Groundwater in the new intertidal area Perkpolder

Monitoring groundwater and soil of the new intertidal area Perkpolder

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Cover photo:	Perkpolder (Bron: http://www.viadrupsteen.nl/perkpolder/#/loc03/20 tot 30 jaar)

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Summary

Intertidal areas in the Netherlands suffer from divers pressures in the delta. The Western Scheldt has an open connection to the sea. This system is in use for the Port of Antwerp, for which dredging is required. Therefore, Rijkswaterstaat has to compensate natural areas, among which intertidal areas.

Area development Plan Perkpolder is one of these projects. In addition to the marina, houses and golf course, a 75 hectare intertidal area is created. Of these 75 ha, 40 ha is a compensation for the second dredging of the Western Scheldt. The remaining 35 ha is for the "Natuurpakket Westerschelde", a project for the development of 600 ha of intertidal flats and salt marshes. This research focusses on describing the current situation of the groundwater and soil chemistry of the intertidal area at Perkpolder. The groundwater and soil chemistry are of high importance for the development of salt marshes because they are the most important conditions for vegetation settlement. Perkpolder's intertidal area has been given back to nature only recently (less than one year before this research), this research focusses on the response of the area to the presence of saline water.

The research question is:

- What are the current properties of the subsurface and groundwater system of the tidal restoration area Perkpolder?

The sub questions used to answer this question are:

- What is the current surface level of the intertidal basin Perkpolder?
- At what depth is the fresh-saline interface of the ground water?
- What are the soil properties of the soil layers found in the area during measurements?
- What is the current situation of the soil chemistry (Eh, salinity and oxygen content) of the intertidal area?
- Are there differences between the measuring points relating to the distance to the channels?

Soil water samples were taken with MacroRhizons (micro filters) and analysed on oxygen content, redox potential and salinity. Soil samples were taken while placing piezometers. The soil samples were analysed on the particle size and organic matter. The piezometers function was to register the pressure head in different groundwater layers.

The intertidal area was previously used for agriculture. The soil and groundwater was a fresh water system with saline groundwater in the deeper layers. Parts of the area suffered from saline seepage. The soil becomes completely saline again now, but the origin of the present salt in deeper layers is not determined. It could be that this is still present from floods in the Holocene.

The measurements and analysis provided data of the groundwater and subsurface. This resulted in the conclusion that the system is already influenced by the saline water, but mostly in the top layer. The influences on the deeper layers are not proven with this research and the measured parameters show no clear relation with the distance to the channel, but it seems to be depending on the soil type. These soil layers are mostly formed during the Holocene and these layers have a low permeability.

The newly settled sediment will have an impact on the groundwater system. This can be a topic for further research. This can also focus on the benthos and soil properties related to plant settlement. A thicker sediment layer can be analysed on its hydraulic properties and impact on the system.

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1. Introduction

The projects Tidal Restoration Rammegors and Plan Perkpolder are both tidal restoration projects. These projects both comprise the development of an intertidal area, but there are differences between them. Rammegors has been part of the Eastern Scheldt until the 1970's, then at the east side the Scheldt-Rhine dike was constructed and at the west side the Krabbenkreekdam. This project from Rijkswaterstaat covers the restoration of the tidal influence in this area by constructing a culvert in the Krabbenkreekdam. The acreage of intertidal area and salt marsh increases this way.
The Plan Perkpolder covers an area between Perkpolder and Walsoorden, in Zeeuws Vlaanderen. The plan is an integrated area development plan, consisting of plans for a natural area, housing and recreation. The natural area is an intertidal flat, in which channels have already been dug. Both areas are indicated on the maps below in Figure 1.

First, a description of Perkpolder will be given, then similarities between Rammegors and Perkpolder are explained and problems are described. After this, the research questions are listed.

