it is not a local minima, but the global minimum, *i.e.* the preferable solution.

All of the previously mentioned statistics are useful for producing a model with a good fit, but it is even more important to realise that a perfect fit, although achievable, does not correspond to a perfect and realistic model. Measurements almost always have measurement errors in both height and in time which are often in the order of 0.01 m for height. Also in reality the subsurface is almost never uniform and will therefore not react exactly like a set of parameters. To attain a clearer image of certain aspects such as *e.g.* surface water level variations the pumping test is also modelled in Triwaco.

3.5 Triwaco

Triwaco is a full 3D finite element model which is highly adaptable to local variations and includes water bodies such as rivers and ditches. Infiltration resistance and drainage resistance are parameters available in the model for both layer 1 and layer 2. Which can therefore be analysed during the calibration process (Royal Haskoning, 2015).

Multiple codes are available in Triwaco and for steady state calculations 'Flairs VD' was used. Transient calculations were done with 'Flairs.' For further information about the software Triwaco version 4.1, readers are referred to the manual (Royal Haskoning, 2015).

General model parameters
The values of the general model parameters which were used during all the runs can be found in Table 3.2.

Table 3.2 General model parameters used during steady state and transient modelling.

Parameter	Steady state	Transient	Information
Convergence	1e-06	1e-05	Indicates whether differences are small enough
Dtinitial	0.5	0.001	Initial time step size for time period to be considered
Dhmax	0.25		Maximum change in groundwater head per time step for the time period in consideration
Inner iterations*	1000		Used to determine the solution of the linear equations
Outer iterations*	100		Used for the nonlinear equations
Phreatic conditions	All layers fixed transmissivity		Used for variable transmissivities of the top aquifer
Density conditions	Constant density		Can be used for variable density calculations
Topsystem**	4		Three level drainage and infiltration system, defined by thirteen parameters

* The finite element equation used by the program can be nonlinear, which means that both nonlinear and linear iterations have to be used to solve the equations.

** Each level includes a drainage resistance, an infiltration resistance, which in this model are used to define the resistance from the ditches to the different aquifers.

Manual calibration

Calibration was done manually, with the help of Microsoft Excel. This entailed compiling a checkpoint file which holds the location (x,y coordinates) and the aquifer in which the observation wells where located. Also needed was a windows batch-file to read the necessary hydraulic head measurements from the output file. This windows batch-file makes use of a tool implemented in Triwaco called ‘Mikado’. Drawdown can then be calculated in Excel and compared visually with observed values. Residual Sum of Squares (RSS) was also calculated, to be able to find the best fit. The batchfile and calib.chi file are located in Appendix E.

Grid

The Amsterdam model present in the program Triwaco includes the complete Amstel, Gooi and Vecht area (AGV-area). As this is much larger than the area influenced by the pumping test, a smaller grid was made to decrease calculation times.

3.6 Pumping test Huntumdreef

3.6.1 General information

Location

The pumping test was carried out near the overpass Gaasperdammerweg and Huntumdreef (Figure 3.5). The observation wells were installed in a SW to NE direction alongside the Gaasperdammerweg and at distances between 5 and 830 m from the pumping well. The smallest map includes the furthest observation wells, while the main large map is zoomed into the site, excluding observation well 14 and 7. During the pumping test the groundwater was discharged into the nearby surface water (Jongerius, 2013).

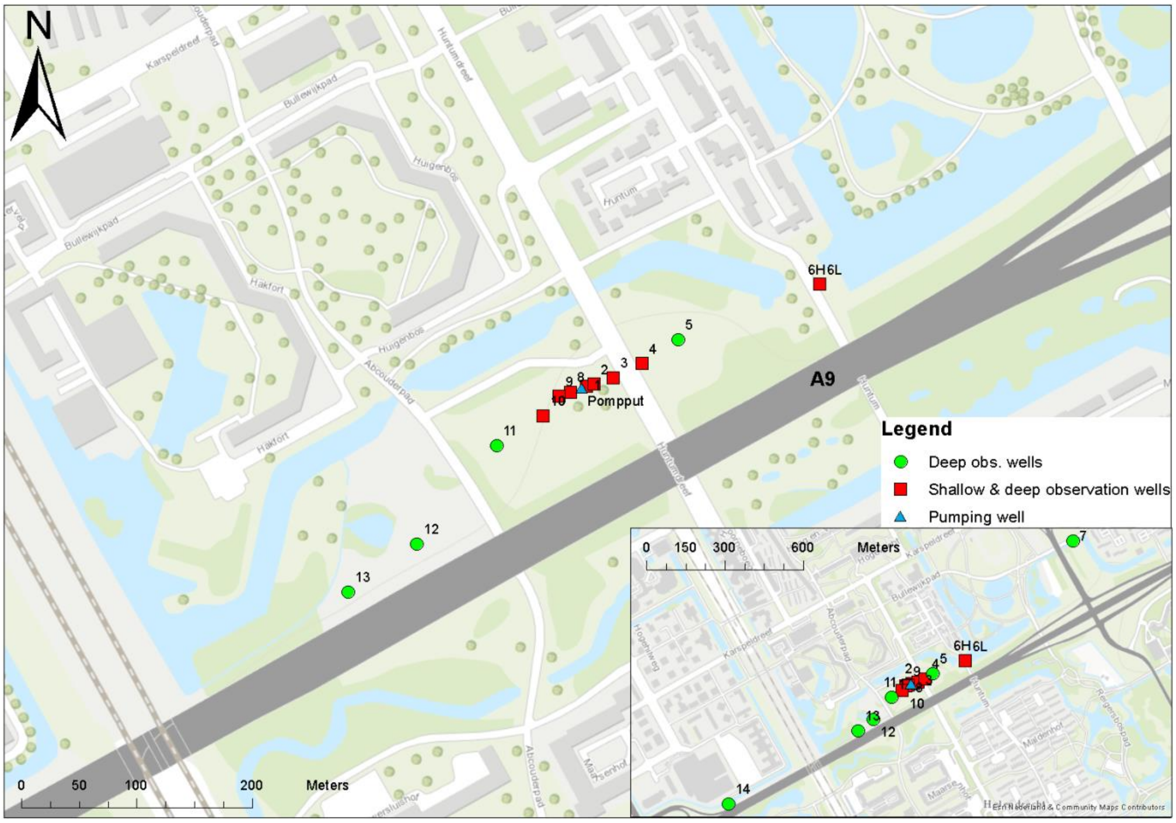

Figure 3.5 Location of the observation wells and pumping well at the Huntumdreef.

Test period

The pumping test was executed in December 2012 and lasted for seven days. Detailed information can be found in Table 3.3.

Table 3.3 Test period of the pumping and infiltration test Huntumdreef.

Activities	**Start**	**End**
Installation of observation wells	23-11-2012	3-12-2012
Groundwater level observations first period	3-12-2012	4-12-2012
Pumping test (water discharged into surface water)	4-12-2012 9:20	11-12-2012 13:30
Groundwater level observations second period	11-12-2012 13:30	17-12-2012 10:00
Infiltration test	17-12-2012 10:00	20-12-2012 10:30
Groundwater level recovery	20-12-2012 10:30	4-01-2013

Well data

All the observation well boreholes were drilled with a diameter of either 178 mm or 219 mm (Appendix G). The well screens have a diameter of 50 mm and a length of 1 m, but the shallow well screens have a screen length of 2 m. The pumping well borehole was drilled with a diameter of 500 mm and has a well screen 315 mm wide and 10 m long. The return wells have a well screen length of 15 m. The well screens where installed at two different depths, in the first aquitard layer and in the pumped aquifer. Detailed information about surface elevation and well screen depth can be found in Appendix B.

Screen depth

Figure 3.6 is a cross section along the observation wells. The geology of the upper layer until NAP -14 m is derived from the bore hole descriptions (Appendix G) or (when not available) it is an interpolation between the nearest available descriptions. The geology from NAP -15 m and deeper is from a cone penetration test (CPT) (Appendix J) or from Geotop (Dinoloket, 2015). The seven shallow groundwater well screens are all fitted with a well screen around NAP -4 to -6 m. Shallow observation wells 1a-3a are on top and partly in the peat layer, while wells 4a and 8a are partly below the peat layer (Dutch: Hollandveen) and at the location of wells 9a and 10a the peat layer is completely absent. The pumping well is installed on a thin clay layer which is present at NAP -27 m, while the return wells have the well screen until NAP -28 m.

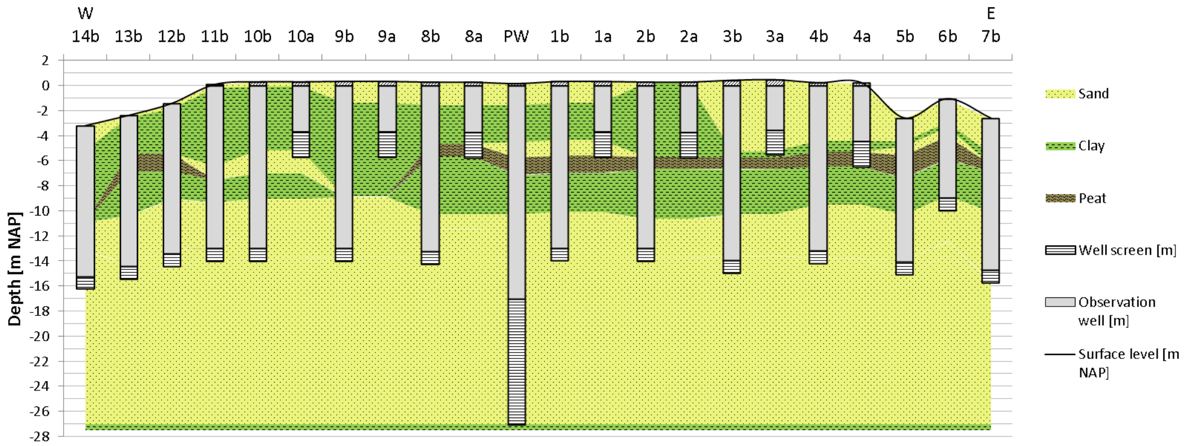

Figure 3.6 *West to East cross section of the depth of well screens, including lithology of the Huntumdreef pumping test. The horizontal axe is not to scale. Location of the well screens are shown in Figure 3.5.*

Extraction rate

The average extraction rate during the pumping test, inferred from readings taken every minute, was 70 m^3/h or 1680 m^3/d. The extraction rate was also determined on three occasions in three different ways: manual measurements and mechanical and electric gauge measurements. Only the drawdown test was modelled in MLU, and the recovery test was not modelled. Detailed information such as extraction rates can be found in Table 3.4.

Table 3.4 *Extraction rates during pumping test Huntumdreef*

	Extraction rate [m^3/h]			**Average**	
Date & Time	**Manual**	**Mechanical**	**Electric**	**[m^2/h]**	**[m^3/d]**
04-12-2012 10:11	71	79	73	74	1786
04-12-2012 13:10	70	77	70	73	1745
07-12-2012 9:00	70	77	70	72	1739

Infiltration test

The return test data was not used during the course of this research, but data can be found in the rapport by Fugro (Jongerius, 2013).

3.6.2 Data preparation

For this pumping test the corrected water levels by Fugro (Jongerius, 2013) were used**.** The original measurements from the pressure transducer were already corrected for atmospheric pressure and depth in the observation wells. However these files do still include erroneous measurements in the time-series. The following data preparations were made before the data was used for modelling:

1. Remove erroneous measurements from when the pressure transducer was apparently outside the observation well.
2. Calculate the amount of drawdown, because MLU uses drawdown and not water levels.
3. Extract 15 measurements per log cycle in time to avoid that the large amount of data near the end of the pumping test will dominate the results.

3.6.3 Flowchart

During the steady state calibration process only the furthest observation wells were used (4 to 7 and 10 to 14) in an one-layer model schematisation. Both parameters, hydraulic conductivity of the aquifer and vertical resistivity of the aquitard, where optimised simultaneously.

For the transient calibration process a four-layer model schematisation was used. Figure 3.7 is a flowchart with the different steps taken during the transient optimisation process. During step 5 observation well 5b was removed from the calibration process, because it proved to be erroneous. The reasoning behind calibrating the model again with aquifer layer two and three coupled was to check if a good fit could be achieved with them combined or if the two aquifers should be calibrated separately. The most important results can be seen in section 4.1.3, with the different run numbers correlating to the different steps in the flowchart.

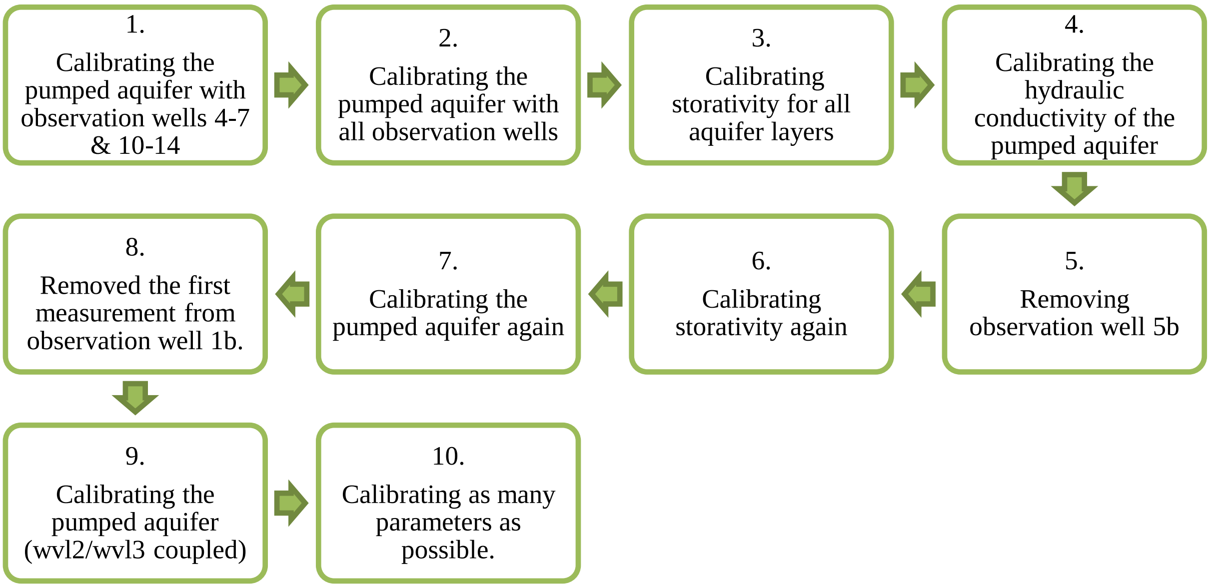

Figure 3.7 Flowchart for transient calibration with step numbers correlating to the different runs mentioned in the results.

3.7 Pumping test Nellesteinpad

3.7.1 General information

Location

The pumping test was carried out near the overpass Gaasperdammerweg and Nellesteinpad (Figure 3.8). Eight observation wells were used to measure hydraulic head and they where installed in a SW direction from the location of the pumping well. The observation wells are spaced at a distance of five to 1000 m from the pumping well. No phreatic observation wells where installed, nor observation wells deeper than the well screen of the pump. Ditches are in lightblue and the Gaasperdammerweg is darkgrey (with the junction Gaasperdammerweg and Gooiseweg). During the pumping test, the extracted water was discharged into the nearby surface water (Jongerius, 2013).

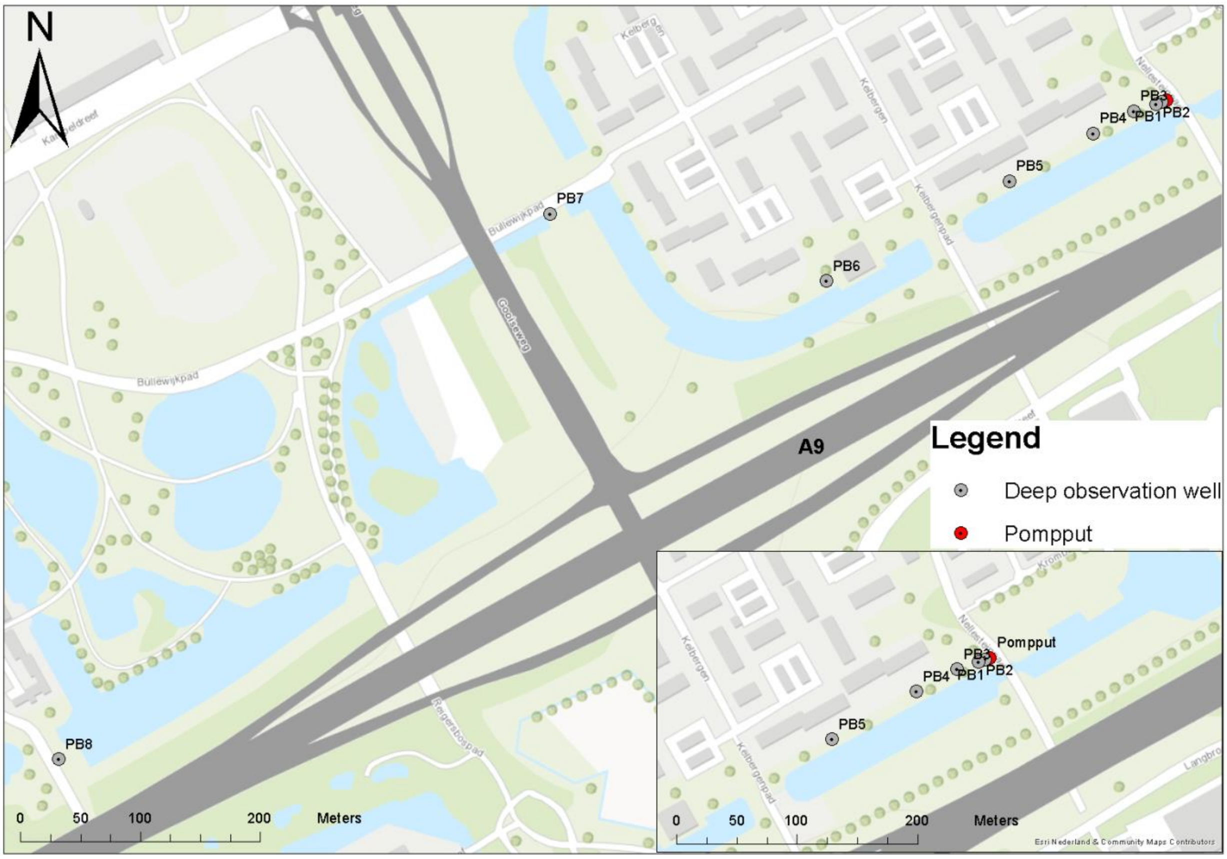

Figure 3.8 Location of the eight observation wells and the pumping well at location Nellesteinpad.

Test period

The pumping test was executed in march 2013 and lasted for seven consecutive days. Detailed information concerning time can be seen in Table 3.5.

Table 3.5 Time schedule for all the different activities pertaining the Nellesteinpad pumping test.

Activities	Start	End
Groundwater level observation	15-03-2013 16:00	18-03-2013 08.46
Pumping test	18-03-2013 08:46	25-03-2013 10:25
Groundwater level recovery observation	25-03-2013 10:25	28-03-2013 09:45

Well data

The well screen of the pump has a length of 10 m and is installed at a depth of NAP -16.6 to -26.6 m. All the observation well screens have a diameter of 50 mm and are 1 m long. The observation well boreholes have a diameter of 178 mm. On average the well screens where installed at a depth of NAP -15.5 to -16.5 m. No well screens where installed in an aquitard above or below the pumped aquifer nor in the aquifers below the pumping aquifer. Detailed information about surface elevation and well screen depth can be found in Appendix C.

Screen depth

Figure 3.9 is a graphic representation of the lithology near the pumping test Nellesteinpad. The sedimentological information is either from the corresponding bore hole description (observation wells 1 to 6) or it is an interpolation from the nearest available descriptions (Appendix H).

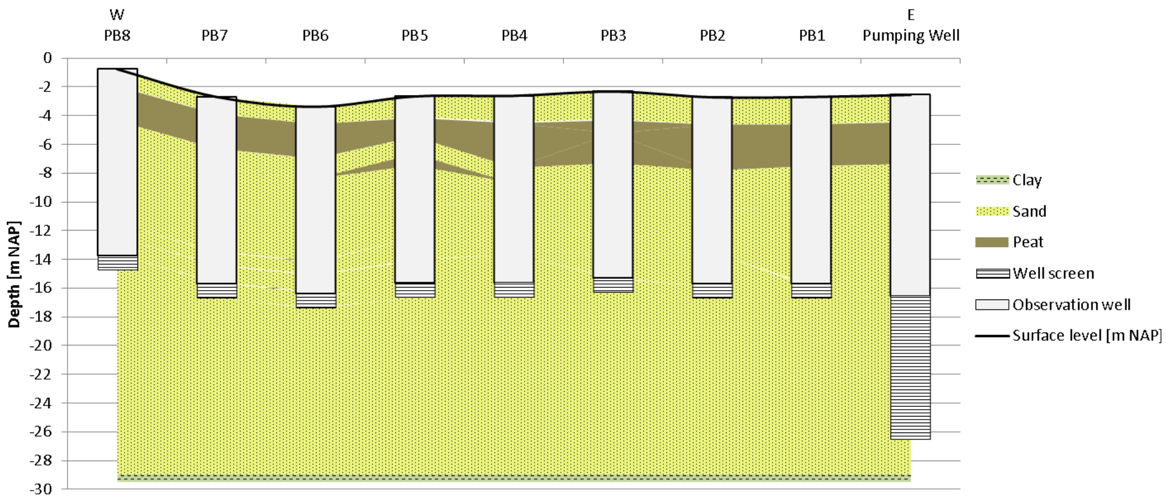

Figure 3.9 West to East cross section of the depth of well screens, including lithology of the Nellesteinpad pumping test. The horizontal axe is not to scale. Location of the well screens are shown in Figure 3.8.

Extraction rate

Table 3.6 shows the time series for the extraction rate of the pump. The average pumping rate was 1255 m^3/d. The extraction rate was measured at several times during the seven-day pumping test.

Table 3.6 Extraction rates during pumping test Nellesteinpad

Date and time	Extraction rate [m^3/h]	Extraction rate [m^3/d]
18-03-2013 8:56	66.0	1584
18-03-2013 9:21	50.4	1210
18-03-2013 9:52	52.3	1254
18-03-2013 10:48	51.4	1234
20-03-2013 9:56	51.4	1234
25-03-2013 10:25	51.4	1234

3.7.2 Data preparation

Original output files were obtained from Fugro and used for this pumping test. The following steps were observed before data was used for modelling.

1. Data files where transferred to a uniform format.
    a. Data points were set to the same unit (cm and ^{o}C).
    b. Time series where transferred to a uniform format.
    c. Comma separated numbers were altered to point separated numbers.
2. Time-series with faulty data points where removed. After a visual check of the data in graph form, it was determined that after the 28th of March 2013 the temperature points changed from water temperature to air temperature measurements. A step was also visible in the hydraulic head, all the pressure transducers returned to the same value as the barometric pressure transducer after the 28th of March.
3. Time series where corrected for atmospheric pressure, by subtracting atmospheric pressure from every corresponding data point. Atmospheric pressure was measured at the site with a barometer.
4. A regional trend correction was accomplished by subtracting the measured value of the furthest observation well 8 from the other observation wells.
5. Hydraulic head was changed to the correct height. This was accomplished by adding the manual measurements for each observation well to a graph of the hydraulic head and then fitting the line to the manual measurements. The correction made for the difference between manual and automatic measurements was then subtracted from the data-points to obtain the correct hydraulic head.
6. Remove erroneous measurements taken when the pressure transducer was apparently outside the observation well.
7. Calculate the amount of drawdown, because MLU uses drawdown and not water levels.
8. Extract 15 measurements per log cycle in time to avoid the large amount of data near the end of the pumping dominating the results.

3.7.3 Flowchart for MLU

During the steady state calibration process only the furthest observation wells were used (4 to 7) in an one-layer model schematisation. Both parameters, hydraulic conductivity of the aquifer and vertical resistivity of the aquitard, where optimised simultaneously.

Figure 3.10 is a flowchart with the different steps taken during the transient optimization process. The most important results can be seen in section 4.2.3, with the different run numbers correlating to the different steps in the flowchart

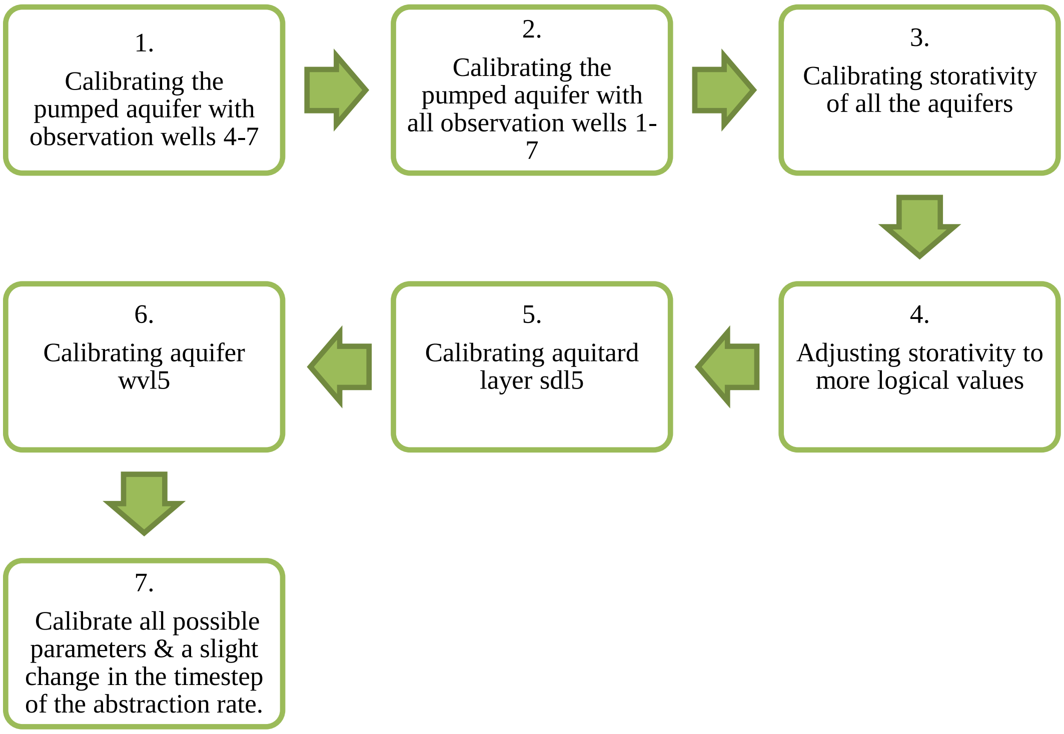

Figure 3.10 *Flow chart for Nellesteinpad calibration process, numbers correlate to run numbers in the results chapter.*

3.7.4 Flowchart for Triwaco

Information such as location of the pumping test, test period, well information, extraction rate and screen depth are all available in paragraph 3.7.1. The same measurement points as described in paragraph 3.7.2 are also used for calibration in Triwaco. During steady state calculations the same extraction rate was used as was used during the steady state calculation in MLU, this also holds for transient calculations. Figure 3.11 is a flowchart of the calibration process for the Nellesteinpad pumping test.

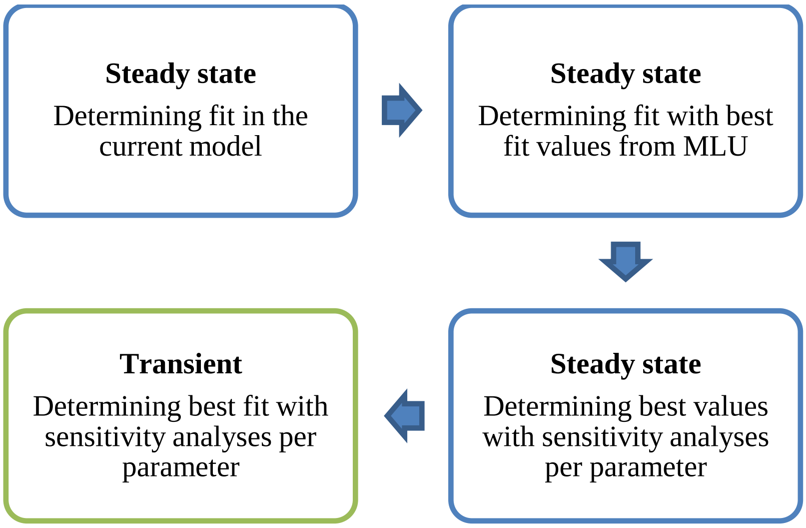

Figure 3.11 Method for calibration of the Nellesteinpad pumping test in the full 3D Triwaco model.

3.8 Pumping test Amstelveen

3.8.1 General information

Location

The pumping test in Amstelveen was executed near the Keizer Karelweg. All the observation wells, and the pumping well can been seen in Figure 3.12. The observation wells where installed in a northwest to southeast direction, alongside the Burgemeester van Sonweg. Spacing between observation wells and pumping well is to a distance of 915 m. The extracted water was discharged into nearby surface water (Witteveen+Bos, 2014)

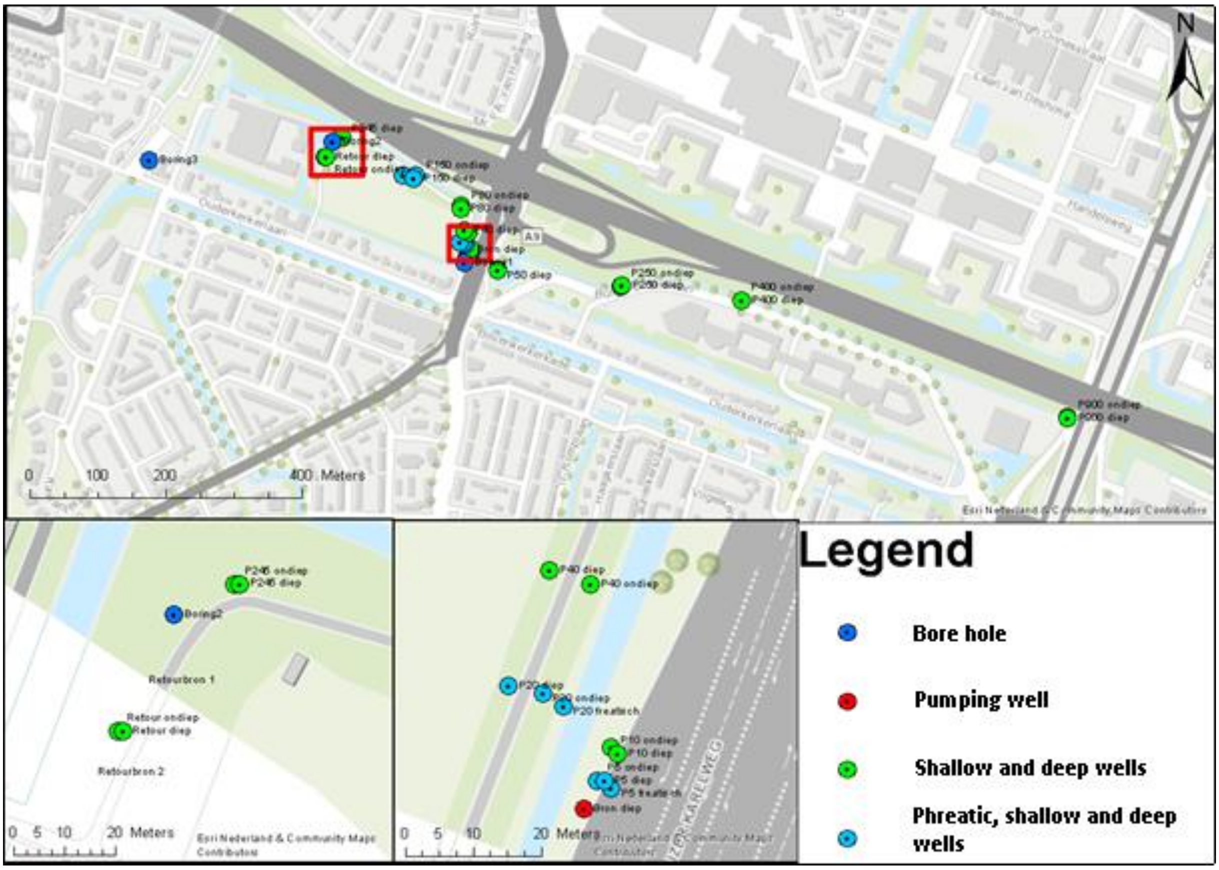

Figure 3.12 Location of observation wells, return wells, boreholes and pumping well.

Test period

The six day pumping test took place in September 2014 and was followed by a infiltration test. Only after the pumping test two phreatic wells were installed at the location of observation well P20 and P150. More detailed time information is available in Table 3.7.

Table 3.7 Time schedule for all the different activities pertaining the Amstelveen pumping test..

Activities	**Start**	**End**
Monitoring groundwater levels	29-08-2014	7-10-2014 15:00
Pumping test	02-09-2014 10:45	08-09-2014 16:40
Installation infiltration wells	08-09-2014	09-09-2014
Installation of phreatic observation wells	16-09-2014	
Test infiltration well	19-09-2014	to 26-09-2014
Return test with 50%	26-09-2014 9:00	
Regeneration of infiltration wells	29-09-2014	
Higher flow rate	30-09-2014	
End of infiltration test	03-10-2014 11:00	

Well data

The pumping well and two return wells were drilled with a diameter of 500 mm. The well screen has a length of 15 m and a diameter of 250 mm. The observation wells where placed with an unknown diameter and a well screen with a length of 1 m.

Generally, the deep observation wells where installed at a depth of NAP -15 to -16 m and the shallow observation wells where installed at a depth of NAP -9 to -10 m. All the deep observation wells where installed in the pumped aquifer beneath the top aquitard layer, while the shallow observation wells are generally installed in the top aquitard layer. Detailed information about surface elevation and well screen installation depth can be found in Appendix D.

Screen depth

Figure 3.13 shows a representation of the depth of the well screens at the Amstelveen pumping test. Three borehole descriptions at the location give a general indication of the lithology found at the Amstelveen pumping test (Appendix I). The horizontal axes is not to scale, though the observation wells are shown from west to east(left to right) in the graph.

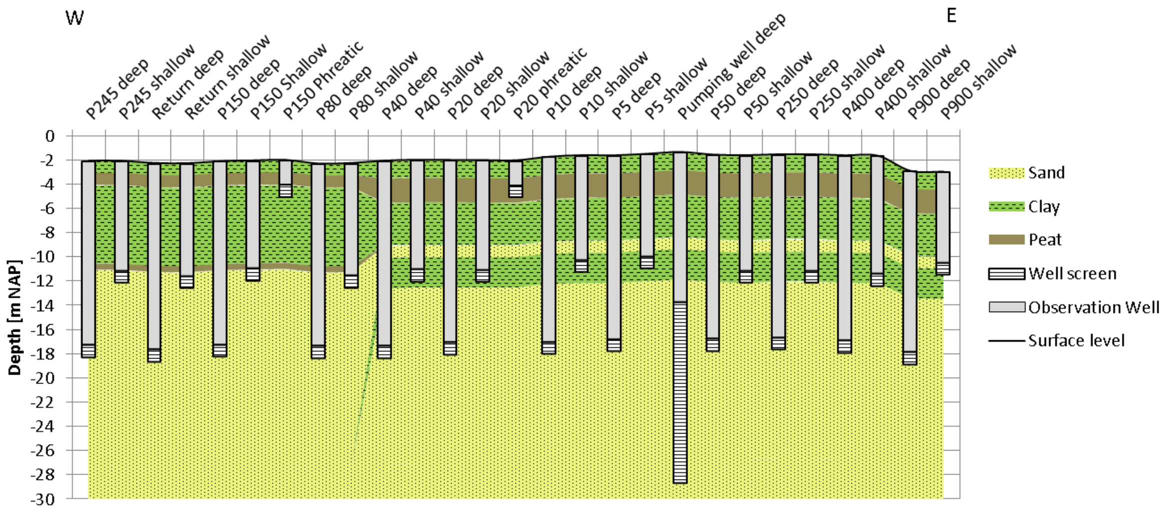

Figure 3.13 *West to East cross section of the depth of well screens, including lithology of the Amstelveen pumping test. The horizontal axe is not to scale. Location of the well screens are shown in Figure 3.12.*

Extraction rate

The extraction rate varies between 1177 m^3/d and 1213 m^3/d, the average extraction rate is 1195 m^3/d. The extraction rate was measured on several occasions during the pumping test and the exact rates can be found in Table 3.8.

Table 3.8 Extraction rates during pumping test Amstelveen

Date and time	Extraction rate [m^3/h]	Extraction rate [m^3/d]
02-09-2014 10:45	49.1	1177
02-09-2014 15:30	50.6	1213
03-09-2014 14:55	50.2	1205
08-09-2014 09:00	49.6	1190
08-09-2014 14:45	49.5	1188

Infiltration test

The infiltration test was not used during the course of this research, but data and results can be found in the rapport by Witteveen+Bos (2014).

3.8.2 Data preparation

For this pumping test the corrected water levels were used (Witteveen+Bos, 2014).
The following data preparations were made before data was used for modelling:

1. Remove erroneous measurements from when the pressure transducer was apparently outside the observation well.
2. Calculate the amount of drawdown, because MLU uses drawdown and not groundwater levels.
3. Extract 15 measurements per log cycle in time to avoid the large amount of data near the end of the pumping test dominating the results.

3.8.3 Flowchart

During the steady state calibration process only the furthest observation wells were used (80 m to 900 m) in an one-layer model schematisation. Both parameters, hydraulic conductivity of the aquifer and vertical resistivity of the aquitard, where optimised simultaneously.

Figure 3.14 is a flowchart of the transient optimisation process for the Amstelveen pumping test. Run numbers match the numbers found in the results section.

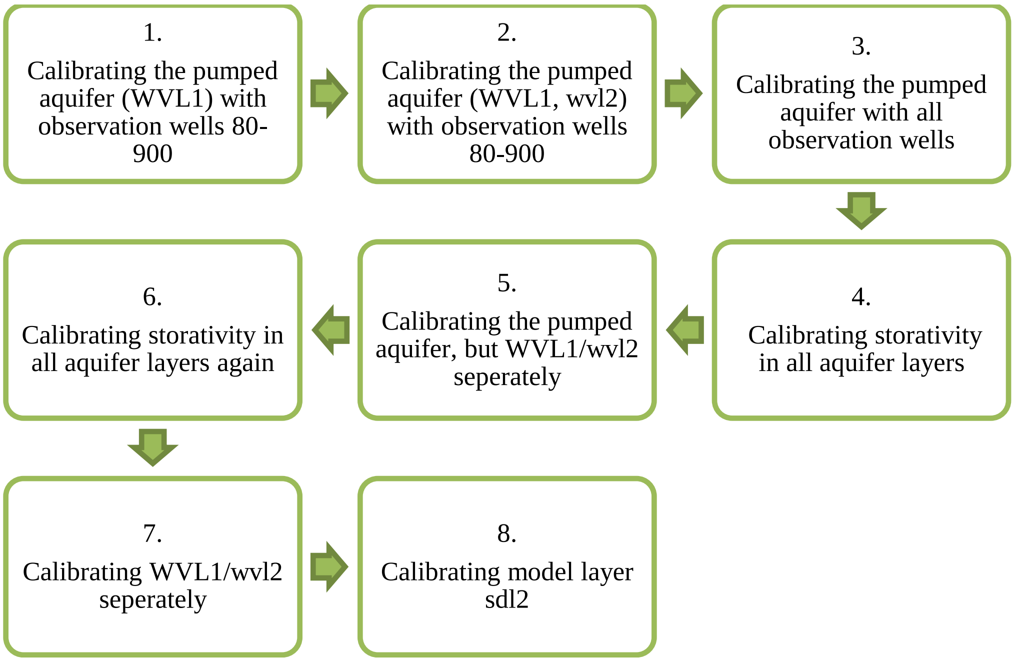

Figure 3.14 Flow chart for calibration of pumping test Amstelveen, with run numbers matching with results.

3.9 Predicting the effects of tunnel construction

3.9.1 General information

Construction of both the western and eastern tunnel parts will take place in consecutive phases. With each phase entailing a specific part of the tunnel as can be seen in the rapport by Kramer (2015). Phase 3 of the Eastern tunnel will be modelled as an example to estimate the extraction rate needed to give an indication of the sphere of influence. Phase 3 will be modelled in both Triwaco and in MLU.

Location and test period

Construction of the tunnel at the A9 Gaasperdammerweg will be completed in several phases. The first phase from November 2015 to May of 2016 includes the construction of the midsection of the tunnel for both the Western and Eastern tunnel parts. The eastern tunnel will be 900 m long when finished, and phase 3 is a 250 m section of this tunnel. In this phase from 8-12-2015 to 22-01-2016 (46 days) this section will be constructed in 50 m parts with a width of 10 m. Figure 3.15 shows the location of the two tunnel parts. This specific phase was chosen because of its proximity to the Nellesteinpad pumping test location.

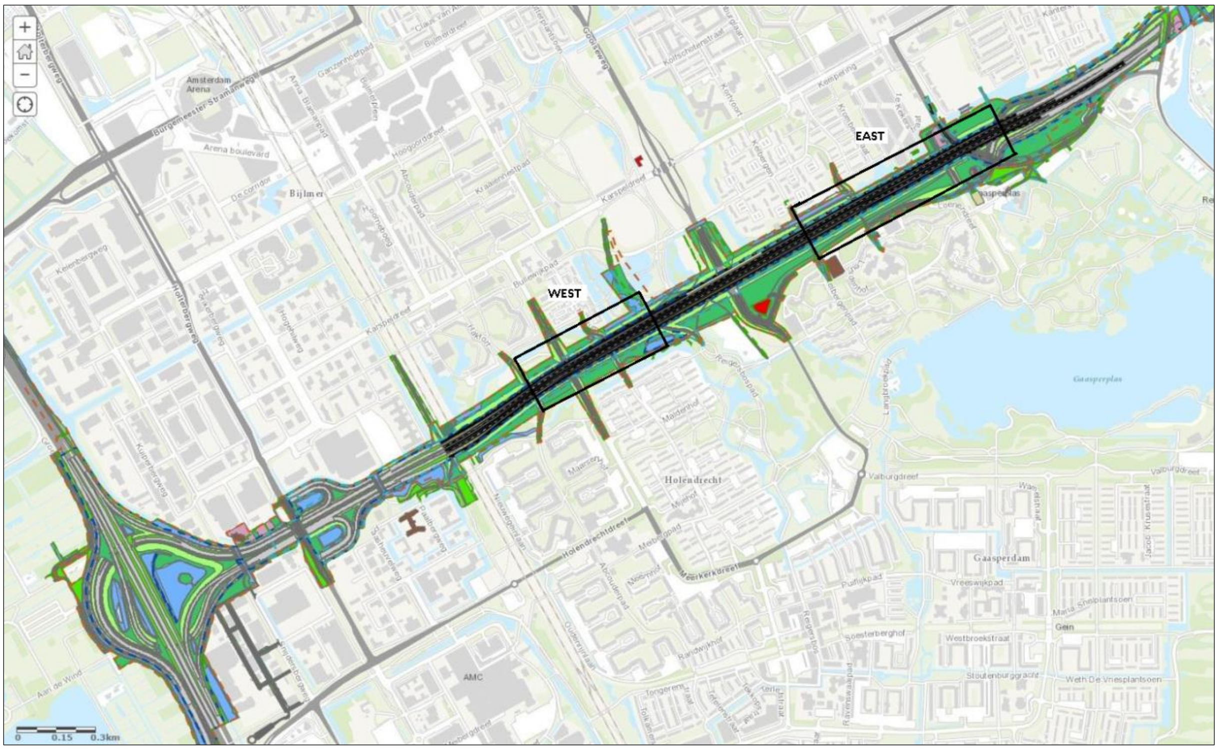

Figure 3.15 Location of both the western & eastern tunnel sections (Kramer, 2015).

