

REANALYSIS OF HYDRAULIC HEAD VARIATIONS IN AN ANCIENT CLAY DIKE CAUSED BY CHANGING ATMOSPHERIC CONDITIONS

Geotechnical site interpretation of a dike in the Leendert de Boerspolder

Additional thesis work
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TABLE OF CONTENTS

1	INTRODUCTION	3
1.1	Leendert de Boerspolder.....	3
1.2	Research scope and objectives.....	5
1.3	Definitions	6
2	Boundary CONDITIONS LEENDERT DE BOERSPOLDER	7
2.1	Adjacent water levels Leendert de Boerspolder	7
2.2	Atmospheric conditions	8
2.2.1	Evapotranspiration	9
2.2.2	Net rainfall.....	11
3	MEASUREMENT ERRORS AND EQUIPMENT LIMITATIONS	13
3.1	Atmospheric pressure	13
3.2	Time lag piezometers	13
3.3	Installation errors	14
4	HYDRAULIC HEAD VARIATIONS AND ATMOSPHERIC CONDITIONS	16
4.1	Hydraulic head variations in dike material caused by rainfall.....	17
4.2	Hydraulic head variations in peat caused by rainfall	19
5	GEOTECHNICAL SITE INTERPRETATION	23
5.1	Dike material	23
5.2	Peat layer.....	24
6	DISCUSSION	26
7	CONCLUSION AND RECOMMENDATIONS	27
	REFERENCES	29
A	PROJECT LOCATION AND SITE INVESTIGATION.....	31
B	CROSS-SECTION STANDPIPES	32
C	CROSS-SECTION SOUTH PIEZOMETERS	33
D	CROSS-SECTION CENTRE PIEZOMETERS.....	34
E	CROSS-SECTION NORTH PIEZOMETERS.....	35
F	PORE WATER PRESSURE OBSERVATIONS DIKE – RAINFALL	36
G	PORE WATER PRESSURE OBSERVATIONS PEAT – RAINFALL	37

1 INTRODUCTION

In the Netherlands the total area protected by dikes is enormous. An ideal dike is strong and waterproof: sand in combination with a clay core provide such properties. However, most of the dikes in the Netherlands are constructed long ago with local materials which are less suitable. Especially ancient dikes containing heterogeneous material like peat are prone to stability problems. Dikes play a vital role in the Netherlands and therefore their safety must be guaranteed in the future. Research is continuously performed to gain knowledge on different processes affecting the performance of ancient and modern dikes.

One of the processes affecting the stability of dikes and the material properties is the changing water level in the dike. The location of the phreatic level in the dike is changing continuously due to time dependent external conditions. For example, rainfall, transpiration, evaporation, water extraction by vegetation, the river level and the pore water pressure in the Pleistocene sand all affect the amount of water in the dike. Besides external conditions the soil type is also very important for the pore water pressure in the dike. Heterogeneity causes big differences in permeability and therefore also in hydraulic head. During dry periods microscopic cracks can develop due to shrinkage of clayey materials. In such a case the permeability of the system becomes a combination of matrix and preferential flow (Jommi, et al., 2016). The amount of suction in the unsaturated zone of the dike is described by soil water characteristic curve, which is not available for all soil types.

Information on the varying groundwater table and amount of water in the unsaturated zone of the dike is interesting because of several reasons. Material degradation of organic soils due to wetting and drying cycles might affect the stability and the permeability properties of the soil on the long term (Kazemian, et al., 2011). On the other hand some materials tend to gain strength by the process called ripening (Pons, 1965). Besides that, the current limit equilibrium slope stability calculations do not consider the additional strength which is available in the unsaturated zone due to suction. The amount of hidden strength might be interesting for the determination of the factor of safety.

Varying external conditions and heterogeneous, and anisotropic soil properties indicate the potential complexity of dike structures. A good understanding of different processes related to the piezometric head in dikes can contribute to dike assessments in the future. This research is a reanalysis of pore water pressure variations in an ancient clay dike caused by changing atmospheric conditions.

1.1 Leendert de Boerspolder

The Leendert de Boerspolder was a small island nearby the Kagerplassen, south of Haarlemmermeer in the Netherlands, see Figure 1-1. In 2012 the water board Rijnland decided to flood the polder because the surrounding dike did not meet the requirements, the pumping station needed an expensive update, and to create a natural reservoir. An extensive research project was initiated to trigger a controlled failure and obtain more knowledge on the behaviour and strength of ancient clay dikes in the Netherlands. The stress test started on 21 September 2015 and the dike failed on the 14 October 2015 after several phases in which the dike was weakened.

On 26 and 29 of August 2014 a site investigation campaign was executed to obtain knowledge on soil and ground water conditions (Wiertsema & Partners, 2014). The dike was subdivided in three different sections: south, centre, and north. In total 18 cone penetration tests (CPT's) were executed, six in each section, see Appendix A. In each intermediate section north-centre and centre-south three borings were conducted. From the crest of the dike four open piezometers, or standpipes were installed to measure the water level for a longer period in the dike material, the peat layer, the clay layer and the Pleistocene sand. In august 2015, 25 closed piezometers were installed in the sections north-centre, centre and centre-south to monitor pore water pressures in the dike during failure.



Figure 1-1: Weather stations Roelofarendsveen (RAV), Schiphol (SH), Valkenburg (VB), and other weather stations (points) in the surrounding of the Project location Leendert de Boerspolder (LdB).

The soil profile of the dike was based on (Wiertsema & Partners, 2014; Rodriguez Barragan, 2015) and was subdivided in five different soil layers, see Figure 1-2 for the northern cross-section. The first layer was the dike material which consisted of multiple materials. A very heterogeneous sandy silt core was surrounded by a cover layer and clayey bottom layer. These less impermeable layers were functioning as a hydraulic sealing protecting the core of the dike against external conditions. It was not confirmed by the site investigation that the top layer was covering the whole dike section.

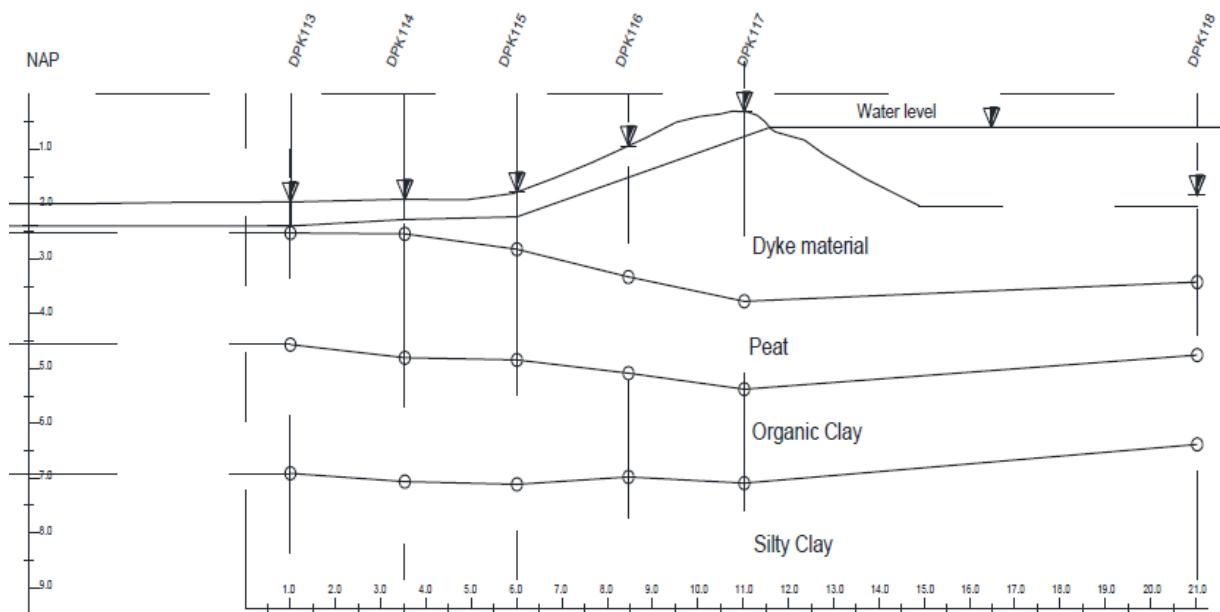


Figure 1-2: Northern cross-section at the Leendert de Boerspolder indicating the soil profile of the dike.

The second layer in the system was a peat layer with a varying thickness. Due to compression caused by the weight of the dike material the thickness of the peat layer was smaller below the crest, and was increasing towards the polder and water side. In the site investigation two types of peat were distinguished. The upper section consisted of a so-called moss peat and the lower section was described as a clayey peat. Based on the site investigation it was expected that the peat was in connection with the 'Rijnland boezem'.

The third layer in the dike was an organic clay layer. Similar to the peat layer this layer was more compressed underneath the core compared to the water and polder side. The organic clay was situated above a silty clay layer which was followed by the Pleistocene sand. For this research these underlying layers were disregarded because a quick check showed that they were not affected by weather conditions. The research focussed on the dike material and the peat layer.

The following Appendices are included to illustrate the project location, the soil investigation and the installed measurements equipment.

- Appendix A: site investigation and subdivision in dike sections south/centre/north.
- Appendix B: installation depth of open piezometer in north cross section.
- Appendix C: installation depth of closed piezometers in dike south cross section.
- Appendix D: installation depth and location of closed piezometers in centre cross section.
- Appendix E: installation depth and location of closed piezometers in north cross section.

1.2 Research scope and objectives

The main objective of this research was to reanalyse the hydraulic head variations caused by changing atmospheric conditions. The project was subdivided in several sections, and each section treated an important feature of the problem. A brief description of the different sections and their objectives is given below.

1. **External conditions Leendert de Boerspolder:** knowledge on external conditions is needed because the water level in the dike and the pore water pressures distribution were affected by these conditions. First the water level variation in 'Rijnland boezem' and the Leendert de Boerspolder is treated, and secondly an analysis on the atmospheric conditions like rainfall and evapotranspiration is included.
2. **Measurement errors and equipment limitations:** the hydraulic head was measured using closed and open piezometers. In order to understand the data, knowledge on measurement errors and the limitations of the equipment is needed. The goal of this section is to appoint the most important aspects regarding the equipment.
3. **Hydraulic head and atmospheric conditions:** measurements of four open and 25 closed piezometers were available for this project. The goal of this section is to determine if there is any correlation between the atmospheric conditions and the measurements in the dike material and peat layer.
4. **Geotechnical site interpretation:** The geotechnical situation of the site was expected to be very complicated due to the heterogeneity of the dike material and the permeability properties of the peat layer. The goal of this section is to combine the available data and use this for a brief geotechnical site interpretation.

1.3 Definitions

- **Hydraulic head** – Expresses water pressure (kN/m²) in pressure head (m) with respect to a geodetic datum. Within this project NAP (Normaal Amsterdams Peil) is used as reference level. Synonym for hydraulic head is **Piezometric head**.
- **Absolute pressure** – Pressure measured with respect to the absolute zero pressure, the pressure at absolute vacuum. Piezometers measure the absolute pressure, i.e. the sum of the atmospheric pressure and the water pressure.
- **Pore water pressure** – Refers to the pressure of groundwater held within pores of the soil skeleton. In hydrostatic conditions a pore water pressure of zero corresponds to the phreatic surface. The pore water pressure can be measured using closed piezometers and expressed in hydraulic head and water pressure.
- **Groundwater table** – Refers to the location where the pressure head is equal to the atmospheric pressure. In hydrostatic conditions the phreatic surface in the soil coincides with the water level in a standpipe. Synonyms for groundwater table are: **Phreatic surface**, and **Water level**.
- **Piezometers** – Equipment which measures absolute pressure to obtain the water pressure. The Casagrande standpipe is an open, vented piezometer which measures the water level in a tube (standpipe) installed in a layer. A closed piezometer measures absolute pressure within the soil. This corresponds to the pore water pressure rather than the height of a water column in a tube like the open piezometer does. In Figure 1-3 the two piezometers are schematized.

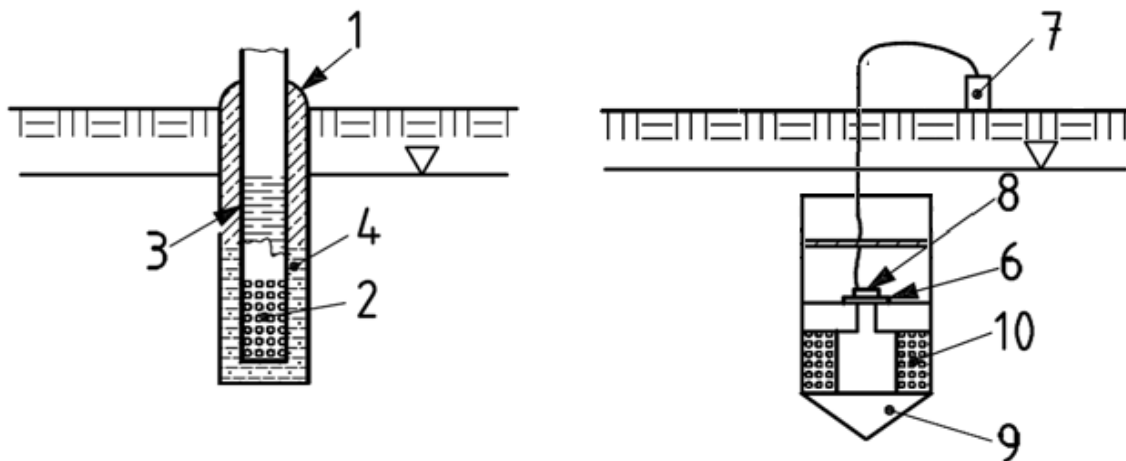


Figure 1-3: Open piezometer (left): 1. Seal, 2. Filter, 3. Tube, 4. Filter pack. Closed piezometer (right): 6. Membrane, 7. Measuring instrument, 8. Electrical transducer, 9. Filter tip, 10. Filter.

2 BOUNDARY CONDITIONS LEENDERT DE BOerspolder

This chapter contains an analysis of the external conditions at the Leendert de Boerspolder which might affect the hydraulic head in the dike. First a review is done on external water levels, i.e. the 'Rijnland Boezem' and the water level in the Leendert de Boerspolder. The second section contains an analysis on the atmospheric conditions. The most appropriate weather station is determined and the actual evapotranspiration estimated.

2.1 Adjacent water levels Leendert de Boerspolder

External water levels like the water level in the 'Rijnland Boezem' and the water level in the Leendert de Boerspolder can affect the piezometric head in the dike. This section is included to determine the impact of the adjacent water levels.

The water level in the water body is given in Figure 2-1 for one year provided by (Waterschap Rijnland, 2016). Unfortunately it was not possible to obtain the whole data set of 2015 and 2016. The maximum measured level equals -0.62m NAP, the minimum is approximately -0.69m NAP and the average is -0.65m NAP. The water level in the polder is maintained at a level of -2.53m NAP during summer and -2.64m NAP during winter (Waterschap Rijnland, 2016). The maximum observed variation in the 'Rijnland Boezem' is 0.07m and the variation in polder is only 0.11m.

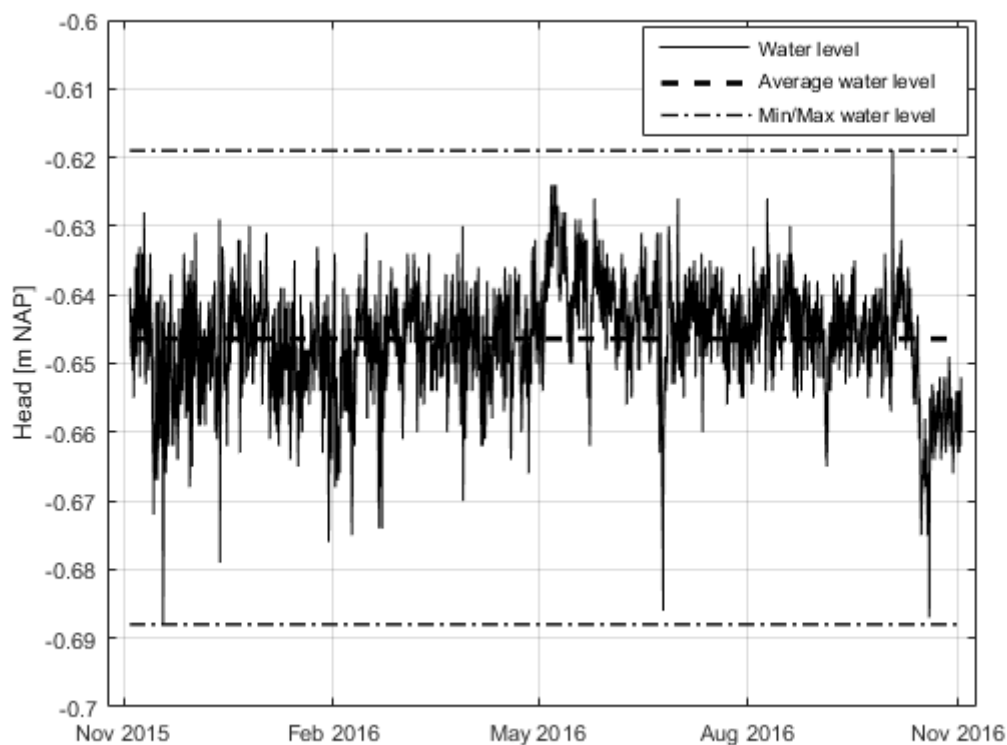


Figure 2-1: Observed water level in the 'Rijnland Boezem' near the Leendert de Boerspolder from November 2015 until November 2016, source data (Waterschap Rijnland, 2016).

It can be concluded that the adjacent water levels of the 'Rijnland Boezem' and the Leendert de Boerspolder are almost constant in time, and therefore cannot have a significant effect on the variation of hydraulic head in the dike.

2.2 Atmospheric conditions

Three KNMI weather stations were available to determine atmospheric conditions at the Leendert de Boerspolder, see Figure 1-1 for the locations of the weather stations Roelofarendsveen, Schiphol, and Valkenburg. The most appropriate weather station was selected based on distance and the measurement interval of atmospheric quantities. The time interval cannot be too big because vital important features on rainfall and evapotranspiration can be lost due to averaging (Allen, et al., 1998).

Roelofarendsveen is measuring the amount of rainfall on a daily basis. Schiphol and Valkenburg are measuring temperature, precipitation, wind speed, wind direction, solar radiation and some other quantities on an hourly basis. The time interval of Roelofarendsveen is too large but the distance between the dike and the weather station is only 1.8 km. Therefore Roelofarendsveen was used to determine the most appropriate hourly weather station. Figure 2-2 presents the correlation between the data from the three weather stations for 2015. Due to the lack of differences between the SH and VB weather stations it was impossible to select the most appropriate station. The Schiphol dataset with an hourly time interval was chosen to be representative for the Leendert de Boerspolder, because the weather station at Valkenburg is about to be closed (KNMI, 2016) and the measurement equipment could be outdated, although Figure 2-2 is not confirming this. The evaporation and transpiration calculations are therefore based on the Schiphol weather station rather than the one in Valkenburg.

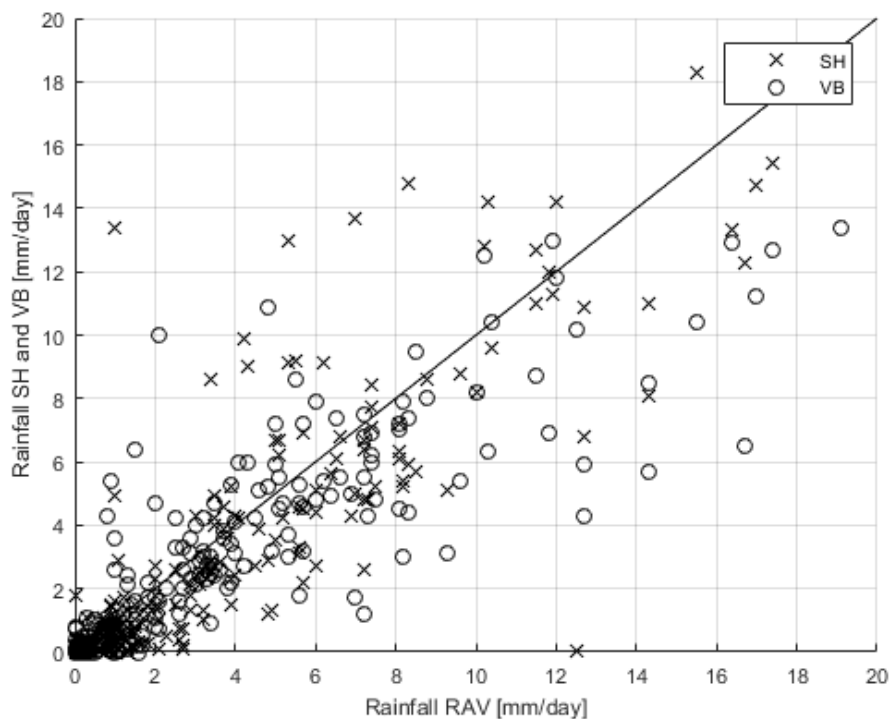


Figure 2-2: Comparison between daily precipitation registered in weather stations Roelofarendsveen (RAV), Schiphol (SH) and Valkenburg (VB) in 2015, source atmospheric data (KNMI, 2016).

It is important to keep in mind that the actual atmospheric conditions at the Leendert de Boerspolder can differ from the registered conditions at Schiphol due to the distance of approximately 15 km. The dominant wind direction in the Netherlands is west to south-west (KNMI, 2016), indicating that in the majority of cases, rainfall events first pass by the Leendert de Boerspolder before something is registered at Schiphol. Using the yearly average wind speed in the Netherlands of 5m/s (KNMI, 2016), the maximum time delay is approximately at 50 minutes and the minimum at 30 minutes.

2.2.1 Evapotranspiration

Evapotranspiration is the combined process of transpiration by plants and evaporation of water from the soil, and is an important aspect in the reanalysis of the pore water pressure variations observed in the dike. The amount of evapotranspiration at the Leendert de Boerspolder is determined using the well-known Penman-Monteith equation (Zotarelli, et al., 2015; Allen, et al., 1998; Penman, 1948).

The first step in the analysis is the determination of the reference evapotranspiration (ET_0) which is a function of temperature, wind speed, solar radiation and relative humidity, see Equation 2-1 (Penman, 1948; Allen, et al., 1998). The reference evapotranspiration is only valid for a given (reference) type of grass with unlimited availability of soil water.

Accounting for the vegetation on the dike and the water availability in the dike the actual evapotranspiration (ET_c) can be determined using the single crop coefficient method, see Equation 2-2 (Allen, et al., 1998). This method suffices because the dike is fully covered with grass. The more advanced dual crop coefficient method is needed when the soil is partly covered by the crop, for example in a potato field. The crop coefficient (K_{cb}) accounts for the type of vegetation and the corresponding growing stages. These stages are estimated using (Remmelink, et al., 2015; Visscher, 2010) and K_{cb} is adjusted using Equation 2-3 given in (Allen, et al., 1998). The K_{cb} outside the growing season is set to 0.20 to include some evapotranspiration during the year, see Table 2-1. The method (Penman, 1948) assumes unlimited availability of soil water which is not true when the soil is not fully saturated. In (Yunusa & Gofar, 2012; Wilson, et al., 1997; Caruso & Jommi, 2011) is stated that the evapotranspiration rate is lower for unsaturated soils. The ET_c is therefore adjusted for the amount water available in the soil by using the water stress coefficient (K_s). The K_s is a function of the water content of the soil, see Equation 2-4. The total available soil water in the root zone (TAW) is the maximum amount of water which can be extracted by the crop and is a function of the soil type. The readily available soil water in the root zone (RAW) is the amount of water which can be extracted by the crop without inducing moisture stress and is a function of the crop type. The TAW and RAW are calculated based on the parameters given in Table 2-2. The parameters are based on values proposed in (Allen, et al., 1998) for a silty clay, the cover of the dike. The water content in the soil is estimated based on an hourly water balance in the root zone, see Figure 2-3 and Equation 2-5. Irrigation is not relevant for this project and capillary rise and runoff are disregarded for simplification. Deep percolation is determined with Equation 2-6 which assumes that deep percolation occurs when the field capacity of the topsoil is reached. The initial root zone depletion must be estimated to predict K_s in time, see Equation 2-6. A fully saturated soil is used as initial condition, which is a valid assumption in the Netherlands in the winter (Allen, et al., 1998).

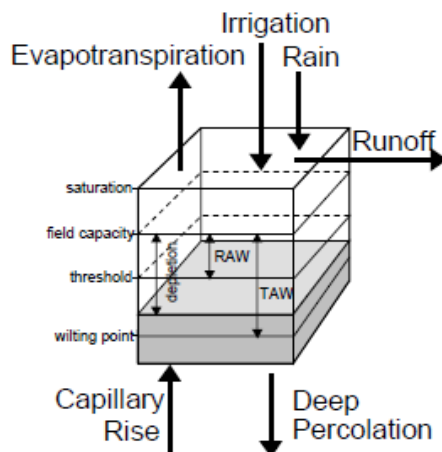


Figure 2-3: Water balance in root zone of soil (Allen, et al., 1998).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{37}{T_{hr} + 273} u_2 (e^0(T_{hr}) - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{Equation 2-1}$$

ET_0	= Reference evapotranspiration	[mm/hour]
R_n	= Net radiation at grass surface	[MJ/m ² /hour]
G	= Soil heat flux density	[MJ/m ² /hour]
T_{hr}	= Mean hourly air temperature	[°C]
Δ	= Saturation slope vapour pressure curve at T_{hr}	[kPa/°C]
γ	= Psychrometric constant	[kPa/°C]
e^0	= Saturation vapour pressure at T_{hr}	[kPa]
e_a	= Average hourly actual vapour pressure	[kPa]
u_2	= Average hourly wind speed	[m/s]

$$ET_c = (K_s K_{cb}) ET_0 \quad \text{Equation 2-2}$$

ET_c	= Actual evapotranspiration	[mm/hour]
K_{cb}	= Crop coefficient for transpiration	[-]
K_s	= Water stress coefficient for limited water availability	[-]
ET_0	= Reference evapotranspiration	[mm/hour]

$$K_{cb,period} = K_{cb} + (0.04 * (u_2 - 2) - 0.004(RH_{min} - 45)) \left(\frac{h}{3}\right)^{0.3} \quad \text{Equation 2-3}$$

$K_{cb,period}$	= Adjusted crop coefficient for transpiration	[-]
u_2	= Average wind speed in period	[m/s]
RH_{min}	= Mean value for daily minimum relative humidity	[%]
h	= mean plant height	[m]

$$K_s = \frac{TAW - D_r}{TAW - RAW} = \frac{TAW - D_r}{(1-p)TAW} \quad \text{Equation 2-4}$$

K_s	= Transpiration reduction factor	[-]
TAW	= Total available soil water in root zone	[mm]
RAW	= Readily available soil water in root zone	[mm]
D_r	= Root zone depletion	[mm]
p	= Water stress development	[-]

$$D_{r,i} = D_{r,i-1} - P_i + ET_{c,i} + DP_i \quad \text{Equation 2-5}$$

$D_{r,i}$	= Root zone depletion at end of interval i	[mm]
$D_{r,i-1}$	= Root zone depletion at end of the previous interval	[mm]
P_i	= Precipitation on interval i	[mm]
$ET_{c,i}$	= Evapotranspiration interval i	[mm]
DP_i	= Deep percolation on interval i	[mm]

$$DP_i = -D_{r,i-1} + P_i - ET_{c,i} \quad \text{Equation 2-6}$$

DP_i	= Deep percolation on interval i	[mm]
$D_{r,i-1}$	= Root zone depletion at end of the previous interval	[mm]
P_i	= Precipitation on interval i	[mm]
$ET_{c,i}$	= Evapotranspiration interval i	[mm]

	Start [date]	End [date]	Length [days]	Kcb [-]
Initial stage	01-04-2015	10-04-2015	10	0.30
Growing stage	11-04-2015	30-04-2015	20	0.30-0.95
Mid-season	01-05-2015	30-09-2015	153	0.95
Late season	01-10-2015	30-11-2015	61	0.95-0.76
Remaining days	-	-	-	0.20

Table 2-1: Crop coefficient (Kcb) for different growing stages of grass in the Netherlands (Remmelink, et al., 2015; Visscher, 2010).

Plant height	h_plant	0.50	[m]
Rooting depth	z_root	0.30	[m]
Water content at field capacity	θ_{fc}	0.36	[-]
Water content at wilting point	θ_{wp}	0.23	[-]
Water stress development	p	0.50	[-]

Table 2-2: Plant characteristics and soil parameters for calculating the total available water (TAW) and readily available soil water (RAW) for silty clay.

The results of the described procedure are plotted in Figure 2-4. Temperature and solar radiation are varying over the year causing a clear seasonal pattern where ETO is lower in winter and higher in summer, see the top graph. The middle graph is representing the crop (Kcb) and the water stress (Ks) coefficients which transform the reference evapotranspiration (ETO) to the actual evapotranspiration (ETc) using Equation 2-2.

The crop activity, represented by Kcb, is maximal in summer and negligible in winter, resulting in the biggest reduction on ETO during winter. When soil water is available the water stress coefficient (Ks) equals 1.00 and when no soil water is available Ks is 0.00. This can be the case for example in the summer when rainfall is less than evapotranspiration. It can be seen that there are two major periods where the amount of evapotranspiration is reduced due to the lack of soil water. In the winter Ks equals 1.0 and the dike is fully saturated according to this method. Combining the reduction coefficients and the reference evapotranspiration according to Equation 2-2 will result in the actual evapotranspiration, see the bottom graph. Again, a seasonal pattern is detected and the effect of limited soil water is also clearly visible.

It is important to state that the vegetation on the dike was cut at the end of July. This is not included in the analysis but it would reduce the actual evapotranspiration because Kcb is lower for the initial stage. Besides that, the water stress coefficient equals 1.0 for the major part of the year, indicating a fully saturated soil. In reality the dike at the Leendert de Boerspolder is almost never fully saturated in the whole cross-section due to the water level difference in the 'Rijnland Boezem' and the adjacent polder. The phreatic level, closely related to saturation, in the dike is not in accordance with the ground level causing unsaturated conditions, especially in crest towards the polder. The amount of evapotranspiration will be lower when this unsaturated zone will be taken into account.

2.2.2 Net rainfall

In Figure 2-5 the net rainfall at the Leendert de Boerspolder is plotted. The top graph represents the hourly water balance and the cumulative rainfall, evapotranspiration and net evapotranspiration are given in the bottom graph. In major part of the year evaporation is less than the rainfall, especially in the winter and the autumn this is true. The total sum of rainfall equals 883 mm and the cumulative actual evapotranspiration is 492 mm. The difference between both, the net rainfall is 390mm.