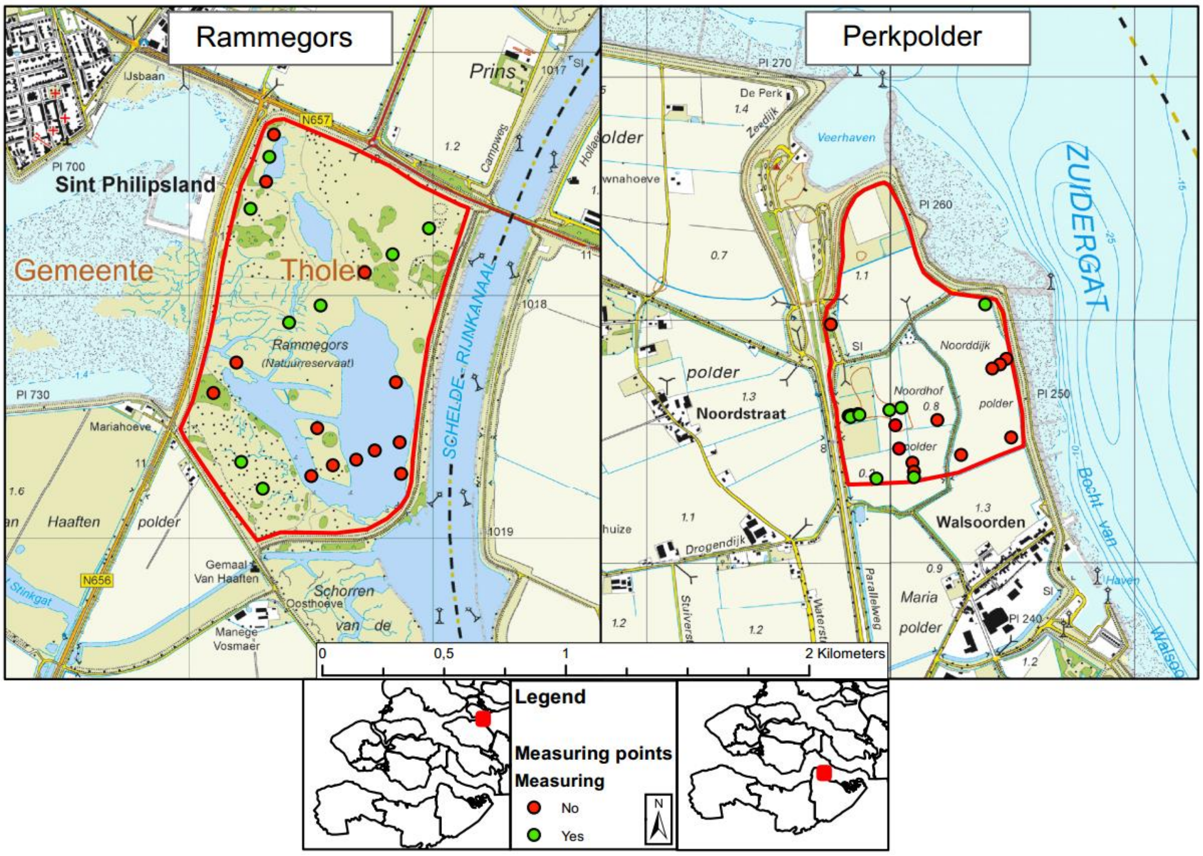

Figure 1 Map with the project areas and the measuring points from The Royal NIOZ.

1.1 Estuarine nature

The nature in estuaries has decreased over the past decades because of the demand for more space for agriculture, industry and urbanisation. Safety also plays a large role in the development of the coastline and surrounding area on both sides. Water and land are separated by a dune or dike at many places. The natural situation has given way to coastal defence. According to Van Buuren & Warner (2010) this is partly due to the anthropocentric attitude of The Netherlands. Men want to control the situation while embracing nature and working in an ecocentric way could be more efficient (Van Buuren & Warner, 2010). This means that men have to use nature and think with a focus on nature.

1.2 Perkpolder

Plan Perkpolder is an integrated area development plan in which nature, housing and recreation are combined. Until 2003 the ferry crossing the Western Scheldt sailed between Kruiningen and Perkpolder. This was one of the connections between Zeeuws Vlaanderen and the rest of Zeeland. This connection was terminated when the Western Scheldt Tunnel was opened. The former port will be reconstructed into a marina, houses will be built and a golf course will be constructed. Apart from that, an intertidal flat was constructed. This is all done to improve the attractiveness of the area. This is needed because of the decreasing number of visitors and employment.