Screen depth

Extraction wells are spaced 20 m from each other across the entire length of the construction site. Well screen depth is to NAP -20 m and are 10 m in length, a total of 12 wells are used in phase 3. 'Düsensauginfiltration' or DSI is a type of groundwater infiltration (Stichting O2DIT, 2014). DSI-injection will be used during construction but for calculation purposes regular injection fields are used. Injection wells are at the same depth as the extraction wells (to a maximum of NAP -30 m for DSI) and are spaced 12 m apart. Three injection fields (130, 200, and 200 m) are planned along the phase 3 site of the tunnel. A total of 60 % of the abstracted groundwater is planned to be returned. Location of the injection fields are available in the rapport by IXAS (Kramer, 2015).

Extraction rate

A drawdown of 1.60 m is needed for the work to be completed and this will be obtained with both extraction and injection wells. The planned amount of injection and extraction is available in Table 3.9. A total of 16 m^3/h is planned to be abstracted per extraction well and 5 m^3/h per well injected, which totals 60% of the abstracted groundwater.

Table 3.9 Planned extraction and injection rate for the entire length of the Eastern tunnel.

Eastern tunnel	Time [d]	Wells	Total [m^3/d]	Per well [m^3/d]	Per well [m^3/h]	Percentage [%]
Extraction	90	45	17300	384	16	
Injection	90	84	10250	122	5	60

3.9.2 Prediction in MLU

Location of observation, extraction and injection wells

Determination of the X,Y coordinates of all the observation, injection, and observation wells was done manually with the aid of a map. Begin and end points where determined and then interpolated in Excel, because the exact location was not yet known. Observation wells are placed at the North and South side of the building pit to check if the right amount of drawdown is attained.

Flowchart

Phase 3 is near the site of the Nellesteinpad pumping test and therefore the calibrated model of this pumping test is used. By adding the injection and extraction wells in MLU, the drawdown is calculated. First the planned extraction and injection rates are used and if needed rates are adjusted until the desired drawdown of 1.60 m is reached. Figure 3.16 shows the flowchart for the eastern tunnel analyses.

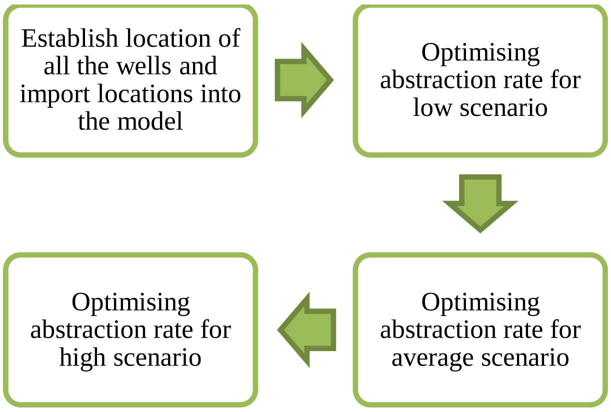

Figure 3.16 *Flowchart for calibration of part of the Eastern tunnel.*

3.9.3 Prediction in Triwaco

Due to time constraints only the planned extraction rate will be tested in the calibrated model of Triwaco, with only one extraction well present. This extraction well is at the same location of the Nellesteinpad pumping well. This test can therefore only be used as indication of the location and shape of the sphere of influence.

Due to the nature of this test with only one available extraction well and no infiltration wells, the extraction rate is re-calculated. This is achieved by using 40 % of the total abstracted groundwater per day as the extraction rate.

4 Results

4.1 Pumping test Huntumdreef

4.1.1 Observations

Precipitation and Makkink potential evapotranspiration

Figure 4.1 shows daily values for the Makkink reference evapotranspiration and precipitation during the first part of December 2012 from meteorological station Schiphol. During the pumping test from 4-11 December there were some small rainstorms of maximal 6 mm (KNMI, 2015).

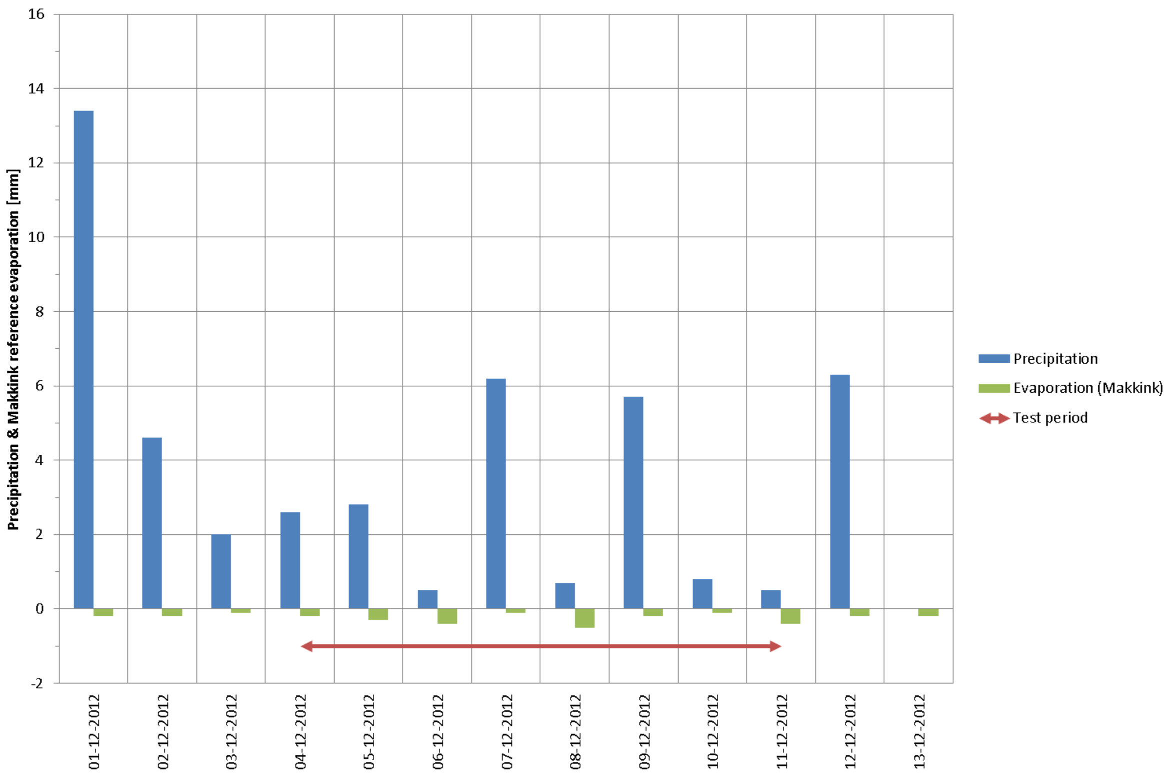

Figure 4.1 Precipitation and Makkink reference evaporation for the first part of December 2012.

Hydraulic head

The hydraulic head was measured from the 3rd of December 2012 until the 4th of January 2013 (Figure 4.2). Time series from the 14 well screens show the hydraulic head in the first aquifer before, during and after extraction. Before extractions the hydraulic head is around NAP -3.50 m. The largest drawdown can be seen in the observation well nearest the pumping well, which is well 1b with a drawdown of at least four m. The furthest observation wells are well 7 and 14 and show little to no drawdown during the extraction period. Drawdown lessens after one day, but does not become stable. Fluctuations in the extraction rate cause some of the variations visible. In Appendix B a graph can be found with only the deep well screens at a distance of 55 m.

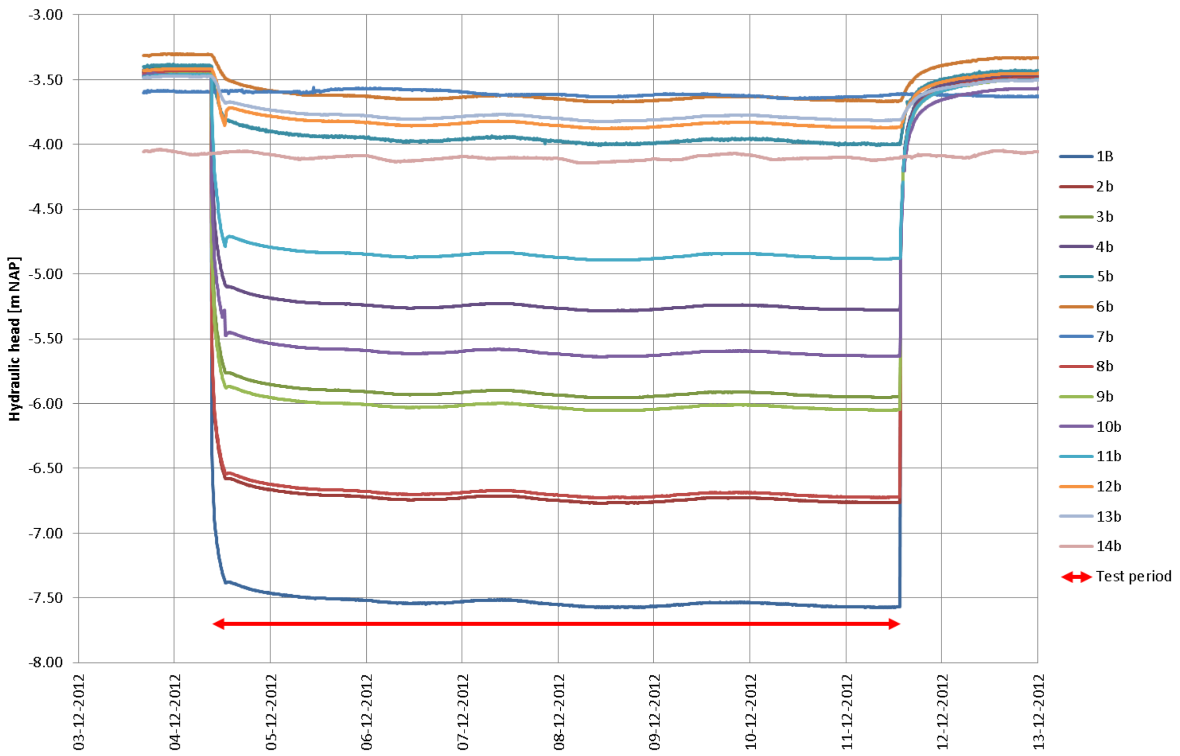

Figure 4.2 *Hydraulic head time series of all the deep well screens for the pumping test Huntumdreef.*

Groundwater levels

Groundwater levels were also measured in shallow top aquitard well screens (Figure 4.3). None of the time series of the shallow observation wells show a clear reaction to the pumping test. Heads in observation wells 8a, 9a and 10a (east of the pumping well) react strongly to precipitation, while the heads in three observation wells west of the pumping well (2a, 3a, 4a) have a limited reaction to precipitation and show a steady rise. Only the relatively larger rainstorms, such as the rainstorm of 6,5 mm from the 23rd of December 2012 gives a small reaction in these three observation wells (Appendix B).

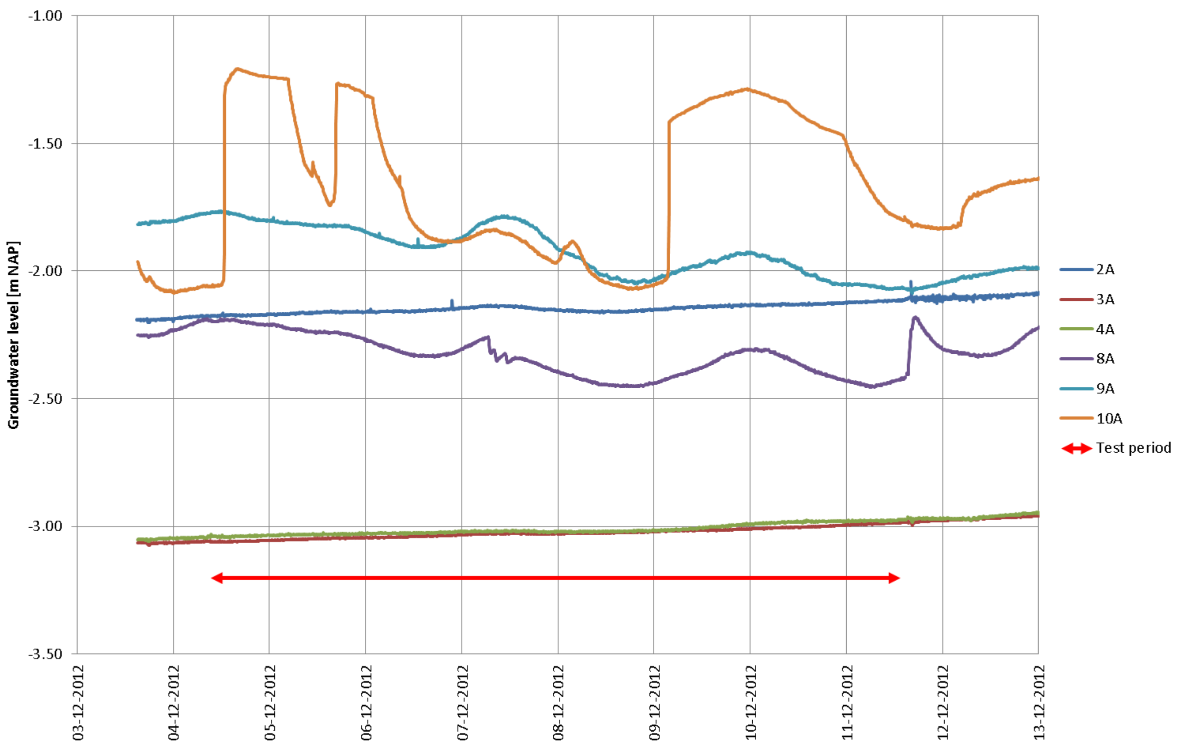

Figure 4.3 Groundwater level time series of the shallow well screens during the pumping test Huntumdreef.

4.1.2 Surface water levels and hydraulic heave

Surface water levels

Surface water levels are measured at several locations in the Bijlmer polder and as can be seen in Figure 2.4 the surface water level near the pumping test Huntumdreef should be around NAP -4.20 m. Three time series from the ditches near the pumping test Huntumdreef are available and the most complete time series is from the location 'Zandpad' where the water is pumped from the polder (Figure 4.4). The ditches in the polder are connected to each other and each day a pump is turned on at the 'Zandpad' location to lower the water level, which gives a sharp daily rhythm.

If similarities in surface water time series and hydraulic head time series are apparent, a contact between surface water and aquifer is obvious. The time series from the surface water have an interval of one hour, while hydraulic head measurements have an interval of 5 minutes. After comparison it becomes apparent that the hydraulic head in the first aquifer is indeed similar to the surface water time series although time lag, location and amplitude differences are present (Appendix B) A time lag is partially explained by the location of the measurement point downstream of the pumping test site. Amplitude differences suggest some infiltration resistance remains between aquifer and surface water. Furthermore, the influence is most clear in the observation wells which are least influenced by the pumping well (Appendix B).

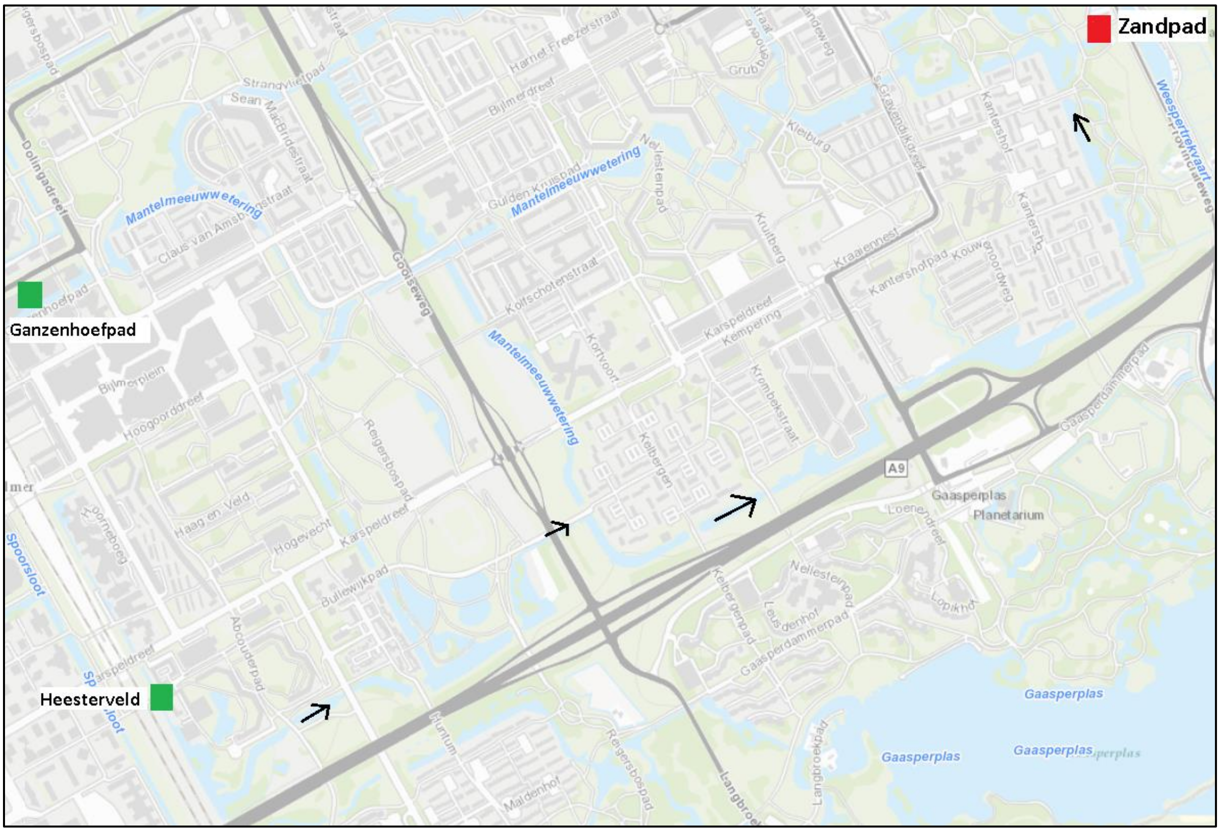

Figure 4.4 *Direction of surface water flow with location of pumping station 'Zandpad,' and two weirs 'Heesterveld' and 'Ganzenhoefpad.'*

Hydraulic heave

The bottom of the ditches near the pumping test are at NAP -5.00 m, meaning another four meters of aquitard is still present to separate the aquifer from the surface water. A safety factor of 1.1 is calculated with a hydraulic head of NAP -3.40 m indicating that hydraulic heave is not present at this location, but could be present in the vicinity of this area. In Appendix B the calculations of the Huntumdreef pumping test are present.

4.1.3 Semi logarithmic graphs

Time-drawdown

A semi log plot of the time-drawdown relationship for unconsolidated aquifers can diagnose if the aquifer is confined, unconfined or leaky. Figure 4.5 shows a semi log plot of the time-drawdown relation of the deep observation well 1. At first a relatively straight line is visible until 0.1 days, then drawdown seems to be reach a ceiling (but not completely flat). At 0.1 days a slight reduction of extraction is visible in the semi log plot. This relationship can be best compared to a leaky aquifer, when compared with Figure 3.1.

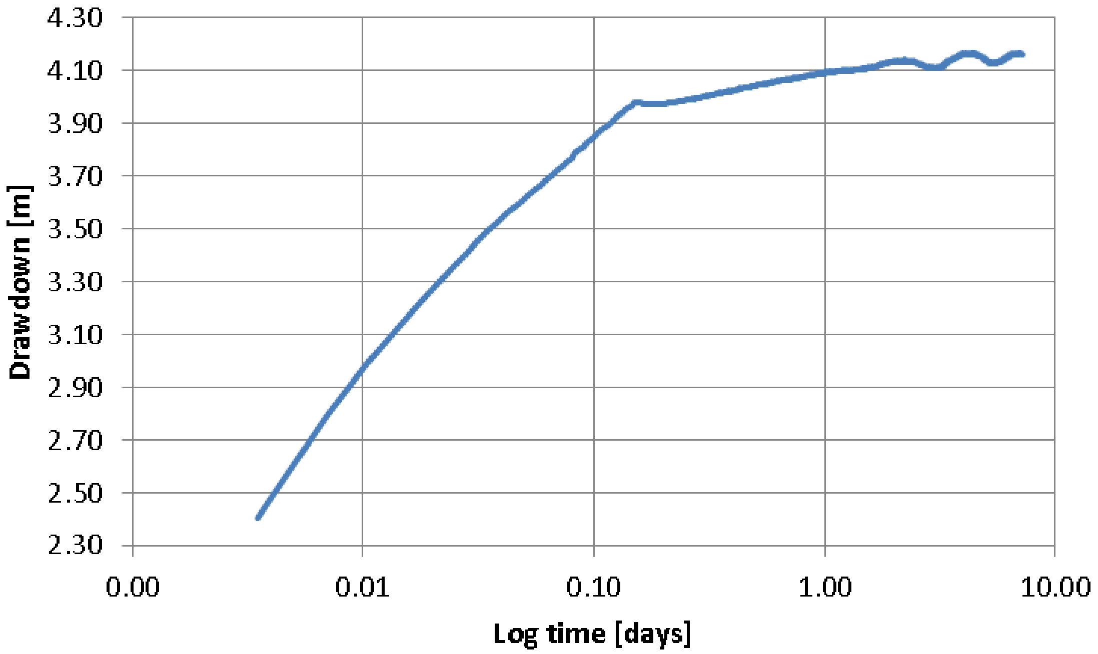

Figure 4.5 *A semi log plot of the time-drawdown relationship for observation well 1 from the Huntumdreef pumping test. Observation well 1 is at a distance of 5 m from the pumping well.*

Distance-drawdown

Figure 4.6 is a semi log graph of the distance-drawdown relationship, numbers are available in Appendix B. Each point represent the amount of drawdown at the end of the pumping test (11-12-2012 13:30) in each of the deep well screens. The measurement points plot on a relatively straight line, that when extrapolated seems to reach the zero-drawdown point at a distance of 400 m. This suggest the sphere of influence of the pumping well has a radius of around 400 m.

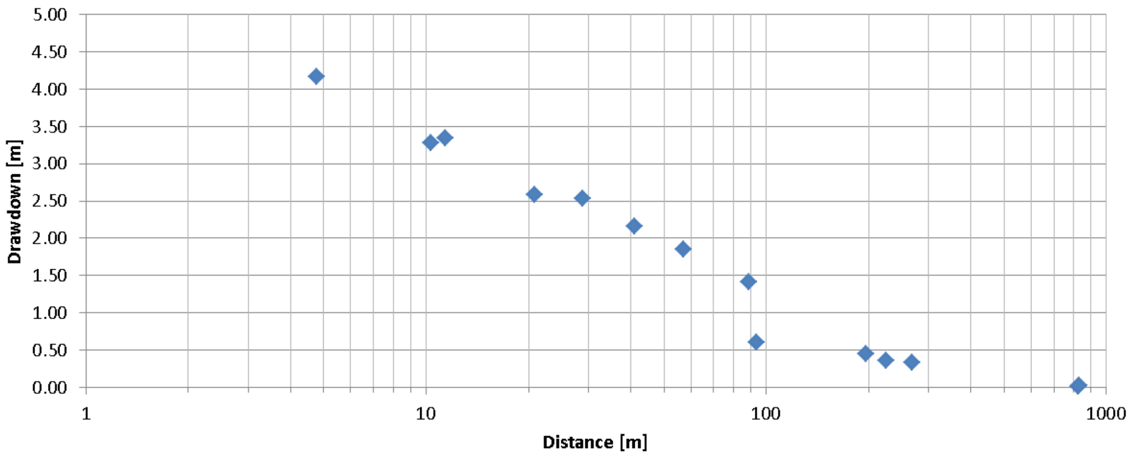

Figure 4.6 *A semi log distance-drawdown graph of drawdown near the end of the pumping test Huntumdreef.*

4.1.4 Steady state optimisation in MLU

One layer model

A one layer-model with a top leaky aquitard (7 m thick) and lower aquifer (18 m thick) is used to create a steady state model of the Huntumdreef pumping test. The bottom boundary of the model is impervious. The aquifer is 18 m thick because of the clay layer found beneath the pumping well (Figure 3.6). One measurement per observation well is used in the calibration process from observation wells 4 to 7 and 10 to 14. Values correspond to the measurement shown in Figure 4.6 near the end of the pumping test (Appendix B).

Calibration results

When both wvl1 and sdl1 are calibrated wvl1 has a transmissivity of 177 m^2/day and sdl1 has a vertical resistivity of 121 days (Table 4.1). The difference between calibrated and observed values varies from 0.50 m for observation well 5 and 0.02 m for observation well 10. The RSS for this run is 0.35 m.

Table 4.2 shows the model composition and result for log drawdown curve fitting, with a transmissivity of 312 m^2/day and a vertical resistivity of 213 days. The RSS for this run is 0.12 m, therefore the log drawdown curve fitting method is better in this instance. The full calibration result of both runs is presented in Appendix B.

Table 4.1 Model composition for linear drawdown curve fitting, RSS = 0.35 m. Percentages indicate standard deviation.

Name	Base [m]	Thickness [m]	Kh [m/d]	Kv [m/d]	T [m^2/d]	C [d]
sdl1*	-10.5	7		0.06		121 (34%)
wvl1*	-28.5	18	10		177 (24%)	

* sdl = aquitard layer and wvl = aquifer layer

Table 4.2 Model composition for log drawdown curve fitting, RSS = 0.12 m. Percentages indicate standard deviation.

Name	Base [m]	Thickness [m]	Kh [m/d]	Kv [m/d]	T [m^2/d]	C [d]
sdl1	-10.5	7		0.03		213 (11%)
wvl1	-28.5	18	17		312 (17%)	

4.1.5 Transient optimisation in MLU

Four layer model

A four layer model with observation well screens situated in the second aquifer (wvl2) and the pump well screen in layer the third aquifer (wvl3). The top and bottom boundary of the model is impervious. Table 4.3 includes the structure of the model, contents of each layer and starting values (Beemster, 2014) for both hydraulic conductivity and vertical resistivity. The standard value for storativity in a aquitard layer is zero and for a confined aquifer is $1 \cdot 10^{-4}$ (Hemker & Post, 2014). A phreatic aquifer has a storativity of 0.15 (Bear, 1972). All layers are optimised in at least one step of the optimisation process except for wvl1.

Table 4.3 Model schematisation for the transient optimisation of the Huntumdreef pumping test.

Model layer	**Base [m]**	**Thickness [m]**	**Content**	**K* [m/d]**	**c* [days]**
wvl1	-5.5	2**	Phreatic top	5	
sdl2	-9.5	4	Resistivity layer		1000
wvl2	-17.5	8	Aquifer with observation wells	2	
sdl3	-17.5	0	Virtual resistivity layer****		2.1****
wvl3	-27.5	10	Aquifer with pump well screen	37.5	
sdl4	-28	0.5	Clay layer***		50
wvl4	-188.5	160.5	Rest of the profile Until Maassluis Formation	37.5	

* (Beemster, 2014)
** Thickness of the soil column
*** See appendix L for the cone penetration test in which this clay layer is found.
**** This layer is added to separate the pumping well from the rest of the aquifer to account for the partially penetrating well. Value of sdl3 is calculated with Formula 3:

$$c3 = \frac{1}{2}\frac{D_{T2}}{K_{T2}} + \frac{1}{2}\frac{D_{T3}}{K_{T3}} \tag{3}$$

Optimisation process

Table 4.4 summarizes the steps of the calibration process of the Huntumdreef pumping test. The full calibration results can be found in Appendix B. The storativity is mentioned separately per aquifer layer *e.g.* S1 is the storativity for aquifer layer wvl1. The run numbers are the same as can be found in the flowchart in Figure 3.7. Run 1 only uses observation wells 4 to 7 and 10 to 14, while run 2 to 4 uses measurements from observation wells 1 to 14. From run 5, only measurements from observation well 1 to 4 and 6 to 14 are used.

The best results are given by run eight and ten with an RSS of 9.2, the main improvement from run six to eight is made by a higher vertical resistivity for clay layer sdl4. While in run 10, the vertical resistivity of the first aquitard is reduced. The visual fit with a RSS of 9.2 is shown in Figure 4.7.

Table 4.4 Optimisation steps for the Huntumdreef pumping test.

<table>
<tr><th>Run</th><th>1</th><th>2</th><th>3*</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10**</th></tr>
<tr><td>RSS
[m²]</td><td>120</td><td>137</td><td>80</td><td>39</td><td>31</td><td>19</td><td>9.7</td><td>9.2</td><td>23</td><td>9.2</td></tr>
<tr><td>Model
layer</td><td colspan="10"></td></tr>
<tr><td>wvl1
[m/d]</td><td colspan="10">5</td></tr>
<tr><td>S1
[-]</td><td colspan="2">$1 \cdot 10^{-4}$</td><td>7.9
(100 %)</td><td colspan="7">0.15</td></tr>
<tr><td>sdl2
[day]</td><td colspan="9">1000</td><td>733
(7 %)</td></tr>
<tr><td>wvl2
[m/d]</td><td>1.9
(11 %) #</td><td>7.5
(7 %) #</td><td>7.5</td><td>1.2
(16 %)</td><td>1.0
(15 %)</td><td>1.0</td><td>0.3
(16 %)</td><td>0.3
(18 %)</td><td>11
(1 %) a</td><td>2.1
(23 %)</td></tr>
<tr><td>S2
[-]</td><td colspan="2">$1 \cdot 10^{-4}$</td><td>$9 \cdot 10^{-4}$
(13 %)</td><td>$9 \cdot 10^{-4}$</td><td>$9 \cdot 10^{-4}$</td><td>$5 \cdot 10^{-4}$
(2 %) #</td><td>$4 \cdot 10^{-4}$
(3 %) #</td><td>$4 \cdot 10^{-4}$ (3 %)
#</td><td>$5 \cdot 10^{-4}$
(3 %) #</td><td>$4 \cdot 10^{-4}$
(2 %)</td></tr>
<tr><td>sdl3
[day]</td><td colspan="9">2.1</td><td>4</td></tr>
<tr><td>wvl3
[m/d]</td><td>1.9
(11 %) #</td><td>7.5
(7 %) #</td><td>7.5</td><td>21
(2 %)</td><td>22
(2 %)</td><td>22</td><td>27
(1%)</td><td>27
(1%)</td><td>11
(1%) a</td><td>25
(2 %)</td></tr>
<tr><td>S3
[-]</td><td colspan="2">$1 \cdot 10^{-4}$</td><td>$2 \cdot 10^{-8}$</td><td>$9 \cdot 10^{-4}$</td><td>$9 \cdot 10^{-4}$</td><td>$5 \cdot 10^{-4}$
(2 %) #</td><td>$4 \cdot 10^{-4}$
(3 %) #</td><td>$4 \cdot 10^{-4}$
(3 %) #</td><td>$5 \cdot 10^{-4}$
(3 %) #</td><td>$4 \cdot 10^{-4}$
(2 %)</td></tr>
<tr><td>sdl4
[day]</td><td>46
(7 %)</td><td>39
(8 %)</td><td>39</td><td>120
(6 %)</td><td>156
(6 %)</td><td>156</td><td>269
(4 %)</td><td>273
(4 %)</td><td>122
(4 %)</td><td>239 (2 %)</td></tr>
<tr><td>wvl4
[m/d]</td><td colspan="9">37.5***</td><td>48 ***
(12 %)</td></tr>
<tr><td>S4
[-]</td><td colspan="2">$1 \cdot 10^{-4}$</td><td>$6 \cdot 10^{-9}$</td><td>$9 \cdot 10^{-4}$</td><td>$9 \cdot 10^{-4}$</td><td>$5 \cdot 10^{-4}$
(2 %) #</td><td>$4 \cdot 10^{-4}$
(3 %) #</td><td>$4 \cdot 10^{-4}$
(3 %) #</td><td>$5 \cdot 10^{-4}$
(3 %) #</td><td>$4 \cdot 10^{-4}$
(2 %)</td></tr>
</table>

* S1: 0.15 and S2, S3, and S4: 9E-04 for further runs

** Furthermore, the standard deviation of all the parameters was determined in four separate runs. 1. (wvl2, wvl3, and sdl2), 2. (sdl4), 3. (wvl4) and 4. (S2, S3, and S4: all three storativity parameters coupled during calibration). The model was not stable enough to optimise all the parameters together.

*** In run 10, the thickness of aquifer wvl4 is reduced to 42 m and transmissivity is 2002 m^2/day, while transmissivity for wvl4 in run 1 to 9 was 6019 m^2/day.

(..%) Parameters calibrated during a run can be identified by their added standard deviation.

\# Parameters are coupled during a run with a parameter with the same symbol.

a Parameters are coupled during a run with a parameter with the same symbol.

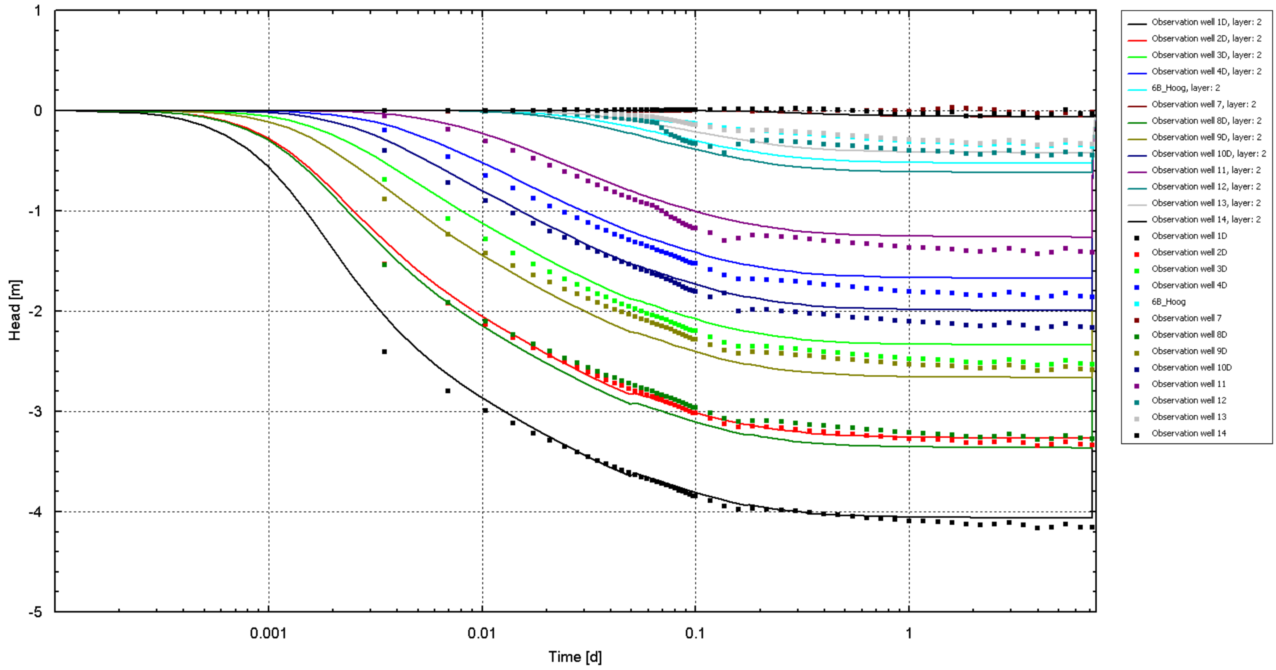

Figure 4.7 *Model (lines) and measurements (points) of run 8 with an RSS of 9.2 for the Huntumdreef pumping test.*

Residual analyses

The residual is the difference between calibrated and observed per measurement point. Figure 4.8 shows the average, minimum and maximum residual for each observation well. A total of 741 measurement points were used for 13 observation wells. The average of the residual for all the observation wells in this run is 0.012 m, a positive bias that indicates a general overestimation. The standard deviation indicates that on average the fit deviates with 0.11 m. Near the pumping well drawdown is generally underestimated (except well 9 and 8), while further away from the well drawdown is overestimated (Figure 4.7).

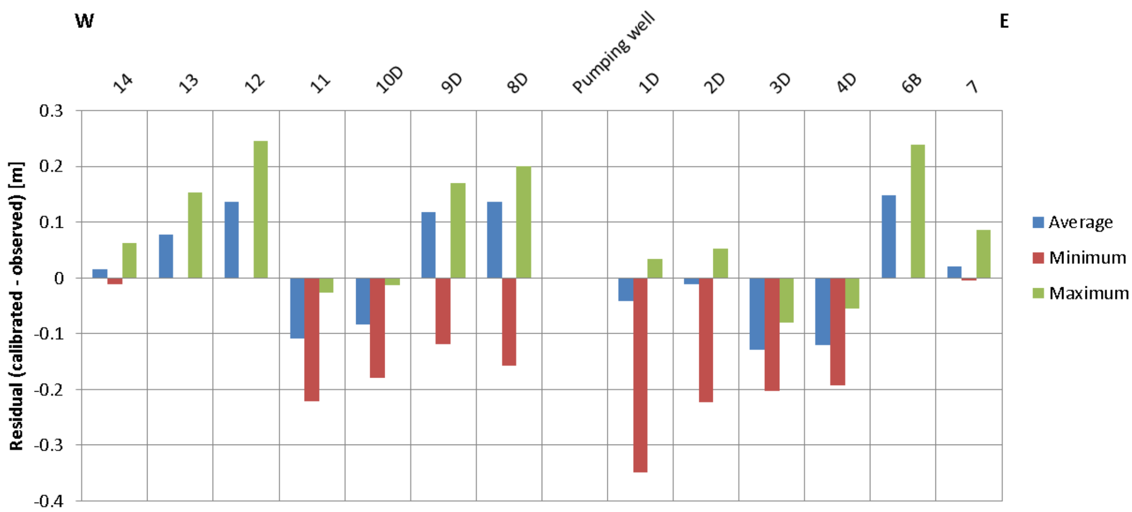

Figure 4.8 *Run 8 residual analyses for the Huntumdreef pumping test, with average, minimum and maximum residuals per observation well.*

Best fit

The best fits for the Huntumdreef pumping test are run 8 and 10, which both have an RSS of 9.2. The best fit for the Huntumdreef pumping test is shown in Table 4.5. The full optimisation result is available in Appendix B, which includes correlation matrices for the different runs.

Run 8 and 10 have the same RSS, and therefore they are statistically equally good. However, there is a difference in the optimised value for the first aquitard (sdl2) and the second aquifer (wvl2). For the vertical resistivity of sdl2 the optimised values differs by 36 %, in which the value of a 1000 days is an estimated value. The value was given to this layer because the shallow well screens did not or only very slightly react on the drawdown in the pumped aquifer. The second optimised value of 733 days is lower and indicates that some water is entering the model from above. This value of 733 days is indicative of the infiltration resistance near the ditches in the area surrounding the pumping test. A hydraulic heave calculation near the pumping test indicates that hydraulic heave could be present.

Furthermore, the difference between the hydraulic conductivity of the second aquifer is 700 %. A value of 0.3 m/day indicates the presence of clay, because fine sand has a range of 1 to 5 m/day (Kruseman & de Ridder, 1994). Therefore a value of 2.1 m/day is the better option. The correlation matrix of run 10 indicates that wvl2 and sdl2 have a correlation coefficient of -32 %, indicating they are only slightly negatively correlated. The best option is run 10, but this is probably only true for the area surrounding the ditches were water can infiltrate from the surface water to the pumped aquifer.

Table 4.5 Final optimisation results for the Huntumdreef pumping test.

Model layer	Formation	Thickness [m]	K (*) [m/d]	c (*) [day]
wvl1	Holocene	2	5	
sdl2	Holocene	4		733 (7)
wvl2	Boxtel	8	2.1 (23)	
sdl3	vrl**	0		4
wvl3	Boxtel and glacially reworked	10	25 (2)	
sdl4	Glacially reworked	0.5		239 (2)
wvl4	Sterksel, Peize, Waalre, and Maassluis	160.5	48 (12)	

* Standard deviation in percentages.
** Virtual resistivity layer

4.2 Pumping test Nellesteinpad

4.2.1 Observations

Precipitation and potential evaporation (Makkink)

Figure 4.9 shows the precipitation and Makkink potential evapotranspiration during March 2013. Very little rain fell during the pumping test itself, though there was a large rainstorm of 22.5 mm before the test started on the 9th of March.

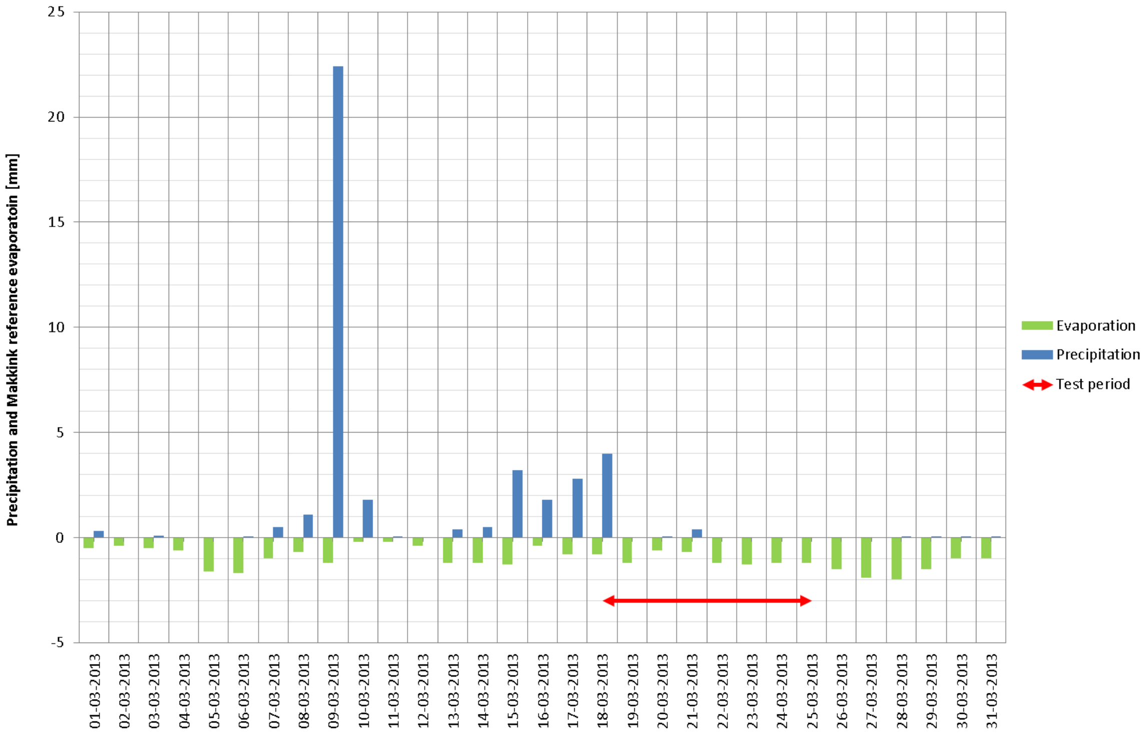

Figure 4.9 Precipitation and Makkink potential evaporation in March 2013during the Nellesteinpad pumping test (KNMI, 2015).

Hydraulic head

Figure 4.10 shows the hydraulic head time series from the observation wells. Observation wells 1 to 5 shows a clear drawdown. And observation well 1 has a maximum drawdown of 1 m, while observation wells 6 to 8 shows very little to almost no drawdown at all. Drawdown becomes stationary after one day, and stays stable throughout the pumping test.