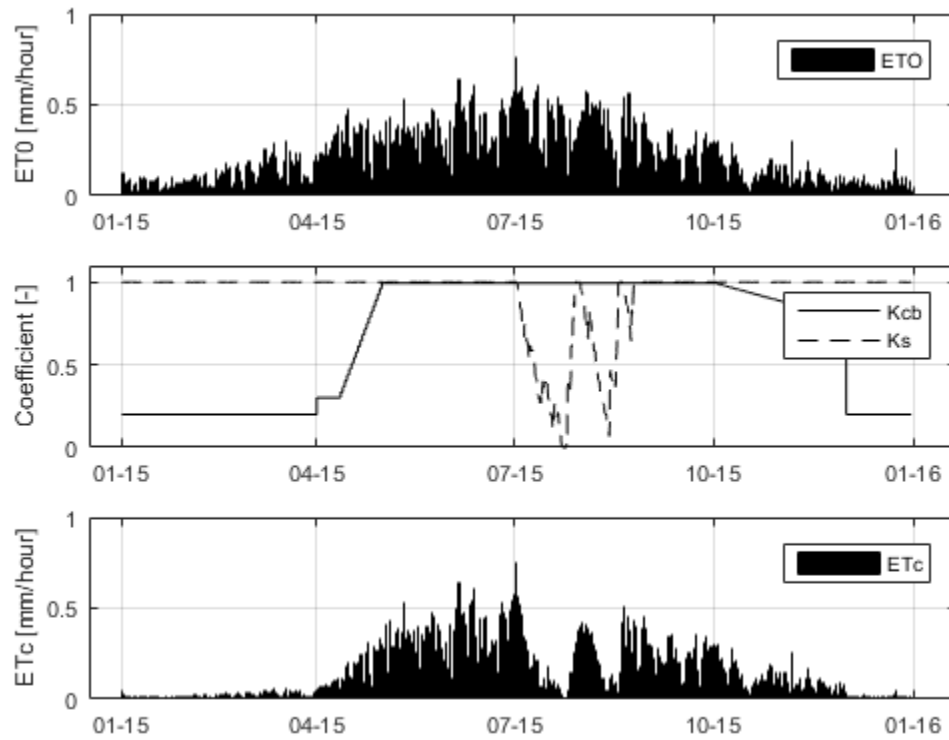


Figure 2-4: Hourly evapotranspiration at Leendert de Boerspolder in 2015, based on (Allen, et al., 1998) and atmospheric data registered at Schiphol (KNMI, 2016). Top: reference evapotranspiration (ETO) in mm/hour. Middle: coefficient on reference evapotranspiration for crop type (Kcb) and lack of soil water (Ks). Bottom: actual evapotranspiration (ETc) in mm/hour.

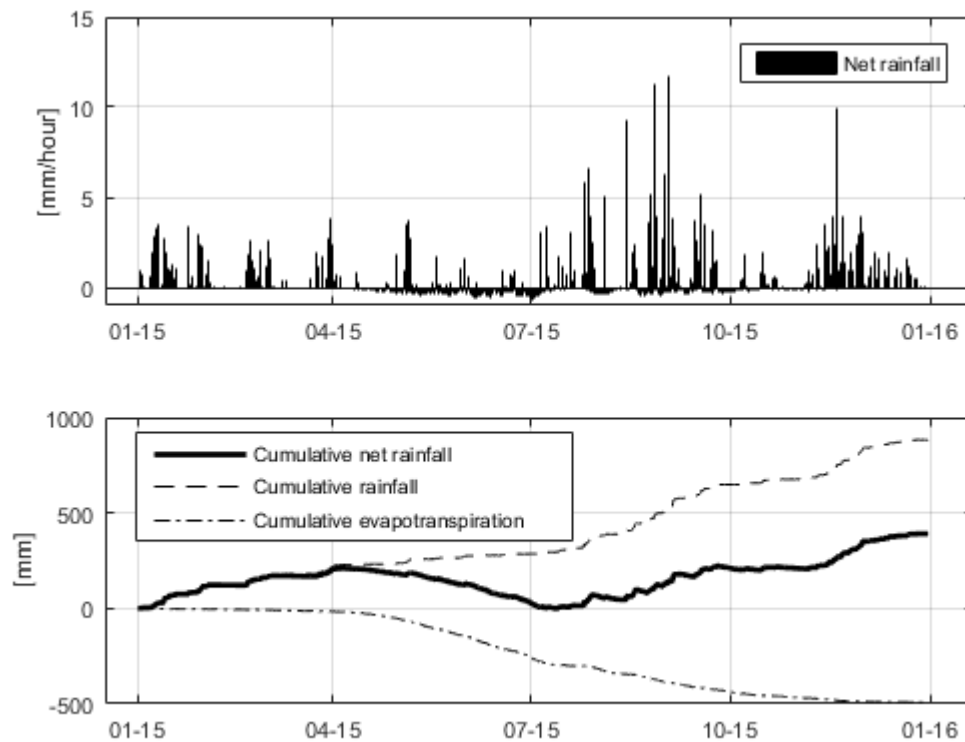


Figure 2-5: Net rainfall at Leendert de Boerspolder in 2015, based on atmospheric data registered at Schiphol (KNMI, 2016). Top: Hourly net rainfall in mm/hour. Bottom: cumulative net rainfall, rainfall and evapotranspiration in mm.

3 MEASUREMENT ERRORS AND EQUIPMENT LIMITATIONS

3.1 Atmospheric pressure

The piezometers within this project were measuring absolute pressure rather than solely water pressure. This means that measurements must be adjusted for the local atmospheric pressure. The pore water pressure is obtained by subtracting the atmospheric pressure from the absolute pressure, as shown in Equation 3-1.

$$P_{water} = P_{absolute} - P_{atmospheric} \quad [N/mm^2] \quad \text{Equation 3-1}$$

$$\begin{aligned} P_{water} &= \text{water pressure} & [N/mm^2] \\ P_{absolute} &= \text{absolute pressure} & [N/mm^2] \\ P_{atmospheric} &= \text{atmospheric pressure} & [N/mm^2] \end{aligned}$$

For the 25 closed piezometers the procedure is straight forward, because atmospheric pressure was registered onsite in the same period. For the four open piezometers no local atmospheric data was available, therefore the atmospheric pressure measured at Schiphol (KNMI, 2016) was used to calculate the water pressure. In Figure 3-1 the water pressure, expressed in hydraulic head (m NAP), was obtained by subtracting the yearly mean atmospheric pressure and an hourly atmospheric pressure from the measured absolute pressure in the piezometers. The variation in hydraulic head should be negligible small because almost no rainfall events were registered in May 2015, but the piezometric head obtained with a yearly mean atmospheric pressure was varying in time without any forcing condition. A second interesting observation in the top graph is that the hydraulic head decreases just before a rainfall event was registered. This was explained by the fact that rainfall events are more likely during unstable weather conditions, i.e. low atmospheric pressures. Figure 3-1 indicates that local atmospheric data with a small measurement interval is needed for a good interpretation of pore water pressure variations. A yearly mean atmospheric pressure results in unexplainable head variations, and non-local atmospheric pressure data results in mistiming of the variations.

3.2 Time lag piezometers

The 25 closed piezometers were installed in the soil and therefore the pressure cell was in direct contact with the water pressure within the pores of the soil. Due to this direct contact the time lag of the closed piezometers is negligible small and the observed data represents the current absolute pressure. As stated before pore water pressure was obtained by subtracting atmospheric pressure from the absolute pressure.

The four open piezometers measured the absolute pressure within a standpipe installed in the soil which means that the pressure cell is in contact with the water pressure in the standpipe rather than the water pressure in the pores of the soil. This indirect method introduces a time lag because the water level in the standpipe needs to adjust to the pore water pressure nearby the filter of the standpipe. The time lag of a standpipe is a function of the permeability of the soil layer and the dimensions of the standpipe, see Equation 3-2 for the expected time lag T_{90} (Hvorslev, 1951). The standpipe diameter equals 0.04m, the diameter of the sand filter around the tube is 0.10 m and the length of the water filter is 1.00m, provided by (Wiertsema & Partners, 2014).

$$T_{90} = 2.3 * (d^2 \ln(\frac{2 * L * m}{D})) / (8 * L * k_h) \quad [-] \quad \text{Equation 3-2}$$

T_{90} = Time lag corresponding to 90% adjustment	[s]
d = Inner diameter standpipe	[m]
D = Diameter of filter around standpipe	[m]
L = Length standpipe	[m]
$m = \sqrt{k_h/k_v}$	[-]
k_h and k_v = horizontal and vertical permeability	[m/s]

In Figure 3-2 the relation between the time lag and the permeability is plotted for an isotropic and two anisotropic situations. The largest time lag was found for the anisotropic situation where the horizontal permeability (k_h) is bigger than the vertical permeability (k_v), and the smallest time lag is found for the opposite situation. The vertical permeability for the dike material was probably higher than the horizontal permeability because a quick and high response is detected in the standpipes, which will be shown in the next section. A high and quick response is not possible when the infiltration limit, or saturated vertical permeability is limited. For an organic materials it is well known that in many cases k_h is higher than k_v due to the orientation of the particles and fibres.

3.3 Installation errors

The open piezometers, or standpipes are installed in the ground using a drilling rig, this rig creates a hole in the ground bigger than the standpipe. Afterwards the borehole around the filter is refilled with a permeable material, and above the filter a hydraulic sealing is created using bentonite. This clay swells enormously when it gets in contact with water, which eventually results in an impermeable layer within the borehole. The purpose of such an impermeable layer is to prevent infiltration of water from layers in which the filter is not installed. When the installation is not executed properly water can infiltrate quickly causing measurement errors. For standpipes with a filter near the soil surface it is not impossible that such a preferential flow path, or a local higher permeability can develop and affect the measurements. In this project standpipe PBD in the dike material has a soil cover of only 1.40 m making it susceptible to a preferential flow path. The soil cover of the other standpipes is big enough which means that a preferential flow path is unlikely. Also for the closed piezometers it is not likely that they are affected by a preferential flow path because they are pushed into the ground without a large borehole.

Within this project it is generally recognised that installation depths of open and closed piezometers are not perfectly known. The depth of the standpipes are known, but the exact depth of the piezometers in the standpipe are unknown. By matching the maximum registered measurements with the surface level, i.e. assuming a fully saturated system, the installation depth of the piezometers was estimated to be in the middle of the standpipe filter. The installation depth of the closed piezometers is measured using a GPS system, this system has a measurement error of +/- 10cm. This causes uncertainty in reference level, needed to obtain the hydraulic head. For this reason, relative changes are more important than absolute values. This feature should be taken into account when analysing the pore water pressure observations.

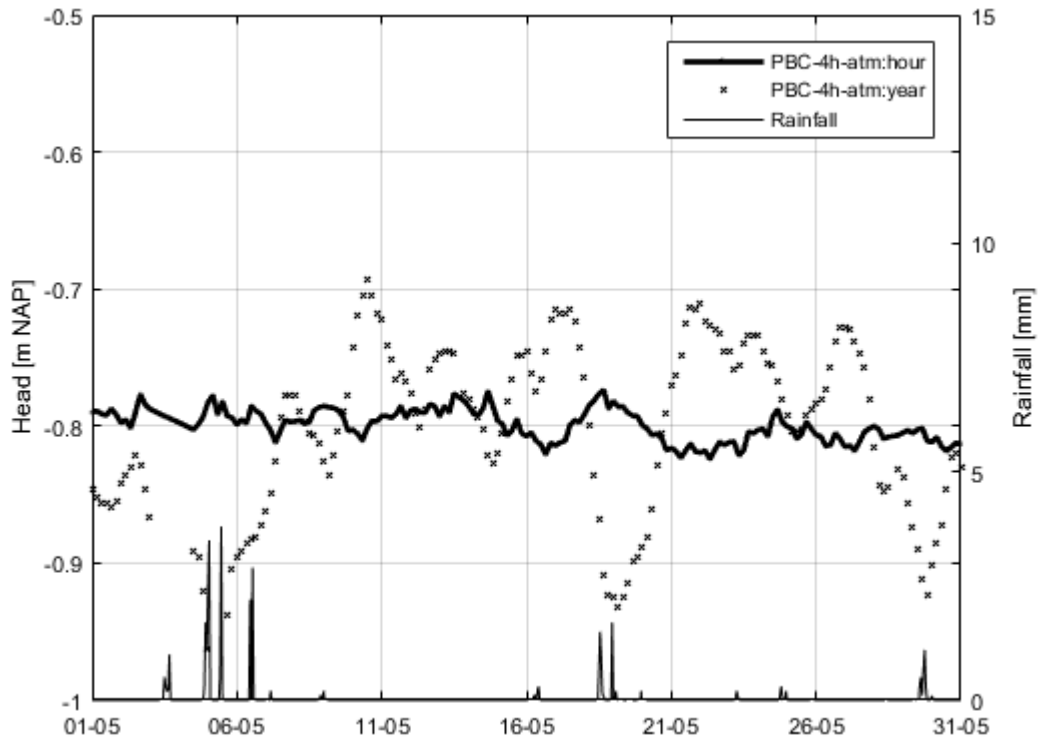


Figure 3-1: Effect of atmospheric pressure on interpretation of hydraulic head in open piezometer in peat, standpipe PBC. Measurements adjusted for yearly mean atmospheric pressure and hourly atmospheric pressure, source atmospheric data (KNMI, 2016).

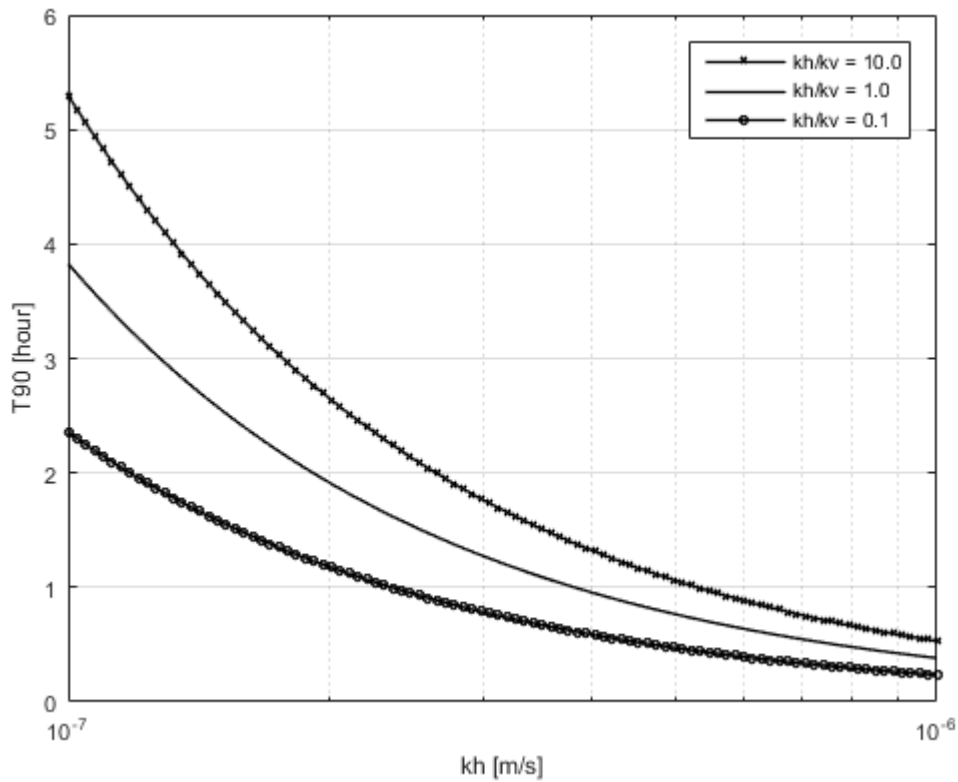


Figure 3-2: Sensitivity between time lag in standpipe ($d=0.04\text{m}$, $D=0.10\text{m}$, $L=1.00\text{m}$) and permeability for an isotropic ($kh/kv=1.0$) and anisotropic ($kh/kv=10$, $kh/kv=0.1$) situation, based on (Hvorslev, 1951).

4 HYDRAULIC HEAD VARIATIONS AND ATMOSPHERIC CONDITIONS

The hydraulic head in the dike material and peat layer were solely affected by atmospheric conditions, because the water level in the 'Rijnland Boezem' and the Leendert de Boerspolder polder were constant. The organic clay, silty clay, and Pleistocene sand were excluded because they were situated below superficial layers, and therefore not directly affected by weather conditions. Figures in this chapter illustrate the most important conclusions, remaining measurements are elaborated in Appendix F and G.

Locations of closed piezometers are indicated using its label, use the definitions below for correct interpretation of the labels. In Figure 4-1 the location of the closed piezometers in the cross-section of the dike are given.

- Location: toe (t), middle (m), crest (c), and waterside (w).
- Dike sections: south (S), centre (C), and north (N).
- Number: Leendert de Boerspolder (1) ascending to 'Rijnland Boezem' (8).
- Example PtS2: closed piezometer number two in dike toe, dike section south.

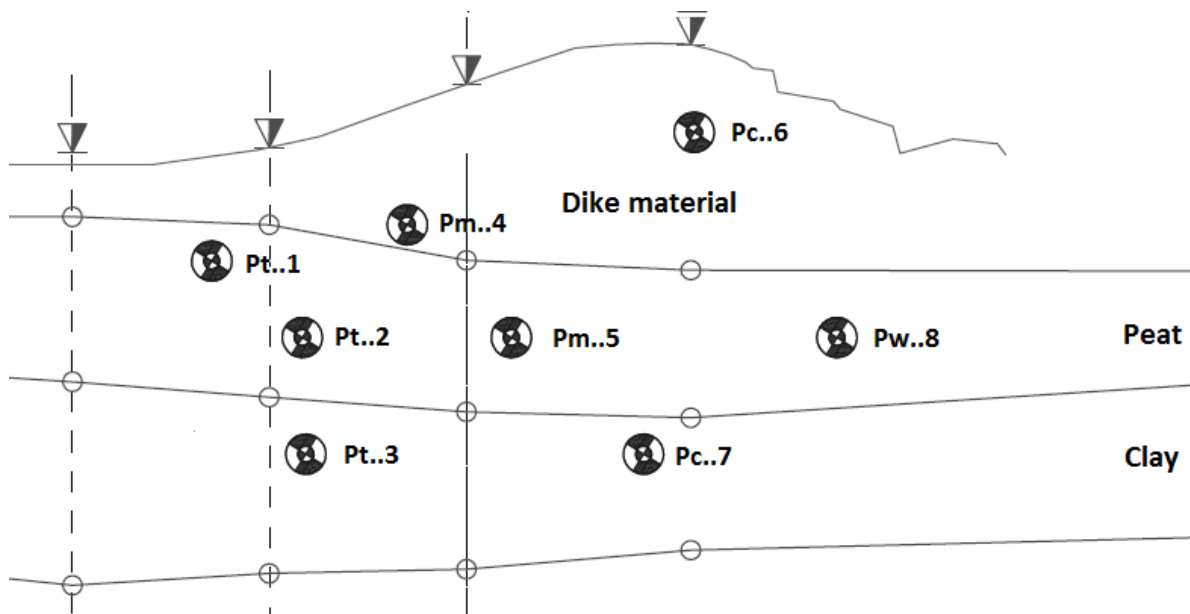


Figure 4-1: Locations of closed piezometers in cross-section of the dike system. Dike sections are indicated by replacing (...) with (S) south, (C) centre, and (N) north.

A general overview of the data is included in Figure 4-2, which gives a first indication of variations in hydraulic head. Due to malfunctioning piezometer PtC2 was excluded. Outliers in Figure 4-2 are not necessarily caused by malfunctioning equipment, or erroneous observations because all the data from installation until failure are included. The variation in the dike material is similar for the south and north section and different for the centre section. In the north and south section, there is low variation in Pc6 and higher variation in Pc4 where in the centre section higher variations were measured in Pc6. The hydraulic head, and variations in PmC4 were significantly lower compared to PmS4 and PmN4. Standpipe PBD had the biggest variations, but the hydraulic head was in good correlation with the closed piezometers Pc6 in the central part of the dike. In the peat an overall trend was found for the south, centre and north dike section: the hydraulic head increased towards the 'Rijnland Boezem' and the variation decreased in the same direction.

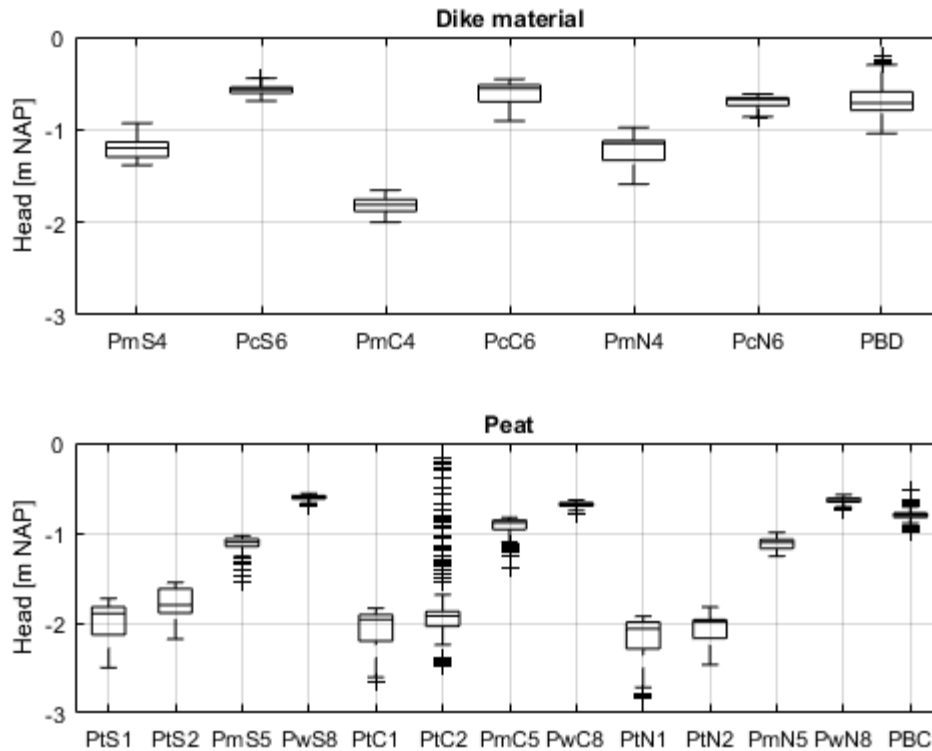


Figure 4-2: Boxplot of available measurements from the open and closed piezometers in the dike material (top) and peat layer (bottom) indicating the observed variation in hydraulic head. Boxplot indicates median, 25th and 75th percentile, coverage whiskers equals 99.3%, and outliers.

4.1 Hydraulic head variations in dike material caused by rainfall

The hydraulic head varied in PBD approximately 0.70m over the whole measurement period in the dike material. In Appendix F the observations of the open and closed piezometers in the dike material are plotted together with rainfall events registered in Schiphol.

For the open piezometers a clear correlation between rainfall and the hydraulic head measurement was found: the hydraulic head increased quickly after rainfall events, see Figure 4-3. A discrepancy with the previous statement was found in June 2015, when the hydraulic head was varying 0.40m without big rainfall events. This variation was explained by using atmospheric data registered at Roelofarendsveen rather than Schiphol. This indicates that local atmospheric data is crucial, because rainfall events in the Netherlands during summer became more intense and local. The time lag between a rainfall event and peaks in hydraulic head varied in general between 30 minutes and three hours. The time lag represents the combined effect of miss timed atmospheric conditions due to spacing (approximately +/- 50 minutes), and the time lag related to the permeability (Hvorslev, 1951).

For the closed piezometers in the dike material the correlation between rainfall and hydraulic head was much weaker and less consistent, see Figure 4-4. The piezometers Pm6 in the south and centre were responding to rainfall, but the one in the north was not observing clear responses. At different locations similar conclusions were drawn. Closed piezometers PmN4, PcC6, and PcS6 did respond to rainfall, and piezometers PmS4, PmC4, and PcN6 were responding less obvious.

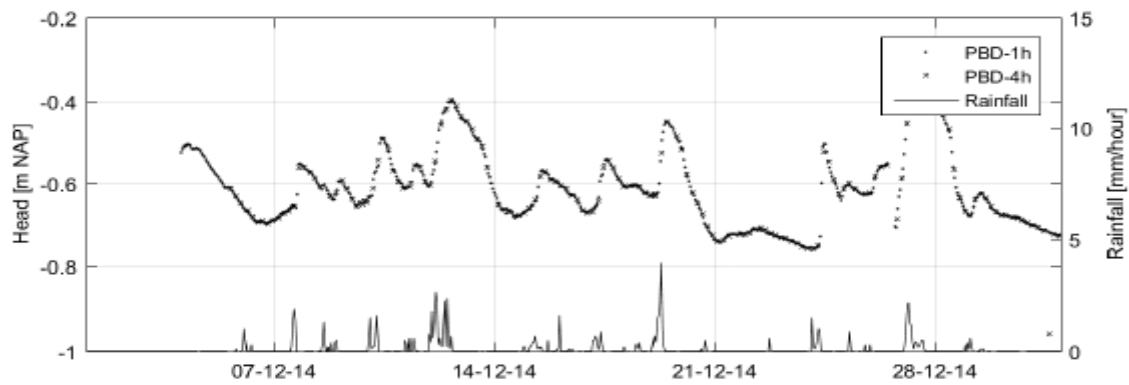


Figure 4-3: Correlation between rainfall and hydraulic head in dike material, observed in standpipe PBD in December 2014 (see Appendix F for remaining months), source atmospheric data: Schiphol (KNMI, 2016).

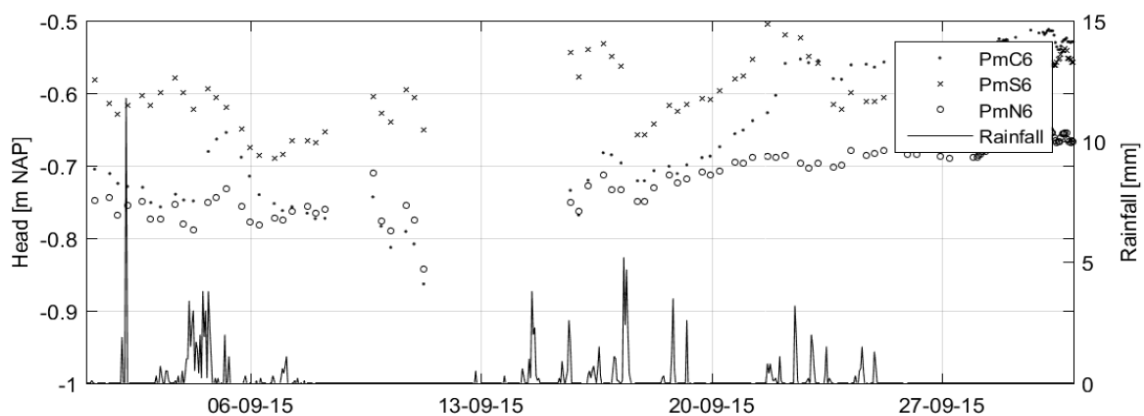


Figure 4-4: Correlation between rainfall and hydraulic head in dike material, observed in piezometer Pm6 in September 2015 (see Appendix F for remaining observations), source atmospheric data: Schiphol (KNMI, 2016).

In Figure 4-7 relative changes in hydraulic head are included to compare the observations without the possible reference height error, as was stated in paragraph 3.3. All the measurement were set to zero at 10-8-2015 to compare the development of hydraulic head in time. Although, the response on rainfall events was different for each piezometer, the piezometers could be grouped according to their response variation:

1. Variation between -0.10 and +0.30

The only piezometer where the adopted hydraulic head varied between -0.10 and +0.30 was standpipe PBD. The correlation between PmC6, PmN4 and standpipe PBD was rather good as well, the peaks were aligned, but response was lower.

2. Variation between +0.00 and +0.25m:

The response in piezometers PmC6 and PmN4 was quickly after rainfall, and large with a variation of approximately +0.25m. Peaks in adopted hydraulic head were in good correlation with rainfall events. Despite the totally different location within the project, piezometers PmC6 and PmN4 were reacting almost similar.

3. Variation between -0.10 and +0.10m:

The remaining piezometer in the dike material definitely did respond to rainfall events, but the variations were significantly different compared to the other groups. Disregarding small differences, the remaining piezometers were responding in a similar way: the adopted hydraulic head was

increasing after rainfall and decreasing during dry periods. The correlation between rainfall events and the maximum adopted hydraulic head was much lower compared to the first two groups.

4.2 Hydraulic head variations in peat caused by rainfall

In Appendix G the observations of hydraulic head in the dike material are plotted together with rainfall registered at Schiphol, this section is discussing the results given in the appendix and most of the figures are not included here.

For the peat layer no clear correlation was found between the standpipe PBC and the weather conditions, see Figure 4-5. The variation in head in the whole measurement period for the peat layer was only 0.2m, and after a rainfall event only a few centimetres. The scatter in the measurements, especially in January and February 2015, could indicate that the standpipe did not work properly. Besides that, in August 2015 a sudden quick increase in hydraulic head was detected, totally not in line with other months. In Figure 4-6 the data for piezometers Pt1 are shown for September. There were differences between the south, centre, and north. This difference could not be solely assigned to a reference height error because it was changing in time.

In Figure 4-8 the relative changes in hydraulic head are included for the peat layer. The responses in the peat were much more consistent compared to the dike material. In contrary to the measurements in the dike material, the location in the dike was determinative for the type of response. The biggest variations and the best correlation with rainfall were observed in Pt1, in the toe of the dike. The pore water pressure increased with 0.68, 0.56, and 0.48m in the north, centre and south respectively. Despite this absolute hydraulic head difference observed at 20-09-2015, the variations were very comparable in different dike sections.

For the second row of piezometers in the toe of the dike (Pt2) a similar response was observed. The pore water pressure in closed piezometers was increasing after rainfall events, and south and north reacted similar. The total increase in pore water pressure until 20-09-2015 was 0.32m, and the absolute difference was negligible small. The closed piezometers in the centre (Pm5) and at the waterside (Pw8) did not respond to rainfall, and did not increase in time. For these closed piezometers there was no correlation with atmospheric conditions. Besides that it was hard to find a correlation between the standpipe and closed piezometers in the crest. The amount of variation was low for both, but some observations could not be confirmed by the closed piezometers.