The development of new nature is done in two agricultural polders South of the former port. Figure 3 shows the four parts of the area development plan, in which area “D” is the intertidal area. On June 25th 2015, the dike was broken to let the first water flow into the area. With this, the tidal influence in an area of 75 hectares is restored. 40 hectares of this area are for the compensation of the second dredging of the Western Scheldt. 35 hectares are for the “Natuurpakket Westerschelde”, which is a project for the development of 600 hectares of intertidal flat and salt marsh. (Speets & Van Ginkel, 2009)

Figure 2 Overview of Plan Perkpolder, ‘A’ indicates housing, ‘B’ is the former port which will become a marina, ‘C’ is where the golf course will be and area ‘D’ is the intertidal flat (Speets & Van Ginkel, 2009).

1.3 Similarities and differences

Both Rammegors and Perkpolder are areas in which the tidal influence is restored after a long time of being closed off by dikes. The recovery of the ecosystems will be monitored in Rammegors for at least two years and in Perkpolder for five years. Both biotic and abiotic parameters will be measured. The vegetation, groundwater and soil properties will be monitored over time and will vary between the areas because of the height. The height determines the inundation time per tidal cycle. With the inundation time, the influence of the

saline water on the soil changes. Both areas are connected to the sea again in 2015. Saline water enters the areas again and has an influence on the soil, groundwater and vegetation.
The Eastern Scheldt covers an area of about 350 km^2 of which one third is above mean low tide. These mudflats and salt marshes decreased in surface area because of the imbalance in sedimentation and erosion. The net transport of sediment is from the mudflats towards the channels, so the recovery of intertidal area is necessary. The discharge at the mouth of the Eastern Scheldt decreased with the completion of the Eastern Scheldt storm surge barrier. This also decreased the flow velocities and therefore the sediment transport. (Provincie Zeeland, 2009)

The Western Scheldt is an estuary with an open connection to the sea. This open connection facilitates the sediment transport. The development plan Perkpolder uses this sediment transport for the development of the intertidal flat. When opened, the to layer was the agricultural soil with the artificial channels to stimulate flow and sedimentation. Sedimentation will start rapidly and continue in high rates until the system reaches its equilibrium phase. The transport decreases when Perkpolder is approaching the equilibrium, but will never be completely stable since the environment will change by for instance the growth of plants. Less than one year after opening the area, in some places there is already 25 cm of sediment (Van IJzerloo, 2016).

1.4 Problem description

The area at Perkpolder is an intertidal area which has recently been given back to nature. This research focusses on the response of the area on the presence of saline water at different distances to the channels. These channels are manmade and are probably too large, compared to a natural situation. The influence on the groundwater system will also be determined by the (hydraulic) soil properties and soil chemistry.

This research focusses on describing the current situation of the groundwater and soil chemistry in the intertidal area of Perkpolder. The ground water and soil chemistry are of high importance for the development of salt marshes. These environmental parameters are influencing the settlement of vegetation in the area. Reconnecting the area with the sea lets saline water flow into it and change the ground water system, which had a fresh water lens before. Halophytes would not be able to settle here under fresh circumstances, but they can start growing on a saline soil.
When the ground water becomes more saline, salt resistant species get the chance to establish in this area. The presence of vegetation will stimulate the process of sedimentation and soil formation. This increases the function in coastal defence of the area.

Research question:

> What are the current properties of the subsurface and groundwater system of the tidal restoration area Perkpolder?

Sub-questions:

- What is the current surface level of the intertidal basin Perkpolder?
- At what depth is the fresh-saline interface of the ground water?
- What are the soil properties of the soil layers found in the area during measurements?
- What is the current situation of the soil chemistry (Eh, salinity and oxygen content) of the intertidal area?
- Are there differences between the measuring points relating to the distance to the channels?

2. Theoretical framework

This theoretical framework provides more background information of the intertidal area and research to the area. First intertidal areas are described, after which a description of salinization and groundwater are given.