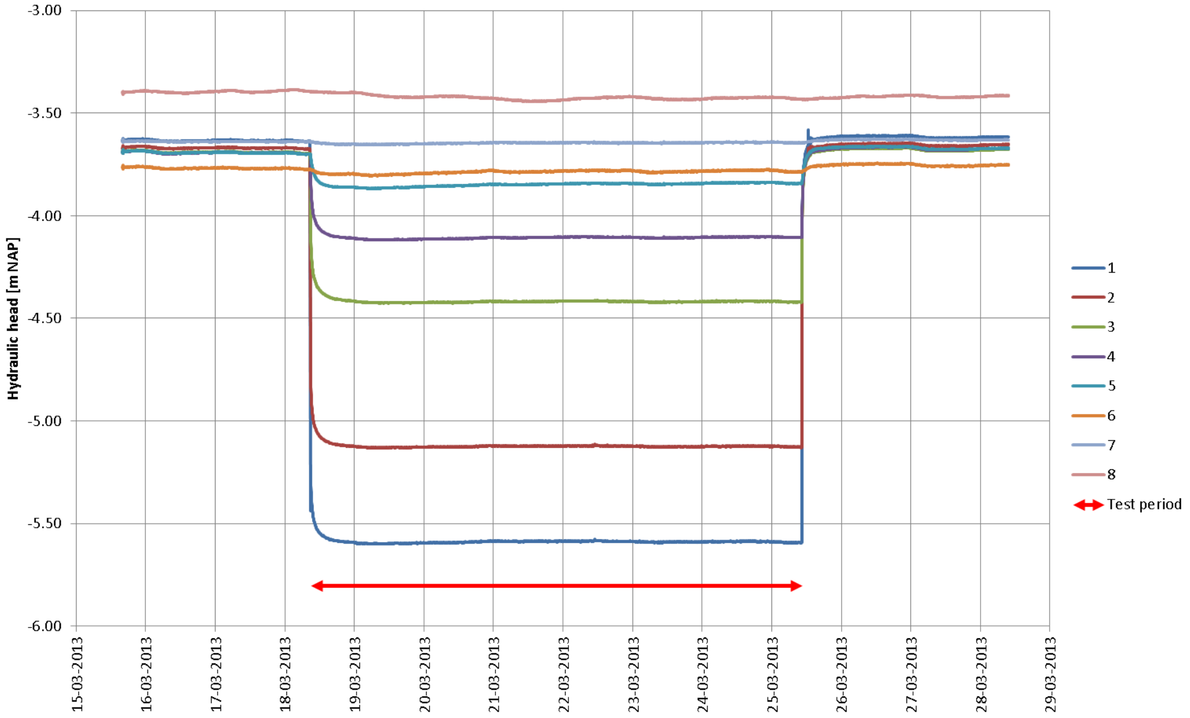

Figure 4.10 *Hydraulic head time series of all the well screens for the pumping test Nellesteinpad. Drawdown is corrected for observation wells 1 to 7 for surface water influence with observation well 8. Observation well 8 is therefore not corrected for surface water influences.*

4.2.2 Surface water levels and hydraulic heave

Surface water levels

Surface water levels are measured at several different locations in the Bijlmer polder and as can be seen in Figure 2.4 the surface water level near the pumping test Nellesteinpad should be around NAP -4.20 m. Three time series from the ditches near the pumping test Nellesteinpad are available and the most complete time series is from the location ‘Zandpad’ where the water is pumped out of the polder (Figure 4.4)

The time series from the surface water have an interval of one hour, while the groundwater level measurements have an interval of 5 minutes. After comparison it becomes apparent that the hydraulic head time series from all the different observation wells in the first aquifer are similar to the surface water time series although time lag, location and amplitude differences are present (Appendix C). A time lag is partially caused by the fact that the measurement point is downstream and amplitude difference suggest some resistance remains between aquifer and surface water.

Hydraulic heave

The bottom of the ditches near the pumping test are at NAP -5.00 m, meaning only 1.25 m of aquitard is still present to separate hydraulic head from surface water. A safety factor of 0.8 is calculated with a hydraulic head of NAP -3.70 m indicating failure of the separating layer. It is therefore likely little vertical resistance remains between surface water and the aquifer. See Appendix C for the calculations.

4.2.3 Semi logarithmic graphs

Time drawdown

Figure 4.11 is a semi log graph of the time-drawdown relation of the deep observation well 1, which is at a distance of 5 m from the pumping well. At first a relatively straight line is visible until 0.5 days, then drawdown seems to reach a ceiling. After 1 day drawdown goes down several centimetres, this is discussed in the Discussion in chapter six. This relationship is best represented by a leaky aquifer, when compared with confined, unconfined, and leaky aquifer relationships as presented by Kruseman & de Ridder (1994).

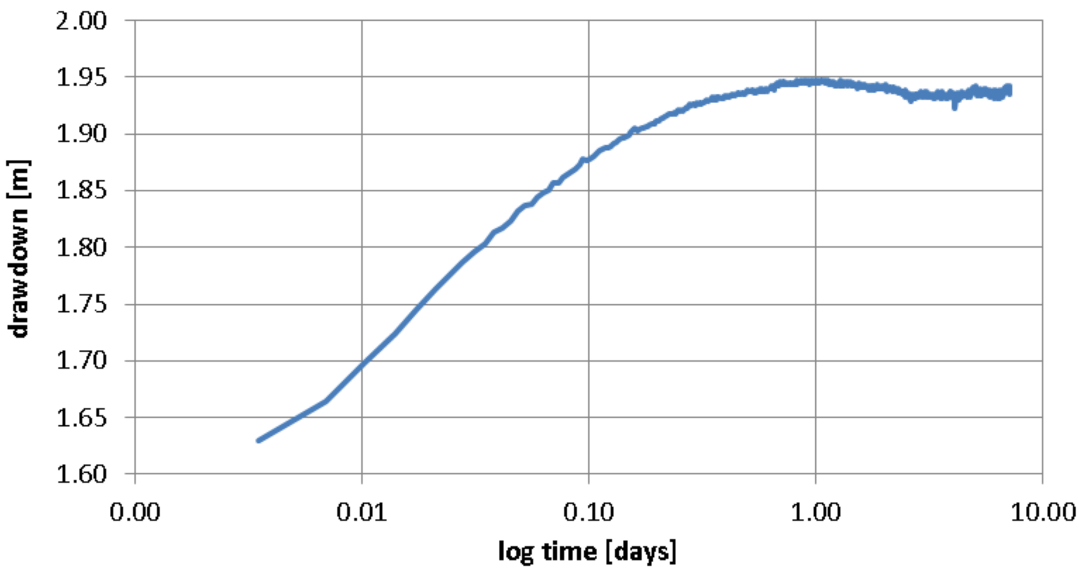

Figure 4.11 *A semi log plot of the time-drawdown relationship for observation well 1 from the Nellesteinpad pumping test. Observation well 1 is at a distance of 5 m from the pumping well.*

Distance drawdown

Figure 4.12 is a semi log graph of the distance-drawdown relationship for the Nellesteinpad pumping test. Maximum drawdown from all the observations wells is presented in the graph. Drawdown seems to cut the horizontal axes around the 300 m mark, suggesting the sphere of influence of the pumping test has a radius of 300 m. The furthest point suggest a drawdown of several centimetres, but this is likely due to influences other than the pumping well. A table is present in Appendix C which gives the drawdown values of each observation well at 25-03-2013 10:25.

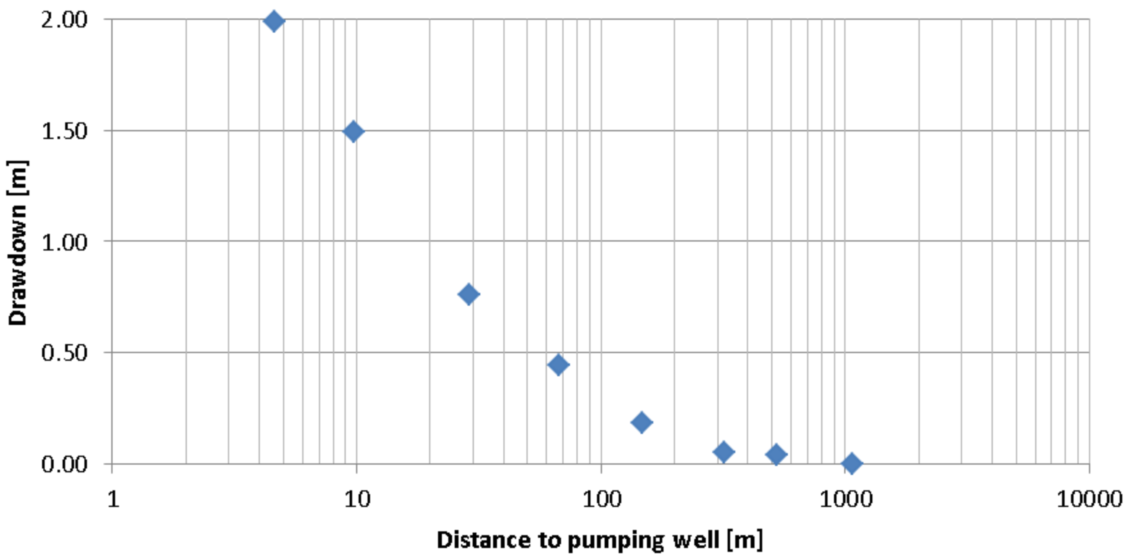

Figure 4.12 *A semi log plot for the distance-drawdown relationship of all the observation wells at the Nellesteinpad pumping test on 25-03-2013 at 10:25.*

4.2.4 Steady state optimisation in MLU

Model

The steady state run is a one layer model with a leaky top aquitard (sdl1) and an aquifer (wvl1). The bottom boundary in this model is impervious. Only the maximum drawdown near the end of the pumping test Nellesteinpad is used and only from wells 4 to 7 (Appendix C).

Calibration results

The initial resistance for the aquitard (sdl1) is 1000 days, and the initial transmissivity for the aquifer (wvl1) is 925 m^2/day. If both sdl1 and wvl1 are optimised with linear drawdown curve fitting, then the resistance of sdl1 becomes 32.5 days, while the transmissivity of wvl1 becomes 374 m^2/day (Table 4.6). The residuals vary from 0.001 m for observation well 4 to 0.009 m for observation well 6.

With log drawdown curve fitting (Table 4.7) transmissivity becomes 511 m^2/day and the vertical resistivity becomes 30 days. Residuals very from 0.07 m for observation well 4 to 0.002 m for observation well 7. The linear drawdown curve fitting result is the better result because of the smaller RSS of 0.0001 m^2 than the RSS of 0.13 m^2 for log drawdown curve fitting.

Table 4.6 *Model composition and result for linear drawdown curve fitting, RSS = 0.0001. Percentages indicate standard deviation.*

Name	Base [m]	Thickness [m]	Kh [m/d]	Kv [m/d]	T [m^2/d]	C [d]
sdl1	-6.65	3		0.09		33 (6 %)
wvl1	-43.65	37	10		374 (8 %)	

Table 4.7 Model composition and result for log drawdown curve fitting, RSS = 0.13. Percentages indicate standard deviation.

Name	Base [m]	Thickness [m]	Kh [m/d]	Kv [m/d]	T [m^2/d]	C [d]
sdl1	-6.65	3		0.1		30 (31 %)
wvl1	-43.65	37	14		511 (60 %)	

4.2.5 Transient optimisation in MLU

Model

A transient model with five aquifers and initial values (Beemster, 2014) is used for the Nellesteinpad pumping test. The top and bottom boundary are impervious in this model. Table 4.8 includes the structure of the model, contents of each layer and starting values (Beemster, 2014) for both hydraulic conductivity and the vertical resistivity. The clay layer in model layer sdl5 can be found in a CPT (Appendix K). The standard value for storativity in a aquitard layer is zero and for a confined aquifer is 1e-04 (Hemker & Post, 2014). A phreatic aquifer has a storativity of 0.15 (Bear, 1972). All layers are optimised in at least one step of the optimisation process except for wvl1.

Table 4.8 Model schematisation for the transient optimisation of the Nellesteinpad pumping test.

Model layer	Base [m]	Thickness [m]	Content	K* [m/d]	c* [days]
wvl1	-5.65	2	Phreatic top	5	
sdl2	-8.65	3	Resistivity layer		1000
wvl2	-17.65	9	Aquifer with observation wells	2	
sdl3	-17.65	0	Virtual resistivity layer**		1.0 ***
wvl3	-27.65	10	Aquifer with pump well screen	37.5	
sdl4	-27.65	0	Virtual resistivity layer**		1.0***
wvl4	-41.1	13.45	Rest of aquifer	37.5	
sdl5	-42.6	1.5	Clay layer		150
wvl5	-192.6	150	Rest of the profile until Maassluis Formation	37.5	

* (Beemster, 2014)
** This layer is added to separate the pumping well from the rest of the aquifer to account for the Dupuit effect.
*** sdl2 and sdl3, virtual resistivity layers, are given the value of 1.0 days.

Optimisation process

Table 4.9 gives a summary of the steps of the calibration process for the Nellesteinpad pumping test. The full results from the runs can be found in Appendix C and run numbers are the same as in the flowchart in paragraph 3.7.3. The storativity is mentioned separately per aquifer layer *e.g.* S1 is the storativity for aquifer layer wvl1. Run 1 only used wells 4 to 7 in the calibration process, while runs 2 to 7 use observation wells 1 to 7. The run with the best results is run 7 with an RSS of 0.2 m^2 (Figure 4.14). However, the top aquitard is optimised to a lower vertical resistivity of 117 days, when the aquitard in general has a high vertical resistivity and only near the ditches this value is reliable (Paragraph 4.2.2.). Furthermore, the first extraction time step on the 18th of March 2013 was changed from 8:56 to 8:50. Therefore, run 5 with a RSS of 1.46 m^2 is already a good fit, as becomes clear in Figure 4.13 which shows the difference between model and measurements. An important change from run 4 to 5 is a larger vertical resistivity for layer sdl5, but adding the bottom aquifer from run 5 to 6 did not improve the RSS.

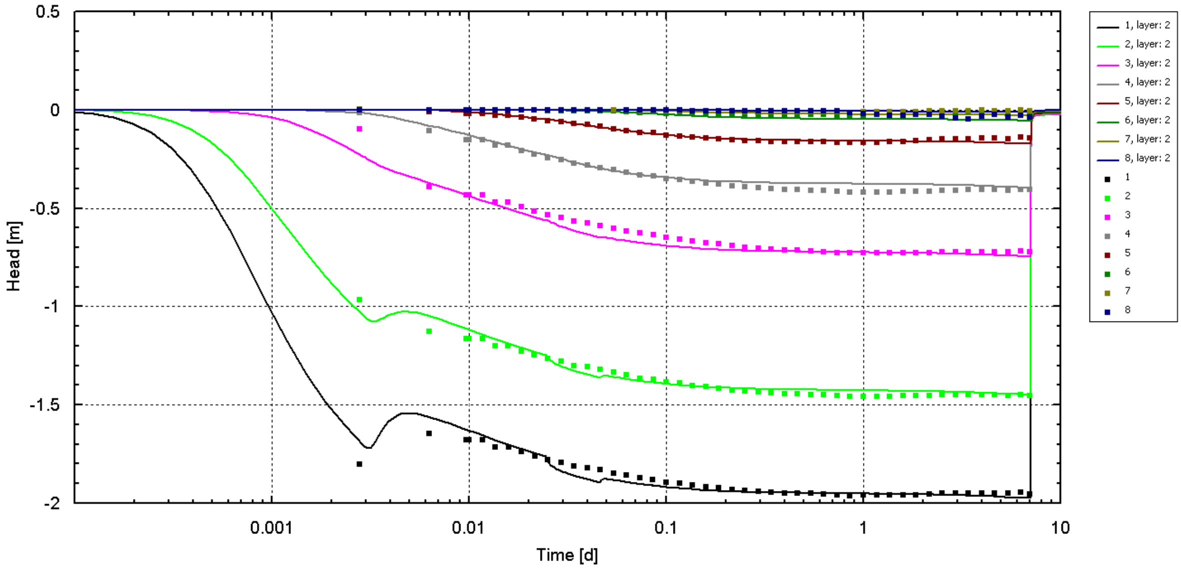

Figure 4.13 *Model (lines) and measurements (points) of run 7 with an RSS of 0.2 m^2 for the Nellesteinpad pumping test. Time step size for extraction is different with regard to Figure 4.14.*

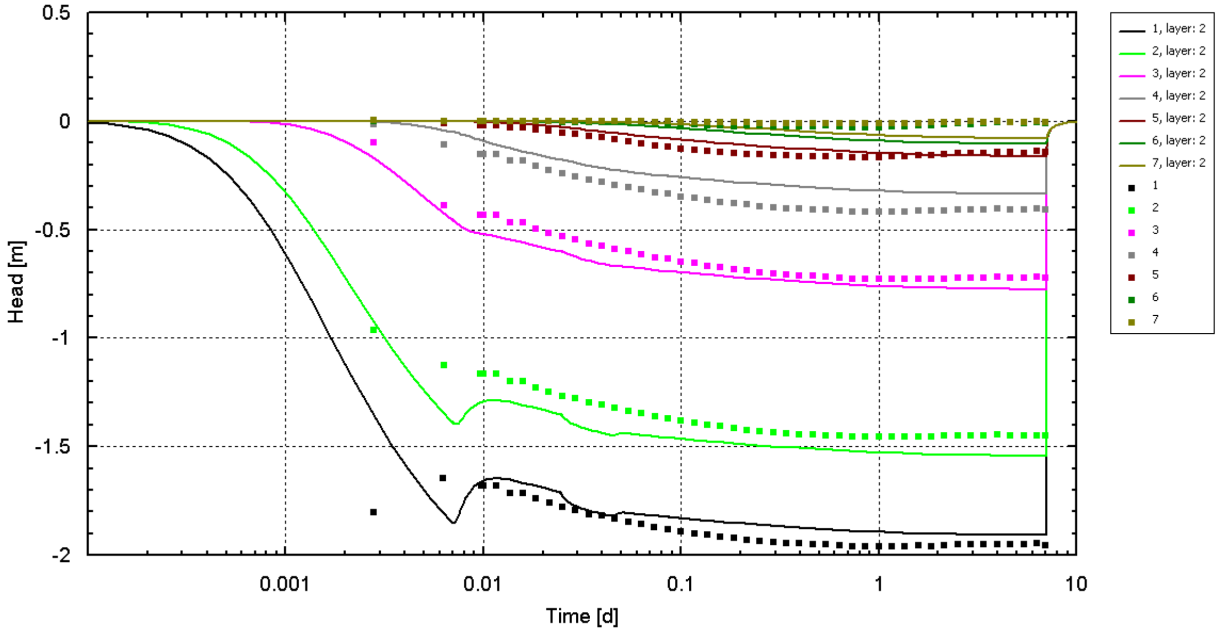

Figure 4.14 *Model (lines) and measurements (points) of run 5 with an RSS of 1.46 m^2 for the Nellesteinpad pumping test.*

Table 4.9 Optimisation steps for the Nellesteinpad pumping test.

<table>
<tr><th>Run</th><th>1****</th><th>2</th><th>3</th><th>4*</th><th>5</th><th>6</th><th>7***</th></tr>
<tr><td>RSS [m^2]</td><td>0.8****</td><td>2.8</td><td>2.7</td><td>2.8</td><td>1.46</td><td>1.58</td><td>0.2</td></tr>
<tr><td>Model layer</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>wvl1 [m/d]</td><td colspan="7">5</td></tr>
<tr><td>S1 [-]</td><td colspan="2">$1 \cdot 10^{-5}$</td><td>$9 \cdot 10^{-6}$(>100 %)</td><td colspan="3">0.15**</td><td>0.15 (8 %)</td></tr>
<tr><td>sdl2 [day]</td><td colspan="6">1000</td><td>117 (5 %)</td></tr>
<tr><td>wvl2 [m/d]</td><td>0.001 (23 %)</td><td>0.01 (8 %)</td><td>0.01</td><td>0.01</td><td>0.1 (12 %)</td><td>0.1 (14 %)</td><td>1.4 (7 %)</td></tr>
<tr><td>S2 [-]</td><td colspan="2">$1 \cdot 10^{-5}$</td><td>$3 \cdot 10^{-7}$(>100 %)</td><td colspan="3">$2 \cdot 10^{-4}$</td><td>$6 \cdot 10^{-4}$(2 %) #</td></tr>
<tr><td>sdl3 [day]</td><td colspan="6">1</td><td>0.5 (5 %)</td></tr>
<tr><td>wvl3 [m/d]</td><td>8 (46 %) #</td><td>20 (1 %) #</td><td>20</td><td>20</td><td>22 (1 %) #</td><td>19 (1 %) #</td><td>20 (1 %) a</td></tr>
<tr><td>S3 [-]</td><td colspan="2">$1 \cdot 10^{-5}$</td><td>$5 \cdot 10^{-7}$(>100 %)</td><td colspan="3">$2 \cdot 10^{-4}$</td><td>$6 \cdot 10^{-4}$(2 %) #</td></tr>
<tr><td>sdl4 [day]</td><td colspan="6">1</td><td>1.5 (3 %)</td></tr>
<tr><td>wvl4 [m/d]</td><td>8 (46 %) #</td><td>20 (1 %) #</td><td>20</td><td>20</td><td>22 (1 %) #</td><td>19 (1 %) #</td><td>20 (1 %) a</td></tr>
<tr><td>S4 [-]</td><td colspan="2">$1 \cdot 10^{-5}$</td><td>$9 \cdot 10^{-7}$(>100 %)</td><td colspan="3">$2 \cdot 10^{-4}$</td><td>$6 \cdot 10^{-4}$(2 %) #</td></tr>
<tr><td>sdl5 [day]</td><td colspan="4">10</td><td>29 (6 %)</td><td>23 (10 %)</td><td>38 (8 %)</td></tr>
<tr><td>wvl5 [m/d]</td><td colspan="5">37</td><td>31 (10 %)</td><td>29 (23 %)</td></tr>
<tr><td>S5 [-]</td><td colspan="2">$1 \cdot 10^{-5}$</td><td>$2 \cdot 10^{-4}$(>100 %)</td><td colspan="3">$2 \cdot 10^{-4}$</td><td>$6 \cdot 10^{-4}$(2 %) #</td></tr>
</table>

* Storativity adapted to the best value ($2 \cdot 10^{-4}$) for all aquifers except phreatic (S1)
** (Bear, 1972)
*** For run 7 standard deviation was determined in two separate runs. Only sdl2, sdl3, and sdl4 where calibrated in the second run. The model was not stable enough to optimise all the parameters together.
**** Run 1 uses only observation wells 4 to 7 (Paragraph 3.7.3).
(..%) Parameters calibrated during a run can be identified by their added standard deviation.
\# Parameters are coupled during a run with a parameter with the same symbol.
a Parameters are coupled during a run with a parameter with the same symbol.

Residual analyses

The residual is the difference between calibrated and observed per measurement point. A total of 329 measurement points were used for 7 observation wells. Figure 4.15 shows the average, minimum, and maximum residual value for each observation well for run 7. The average residual for run 7 is 0.001 m, which indicates that, while the standard deviation is 0.02 m. Figure 4.16 shows the average, minimum and maximum residual for each observation well for run 5. The average residual for this run is 0.02 m, a positive bias that indicates a general overestimation. The total standard deviation of 0.06 m indicates that on average the fit deviates with 0.06 m. A spatial pattern is visible, because with distance from the pumping well less extreme values are present, although the average value of the residuals does not show this pattern.

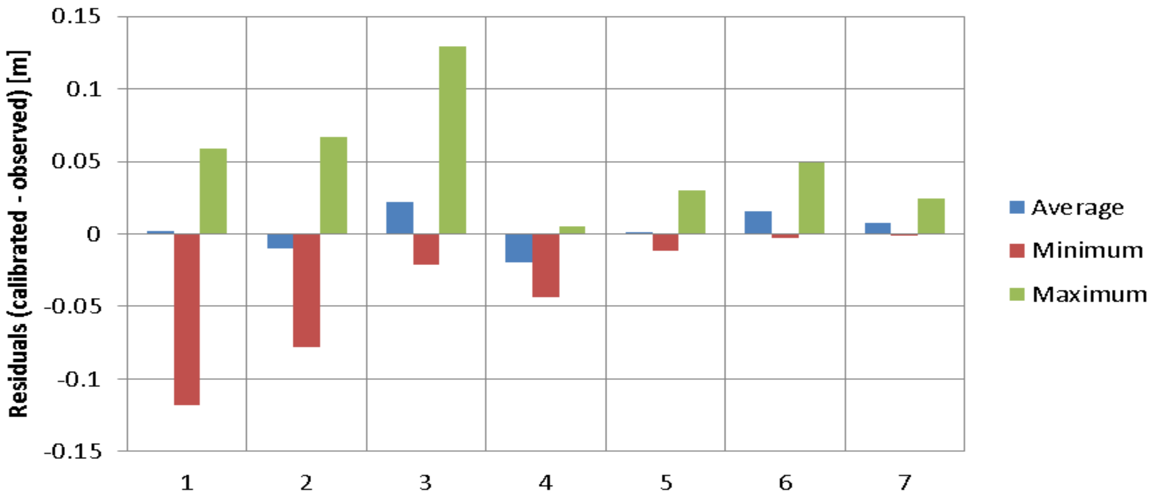

Figure 4.15 *Run 7 residual analyses for the Nellesteinpad pumping test, with average, minimum and maximum residuals per observation well.*

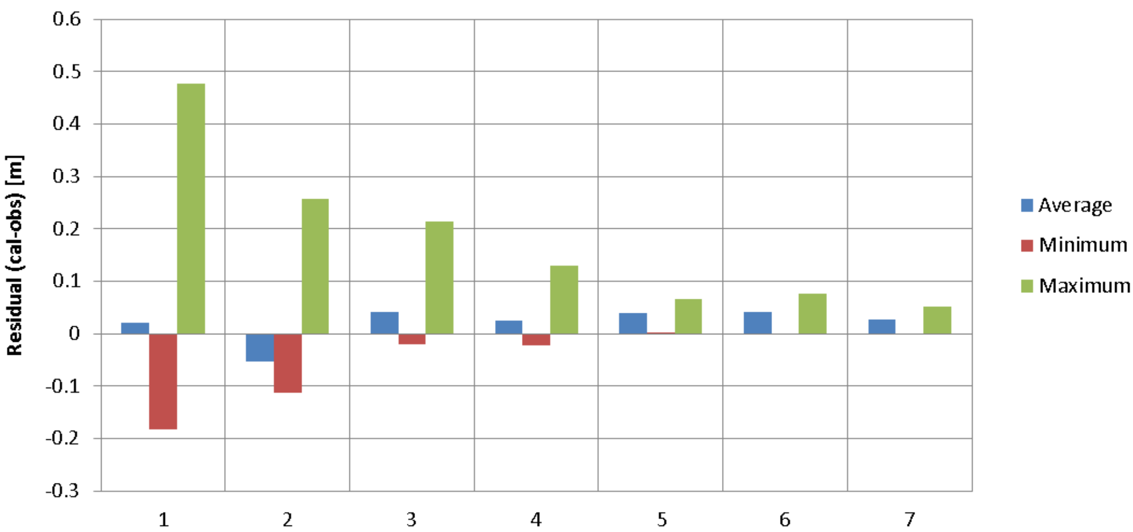

Figure 4.16 *Run 5 residual analyses for the Nellesteinpad pumping test, with average, minimum and maximum residuals per observation well.*

Best fit

The best fits for the Nellesteinpad pumping test are run 7 and 5, which have a RSS of respectively 0.20 m^2 and 1.46 m^2. Optimised values for the Nellesteinpad pumping test are shown in Table 4.10. The full optimisation result is available in Appendix C, which includes correlation matrices for the different runs.

The best fit for this pumping test is run 7 with an RSS of 0.20 m^2, and the difference between run 5 and 7 is mainly due to the vertical resistivity of the first aquitard (sdl2). As was made clear in the hydraulic heave calculation at the site of the Nellesteinpad pumping test there is good contact between the surface water and the pumped aquifer. Therefore the value of 117 days is indicative of the infiltration resistance from the surface water to the pumped aquifer.

A hydraulic conductivity of 1.4 m/day is more realistic for a fine sand lithology than 0.1 m/day which is in the range of clay (Kruseman & de Ridder, 1994). The difference of 10 % for model layer wvl3 and wvl4 is minimal, as is the difference between the hydraulic conductivity of wvl5. Vertical resistivity in model layer sdl5 differs with 31 %, but both values are still realistic values for clay.

Run 7 is the best result with a low RSS, but the vertical resistivity of 117 days is probably only valid in the area near the ditches where there is good contact between surface water and the pumped aquifer.

Table 4.10 Final optimisation results for the Nellesteinpad pumping test.

Model layer	Formations	Thickness [m]	K (*) [m/d]	c (*) [days]
wvl1	Holocene	2	5	
sdl2	Holocene	3		117 (5)
wvl2	Boxtel	9	1.4 (7)	
sdl4	vrl**	0		0.5 (5)
wvl3	Glacially reworked	10	20 (1)	
sdl4	vrl**	0		1.5 (3)
wvl4	Glacially reworked	13.45	20 (1)	
sdl5	Glacially reworked	1.5		38 (8)
wvl5	Sterksel, Peize, Waalre, and Maassluis	150	29 (23)	

* Standard deviation in percentages.
** Virtual resistivity layer

4.3 Pumping test Amstelveen

4.3.1 Observations

Precipitation and evaporation

Precipitation and Makkink potential evapotranspiration are shown in Figure 4.17. There was little precipitation during the pumping test but some larger rainstorms up to 8 mm happened before the pumping test. The Makkink reference evapotranspiration averages around 2 mm/d.

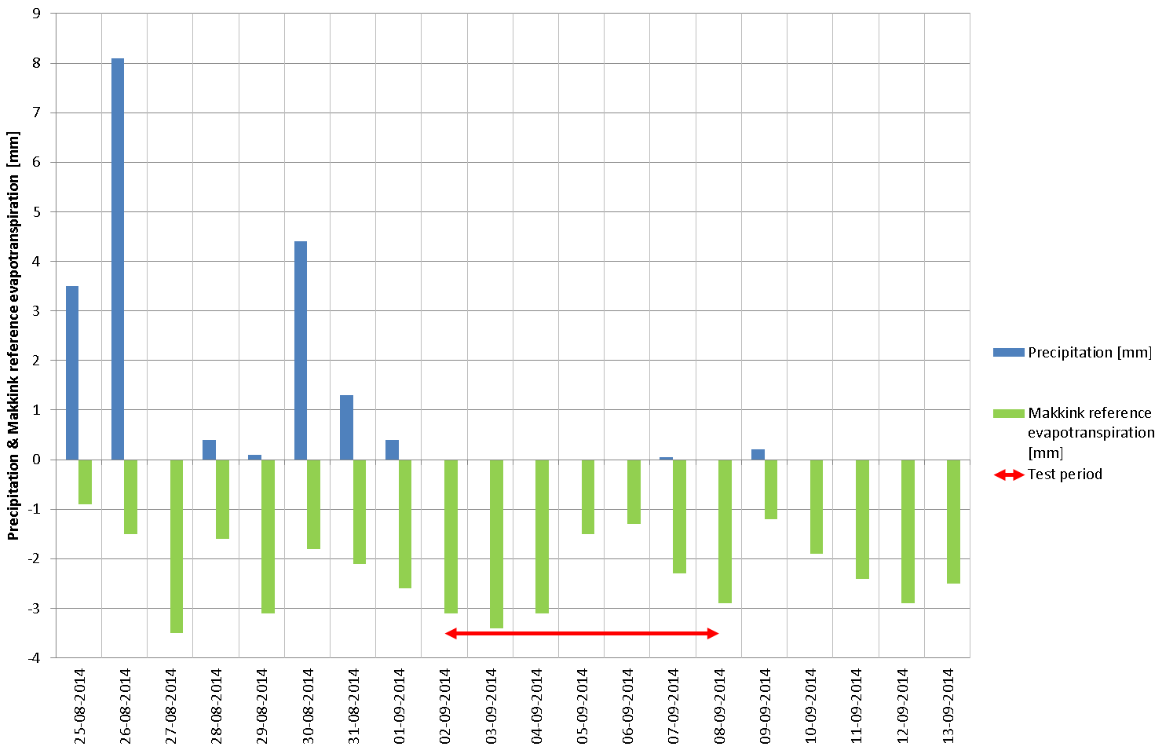

Figure 4.17 Precipitation and Makkink reference evapotranspiration mm/d during pumping test Amstelveen.

Hydraulic head

Measurements from the deep observation wells during the pumping test can be seen in Figure 4.18. The nearest well screen was installed in the pumping well, making it difficult to observe the more distant observation wells due to the large amount of drawdown near the pumping well. Therefore a graph is present in Appendix D which shows the time series from only the furthest observation wells.

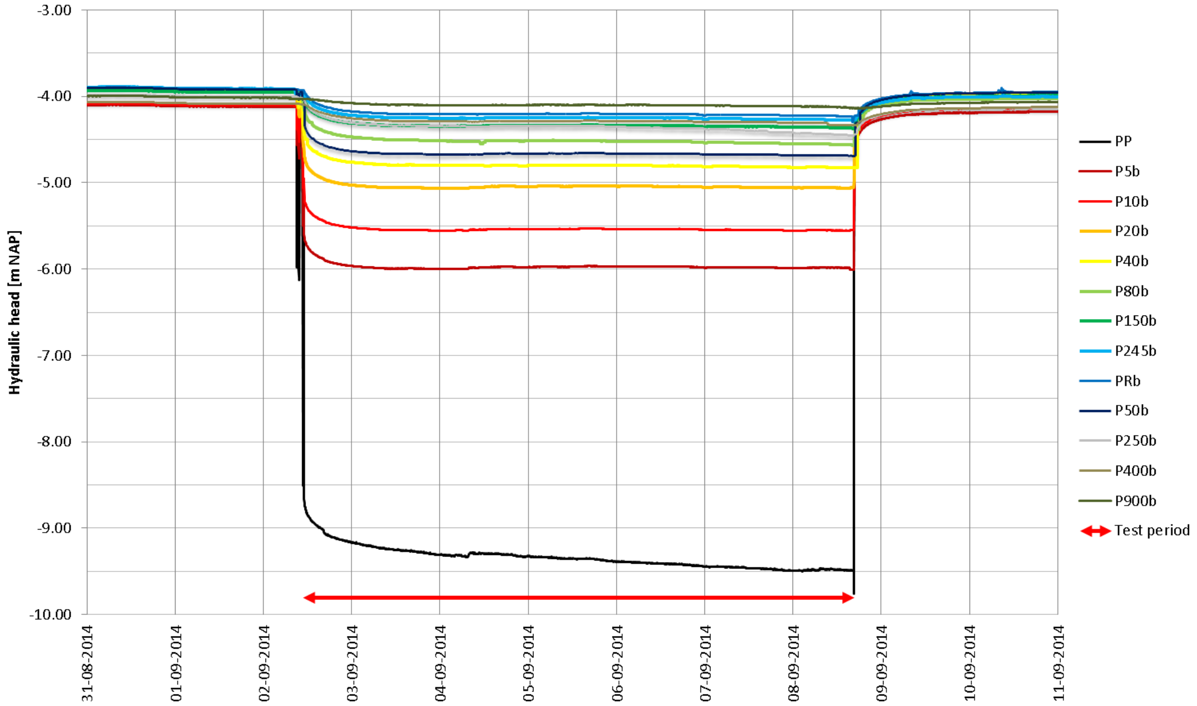

Figure 4.18 Time series from deep well screens during the Amstelveen pumping test.

Groundwater level

Figure 4.19 shows the time series from the shallow observation wells during the pumping test Amstelveen. Not all time series are present because some were found to be unreliable, these are P150 and P900 (Witteveen+Bos, 2014). The time series from the phreatic well screen can be found in Appendix D. Also in Appendix D a graph can be found which combines precipitation with the shallow well screens.

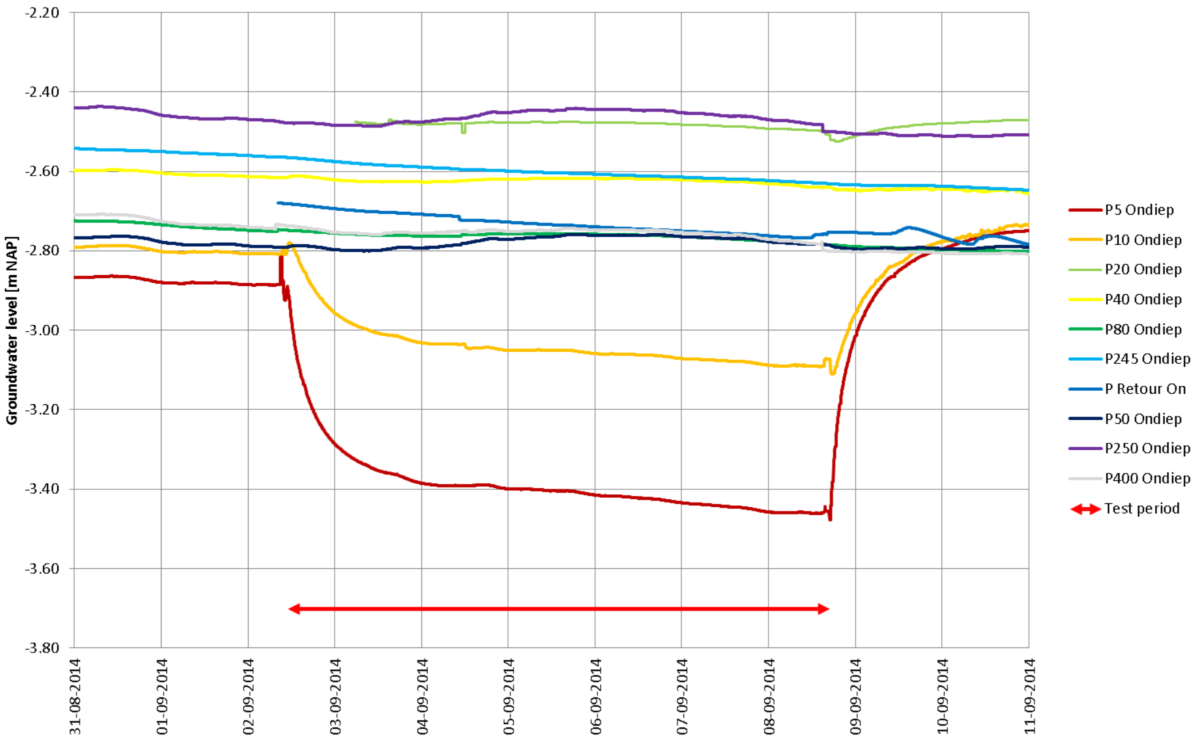

Figure 4.19 Shallow observation well time series during the pumping and return test Amstelveen.

4.3.2 Surface water levels and hydraulic heave

Surface water level

The surface water in the polder surrounding the Amstelveen pumping test has a target level of NAP -2.25 m. Surface water level was measured manually, but no useable time series where available for comparison with hydraulic head time series.

Hydraulic heave

The bottom of the ditches near the pumping test are at NAP -3.05 m, meaning another eight meters of aquitard is still present to separate the aquifer from the surface water. A safety factor of 1.6 is calculated with a hydraulic head of NAP -4.00 m indicating the existing vertical equilibrium is unlikely to fail. See Appendix D for the entire calculation.

4.3.3 Semi logarithmic graphs

Time-drawdown

Figure 4.20 is a semi log plot of the time-drawdown relation of the deep observation well 1. At first a relatively straight line is visible up to the end of day one, then drawdown seems to reach a ceiling. This relationship is best represented by a leaky aquifer, but not completely explained.

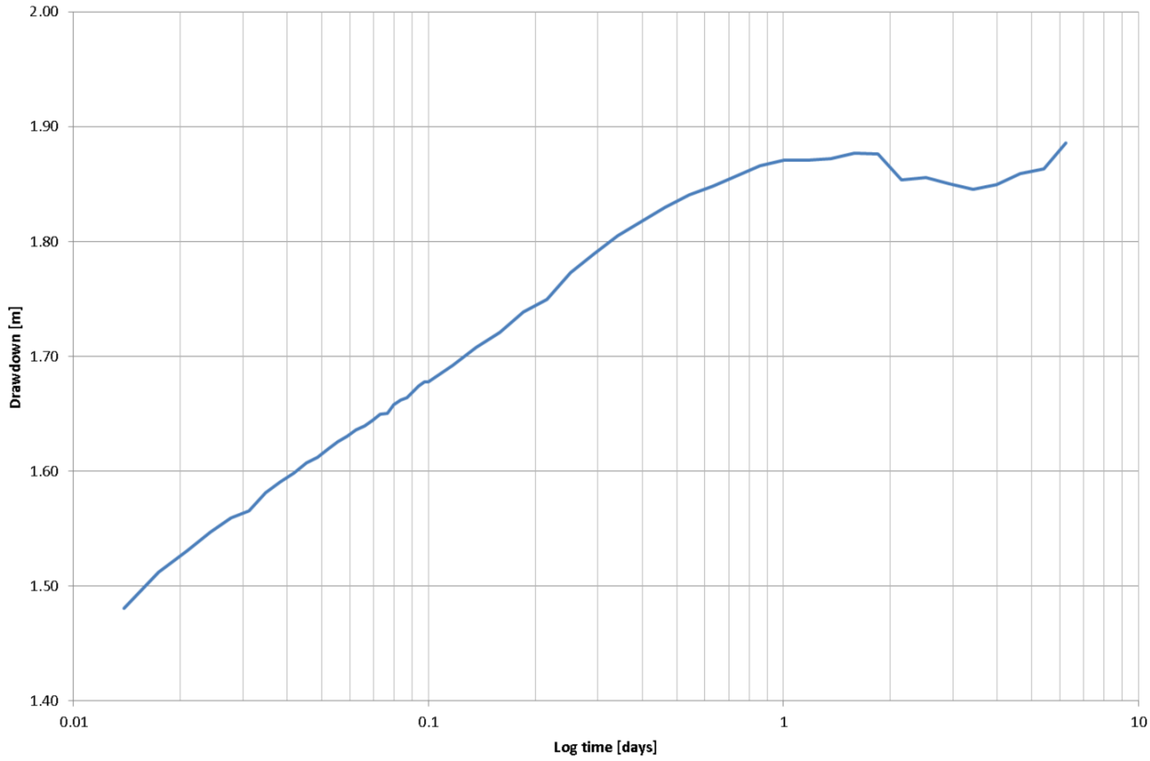

Figure 4.20 *A semi log plot of the time-drawdown relationship for observation well 5 from the Amstelveen pumping test. Observation well 5 is at a distance of 5 m from the pumping well.*

Distance-drawdown

Figure 4.21 is a semi log graph with the distance-drawdown relationship for all the deep observation wells in the pumping test Amstelveen. The sphere of influence of this pumping test extends to at least a distance of 1000 m from the pumping well. One of the point around 200 m falls outside the curved line, indicating that that point might have erroneous measurements. A table is present in Appendix D which shows the drawdown on 8-9-2014 at 16.35 of all the deep well screens.

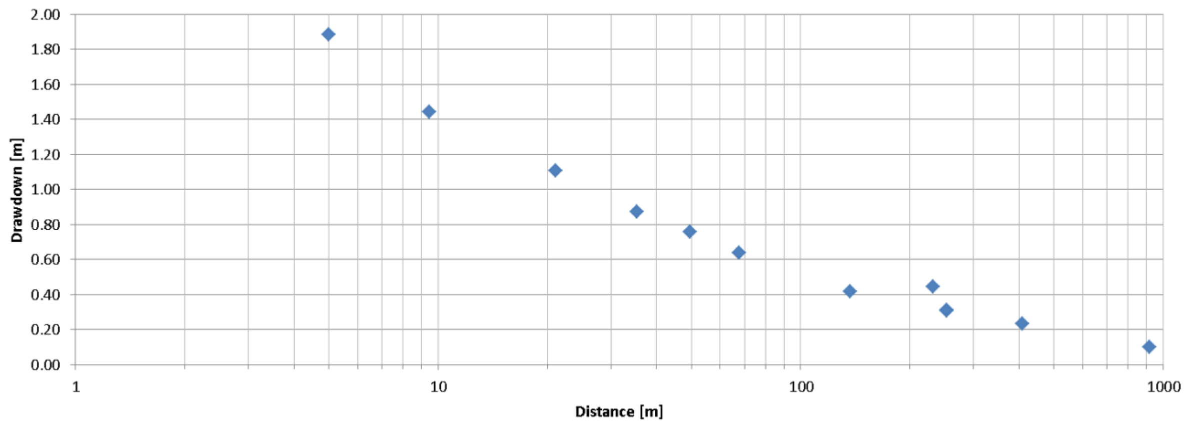

Figure 4.21 *A semi log plot for the distance-drawdown relationship of all the observation wells at the Amstelveen pumping test on 8-9-2014 at 16:35.*

4.3.4 Steady state optimisation in MLU

Model

In the steady state run the one layer model has a top leaky aquitard (9 m) and a impervious bottom aquifer (41 m). During optimisation only observation wells 80 to 900 were used. The drawdown values used were from near the end of the pumping test and are available in Appendix D.