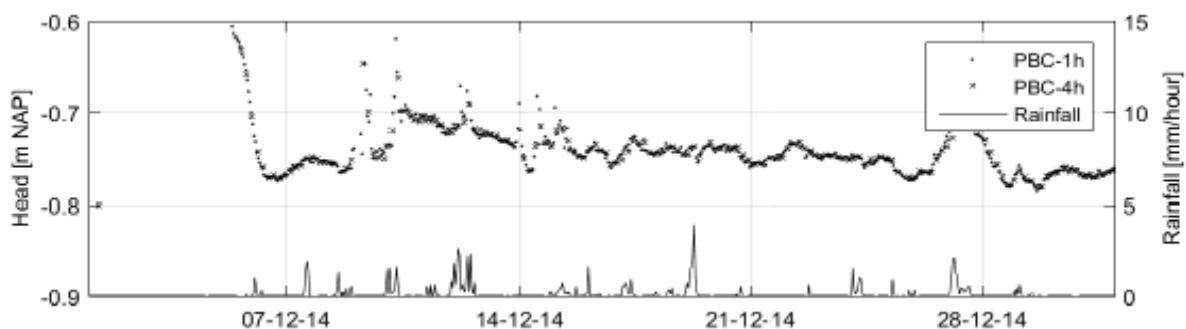


Figure 4-5: Correlation between rainfall and hydraulic head in peat layer, observed in standpipe PBC in December 2014 (see Appendix G for remaining months), source atmospheric data: Schiphol (KNMI, 2016).

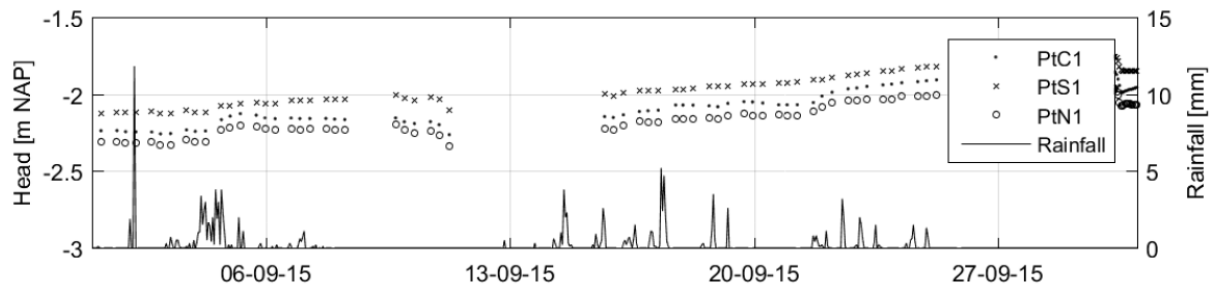


Figure 4-6: Correlation between rainfall and hydraulic head in dike material, observed in piezometer Pt1 in September 2015 (see Appendix G for remaining observations), source atmospheric data: Schiphol (KNMI, 2016).

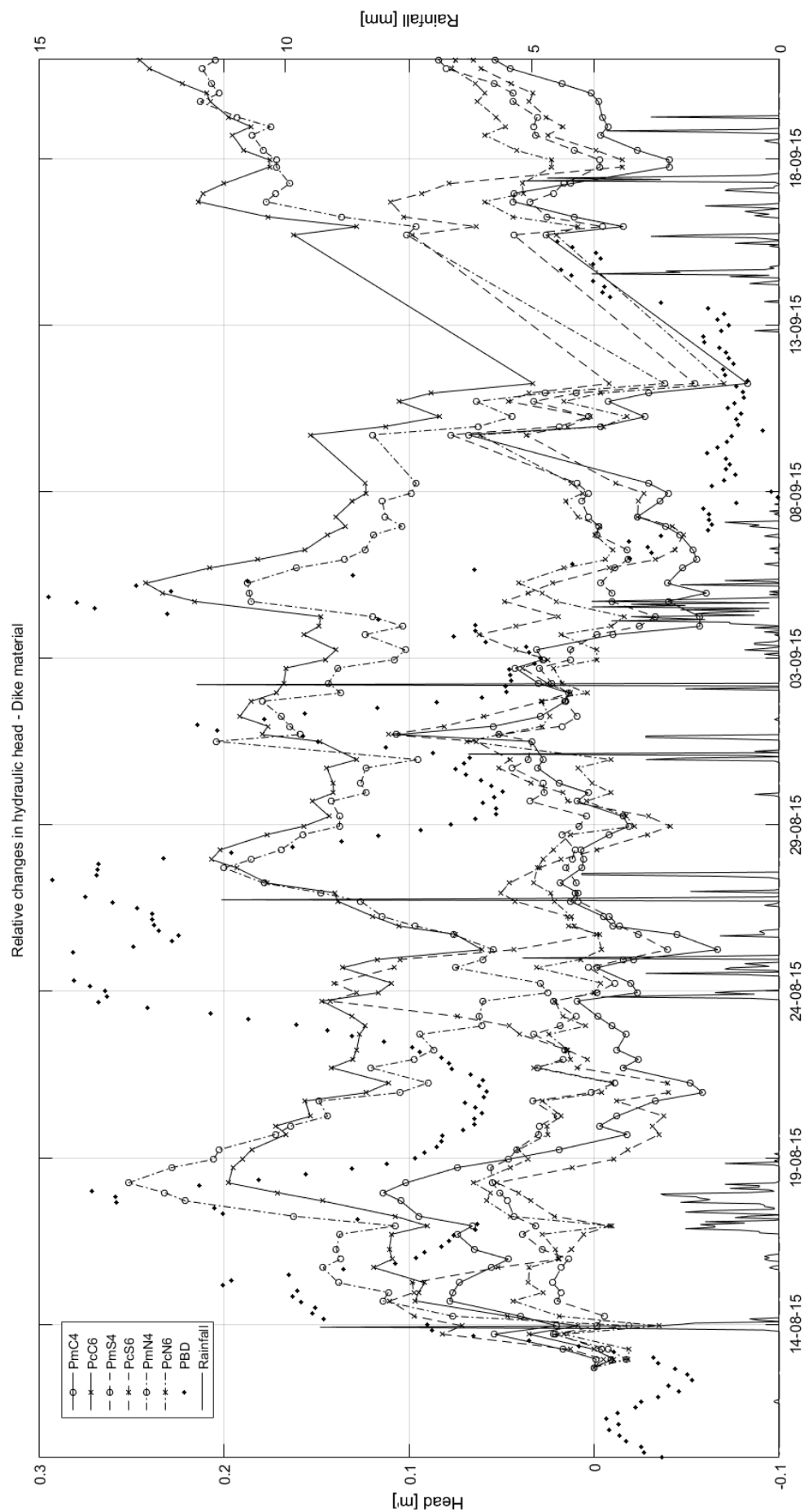


Figure 4-7 Relation between relative change in hydraulic head with in dike material respect to 10-08-15, measured using closed and open piezometers and the atmospheric conditions

Dike section: South (line style: ---), Centre (line style: ---), and North (line style: ---)

Location: middle crest (marker o), and centre crest (marker x)

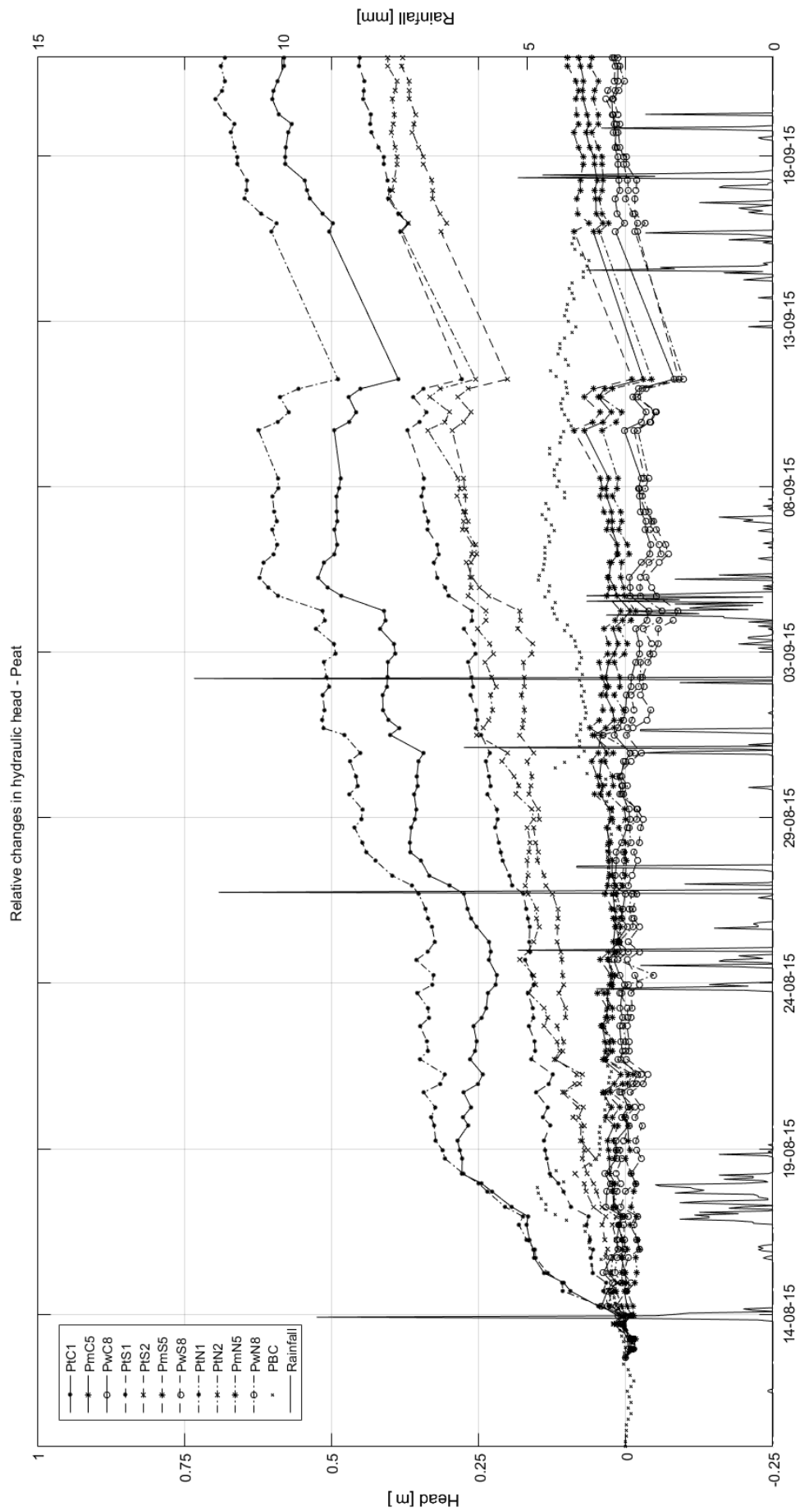


Figure 4-8: Relation between relative change in hydraulic head in peat with respect to 10-08-15, measured using closed and open piezometers and the atmospheric conditions

Dike section: South (line style: ---), Centre (line style —), and North (line style:----)

Location: Toe dike 'shallow' (marker .), toe dike 'deep' (marker x), middle crest (marker *), and water side (marker o).

5 GEOTECHNICAL SITE INTERPRETATION

In chapter 4 the relation between weather conditions and hydraulic head was reviewed, and in this chapter these observations were used for a geotechnical site interpretation.

5.1 Dike material

In the introduction it was described that the dike material consisted of three different layers. The first layer was the dike cover, the second a sandy silt, and the last one was a clay layer situated above the peat. In ideal situations the cover of a dike protects underlying material against external conditions like the weather. Therefore, variations in hydraulic head are limited, and the correlation with weather low because rainfall cannot infiltrate quickly into the dike system. In closed piezometers PmS4, PmC4, PcS6 and PcN6 (group 3) the variation in hydraulic head was limited, but the variation in piezometers PmN4, PcC6, and especially PBD were quicker and higher. A quick response in hydraulic head for closed piezometers is only possible when the permeability of the soil cover is high enough. This indicates that the impermeable clay cover was locally interrupted such that rainfall could infiltrate quickly into the system. In paragraph 3.3 it was recognized that a preferential flow path in the borehole of standpipe PBD could affect the measurements. However, piezometers PmN4 and PcN6 were responding in a similar way indicating that a quick response in PBD is probably caused by a combination of preferential flow and infiltrating water through a partially interrupted clay cover.

For modelling a dike in a finite element program, like Plaxis2D a homogeneous permeability must be specified for each soil layer. However, the hydraulic head observations and the site investigation (Wiertsema & Partners, 2014) were indicating that the permeability in the dike material was heterogeneous. During the execution of the cone penetrations tests (CPT) the excess pore water pressure (u_2) was measured. A linear increasing u_2 indicates that the permeability is homogeneous, and a fluctuating u_2 profile indicates a heterogeneous permeability. The observed excess pore water pressure u_2 in CPT's DPK104, DPK105, DPK110, DPK111, DPK116, and DPK117 were variable with depth indicating that the permeability of the dike material was heterogeneous, see Appendix A. A comparison was made between soil cover above the measurement equipment and the observed variation in hydraulic head. In a homogeneous situation hydraulic head variations would decrease with an increasing soil cover. In Table 5-1 the soil cover and variation, the 95th percentile minus the 5th percentile (P95-P05), are given for all the piezometers in the dike material. The results in the table indicate that there is no correlation between soil cover and variation in hydraulic head for the dike material.

	Middle P4		Centre P6		Centre PBD	
	P95-P05	Cover	P95-P05	Cover	P95-P05	Cover
[-]	[m]	[m]	[m]	[m]	[m]	[m]
South	0.07	1.50	0.15	1.00	-	-
Centre	0.13	1.40	0.18	0.90	0.57	1.40
North	0.19	1.24	0.08	1.18	-	-

Table 5-1: Relation between hydraulic head variations and soil cover above measurement equipment in dike material. Hydraulic head observed from 12-08-2015 to 14-10-2015 for open piezometers and 01-09-2014 to 07-07-2015 for standpipe PBD.

Piezometer Pm4 was intended to be installed in the lower part of the dike material, the clay layer which was functioning as a hydraulic sealing to protect the underlying peat layer. If the piezometer were installed at the right depth the variation in hydraulic head should be limited. However, the hydraulic head in PmN4 was reacting quickly after rainfall. Three options, or a combination could explain these observations: (1) the piezometer was not installed in the lower clay layer but in the

permeable silty sand, (2) the lower clay layer was not everywhere available, and (3) the topsoil in the north was more permeable. Although piezometers PtN1/PtN2 and PmN4 are not aligned, the variations in these piezometers were higher compared to the response in the south (PtS1/PtS2) and centre (PtC1). Assuming that the piezometers were installed at the correct depth, these observations could confirm the second explanation.

Based on time lags observed in measurement of standpipe PBD the hydraulic conductivity was estimated using Equation 3-2 (Hvorslev, 1951). Rewriting this equation, and assuming an anisotropy (k_h/k_v) ratio, a range of possible permeability's was found. The upper bound (T_{90} is 30 minutes) was estimated to vary between $9E^{-7}$ and $4E^{-7}$ m/s, and the lower bound (T_{90} is three hours) varied between $1.2E^{-7}$ and $7E^{-8}$ m/s. Within these boundaries local permeability's were varying depending on anisotropy, and the presence of local sand intrusions and thin clay layers. The hydraulic head variations in the dike material were neither correlated with position or dike section.

5.2 Peat layer

The second layer in the system was peat layer with a varying thickness. Below the crest the thickness was lower due to compression caused by the weight of the dike material. Two different peats were distinguished: the upper section consisted of a so-called moss peat and the lower section was described as a clayey peat.

In contrast to what was found for the dike material the variations in hydraulic head were depending on the location of the piezometer. It was already concluded that the hydraulic head in the peat increased towards the 'Rijnland Boezem' and the variation decreased in the same direction. In Table 5-2 the relation between variations in hydraulic head and the soil cover are given. The table shows a consistent relation between the two: the variation is decreasing with increasing soil cover. These observations were explained by two main factors: (1) permeability of compressed peat is lower compared to an uncompressed peat (O'Kelly, 2007), and (2) increasing soil cover implies a higher protection against varying atmospheric conditions.

	Toe P1		Toe P2		Middle P5		Centre PBC		Water P8	
	P95-P05	Cover	P95-P05	Cover	P95-P05	Cover	P95-P05	Cover	P95-P05	Cover
[-]	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
South	0.40	1.30	0.35	2.45	0.08	3.30	-	-	0.08	2.85
Centre	0.53	1.23	excluded	2.40	0.07	3.26	0.20	3.00	0.07	2.76
North	0.63	1.18	0.38	2.24	0.07	3.14	-	-	0.07	3.30

Table 5-2: Relation between hydraulic head variations and soil cover above measurement equipment in peat. Hydraulic head observed from 12-08-2015 to 14-10-2015 for open piezometers and 01-09-2014 to 07-07-2015 for standpipe PBC.

The highest variations were found in piezometers Pt1 located in the toe of the dike. At the Leendert the peat layer was not compressed and covered by man-made sandy soil. Rainfall could infiltrate into the underlying peat layer through this agricultural soil, causing quick variations in hydraulic head. The variations in the second row (Pt2) were slightly smaller, despite the big increase in soil cover. This indicates that the effect of the soil cover on the variations was limited. The third and the fourth row of piezometers were located in the compressed zone of the peat layer, and with a high soil cover of approximately 3m. It is well-known that the permeability in peat layer decreases together with its void ratio. The permeability of a compressed peat layer can be orders of magnitude lower compared to an uncompressed peat. The hydraulic head observations indicated that the variation in pore water pressure is much lower in the crest compared to the toe. Next to that, a slightly higher excess pore water pressure (u_2) was measured in the compressed peat layer, confirming that permeability was lower, see Appendix A. The hydraulic head in the piezometers closest to the 'Rijnland Boezem' was nearly constant in time, and the level was almost equal to the water level in the Boezem. The water

level in the Boezem was varying from -0.62m NAP to -0.69m NAP and the pore water pressure measurements were varying approximately between -0.60m NAP and -0.70m NAP. Assuming that the reference height was correct, it can be concluded that there was a hydraulic connection between the peat layer and the water body, so the water level in the peat layer near the Boezem is maintained by the Boezem level. No big differences were found between the upper and lower type of peat but the lower type of peat was probably slightly less permeable because of its clayey consistency. This prediction was not confirmed by the measurements of the excess pore water pressure during CPT's, where a constant increasing pore water pressure was found.

In general it can be stated that the permeability was high near the toe of the embankment and lower underneath the crest due to compression. A good correlation was found with the soil cover and the variations in hydraulic head. It was very hard to determine a range of possible permeability because no detailed sample descriptions were available which are very important for the assessment of the permeability.

6 DISCUSSION

The total amount of evapotranspiration was approximately 490mm in 2015. This value seems to be somewhat high but is not impossible according to the KNMI. An improvement for the determination of the actual evapotranspiration would be to include the moment at which the vegetation is cut. This would result in a better approximation of the crop-coefficient graph, and therefore the total amount of evapotranspiration. Within this project, runoff was disregarded in the water balance of the Penman-Monteith method. This could be a bad assumption because runoff happens when rainfall intensity is higher than the saturated permeability of the topsoil. Especially in summer with intense rainfall events (van Minnen, et al., 2013) and lower permeability's due to unsaturated conditions runoff is likely. Taking into account the runoff would result in a lower amount of actual evapotranspiration because less soil water is available.

The weather data of Schiphol was used within this project. It is important to state that there can be big differences in weather conditions, especially in summer the rainfall events are often very local, and in the winter the weather fronts are much bigger. For example the measurements in the month July 2015 for standpipe PBD: using local weather data of Roelofarendsveen it was possible to explain the observations, using data registered at Schiphol it was not. Some measurements were showing an increase in pore water pressure before the rainfall was observed. This can be explained by the fact that the dominant wind direction in the Netherlands is South-West. Comparing the location of the embankment and the location of Schiphol it was concluded (assuming the dominant wind direction) that a rainfall event arrives first at the Leendert de Boerspolder, causing an increase in pore water pressure, and hereafter arrives at Schiphol causing a registered rainfall event. Again, this is indicating that local weather data is crucial in explaining all the interesting features in the observations. Another interesting point of discussion is the effect of the atmospheric pressure. The pore water pressure was determined by measuring the total pressure and subtracting the atmospheric pressure. Atmospheric pressure measured with a small time interval is needed for a correct interpretation of the data. Rainfall events are often happening with unstable weather conditions, i.e. low atmospheric pressures. Using an annual mean atmospheric pressure will result in a drop in pore water pressure just before the event which is physically not possible. This is confirming that the timing of the atmospheric pressure is crucial for the analysis of the pore water pressure measurements. A good improvement would be to combine weather data of more than one weather station. Taking into account daily wind directions the local weather conditions could be determined in more detail. This will result in a better estimation of the measurement time lag in the standpipes because mistiming in rainfall events will be decreased.

As explained in the last chapter the dike material was very heterogeneous and a good estimation on the permeability of the dike material was very difficult. The given range in permeability's was based on a varying time lag in standpipe PBD obtained with visual inspection, a quantitative method. This together with a possible mismatching of atmospheric conditions indicate uncertainty within the given permeability range.

7 CONCLUSION AND RECOMMENDATIONS

The soil cover at PBD was very low resulting in a higher chance on preferential flow due to a malfunctioning hydraulic clay sealing. Variation in hydraulic head in the closed piezometers in the dike material were indicating that PBD, and the hydraulic sealing the borehole were functioning correctly. Standpipe PBD and closed piezometers PcC6 and PmN4 were showing a clear relation with atmospheric variations, the correlation for the remaining closed piezometers in the dike material was much lower. These quick responses indicated that the clay cover was not functioning properly everywhere. For future researches a quality assessment, or visual inspection of the clay cover is recommended. Such an inspection should give insight to the quality of the cover and might help to interpret/explain the observations. A good clay cover is crucial because it limits the variation in pore water pressure in dikes. Fibrous materials degrade upon wetting and drying cycles. This material degradation might affect the stability and the permeability properties on the long term. On the other hand some materials tend to gain strength by the process called ripening.

The permeability of the dike material was estimated using a reversed Hvorslev analysis on the observed time lags between atmospheric conditions and peaks in hydraulic head. The upper bound was estimated to vary between $9E^{-7}$ and $4E^{-7}$ m/s, and lower bound varied from $1.2E^{-7}$ until $7E^{-8}$ m/s. Observations in the piezometers were not consistent indicating a heterogeneous dike material with a varying permeability due to local sandy or clay layers. The permeability of the peat layer was hard to determine based on hydraulic head measurements, but some expectations were confirmed by the data. The variations in hydraulic head were maximum near the toe, and were decreasing towards the 'Rijnland Boezem'. The hydraulic head in the toe of the dike was affected by weather conditions, because rainfall could infiltrate quickly into the peat through a permeable man-made agricultural topsoil. Compression of the peat layer was the most important reason for the decreasing variations in hydraulic head. Besides that the variations were flattened because of a hydraulic connection with the 'Rijnland Boezem', and an increasing soil cover.

A crucial improvement for a next research project is a proper documentation on the installation depths of the measurement equipment. When the installation depth is known a better analysis can be made on the heterogeneity of the site. For this project differences in observations cannot be solely assigned to heterogeneity because reference level errors have to be taken into account. Also, other research on the same project has shown that information on the pore water pressure development during failure of the dike was not enough to understand everything. A longer measurement period for the closed piezometers would provide a better understanding of the correlation between hydraulic head and weather conditions. However, a longer measurement period of open piezometers would not result in an improvement of the assessment. It was shown that single measurements are definitely not enough for good interpretation of the data. There is no change of detecting erroneous data because reference data is not available. Also, measurements at different locations are needed to understand a heterogeneous soil because of the local variations.

Another interesting step in the research would be to include a Plaxis2D analysis. Two types of analysis could give insight in the permeability properties of the site. The first option is a hydro-mechanical analysis on the stress test of the dike. Wrong permeability parameters would result in a slower or quicker failure of the dike because the permeability is an important parameter in the development of excess pore water pressure. The second option is a Plaxis2D analysis which could give insight in the permeability is a flow analysis. Implementing effective precipitation as forcing hydraulic boundary conditions, and back-figuring the observations in the closed piezometers and standpipes could give an indication on the permeability. For both models it is needed to adjust the permeability parameters based on compression. It was shown that the permeability, especially in the peat layer, was much lower in the compressed zone of the dike. Disregarding this effect would highly

reduce the quality of the assessment. A major draw-back with the Plaxis2D analysis is the heterogeneity of the soil which cannot be modelled. A random finite element analysis is needed to account for the varying permeability and strength properties in the embankment.

In this research a thorough comparison was made between semi-local atmospheric data, and observations in hydraulic head in the dike material and underlying peat layer. It was shown that many features in the observations could be explained by looking at rainfall events. This finding is supporting the idea that information on atmospheric data cannot be disregarded and really can provide interesting insights in the behaviour of the system. These results are indicating that on-site weather data would highly improve the quality of the assessment. Especially information on the atmospheric pressure and rainfall events is needed to minimize uncertainties and truly understand the observations and responses.

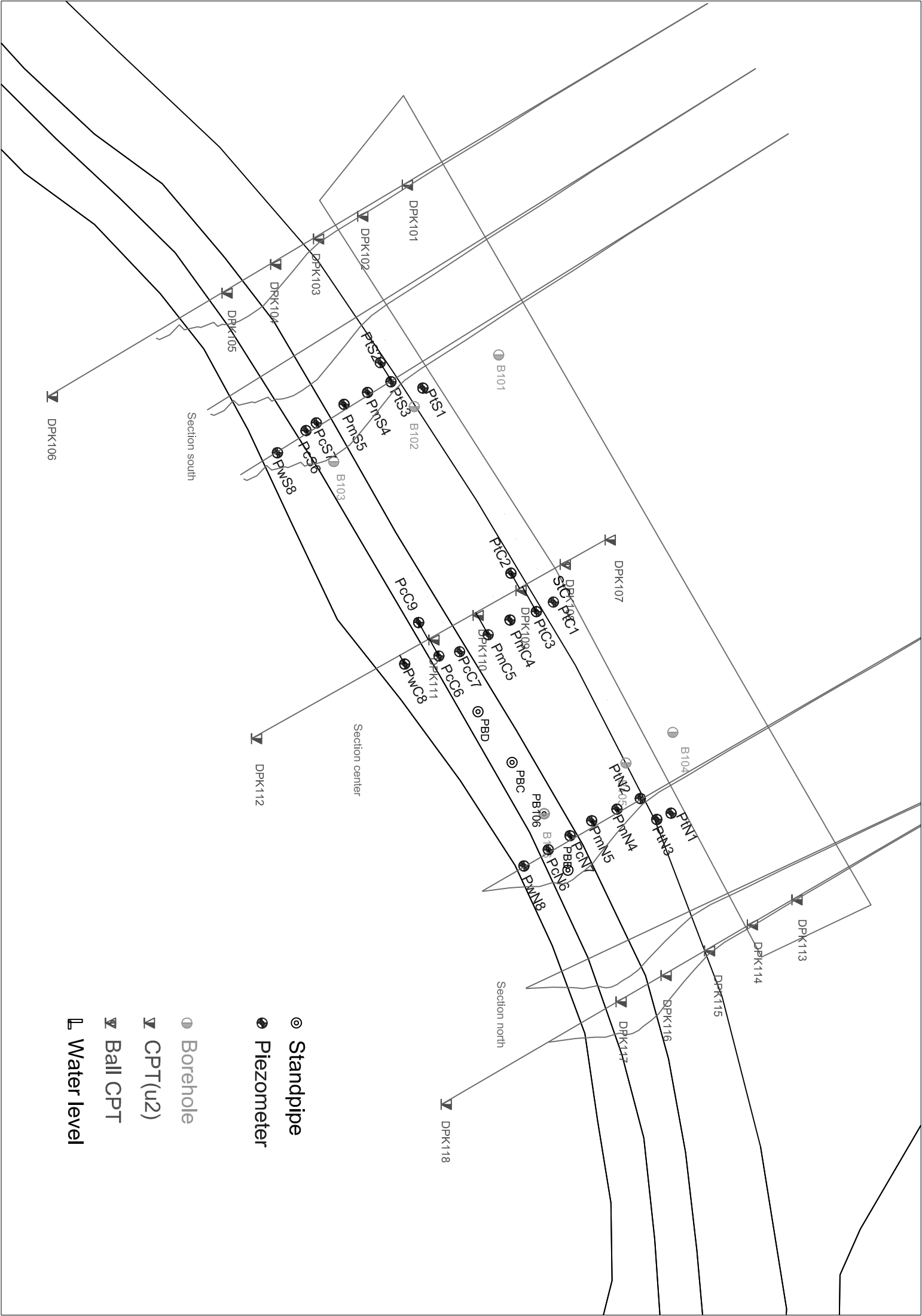
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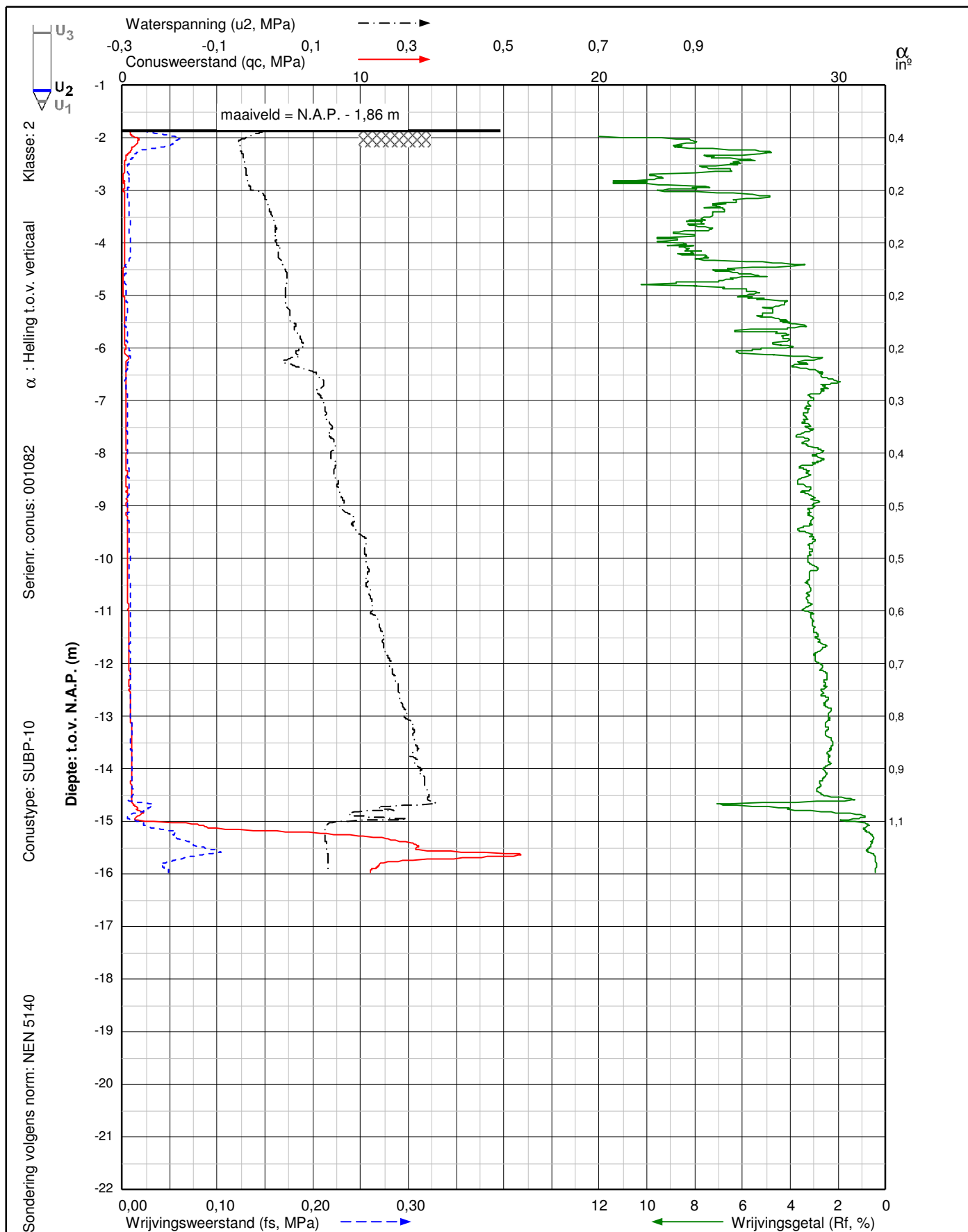
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A PROJECT LOCATION AND SITE INVESTIGATION





Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP101**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.198,54

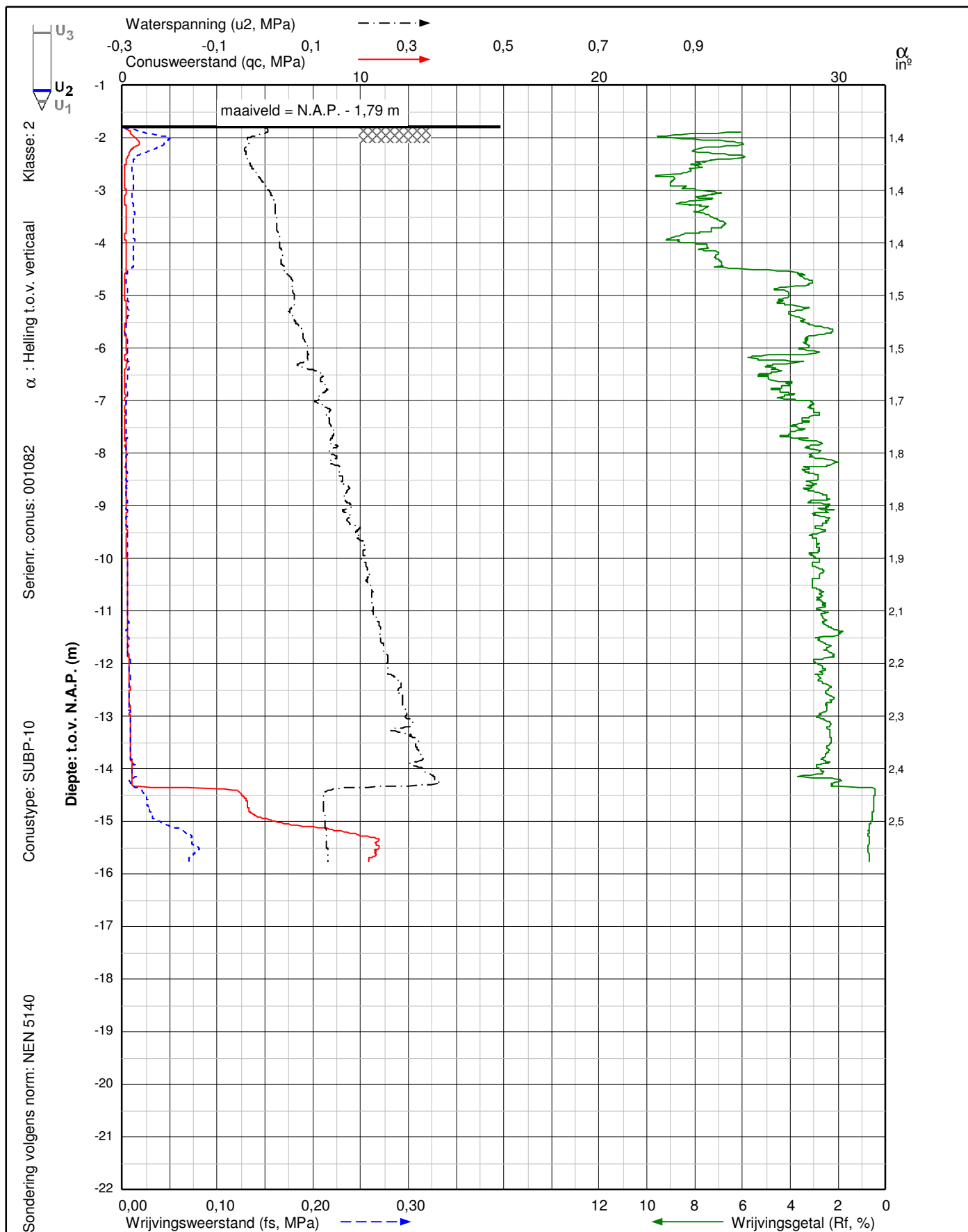
Y = 469.732,65

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 27-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP102**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.200,07

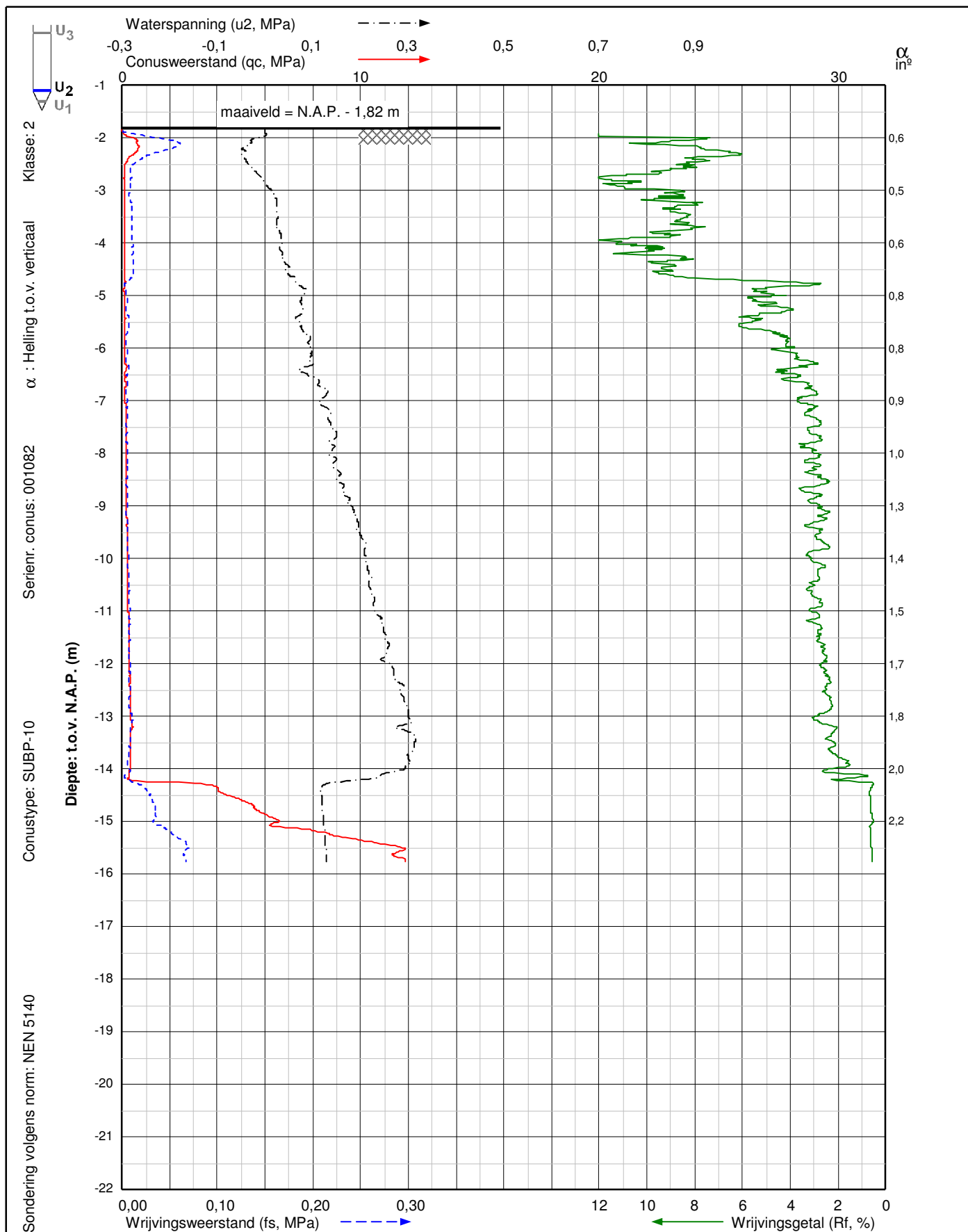
Y = 469.730,45

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 27-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP103**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.201,19

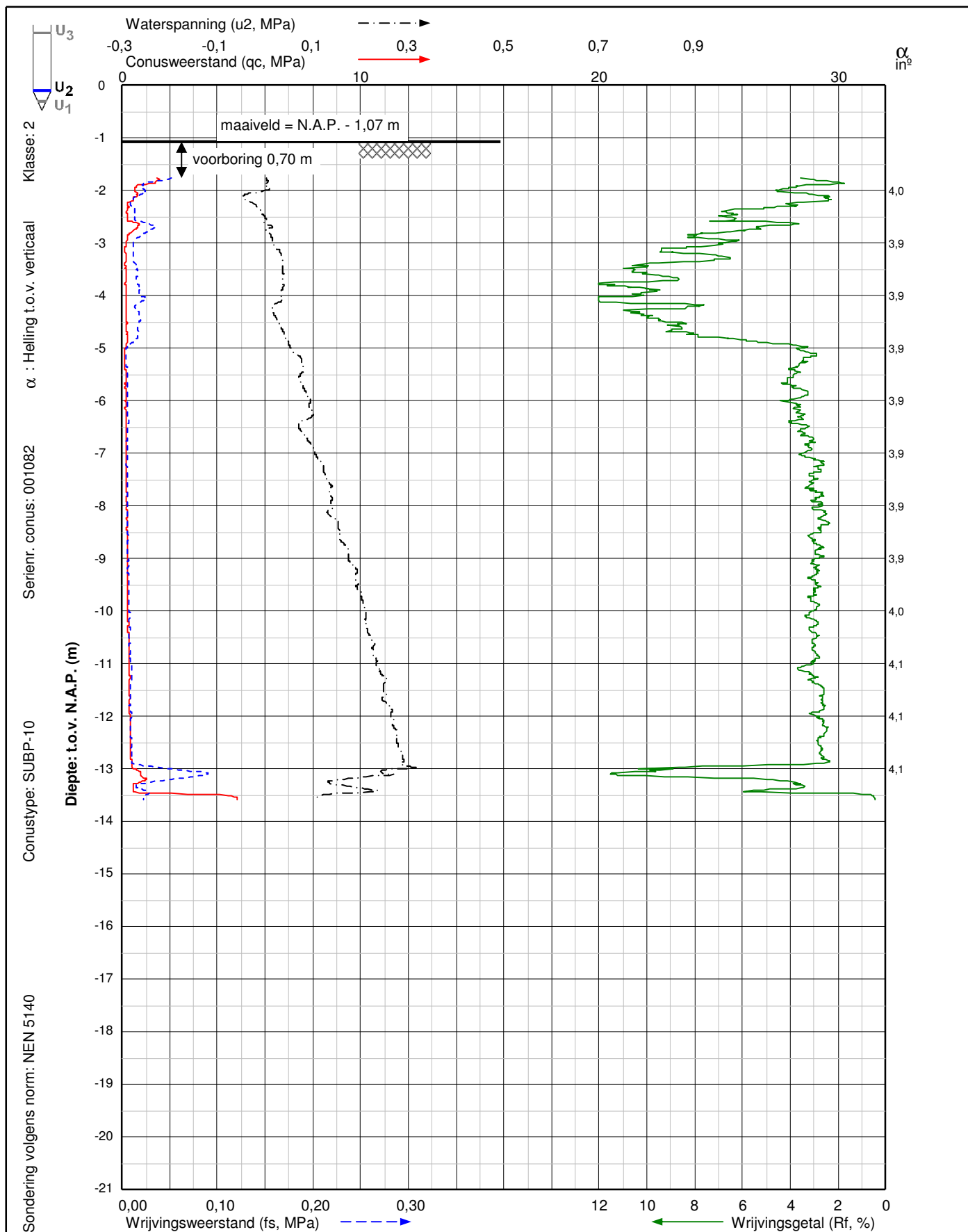
Y = 469.728,27

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 27-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP104**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.202,44

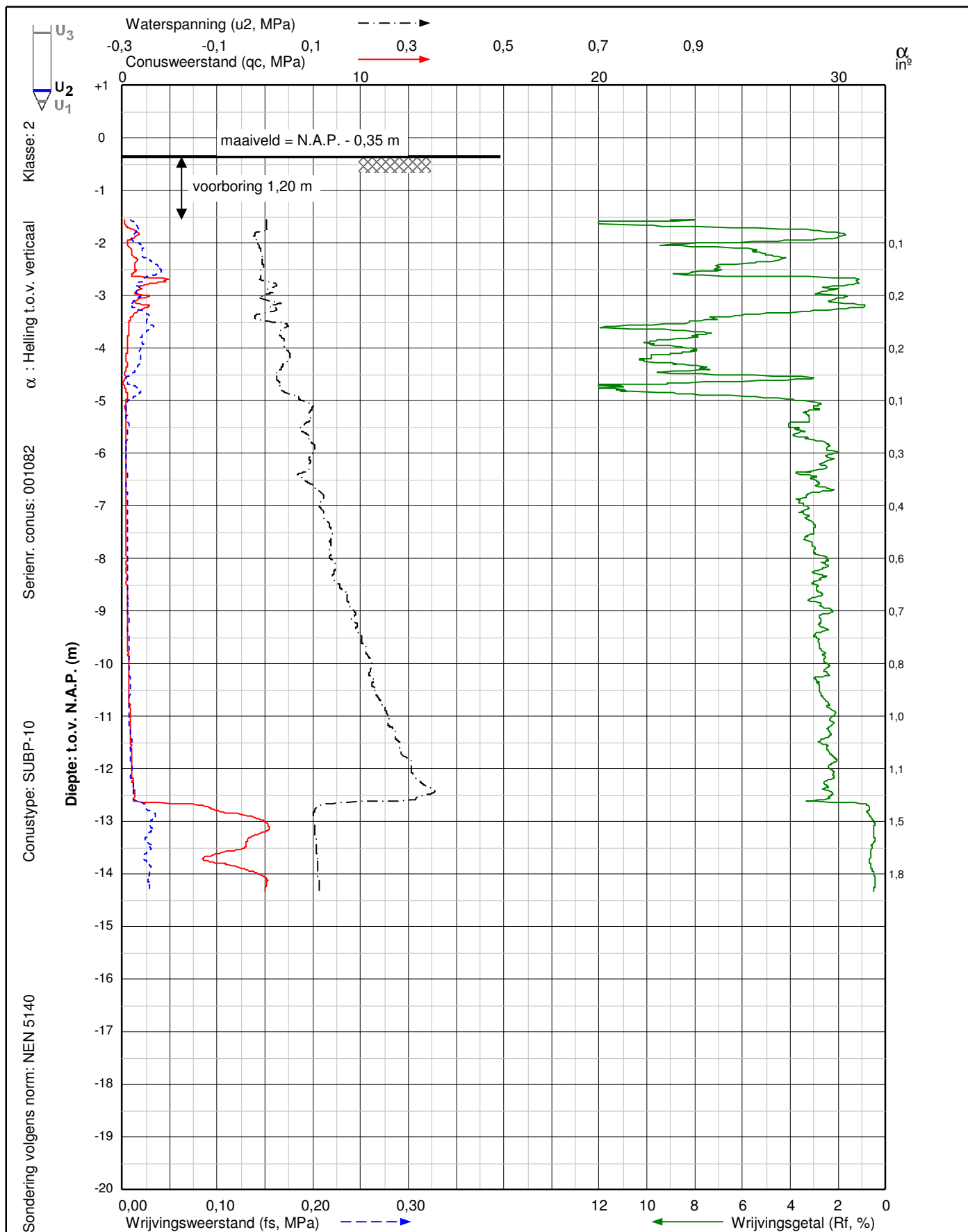
Y = 469.726,16

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 29-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP105**



Wiertsema & Partners

RAADGEVEND INGENIEURS

X = 101.203,86

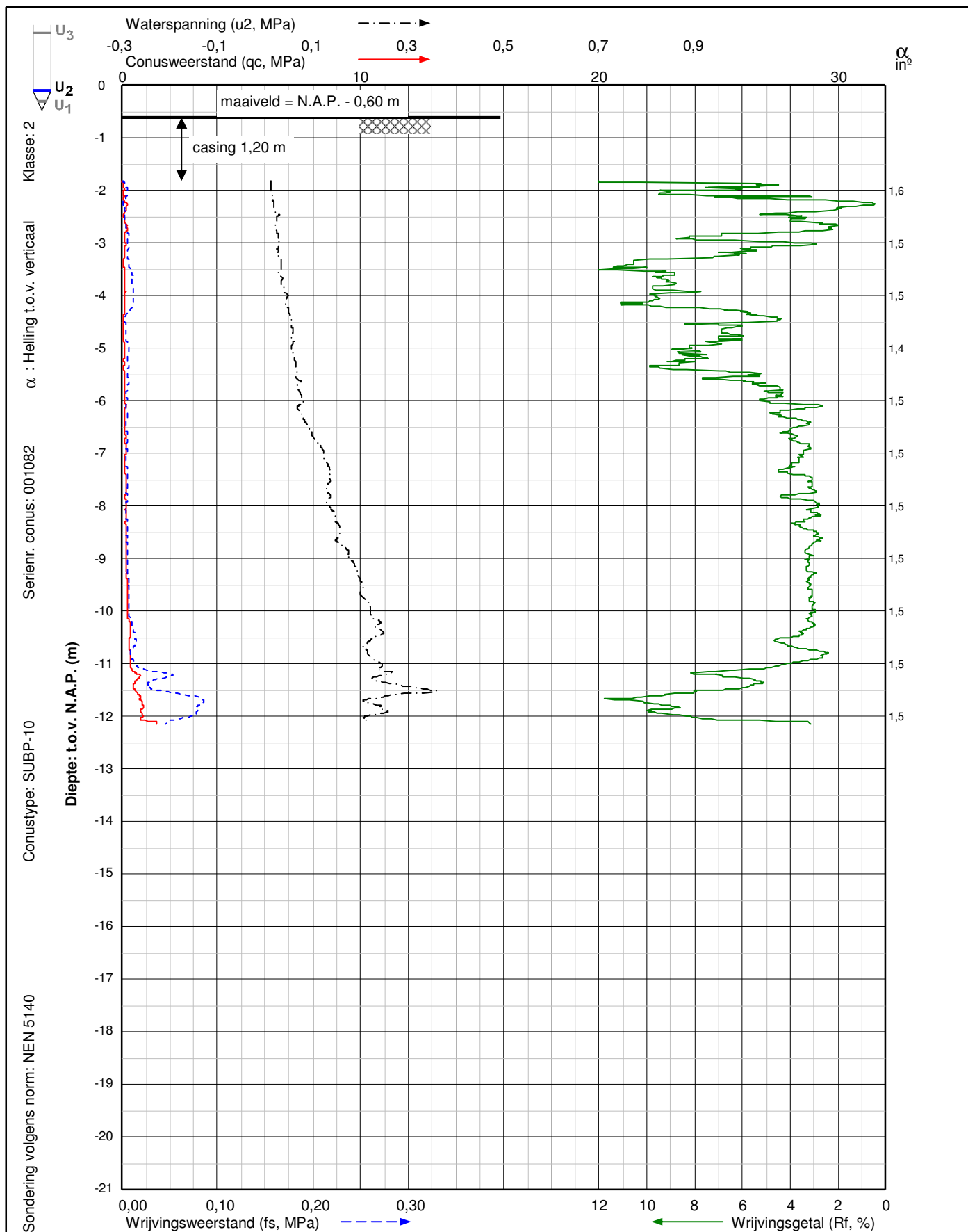
Y = 469.723,76

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 26-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP106**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.208,96

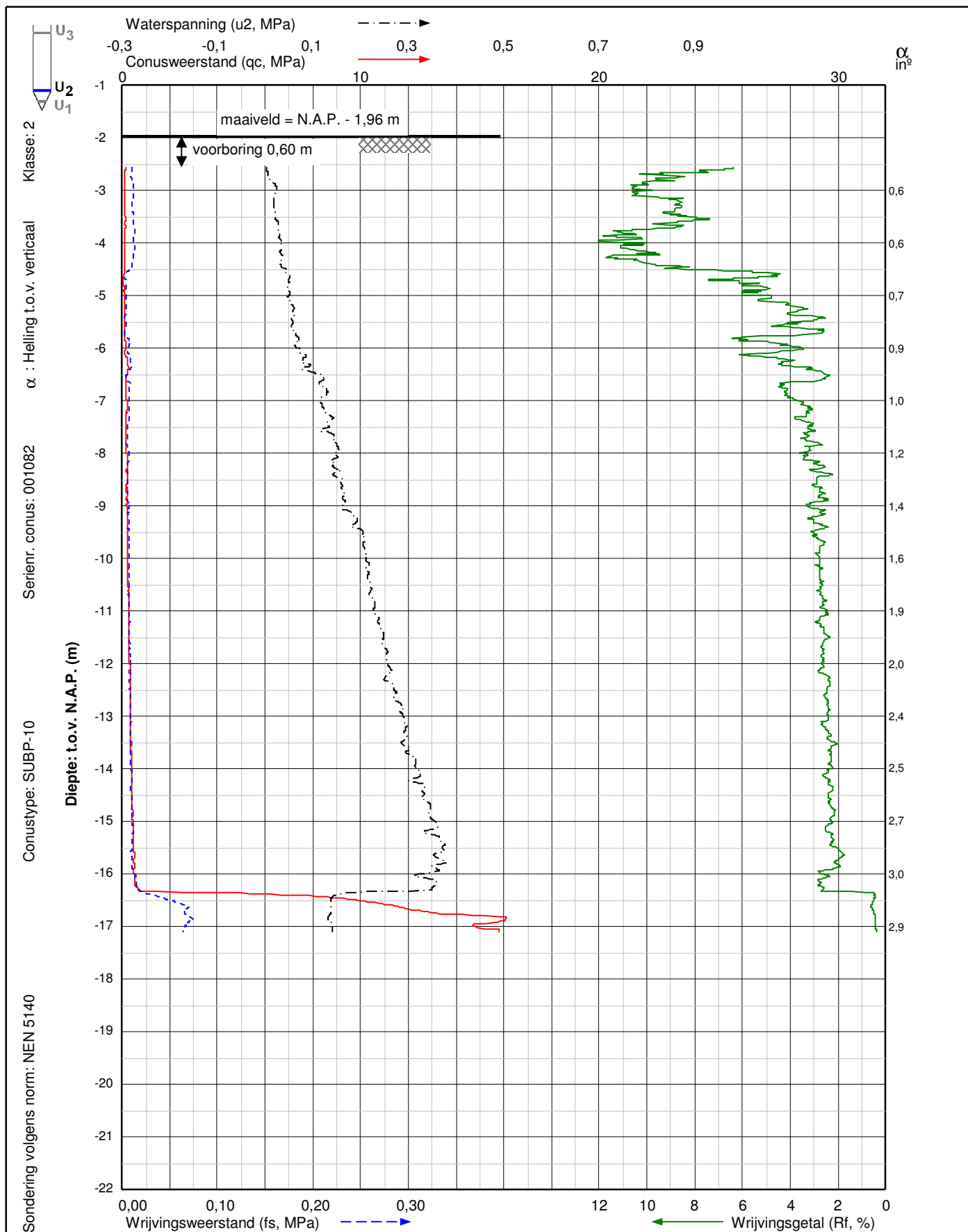
Y = 469.715,15

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 28-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP107**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.216,02