2.1 Intertidal areas

An intertidal area is an area which is flooded at high tide and falls dry at low tide. The surface level of the area lies between the average low water level and the average high water level. An intertidal flat often has channels through which the water flows in and out of the area and it is a dynamic area, because of sedimentation and erosion. (Oranjewoud & Soresma, 2007)

The Southwestern Delta is a unique area. In the major part, tidal influence is still present and this creates great opportunities for nature restoration. Nature restoration is necessary because the ecosystem is not a healthy system at this moment, although it is very diverse. The nature in the delta suffers from pressure of agriculture, industry and urbanisation. The most important and largest pressure on the system is the Delta Works. In contrast to this pressure, it is the scene of many nature restoration projects, of which “Plan Perkpolder” is one. This is also an obligation from the European Union, within the framework of nature conservation and recovery Natura 2000 (Oranjewoud & Soresma, 2007). Intertidal areas can be created in several ways. Perkpolder is an area in which the tidal influence is restored, since it belonged to the sea in the distant past. The area was embanked in the past and is now returned to nature. At Perkpolder, a second dike is constructed first. Then a part (of 400 m) of the original dike was removed (Boersema, et al., 2015).

Intertidal areas play an important role in the estuarine ecosystem. They house several species of birds, benthos and halophytes permanently. Besides that, it is a spawning, feeding and resting place for fish and birds. Over time, the areas can develop morphologically, which means the shape of the mudflats and channels change. The number of channels will decrease, but their average size will increase. Sediment dynamics change due to the change in flow velocities and morphology. During this process, salt marshes can form. (Schaafstra & Goud, 2015)

Intertidal flats also have an important function in coastal defence. The mudflats and salt marshes absorb a large part of the wave energy, which would otherwise reach the dikes. The dikes get less stress this way and the land behind it is protected better. In addition to this the intertidal areas will grow with the sea level rise and climate change. The Drowned Land of Saeftinghe is one of the highest areas in Zeeland, because the mudflats and salt marshes were raised by sedimentation. Sedimentation is influenced by amongst other vegetation. Vegetation captures sediment, so from the moment vegetation is starting to grow in the area, sedimentation will increase. This natural process needs plenty of time and space, so sediment can settle in the area during a tidal cycle. (Chen, Wartel, & De Smedt, 2006)

2.2 Salinization

In the West of the Netherlands, where there are intertidal areas, the fresh water lens is generally shallow. Below this lens, a layer of brackish groundwater is present. Underneath this layer, completely saline ground water can be found. This is mostly sea water which is still in the subsurface from the sea level variations and flooding during the Holocene. (De Louw, 2013) When the sea level rose, the land flooded and saline water infiltrated in the soil. This water remained when the sea withdrew and a fresh water lens formed from precipitation and river discharge. The depth of the interface differs, but in coastal areas it is always less than 100 metres below NAP (Huisman, 2004).

The presence of saline water in an intertidal area can influence the salinity of the groundwater in the area itself and surrounding areas. The area around Perkpolder is in use for agriculture. This requires fresh ground- and surface water. The crops which are cultivated generally have a minimal salt tolerance, so the production can suffer from salinization. Saline water can flow upward causing salinization of surface waters, salinization of groundwater or directly affect crops in the dry season. (De Louw, 2013)

The hydrogeology in the Southwestern Delta is characterized by the presence of a cover layer from the Holocene. This cover layer consist predominately of peat, loam and clay with a low hydraulic conductivity. This low permeable layer covers the sandy aquifer below. The REGIS model (2015) shows that only the cover layer and first aquifer are important for the saline seepage. The figure below (figure 3) shows the thickness of the fresh water lens in the area in centimetres.