Calibration results

With linear drawdown curve fitting the result is 797 m^2/day for transmissivity of the aquifer and a vertical resistivity of 919 days for the aquitard (Table 4.11). Log drawdown curve fitting has similar values and the RSS only differs by 0.002 m^2 (Table 4.12).

Table 4.11 Model composition and result for linear drawdown curve fitting, RSS = 0.015 m^2. Percentages indicate standard deviation.

Name	Base [m]	Thickness [m]	Kh [m/d]	Kv [m/d]	T [m^2/d]	c [d]
sdl1	-13	9		0.018		919 (37 %)
wvl1	-54	41	19		797 (12 %)	

Table 4.12 Model composition and result for log drawdown curve fitting, RSS = 0.017 m^2. Percentages indicate standard deviation.

Name	Base [m]	Thickness [m]	Kh [m/d]	Kv [m/d]	T [m^2/d]	c [d]
sdl1	-13	9		0.009		1040 (18 %)
wvl1	-54	41	20		813 (10 %)	

4.3.5 Transient optimisation in MLU

Model

A transient model with three model layers and initial values for hydraulic conductivity (K) and vertical resistivity (c) (Beemster, 2014). The top and bottom boundary of the model are impervious. Table 4.13 shows the structure of the model and contents of each layer. The standard value for storativity in a aquitard layer is zero and for a confined aquifer is 1e-04 (Hemker & Post, 2014). A phreatic aquifer has a storativity of 0.15 (Bear, 1972). All layers are optimised in at least one step of the optimisation process except for sdl1, sdl3 and wvl3.

Table 4.13 Model schematisation for the transient optimisation of the Amstelveen pumping test.

Model layer	**Base [m]**	**Thickness [m]**	**Content**	**K [m/d]***	**c [days]***
sdl1	-13	9	Top resistivity		1000
wvl1	-29	16	Aquifer with observation wells and pump	26.75	
sdl2	-29	0	Virtual resistivity layer**		1 ***
wvl2	-54	25	Aquifer	37.50	
sdl3	-64	10	Sterksel clay layer		250
wvl3	-194	130	Rest of the profile until the Maassluis Formation.	37.50	

* (Beemster, 2014)

** This layer is added to separate the pumping well from the rest of the aquifer to account for the partially penetrating well.

*** sdl2 is calculated with the following Formula 4:

$$C2 = \frac{1}{2}\frac{D_{T1}}{K_{T1}} + \frac{1}{2}\frac{D_{T2}}{K_{T2}} \qquad (4)$$

Optimisation process

Table 4.14 summarizes the steps of the calibration process for the Amstelveen pumping test. The run numbers are compliant with the flowchart available in paragraph 3.8.3. The storativity is mentioned separately per aquifer layer *e.g.* S1 is the storativity for aquifer layer wvl1. Run 1 and 2 only use observation well 80 to 900, while run 3 to 8 use all the deep observation wells. Run 8 has the smallest RSS with 1.3 and is the best fit. Run 1 and 2 have a relatively low RSS because then only observation wells 80 to 900 are optimised. Figure 4.22 shows the visual fit of run 8.

Table 4.14 Optimisation steps for the Huntumdreef pumping test.

Run	**1**	**2**	**3**	**4**	**5****	**6**	**7**	**8***
RSS [m^2]	2.0	2.0	4.0	2.3	3.3	2.0	1.4	1.3
Model layer								
sdl1 [day]	1000							
wvl1 [m/day]	26 (5 %)	23 (3 %) #	21 (1 %) #	21	21 (1 %) #	21	22 (1 %)	20 (2 %)
S1 [-]	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$ (90 %)	$1 \cdot 10^{-4}$	$4 \cdot 10^{-4}$ (4 %) #	$4 \cdot 10^{-4}$	$4 \cdot 10^{-4}$
sdl2 [day]	1							2 (14 %)
wvl2 [m/day]	20	23 (3 %) #	21 (1 %) #	21	19 (4 %) #	19	14 (3 %)	13 (2 %)
S2 [-]	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$6 \cdot 10^{-4}$ (27 %)	$1 \cdot 10^{-4}$	$4 \cdot 10^{-4}$ (4 %) #	$4 \cdot 10^{-4}$	$4 \cdot 10^{-4}$
sdl3 [day]	250							
wvl3 [m/day]	37.5							
S3 [-]	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-6}$ (>100 %)	$1 \cdot 10^{-4}$	$4 \cdot 10^{-4}$ (4 %) #	$4 \cdot 10^{-4}$	$4 \cdot 10^{-4}$

* RSS of 1.1 m^2 for wvl3 of 25 m/d (NOT a calibrated value)

** Storativity adjusted to one value of $1 \cdot 10^{-4}$for all the aquifers

(..%) Parameters calibrated during a run can be identified by their added standard deviation.

\# Parameters are coupled during a run with a parameter with the same symbol.

a Parameters are coupled during a run with a parameter with the same symbol.

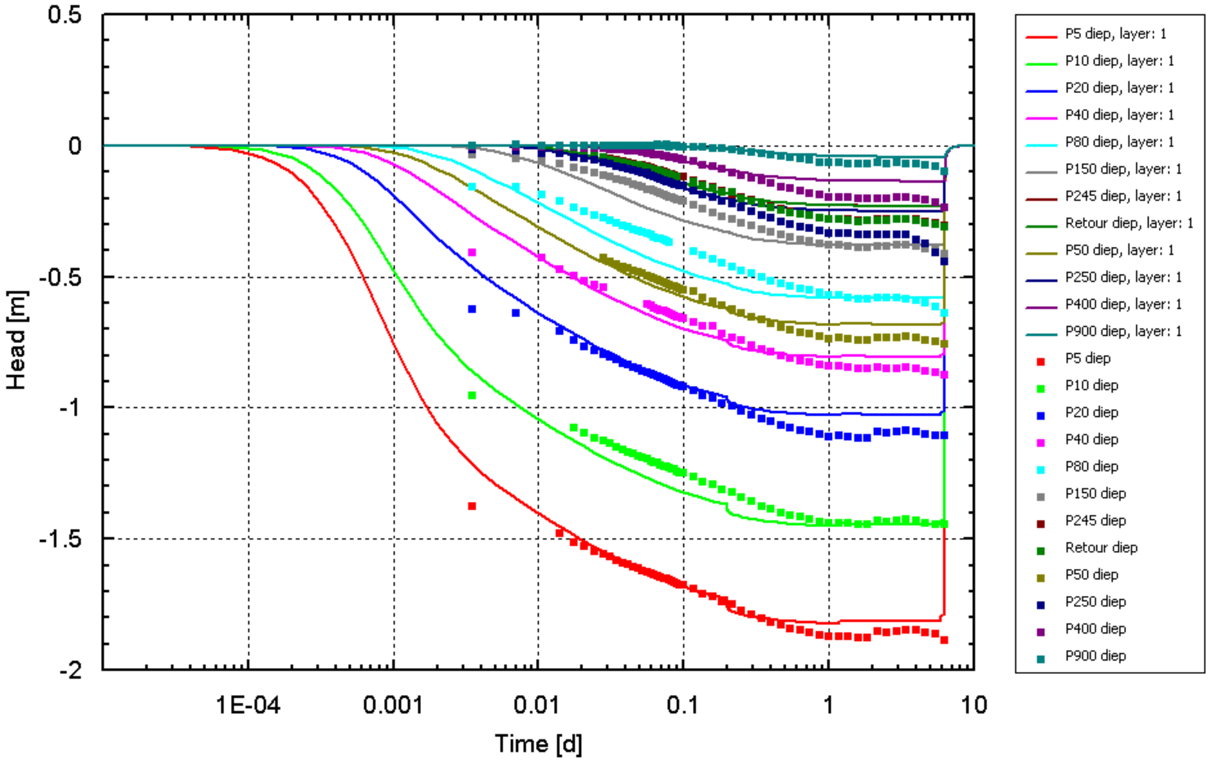

Figure 4.22 *Model (lines) and measurements (points) of run 8 with an RSS of 1.3 m^2 for the Amstelveen pumping test.*

Residual analyses

Figure 4.23 is a graph with the average, minimum and maximum residuals of run 8 for each observation well and the location of the pumping well. A total of 642 measurement points where used for 12 observation well. The average residual is -0.002 m, indicating a very minor overestimation. Total standard deviation is 0.05 m, which is also very small.

Figure 4.23 *Run 8 residual analyses for the Amstelveen pumping test, with average, minimum and maximum residuals per observation well.*

Best fit

The best fits for the Amstelveen pumping test are run 7 and 8, which have a RSS of respectively 1.40 m^2 and 1.30 m^2. Optimised values for the Amstelveen pumping test are shown in Table 4.15.

The optimised values differ only 10% for model layer wvl1 and with 8 % for model layer wvl2. Therefore the run with lowest RSS is chosen as the best fit for this location and will be used in the synthesis paragraph 4.5. As the hydraulic heave calculation in the vicinity of the pumping test shows, there is not hydraulic heave at this location. Therefore the vertical resistivity of 1000 days was not optimised. The full optimisation result is available in Appendix D, which includes correlation matrices for the different runs.

Table 4.15 Final optimisation results of the Amstelveen pumping test.

Model layer	Formations	Thickness [m]	K* [m/d]	c* [day]
sdl1	Holocene	9		1000
wvl1	Boxtel, Kreftenheye, and Drente	16	20 (2)	
sdl2	vrl**	0		2 (14)
wvl2	Urk and glacially reworked	25	13 (2)	
sdl3	Sterksel	10		250
wvl3	Sterksel, Peize, Waalre, and Maassluis	130	37.5	

* Standard deviation in percentages.
** Virtual resistivity layer.

4.4 Parameter optimisation in Triwaco

4.4.1 Grid and model

Model

The original model has eight layers as can be seen in Appendix E. Table 4.16 is specific for the pumping test, with depth and parameter values adjusted to the specifics of the location. The K and c-value are still the same as in the original model found in Appendix E. Some layers are empty and function as virtual model layer in the model, or are filled in different areas in Amsterdam, but are empty at this specific location.

Grid

The new grid has one source to accommodate the pumping well for the Nellesteinpad pumping test. The grid includes the A9 pump test sites, and the grid density polygons are the same as in the larger grid to decrease differences between the models. The density polygons vary between 250, 100, 50 and 25 m for the area around the A9 highway. The density polygons around the pump are: 5, 10 and 25 m. See Appendix E for the location of the grid with boundary.

Table 4.16 Original model of Waternet specific to the area near the Nellesteinpad pumping test.

Depth [m NAP]	Model layer*	Content: REGIS II.1 and Geotop	K-value (m/d)	c-value (days/m)
-2.5 to -4	wvl1	Anthropogenic + Naaldwijk Formations	5	
-4 to -7.5	sdl 1	Hollandveen + Wormer layer + Basisveen		Hollandveen: 20 to 100 Wormer: 1500 Basisveen: 5000
-7.5 to -16.5	wvl 2	Boxtel sand 2 + 3	2	
	sdl 2	*(virtual model layer)*		1
-16.5 to -30	wvl 3	Glacially reworked formation + pump	37.5	
	sdl 3	*(virtual model layer)*		1
-30 to -56	wvl 4	Glacially reworked	37.5	
	sdl 4	*(virtual model layer)*		1
-56 to -56	wvl 5	*empty*	37.5	
	sdl 5	*(virtual model layer)*		1
-56 to -70	wvl 6	Sterksel sand 2 + Peize/Waalre sand 2	37.5	
-70 to -89	sdl 6	Waalre clay 2		6
-89 to -172	wvl7	Peize/Waalre sand 3 + 4 + 5	37.5	
	sdl 7	*(virtual model layer)*		1
-172 to -189	wvl 8	Peize complex + Maassluis	25	

* sdl = aquitard layer and wvl = aquifer layer

4.4.2 Steady state optimisation in Triwaco

Model

During the steady state simulations, the pumping test is modelled in the groundwater model. The performance of the model is checked visually by comparing calculated and observed drawdown values, and by calculating the RSS.

Parameters changed during the different steady state model runs are available in Table 4.17. First, the pumping test is modelled in a model similar to the original model. Then, the pumping test is simulated in a second model with parameters similar to the best fit found in MLU. Finally, with the aid of parameter optimization analyses the model is calibrated to an acceptable fit of which the result can be seen in the third model.

Table 4.17 Parameters changed during calibration.

Parameters explained	Parameters	Model 1	Model 2	Model 3
Hydraulic conductivity of wvp 2	K2* [m/d]	2	1	1
Hydraulic conductivity of wvp 3 & 4	K3 & K4 [m/d]	37.5	20.5	15
Vertical resistance of sdl 3	Cl3 [day]	1	1	5
Vertical resistance of sdl 4	Cl4 [day]	1	30	30
Infiltration resistance ditch in wvp 2	Cinf2 [day]	50	50	25

* In the model the vertical resistance of aquitard 2 (CL2) is calculated by a formula, which includes the hydraulic conductivity of the Boxtel formation. Therefore this parameter was not optimised.

Optimisation process

Figure 4.24 shows the difference between the modelled and measured drawdown values for the three different model runs. Furthermore, in Table 4.18 corresponding residual (calibrated – observed) values and statistics are available.

Model 1 has an average residual of 0.43 m and a RSS of 3.1 m^2 and therefore does not have a good fit. Model 2 has an average residual of 0.25 m and a RSS of 1.2 m^2. The best fit found is with model 3 and has an average residual of 0.04 m and a RSS of 0.1 m^2. After a visual inspection of model 3 it becomes clear that the first observation well is not performing correctly. Therefore a second RSS is calculated in which the residual of the first observation well is removed. This issue is addressed in the discussion chapter.

Also notable is that in all three models observation well 6 to 8 are overestimated, with observation well 5 overestimated in model 2 and 3. An explanation for this phenomenon is given in the discussion.

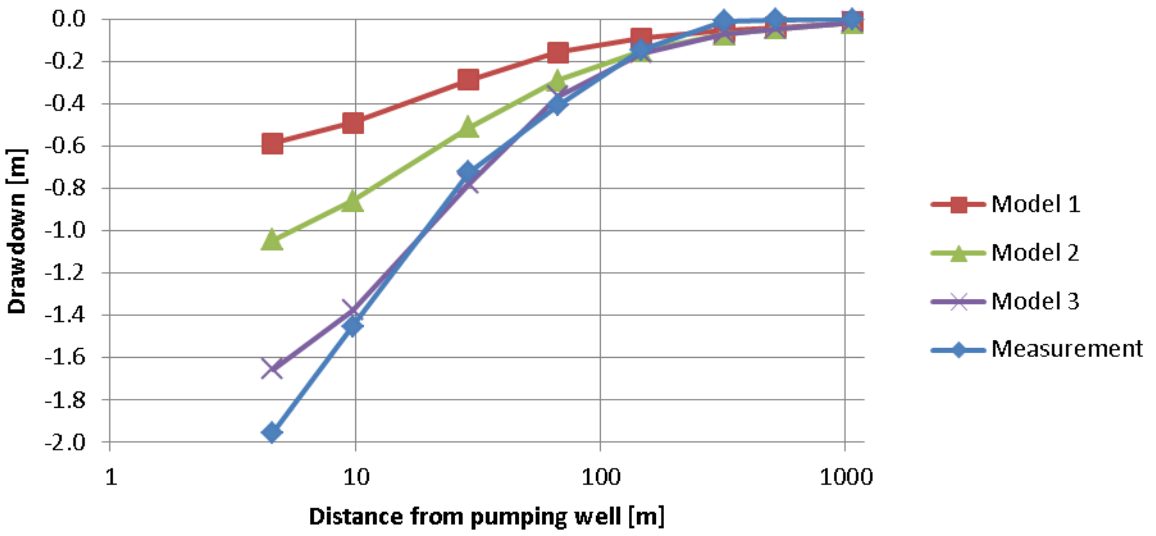

Figure 4.24 Drawdown of three consecutively better fitting model, see Table 4.18 for the RSS, average and standard deviation of all three models.

Table 4.18 Residual and statistics for steady state models.

	Model 1	Model 2	Model 3
RSS 1 to 7	3.05	1.25	0.11
RSS 2 to 7	1.19	0.42	0.02
Average	0.37	0.21	0.03
St. dev.	0.53	0.35	0.12

Parameter optimisation

The result of the best fit in model 3 was found by using parameter optimisation. Parameter optimisation was used to be able to make sure the best optimised value was used. By varying the parameters and checking the RSS, the parameters correlating with the lowest RSS could be found. The results of these analyses are available in Table 4.19. The discrepancy between the previous values found in MLU and the start values found in Table 4.19 can be explained by a trail-and-error method used previously. The process of analysing the sensitivity of the different parameters can be found in Appendix E. Only six parameters where optimised due to the lack of observation wells in aquifers above the first aquitard and below the pumped aquifer.

During optimisation of the model it became apparent that the 1st observation well was not properly modelled in the grid. Afterwards the RSS without the 1st obvious well was also taken into account. As can be seen in Table 4.19 the RSS without the first observation well goes down from 0.022 to 0.016, while the RSS of observation wells 1 to 7 goes up during the last step. More on this topic can be found in the discussion chapter.

Table 4.19 Parameter optimisation for the steady state model.

Parameters explained	Parameters	k3 & k4	K2	Cl3	Cinf2	Cl4
Hydraulic conductivity of wvp 3 & 4	K3 & K4 [m/d]	15	15	15	15	15
Hydraulic conductivity of wvp 2	K2 [m/d]	2	1	1	1	1
Vertical resistance of sdl 3	Cl3 [days]	5	5	5	5	5
Infiltration resistance ditch in wvp 2	Cinf2 [days]	50	50	50	25	25
Vertical resistance of sdl 4	Cl4 [days]	50	50	50	50	30
RSS of observation wells 1 to 7 [m^2]		0.1527	0.0834	0.0834	0.0858	0.1054
RSS of observation wells 2 to 7 [m^2]		0.0220	0.0174	0.0174	0.0172	0.0166

Sphere of influence

Figure 4.25 gives an overview of the sphere of influence of the pumping test Nellesteinpad. The influence of the ditches surrounding the pumping test becomes immediately noticeable, and water from the Gaasperplas could be drawn to the pumping test. As the Gaasperplas is a large water body it could potentially contribute during long exfiltration process. In a non-stressed situation the ditches are draining due to the elevated hydraulic head in the confined aquifers and the lower surface water level. Due to lowering of the hydraulic head in the first confined aquifer during the pumping test, surface water could infiltrate. Which is what happens during the Nellesteinpad pumping test.

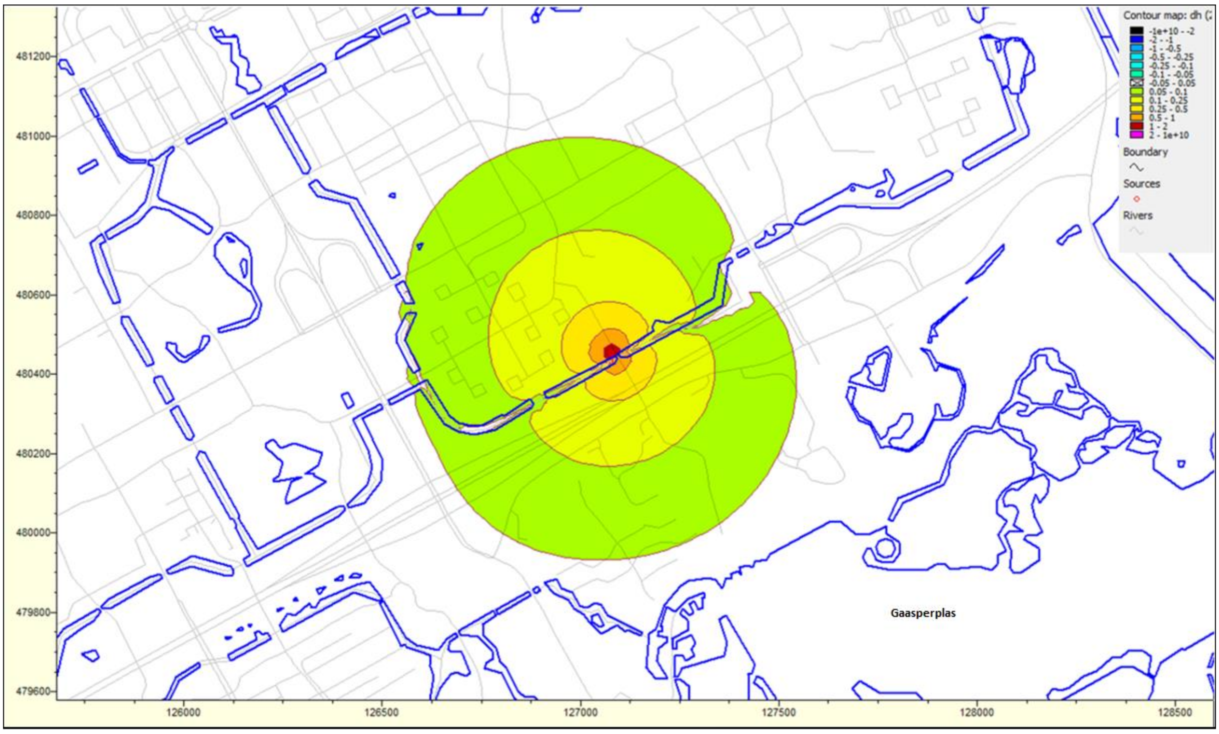

Figure 4.25 *Sphere of influence of the steady state calibration of the pumping test Nellesteinpad, with the outer line indicating the 0.05 m drawdown line. Roads are in grey lines, while ditches and lakes are drawn in thicker blue lines.*

4.4.3 Transient optimisation in Triwaco

Model

The model during transient calibration is nearly the same as during steady state calibration. A difference with the steady state model is the addition of transient parameters such as storativity. The value for storativity was determined during parameter optimisation. Table 4.20 shows the result of the parameter optimisation during transient calibration. The result of the storativity analyses can be found in the Appendix E.

Table 4.20 *Parameters for the transient model calibration of the Nellesteinpad pumping test.*

Parameters explained	Parameters	Model 3
Hydraulic conductivity of aquifer 2	K2 [m/d]	1
Hydraulic conductivity of aquifers 3 and 4	K3 and K4 [m/d]	15
Vertical resistance of aquitard 3	Cl3 [day]	5
Vertical resistance of aquitard 4	Cl4 [day]	50*
Infiltration resistance ditch in aquifer 2	Cinf2 [day]	25
Storativity of all confined aquifers	SC1-8 [-]	4e-04

* During the transient modelling, the fit improved with 50 days instead of 30 days.

Optimisation process

Calibrated and observed drawdown for all the observation wells are available in Figure 4.26. Furthermore in Figure 4.27 the average, minimum and maximum residual is shown for all the observation wells. The RSS for observation well 1 to 7 is 4.66 m^2, while the RSS for observation well 2 to 7 is just 0.71 m^2.

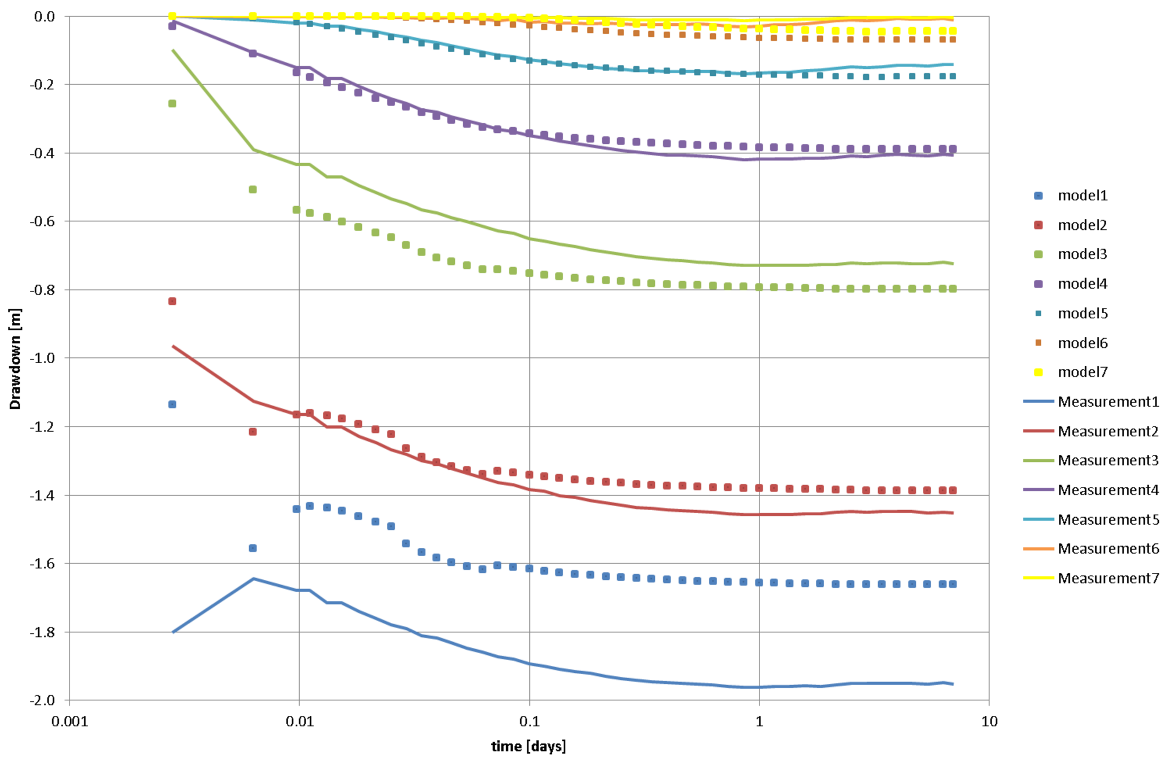

Figure 4.26 Best fit of the transient model. Calibrated (points) and observed (lines) drawdown.

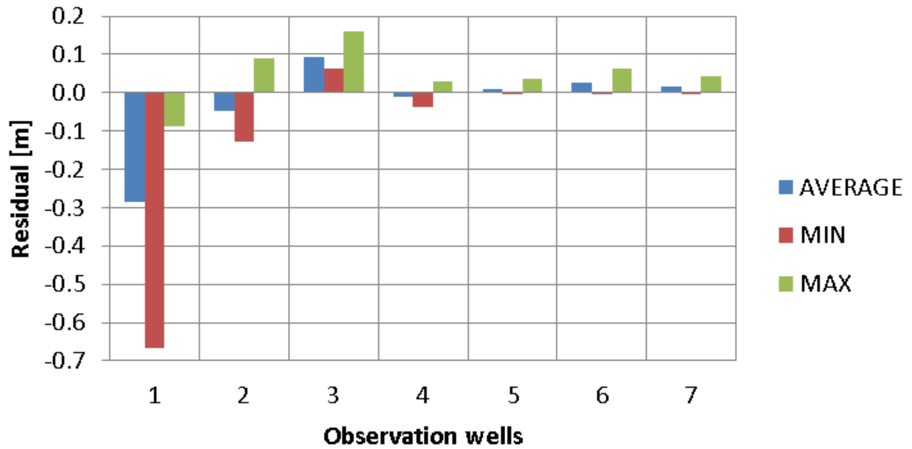

Figure 4.27 Residual analyse of the best fit for transient.

Sphere of influence

Figure 4.28 shows the sphere of influence of the pumping test Nellesteinpad. Again, the influence of the Gaasperplas and the ditches surrounding the pumping test is noticeable. Nellesteinpad, with the outer line indicating the 0.05 m drawdown line. The map was made after 7 days of extraction. The radius of the sphere of influence is on average around 500 m, but as can be seen in Figure 4.28 the sphere has an elongated shape.

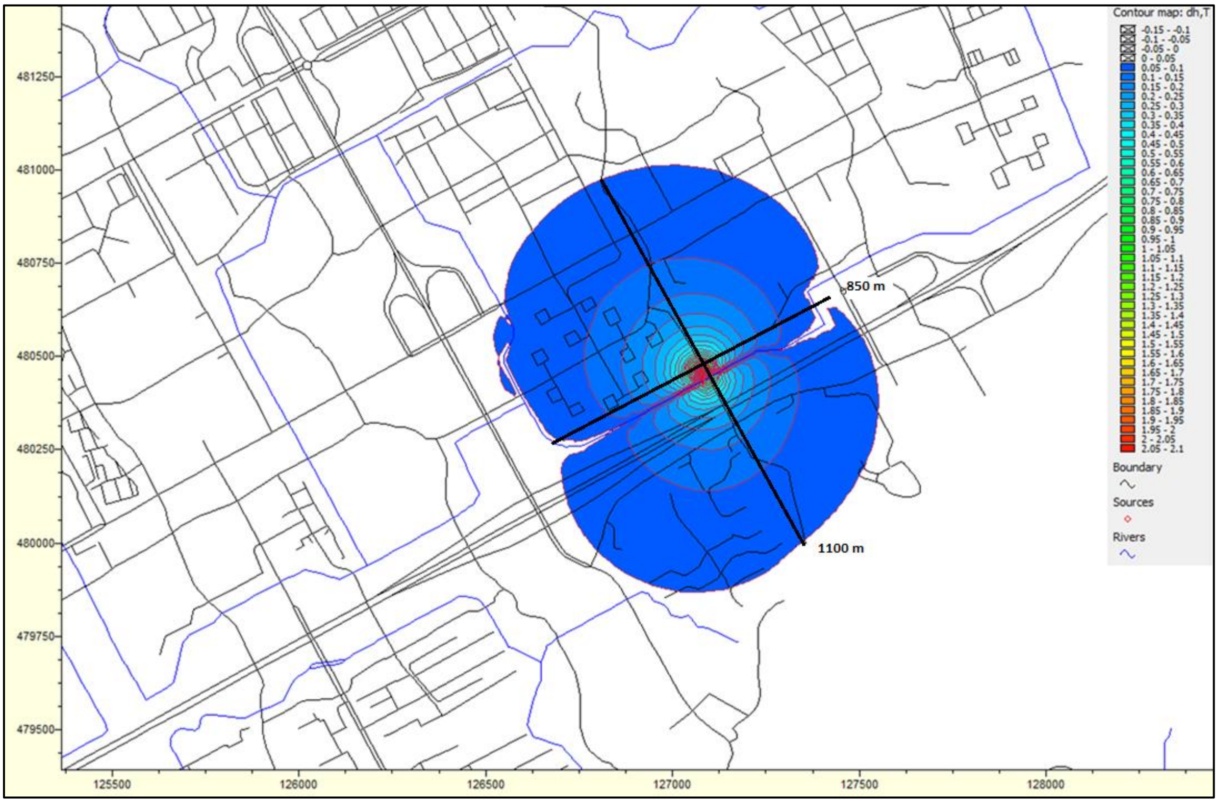

Figure 4.28 *Sphere of influence of the transient calibration of the pumping test, with a diameter from North to South of around 1100 m and a diameter from West to East of around 850 m.*

4.5 Synthesis

Table 4.21 shows some general values for the three different pumping test locations. The duration of the three pumping tests was very comparable with 7 days of extraction for both the Huntumdreef and the Nellesteinpad pumping test and 6 days of extraction for the Amstelveen pumping test. Although extraction rate varied little between the Nellesteinpad and Amstelveen pumping tests, respectively 1255 m3/day and 1213 m3/day. The sphere of influence of the Amstelveen pumping test is more than thrice that of the Nellesteinpad pumping test. More than a 1000 m for the Amstelveen pumping test and just 300 m for the Nellesteinpad pumping test. The radius of the sphere of influence for the Huntumdreef and Nellesteinpad pumping tests varied much less, with a difference of 25 %. The average extraction rate of the Huntumdreef pumping test is 34 % more than the Nellesteinpad extraction rate. And the drawdown at a distance of 5 m from the pump at the Huntumdreef location is more than twice as large as the drawdown at the Nellesteinpad location.

Table 4.21 Duration of extraction, average extraction rate, drawdown, and sphere of influence for the three pumping test locations.

Location	Duration of extraction [day]	Average extraction rate [m^3/day]	Drawdown at a distance of 5 m from the pump [m]	Sphere of influence [m]
Huntumdreef	7	1680	4.20	400
Nellesteinpad	7	1255	2.00	300
Amstelveen	6	1213	1.90	>1000

* Sphere of influence is from the distance drawdown graphs.

Table 4.22 is a combination of the best results for the three locations, with corresponding ranges of the optimised values in brackets. The ranges are calculated from the standard deviation. As can be expected due to the difference in hydraulic heave at the three locations, the optimised values of the first aquitard vary considerably. The value of 25 days is the specific infiltration resistance beneath the ditches, while the vertical resistance of the first aquitard is in the region of 10.000 days. The Boxtel Formations has an optimised value of 1 to 2.1 m/day at Huntumdreef and Nellesteinpad, which includes the original value of 2 m/day from Beemster (2014). The pumped aquifer varies with contents across the three locations, with Boxtel, Dtc, Kreftenheye and Urk. However the optimised value varies only from 15 to 25 m/day, which is a difference of between 1.5 to 2.5 times less than the original value of 37.5 m/day (Beemster, 2014). Optimised values for virtual resistivity layers vary from 0.5 to 5 days. The three aquitard layers, Dtc1, Dtc2 and Sterksel are all at different depths and have different thickness’ and this is why they vary from 38 to 250 days.

Table 4.22 Best fit results from MLU for the three pumping test locations, including the Triwaco results for the Nellesteinpad pumping test. Ranges for optimised parameters are in brackets, and Formations are abbreviated.

<table>
<tr><th colspan="2">Huntumdreef</th><th colspan="3">Nellesteinpad</th><th colspan="2">Amstelveen</th></tr>
<tr><th>Formations</th><th>Values</th><th>Formations</th><th>Values</th><th>TRIWACO Nellesteinpad</th><th>Values</th><th>Formations</th></tr>
<tr><td>An [m/day]</td><td>5</td><td>An [m/day]</td><td colspan="2">5</td><td rowspan="2">1000</td><td rowspan="2">Nw, Ni [day]</td></tr>
<tr><td>Nw, Ni [day]</td><td>733 (682 to 784)</td><td>Nw, Ni [day]</td><td>117 (111 to 123)</td><td>25***</td></tr>
<tr><td>Bx [m/day]</td><td>2.1 (1.6 to 2.6)</td><td>Bx [m/day]</td><td>1.4 (1.3 to 1.5)</td><td>1</td><td rowspan="3">20 (19.6 to 20.4)</td><td rowspan="3">Bx, Kr,
Dr [m/day]</td></tr>
<tr><td>vrl [day]</td><td>4</td><td>vrl [day]</td><td>0.5*</td><td>5</td></tr>
<tr><td>BX, Dtc [m/day]</td><td>25 (24.5 to 25.5)</td><td>Dtc [m/day]</td><td>20 (19.8 to 20.2)</td><td>15</td></tr>
<tr><td rowspan="3">Dtc1 [day]</td><td rowspan="3">239 (234 to 244)</td><td>vrl [day]</td><td>1.5*</td><td>5</td><td>2 (1.7 to 2.3)</td><td>vrl [day]</td></tr>
<tr><td>Dtc [m/day]</td><td>20 (19.8 to 20.2)</td><td>15</td><td>13 (12.7 to 13.3)</td><td>Dtc, Ur [m/day]</td></tr>
<tr><td>Dtc2 [day]</td><td>38 (35 to 41)</td><td>****</td><td>250</td><td>St [day]</td></tr>
<tr><td>St, Pz,
Wa, Ms [m/day]</td><td>48 (42.2 to 53.8)**</td><td>St, Pz,
Wa, Ms [m/day]</td><td>29 (22.3 to 35.7)</td><td>37.5 (Maassluis 25)</td><td>37.5</td><td>Pz,
Wa, Ms [m/day]</td></tr>
</table>

* Values were optimised but standard deviation was too small to show a range.

** Value for an aquifer thickness of 42 m,

*** The value of 25 days is the infiltration resistance beneath the ditches in this area. The vertical resistance of this layer when not intervened by ditches is 10.000 days.

**** Not modelled in Triwaco.

5 Prediction

5.1 Eastern tunnel in MLU

Location

Coordinates of all the extraction, injection and observation wells can be found in Appendix F. An overview of all the wells can be found in Figure 5.1.

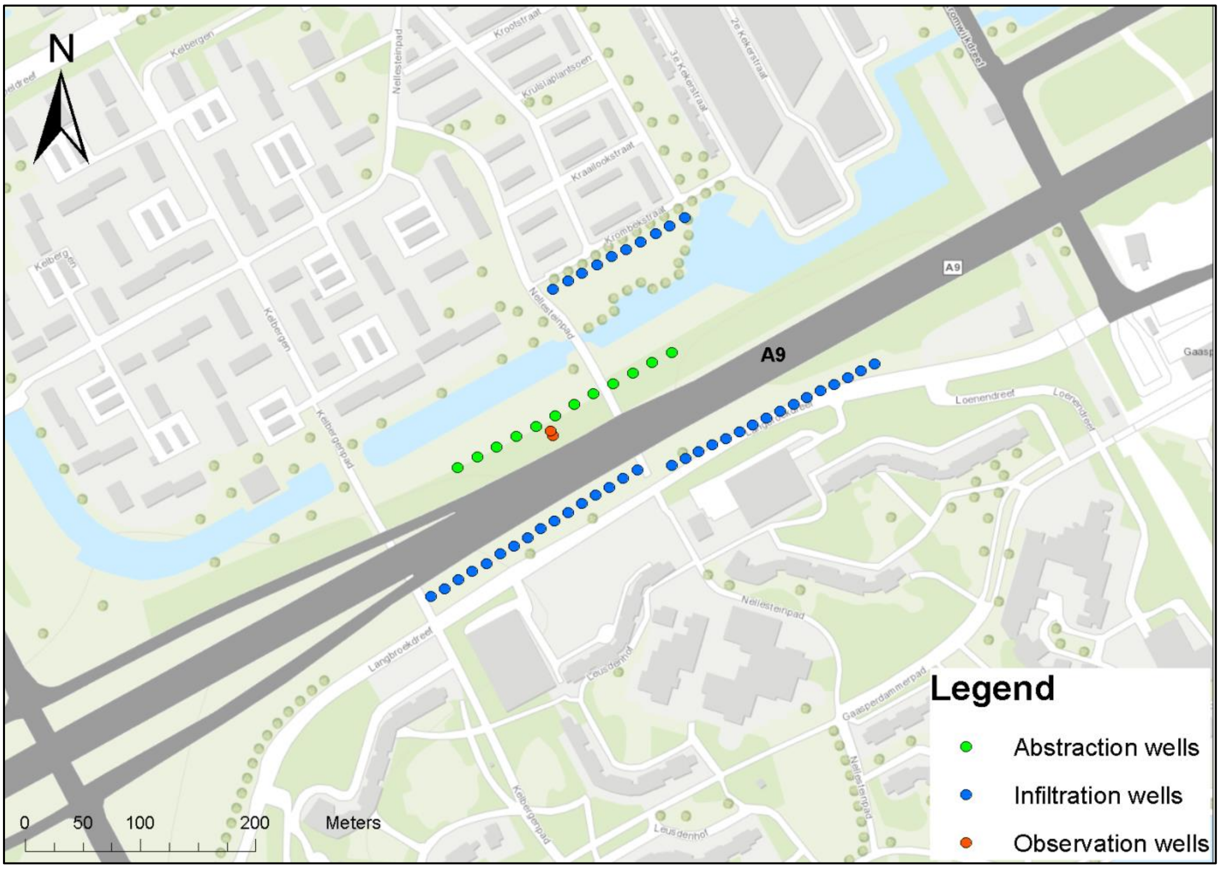

Figure 5.1 Overview of all the wells present in the MLU model.

Model

The average scenario which is presented in Table 5.1 is the calibrated Nellesteinpad model with the best fit parameters from MLU (Table 4.9). The low and high scenario deviate 10 % from the average scenario, which was chosen to be able to analyse the abstracted amount needed for a drawdown of 1.60 m in the building pit, and the difference in the sphere of influence.

In the low scenario the hydraulic conductivity is 10 % less and vertical resistivity is increased with 10 %. While in the high scenario the hydraulic conductivity is increased with 10 % and the vertical resistivity is reduced with 10 %. The only model layer that is not changed is wvl1, because this layer was not optimised. Pumping and injection wells have their well screen in both wvl2 and wvl3, and the observation wells are located in layer wvl2.

Table 5.1 Calibrated model with low, average, and high scenario.

			Low scenario		Average scenario		High scenario	
Model layer	**Base [m]**	**Thickness [m]**	**K [m/d]**	**c [days]**	**K [m/d]**	**c [days]**	**K [m/d]**	**c [days]**
wvl1	-5.65	2	5		5		5	
sdl2	-8.65	3		128.7		117		105.3
wvl2	-17.65	9	1.24		1.38		1.52	
sdl3	-17.65	0		0.52		0.47		0.42
wvl3	-27.65	10	18.15		20.17		22.19	
sdl4	-27.65	0		1.64		1.49		1.34
wvl4	-41.1	13.45	18.15		20.17		22.19	
sdl5	-42.6	1.5		41.69		37.9		34.11
wvl5	-192.6	150	25.65		28.5		31.35	

Extraction and injection rates

Extraction and injection rates per well are calculated from the data found in the rapport by IXAS (Kramer, 2015). The planned amount of wells for the entire section of 900 m is 45 which results in an average extraction rate of 16 m^3/h for every well. And the amount of injection wells planned totals 84, which results in an average injection rate per well of 5 m^3/h. The calculated amount of injection is set at 60 % of the abstracted water.

12 extraction wells (every 20 m for 250 m) and 42 injection wells (every 12 m for 530 m), in three well fields of 200, 200, and 130 m length are needed for the project. Therefore the first extraction rate used is 16 m^3/h per well and if 60 % of the total amount of abstracted water is returned this culminates to 3 m^3/h per injection well. Extraction and injection rate used for MLU can be found in Table 5.2

Table 5.2 Input for the MLU model.

		Low scenario		Average scenario		High scenario	
46 days of extraction	**Number of wells**	**Per well [m^3/day]**	**Per well [m^3/h]**	**Per well [m^3/day]**	**Per well [m^3/h]**	**Per well [m^3/day]**	**Per well [m^3/h]**
Extraction	12	384*	16	408	17	456	19
Injection	42	66	3	70	3	78	3

* The total amount of groundwater abstracted with 12 extraction wells is 4608 m^3/day.

Results

A drawdown of 1.60 m at the southern edge of the building pit is required. An extraction rate of 16 m^3/h proved to result in a drawdown with a minimum of 1.60 m in the southern edge of the building pit for the low scenario. For the average scenario an extraction rate of 17 m^3/h was needed to achieve 1.60 m of drawdown. For the high scenario a minimum of 19 m^3/h was needed to achieve 1.60 m of drawdown in the building pit. See Table 5.3 for an overview of the results.

Table 5.3 *Drawdown at the site of the building pit.*

Scenarios	K-values	c-value	Extraction rate per well [m^3/h]
Low	Optimised value -10 %	Optimised value +10 %	16.0
Average	Optimised value		17.0
High	Optimised value +10 %	Optimised value -10 %	19.0

Sphere of influence

Figure 5.2 shows the calculated 0.05 m drawdown line of the three different extraction rates. This image shows that the sphere of influence crosses the Gaasperplas which is an infiltrating water body and that the model is also not influenced by ditches. This is as expected, because the influence of the Gaasperplas and the ditches cannot be taken into account in the schematisation of the model in MLU. Figure 5.3 shows the calculated 0.05 m contour line for the average scenario in the phreatic aquifer. The differences between the three scenarios is small in the phreatic aquifer.