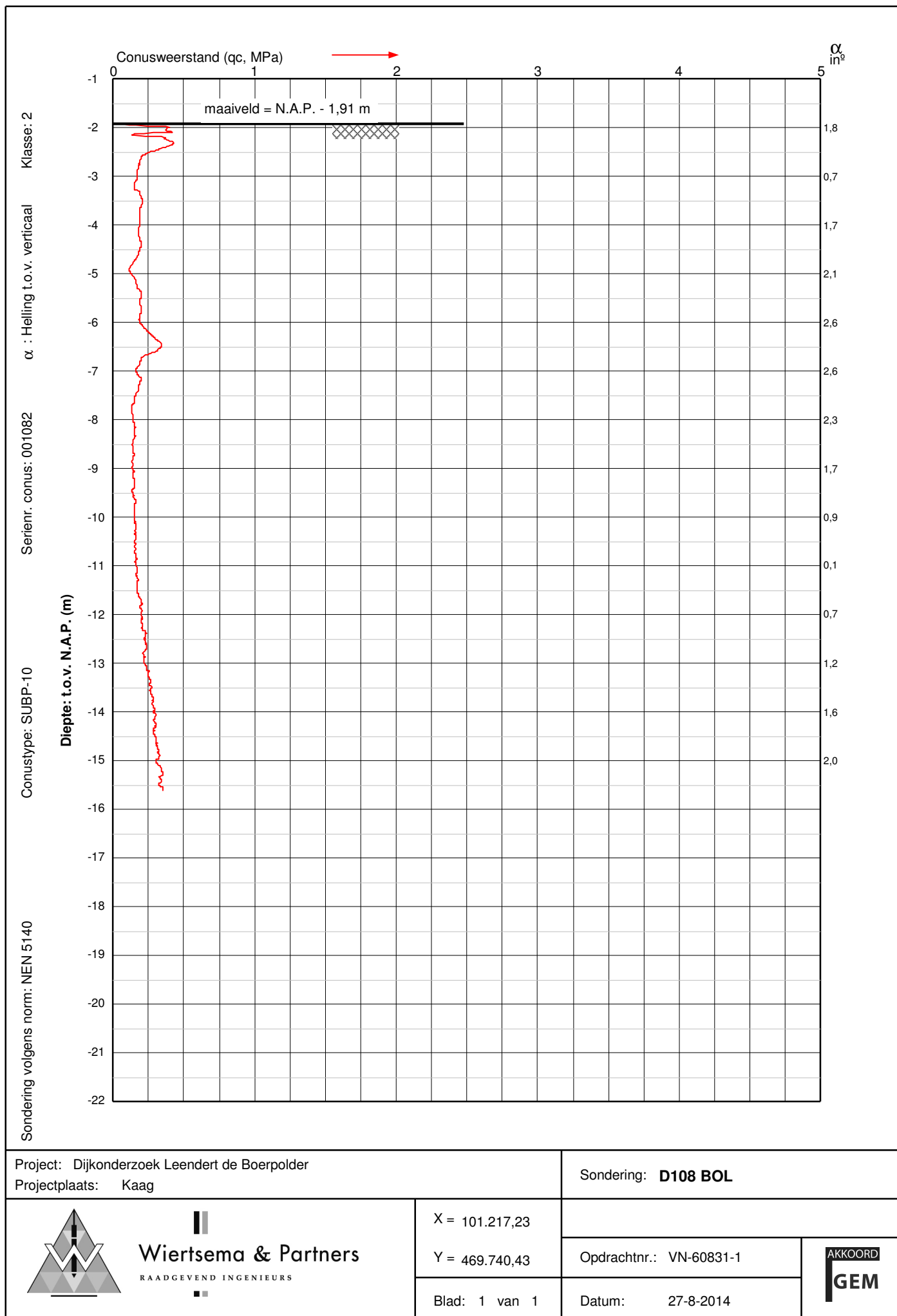
Y = 469.742,65

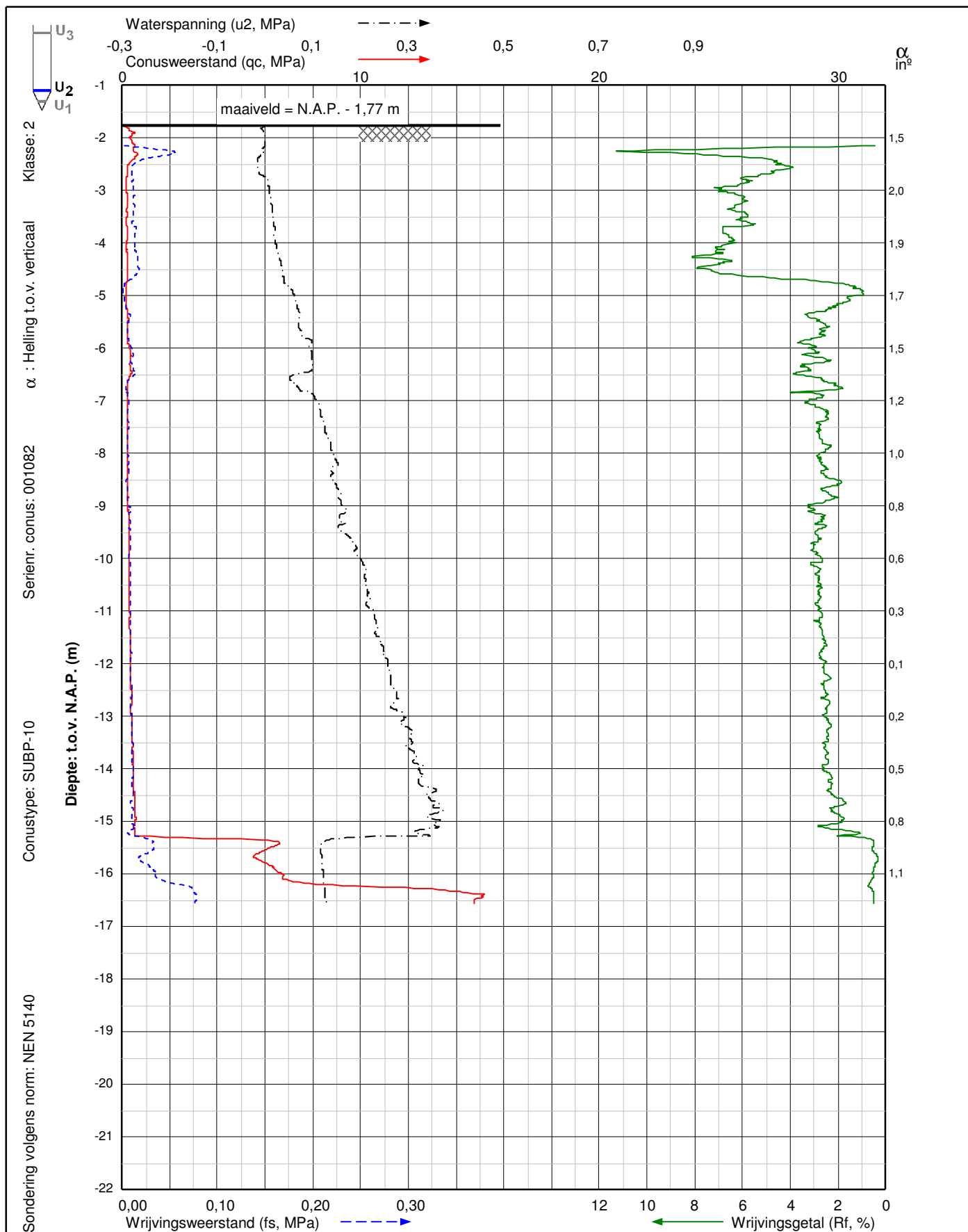
Blad: 1 van 1

Opdrachtnr.: VN-60831-1

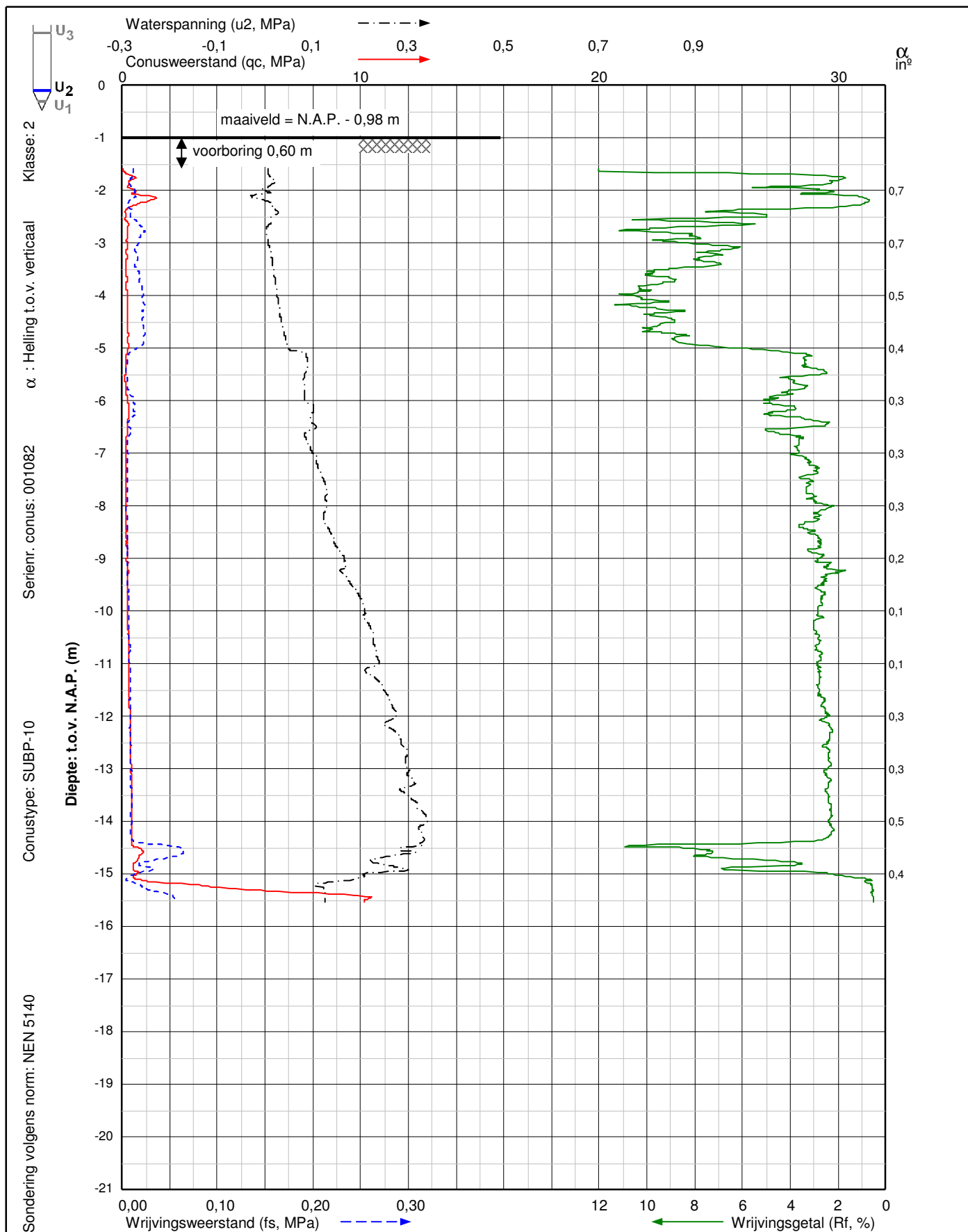
Datum: 26-8-2014

AKKOORD
GEM





Project: Dijkonderzoek Leendert de Boerpolder		Sondering: DKP109	
Projectplaats: Kaag			
 Wiertsema & Partners RAADGEVEND INGENIEURS	X = 101.218,51	Opdrachtnr.: VN-60831-1	
	Y = 469.738,25		
	Blad: 1 van 1	Datum: 27-8-2014	



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP110**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.219,74

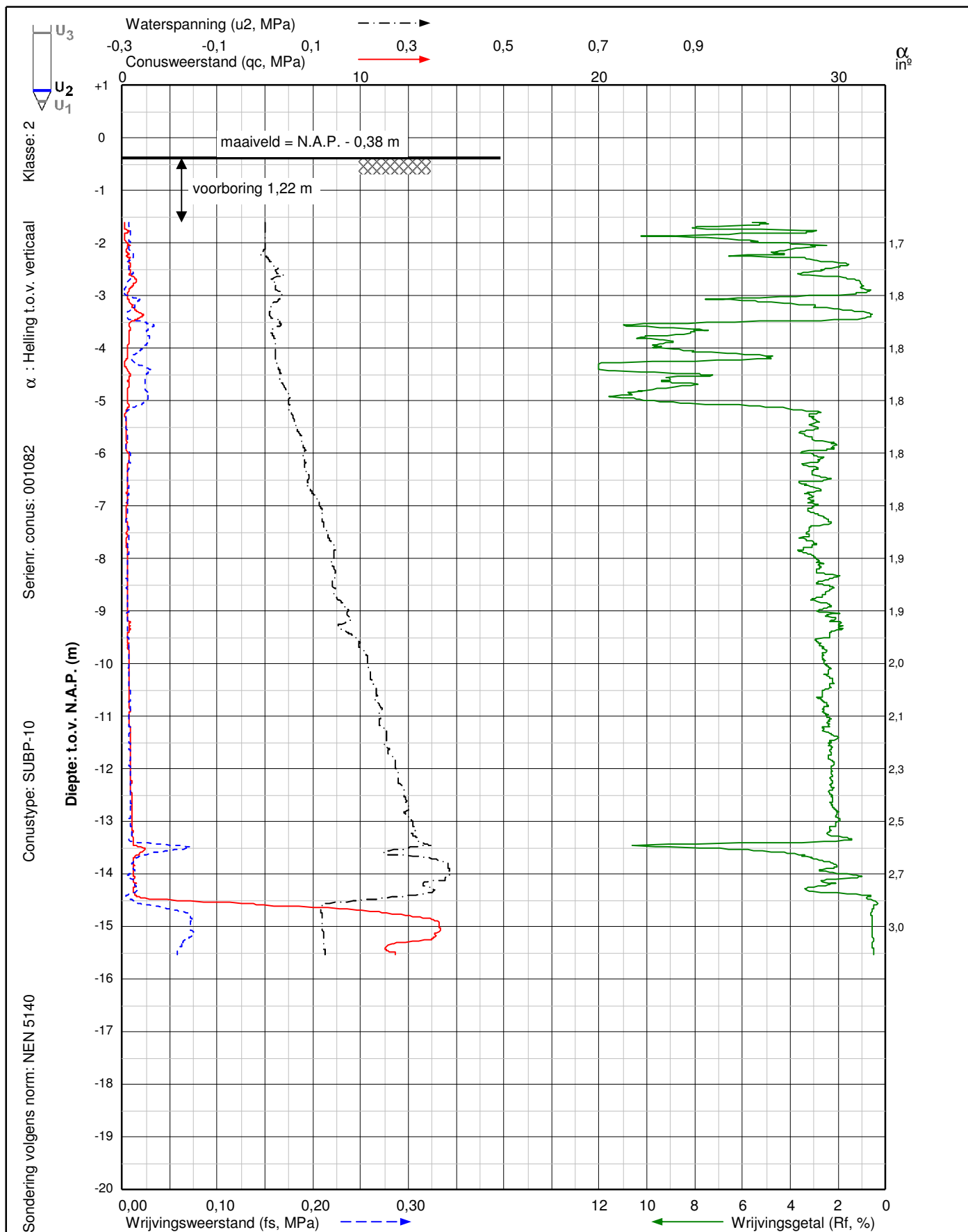
Y = 469.736,14

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 29-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP111**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.220,95

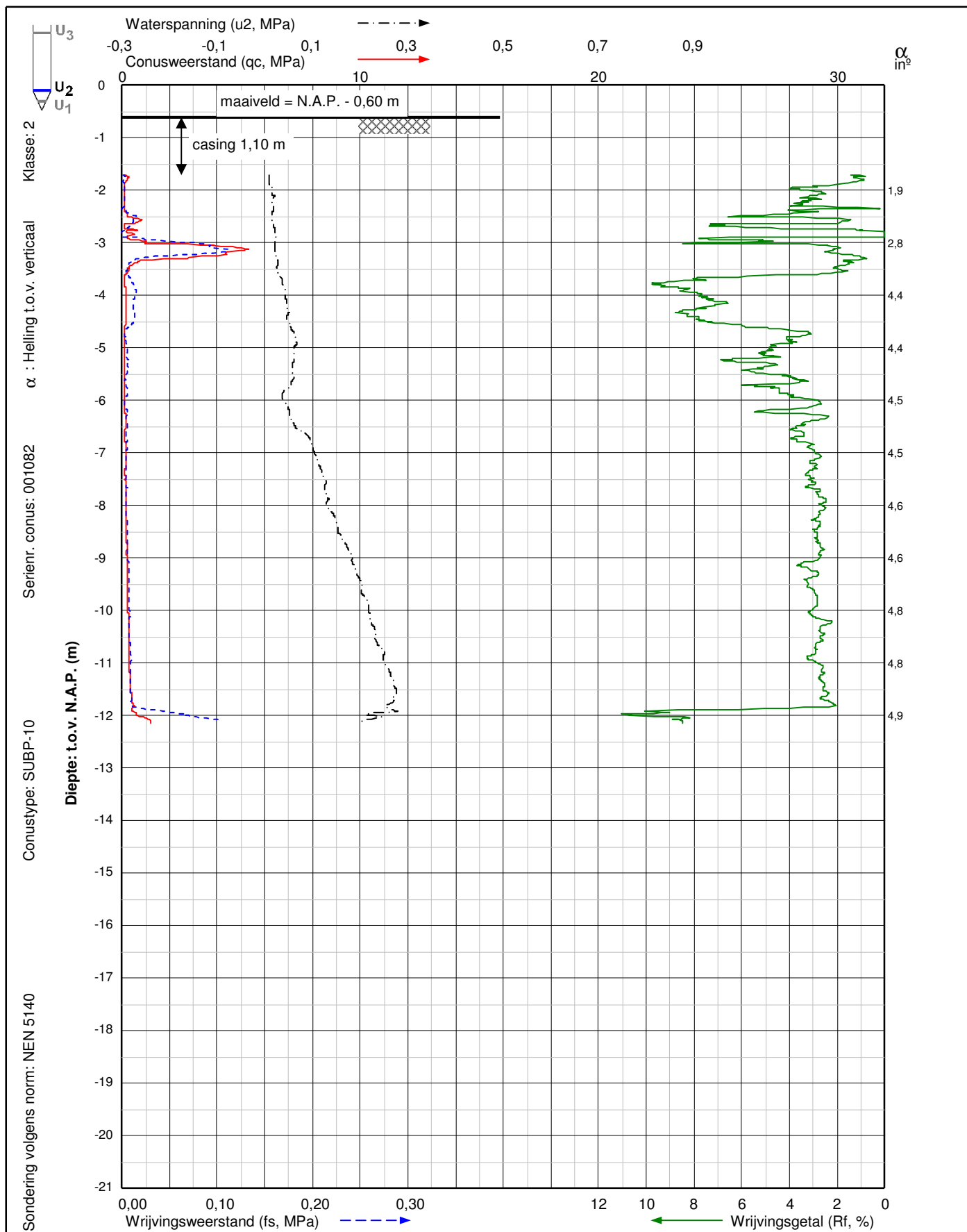
Y = 469.733,96

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 26-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP112**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.225,81

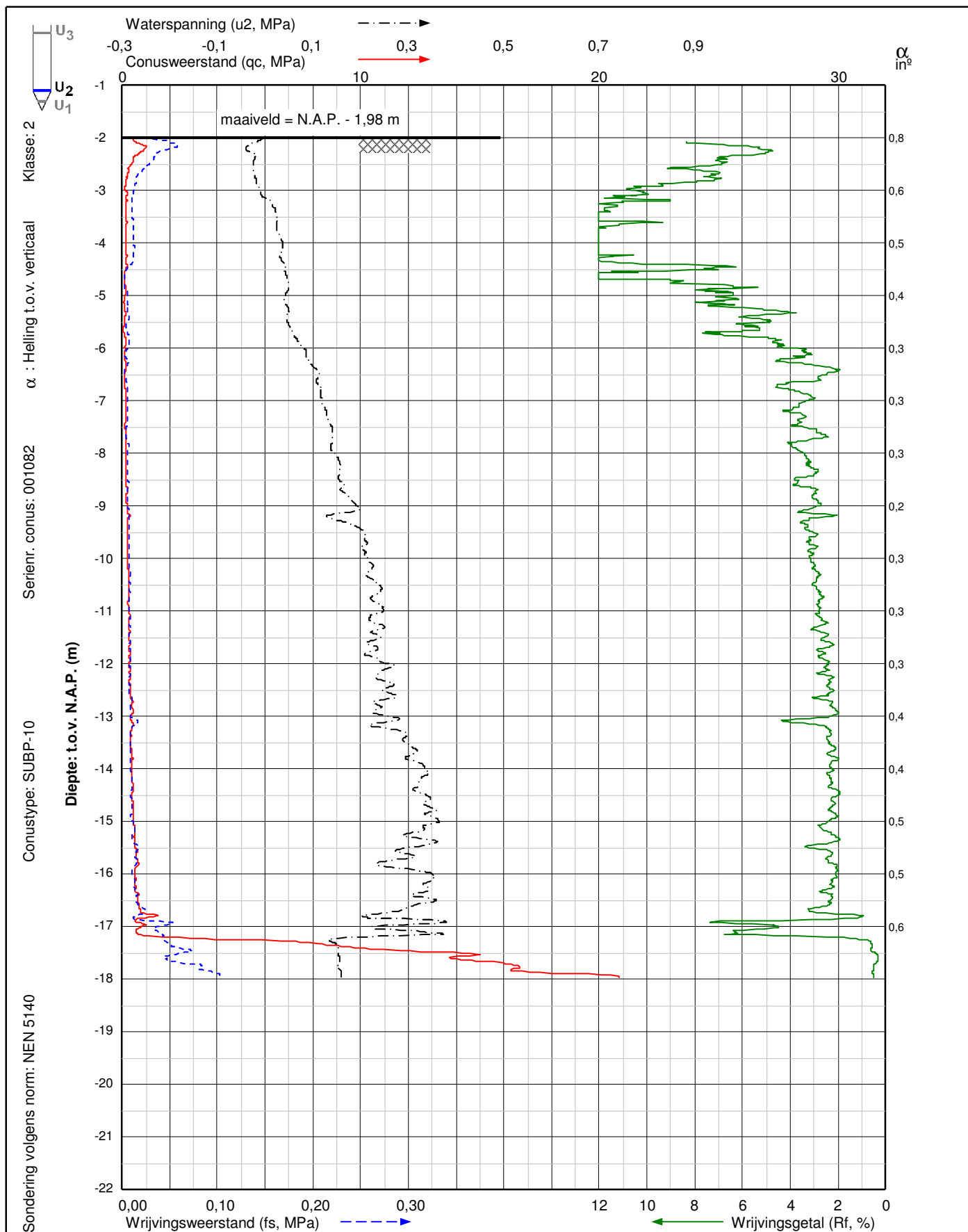
Y = 469.725,22

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 28-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP113**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.233,75

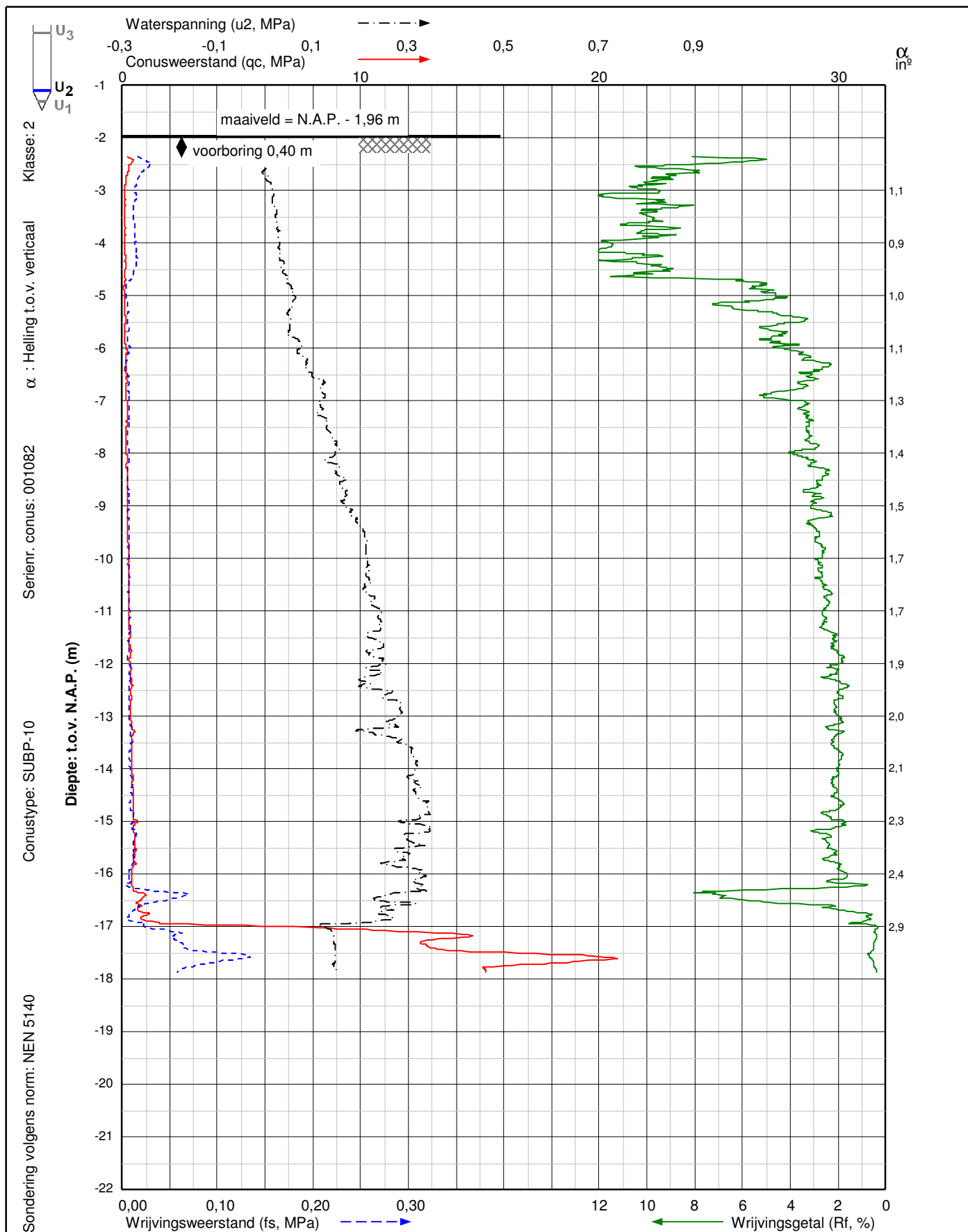
Y = 469.751,86

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 27-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP114**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.234,99

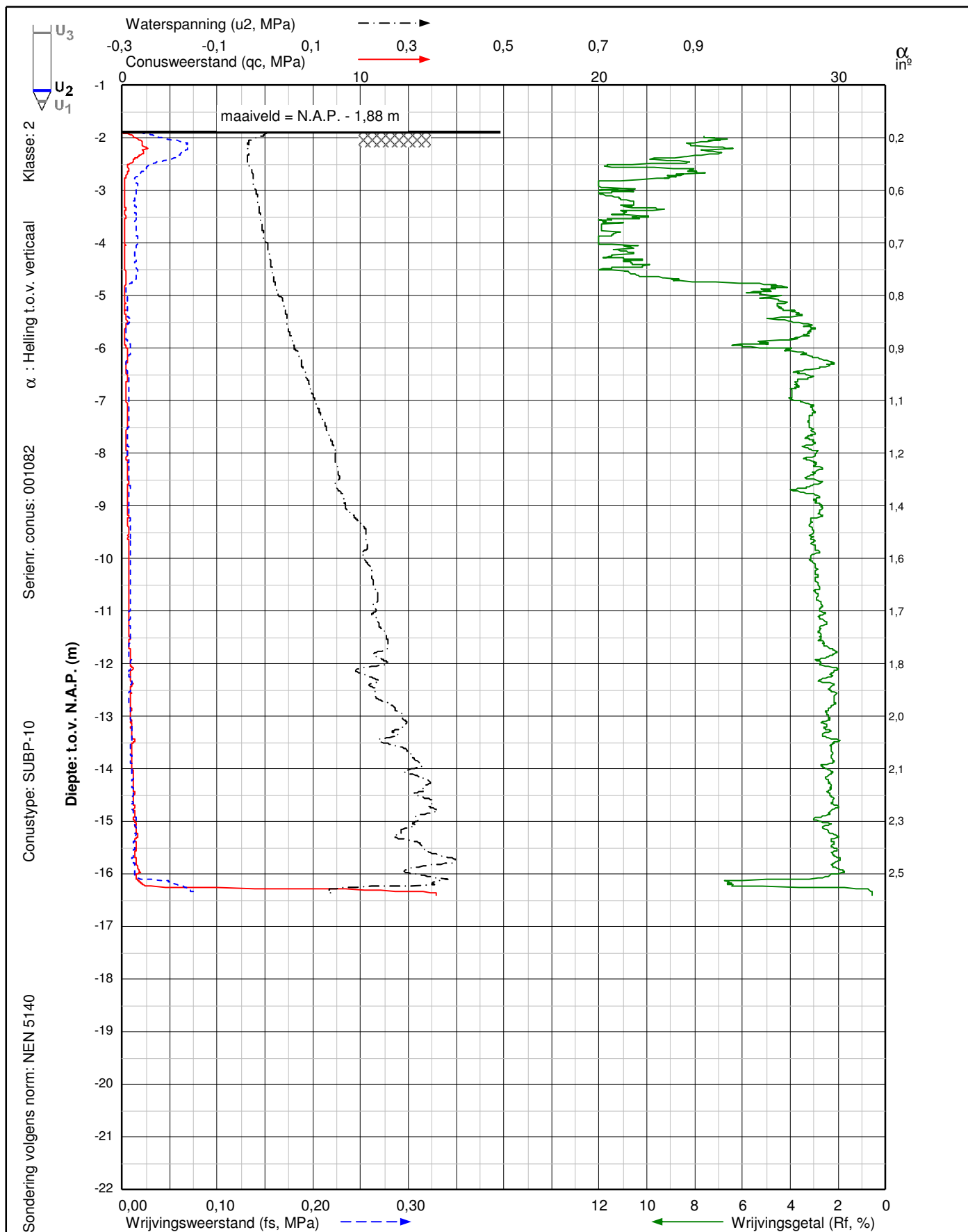
Y = 469.749,66

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 28-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP115**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.236,27

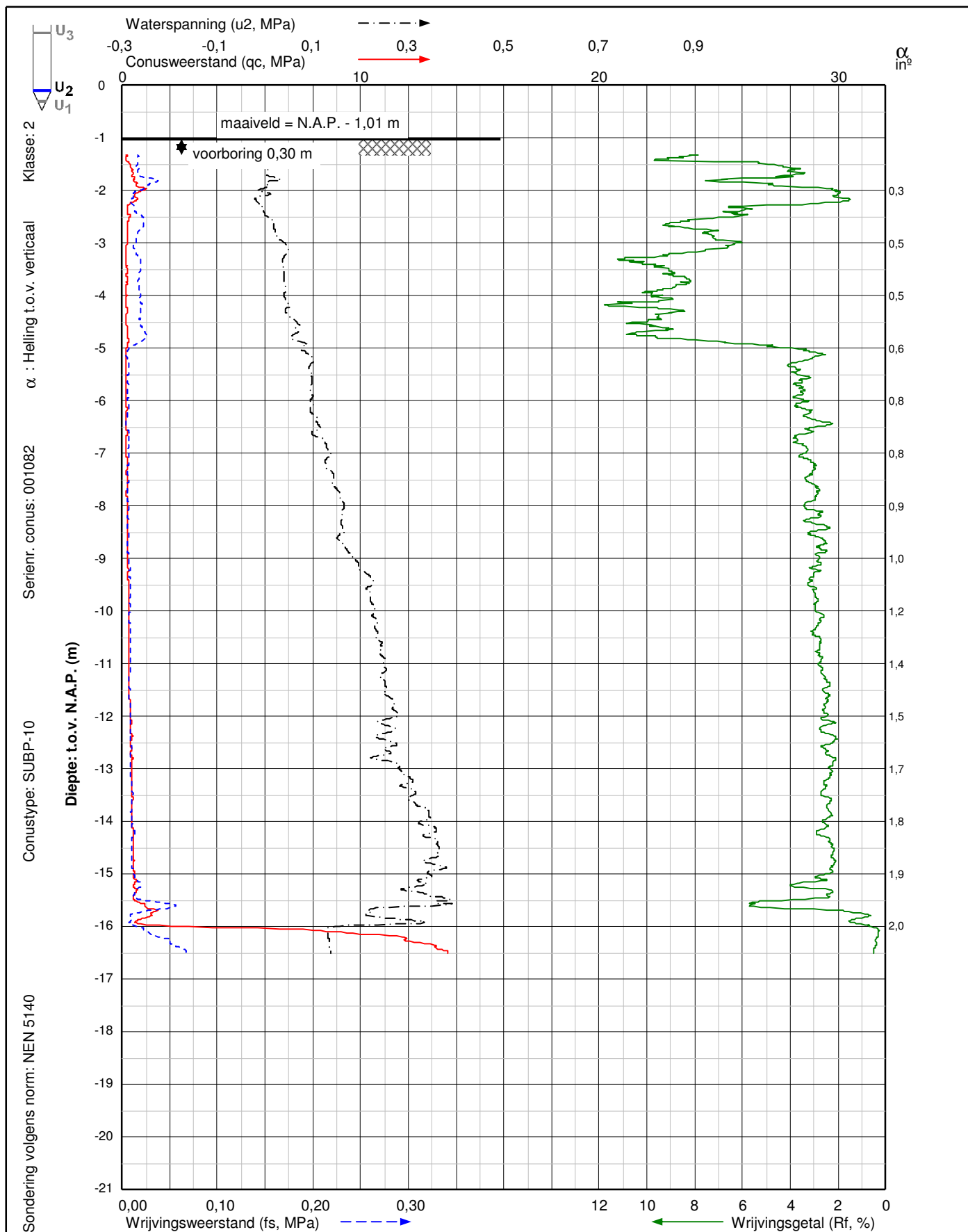
Y = 469.747,54

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 28-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP116**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.237,49