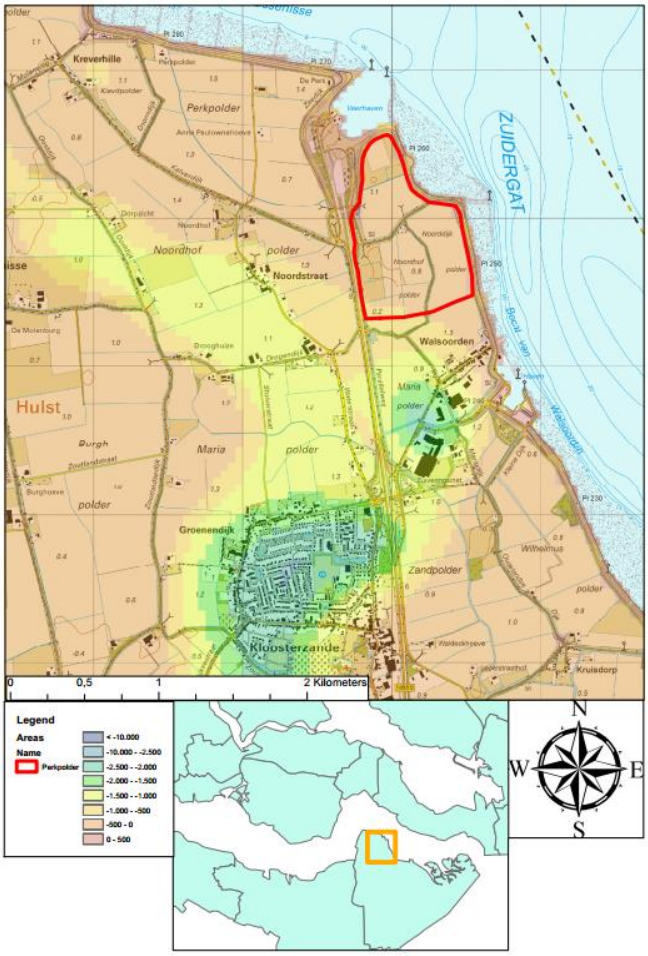

Figure 3 Depth of the fresh-saline interface of the groundwater in centimetres below surface level (REGISII, 2015).

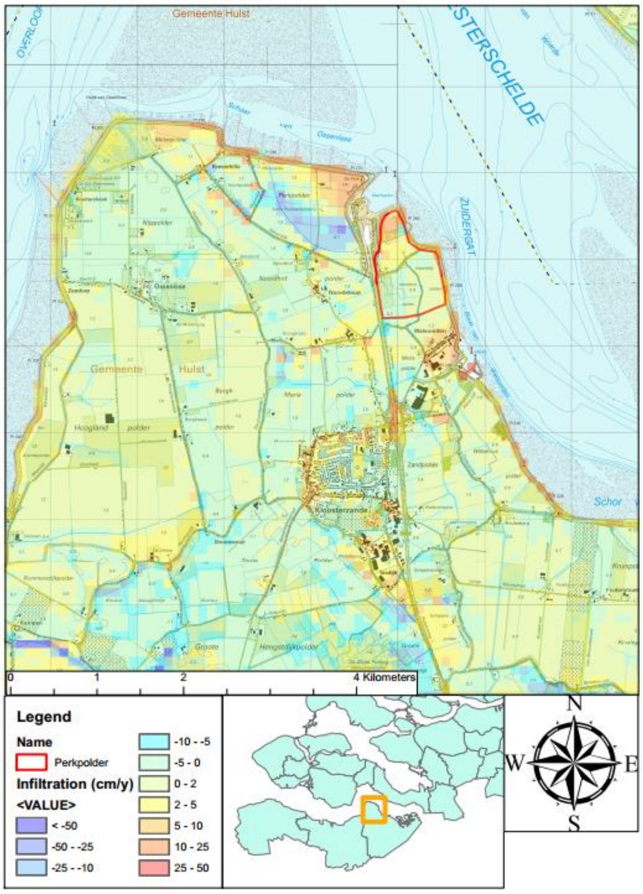

Figure 4 Infiltration in the area around Perkpolder and Kloosterzande, negative values indicate seepage (REGISII, 2015).

In coastal regions with an elevation below mean sea level, saline groundwater can reach to the surface by the pressure of the sea water. A quarter of The Netherlands is below sea level and therefore a major part of the country has the risk of salinization. Sea water infiltrated into the groundwater system during the Holocene. This saline water is still present in the subsurface, often below a layer of fresh groundwater, in some cases below a freshwater lens. By the pressure causing seepage, this saline water can locally reach up to the surface level. (De Louw, et al., 2015)

The polders at Perkpolder were areas with saline seepage. Nowadays, the returning tide is expected to increase the salinity level in the phreatic groundwater. This probably influences the decay of the remains of vegetation and the settlement of new intertidal vegetation. Settlement of vegetation has an impact on the sediment balance of the system. Sediment building up creates a new soil layer with its own properties, which will change if the soil formation process is going on. (College of Tropical Agriculture and Human Resources, 2007)

The pressure head in the top aquifer is expected to rise when the dike is moved further inland to create an intertidal area (Boersema, et al., 2015). At Perkpolder, a seepage system was put in place to protect the fresh water lens in the surrounding area. The system will be monitored to keep track of its functioning and to see if the groundwater system reacts as expected. This will be done predominately in the first three years, because then the biggest changes in the system are expected.