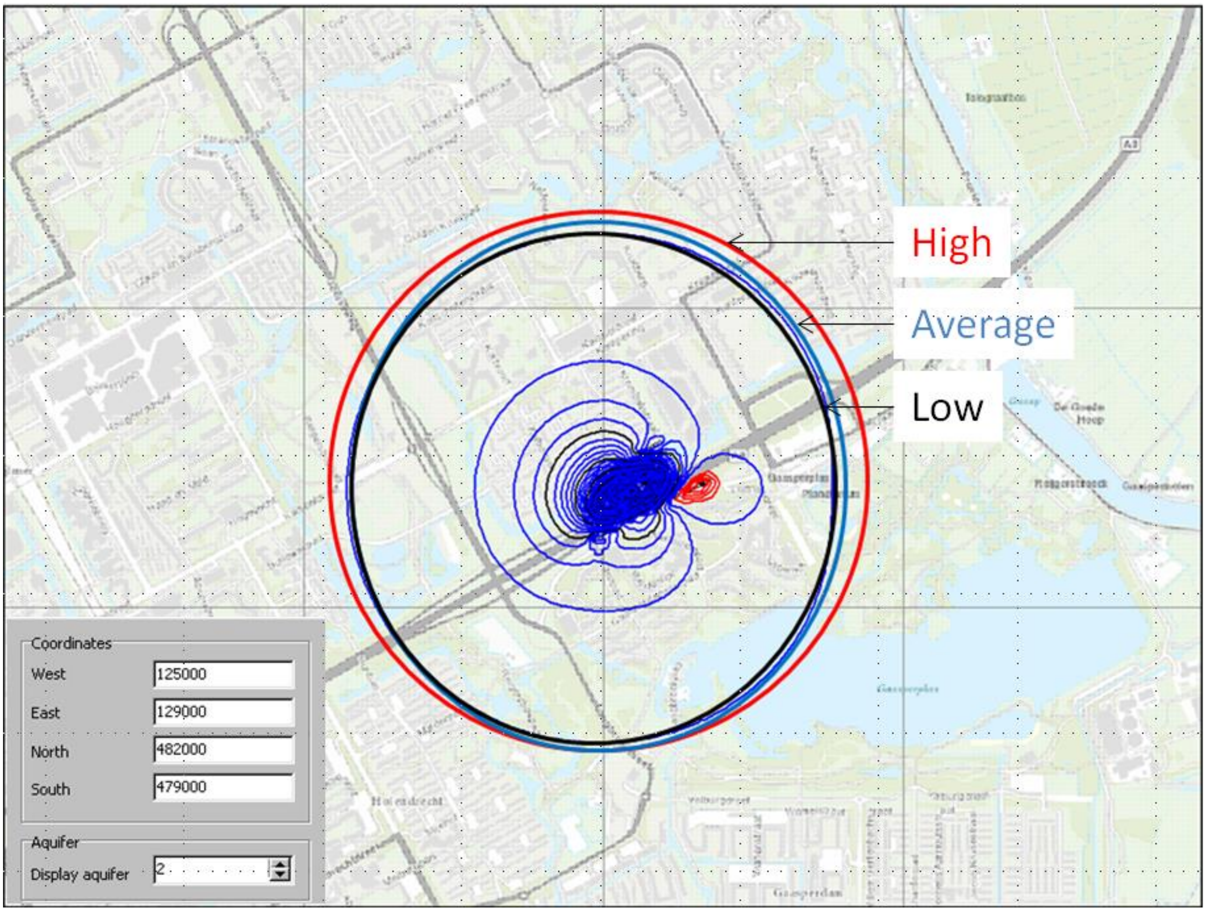

Figure 5.2 *The calculated 0.05 m contour line (the outer contour line) for the three different scenarios in the first confined aquifer.*

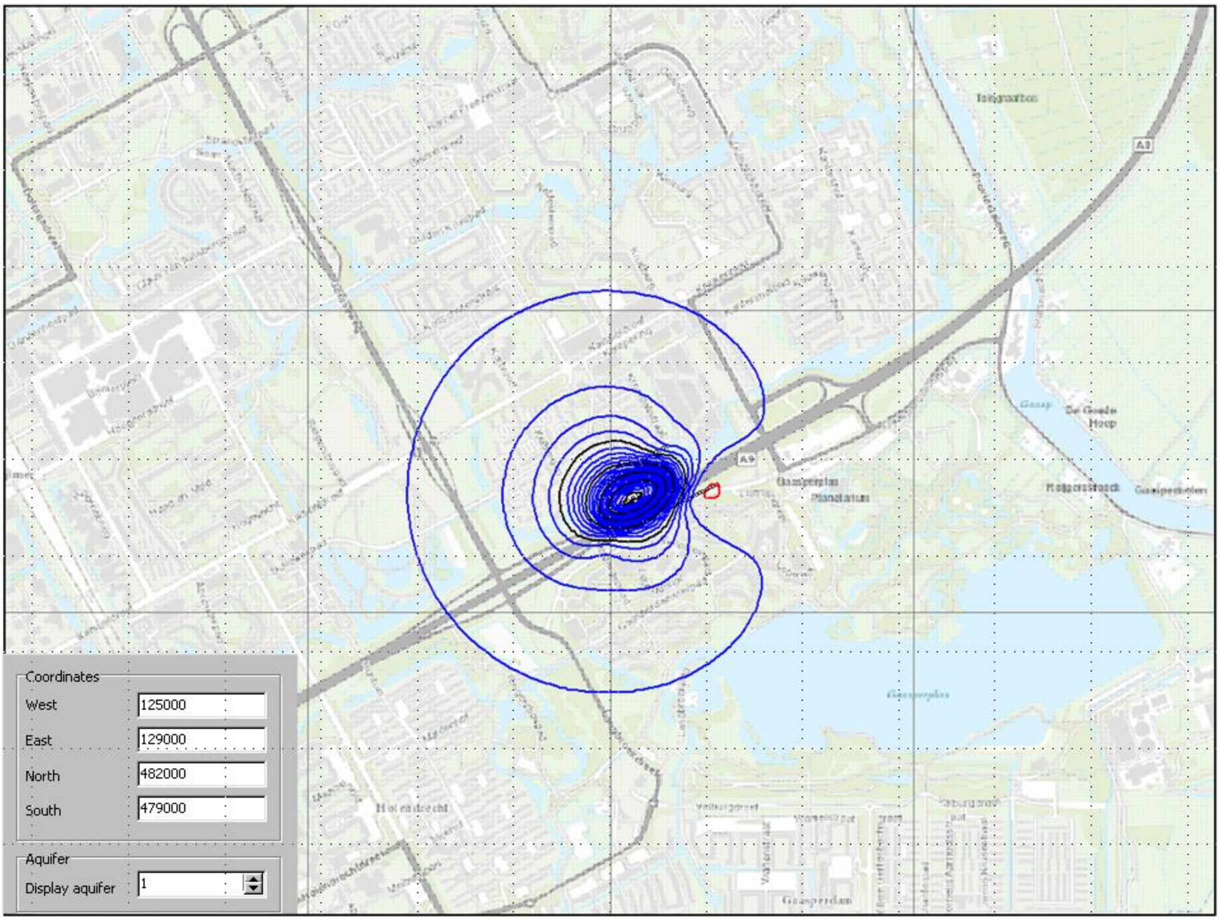

Figure 5.3 *The calculated 0.05 m contour line (the outer contour line) for the average scenarios in the phreatic aquifer. The difference between the three scenario's is small, and therefore only one scenario is shown.*

5.2 Eastern tunnel in Triwaco

Model

The model used is the best fit model described in paragraph 4.4.3.

Extraction rate

The extraction rate was calculated by taking the remaining 40 % of the total extraction. Due to time constraints no injection wells were used during this prediction, and only one scenario is calculated. The extracted volume used in this model can be found in Table 5.4.

Table 5.4 Extraction rate calculation.

Extraction or injection	Total [m^3/day]	Percentage of total [%]
Extraction rate from average scenario	4608*	100
Injection rate from average scenario	2772	60
Extraction rate for prediction in Triwaco	1843	40

* Total abstracted amount available in Table 5.2.

Sphere of influence

Figure 5.4 shows the sphere of influence of the extraction. Figure 5.5 is a profile drawn across the approximate location of the building pit and shows a maximum drawdown of 1.90 m. The 1.60 m drawdown line spreads across a length of a minimum of 25 m. The building pit begins at a distance of 10 m from the extraction wells and ends at 15 m. Therefore it is possible that the drawdown is only enough in part of the building pit.

5.3 Differences

In this calculation there is a big difference between the amount of infiltration and extraction wells. As there should have been twelve extraction wells and 42 infiltration wells and there is only one extraction well. But by only extracting 40 % of the total abstracted volume, this is more or less compensated.

A clear difference is found between the nearly round or elliptical shape of the extraction in MLU, which crosses the boundary of the Gaasperplas and is not locally influenced by the ditches. This is a contrast with the wobbly shape of the sphere of influence in the program Triwaco. The sphere of influence is clearly influenced by the ditches on the North side of the A9. The Gaasperplas appears to reduce drawdown South of the A9, as the 0.05 m drawdown line is much closer to the pumping well then at the North side of the A9 near the marked A of the profile line. This is as expected, because the ditches and the Gaasperplas are in the schematisation of the Triwaco model.

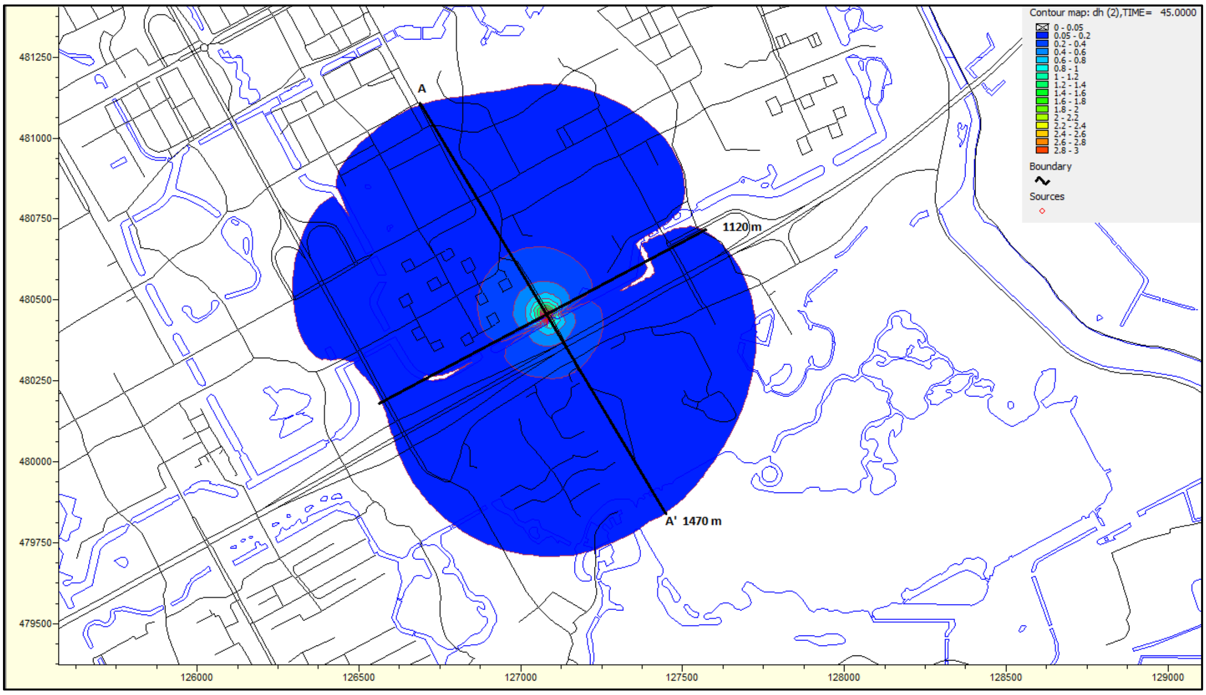

Figure 5.4 Calculated sphere of influence (0.05 m drawdown), with a profile from A to A' that can be seen in Figure 5.4.

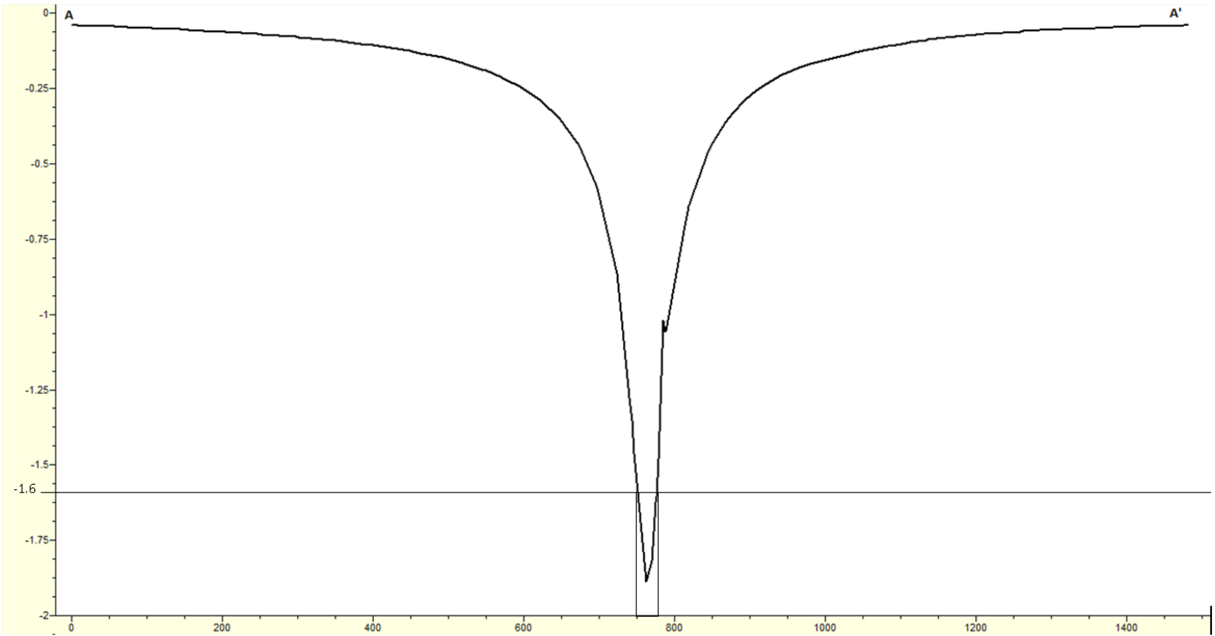

Figure 5.5 Profile from A (north) to A'(South) with the calculated amount of drawdown. For the location of the profile see Figure 5.4.

6 Discussion

Precipitation

When groundwater level measurements in the phreatic aquifer are present, a part of the variation seen can be explained by precipitation. However, precipitation has very little to no influence on hydraulic head in the deeper aquifer and cannot explain the variation visible in the drawdown curve at all the pumping test locations. Shallow observation well measurements in the top aquifer and a time series of precipitation are always necessary to assess the influence of precipitation. During the pumping test there was very little or no rainfall, and therefore the influence of precipitation is neglected.

Extraction rate

One of the assumptions for a pumping test is known extraction, which is valid for all three pumping tests. The extraction rate was not measured continuously, but only at certain moments. Therefore changes in the extraction rate could only be recorded after the event happened, which means detailed measurements of the extraction rate are missing. The average extraction rate which is sometimes used during steady state modelling is slightly higher than the extraction rate dominant at the end of the pumping test. Therefore, the difference between steady state and transient runs could partly be attributed to the difference in extraction rate.

Surface water

All three pumping tests are in the vicinity of ditches into which the water was discharged during the pumping tests. The ditches surrounding the Nellesteinpad and Huntumdreef pumping test are set at a target level and therefore the surface water level will not have risen significantly by the addition of the extracted water. No surface water level time series could be found near the Amstelveen pumping test, but a safety factor of 1.6 is calculated for this location. The value for the safety factor indicates that it is unlikely hydraulic heave is present near the Amstelveen pumping test, and therefore the vertical resistance of the first aquitard is high at around 1000 days.

The hydraulic head measurements of the confined aquifer at both Huntumdreef and Nellesteinpad show the influence of the surface water level. The surface water level is kept at a target level by pumping station ‘Zandpad’ and it is the turning on and off again signal of the pumping station that is visible in the hydraulic head time series. This indicates a hydraulic contact between the surface water level and the first confined aquifer. Which is confirmed at the Nellesteinpad location by a safety factor of 0.8. At the location Huntumdreef a safety factor of 1.1 is calculated, which indicates that in the area surrounding the pumping test hydraulic heave could be present, although it is not present exactly at the calculated location. Both at the Huntumdreef and Nellesteinpad locations, the pumped aquifer is a bounded aquifer and the assumption of infinite areal extent is no longer valid.

For the Nellesteinpad pumping test, hydraulic head was corrected for the surface water influence. By subtracting the time series of the furthest observation well from the rest of the observation well, the surface water signal was removed. However, after one day the drawdown goes down again in observation well, as can be seen in the time-drawdown graph in paragraph 4.2.3. This might be a side-effect of the surface water level correction. The furthest observation well might have been too close to the pump, and therefore a couple of centimetres of drawdown could be caused by the extraction rate. Another possibility is that due to the distance of the observation wells from the ditches being variable, the correction might simply be too large for some of the time series of the observation wells.

Groundwater and extraction levels

As the Nellesteinpad pumping test does not include groundwater level measurements these cannot be analysed. For the Huntumdreef and Amstelveen pumping test the groundwater levels react differently.

The groundwater level does not seem to respond to the drawdown in the aquifer at the Huntumdreef pumping test location. The time series of observation wells 2, 3, and 4 show a steady rise of 0.30 to 0.40 m during the month of December 2012, while the time series from observation well screens 8, 9, and 10 show a reaction to precipitation. This suggest a high resistance of the resistivity layer above the pumped aquifer. The shallow well screens were only used qualitatively and not during the optimisation process. This is done because the shallow well screens were installed in the aquitard and not in the phreatic top aquifer, which made it difficult to model these well screens.

Some well screens react very clearly to the water extraction, such as observation well P5 and P10 during the Amstelveen pumping test, while others do not. A reason for this could be that the vertical resistivity of the aquitard varies at the locations. And that these observation wells are very close (5 and 10 m distance) to the pumping well and therefore are more influenced by water extraction. The rise visible in some of the observation wells could perhaps be caused by a rise in the surface water due to discharge of the pumped water into the ditches, but this could not be checked.

Hydraulic head and drawdown

The semi log time-drawdown relationship is most similar to that of a leaky aquifer for all three pumping tests.

The maximum drawdown at the Huntumdreef pumping test can be seen in observation well 1b (4.20 m) at a distance of five meters from the pumping well and the least drawdown can be seen in observation well 14 (0.03 m), the most remote at a distance of 831 m. The semi log drawdown distance graphs suggest drawdown during this pumping test extends to a distance of at least 300 to 400 m.

The largest drawdown at the Nellesteinpad pumping test is in observation well 1 with 2 m of drawdown at a distance of 5 m from the pumping well. At a distance of 522 m drawdown is 0.04 m. The semi log drawdown and distance graph shows a sphere of influence of 300 m.

During the Amstelveen pumping test the drawdown varied between 5.80 m at the location of the pumping well and 0.10 m at the furthest observation well P900 which is at a distance of 915 m from the pumping well. After one day of extraction drawdown seems to become stable, except for the well screen in the pumping well. However, near the end of the pumping test hydraulic head goes down again slightly. In the distance-drawdown graph observations fit on a curved line, except for P250 with a drawdown of 0.45 m. At a distance of 915 m from the pumping well the drawdown is still 0.10 m, suggesting a sphere of influence of at least 900 m.

Lastly, a lake ‘De Poel’ lies at a distance of around 900 meters from the pumping well, which could supply water near the end of the pumping test when drawdown reaches the lake.

Optimisation results

Steady-state modelling was only used to gain insight into the pumping test and to build up complexity slowly during the optimisation process. During transient modelling all three pumping test location have a different model schematisation in MLU. However there is always an aquitard layer, either a virtual resistivity layer or an existing aquitard layer, beneath the well screen of the pump. Only the Nellesteinpad pumping test is also modelled in Triwaco with both steady-state and transient models.

During transient modelling the pumped aquifer was split into a top part (Boxtel Formation) and a lower part (Boxtel Formation and glacially reworked layer). The top aquifer (8 m) was calibrated to a value of 2.1 m/d, which can be supported by a cone penetration test made at the site of the pumping test that shows the Boxtel Formation at the site has a fine sand lithology (Appendix J and K). The lower part of the aquifer (Boxtel and glacial formations) is calibrated to a value of 25 m/d. And the aquitard layer beneath the pump is calibrated to a vertical resistivity of 239 days. The top aquitard layer was calibrated to a value of 733 days.

For the Nellesteinpad pumping test in MLU the first confined aquifer layer completely consists of Boxtel sands and is calibrated to a low hydraulic conductivity of 1.4 m/d. While the pumped aquifer layer is calibrated to a value of 20 m/d. This layer completely consists of the glacially reworked layer. Both the pumped aquifer and the aquifer layer below this layer comprise of the glacially reworked layer and are optimised together. A clay layer of 1.5 m represented by model layer sdl5 is calibrated to a value of 38 days. The top aquitard layer is optimised to a relatively low value of 117 days, which can be explained by the hydraulic heave present at the location of the ditches.

For the Nellesteinpad pumping test in Triwaco the first confined aquifer layer was calibrated to a value of 1 m/day and the pumped aquifer was optimised to a hydraulic conductivity of 15 m/day. Although the first aquitard layer was not optimised and remained unaltered at a high vertical resistivity of 10.000 days, the infiltration resistance from the ditches to the first confined aquifer was optimised to a value of 25 days.

For the Amstelveen pumping test hydraulic conductivity for the pumped aquifer was 20 m/d, and hydraulic conductivity of the aquifer layer below the pumped aquifer is optimised to a value of 13 m/d. The vertical resistivity of the aquitard layer beneath the pump was optimised to a value of 2 days.

Comparison with results from other sources

In a rapport by the consortium IXAS, the Huntumdreef pumping test was also modelled with the program MLU, only the observation wells in the pumped aquifer were used as was also done in this research. For the Huntumdreef pumping test a value of 200 days was calculated for the first aquitard layer (5 m thick), while the main aquifer (23 m thick), which includes the pumping well and the observation well, received a hydraulic conductivity of 9 m/d. The aquitard clay layer of 0.5 meter below the well screen of the pump was modelled to a value of 25 days. A value of 200 days for the first aquitard layer is smaller than the 733 days found in this thesis. The value of 25 days for the aquitard layer beneath the pump is ten times smaller than the value of 239 days found in this thesis. A hydraulic conductivity of 9 m/day falls between the values of 2.1 and 25 m/day found for the aquifer.

In a rapport by the consortium IXAS the Nellesteinpad pumping test was also modelled with the program MLU. A 5 m thick aquitard was modelled to a vertical resistivity of 200 days, while the pumped aquifer of 23 m thick was calibrated to a value of 14 m/d. The value of 14 m/d is lower than the optimised value of 15 m/day from the Triwaco model and lower than the optimised value of 20 m/day in MLU. A clay layer mentioned beneath the pump in the rapport by Fugro (2013) was also mentioned in the rapport by IXAS (2015). However, a CPT (Appendix K) does not show this clay layer and was therefore not used in this thesis.

According to the rapport by Witteveen+Bos for the Amstelveen pumping test the value of 10.000 days for the entire first aquitard layer has been assessed with the two phreatic well screens installed after the pumping test. During the return test these do not react on the water extraction according to the report and therefore a high vertical resistivity is needed to achieve this. Furthermore, a large part of the resistance is due to the presence of the basal peat layer at the bottom of the first aquitard layer. The increase in groundwater level that can be seen on the 24th of august is likely due to precipitation on the same day. The hydraulic conductivity for the pumped aquifer, with a thickness of 44 m, was 15 m/d, which is near the values of 13 to 20 m/d. For a complete aquitard, a value of 10.000 days is not strange to assume, but a lateral variety is apparent in the aquitard when one takes the reaction of the shallow observations wells into account, as can be seen in the well screens nearby the pumping well. However, in the other well screens, this reaction is not visible, and in some well screens groundwater levels even go up during the pumping test.

Triwaco model

The first observation well was not modelled properly due to the grid being too large around the pump. The first observation well stood at a distance of 4.6 meter, while the grid refinement around the pump was done in circles of consecutively 5, 10 and 25 m. This is likely to be part of the cause of the large error found at the first observation well.

Infiltration resistance in the Triwaco model

Infiltration from the ditches is an important but difficult to quantify parameter. In MLU it is possible to simulate infiltration from above with a top leaky boundary, but this is not an optimal solution because ditches are present only at certain locations. In the Triwaco topsystem 4, there is a parameter for both infiltration resistance from the ditches to the aquifer and drainage resistance from the aquifer to the ditches. The optimised infiltration resistance of 25 days in Triwaco indicates the importance of infiltration from the ditches towards the aquifer. However, the infiltration resistance was not measured directly and it is an important parameter worth investigating in more depth. By measuring flow from the ditches to the confined aquifer, the parameter could be optimised in a more quantitative manner.

Prediction

In the prediction chapter the influence of the drainage of the building pit of the tunnel in both MLU and Triwaco is calculated. The MLU model schematisation used is based on the best fit from the Nellesteinpad optimisation in MLU. From the low to the average and to the high scenario, consecutively a higher abstraction rate is needed to achieve the planned amount of drawdown of 1.60 m. Also, the sphere of influence is consecutively slightly larger.

The building project was also modelled in Triwaco to better model the influence of local variations such as the ditches. Due to time constraints only the planned amount of extraction was used in the best fit model, and only one abstraction well was used with no infiltration wells. In the maps of the calculated drawdown, it becomes obvious that the ditches and the Gaasperplas are important parameters in the shape of the sphere of influence.

The sheet pilings which are present during construction are not modelled in MLU and Triwaco. This can however have a large influence on the sphere of influence if the sheets are (nearly) fully penetrating. But because it was unclear at what depth these would be installed, they were not taken into account in the model. Moreover, the depth of the aquifer (NAP -70 m) indicates that the sheet pilings will not be fully penetrating and groundwater flow can likely flow below the sheet pilings.

7 Conclusions

The primary objective of this research is to improve the local groundwater model by determining the hydraulic conductivity of the pumped aquifer and the hydraulic resistance of the top aquitard at the location of the polders Bijlmer and Zuid-Bijlmer by using three available pumping tests. The secondary objective is to predict the influence of the drainage of the building pit for the construction of a tunnel at the A9 highway in Amsterdam.

The pumped aquifer at the site of the Huntumdreef and Nellesteinpad pumping test is a combination of several different Formations (Boxtel, Sterksel, Peize, and Waalre) and the glacially reworked layer to the first probably aquitard at NAP -70 m. A partially penetrating well was set into the Boxtel Formation and the glacially reworked layer. Although the pump well screen was installed on a clay layer (0.5 m thick) for the Huntumdreef pumping test, this aquitard is probably of minimal lateral extent due to its origin in the glacially reworked formation. The hydraulic conductivity of the top part of the pumped aquifer is optimised to an average value of 2 m/day (range of 1.0 to 2.6 m/day). The hydraulic conductivity of the second part of the pumped aquifer is considerably higher with an average optimised value of 20 m/day (range of 15.0 to 25.5 m/day). The vertical resistance of the top aquitard in the area surrounding both the Huntumdreef and Nellesteinpad pumping test is variable due to the local presence of hydraulic heave at the location of the ditches. The vertical resistance of the top aquitard near the ditches is optimised to a value of 733 days (682 to 784 days) at the site of the Huntumdreef pumping test. The vertical resistance of the top aquitard near the ditches is optimised to a value of 117 days (111 to 123 days) at the site of the Nellesteinpad pumping test in MLU. And the infiltration resistance from the ditches to the aquifer near the Nellesteinpad pumping test is optimised to a value of 25 days in Triwaco, while the vertical resistance of the first aquitard has a value of 10.000 days.

The first confined aquifer at the site of the Amstelveen pumping test is a combination of Boxtel, Kreftenheye, Drente, Urk, and Sterksel Formations and a glacially reworked layer. The first aquitard underneath this aquifer is likely to be the Waalre clay layer at NAP -72 m, but could also be the Sterksel clay layer at NAP -50 m. A partially penetrating well was used and installed in the Boxtel, Kreftenheye and Drente Formations. The transition between the Drente Formation and the glacially reworked layer should correspond with the end of the pump well screen. Hydraulic conductivity of top part of the aquifer was optimised to a value of 20 m/day (19.6 to 20.4 m/day). The bottom part of the aquifer is calibrated to a value of 13 m/day (range of 12.7 to 13.3 m/day). No hydraulic heave is present at the site of the Amstelveen pumping test and therefore the vertical resistivity of the top aquitard is thought to be of a high value of at least 1000 days. However, *e.g.* downward seepage could cause the vertical resistance to be lower.

Summarizing the most important conclusions, the pumped aquifer is optimised to a hydraulic conductivity of 15 to 25.5 m/d for all three pumping test locations. The vertical resistance of the first aquitard layer is variable due to the local presence of hydraulic heave near the ditches, especially in the area surrounding the Nellesteinpad pumping test.

After analyses of the extraction rate for the building pit in both MLU and Triwaco, it appears that an extraction rate of 16 m^3/day with an injection amount of 60 % will be an adequate estimation of the amount of drawdown needed. However, this is only an indication because of the way the test was modelled, especially in Triwaco, and because other factors are not taken into account such as DSI-injection and the possible presence of sheet pilings.

8 Recommendations

Well screen depths

For future pumping tests it is recommended to plan a pumping test with observation wells at several different depths above and below the depth of the pumping well to obtain the best image of the reaction of the subsurface. To obtain information about the vertical resistivity of an aquitard, an observation well screen above and below the aquitard is necessary. If observation well screens are included below, at the same height and above the pumping well this will aid in obtaining the vertical resistivity caused by the Dupuit effect in partially penetrating pumping wells. It will also give more information about resistivity and transmissivity of the rest of the aquifer beneath the pumping well.

Stopping test

In hindsight, with the data obtained from all three pumping tests, it would have been useful to focus not only on the pumping test itself, but also on the stopping test. The stopping test was rather well documented and could give further insight into the aquifer and aquitard. Especially because during the stopping test the extraction rate is zero, which then validates the assumption of a known abstraction rate, which is needed for a pumping test. However, the extraction rate during the pumping test does still need to be known.

Model

For extraction rates in the steady-state model, it would have been better to take the last measured extraction rate instead of the average weighted extraction rate. And, in the case of Triwaco, always make the grid as fine as needed to prevent results being skewed, because otherwise the model cannot properly calculate the hydraulic head near the extraction well. Furthermore, due to the nature of the location with infiltration possibilities from the ditches, it would have been favourable to make more use of the possibilities of a finite element model such as Triwaco. And for the research it would have been useful to make more use of the Triwaco model and not just model one pumping test but all.

Surface water

At the location of the Gaasperdammerweg pumping tests it would have been useful if the surface water nearest to the pumping well would have been observed by means of for example an automated pressure transducer. With this data, the influence of the surface water on the measured heads in the observation wells could be estimated in more detail. After which the surface water can then be modelled as an image well with a particular amount of infiltration in a model such as MLU. However, it is more favourable to use a model such as Triwaco in which spatial variations can be added.

Cone penetration test

For a lateral information database, it would be interesting to investigate the more than hundred cone penetration tests set alongside the A9 Gaasperdammerweg. Unfortunately, the extent of the research done during this internship, did not include looking through this dataset. These cone penetration tests should give an invaluable image of the lateral extension and variability of the aquitard with the Holland peat and Basal peat layers, the Boxtel Formation and the glacially reworked layers.

Borehole

The actual depth of the aquifer is still not 100 % known and therefore it could give invaluable information to execute a drilling to a depth of at least 100 m. The information gained from this drilling could especially elucidate the presence of the clay layer of the Waalre and or Sterksel Formations.

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11 Appendices

A. Geology of Amsterdam

Small descriptions of all the Formations and layers that are mentioned in this thesis. The information in this paragraph is very general and only gives an indication of the range of the hydraulic conductivity and vertical resistivity. The information is from Dinoloket, and the hydraulic conductivities and vertical resistivities are from Bear (1974).

1. Anthropogenic

This generally indicates manmade layers such as extra sand layers for building works, or farmed landed which has been worked. The hydraulic conductivity of this layer is in the range of less than 1 m/day for dredgings to a maximum of 10 m/day (Waternet, 2016).

2. Naaldwijk Formation

The dominant lithology in the Naaldwijk Formation is clayey or very silty very fine to fine sand (105-210 µm). Several sublayers can be present in the Formation such as: Wormer and Walcheren. The entire Formation includes depositional environments such as: marine and lagoon deposits under influence of the rising sea level. The entire Formation is of Holocene age. The Wormer sublayer lithology is clayey to silty very fine to fine sand (105-210 µm) and clay. The environment in which this sublayer was deposited includes tidal areas behind the open shoreline. The hydraulic conductivity of these layers are in the range of 0.01 to 10 m/day.

3. Nieuwkoop Formation

The dominant lithology of the Nieuwkoop Formation is peat, which was deposited during the Holocene. Several sublayers are present in the Nieuwkoop Formation such as the Holland peat and Basal peat layers. Holland peat (Dutch: Hollandveen) can be found where the Nieuwkoop Formation is alternated with the Naaldwijk Formation and the dominant lithology is peat. The basal peat layer (Dutch: Basisveen) is usually a compact peat layer found directly on the Pleistocene sands. Due to sea level rise and consequently groundwater rising this peat layer was deposited. The vertical resistivity of these layers are in the range of 10 to 1000 days.

4. Boxtel Formation

The dominant lithology in the Boxtel Formation can be very fine to medium coarse (silty) sand (105-300 µm) sometimes including loam layers. The Formation includes a variety of sublayers which are formed in a variety of environments. Typical depositional environments are Aeolian, fluviatile and sometimes lacustrine or organogene. Deposited during Cromerian (Mid-Pleisotocene) to Holocene. The hydraulic conductivity of the Boxtel Formation is in the range of 0.05 to 10 m/day.

5. Kreftenheye Formation

The dominant lithology found in the Kreftenheye Formation is medium coarse to very coarse sands (210-2000 µm). The fluviatile deposits were deposited by the river Rhine system (or predecessor) during the Late-Saalien to Early Holocene). The hydraulic conductivity in the range of 30 to 200 m/day.

6. Drenthe Formation

The dominant lithology found in the Drenthe Formation is fine to very coarse sand (150-2000 µm), clay, and loam. The glacial deposits where formed by or near ice sheets during the Middle and Late Saalien. The hydraulic conductivity is in the range of 0.01 to 200 m/day.

7. Dtc

Dtc or glacially reworked layer, is a glacial complex of multiple layers that are difficult to specify to specific Formations (Vernes, et al., 2005).

8. Urk Formation

The dominant lithology found in the Urk Formation is medium fine to very coarse sand (150-2000 µm) and gravel (2-63mm). Three sublayers can also be present in the Formation: Veenhuizen, Tynje and Lingsfort. The Formation is part of the fluviatile rhine deposits deposited from the end of the Cromerien to the Middle of the Saalien period. The hydraulic conductivity of the Urk Formation is in the range of 10 to 500 m/day.

9. Sterksel Formation

The dominant lithology found in the Sterksel Formation is medium coarse to very coarse sands (210-2000 µm). Occasionally clay layers can be present, with thin (mm-cm) sand layers. These fluviatile deposits were also deposited by the river Rhine system but from the Early-Pleistocene to the Mid-Pleistocene. The hydraulic conductivity of the Sterksel Formation is in the range of 30 to 200 m/day, while the vertical resistivity of the clay layers can be around 20 days/m.

10. Peize Formation

The dominant lithology found in the Peize Formation is medium coarse to very coarse sands (210-2000 µm). The Formation is of fluviatile origin and created by the Baltic river system (Eridanos). The Formation was deposited from the Reuverien to the start of the Waalien. The hydraulic conductivity of the Peize Formation is in the range of 30 to 200 m/day.

11. Waalre Formation

The dominant lithology found in the Waalre Formation is very fine to very coarse sands (63-2000 µm). Occasionally clay layers with fine sand layers can be present. The fluviatile depositions where deposited by the Rhine River system during the Reuverien (Late-Pliocene) to the early Pleistocene (Praetiglien to Menapien). The hydraulic conductivity of the Waalre Formation is in the range of 1 to 200 m/day, and the clay layers can have a vertical resistivity of around 20 days.

12. Maassluis Formation

The dominant lithology in the Maassluis Formation is very fine to coarse sand (63-300 µm) and clay. The Formation was deposited in shallow marine and near coastal environment during the Pretiglien to Tiglien (Early Pleistocene). Generally speaking the clay and sand layers show a coarsen-upward sequence indicating sea regression. The hydraulic conductivity of the Maassluis Formation is in the range of 0.01 to 30 m/day. However the Maassluis Formation is seen as the geohydrological base and the clay layers can have a vertical resistivity of 10000 days (Dinoloket, 2015).

B. Huntumdreef

1. Tables and Figures

Table 11.1 Observation well screen information of the Huntumdreef pumping test.

Names*	X	y	Borehole description availability	Surface elevation [m NAP]	Top well screen [m NAP]	Bottom well screen [m NAP]	Distance to pumping well** [m]
Pumping well	125948.9	479812.3	-	0.15	-17.00	-27.00	
1a	125953.3	479814.9	✓	0.32	-3.65	-5.65	4.7
1b	125953.3	479814.9	✓	0.32	-12.63	-13.63	4.7
2a	125959.7	479816.8	✓	0.27	-3.73	-5.73	11.4
2b	125959.7	479816.8	✓	0.27	-12.72	-13.72	11.4
3a	125976.3	479822.3	✓	0.46	-3.53	-5.53	28.9
3b	125976.3	479822.3	✓	0.42	-13.53	-14.53	28.9
4a	126001.9	479834.5	✓	0.22	-4.56	-6.56	57.1
4b	126001.9	479834.5	✓	0.22	-12.92	-13.92	57.1
5b	126032.6	479855.1	✓	-2.59	-14.04	-15.04	93.6
6b	126155.5	479903.5	-	-1.05	-8.97	-9.97	225.5
6a	126155.5	479903.4	-	-1.05	-	-	225.5
7b	126565.2	480358.9	✓	-2.60	-14.69	-15.69	823
8a	125939.1	479809.9	✓	0.26	-3.93	-5.93	-10.3
8b	125939.1	479809.9	✓	0.26	-12.95	-13.95	-10.3
9a	125929.3	479806.1	✓	0.33	-3.67	-5.67	-20.9
9b	125929.3	479806.1	✓	0.33	-12.66	-13.66	-20.9
10a	125915.4	479789.2	✓	0.29	-3.67	-5.67	-41.1
10b	125915.4	479789.2	✓	0.29	-12.70	-13.70	-41.1
11b	125875.0	479763.3	✓	0.08	-12.90	-13.90	-89.1
12b	125805.8	479678.3	✓	-1.44	-13.40	-14.40	-196.5
13b	125746.3	479636.7	✓	-2.39	-14.38	-15.38	-268.6
14b	125253.3	479357.9	✓	-3.21	-15.20	-16.20	-831.3

* The observation well number is followed by either an a or a b. The letter a indicates that the well screen is located in the phreatic aquifer, while the letter b indicates that the well screen is located in the first confined aquifer.

** A positive distance indicates west from the pumping well, and a negative distance to the east of the pumping well.

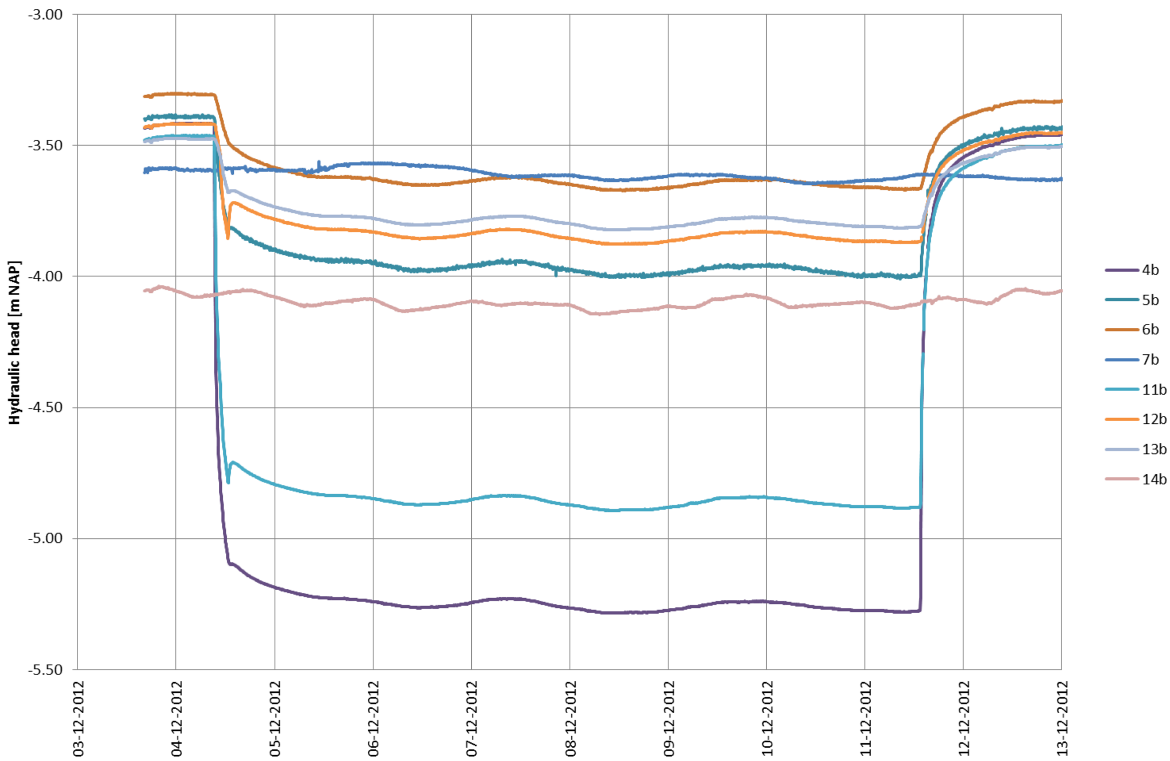

Figure 11.1 Hydraulic head time series of the deep well screens at a distance of more than 55 m from the pumping well for the pumping test Huntumdreef.

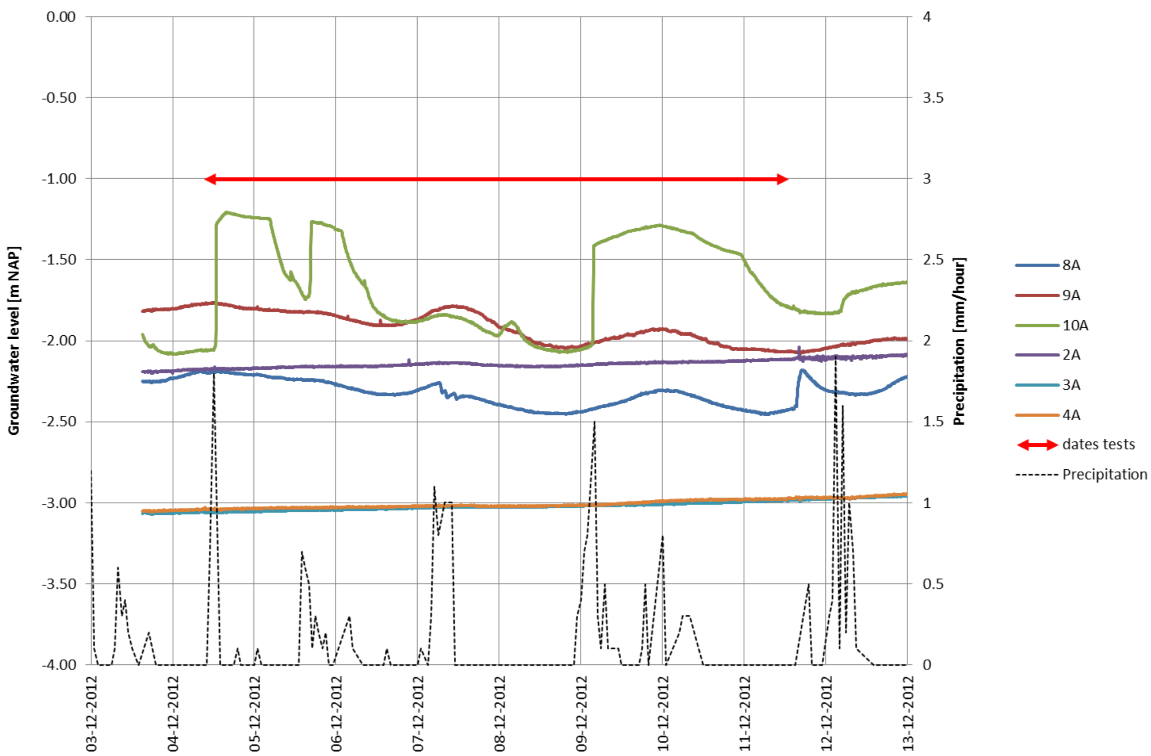

Figure 11.2 Groundwater level time series of the shallow well screens for the pumping test Huntumdreef with the precipitation time series in the first part of December 2012 (KNMI, 2015).