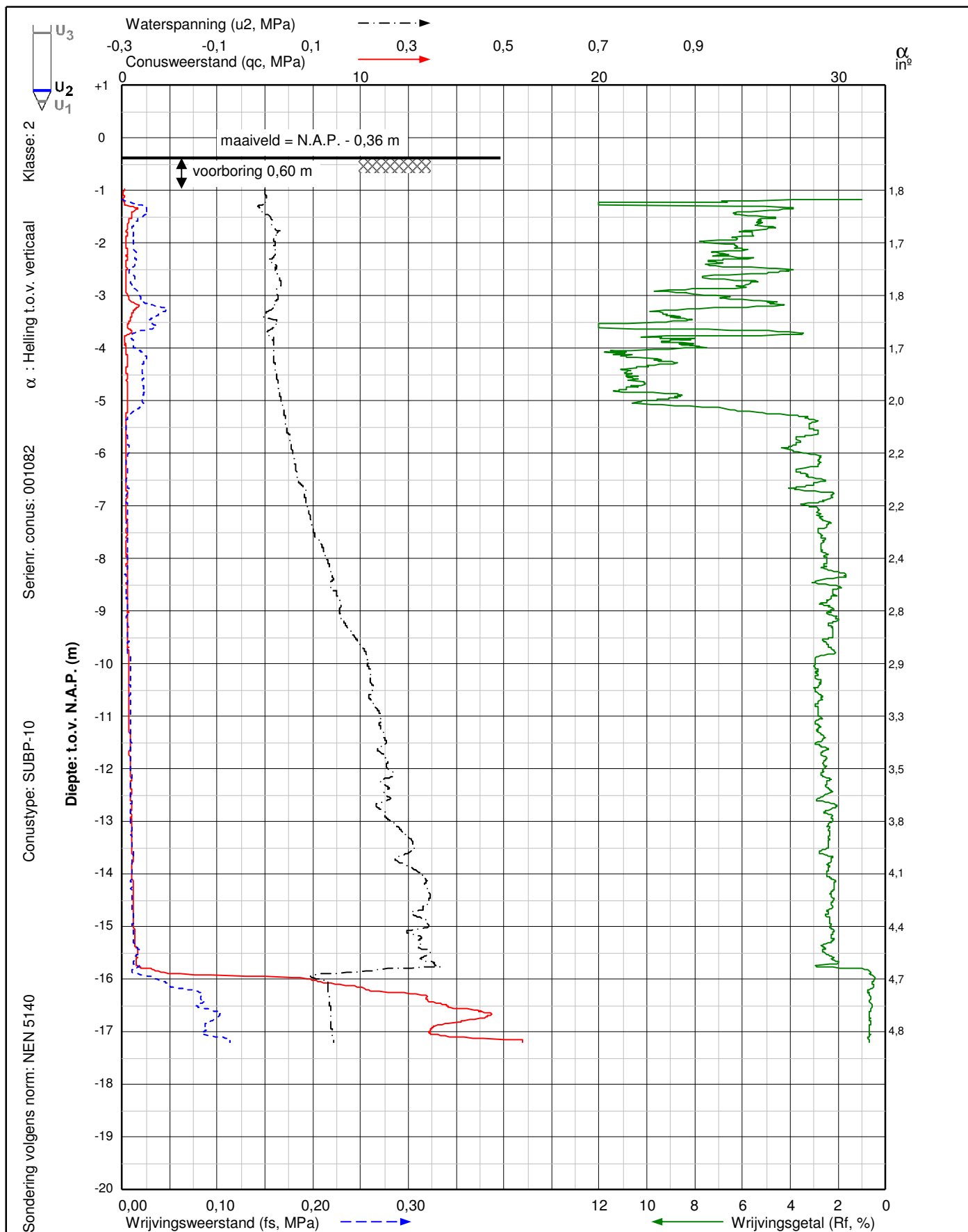
Y = 469.745,40

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 29-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP117**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.238,78

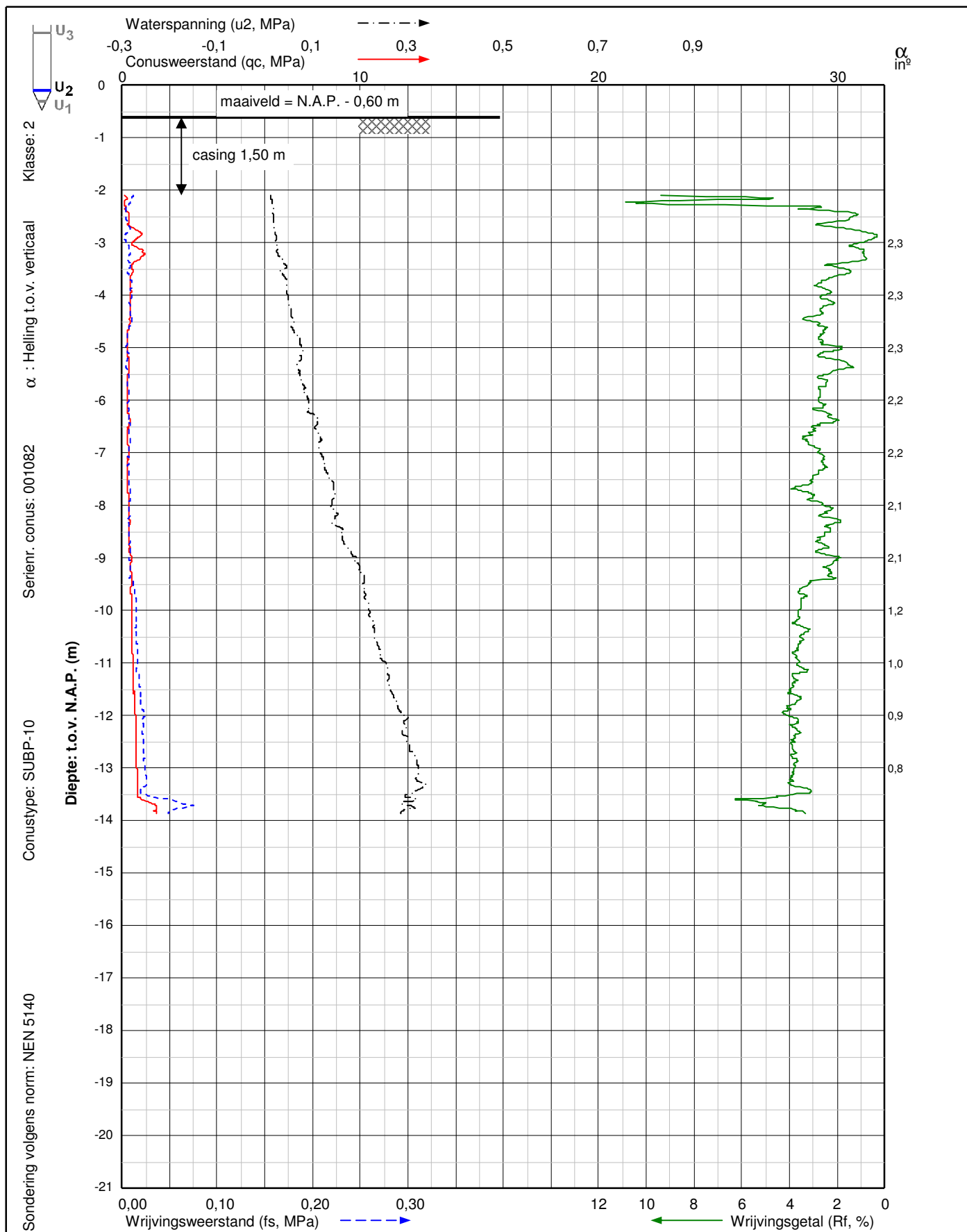
Y = 469.743,19

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 26-8-2014

AKKOORD
GEM



Project: Dijkonderzoek Leendert de Boerpolder
Projectplaats: Kaag

Sondering: **DKP118**



Wiertsema & Partners
RAADGEVEND INGENIEURS

X = 101.243,84

Y = 469.734,56

Blad: 1 van 1

Opdrachtnr.: VN-60831-1

Datum: 28-8-2014

AKKOORD
GEM

NEN 5104 Grondsoorten

Hoofdgrondsoort / bijmenging

	Grind / grindig
	Zand / zandig
	Leem / siltig
	Klei / kleilig
	Veen / humeus

Niet NEN 5104 hoofdbestanddelen

	Gesloten verharding
	Puin
	Schelpen
	Water
	Overige niet binnen NEN 5104 gedefinieerde hoofdbestanddelen

Geohydrologische gegevens

	Actuele grondwaterstand direct na boren bepaald
	Gemiddeld Hoogste Grondwaterstand (GHG)
	Gemiddeld Laagste Grondwaterstand (GLG)

Monsternamen

	Geroerd monster
	Ongeroid monster

Aanvullingen

	Filterzand
	Filtergrind / Aanvulgrind
	Zwelkleikorrels
	Mikolit / Mikolit 00 / Mikolit 300
	Mikolit B / Bentoniet
	QSE
	Grond (vrijgekomen / opgeboord)
	Aanvulzand
	Klei
	Grout

Peilbuizen

	Blinde buis / stijgbuis
	Filter
	Zandvang

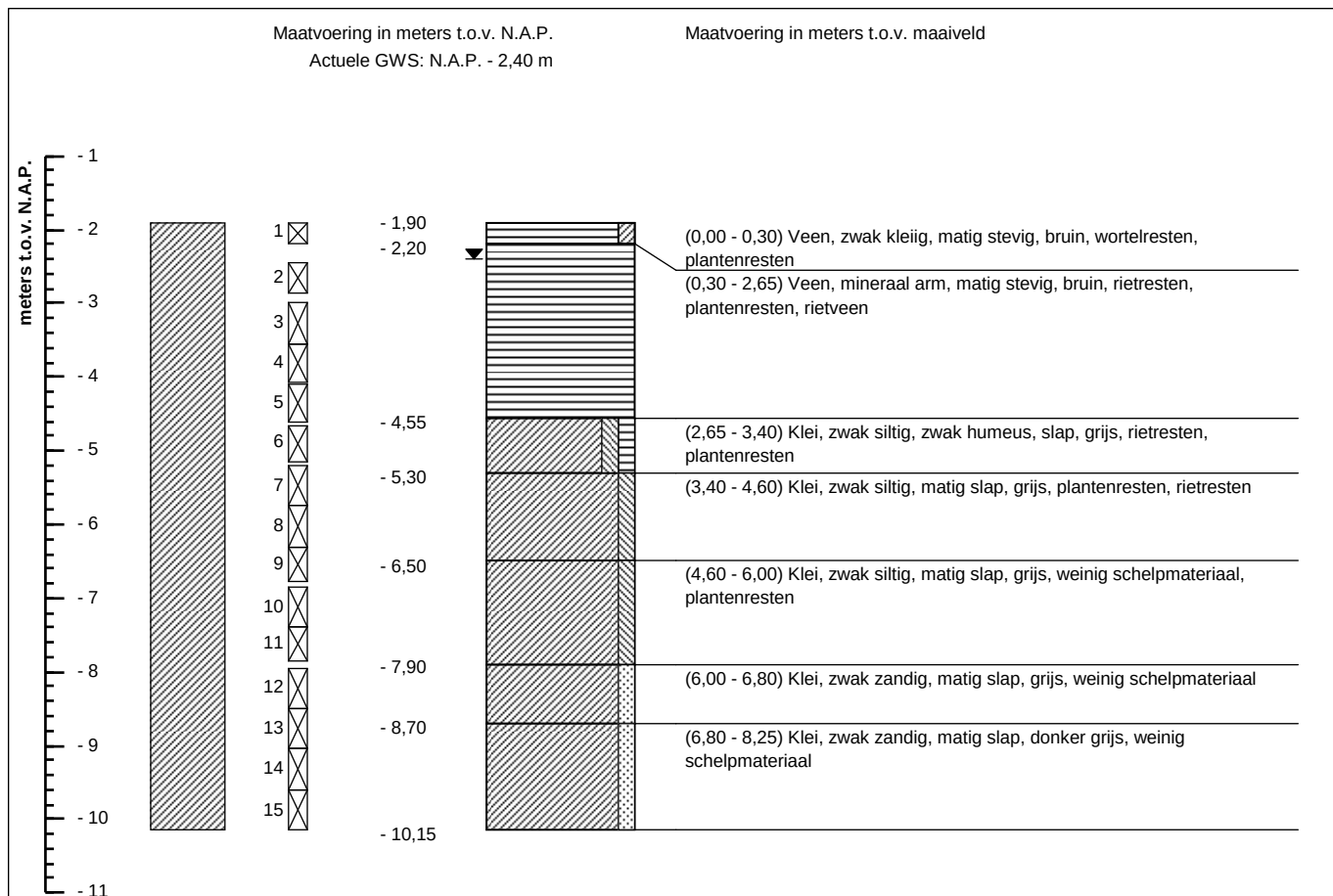
Hellingmeetbuizen

	Hellingmeetbuis
--	-----------------

Legenda boorprofiel met aanvullende gegevens

Wiertsema & Partners
RAADGEVEND INGENIEURS

AKKOORD
GEM

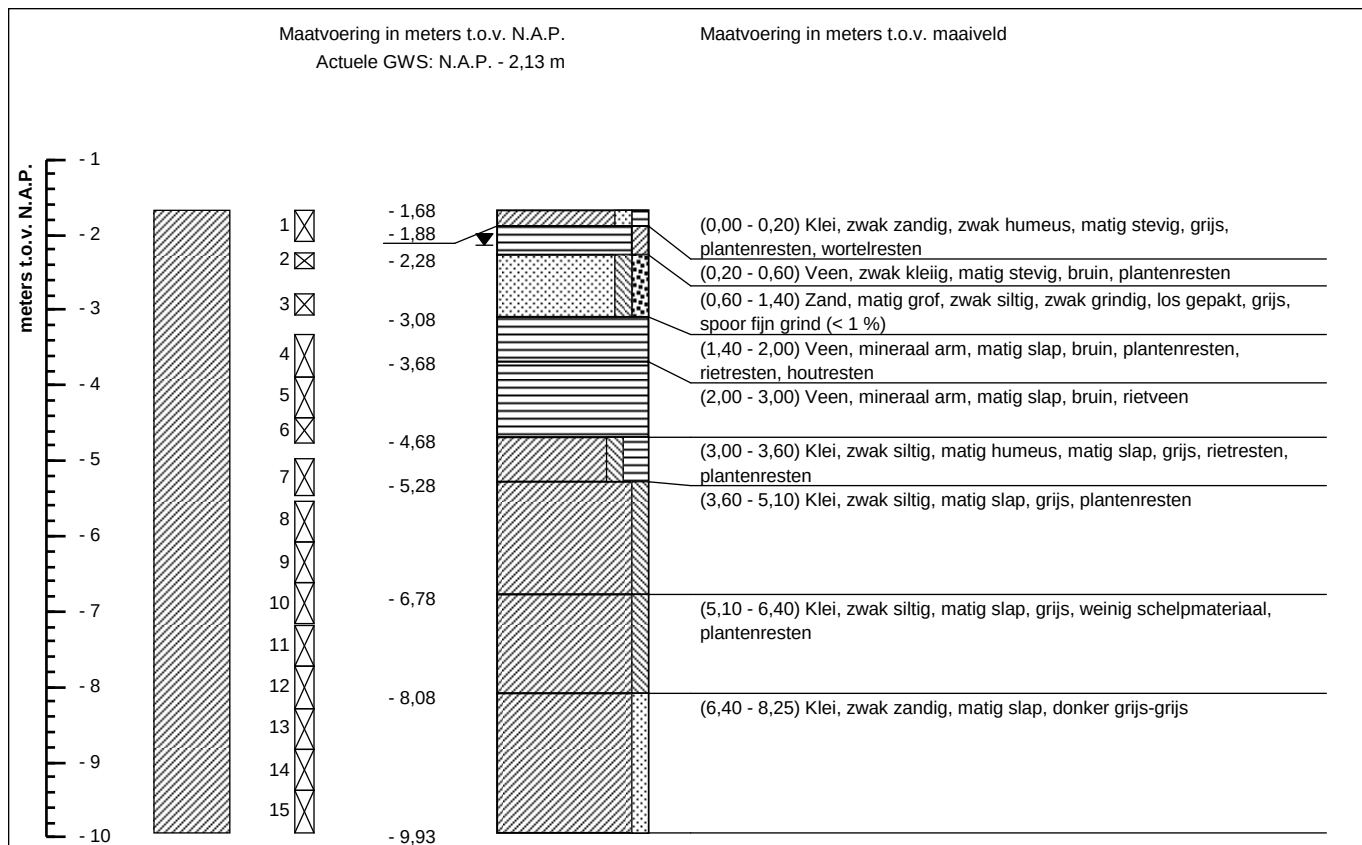


Boorstaat o.b.v. grondidentificatie in het veld (NEN 5104)

Boring conform NEN-EN-ISO 22475-1

Dijkonderzoek Leendert de Boerpolder	RD coördinatensysteem	Kaag	
Stichting IJkdijk	X = 101 206,90	Pulsboring (lichte stelling)	
 Wiertsema & Partners RAADGEVEND INGENIEURS	Y = 469 737,15	Boormeester: Jan Berends	
	Uitgevoerd: 2-9-2014	Opdrachtnr.: 60831-1	AKKOORD GEM
	Blad 1 van 1	Boornummer: B101	

VN-60831-1-B101.110 & VN-60831-1-B101_CH02.110

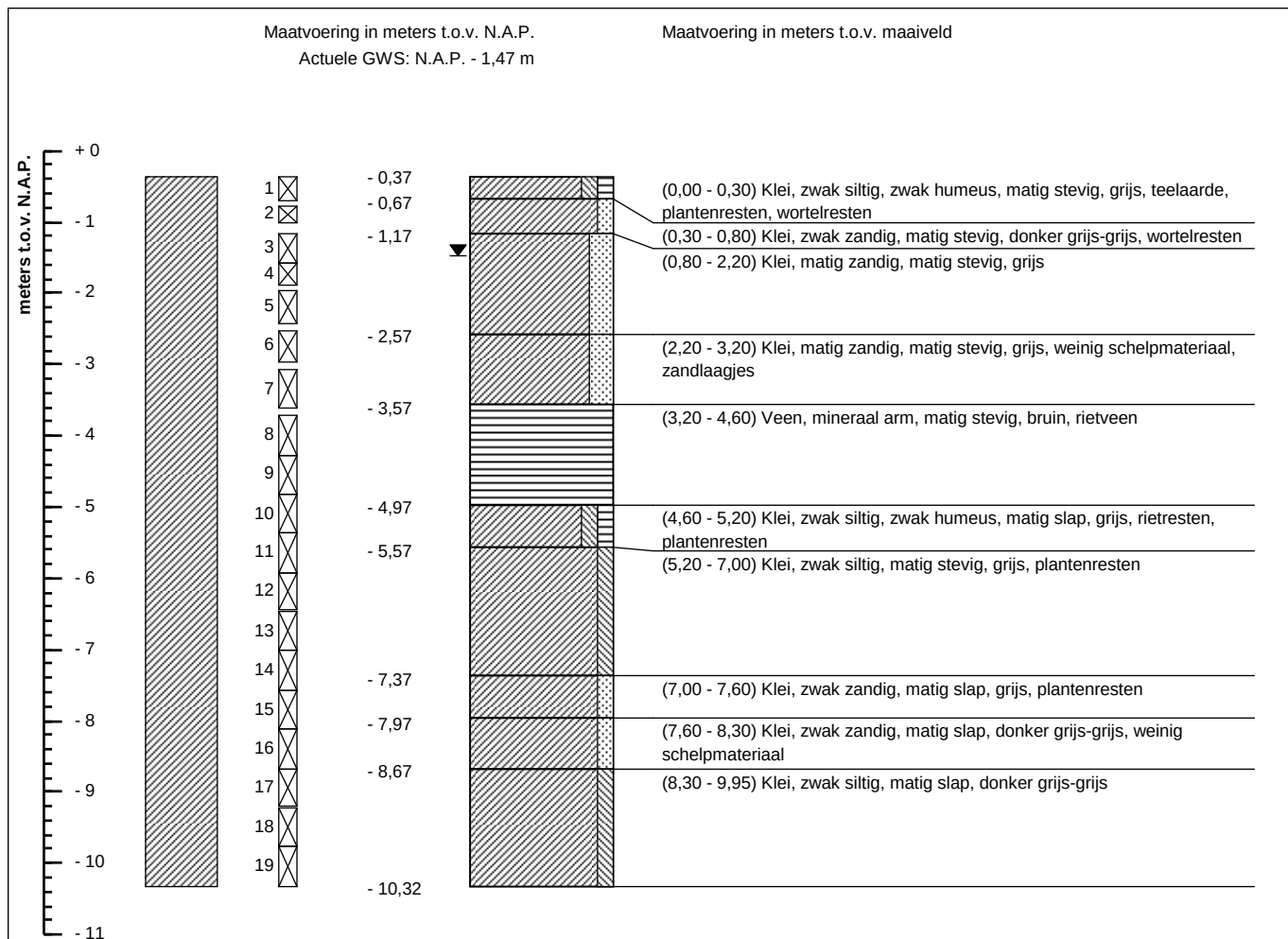


Boorstaat o.b.v. grondidentificatie in het veld (NEN 5104)

Boring conform NEN-EN-ISO 22475-1

Dijkonderzoek Leendert de Boerpolder	RD coördinatensysteem	Kaag	
Stichting IJkdijk	X = 101 209,45	Pulsboring (lichte stelling)	
 Wiertsema & Partners RAADGEVEND INGENIEURS	Y = 469 732,99	Boormeester: Jan Berends	
	Uitgevoerd: 3-9-2014	Opdrachtnr.: 60831-1	AKKOORD GEM
	Blad 1 van 1	Boornummer: B102	

VN-60831-1-B102.110 & VN-60831-1-B102.110

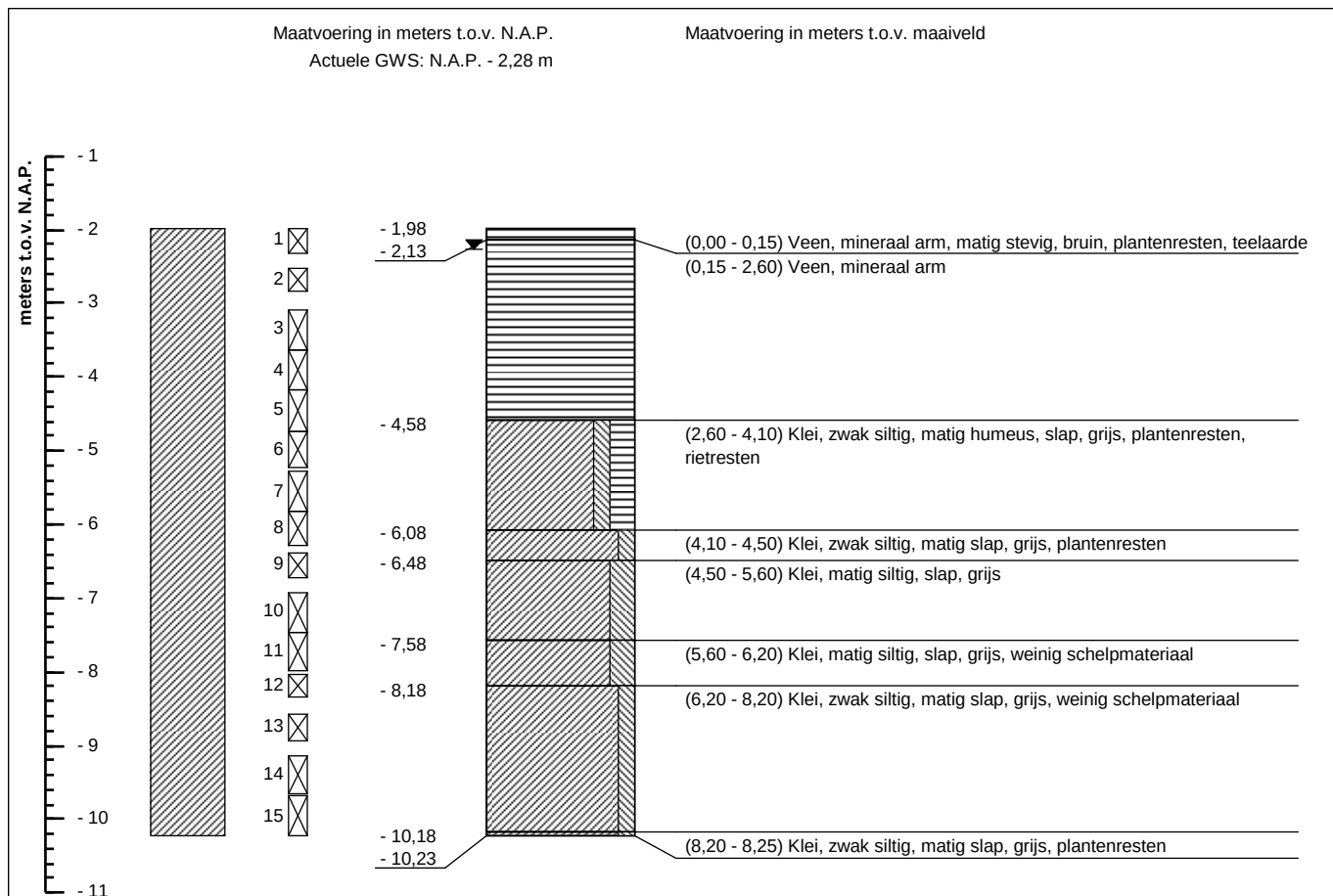


Boorstaat o.b.v. grondidentificatie in het veld (NEN 5104)

Boring conform NEN-EN-ISO 22475-1

Dijkonderzoek Leendert de Boerpolder	RD coördinatensysteem	Kaag	
Stichting IJkdijk	X = 101 212,16	Pulsboring (lichte stelling)	
 Wiertsema & Partners RAADGEVEND INGENIEURS	Y = 469 729,02	Boormeester: Jan Berends	
	Uitgevoerd: 4-9-2014	Opdrachtnr.: 60831-1	AKKOORD GEM
	Blad 1 van 1	Boornummer: B103	

VN-60831-1-B103.110 & VN-60831-1-B103.110



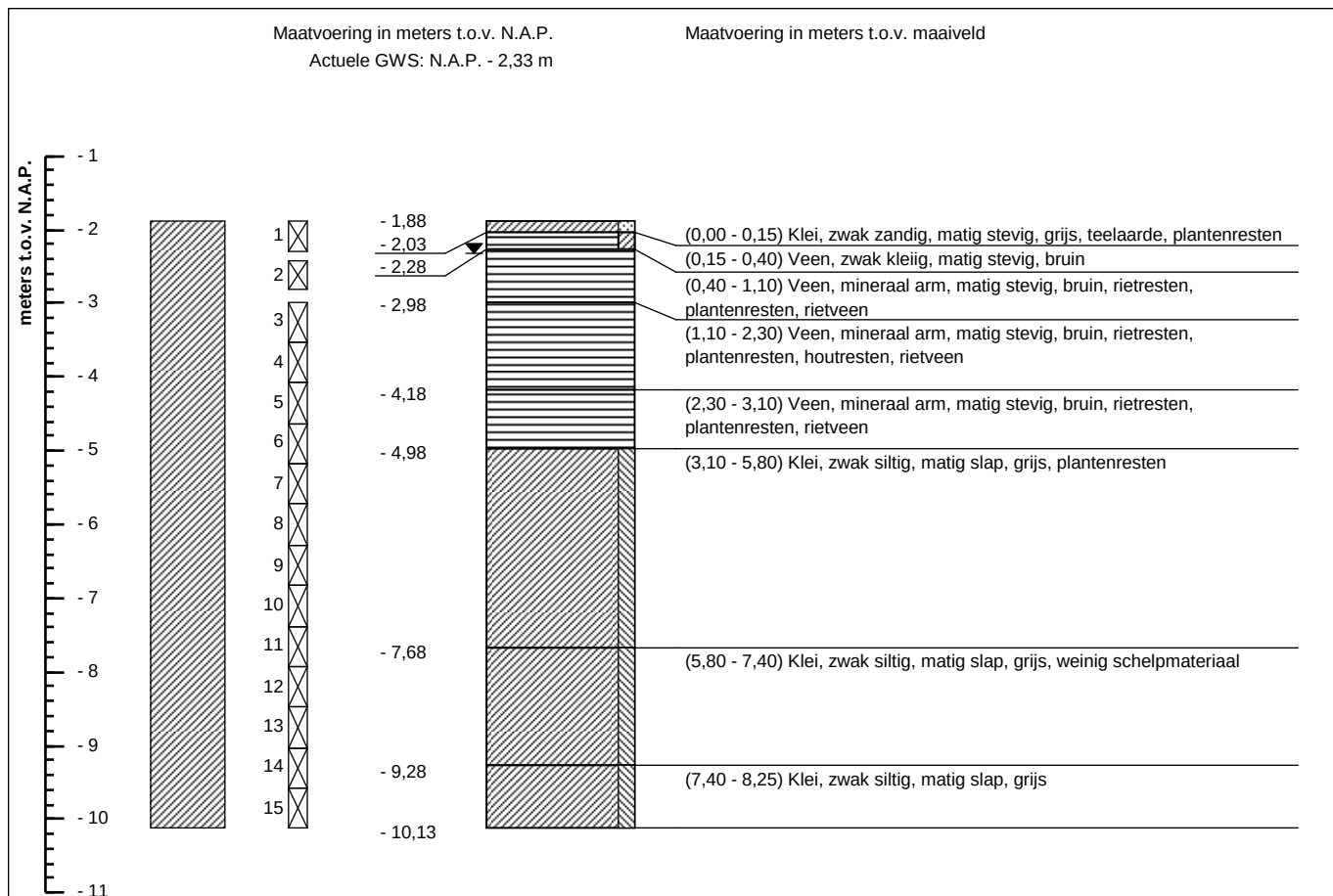
Boorstaat o.b.v. grondidentificatie in het veld (NEN 5104)

Boring conform NEN-EN-ISO 22475-1

Dijkonderzoek Leendert de Boerpolder	RD coördinatensysteem	Kaag
Stichting IJkdijk	X = 101 225,50	Pulsboring (lichte stelling)
 Wiertsema & Partners RAADGEVEND INGENIEURS	Y = 469 745,73	Boormeester: Jan Berends
	Uitgevoerd: 29-8-2014	Opdrachtnr.: 60831-1
	Blad 1 van 1	Boornummer: B104

AKKOORD
GEM

VN-60831-1-B104.110 & VN-60831-1-B104-CH02.110



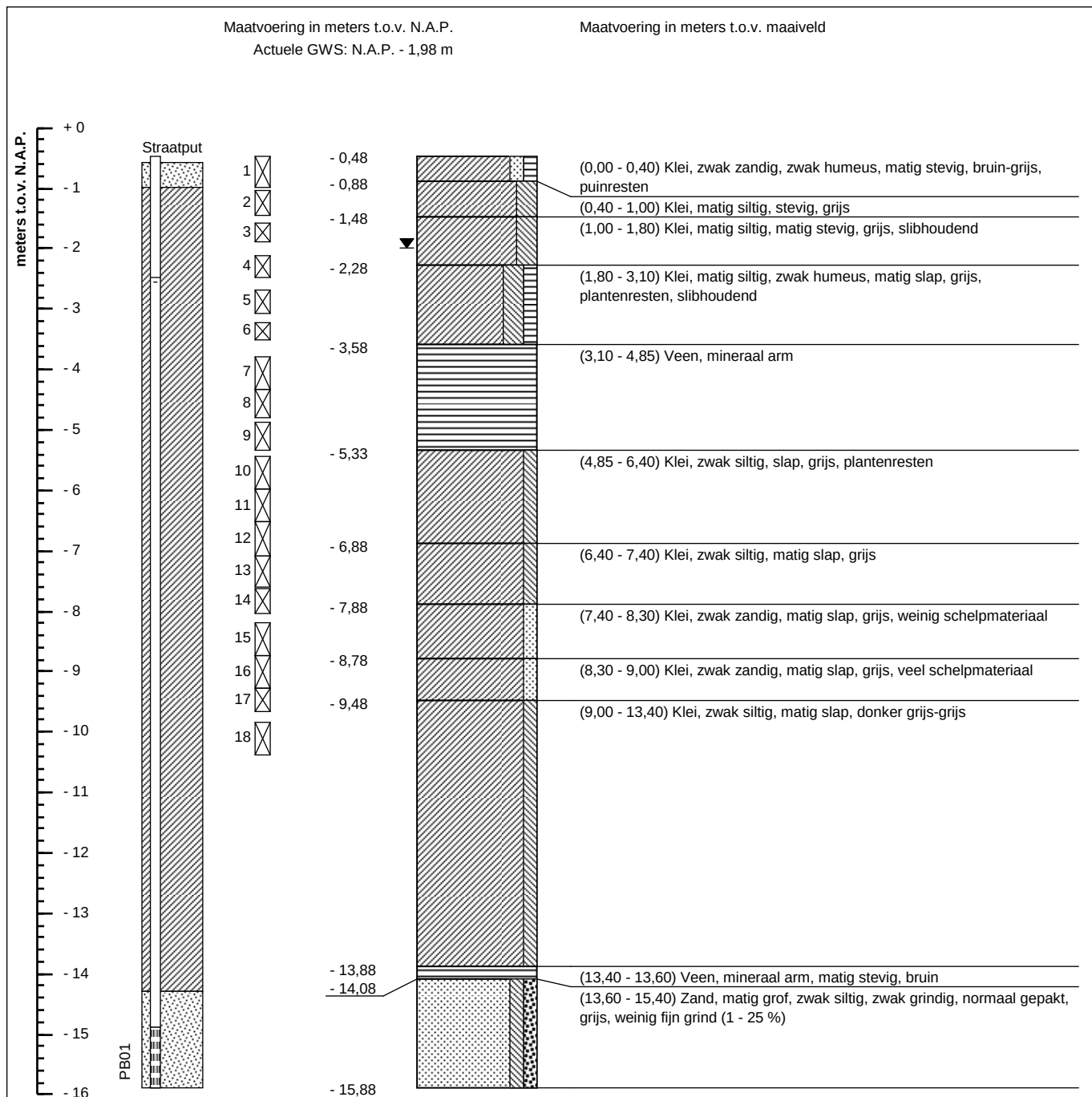
Boorstaat o.b.v. grondidentificatie in het veld (NEN 5104)

Boring conform NEN-EN-ISO 22475-1

Dijkonderzoek Leendert de Boerpolder	RD coördinatensysteem	Kaag
Stichting IJkdijk	X = 101 227,01	Pulsboring (lichte stelling)
 Wiertsema & Partners RAADGEVEND INGENIEURS	Y = 469 743,42	Boormeester: Jan Berends
	Uitgevoerd: 1-9-2014	Opdrachtnr.: 60831-1
	Blad 1 van 1	Boornummer: B105

AKKOORD
GEM

VN-60831-1-B105.110 & VN-60831-1-B105.110



Maatvoering t.o.v. N.A.P.