3. Method

This chapter will cover an explanation of the methods used in this research. First, a general description of the process will be given. This will be followed by a description of the field work and data processing and analysis.

3.1 Process description

Background information about both study areas was collected first. This was selected, processed and made available in GIS-maps, tables and graphs. With collecting and processing data an impression of the study areas was formed. Following, the areas were visited to check the data and get a better understanding of them. Resulting from the research question and based on the collected data and the visit, a monitoring plan was drawn up.

The research focused on Perkpolder. In this area, the salinity profile of the soil and groundwater is measured on seven different measuring points with different distances to the channels in the area. By placing piezometers (and using already present piezometers) the phreatic groundwater table was measured. Soil water was sampled with MacroRhizons. The measuring points used are shown in the map in paragraph 3.4. Measurements were done in the syringes in the field to do the measurements as soon as possible after sampling. The necessity of this was confirmed by the analysis of the oxygen content of the samples in the syringes as described in Appendix 2.

3.2 Measuring point selection

Both Royal NIOZ and Deltaes already have measuring points in Perkpolder. Measuring points from Royal NIOZ are named pk#, the ones from Deltares are named T#. From the measuring points of Royal NIOZ and Deltares, a choice has been made to reduce the number of points for this research. This is done mainly because of the limited timeframe in which the research had to be completed. The locations in Perkpolder were chosen in such a way that within one set of points, only the distance to the channel was variable.

The table below gives information about these locations. In addition to this table, these points are also plotted on a map (Appendix 1 and figure 6).

Table 1 Measuring points Perkpolder, of which coordinates and a map can be found in Appendix 1.

Measuring point	Surface level (T0 height map) (mNAP)	Surface level (T1 height map) (mNAP)	Distance to channel (m)	Sediment depth (cm)	Distance to dike (m)
T2	-0,29	-0,07	2	-	100
T4	-0,39	-0,27	10	-	250
T1	0,34	0,50	40	-	50
pk15	0,37	0,35	80	4,7	40
T3	0,57	0,72	40	-	200
pk5	0,67	0,70	45	9,9	10
pk6	0,61	0,73	65	4,6	15

The distance to the dike is determined using ArcGIS. The groundwater in the dike will have an influence on the groundwater on the measuring points close to it. For this research, the assumption is made that this influence is only minor compared to the impact of the channel.

In the report, measuring points are labelled with their location. In chapter 4, in figures where the depth is also indicated, the coding "Location"_"Depth" is used. This results in names of samples like pk5_25, which means the sample is from location pk5 at a depth of 25 cm.

3.3 Measuring point set up and sampling

On each measuring point a piezometer and MacroRhizons were installed at 25, 50, 75, 100, 125 and 150 cm depth to sample the soil moisture. The 15 cm deep Rhizons was taken to and from the field each time. This was done according to the procedures in appendices 9 and 10. Samples were taken and measured according to the procedure in appendix 11. These procedures are made during this research using manuals delivered with the equipment, own experience and expert advice.