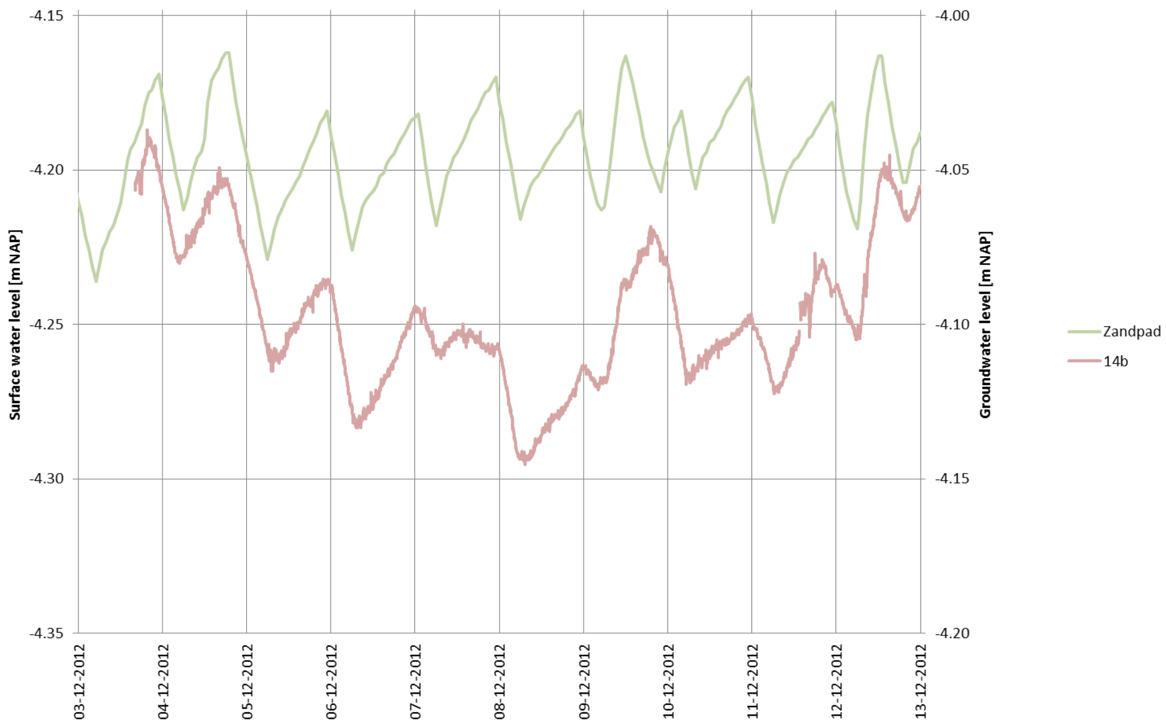

Figure 11.3 *Hydraulic head time series of the deep well screen at a distance of 831 m from the pumping well. The surface water level time series are from pumping station 'Zandpad' in the first part of December 2012.*

Table 11.2 *Drawdown table at time step 11-12-2012 13:30 for all the deep well screens with distance from the pumping well.*

Observation well	Distance [m]	Drawdown [m]
1b	5	4.16
8b	10	3.28
2b	11	3.33
9b	21	2.59
3b	29	2.53
10b	41	2.16
4b	57	1.86
11b	89	1.41
5b	94	0.60
12b	197	0.45
6b	226	0.36
13b	269	0.33
7b	823	0.02
14b	831	0.03

2. Hydraulic heave calculation

Hydraulic heave calculation is for location code Bijlmer041 near the Huntumdreef pumping test location.

$$Sf = \frac{Wd * g + \sum(St_i * \gamma_i)}{(-At + Wg) * g} = \frac{63.4}{57} = 1.1\ (Triwaco = 1.15)$$

Table 11.3 Values and parameters for safety factor calculation at the location Huntumdreef.

Parameters	Value	Parameter explanation [unit]
At	-9.1	Top of the aquifer [m]
g	9.81	Gravitational acceleration [m/s^2]
Sf	1.1 (Triwaco 1.15)	Safety factor [-]
St_i	* Table 0.3	Thickness of different layers of lithology [m]
Wd	0.80	Water depth in ditch [m]
Wg	-3.4 (Triwaco -3.6)	Hydraulic head in aquifer [m NAP]
Ws	-4.2	Surface water level in ditch [m NAP]
y_i	* Table 0.3	Specific weight of the different lithologies [kN/m^3]

Table 11.4 Weight of the soil.

Lithology	**Thickness [m]**	**Depth ** [m NAP]**	**Remaining soil [m]**	**Specific weight [kN/m^3] (*NEN*)**	**Total weight [kN/m^2]**
Clay – humus	0.5	-3.5	-	-	-
Holland peat	1.9	-5.4	0.4	10.5*	4.2
Clay – silty	3	-8.4	3	14.5	43.5
Basal peat	0.7	*-9.1 (start aquifer)*	0.7	11*	7.7
Sand				**Sum [kN/m2]**	**55.4**

* Values further specified by previously taken soil samples at Waternet

** Surface level is NAP -3 m, at location of B25G1568 (Dinoloket, 2015).

3. Calibration result Huntumdreef

T = aquifer layer or wvl
c = aquitard layer or sdl

Time independent and log curve fitting

Parameter	value	+	Standard deviation	
T 1	311.7	+	5.200E+01	(17 %)
c 1	212.5	+	2.326E+01	(11 %)

Obs well	Aq.	Time	Calc	Obs	Cal-Obs
4D	1	1.00E+08	1.421	1.86	-0.439
D	1	1.00E+08	1.029	0.6	0.429
6B	1	1.00E+08	0.433	0.36	0.073
7	1	1.00E+08	0.024	0.02	0.004
10D	1	1.00E+08	1.693	2.16	-0.467
11	1	1.00E+08	1.068	1.41	-0.342
12	1	1.00E+08	0.514	0.45	0.064
13	1	1.00E+08	0.34	0.33	0.01
14	1	1.00E+08	0.023	0.03	-0.007

Initial sum of squares is 0.5439
Residual sum of squares is 0.1235
Residual sum of squares (m^2) 0.7209
Improvement last iteration 4.2E-19
Number of iterations 4
Condition number 2.8
Correlation matrix (%)
T 1 100
c 1 -28 100

Eigenvalues and Eigenvectors: 3 1
T 1 -0.9590 0.2835
c 1 0.2835 0.9590

Time independent and linear curve fitting

Parameter	value	+	Standard deviation	
T 1	176.7	+	4.219E+01	(24 %)
c 1	121.2	+	4.136E+01	(34 %)

Obs well	Aq.	Time	Calc	Obs	Cal-Obs
4D	1	1.00E+08	1.722	1.86	-0.138
5D	1	1.00E+08	1.103	0.6	0.503
6B	1	1.00E+08	0.370	0.36	-0.053
7	1	1.00E+08	0.003	0.02	-0.017
10D	1	1.00E+08	2.175	2.16	0.015
11	1	1.00E+08	1.162	1.41	-0.248
12	1	1.00E+08	0.398	0.45	-0.052
13	1	1.00E+08	0.212	0.33	-0.118
14	1	1.00E+08	0.003	0.03	-0.027

Initial sum of squares is 0.7209
Residual sum of squares is 0.3540
Improvement last iteration 1.3E-12
Number of iterations 4
Condition number 17.8

Correlation matrix (%)
T 1 100
c 1 88 100

Eigenvalues and Eigenvectors: 1 18
T 1 0.8318 -0.5551
c 1 -0.5551 -0.8318

Time-dependent

Run 1

Parameter	value	+	Standard deviation	
T 2	1.544E+01	+	1.767E+00	(11 %)
T 3	1.930E+01	+	2.209E+00	(11 %)
c 4	4.648E+01	+	3.393E+00	(7 %)

Initial sum of squares is 159.1057
Residual sum of squares is 120.3979
Residual sum of squares (m^2) 160.1243
Improvement last iteration 1.1E-09
Number of iterations 6
Condition number 2.6

Correlation matrix (%)
T 2 100
c 4 -14 100

Eigenvalues and Eigenvectors: 3 1
T 2 -0.9892 -0.1468
c 4 0.1468 -0.9892

Run 2

Parameter	value	+	Standard deviation	
T 2	5.980E+01	+	3.990E+00	(7 %)
T 3	7.475E+01	+	4.987E+00	(7 %)
c 4	3.851E+01	+	3.117E+00	(8 %)

Initial sum of squares is 202.6680
Residual sum of squares is 137.0695
Residual sum of squares (m^2) 162.9974
Improvement last iteration 6.0E-10
Number of iterations 4
Condition number 2.4

Correlation matrix (%)
T 2 100
c 4 37 100

Eigenvalues and Eigenvectors 1 2
T 2 0.8559 0.5172
c 4 -0.5172 0.8559

Run 3

Parameter	value	+	Standard deviation	
S 1	7.961E+00	+	2687.3	
S 2	8.610E-04	+	1.147E-04	(13 %)
S 3	1.787E-08	+	5.071E-05	
S 4	6.077E-09	+	1.465E-05	

Initial sum of squares is 137.0695
Residual sum of squares is 67.5290
Residual sum of squares (m^2) 97.3193
Improvement last iteration 9.5E-10
Number of iterations 10
Condition number 8.466E+09
Correlation matrix (%)

S 1	100			
S 2	-1	100		
S 3	1	-94	100	
S 4	-0	27	-48	100

Eigenvalues and Eigenvectors 1
92875237 8.5E+09 2.8E+09

S 1	-0.0000	1.0000	0.0005	-0.0004
S 2	-1.0000	-0.0000	-0.0000	0.0000
S 3	-0.0000	-0.0006	0.8136	-0.5814
S 4	-0.0000	0.0000	-0.5814	-0.8136

Run 4

Parameter value + Standard deviation
T 2 9.638E+00 + 1.513E+00 (16 %)
T 3 209.0 + 4.944E+00 (2 %)
c 4 119.6 + 7.189E+00 (6 %)

Initial sum of squares is 73.8546
Residual sum of squares is 39.4596
Improvement last iteration 1.8E-10
Number of iterations 14
Condition number 799.1

Correlation matrix (%)

T 2	100		
T 3	-91	100	
c 4	-53	77	100

Eigenvalues and Eigenvectors 1 799 77

T 2	0.1031	0.9661	-0.2366
T 3	0.9824	-0.1362	-0.1281
c 4	-0.1560	-0.2192	-0.9631

Run 5

Parameter value + Standard deviation
T 2 7.722E+00 + 1.185E+00 (15 %)
T 3 220.5 + 4.203E+00 (2 %)
c 4 155.8 + 9.576E+00 (6 %)

Initial sum of squares is 31.8093
Residual sum of squares is 30.7802
Improvement last iteration 3.0E-11
Number of iterations 8
Condition number 937.3

Correlation matrix (%)

T 2	100		
T 3	-89	100	
c 4	-50	77	100

Eigenvalues and Eigenvectors 1 937 104

T 2	0.0821	0.9692	-0.2321
T 3	0.9876	-0.1103	-0.1114
c 4	-0.1336	-0.2201	-0.9663

Run 6

Parameter value + Standard deviation
S 2 5.304E-04 + 1.189E-05 (2 %)
S 3 5.304E-04 + 1.189E-05 (2 %)
S 4 5.304E-04 + 1.189E-05 (2 %)

Initial sum of squares is 30.7802
Residual sum of squares is 18.5216
Improvement last iteration 2.2E-12
Number of iterations 4
Condition number 1.0

Run 7

Parameter value + Standard deviation
T 2 2.555E+00 + 4.105E-01 (16 %)
T 3 269.7 + 2.373E+00 (1 %)
c 4 268.9 + 1.116E+01 (4 %)
S 2 3.621E-04 + 9.313E-06 (3 %)
S 3 3.621E-04 + 9.313E-06 (3 %)
S 4 3.621E-04 + 9.313E-06 (3 %)

Initial sum of squares is 18.9375
Residual sum of squares is 9.7218
Improvement last iteration 1.6E-10
Number of iterations 8
Condition number 3578.0

Correlation matrix (%)

T 2	100			
T 3	-76	100		
c 4	-43	80	100	
S 2	41	-64	-41	100

Eigenvalues and Eigenvectors 1, 3578 , 199 , 66

T 2	-0.0237	-0.9898	-0.1357	-0.0357
T 3	-0.9902	0.0423	-0.1216	-0.0551
c 4	0.1066	0.1179	-0.9497	0.2699
S 2	-0.0876	-0.0674	0.2548	0.9606

Run 8

Parameter value + Standard deviation
T 2 2.147E+00 + 3.804E-01 (18 %)
T 3 271.0 + 2.269E+00 (1 %)
c 4 273.0 + 1.102E+01 (4 %)
S 2 3.659E-04 + 9.287E-06 (3 %)
S 3 3.659E-04 + 9.287E-06 (3 %)
S 4 3.659E-04 + 9.287E-06 (3 %)

Initial sum of squares is 9.2221
Residual sum of squares is 9.1915
Improvement last iteration 8.5E-17
Number of iterations 8
Condition number 4587.7

Correlation matrix (%)
T 2 100

T 3 -75 100
c 4 -42 80 100
S 2 42 -65 -41 100

Eigenvalues and Eigenvectors: 1, 4588, 67, 203
T 2 -0.0197 -0.9924 0.0348 0.1165
T 3 -0.9904 0.0359 0.0553 0.1216
c 4 0.1053 0.1001 -0.2710 0.9516
S 2 -0.0875 -0.0621 -0.9604 -0.2573

Run 9

Parameter value + Standard deviation
T 2 8.813E+01 + 7.962E-01 (1 %)
T 3 110.2 + 9.952E-01 (1 %)
c 4 122.2 + 4.981E+00 (4 %)
S 2 4.536E-04 + 1.498E-05 (3 %)
S 3 4.536E-04 + 1.498E-05 (3 %)
S 4 4.536E-04 + 1.498E-05 (3 %)

Initial sum of squares is 3964.5767
Residual sum of squares is 23.1015
Improvement last iteration 1.2E-11
Number of iterations 8
Condition number 123.6

Correlation matrix (%)
T 2 100
c 4 84 100
S 2 -51 -26 100

Eigenvalues and Eigenvectors 1 124 61
T 2 0.9822 -0.1879 0.0062
c 4 -0.1671 -0.8873 -0.4299
S 2 0.0863 0.4212 -0.9028

Run 10

Parameter value + Standard deviation
T 2 1.688E+01 + 3.828E+00 (23 %)
T 3 253.7 + 4.866E+00 (2 %)
c 2 733.4 + 4.908E+01 (7 %)

Initial sum of squares is 9.3445
Residual sum of squares is 9.3445
Improvement last iteration 8.4E-14
Number of iterations 1
Condition number 6438.9

Correlation matrix (%)
T 2 100
T 3 -97 100
c 2 -32 47 100

Eigenvalues and Eigenvectors 1 6439 490
T 2 0.0773 0.9913 0.1064
T 3 0.9957 -0.0822 0.0425
c 2 -0.0509 -0.1027 0.9934

===================================

Parameter value + Standard deviation
c 4 239.3 + 5.838E+00 (2 %)

Initial sum of squares is 9.3445
Residual sum of squares is 9.3086
Improvement last iteration 2.4E-13
Number of iterations 2
Condition number 1.0

=================================

Parameter value + Standard deviation
T 4 2002.4 + 232.0 (12 %)

Initial sum of squares is 9.3086
Residual sum of squares is 9.2115
Improvement last iteration 5.3E-13
Number of iterations 3
Condition number 1.0

============================

Parameter value + Standard deviation
S 2 3.872E-04 + 7.237E-06 (2 %)
S 3 3.872E-04 + 7.237E-06 (2 %)
S 4 3.872E-04 + 7.237E-06 (2 %)

C. Nellesteinpad

1. Tables and Figures

*Table 11.5 Observation well information from the Nellesteinpad pumping test.**

Well name	X	Y	Bore hole description availability	Surface elevation [m NAP]	Top well screen [m NAP]	Bottom well screen [m NAP]	Distance to pumping well [m]
Pumping well	127080	480454	-	-2.55	-16.55	-26.55	0.0
PB1	127075	480452	✓	-2.70	-15.70	-16.70	4.6
PB2	127070	480450	✓	-2.72	-15.72	-16.72	9.8
PB3	127052	480444	✓	-2.32	-15.32	-16.32	29.0
PB4	127018	480426	✓	-2.62	-15.62	-16.62	67.2
PB5	126948	480386	✓	-2.66	-15.66	-16.66	147.7
PB6	126796	480303	✓	-3.38	-16.38	-17.38	321.5
PB7	126565	480359	-	-2.69	-15.69	-16.69	522.9
PB8	126156	479903	-	-0.71	-13.76	-14.76	1075.5

* All observation well screens are placed in the first confined aquifer.

Table 11.6 Drawdown for all the observation wells from time step 25-03-2013 10:25.

Observation wells	Distance [m]	Drawdown [m]
1	5	1.99
2	10	1.49
3	29	0.76
4	67	0.45
5	148	0.19
6	321	0.05
7	522	0.04
8	1075	0*

* Drawdown in this observation well is zero because this observation well was used to correct for surface water level influence in the other seven observation wells.

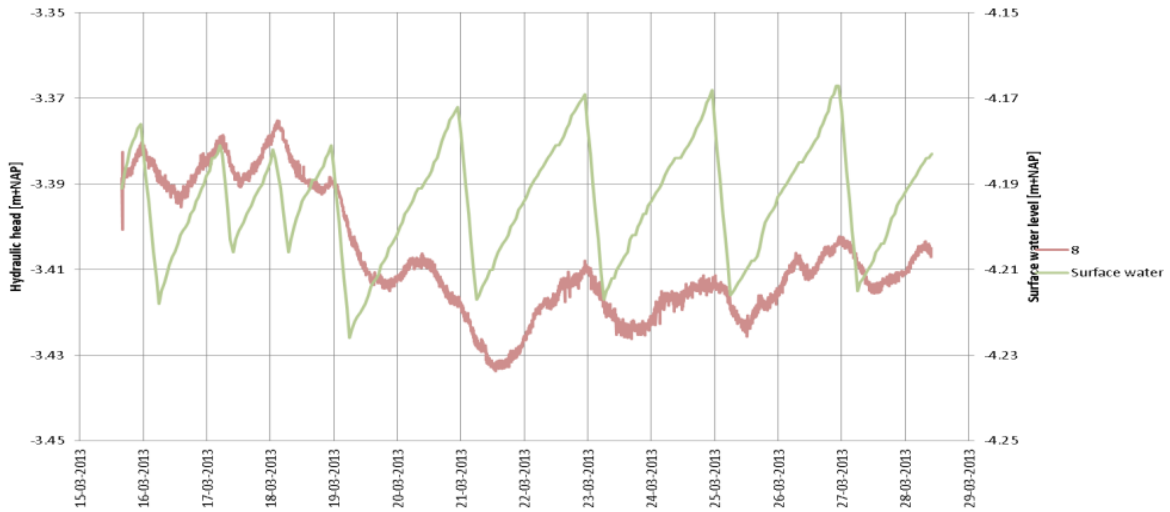

Figure 11.4 Hydraulic head time series of the deep well screen at a distance of 1075 m from the pumping well Nellesteinpad. Together with the surface water level time series from pumping station 'Zandpad' in the second part of March 2013.

2. Hydraulic heave calculation

Values are for location code Bijlmer035 near the Nellesteinpad pumping test location.

$$Sf = \frac{Wd * g + \sum(St_i * \gamma_i)}{(-At + Wg) * g} = \frac{21.1}{25.5} = 0.8$$

Table 11.7 Values and parameters for safety factor calculation at the location Nellesteinpad.

Parameters	Value	Parameter explanation [unit]
At	-6.25	Top of the aquifer [m]
g	9.81	Gravitational acceleration [m/s^2]
Sf	0.8	Safety factor [-]
St_i	* Table 0.7	Thickness of different layers of lithology [m]
Wd	0.80	Water depth in ditch [m]
Wg	-3.7	Hydraulic head in aquifer [m NAP]
Ws	-4.2	Surface water level in ditch [m NAP]
y_i	* Table 0.7	Specific weight of the different lithologies [kN/m^3]

Table 11.8 Weight of the soil column.

Lithology	**Thickness [m]**	**Depth* [m NAP]**	**Remaining soil [m]**	**Specific weight [kN/m^3]**	**Total weight [kN/m^2]**
Clay – humus	1.5	-3.95	-	-	-
Peat	2.3	-6.25 (*start aquifer*)	1.25	10.5	13.125
Sand				**Sum [kN/m^2]**	**13.125**

* Surface level is at NAP -2.45 m (At location of B25G6269) (Dinoloket, 2015)

3. Calibration results Nellesteinpad

T = aquifer layer or wvl
c = aquitard layer or sdl

Time independent and linear curve fitting

Parameter value + Standard deviation
T 1 373.8 + 2.811E+01 (8 %)
c 1 3.251E+01 + 2.013E+00 (6 %)

Obs. well	Aq.	Time	Calc	Obs	Cal-Obs
4	1	1.00E+08	0.409	0.408	0.001
5	1	1.00E+08	0.141	0.145	-0.004
6	1	1.00E+08	0.020	0.011	0.009
7	1	1.00E+08	0.003	0.005	-0.002

Initial sum of squares is 0.0055
Residual sum of squares is 0.0001
Improvement last iteration 2.2E-27
Number of iterations 4
Condition number 15.1

Correlation matrix (%)
T 1 100
c 1 87 100

Eigenvalues and Eigenvectors 15 1
T 1 0.7807 0.6249
c 1 0.6249 -0.7807

Time independent and log curve fitting

Parameter value + Standard deviation
T 1 510.5 + 303.8 (60 %)
c 1 3.026E+01 + 9.436E+00 (31 %)

Obs. well	Aq.	Time	Calc	Obs	Cal-Obs
4	1	1.00E+08	0.337	0.408	-0.071
5	1	1.00E+08	0.127	0.145	-0.018
6	1	1.00E+08	0.022	0.011	0.011
7	1	1.00E+08	0.003	0.005	-0.002

Initial sum of squares is 0.1521
Residual sum of squares is 0.1267
Residual sum of squares (m^2) 0.0055
Improvement last iteration 2.4E-17
Number of iterations 4
Condition number 12.7

Correlation matrix (%)
T 1 100
c 1 -78 100

Eigenvalues and Eigenvectors 13 1
T 1 0.9127 -0.4085
c 1 -0.4085 -0.9127

Time- dependent runs

Run 1

Parameter value + Standard deviation
T 2 9.912E-03 + 2.321E-03 (23 %)
T 3 7.995E+01 + 3.639E+01 (46 %)
T 4 107.5 + 4.894E+01 (46 %)

Initial sum of squares is 1.3306
Residual sum of squares is 0.8167
Improvement last iteration 1.2E-11
Number of iterations 8
Condition number 3.8

Correlation matrix (%)
T 2 100
T 3 7 100

Eigenvalues and Eigenvectors 1 4
T 2 -0.9988 -0.0497
T 3 0.0497 -0.9988

Run 2

Parameter value + Standard deviation
T 2 1.202E-01 + 9.727E-03 (8 %)
T 3 200.4 + 1.769E+00 (1 %)
T 4 269.6 + 2.380E+00 (1 %)

Initial sum of squares is 132.4504
Residual sum of squares is 2.8339
Improvement last iteration 6.3E-10
Number of iterations 11
Condition number 91.7

Correlation matrix (%)
T 2 100
T 3 29 100

Eigenvalues and Eigenvectors 92 1
T 2 -0.9995 0.0318
T 3 -0.0318 -0.9995

Run 3

Parameter value + Standard deviation
S 1 9.200E-06 + 8.039E-04
S 2 2.794E-07 + 7.758E-04
S 3 4.735E-07 + 2.141E-03
S 4 9.449E-07 + 1.693E-03
S 5 1.877E-04 + 7.824E-04 (417 %)

Initial sum of squares is 2.8339
Residual sum of squares is 2.6539
Improvement last iteration 2.1E-09
Number of iterations 7
Condition number 2.721E+08

Correlation matrix (%)
S 1 100
S 2 -13 100
S 3 9 -94 100

S 4 -4 82 -96 100
S 5 -88 -11 26 -38 100

Eigenvalues and Eigenvectors 1 36575 73503 9142234 2.7E+08
S 1 0.0399 -0.4354 0.8993 -0.0126 0.0015
S 2 0.0020 0.3441 0.1783 0.7851 -0.4832
S 3 0.0033 0.4633 0.2263 0.2499 0.8195
S 4 0.0065 0.6909 0.3268 -0.5666 -0.3080
S 5 0.9992 0.0106 -0.0391 0.0018 0.0002

Run 5

Parameter value + Standard deviation
T 2 7.094E-01 + 8.863E-02 (12 %)
T 3 220.7 + 2.149E+00 (1 %)
T 4 296.8 + 2.890E+00 (1 %)
c 5 2.856E+01 + 1.808E+00 (6 %)

Initial sum of squares is 3.6015
Residual sum of squares is 1.4577
Improvement last iteration 4.7E-10
Number of iterations 11
Condition number 519.3

Correlation matrix (%)
T 2 100
T 3 7 100
c 5 8 82 100

Eigenvalues and Eigenvectors 1 519 134
T 2 -0.0003 -0.9984 0.0569
T 3 0.9920 -0.0075 -0.1262
c 5 -0.1264 -0.0564 -0.9904

Run 6

Parameter value + Standard deviation
T 2 8.161E-01 + 1.183E-01 (14 %)
T 3 193.2 + 2.296E+00 (1 %)
T 4 259.9 + 3.088E+00 (1 %)
T 5 4644.7 + 832.3 (18 %)
c 5 2.319E+01 + 2.387E+00 (10 %)

Initial sum of squares is 1.5822
Residual sum of squares is 1.5822
Improvement last iteration 1.7E-12
Number of iterations 1
Condition number 1168.3

Correlation matrix (%)
T 2 100
T 3 6 100
T 5 2 37 100
c 5 6 76 81 100

Eigenvalues and Eigenvectors 1, 90, 616, 1168

T 2 -0.0005 0.0317 -0.9982 -0.0505
T 3 -0.9871 -0.1574 -0.0031 -0.0283
T 5 -0.0469 0.4523 0.0593 -0.8887
c 5 0.1529 -0.8773 -0.0050 -0.4549

Run 7

Parameter value + Standard deviation
T 2 1.238E+01 + 8.416E-01 (7 %)
T 3 201.6 + 2.115E+00 (1 %)
T 4 271.2 + 2.845E+00 (1 %)
T 5 4315.2 + 992.1 (23 %)
c 5 3.792E+01 + 2.899E+00 (8 %)
S 2 5.636E-04 + 1.300E-05 (2 %)
S 3 5.636E-04 + 1.300E-05 (2 %)
S 4 5.636E-04 + 1.300E-05 (2 %)
S 5 5.628E-04 + 1.299E-05 (2 %)

Initial sum of squares is 0.2053
Residual sum of squares is 0.2053
Improvement last iteration 2.2E-11
Number of iterations 1
Condition number 14611.2

Correlation matrix (%)
T 2 100
T 3 -93 100
T 5 -27 36 100
c 5 -54 70 86 100
S 2 15 -26 16 -0 100

Eigenvalues and Eigenvectors: 1, 116, 205, 1249 14611
T 2 0.1012 -0.0355 0.4122 -0.9001 0.0914
T 3 0.9898 0.0212 0.0488 0.1309 -0.0183
T 5 0.0160 0.0937 -0.2058 -0.1931 -0.9547
c 5 -0.0878 -0.2834 0.8395 0.3570 -0.2824
S 2 0.0459 -0.9535 -0.2840 -0.0887 -0.0137
==============================

Parameter value + Standard deviation
c 2 117.2 + 5.721E+00 (5 %)
c 3 4.723E-01 + 2.313E-02 (5 %)
c 4 1.494E+00 + 4.222E-02 (3 %)

Initial sum of squares is 0.2053
Residual sum of squares is 0.2053
Improvement last iteration 8.2E-13
Number of iterations 1
Condition number 33.2

Correlation matrix (%)
c 2 100
c 3 -26 100
c 4 -69 76 100

Eigenvalues and Eigenvectors 1 16 33
c 2 -0.2839 0.7293 -0.6226
c 3 0.3332 0.6838 0.6491
c 4 -0.8991 0.0232 0.4372

D. Amstelveen

1. Tables and Figures

Table 11.9 Observation well information from the Amstelveen pumping test.

Observation well*	Surface Elevation [m NAP]	Top well screen [m NAP]	Bottom well screen [m NAP]	Distance to pumping well [m]
Pump**	-1.34	-10.00	-25.00	0
PB 5 shallow	-1.49	-8.44	-9.44	5
PB 10 shallow	-1.61	-8.62	-9.62	9
PB 20 shallow	-2.01	-9.02	-10.02	21
PB 40 shallow	-1.99	-9.01	-10.01	35
PB 50 shallow	-1.61	-9.49	-10.49	50
PB 80 shallow	-2.25	-9.27	-10.27	68
PB 150 shallow	-2.04	-8.90	-9.90	137
PB 245 shallow	-2.07	-9.03	-10.03	253
PB 250 shallow	-1.53	-9.57	-10.57	232
PB 400 shallow	-1.65	-9.73	-10.73	410
PB 900 shallow	-2.97	-7.49	-8.49	915
PB Return shallow	-2.27	-9.28	-10.28	252
PB 5 deep	-1.62	-15.17	-16.17	4
PB 10 deep	-1.73	-15.29	-16.29	10
PB 20 deep	-2.00	-15.06	-16.06	18
PB 40 deep	-2.05	-15.29	-16.29	33
PB 50 deep	-1.56	-15.20	-16.20	50
PB 80 deep	-2.30	-15.03	-16.03	74
PB 150 deep	-2.10	-15.14	-16.14	139
PB 245 deep	-2.06	-15.21	-16.21	253
PB 250 deep	-1.53	-15.11	-16.11	231
PB 400 deep	-1.62	-15.28	-16.28	409
PB 900 deep	-2.91	-14.96	-15.96	915
PB Return deep	-2.25	-15.37	-16.37	253

* A shallow observation well screen is placed in the phreatic aquifer, while the deep observation well screens is placed in the first confined aquifer.

** Borehole description of the pump is located in Appendix J.

Table 11.10 Drawdown of all deep observation well screen at time 8-9-2014 16.35 for the Amstelveen pumping test.

Deep observation well screen	Distance [m]	Drawdown [m]
PB Pump	0.1	5.81
P5	5	1.89
P10	9	1.44
P20	21	1.11
P40	35	0.87
P50	50	0.76
P80	68	0.64
P150	137	0.42
P245	253	0.31
P Retour	252	0.31
P250	232	0.45
P400	410	0.24
P900	915	0.10

2. Hydraulic heave calculation

Hydraulic heave calculation is for location code Section 2110_1 near the Amstelveen pumping test.

$$Sf = \frac{Wd * g + \sum(St_i * \gamma_i)}{(-At + Wg) * g} = \frac{115.4}{71} = 1.66$$

Table 11.11 Values and parameters for safety factor calculation at the location Amstelveen.

Parameters	Value	Parameter explanation [unit]
At	-11.1	Top of the aquifer [m]
g	9.81	Gravitational acceleration [m/s^2]
Sf		Safety factor [-]
St_i	* Table 0.7	Thickness of different layers of lithology [m]
Wd	0.80	Water depth in ditch [m]
Wg	-4.0	Hydraulic head in aquifer [m NAP]
Ws	-2.25	Surface water level in ditch [m NAP]
y_i	* Table 0.7	Specific weight of the different lithologies [kN/m^3]

Table 11.12 Weight of the soil column.

B25G6269 Lithology	Thickness [m]	Depth* [m NAP]	Remaining soil [m]	Specific weight [kN/m^3]	Total weight [kN/m^2]
Peat	3.4	-5.4	2.35	10.5	24.7
Clay	5.7	- 11.1 (*start aquifer*)	5.7	14.5	82.7
Sand	9.1			**Sum [kN/m^2]**	**107.4**

* Surface level is at NAP -2 m from location of B25G6269 (Dinoloket, 2015).

3. Calibration results Amstelveen

T = aquifer layer or wvl
c = aquitard layer or sdl

Time-independent and log drawdown curve fitting

Parameter value + Standard deviation
T 1 813.4 + 7.939E+01 (10 %)
c 1 1039.8 + 189.0 (18 %)

Deep obs wells	Aq.	Time	Calc.	Obs	Cal-Obs
P80	1	1.00E+08	0.638	0.64	-0.002
P150	1	1.00E+08	0.476	0.42	0.056
P245	1	1.00E+08	0.34	0.31	0.030
Retour	1	1.00E+08	0.34	0.31	0.030
P50	1	1.00E+08	0.71	0.76	-0.050
P250	1	1.00E+08	0.359	0.45	-0.091
P400	1	1.00E+08	0.239	0.24	-0.001
P900	1	1.00E+08	0.099	0.1	-0.001

Initial sum of squares is 0.2829
Residual sum of squares is 0.0167
Residual sum of squares (m²) 0.0157
Improvement last iteration 5.9E-17
Number of iterations 4
Condition number 12.0

Correlation matrix (%)
T 1 100
c 1 77 100

Eigenvalues and Eigenvectors 1 12
T 1 0.9092 0.4164
c 1 -0.4164 0.9092

Time-independent and linear drawdown curve fitting

Parameter value + Standard deviation
T 1 769.5 + 9.071E+01 (12 %)
c 1 918.6 + 336.4 (37 %)

Deep Obs wells	Aq.	Time	Cals	Obs	Cal-Obs
P80	1	1.00E+08	0.653	0.64	0.013
P150	1	1.00E+08	0.482	0.42	0.062
P245	1	1.00E+08	0.339	0.31	0.029
Retour	1	1.00E+08	0.339	0.31	0.029
P50	1	1.00E+08	0.729	0.76	-0.031
P250	1	1.00E+08	0.359	0.45	-0.091
P400	1	1.00E+08	0.234	0.24	-0.006
P900	1	1.00E+08	0.092	0.1	-0.008

Initial sum of squares is 0.0157
Residual sum of squares is 0.0151
Improvement last iteration 8.9E-14
Number of iterations 4
Condition number 59.9

Correlation matrix (%)
T 1 100
c 1 90 100

Eigenvalues and Eigenvectors: 1 60
T 1 0.9591 -0.2830
c 1 -0.2830 -0.9591

Time-dependent runs

Run 1
Parameter value + Standard deviation
T 1 419.3 + 2.263E+01 (5 %)

Initial sum of squares is 2.1373
Residual sum of squares is 2.0223
Improvement last iteration 3.0E-12
Number of iterations 2
Condition number 1.0

Run 2
Parameter value + Standard deviation
T 1 362.5 + 1.001E+01 (3 %)
T 2 566.4 + 1.564E+01 (3 %)

Initial sum of squares is 2.1373
Residual sum of squares is 2.0230
Improvement last iteration 6.7E-19
Number of iterations 3
Condition number 1.0

Run 3
Parameter value + Standard deviation
T 1 335.0 + 1.791E+00 (1 %)
T 2 523.4 + 2.798E+00 (1 %)

Initial sum of squares is 5.2456
Residual sum of squares is 3.9657
Improvement last iteration 5.0E-21
Number of iterations 3
Condition number 1.0

Run 4
Parameter value + Standard deviation
S 1 1.359E-04 + 1.222E-04 (90 %)
S 2 5.997E-04 + 1.614E-04 (27 %)
S 3 1.162E-06 + 2.904E-04

Initial sum of squares is 3.9657
Residual sum of squares is 2.2686
Improvement last iteration 2.9E-09
Number of iterations 9
Condition number 17196991.1

Correlation matrix (%)
S 1 100

S 2   -94   100
S 3   27   -49   100

Eigenvalues and Eigenvectors: 1, 221, 17196991
S 1   0.2539 -0.9672   0.0010
S 2   0.9672   0.2539 -0.0005
S 3   0.0003   0.0011   1.0000

Run 5

Parameter	value	+	Standard deviation	
T 1	341.2	+	3.823E+00	(1 %)
T 2	468.0	+	1.742E+01	(4 %)

Initial sum of squares is	3.3609
Residual sum of squares is	3.2986
Improvement last iteration	1.2E-09
Number of iterations	3
Condition number	41.9

Correlation matrix (%)
T 1   100
T 2   -84   100

Eigenvalues and Eigenvectors   1   42
T 1   0.9681   0.2505
T 2   0.2505 -0.9681

Run 6

Parameter	value	+	Standard deviation	
S 1	3.653E-04	+	1.541E-05	(4 %)
S 2	3.654E-04	+	1.542E-05	(4 %)
S 3	3.654E-04	+	1.542E-05	(4 %)

Initial sum of squares is	3.2986
Residual sum of squares is	1.9742
Improvement last iteration	6.6E-16
Number of iterations	4
Condition number	1.0

Run 7

Parameter	value	+	Standard deviation	
T 1	346.2	+	2.546E+00	(1 %)
T 2	351.8	+	9.876E+00	(3 %)

Initial sum of squares is	1.9742
Residual sum of squares is	1.3703
Improvement last iteration	2.3E-11
Number of iterations	4
Condition number	59.6

Correlation matrix (%)
T 1   100
T 2   -85   100

Eigenvalues and Eigenvectors 1   60
T 1   0.9750   0.2222
T 2   0.2222 -0.9750

Run 8

Parameter	value	+	Standard deviation	
T 1	309.1	+	6.899E+00	(2 %)
T 2	332.9	+	7.319E+00	(2 %)
c 2	2.018E+00	+	2.919E-01	(14 %)

Initial sum of squares is	1.3703
Residual sum of squares is	1.2752
Improvement last iteration	9.6E-11
Number of iterations	8
Condition number	1449.3

Correlation matrix (%)
T 1   100
T 2   -25   100
c 2   92   9   100

Eigenvalues and Eigenvectors 1   37   1449
T 1   0.9324 -0.3327 -0.1412
T 2   0.3343   0.9424 -0.0130
c 2   -0.1374   0.0351 -0.9899

--> sum of squares : 1.1443E+00 m² (for 25)T3
--> sum of squares : 1.2752E+00 m² (for 37.5)T3

E. Triwaco

1. Model adjustment for partially penetrating well

The thickness of the different model layers in Triwaco are made with different expressions. The expressions are made up of different Formations.
Expressions:

- Old expression thickness aquifer 3 = dikte[1]_eez3[2] + dikte_drz1
    - Adjusted = (dikte_eez3+dikte_drz1) + 0.334 * (dikte_dtc + dikte_drz3 + dikte_urz1)
- Old expression thickness aquifer 4 = dikte_dtc + dikte_drz3 + dikte_urz1
    - Adjusted = (dikte_dtc + dikte_drz3 + dikte_urz1) * 0.667

e.g. dikte[1]_eez3[2]

1 With 'dikte' (Dutch for thickness)

2 Formations: eez3 (Eem Formation), drz1 and drz3 (Drenthe Formation), dtc (Glacially reworked layer), and urz1 (Urk Formation) (Dinoloket, 2015).

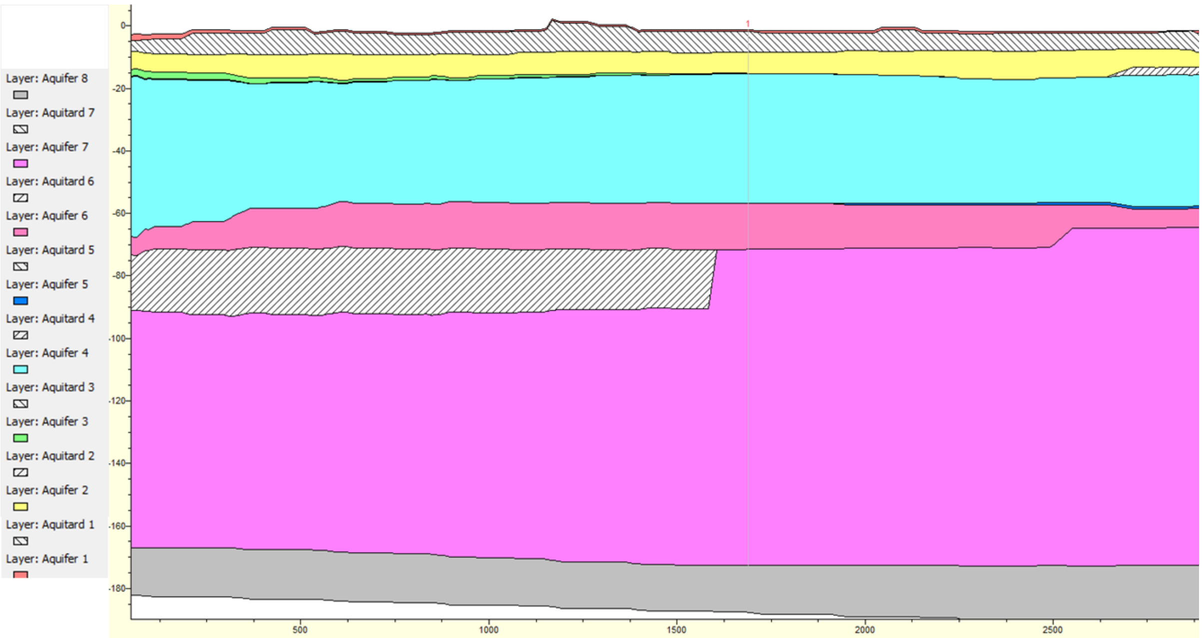

Figure 11.5 Old model of the Bijlmer, with the Nellesteinpad pumping test location indicated by the red number one.