PB01: Peilbuis 1, bovenkant: - 0,48 m, actuele waterniv.: - 2,48 m, $E_c = 9999,00 \text{ mS/cm}$, $\text{pH} = 1,00$

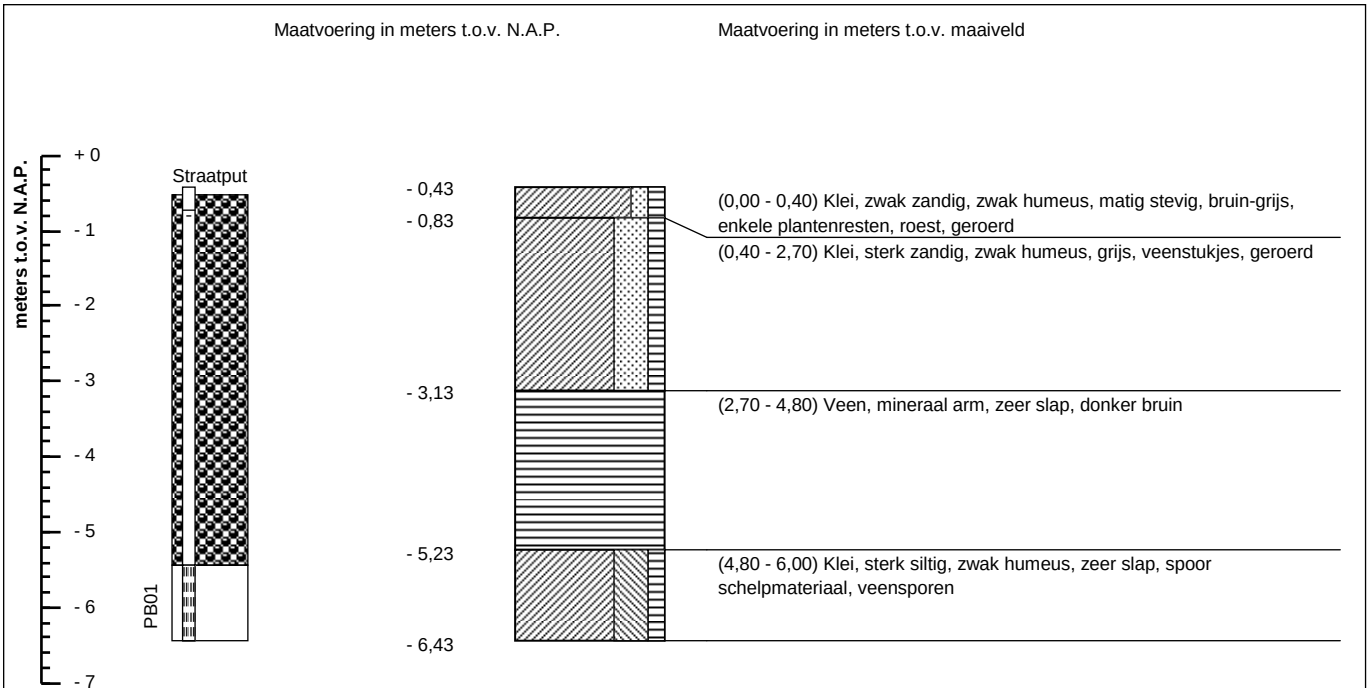
Boorstaat o.b.v. grondidentificatie in het veld (NEN 5104)

Boring conform NEN-EN-ISO 22475-1

Dijkonderzoek Leendert de Boerpolder	RD coördinatensysteem	Kaag
Stichting IJkdijk	X = 101 229,51	Pulsboring (lichte stelling)
 Wiertsema & Partners RAADGEVEND INGENIEURS	Y = 469 739,39	Boormeester: Jan Berends
	Uitgevoerd: 27-8-2014 t/m 28-8-2014	Opdrachtnr.: 60831-1
	Blad 1 van 1	Boornummer: B106

AKKOORD
GEM

VN-60831-1-B106.110 & VN-60831-1-B106.110



Maatvoering t.o.v. N.A.P.

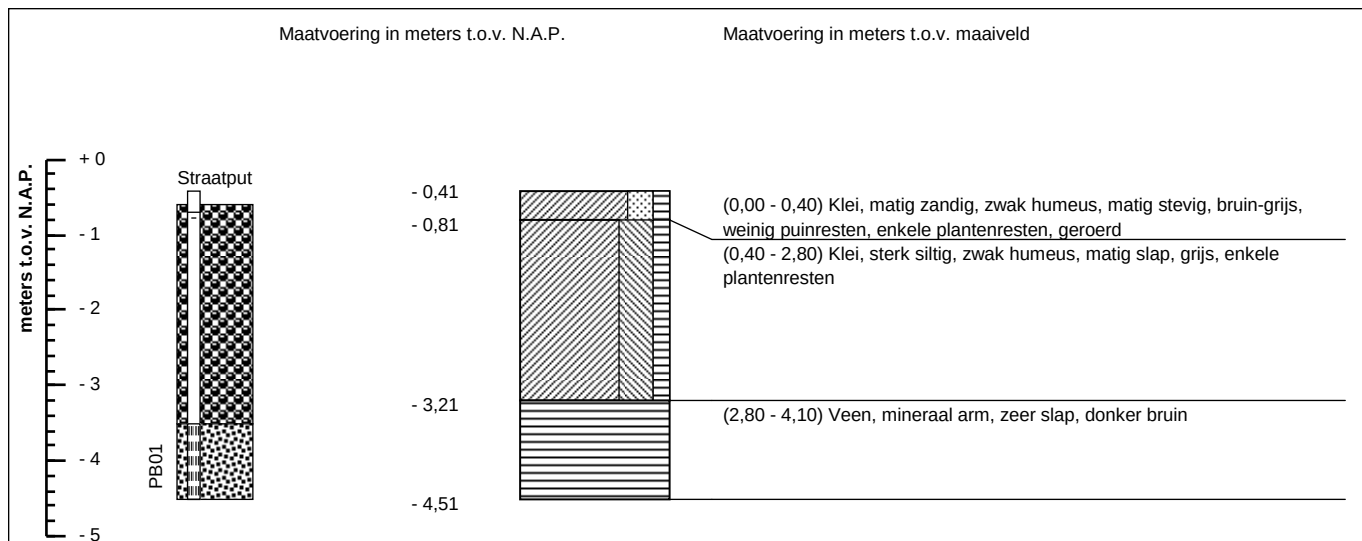
PB01: Peilbuis 1, bovenkant: - 0,43 m, actuele waterniv.: - 0,73 m

Boorstaat o.b.v. grondidentificatie in het veld (NEN 5104)

Boring conform NEN-EN-ISO 22475-1

Dijkonderzoek Leendert de Boerpolder	RD coördinatensysteem	Kaag	
Stichting IJkdijk	X = 101 232,29	Edelmanboring	
 Wiertsema & Partners RAADGEVEND INGENIEURS	Y = 469 740,56	Boormeester: Egbert Wierenga	
	Uitgevoerd: 4-9-2014	Opdrachtnr.: 60831-1	AKKOORD 
	Blad 1 van 1	Boornummer: PB-B	

VN-60831-1-B002.100 & VN-60831-1-B002_CH01.100



Maatvoering t.o.v. N.A.P.

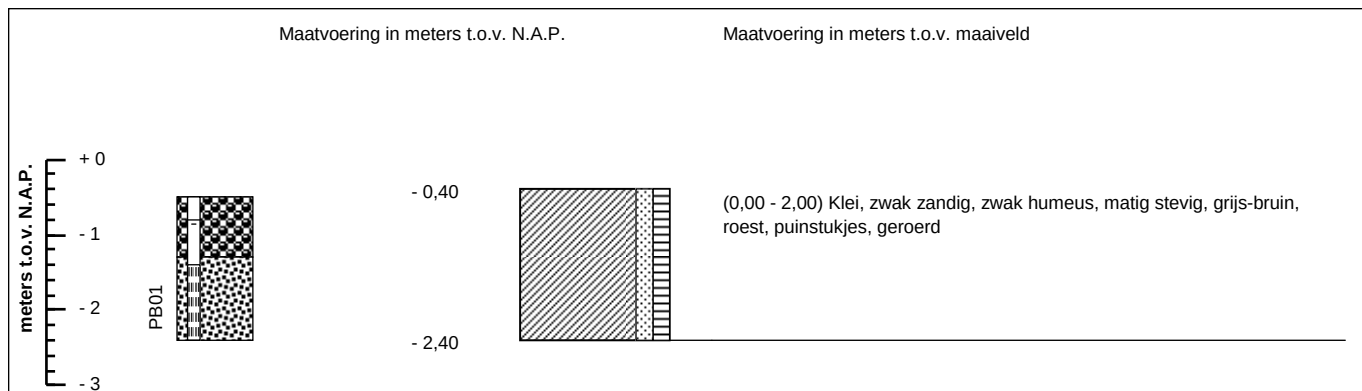
PB01: Peilbuis 1, bovenkant: - 0,41 m, actuele waterniv.: - 0,71 m

Boorstaat o.b.v. grondidentificatie in het veld (NEN 5104)

Boring conform NEN-EN-ISO 22475-1

Dijkonderzoek Leendert de Boerpolder	RD coördinatensysteem	Kaag	
Stichting IJkdijk	X = 101 226,98	Edelmanboring	
 Wiertsema & Partners RAADGEVEND INGENIEURS	Y = 469 737,81	Boormeester: Egbert Wierenga	
	Uitgevoerd: 4-9-2014	Opdrachtnr.: 60831-1	AKKOORD GEM
	Blad 1 van 1	Boornummer: PB-C	

VN-60831-1-B003.100 & VN-60831-1-B003.100



Maatvoering t.o.v. N.A.P.

PB01: Peilbuis 1, bovenkant: - 0,50 m, actuele waterniv.: - 0,80 m

Boorstaat o.b.v. grondidentificatie in het veld (NEN 5104)

Boring conform NEN-EN-ISO 22475-1

Dijkonderzoek Leendert de Boerpolder	RD coördinatensysteem	Kaag
Stichting IJkdijk	X = 101 224,48	Edelmanboring
 Wiertsema & Partners RAADGEVEND INGENIEURS	Y = 469 736,13	Boormeester: Egbert Wierenga
	Uitgevoerd: 4-9-2014	Opdrachtnr.: 60831-1
	Blad 1 van 1	Boornummer: PB-D

AKKOORD
GEM

VN-60831-1-B004.100 & VN-60831-1-B004-CH02.100

B CROSS-SECTION STANDPIPES

STANDPIPES 2014/2015
SECTION NORTH

NAP

DPK113

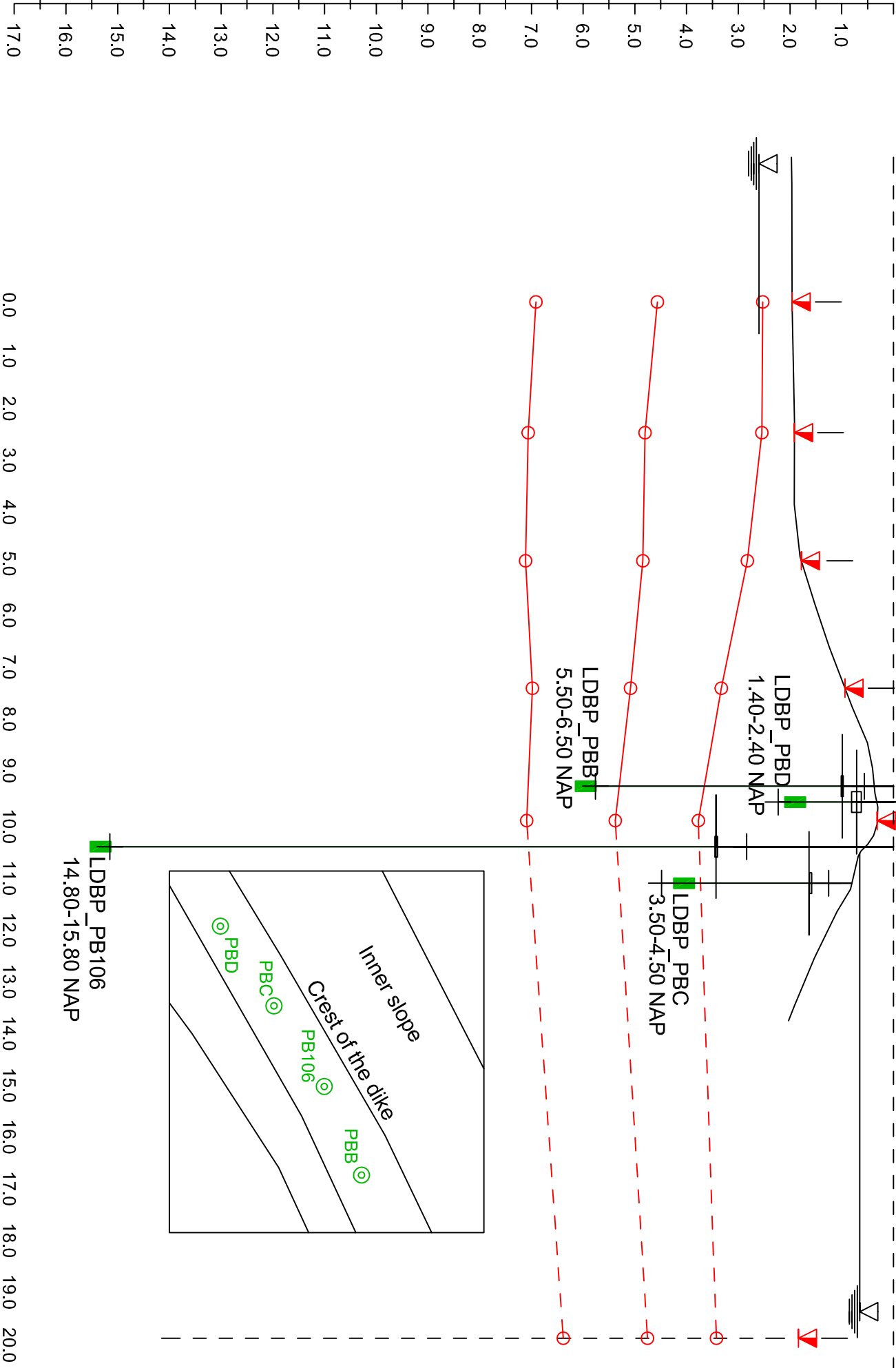
DPK114

DPK115

DPK116

DPK117

DPK118



C CROSS-SECTION SOUTH PIEZOMETERS

Section 5, South

NAP

DPK101

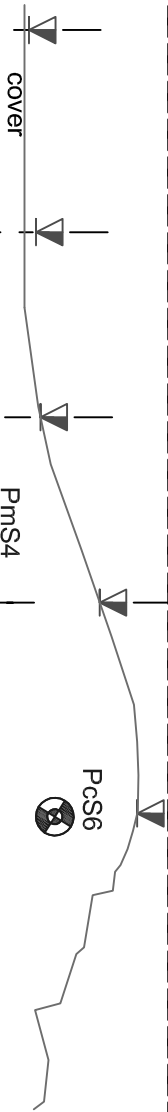
DPK102

DPK103

DPK104

DPK105

DPK106



PtS1

PmS4

PcS6

dyke material

PtS2

PmS5

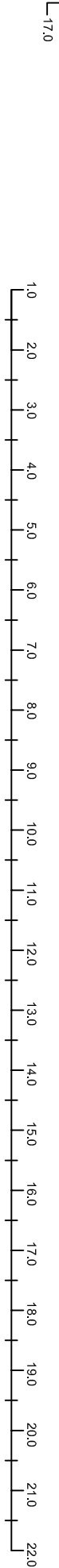
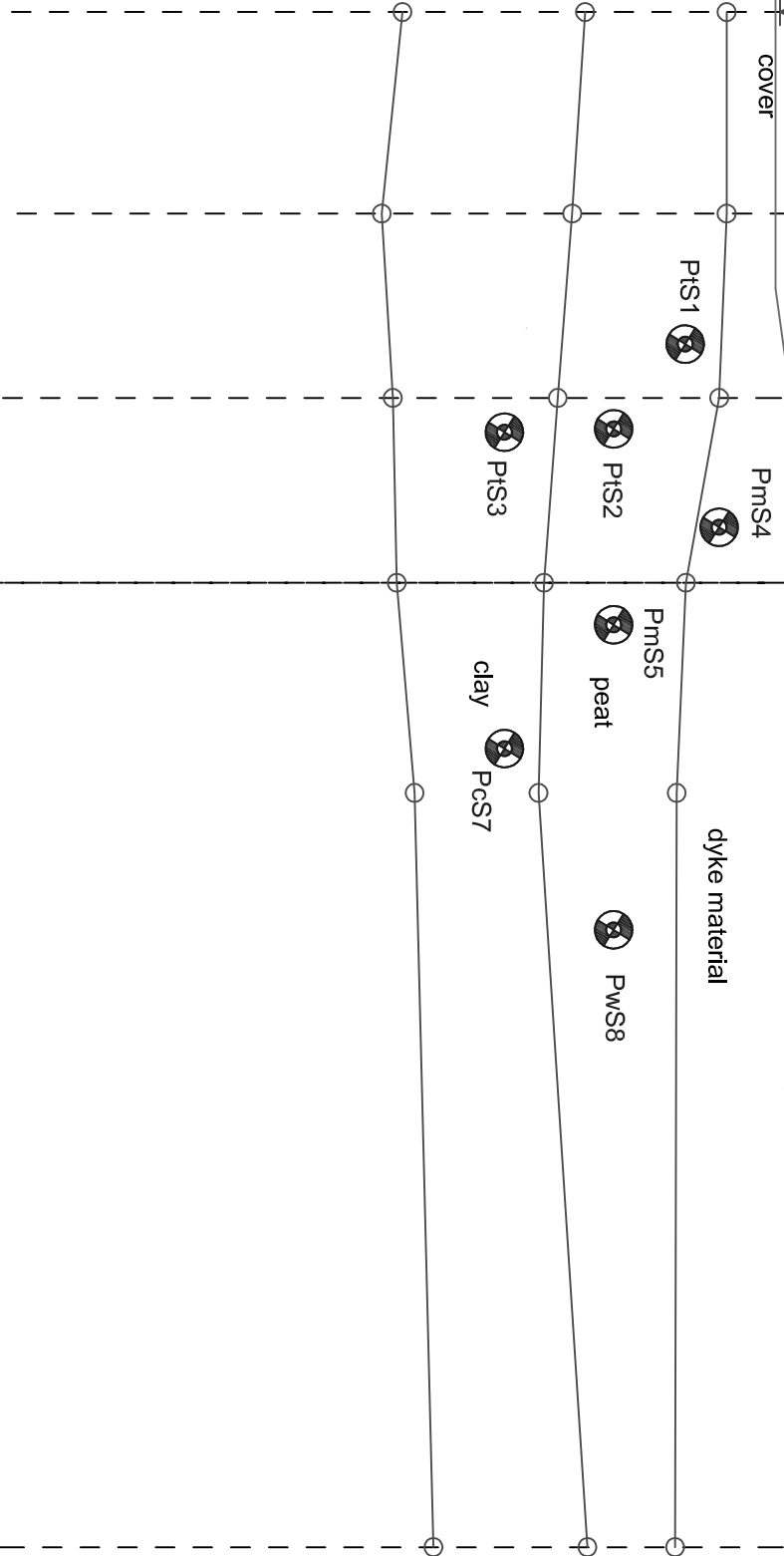
peat

PwS8

PtS3

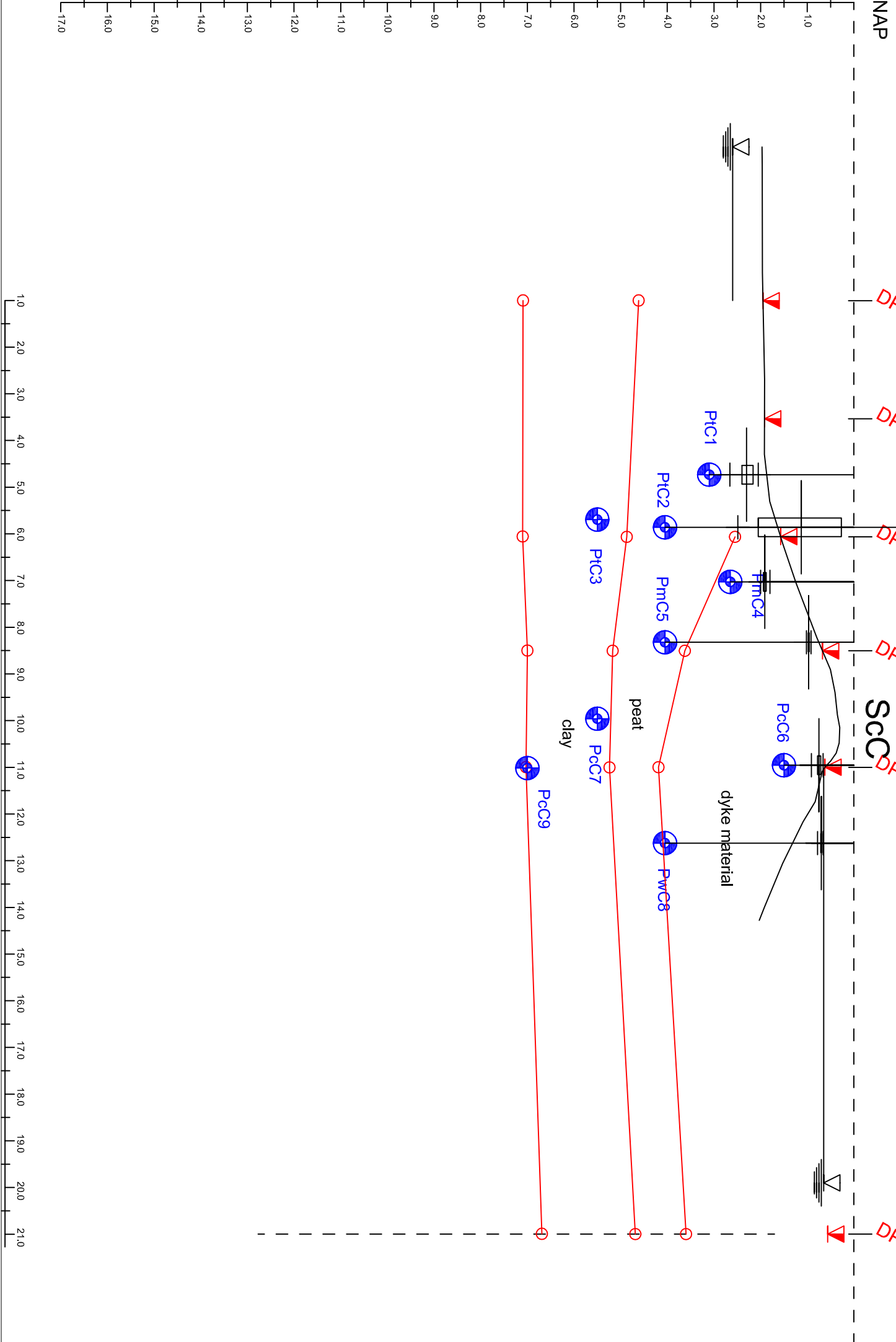
clay

PcS7



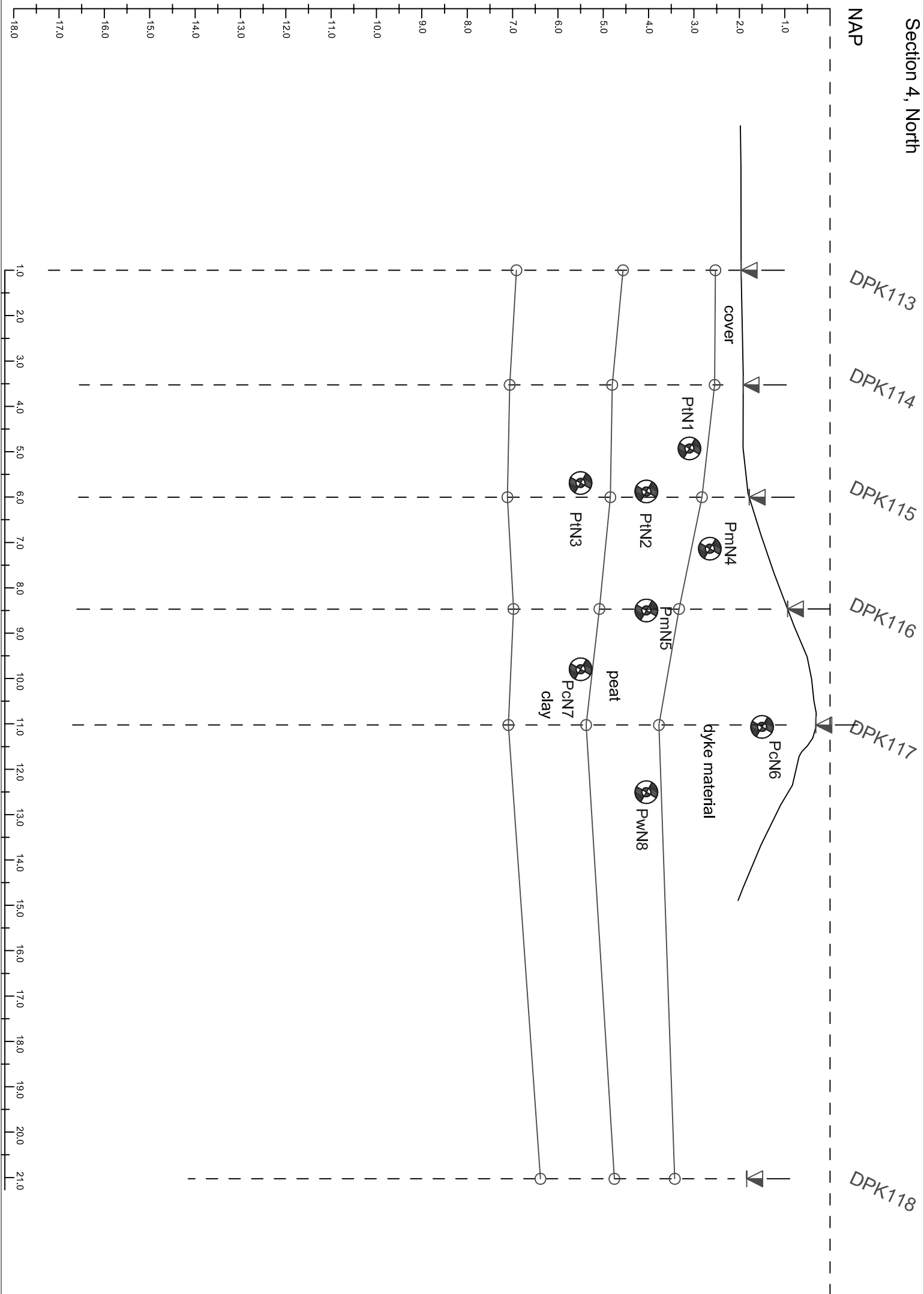
D CROSS-SECTION CENTRE PIEZOMETERS

Section in between 4-5

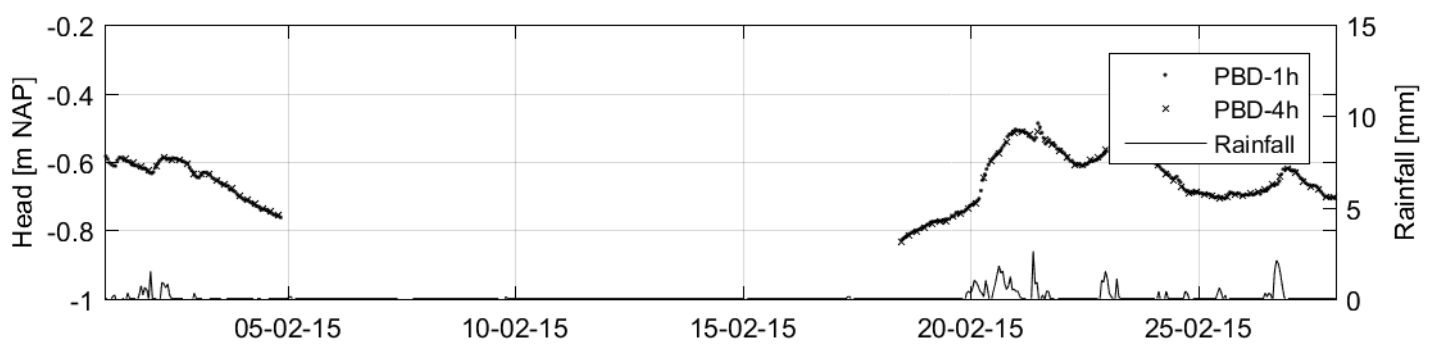
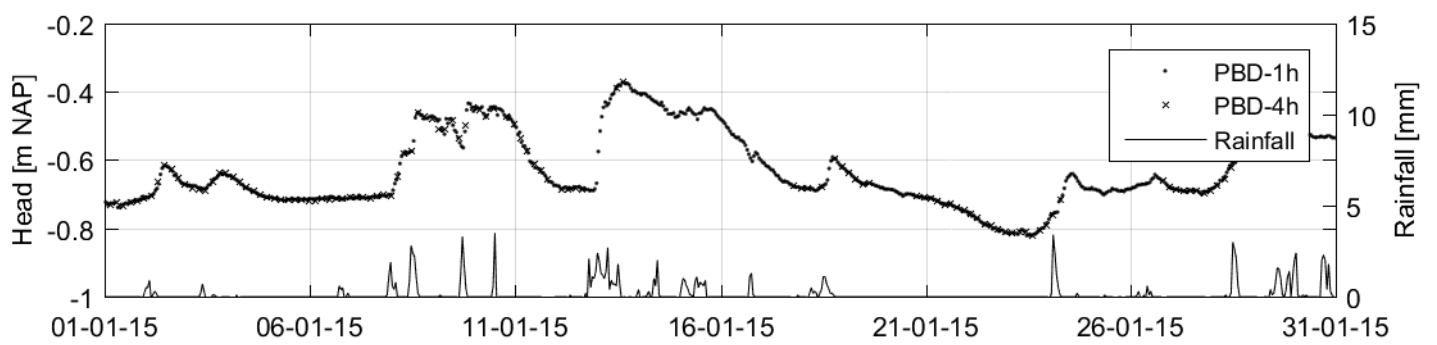
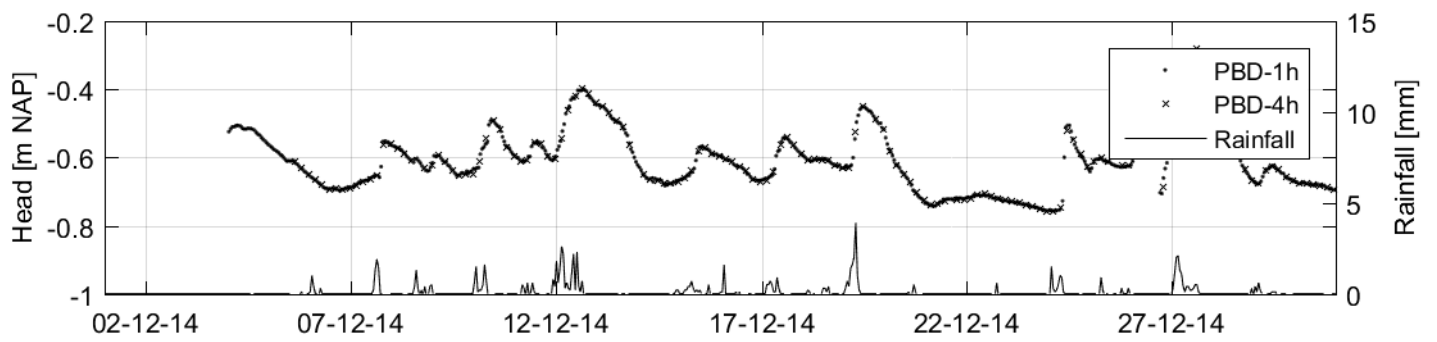
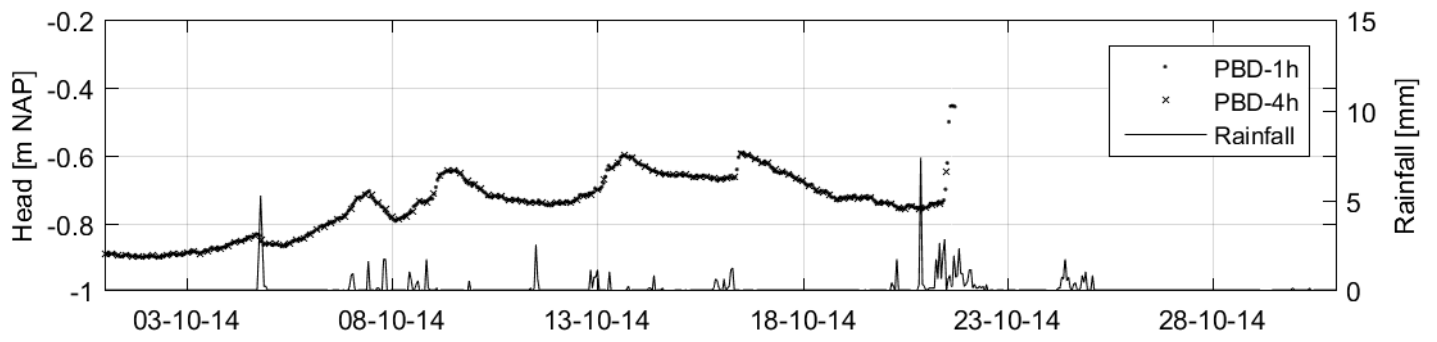
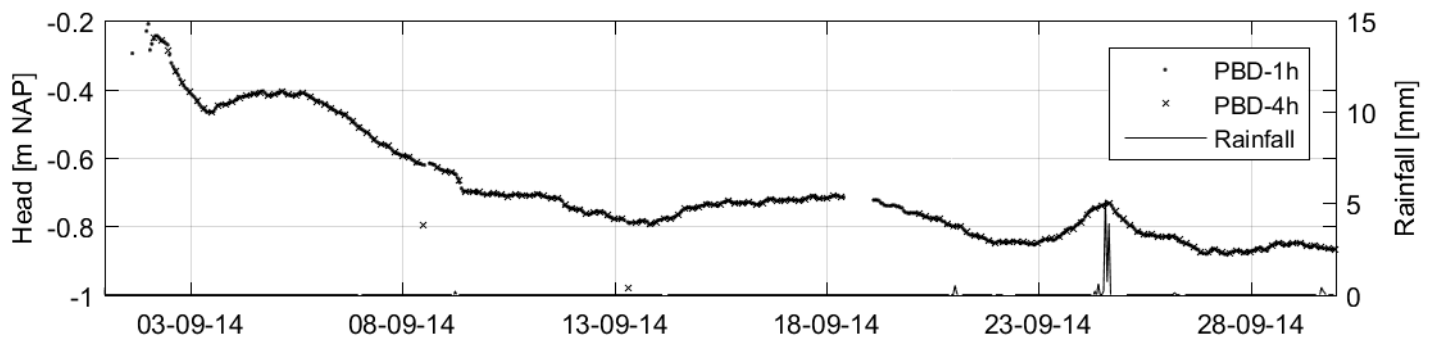


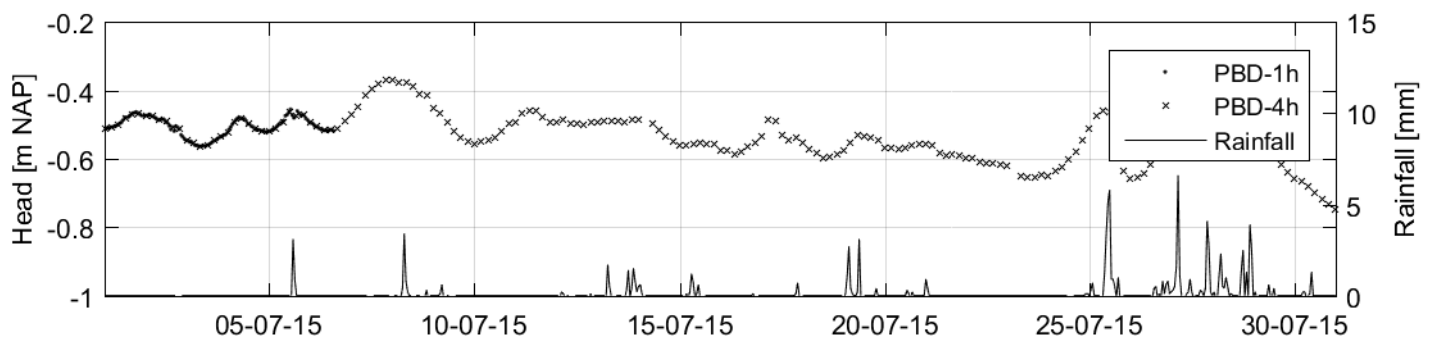
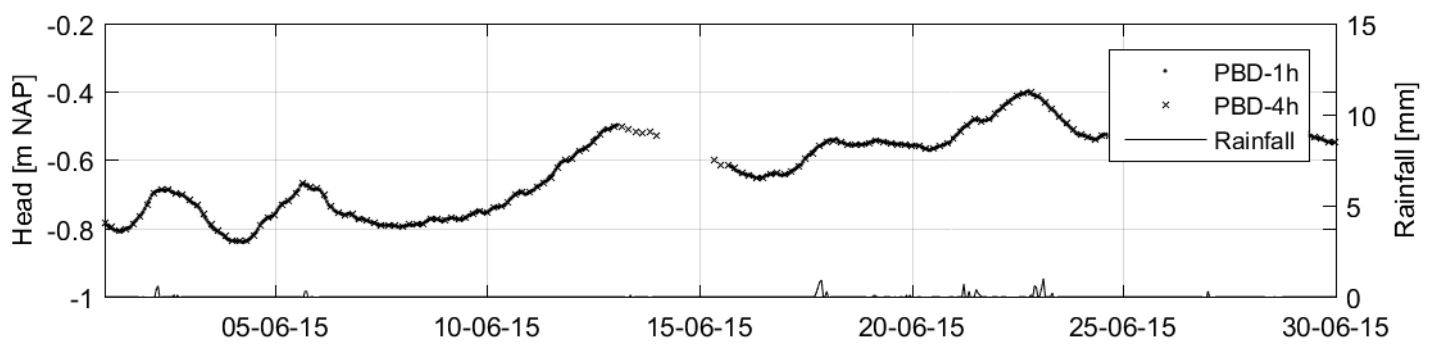
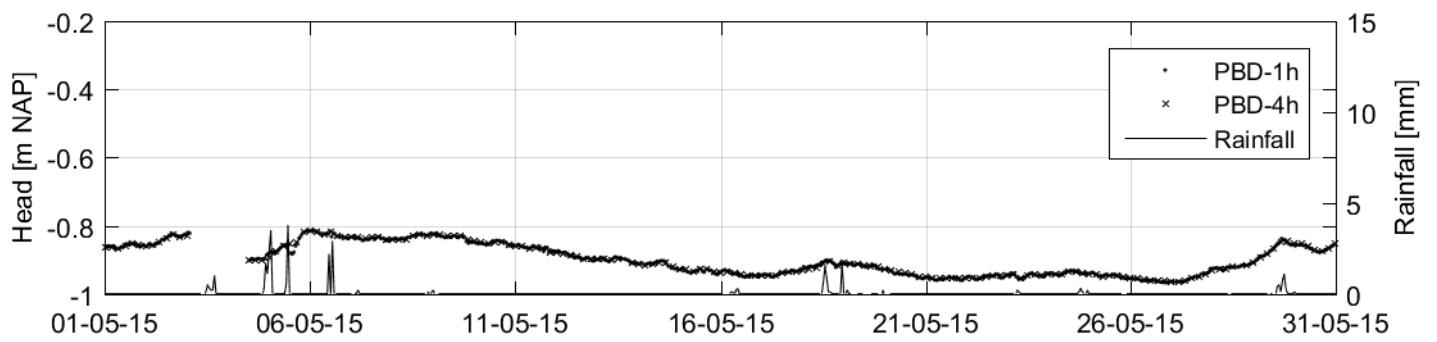
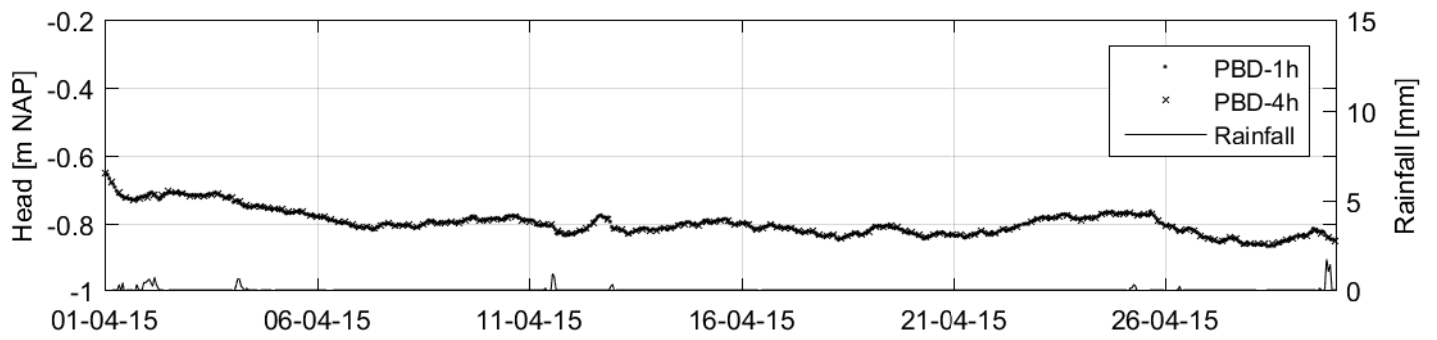
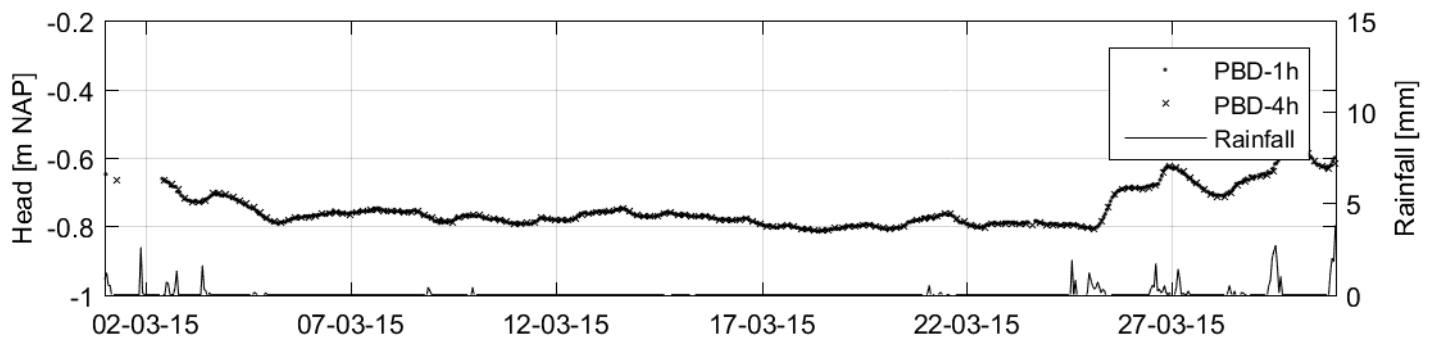
E CROSS-SECTION NORTH PIEZOMETERS

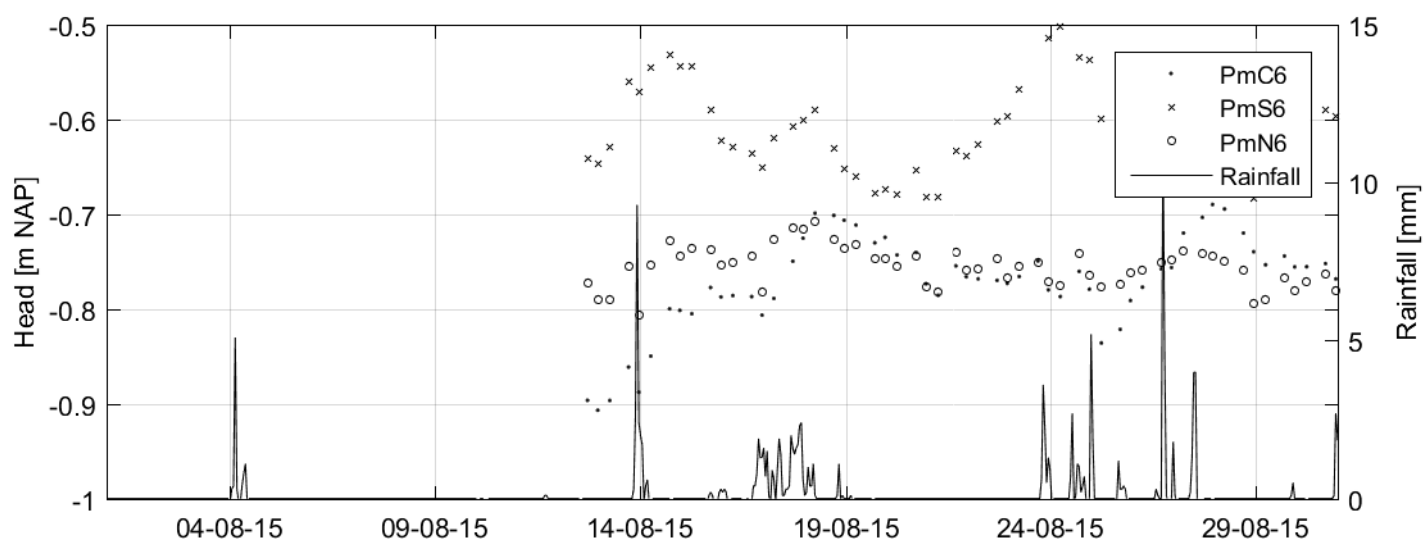
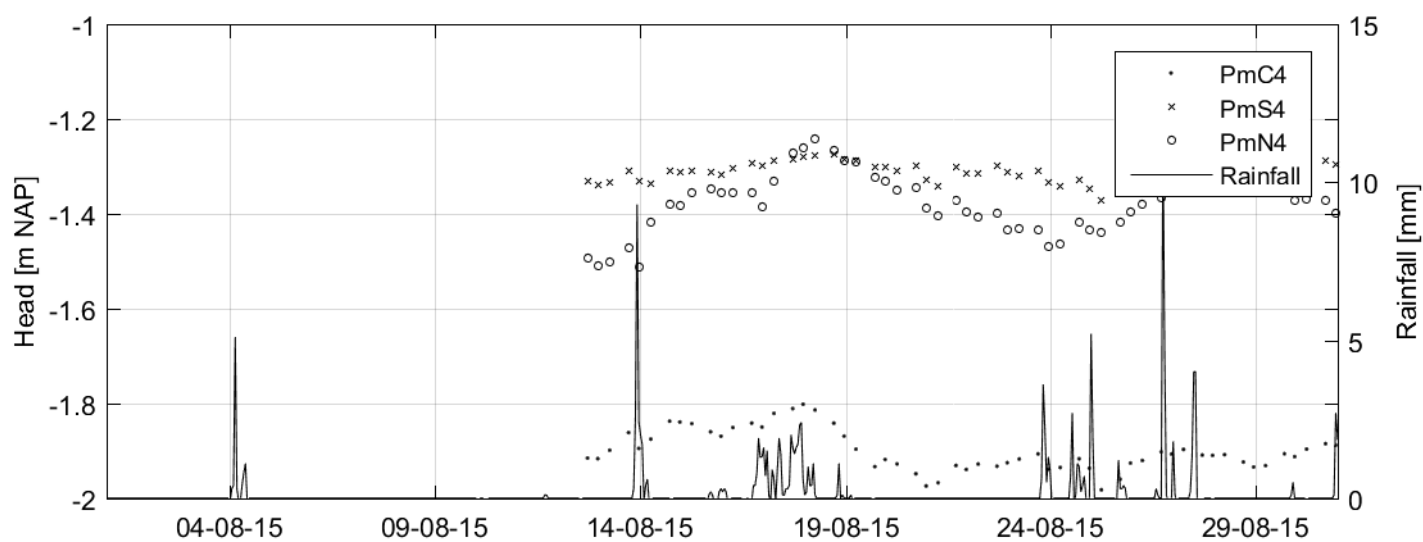
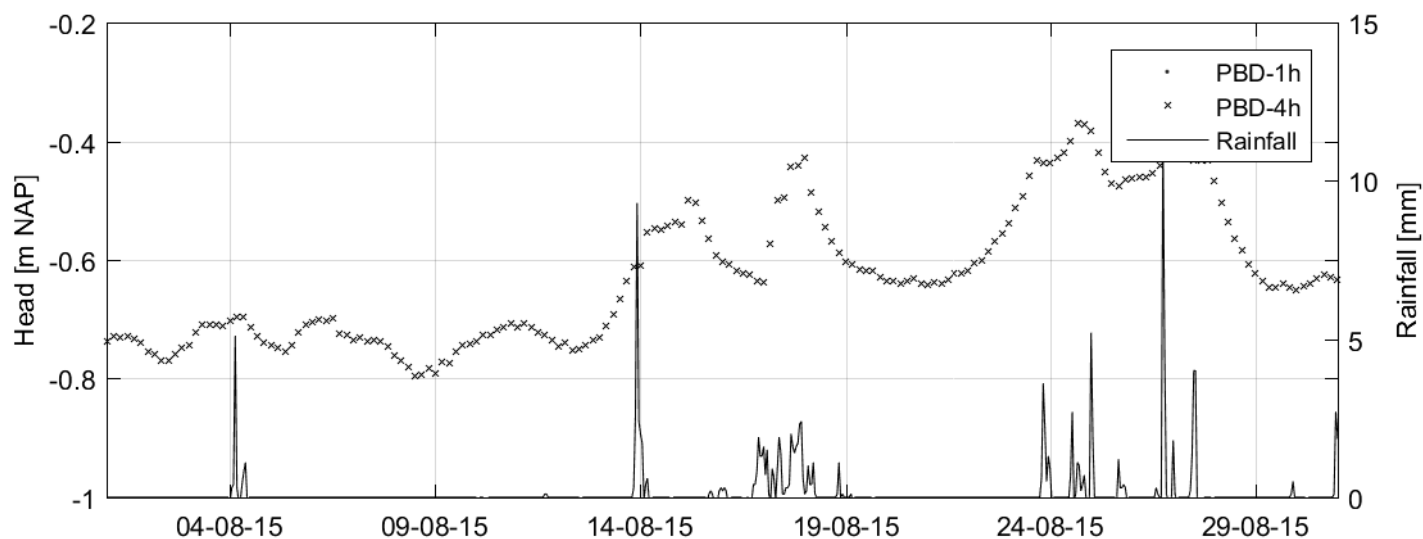
Section 4, North

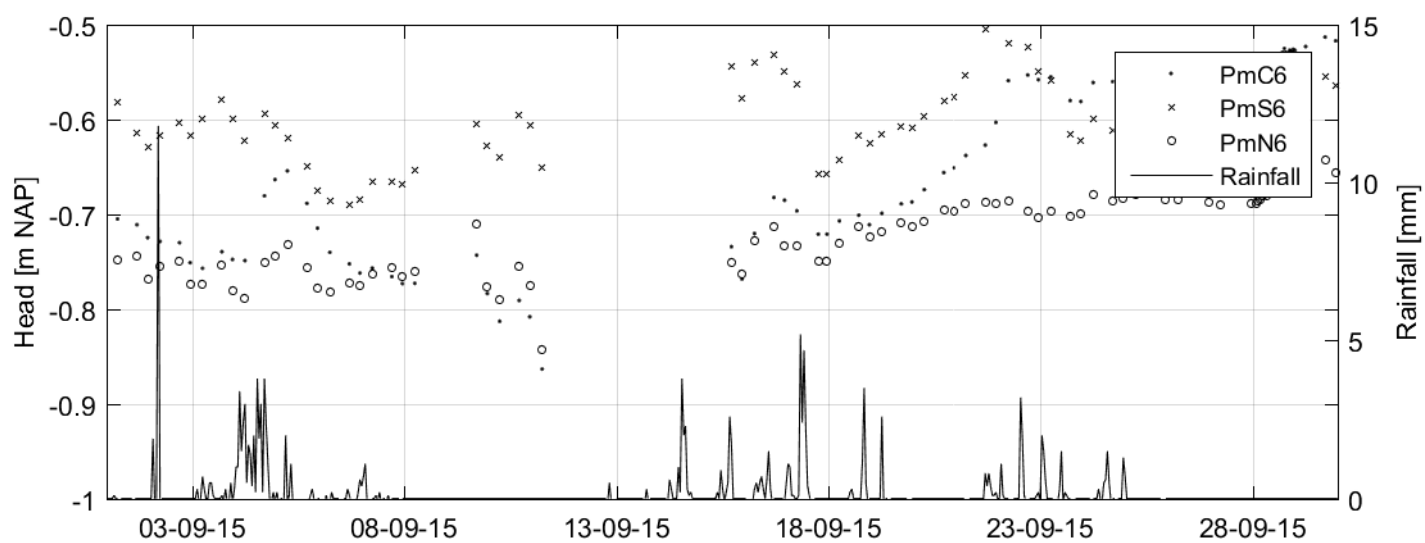
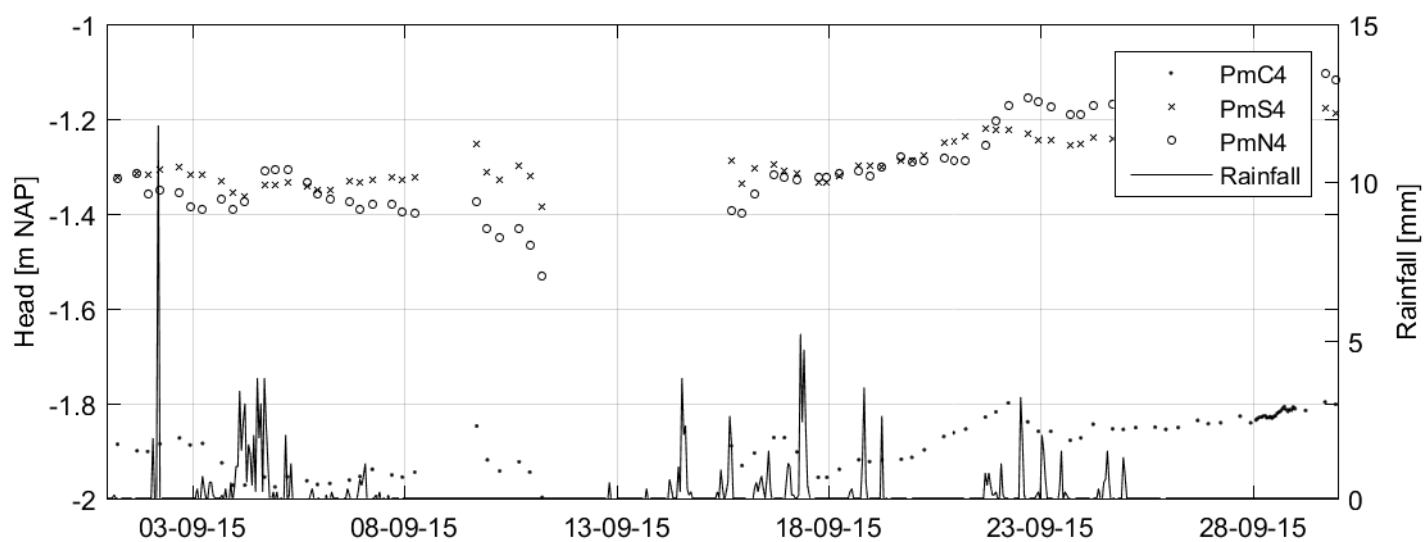
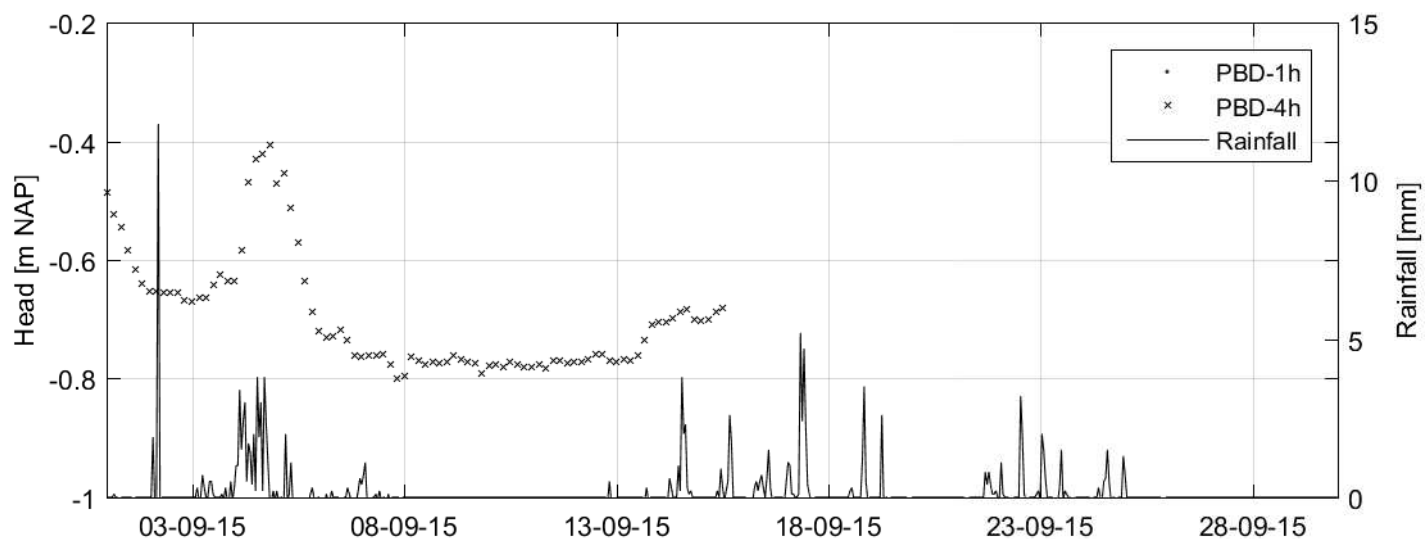


F PORE WATER PRESSURE OBSERVATIONS DIKE – RAINFALL









G PORE WATER PRESSURE OBSERVATIONS PEAT – RAINFALL