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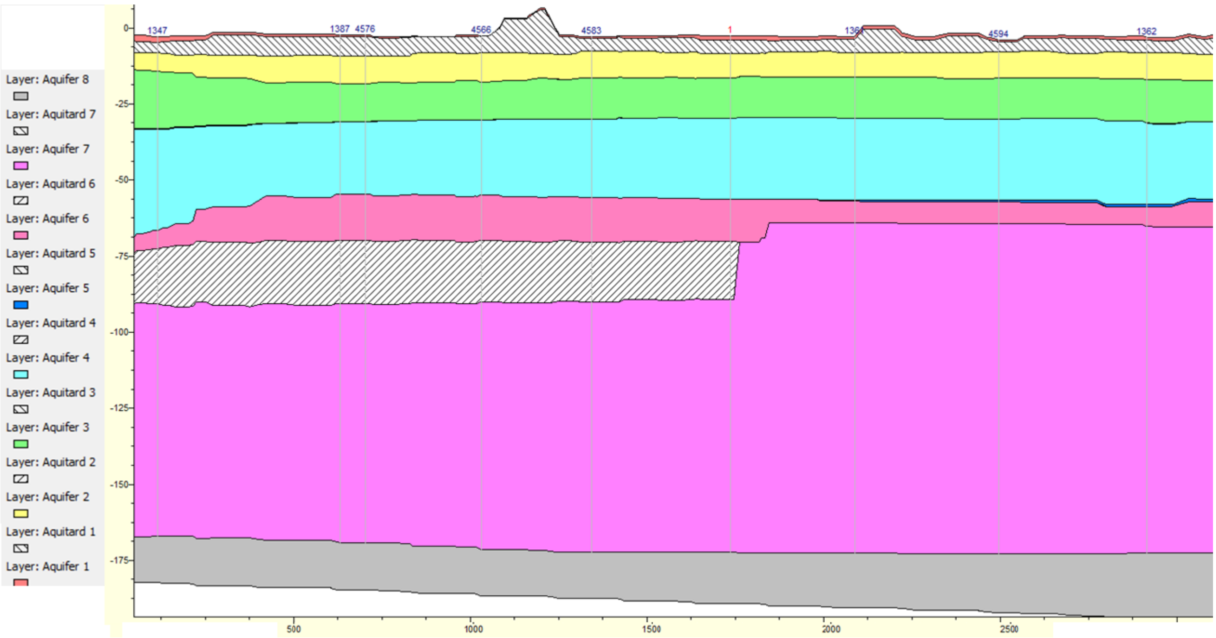


Figure 11.6 *New model of the Bijlmer with the expanded aquifer layer 3 in green and the Nellesteinpad pumping test location indicated by the red number one.*

2. Calib.chi file

The following is an example of the calib.chi file which is needed for the windows-batch file.

chi file A9 Nellesteinpad

2	127075.27	480452.14	0	2	1
3	127070.50	480450.13	0	2	1
4	127052.07	480444.44	0	2	1
5	127018.42	480425.91	0	2	1
6	126948.35	480385.97	0	2	1
7	126795.77	480302.71	0	2	1
8	126565.31	480358.87	0	2	1
9	126155.53	479903.46	0	2	1

3. Windows batch-file

The following is an example of the used windows batch-file.

```
"c:\...\mikado.exe" -o PHI1.csv PHI1 c:\...\grid4\grid.teo flairs.flo
"c:\...\mikado.exe" -o PHI2.csv PHI2 c:\...\grid4\grid.teo flairs.flo
"c:\...\mikado.exe" -o PHI3.csv PHI3 c:\...\grid4\grid.teo flairs.flo
```

Table 3.1 Geohydrological schematisation and parameters (Beemster, 2014).

Depth [m NAP]	Model layer*	codes Waternet	REGIS II.1/Geotop layers	K-value (m/dag)	C-value (dagen/m)
0- -2	wvp1 (ophooglaag+ holocene geulopvullingen)	A	Antropogeen+ Stroombaangeneraties A t/m E van Echteld en Naaldwijk Formaties	5	-
-2- -12	sdl 1 (deklaag)	B	laagp Walcheren+ Hollandveen+ laagp.Wormer+ Echteld+ laag v.Velsen+Basisveen	-	Walcheren:250 H.veen:20-100 Echteld:25-50 Wormer:1500 Velsen+Basisv.: 5000
-12- -20	wvp 2	C+D	Kreftenheije+Eem +Boxtel zand	Kreft 30 Eem 25 Boxt 2	-
	sdl 2		Eem+Boxtel+ Kreftenheije klei	-	200
-20- -30	wvp 3		Drente zand 1+ Eem zand 3	37.5	-
	sdl 3		Gieten+Uitdam klei	-	50
-30- -50	wvp 4	E	gestuwd pakket	37.5	-
	sdl 4		(virtuele modellaag)	-	1
-50- -60	wvp 5	F	Sterksel zand 1 + Urk zand 2+3+4+5	37.5	-
	sdl 5		Sterksel klei 1	-	25
-60- -80	wvp 6		Sterksel zand 2+ Appelscha zand 1 + Peize/Waalre zand 2	37.5	-
	sdl 6		Waalre klei 1+Peize klei 1	-	6
-80- -160	wvp7		Peize/Waalre zand 3 +4+5	37.5	
	sdl 7		Waalre klei 2+ 3	-	75
-160- -220	Wvp8		Peize/Waalre zand 6+7 Peize complex+Maassluis	25	

* sdl= aquitard, wvp= aquifer

Table 11.13 Residual and statistics for time-independent models during the optimisation of the Nellesteinpad pumping test in Triwaco.

	Observation well	**Model 1**	**Model 2**	**Model 3**
Residual	1	1.367	0.910	0.298
Residual	2	0.963	0.594	0.078
Residual	3	0.437	0.213	-0.054
Residual	4	0.249	0.118	0.042
Residual	5	0.052	-0.007	-0.016
Residual	6	-0.043	-0.061	-0.060
Residual	7	-0.034	-0.042	-0.041
Average	All	0.372	0.213	0.029
St. deviation	All	0.528	0.355	0.119
RSS	All	3.054	1.246	0.105
RSS	2-7	1.186	0.418	0.016

4. Model boundary

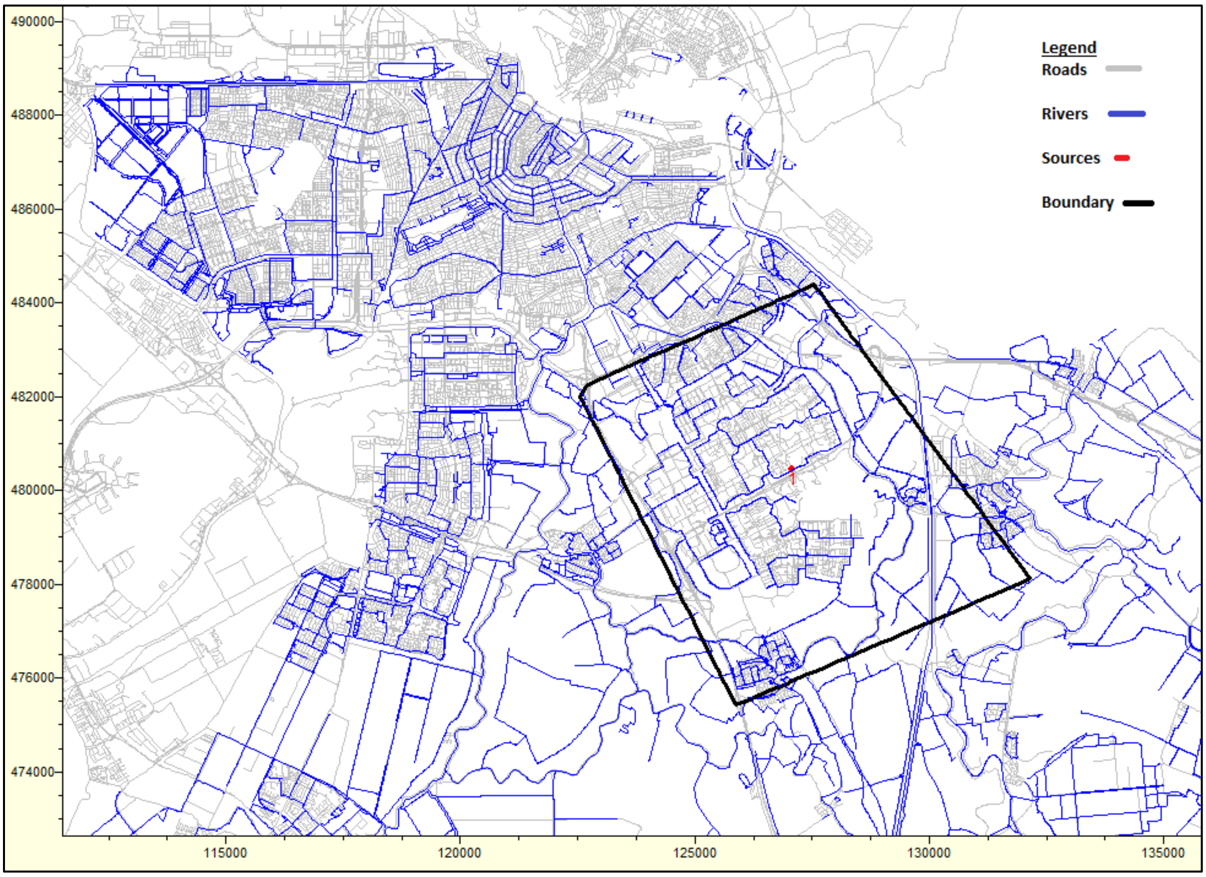


Figure 11.7 Location of the boundary of the model used for this project in Triwaco.

5. Optimisation process

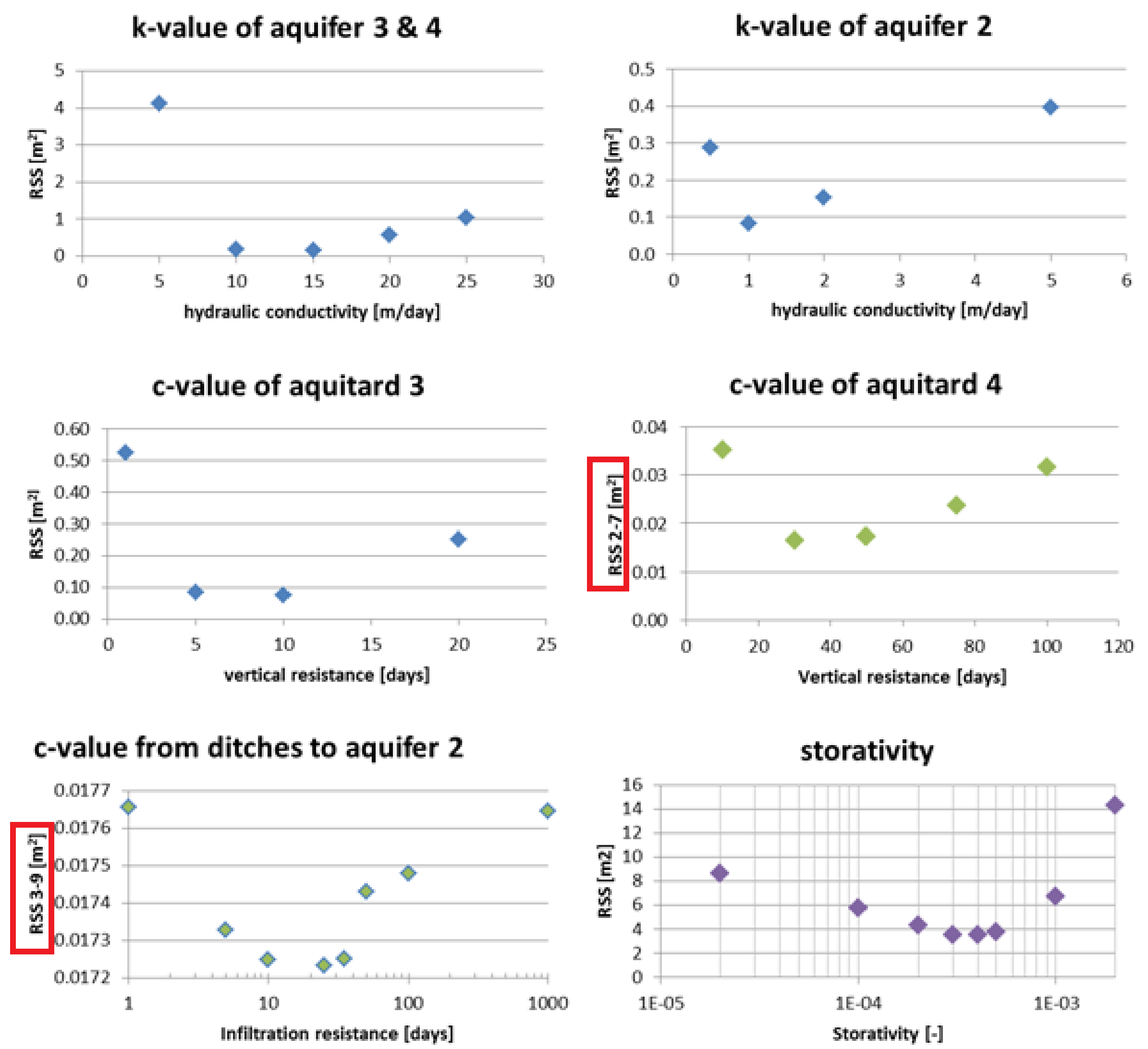


Figure 11.8 All parameters except for storativity were optimised during time-independent runs. Furthermore, all parameters were optimised with the RSS [m^2] of all observations wells EXCEPT for the parameters: c-value of aquitard 4 and the infiltration resistance from the ditches to aquifer 2. These parameters are in green to indicate the difference with the other parameters.

F. Eastern Tunnel coordinates

Table 11.14 X and Y coordinates of observation, infiltration and abstraction wells.

Observation wells	X	Y			
F1 (15 m)**	127074	480361			
F2 (10 m)**	127072	480365			
Infiltration wells	X	Y	**Infiltration wells 1 (North)***	X	Y
1	126991	480333	R1	127074	480488
2	127008	480342	R2	127087	480495
3	127025	480351	R3	127099	480502
4	127042	480360	R4	127112	480509
5	127059	480369	R5	127125	480516
6	127076	480378	R6	127137	480522
7	127092	480388	R7	127150	480529
8	127109	480397	R8	127163	480536
9	127126	480406	R9	127175	480543
10	127143	480415	R10	127188	480550
11	127160	480424			
12	127177	480433			
Infiltration wells 2 (North East)*	X	Y	**Infiltration wells 3 (North West)***	X	Y
NO1	127177	480335	NW1	127147	480331
NO2	127177	480335	NW2	127135	480324
NO3	127177	480335	NW3	127123	480316
NO4	127177	480335	NW4	127111	480309
NO5	127177	480335	NW5	127099	480302
NO6	127177	480335	NW6	127087	480294
NO7	127177	480335	NW7	127075	480287
NO8	127177	480335	NW8	127063	480280
NO9	127177	480335	NW9	127052	480272
NO10	127177	480335	NW10	127040	480265
NO11	127177	480335	NW11	127028	480258
NO12	127177	480335	NW12	127016	480250
NO13	127177	480335	NW13	127004	480243
NO14	127177	480335	NW14	126992	480236
NO15	127177	480335	NW15	126980	480228
NO16	127353	480423	NW16	126968	480221

* North, North East, and North West indicate the location of the infiltration field from the building pit.

** Distance indicates the distance from the pumping well, corresponding to the North (10) and South side (15 m) of the building pit.

G. Borehole descriptions Huntumdreef

Borehole descriptions from the Huntumdreef pumping test (Jongerius, 2013).

VELDWERKRAPPORTAGE BRL 2100

Alards Grondboringen

Opdrachtgever: FA Henk v. Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer: Huntumdreef
Ref. opdrachtgever: Amsterdam

Werkomschrijving / uit te voeren werkzaamheden Pulsboringen t.b.v. monitoring + grw standen

Ingezette medewerkers : ☒ Math / ☒ Michal / ☐ ……

Vooraf bekende informatie m.b.t. veiligheid:

- ☐ Werken op of langs de openbare weg
- ☐ Asbestverdacht
- ☐ verwachte of bekende verontreinigingen, te weten:
- ☐ Werken op of langs het spoor
- ☐ Toxische stoffen

Braak liggend terrein

In te vullen op locatie (per boring):

Datum uitvoering: 23-11 t/m 3-12-2012
Start werkzaamheden (tijd): 5.00 – 19.30
Einde werkzaamheden (tijd):

	JA	NEE	N.V.T.
Voorgegraven?	X		
Kabel en leidinggegevens bekend?	X		
Gekozen/uitgevoerde boormethode ☒ puls / ☐ holle avegaar / ☐ spoelboring			
Boordiameter 148 + 219			X (mm)
Is boorafstand tot gebouwen en funderingen groter dan 10x boordiameter	X		
Was de situatie op locatie, zoals beschreven in opdracht?			X
Is de aan- en afmelding goed verlopen (indien van toepassing)?		X	
Asbest aangetroffen in de bodem of op maaiveld?			X
Aanwezigheid asbest teruggekoppeld met projectleider?		X	
Overige (passieve) (geur)waarnemingen	X		
Inmeting en tekening (boorplan) goed leesbaar?	X		
Scheidende lagen bepaald en vastgelegd?		X	

Let op: als scheidende lagen NIET zijn bepaald> werk hele boorgat af met bentoniet
Indien scheidende lagen WEL zijn bepaald, leg dan bodemopbouw, filterstellingen,afdichtende lagen, grind etc. vast
Scheidende lagen > 10 cm afgedicht en geregistreerd? (in geval van scheidende lagen <10 cm: hele boorgat afdichten
Als er geen scheidende lagen zijn aangetroffen in de bovenste 5m -mv, wordt de eerste 2 meter standaard afgedicht met bentoniet

	JA	NEE	N.V.T.
Verharde gesteenten aangetroffen (mantelbuis van boringen cementeren)	Ec:		µS
Hoeveel liter werkwater is gebruikt (per boring)? ± 600 ltr.			
Boorlocatie vastgelegd (per boring!) X	Y		
Additieven in boorspoeling aanwezig?		X	
Aan- en invulstaten ingevuld?		X	
Resultaat boorgatmeting (zie boorstaat)			
Zijn de peilbuizen goed afgewerkt?	X		
Werkzaamheden volledig onder welke BRL uitgevoerd?	X		
BRL 2000 (peilbuizen plaatsen)	X		
BRL 2100 (mechanische boringen)		X	
Zijn er wijzigingen t.o.v. de opdracht opgetreden?	X		
Foto's genomen en geregistreerd?	X		
Opdracht afgerond (zo nee, reden)			X
Is elke gestaakte boring op tekening aangegeven?	X		
Is overtollige grond achtergebleven op locatie?	X		
Werkten meetinstrumenten naar behoren?	X		
Gereedschappen en materialen schoongemaakt? Zo nee, reden:			

Opmerkingen / afwijkingen en getroffen maatregelen:

Naam Boormeester: Math Alards — Paraaf:
Naam Boormedewerker: Michel Deregowski — Paraaf:

Vergeet niet om een boorbeschrijving te maken (bodem-opbouw)

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Opdrachtgever: Henk v Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer: Amtumde Amsterdam
Ref. opdrachtgever:
Datum uitvoering: 26-11-2012

PB / A-B

Soort boring: ☐ puls / ☐ holle avegaar / ☐ spoelboring

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0-120	Zand F ZW-BR		
120-170	Zand mF	GEEL-ZI BR	
170-280	Klei Zandig	Grys	
280-470	Klei Grys + 10%	STEENSCHROT	
470-590	Zand mF Grys +	10% STEENSCHROT	
590-730	Veen		
730-940	Klei Grys, LAST		
940-1040	Klei zandig Grys	+10% veen houdend	
1040-11	Zand Fyn, Sterk siltig Grys		
11-1160	Zand mF Grys		
1160-1250	Zand m Grof Grys		
1250-14	Zand Grof Grys		
FILTER 50	4-6 CAPACI SLECHT	G	WTR 3.80
" "	13-14 " ZEER GOED	"	"
	Grind 1250-14	380-600	
	Klei 1,70 3,50	6,-12,5	
PB WATER	ph=7,20 ms 216		
POSITIE	125954		1 x STRAATPOT
Rd	479819		GEPL

- Boordiameter 178 mm
- Diepte boring 14 m
- Capaciteit bron
- Grondwaterstand m
- Gebruikt filtergrind 7
- Gebruikt bentoniet 12
- Begintijd boring
- Einddtijd boring

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

PB 2 a+b

Opdrachtgever: Henk v Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer:
Ref. opdrachtgever: Huntumdreef Amsterdam
Datum uitvoering: 3-12-2012
Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0-180	Klei dk grys-zw	+	30% steenschrot
180-600	Steenschrot +	10% klei	zwart-dk grys
600-690	Veen		
690-960	Klei grys	„vast"	
960-1090	Zandige klei,	li veenhoudend	
1090-1150	Zand matig grof		grys
1150-14	Zand grof		grys
Filter A	4-6 capaci	slecht	
Filter B	13-14 "	zeer goed	
	Grind 12,50-14	350 600	
	Klei 650-1150	0-180	
PB water	ph=7,24	ms 2,92	
positie	125959		

- Boordiameter: 219 mm
- Diepte boring: 14 m
- Capaciteit bron:
- Grondwaterstand: m
- Gebruikt filtergrind: 8
- Gebruikt bentoniet: 10
- Begintijd boring:
- Einddtijd boring:

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

PB 3
A+B

Opdrachtgever: Henk v Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer:
Ref. opdrachtgever: Auntumdreef Amsterdam
Datum uitvoering: 3-12-2012

Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0-30	Zand F		ZW
30-510	Zand matig grof		li BR
510-570	Zand " "		Grys
570-620	Klei dk grys		"Vast"
620-710	Veen		
710-960	Klei		Grys
960-1070	Klei-zandig		Licht veenhoudend
1070-1120	Zand fyn		Grys
1120-1180	Zand matig grof		Grys
1180-14	Zand grof		Grys
Filter A	4-6 capaciteit	slecht	Grwtr 3,80
Filter B	13-14 capaciteit	zeer goed	" "
	Grind 1250-14	350-6	
	Klei 570-1070	0-1	
PB water	Ph=7,29	mS 2,86	
positie	125916		
Rd	479823		

- Boordiameter: 219 mm
- Diepte boring: 14 m
- Capaciteit bron:
- Grondwaterstand: m
- Gebruikt filtergrind: 8
- Gebruikt bentoniet: 8
- Begintijd boring:
- Einddtijd boring:

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

PB 4
A+B

Opdrachtgever: Henk van Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer: Huntumdreef Amsterdam
Ref. opdrachtgever:
Datum uitvoering: 27-11-2012
Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0-50	Zand f zw		
50-380	Zand m grof geel	- li bruin	
380-460	Zand m. grof grys		
460-550	klei dk grys	"vast"	
550-670	Veen		
670-970	klei grys		
970-1310	Zand fyn-siltig	grys	
1310-14	Zand matig fyn	grys	
A Filter ø50	470-670 grwh 3,80	capaciteit	slecht
B Filter ø50	13-14 grwh=380	capaciteit	zeer goed
"	grind "1250-14 +	420-670	
1 x	straatpot geplaatsd		
PB	water B = ph=7,21	mS=2,59	
positie	126002		
rd	479836		

- Boordiameter: 178 mm
- Diepte boring: 14 m
- Capaciteit bron:
- Grondwaterstand: 2 x 3,80 m
- Gebruikt filtergrind: 9
- Gebruikt bentoniet: 11
- Begintijd boring:
- Eindtijd boring:

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ____________ ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

PB

5 B

Opdrachtgever: Henk van Toubeker
Contactpersoon: Jaap Gerritsen
Projectnummer: Huntumdreef Amsterdam
Ref. opdrachtgever:
Datum uitvoering: 21-11-2012

Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0 - 130	Zand Fyn	Zw - Br	
130 - 190	Zand matig grof	Grys	
190 - - 230	Klei Grys		
230 - 300	Zand F Grys		
3 - 480	Veen		
480 - 710	Klei Grys		
710 - 960	Zand Fyn Grys		
960 - 1140	Zand matig Fyn	Grys	
1140 - 1250	Zand matig grof	Grys	
Filter ∅	50 1150 - 1250		
	Grind 11 - 12,50	Klei 1,90 - 7,70	
1 stalen	hoker geplaatst		
PB	Water ph = 7,24	ms = 2,48	
Positie	126030		
Rd	479859		

- Boordiameter: 178 mm
- Diepte boring: 12,50 m
- Capaciteit bron: zeer goed
- Grondwaterstand: 1,10 m
- Gebruikt filtergrind: 3
- Gebruikt bentoniet: 9
- Begintijd boring:
- Einddtijd boring:

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Opdrachtgever: Henk van Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer: Huntumdreef Amsterdam
Ref. opdrachtgever: ~~Huntumdreef~~
Datum uitvoering: 29-11-2012
Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

PB
1B

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0-30	Zand fyn zwart		
30-180	Zand, matig grof grys-li bruin		
180-290	Zand matig fyn dr. grys-zw		
290-310	Klei dr. grys zwart "vast"		
310-430	Veen		
430-580	Klei dr grys "vry vast"		
580-750	Klei, sterk zandig zw-dr grys		
750-910	Zand fyn dr grys siltig		
910-11	Zand f. grys		
11-12	Zand matig f		Li. grys-bruin
12-13	Zand matig fyn grys licht klei houdend		
Filter	50mm 12-13		
	Grind 1150-13	Klei 290-1.50	
1	x kleine straatpot geplaatst		
PB	water ph=7.63	ms=9.87	
positie	126566		
rd	480359		

- Boordiameter 178 mm
- Diepte boring 13 m
- Capaciteit bron zeer goed
- Grondwaterstand 400 m / spanning
- Gebruikt filtergrind 3
- Gebruikt bentoniet 1
- Begintijd boring
- Einddtijd boring

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ____________ ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Possibly Pb 8a+b

Opdrachtgever: Henk van Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer:
Ref. opdrachtgever:
Datum uitvoering: 23-11-2012
Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0-50	Zand F zw-Br		
50-180	Zand MF	Geel-Br	
180-490	Klei Grys + 20%	steen schrot	
490-590	Veen		
590-930	Klei Grys —	Li veenachtig	
930-1050	Klei, zandig +	10% veenhoudend	
1050-11	Zand zeer fyn Grys		
11-1170	Zand M Fyn	Grys	
1170-1240	Zand matig Grof	Grys	
1240-14	Zand Grof Grys		
Filter 50	4-6 capaci	slecht	Gr with 3,80
Filter 50	13-14 capaci	zeer goed	Gr wth 3,80
	Grind 1250-14 +	350-600	
	Klei 6-11 +	180-490	

- Boordiameter: 178 mm
- Diepte boring: 14 m
- Capaciteit bron:
- Grondwaterstand: m
- Gebruikt filtergrind: 8
- Gebruikt bentoniet: 12
- Begintijd boring:
- Einddtijd boring

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

☐ n.v.t.

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie):

☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Opdrachtgever: Henk v Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer:
Ref. opdrachtgever: Hartumdreef Amsterdam
Datum uitvoering: 26-11-2012

PB 9
A+B

Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

BODEMOPBOUW		AANVULSTAAT	
Diepte (m-mv)	Omschrijving grondmonsters (*)	Diepte (m-mv)	Beschrijving (**)
0-40	Zand F ZW		
40-170	Zand mF		Geel-Libr
170-430	Klei Grys + 10%	Steenschrot	
430-7,40	Steenschrot + hout,	beton +30	% Zand F Grys
740-920	Klei dr Grys + 30%	Steenschrot	+ hout
920-1150	Zand mF Grys		
1150-1220	Zand matig grof	Grys	
1220-14	Zand grof Grys		
Filter 50	4-6 capaci zeer slecht	Gr	wtn 3,80
Filter 50	13-14 capaci zeer goed	Gr	wtr 3,80
	Grind 1250-14 +	350-600	
	Klei 600-1250 +	2,00-3,50	

- Boordiameter: 178 mm
- Diepte boring: 14 m
- Capaciteit bron:
- Grondwaterstand: 2 + 3,80 m
- Gebruikt filtergrind: 8
- Gebruikt bentoniet: 11
- Begintijd boring:
- Einddtijd boring:

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Opdrachtgever
Contactpersoon
Projectnummer
Ref. opdrachtgever
Datum uitvoering: 26-11-2012

Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

PB 10

BODEMOPBOUW		AANVULSTAAT	
Diepte (m-mv)	Omschrijving grondmonsters (*)	Diepte (m-mv)	Beschrijving (**)
0 - 40	Zand F zwart		
40 - 360	Klei dk grys + 20% steenschrot		
360 - 550	Steenschrot + beton + hout		
550 - 730	Zand fyn grys + 30% steenschrot		
730 - 930	Klei dk grys + 30% steenschrot		
930 - 1140	Zand fyn grys		
1140 - 12	Zand matig grof		
12 - 14	Zand grof grys		
Filter ø	13 - 14 grind	12,50 - 14	Klei 700 - 1250
	4 - 600 grind	350 - 600	Klei 0 - 350
	1 x straatpot	geplaatst	
Positie:	125915		
RD:	479794		

- Boordiameter 178 mm
- Diepte boring 14 m
- Capaciteit bron
- Grondwaterstand m
- Gebruikt filtergrind 8
- Gebruikt bentoniet 13
- Begintijd boring
- Einddtijd boring

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie):

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

PB 11 B

Opdrachtgever	Henk van Tonberen
Contactpersoon	JAAP GERRITSEN
Projectnummer	HUNTUMDREEF AMSTERDAM
Ref. opdrachtgever	
Datum uitvoering:	30-11-2012
Soort boring:	[x] puls / [ ] holle avegaar / [ ] spoelboring

BODEMOPBOUW		AANVULSTAAT	
Diepte (m-mv)	Omschrijving grondmonsters (*)	Diepte (m-mv)	Beschrijving (**)
0 - 30	ZAnd Fyn		ZWART
30 - 490	KlEi, ZWART - dk	Grys +± 30	% STEENSCHROT
	ASFALT BETON	+ hoUT	
490 - 650	KLEi, dk Grys -	ZWART	„VAST"
650 - 760	VEEN		
760 - 940	KlEi dk Grys	„VAST"	
940 - 1180	ZAnd, ZEER Fyn -	SiLTiG	dk. Grys
1180 - 13	ZAnd Fyn Grys		
13 - 14	ZAnd, MATiG	GROF Grys	
FILTER pvc	ø 50 mm 13-14		
	GRind 1-1.6	1250 - 14	
	KlEi	30 - 940	
positie	125 875		
R.d	479 768		
P.B WATER	pH 7.32		
	mS 3,21		
		1x KlEiNE	STRAATPOT GEPLAA-

- Boordiameter 219 mm
- Diepte boring 14 m
- Capaciteit bron ZEER Goed
- Grondwaterstand 3,80 m
- Gebruikt filtergrind 4
- Gebruikt bentoniet 8
- Begintijd boring
- Einddtijd boring

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ____________ [ ] n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Opdrachtgever: Henk v. Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer: Huntumdreef Amsterdam
Ref. opdrachtgever:
Datum uitvoering: 28-11-2012

PB 12 B

Soort boring: ☐ puls / ☐ holle avegaar / ☐ spoelboring

BODEMOPBOUW		AANVULSTAAT	
Diepte (m-mv)	Omschrijving grondmonsters (*)	Diepte (m-mv)	Beschrijving (**)
0 - 40	Zand Fyn ZW		
40 - 80	Klei, zandig +	40%	STEENSCHROT
80 - 400	Klei dk-grys	"VAST" +20%	STEENSCHROT
400 - 540	VEEN		
540 - 660	Klei Grys		
660 - 760	Klei, zandig +	20% VEEN	houdend
760 - 950	Zand Grys Fyn		
950 - 1170	Zand matig Fyn	Grys	
1170 - 1230	Zand matig	Grof Grys	
1230 - 13	Zand Grof Grys		
FILTER ⌀	50 12-13		
	Grind 1150-13	Klei 0	- 760
1 x	STALEN Koker	Geplaatst	
PB WATER	ph = 7.7 mS =	3.15	
POSITIE	125807		
Rd	479680		

- Boordiameter 178 mm
- Diepte boring 13 m
- Capaciteit bron Zeer Goed
- Grondwaterstand 2,00 m
- Gebruikt filtergrind 3
- Gebruikt bentoniet 10
- Begintijd boring
- Einddtijd boring

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Opdrachtgever: Henk v. Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer: Hintumdreef Amsterdam
Ref. opdrachtgever:
Datum uitvoering: 28-11-2012

PB 13B

Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0-20	ZAnd Fyn		ZW
20-310	Klei Grys, "vast"	+10% STEENSchrot	
310-450	Veen		
450-640	Klei Grys		
640-8,00	Klei Grys, ZAndiG		
8-1010	ZAnd Fyn	Grys	
1010-1180	ZAnd M.F	Grys	
1180-13	ZAnd MATIG GroF		Li Grys-Bruin
FILTER -50	12-13	Grind 1150	-13
		Klei 20-	~~1050~~ 800
	1 x STALEN Koker	GEPLAATSd	
PB WATER	pH=7,19	mS 3,23	
positie	125746		
Rd	479639		

- Boordiameter: 178 mm
- Diepte boring: 13 m
- Capaciteit bron: ZEER GOED
- Grondwaterstand: 1,20 m
- Gebruikt filtergrind: 3
- Gebruikt bentoniet: 9
- Begintijd boring:
- Eindtijd boring:

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Opdrachtgever: Henk v Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer: Huntumdreef Amsterdam
Ref. opdrachtgever:
Datum uitvoering: 29-11-2012
Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

PB 14 B

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0 - 190	Zand F. ZW-	BR- Grys	
190 - 290	Klei Grys-BR	Sterk veen	houdend
290 - 5,00	Klei Grys		
5,00 - 770	Klei Zandig		Grys
770 - 880	Zand Fyn		Grys
880 - 10,00	Zand matig Fyn		Grys
10 - 1090	Zand matig Grof		Li. Grys
1090 - 1250	Zand Grof		Li Grys - Bruin
1250 - 13	Grind Fyn		Li Grys
Filter 50	12 - 13		
	Grind 1150 - 13		
	Klei 190 - 770		
1 x	Kleine straatpot geplaatst		
ph	7,46 ms 9,41		
Positie	125254		
rd	479362		

- Boordiameter: 178 mm
- Diepte boring: 13 m
- Capaciteit bron: zeer goed
- Grondwaterstand: 90 cm m
- Gebruikt filtergrind: 3
- Gebruikt bentoniet: 9
- Begintijd boring:
- Eindtijd boring:

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ________________ ☐ n.v.t.

H. Borehole descriptions Nellesteinpad

Borehole descriptions from the Nellesteinpad pumping test (Jongerius, 2013).

Alards Grondboringen

VELDWERKRAPPORTAGE BRL 2100

Opdrachtgever	HENK VAN TONGEREN BRONBEMALING
Contactpersoon	JAAP GERRITSEN
Projectnummer	Ref. opdrachtgever: KELBERGEN - AMSTERDAM

Voor beschrijving uit te voeren werkzaamheden en te gebruiken materialen: zie werkbon of offerte

Ingezette boormeesters : ☒ Math / ☒ Michal / ☐ ....

Voorbereiding	JA	NEE	NVT	Opmerkingen/anders
meldingen gedaan en vergunningen verkregen?	X			
KLIC gegevens bekend?	X			
planning haalbaar?	X			
toe te passen boortechniek	☒ puls / ☐ holle avegaar / ☐ spoelboring			
te gebruiken boorstelling/machine				
werkzaamheden in verontreinigd gebied?			X	
verwachte GWS	± 1,00 MTR			-M/mV
verwachte scheidende lagen van … (-m/mV) tot… (-m/mV)	n-V-T			
wijze van detectie scheidende lagen:	n-V-T			
wijze van voorkomen verspreiding verontreiniging?	n-V-T			
casing toepassen (indien ja: dameter vermelden)?	178 mm			Ø (mm)

Vooraf bekende informatie m.b.t. veiligheid:

☐ Werken op of langs de openbare weg
☐ Asbestverdacht
☐ Werken op of langs het spoor
☐ Toxische stoffen

LANGS VOETPAD

Uitvoering

Datum uitvoering: 11-03 T/M 13-03 2013 | Start(tijd): 6,00 | Einde (tijd): 18,00

Controles	JA	NEE	NVT	Opmerkingen/anders
Voorgegraven?	X			
vergunning aanwezig?	X			
KLIC gegevens aanwezig?	X			
Gekozen/uitgevoerde boormethode	☒ puls / ☐ holle avegaar / ☐ spoelboring			
Boordiameter (Ø)	178 mm			Ø (mm)
Booradditieven gebruikt (indien ja, welke?)			X	
Boorafstand tot gebouwen/funderingen>10x boor (Ø)			X	
Boorlocatie (per boring vastleggen)	X:			Y: ZIE BOORSTATEN
Situatie op locatie, zoals verwacht?	X			
Scheidende lagen bepaald en vastgelegd?			X	

Als scheidende lagen NIET zijn vastgelegd of <10 cm, werk dan hele boorgat af met bentoniet en noteer gebruikte hoeveelheid.
Als scheidende lagen WEL zijn vastgelegd, maak dan boorstaat met bodemopbouw, filterstelling, grind en wijze van afdichting

	JA	NEE	NVT	Opmerkingen/anders
Hoeveel liter werkwater is gebruikt (per boring)?	300 ltr.			Ec: ZIE BOORSTATEN µS
boormateriaal schoongemaakt na boring?	X			
boorgat (maaiveld) afgedicht?	X			
afwijkingen (opdracht / BRL 2000/2100)?		X		
*gebruikte hoeveelheid bentoniet (aantal zakken)	ZIE BOORSTATEN			zakken
casing toegepast?	JA 178			Ø (mm)
overige aspecten				
verharde gesteenten of formaties aangetroffen?		X		
voldoen slangen/koppelingen (KWO) [ISSO73]?			X	
passieve geurwaarnemingen, asbest, overige		X		

Opmerkingen / afwijkingen (van protocol 2001 en/of 2101), en getroffen maatregelen:

Naam Boormeester: MATH ALARDS | Paraaf: [signature]
Naam Boormedewerker: Michael DEROGOUSKI | Paraaf: [signature]

Vergeet niet om een boorbeschrijving te maken (bodem-opbouw)

BOORSTAAT / BOORBESCHRIJVING

Opdrachtgever: Henk van Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer:
Ref. opdrachtgever: Kelbergen Amsterdam
Datum uitvoering: 12-03-2013

Soort boring: ☐ puls / ☐ holle avegaar / ☐ spoelboring   PB 1

Alards Grondboringen

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0 - 80	Zand fijn	10% steenschm	Bruin-zwart
80 - 190	Zand matig fijn		Bruin-geel
190 - 480	Veen		
480 - 600	Zand dk bruin		sterk veenachtig
600 - 770	Zand fijn		br - grijs
770 - 1050	Zand matig	fijn	grijs
1050 - 1310	Zand matig	grof	grijs
1310 - 14	Zand grof	grijs	
HPE	Filter Ø 50	13 - 14	
Grindomstorting 1 - 1,6mm		12 - 14 mtr	
Klei afdichting 0 - 2,00		mtr	
Werkwater:	pH 7,92 mS 0,39		
PB water:	pH 7,21 mS 14,98		
Positie:	127076		
RD	480452		

- Boordiameter 178 mm mm
- Diepte boring 14,00 m
- Capaciteit bron
- Grondwaterstand 1,00 m
- Gebruikt filtergrind 4
- Gebruikt bentoniet 4
- Begintijd boring
- Einddtijd boring

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Opdrachtgever: Henk van Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer: Kelbergen Amsterdam
Ref. opdrachtgever:
Datum uitvoering: 13-3-2013

Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring PB 2

BODEMOPBOUW		AANVULSTAAT	
Diepte (m-mv)	Omschrijving grondmonsters (*)	Diepte (m-mv)	Beschrijving (**)
0 - 70	Zand fijn + 10% steenslag		Bruin-zwart
70 - 190	Zand matig fijn		Bruin-geel
190 - 510	Veen		
510 - 600	Zand fijn da	Bruin	sterk veenachtig
600 - 780	Zand fijn		Grys
780 - 1080	Zand matig fijn		Grys
1080 - 1320	Zand matig	grof	Grys
1320 - 14	Zand grof		Grys
HDPE Ø50	Filter 13-14		
Grind	omstort 12-14	mtr	1,-1,6 mm
Klei	omstort 0-2,00	mtr	
Werkwater	pH 7,92 mS 0,39		
DW water	pH 7,22 mS 14,23		
Positie:	127071		
RD	480450		

- Boordiameter 178 mm
- Diepte boring 14,00 m
- Capaciteit bron zeer goed
- Grondwaterstand 1,10 m
- Gebruikt filtergrind 4
- Gebruikt bentoniet 4
- Begintijd boring
- Einddtijd boring

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Opdrachtgever: HENK VAN TONGEREN
Contactpersoon: JAAP GERRITSEN
Projectnummer:
Ref. opdrachtgever: KELBERGEN AMSTERDAM
Datum uitvoering: 13-3-2013

Alards Grondboringen

Soort boring: ☐ puls / ☐ holle avegaar / ☐ spoelboring PB 3

BODEMOPBOUW		AANVULSTAAT	
Diepte (m-mv)	Omschrijving grondmonsters (*)	Diepte (m-mv)	Beschrijving (**)
0 - 40	ZAND FIJN		BRUIN - ZWART
40 - 200	ZAND MATIG FIJN		BRUIN-GEEL
200 - 290	VEENACHTIGE	KLEI	GRIJS-BR
290-500	VEEN		
500 - 660	ZAND FIJN DR	BRUIN	STERK VEENACHTIG
660 - 1090	ZAND FIJN		GRIJS
1090 - 1150	ZAND MATIG FIJN		GRIJS
1150 - 13	ZAND MATIG	GROF	GRIJS
13 - 14	ZAND GROF		GRIJS
HDPE	FILTER 50	13-14	
GRINDOMSTORTING	12 - 14 MTR	1 - 1,6 MTR	
~~[illegible]~~	KLEI OMSTORT	0 - 2,00 MTR	
WERK WATER:	pH 7,92 mS 0,39		
PB. WATER:	pH 7,23 mS 14,11		
POSITIE:	127045		
RD	480448		

- Boordiameter 178 mm
- Diepte boring 14,00 m
- Capaciteit bron ZEER GOED
- Grondwaterstand 1,40 m
- Gebruikt filtergrind 4
- Gebruikt bentoniet 4
- Begintijd boring
- Einddtijd boring

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ nvt

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Opdrachtgever: Henk van Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer:
Ref. opdrachtgever: Kelpergen Amsterdam
Datum uitvoering: 12-03-2013
Soort boring: [x] puls / ☐ holle avegaar / ☐ spoelboring   PB4

BODEMOPBOUW Diepte (m-mv)	Omschrijving grondmonsters (*)	AANVULSTAAT Diepte (m-mv)	Beschrijving (**)
0-30	Zand fyn		BR-zwart
30-160	Zand matig fyn		Bruin-geel
160-190	Zand matig fyn		Grys
190-500	Veen		
5,00-610	Zand dk bruin		Sterk veenachti
610-760	Zand fyn		BR-grys
760-1060	Zand matig fyn		Grys
1060-11	Zand matig grof		Grys
11-14	Zand grof		Grys
Filter Hdpe 50	13-14		
Grindomstorting	1-1,6 mv	12-14 mtr	
Klei afdichting	0-2,00 mtr		
Werk water	pH 7,92 mS 0,39		
PB-water	pH 7,17 mS 14,86		
Positie:	127016		
RD	480427		

- Boordiameter 178 mm
- Diepte boring 14,00 m
- Capaciteit bron zeer goed
- Grondwaterstand 1,10 m
- Gebruikt filtergrind 4
- Gebruikt bentoniet 4
- Begintijd boring
- Einddtijd boring

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie):   ☐ n.v.t

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Opdrachtgever: HENK VAN TONGEREN
Contactpersoon: JAAP GERRITSEN
Projectnummer: 5
Ref. opdrachtgever: KELBERGEN AMSTERDAM
Datum uitvoering: 11-03-2013

Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

PB5

BODEMOPBOUW		AANVULSTAAT	
Diepte (m-mv)	Omschrijving grondmonsters (*)	Diepte (m-mv)	Beschrijving (**)
0-40	ZAND F		BR-ZWART
40-150	ZAND MATIG FYN		BRUIN-GEEL
150-280	VEEN		
280-400	ZAND MATIG FYN	DR STERK	VEENHOUDEND
400-480	VEEN		
480-590	ZAND DR BRUIN		STERK VEENACHTIG
590-750	ZAND FYN		BRUIN-GRYS
750-980	ZAND MATIG FYN		GRYS
980-1140	ZAND MATIG	GROF	GRYS
1140-14	ZAND GROF		GRYS
FILTER HDPE 50	13-14		
GRINDOMSTORTING	1,-1,6 mm	12-14 MTR	
KLEI AFDICHTING	0-2,00 MTR		
WERKWATER	pH 7,92 mS 0,39		
PB WATER:	pH 7,17 mS 14,25		
POSITIE:	126948		
RD	480391		

- Boordiameter: 178 mm
- Diepte boring: 14,00 m
- Capaciteit bron: ZEER GOED
- Grondwaterstand: 1,10 m
- Gebruikt filtergrind: 4
- Gebruikt bentoniet: 4
- Begintijd boring:
- Einddtijd boring:

(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

BOORSTAAT / BOORBESCHRIJVING

Alards Grondboringen

Pb 6

Opdrachtgever: Henk van Tongeren
Contactpersoon: Jaap Gerritsen
Projectnummer: 6
Ref. opdrachtgever: Kelbergen Amsterdam
Datum uitvoering: 11-03-2013
Soort boring: ☒ puls / ☐ holle avegaar / ☐ spoelboring

BODEMOPBOUW		AANVULSTAAT	
Diepte (m-mv)	Omschrijving grondmonsters (*)	Diepte (m-mv)	Beschrijving (**)
0-80	Zand F		BR-zwart
80-120	Zand matig fyn		grys
120-360	Veen		bruin
360-500	Zand fyn bruin - sterk		veenachtig
500-710	Zand fyn bruin - grys		
710-1080	Zand matig	fyn	grys
1080-1170	Zand matig grof		grys
1170-1290	Zand grof		middel grys
1290-14	Zand zeer grof		middel grys
HdPE 50	mm filter	13-14 mtr	
Grindomstorting 1-1,6 mm		12-14 mtr	
Klei afdichting 0-2,00 mtr			
Werkwater	pH 7,92 mS 0,39		
Pb. water	pH 6,89 mS 14,42		
Positie	126797		
RD	480309		

- Boordiameter 148 mm
- Diepte boring 14,00 m
- Capaciteit bron zeer goed
- Grondwaterstand 50 cm m
- Gebruikt filtergrind 4
- Gebruikt bentoniet 4
- Begintijd boring
- Einddtijd boring

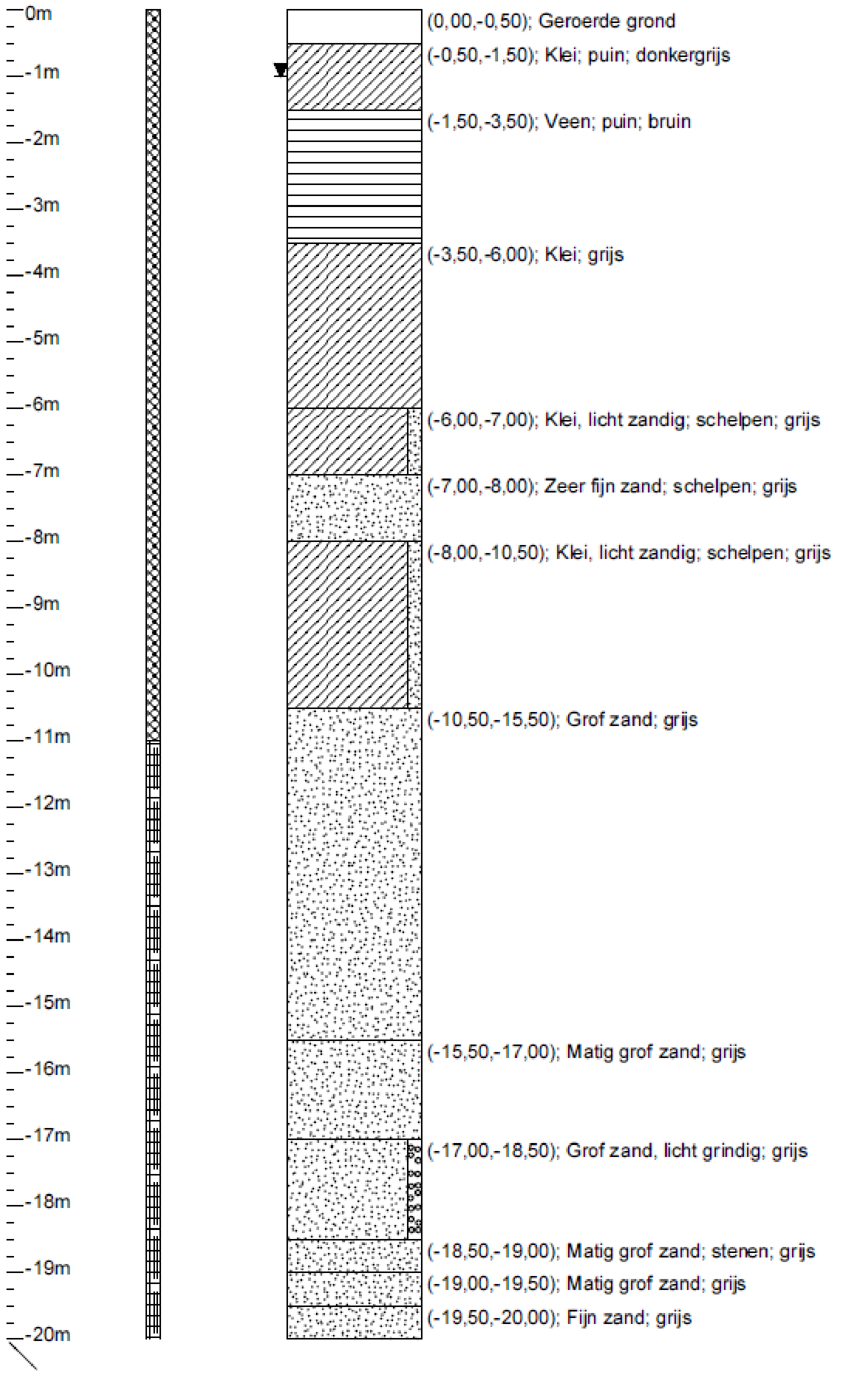
(*) denk aan dubbele kleurnamen (geel, grijs, bruin, zwart, rood, blauw, groen, oranje, paars)
(**) denk aan filterstelling, bentonietafwerking

Let op: alle overige relevante constateringen ook vermelden (waarnemingen, gleyverschijnselen e.d.). Gebruik evt. achterzijde

Overdracht monsters aan (naam / functie): ☐ n.v.t.

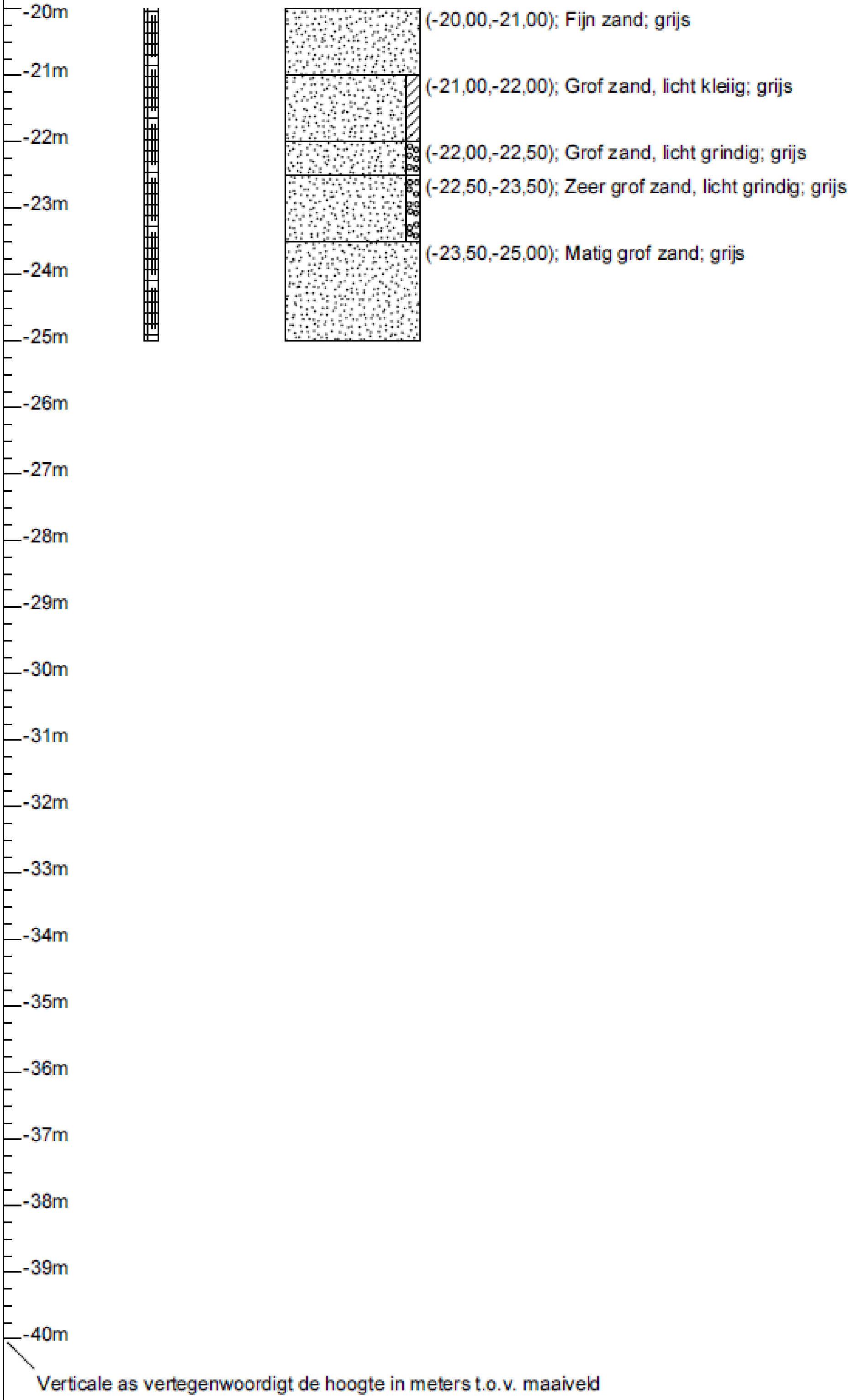
I. Borehole descriptions Amstelveen

Borehole descriptions from the Amstelveen pumping test site (Witteveen+Bos, 2014).

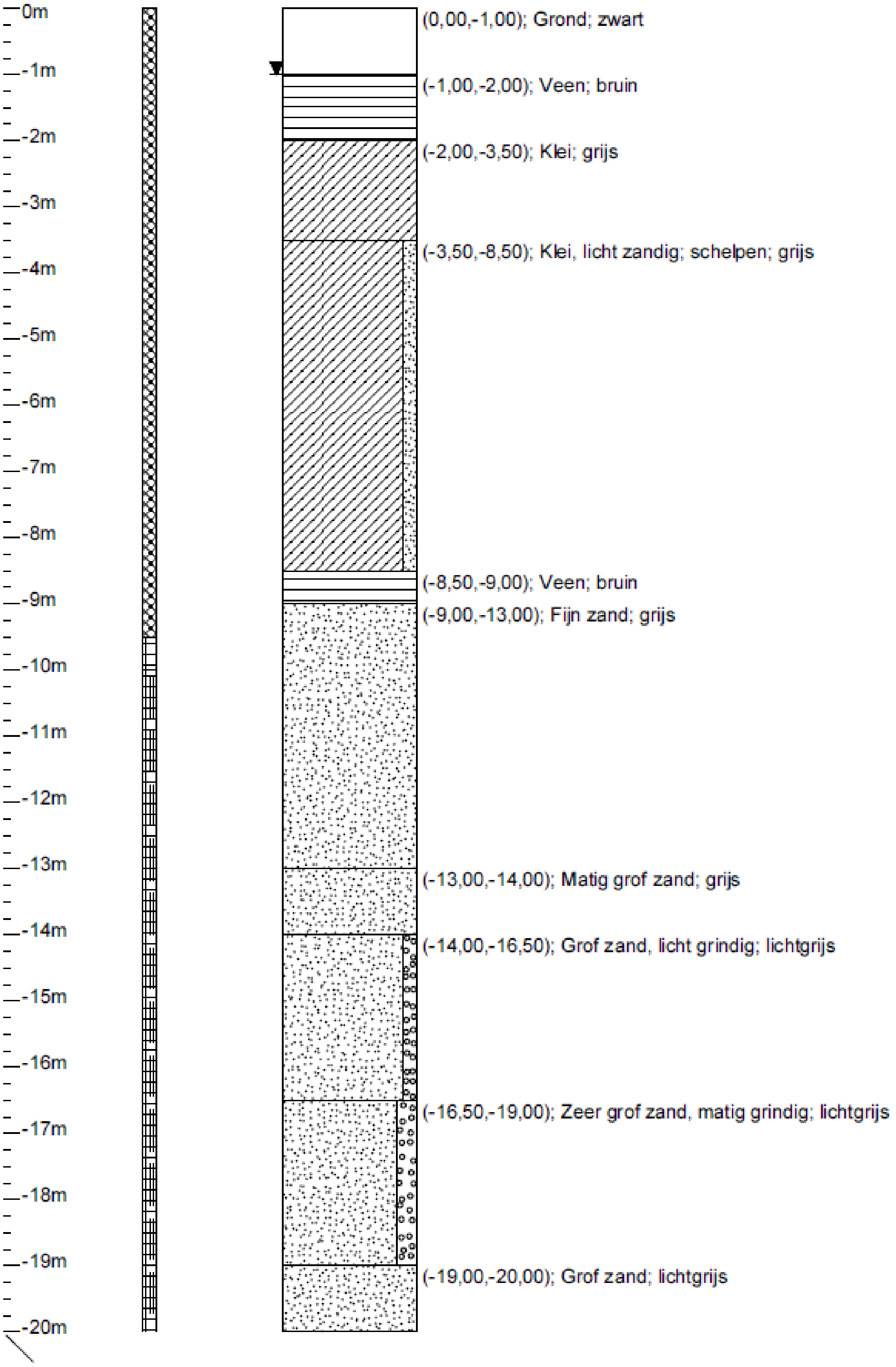


Verticale as vertegenwoordigt de hoogte in meters t.o.v. maaiveld

	Project/Plaats	Amstelveen, Keizer Karelweg	Datum	17-7-2014	Ons kenmerk	
	Opdrachtgever	Witteveen en Bos	X-coordinaat	118.713.885,000 km	Uw kenmerk	9487
	Boormethode	Rotary zuigboor	Y-coordinaat	479.279.759,000 km	Boornummer	
	Boormeester	Glijn Gul	KM		1	
van Velzen grondboortechniek						

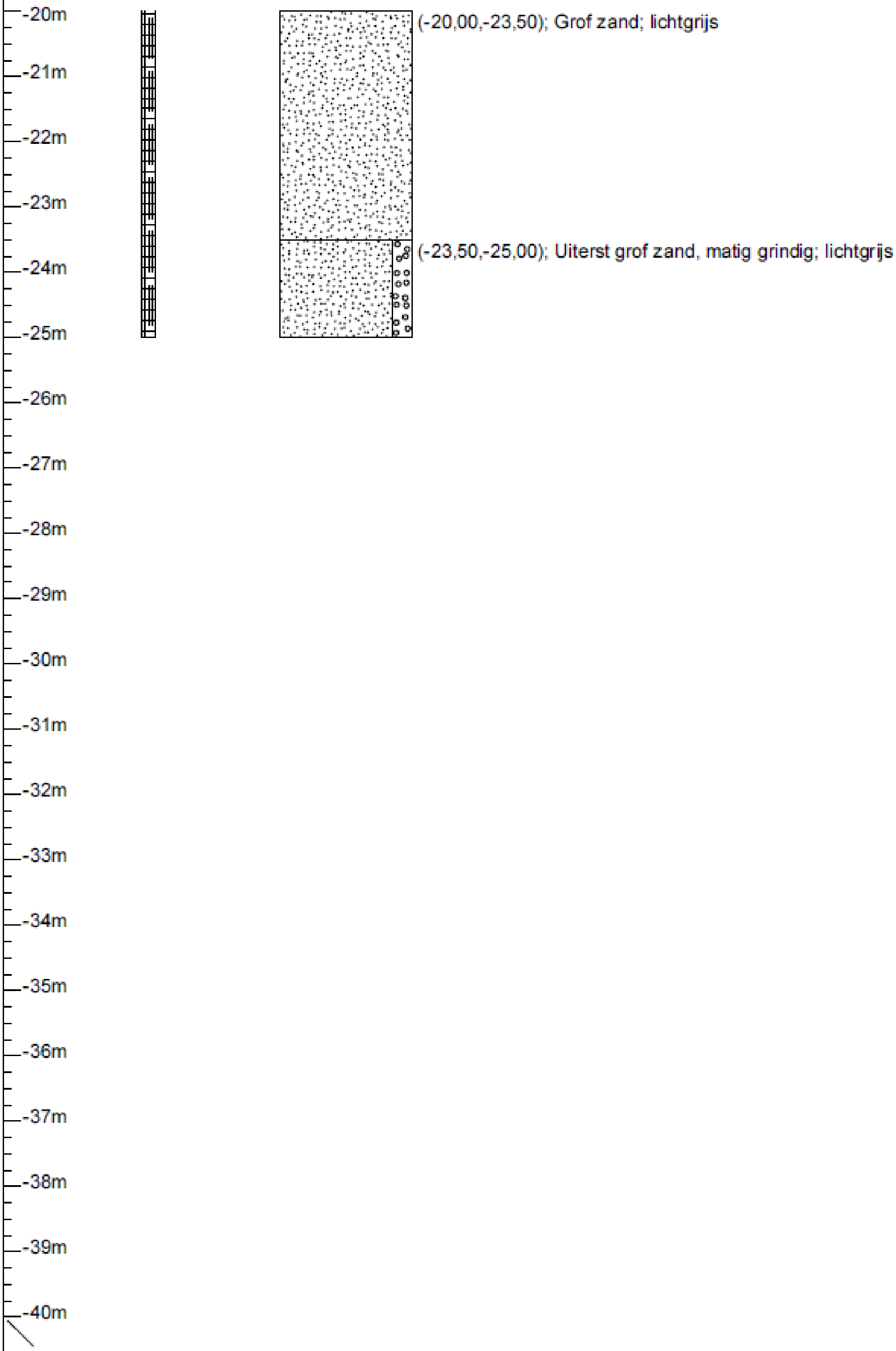


	Project/Plaats	Amstelveen, Keizer Karelweg	Datum	17-7-2014	Ons kenmerk	
	Opdrachtgever	Witteveen en Bos	X-coordinaat	118.713.885,000 km	Uw kenmerk	9487
	Boormethode	Rotary zuigboor	Y-coordinaat	479.279.759,000 km	Boornummer	
	Boormeester	Glijn Gul	KM		1	
van Velzen grondboortechniek						



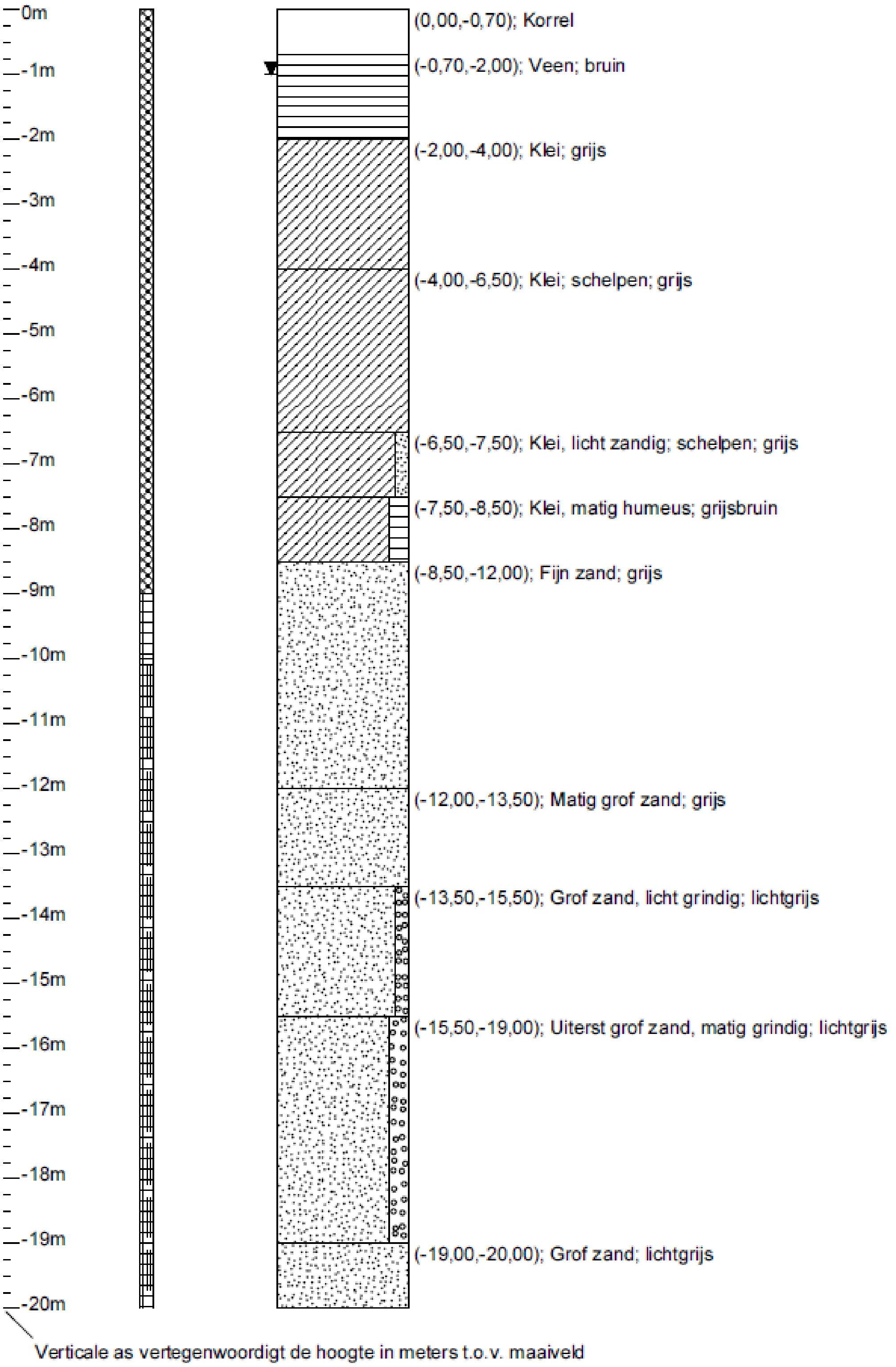
Verticale as vertegenwoordigt de hoogte in meters t.o.v. maaiveld

	Project/Plaats	Amstelveen, Keizer Karelweg	Datum	9-9-2014	Ons kenmerk	9487
	Opdrachtgever	Witteveen & Bos	X-coordinaat	118.521,000 km	Uw kenmerk	
	Boormethode	Rotary zuigboor	Y-coordinaat	479.458,000 km	Boornummer	
	Boormeester	Glijn Gul	KM		2	
van Velzen grondboortechniek						

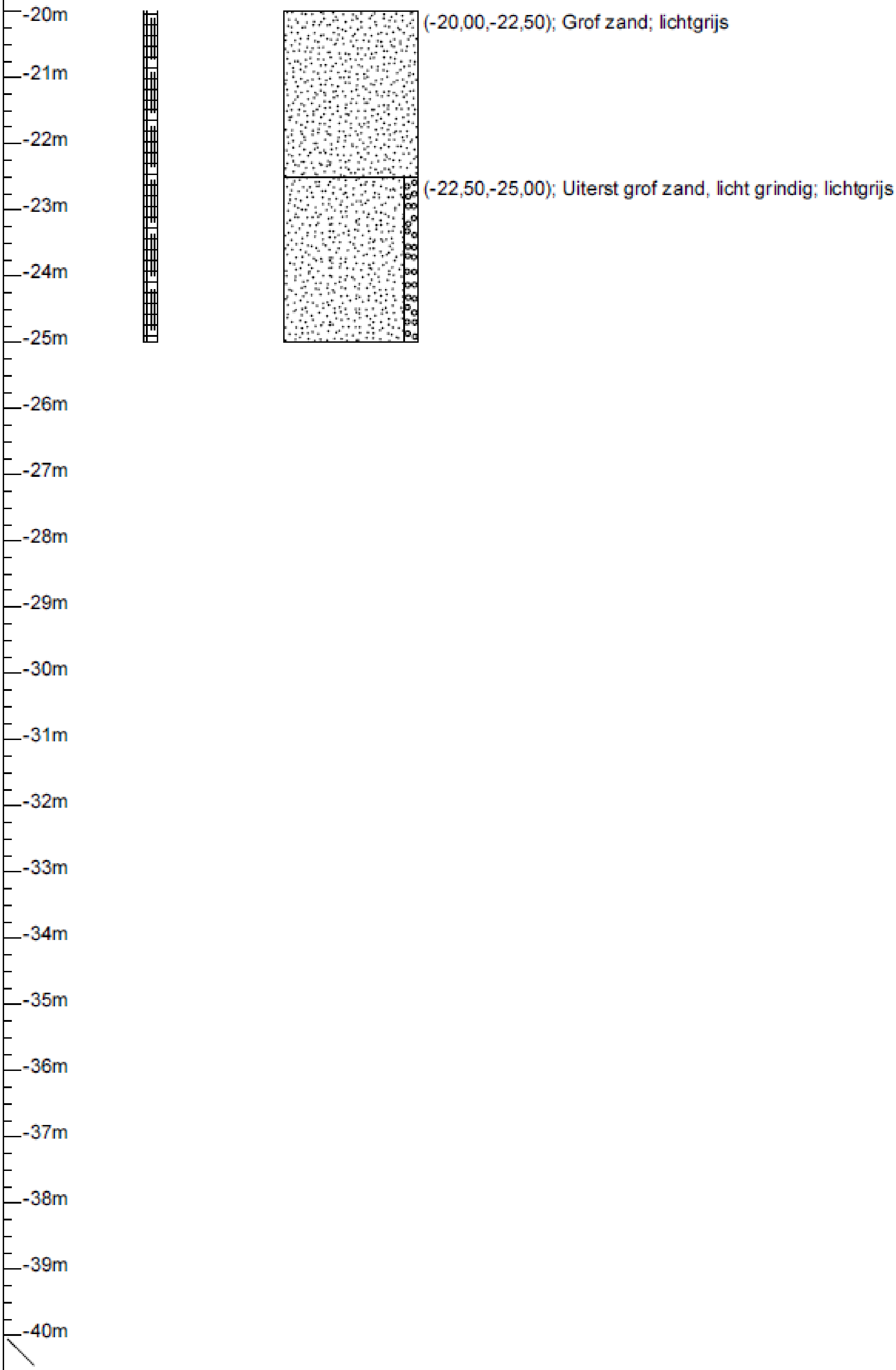


Verticale as vertegenwoordigt de hoogte in meters t.o.v. maaiveld

	Project/Plaats	Amstelveen, Keizer Karelweg	Datum	9-9-2014	Ons kenmerk	9487
	Opdrachtgever	Witteveen & Bos	X-coordinaat	118.521,000 km	Uw kenmerk	
	Boormethode	Rotary zuigboor	Y-coordinaat	479.458,000 km	Boornummer	
	Boormeester	Glijn Gul	KM		2	
van Velzen grondboortechniek						



	Project/Plaats	Amstelveen, Keizer Karelweg	Datum	10-9-2014	Ons kenmerk	9487
	Opdrachtgever	Witteveen en Bos	X-coordinaat	1.182.507,000 km	Uw kenmerk	
	Boormethode	Rotary zuigboor	Y-coordinaat	479.431,000 km	Boornummer	
	Boormeester	Glijn Gul	KM		3	
van Velzen grondboortechniek						

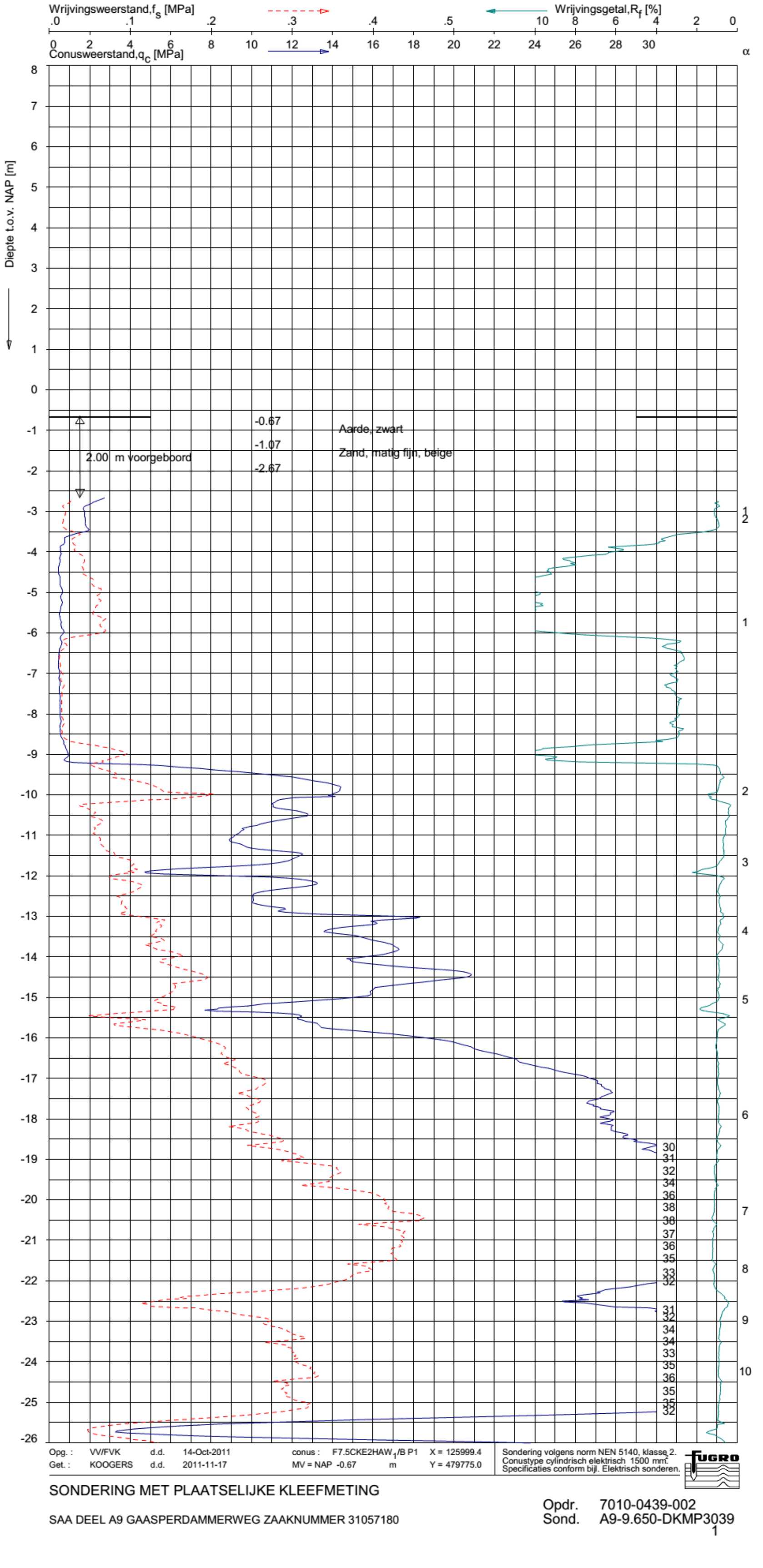


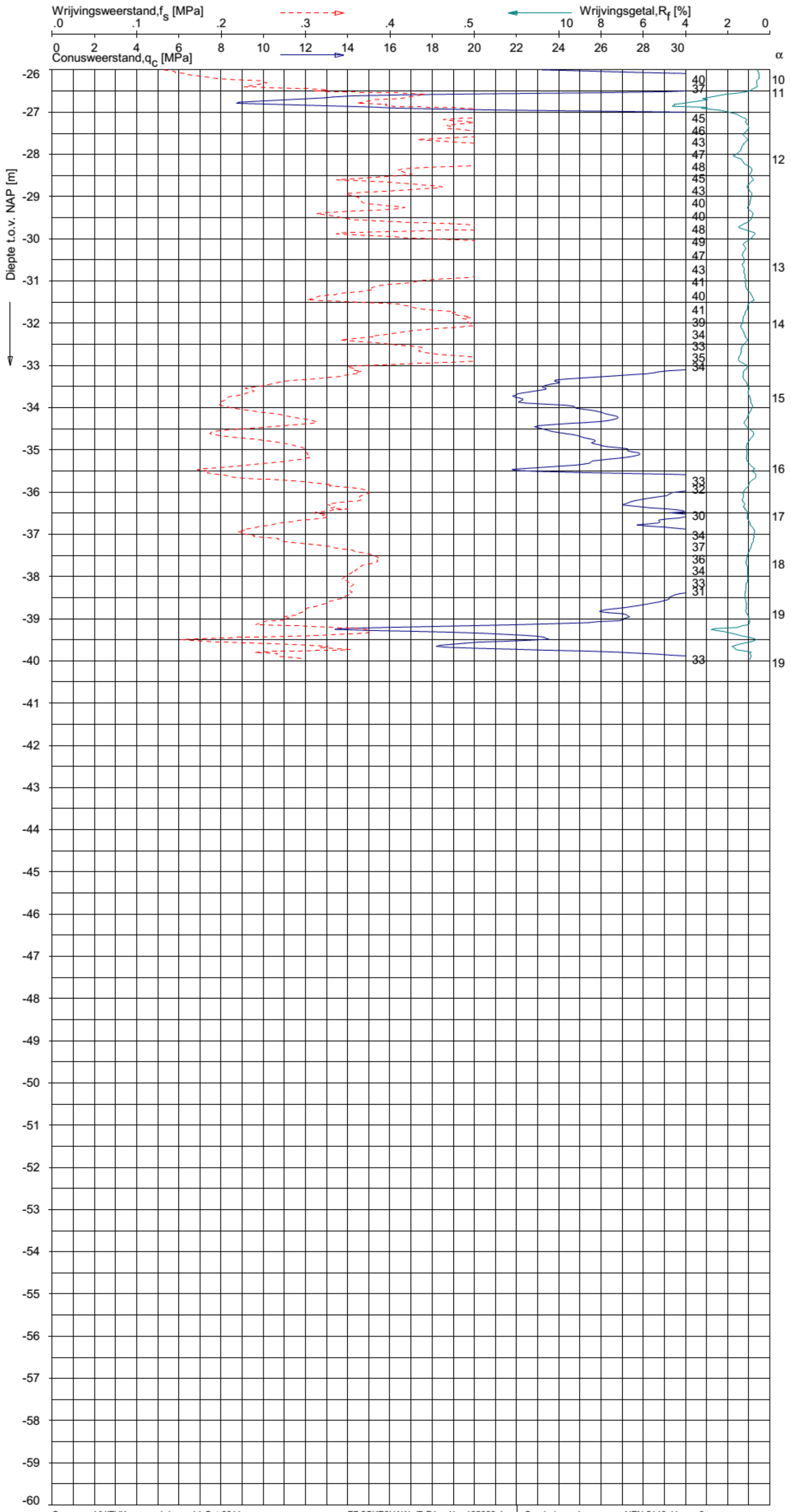
Verticale as vertegenwoordigt de hoogte in meters t.o.v. maaiveld

	Project/Plaats	Amstelveen, Keizer Karelweg	Datum	10-9-2014	Ons kenmerk	9487
	Opdrachtgever	Witteveen en Bos	X-coordinaat	1.182.507,000 km	Uw kenmerk	
	Boormethode	Rotary zuigboor	Y-coordinaat	479.431,000 km	Boornummer	
	Boormeester	Glijn Gul	KM		3	
van Velzen grondboortechniek						

J. Cone Penetration Test near Huntumdreef

Cone penetration test near the Huntumdreef pumping test (Jongerius, 2013).





Opg. : VV/FVK d.d. 14-Oct-2011 conus : F7.5CKE2HAW$_1$/B P1 X = 125999.4
Get. : KOOGERS d.d. 2011-11-17 MV = NAP -0.67 m Y = 479775.0

Sondering volgens norm NEN 5140, klasse 2.
Conustype cylindrisch elektrisch 1500 mm².
Specificaties conform bijl. Elektrisch sonderen.

FUGRO

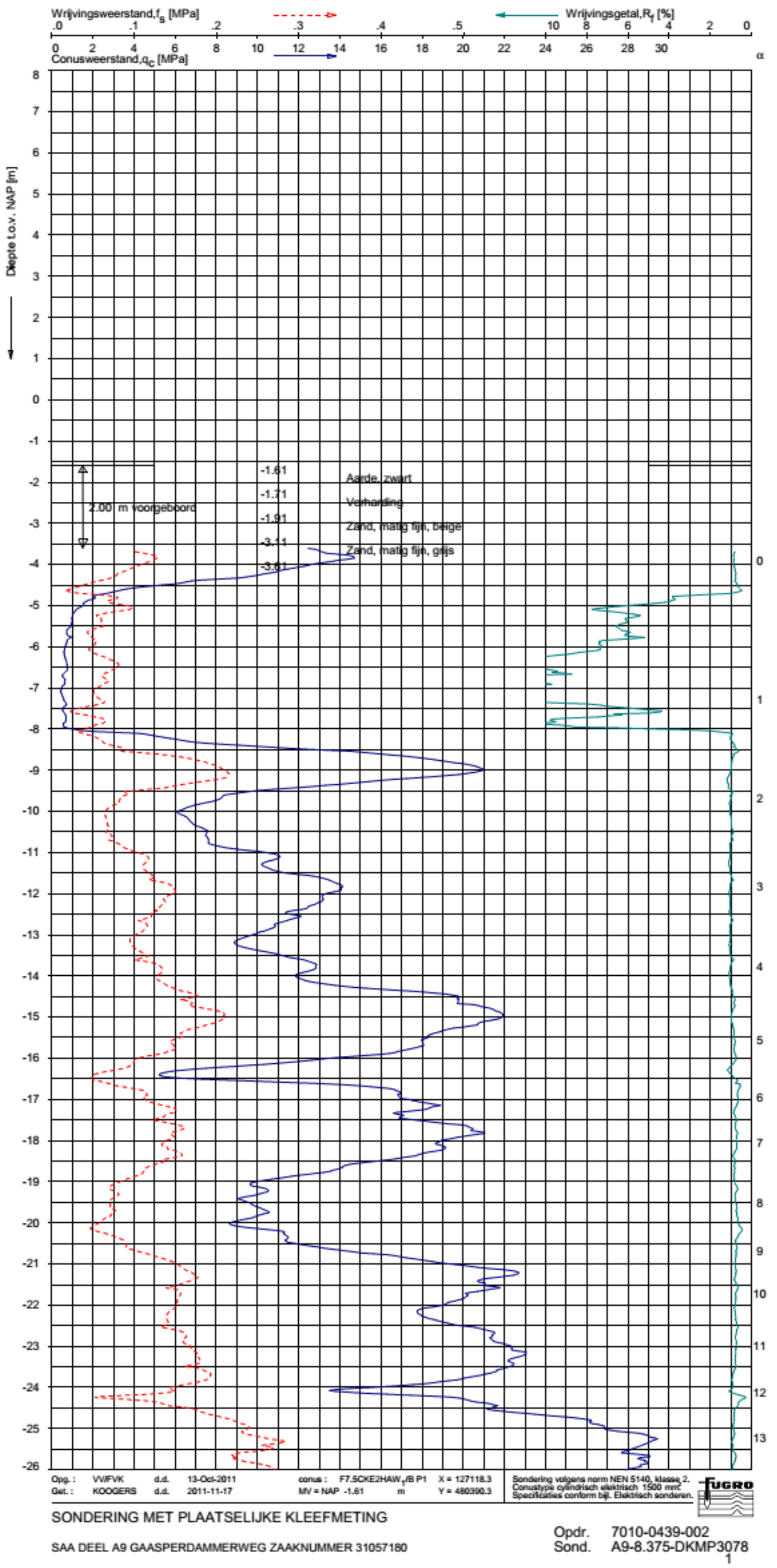
SONDERING MET PLAATSELIJKE KLEEFMETING

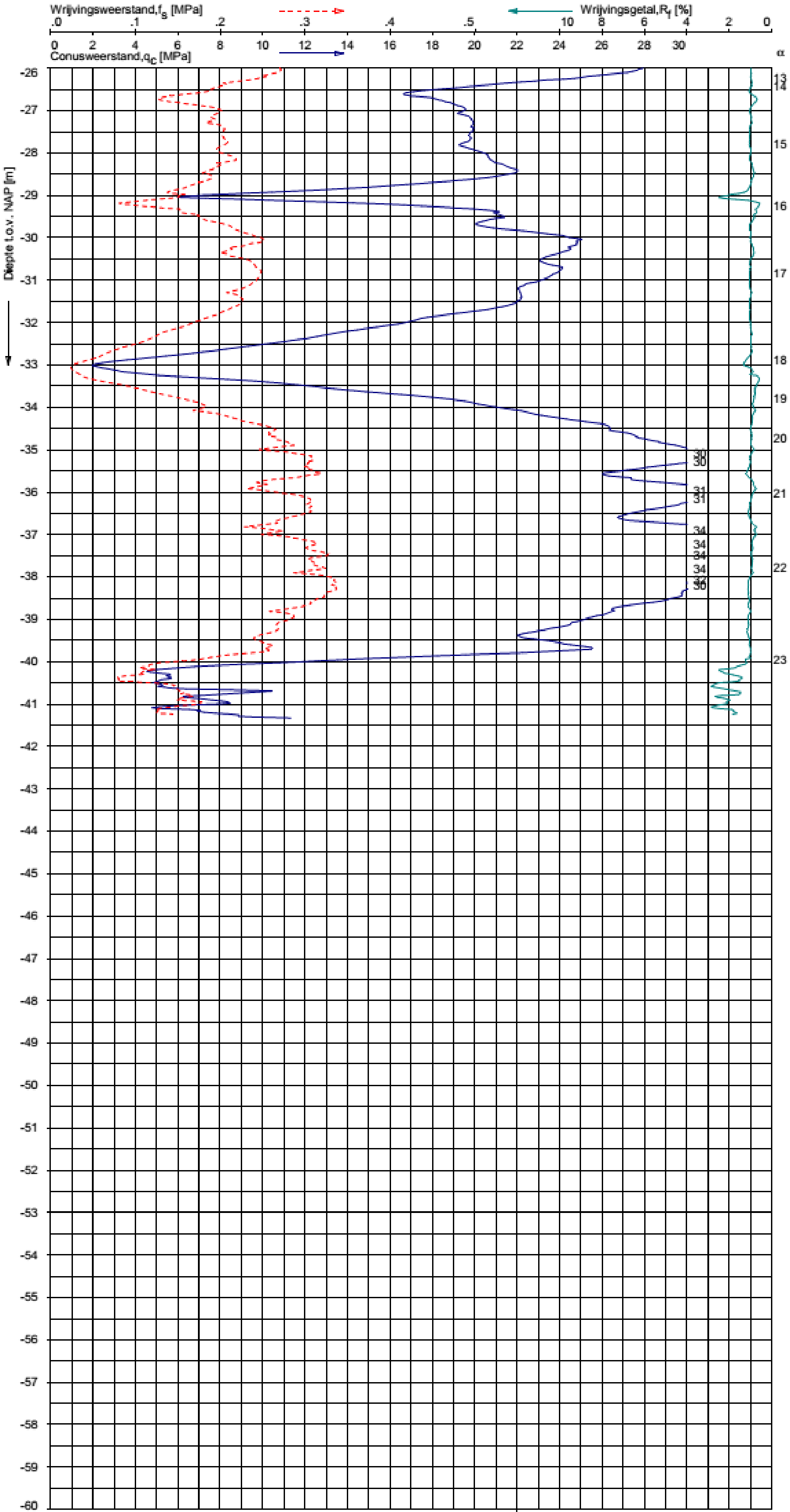
SAA DEEL A9 GAASPERDAMMERWEG ZAAKNUMMER 31057180

Opdr. 7010-0439-002
Sond. A9-9.650-DKMP3039
2

K. Cone Penetration Test near Nellesteinpad

Cone penetration test near the Nellesteinpad pumping test (Jongerius, 2013).





Opg. :	VWFVK	d.d.	13-Oct-2011	conus :	F7.5CKE2HAW$_1$/B P1	X = 127118.3	Sondering volgens norm NEN 5140, klasse 2.
Get. :	KOOGERS	d.d.	2011-11-17	MV = NAP -1.61	m	Y = 480390.3	Conustype cylindrisch elektrisch 1500 mm² Specificaties conform bijl. Elektrisch sonderen.

SONDERING MET PLAATSELIJKE KLEEFMETING

SAA DEEL A9 GAASPERDAMMERWEG ZAAKNUMMER 31057180

Opdr. 7010-0439-002
Sond. A9-8.375-DKMP3078
2