Measurements were done with the following devices:

- Oxygen content:
    - WTW Oxi 320 meter
    - WTW CellOx 325 sensor
- Redox potential:
    - WTW pH 330 meter
    - WTW SensiTix 41 sensor
- Salinity:
    - WTW Cond 3210 meter
    - WTW TetraCon 325 sensor

The measurements were done at three different moments (the 12th, 22nd and 28th of April) at each location at each depth. The shallowest samples, at 15 cm depth, were only taken twice. Sampling was done with Terumo Luer Lock Syringes of 50 ml. Their influence on the oxygen and redox measurements was tested, which is explained in Appendix 2.
Soil samples were taken from the auger directly. The particle size was determined by sieving the sample with a 1 mm sieve. The percentage larger and smaller than 1 mm was calculated from the weight. Then, the samples were analysed with the Malvern Mastersizer 2000 to find the particle size distribution of the particles smaller than 1 mm.
The soil samples were collected at three locations and analysed on particle size and organic matter. The particle size analysis was done with the Malvern Mastersizer 2000 at Royal NIOZ Yerseke. This device is calibrated periodically to ensure the quality of the analysis. The organic matter analysis was done at the HZ University of Applied Sciences. Samples are kept separate from other (soil) samples to make sure no pollution could take place. Incineration was done at 560 degrees Celsius for at least three hours.

3.4 Data processing

The data from the water quality measurements will be collected in tables. Data from the measurements are presented in tables (Appendix 5) and graphs in Chapter 4.1. The averages will be plot in graphs in which the relation between the depth and oxygen content, redox potential or salinity can be seen.

Measurements on the soil samples resulted in an output from the Malvern software. This table contains all data collected from the sample. It is plotted in a chart with the SD10, SD50 and SD90 to give a clear overview of the data. Apart from that, the grain sizes were plotted in a column chart to easily compare the samples and the fraction over 1 mm is calculated and added to the table.

The diver data were converted to a water level by the Diver Office 2016 program. This requires the cable length, piezometer height and barometric data. The barometric data source is the Baro Diver, measuring the air pressure. It was placed inside a piezometer, but above the water table. The data from this Baro Diver is retrieved with Diver Office and the graph in figure 5 shows the data.

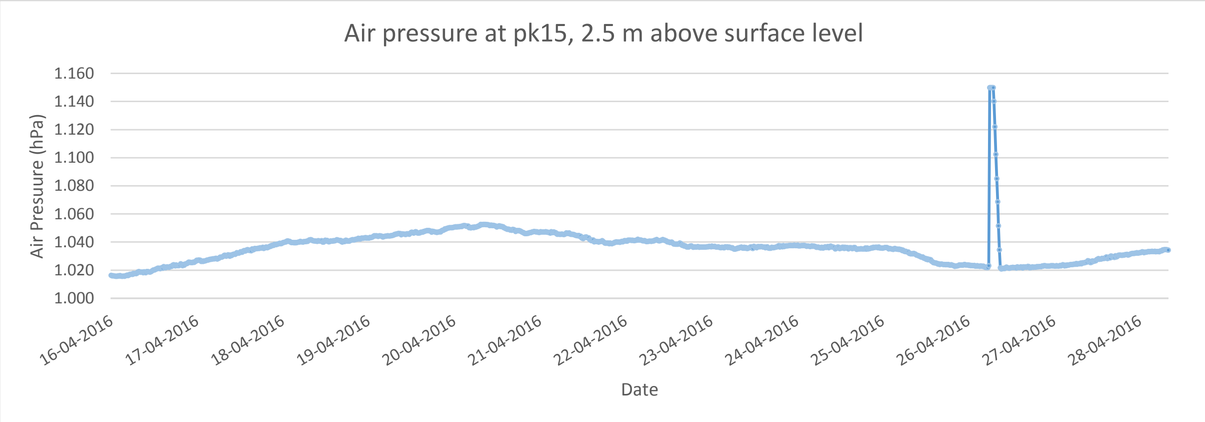

Figure 5 Air pressure measured by the baro Diver in hPa.

The air pressure data from the weather monitoring station at Waterschap Scheldestromen (Middelburg) is shown in Appendix 8. These data show that the measured air pressure by the Baro Diver is slightly higher. The values from the diver are used for the barometric compensation to create graphs with the pressure heads on the measuring points. These all show a tidal pattern, as the graph are in Appendix 6.

Table 2 Parameters measured on the measuring points.

Measuring point	Diver shallow (0,8-1 m)	Diver deep (>1m)	Soil sample	Samples from Rhizons
T2	X		X	X
T4		X		X
T1	X	X		X
pk15		X	X	X
T3		X		X
pk5	X	X	X	X
pk6				X

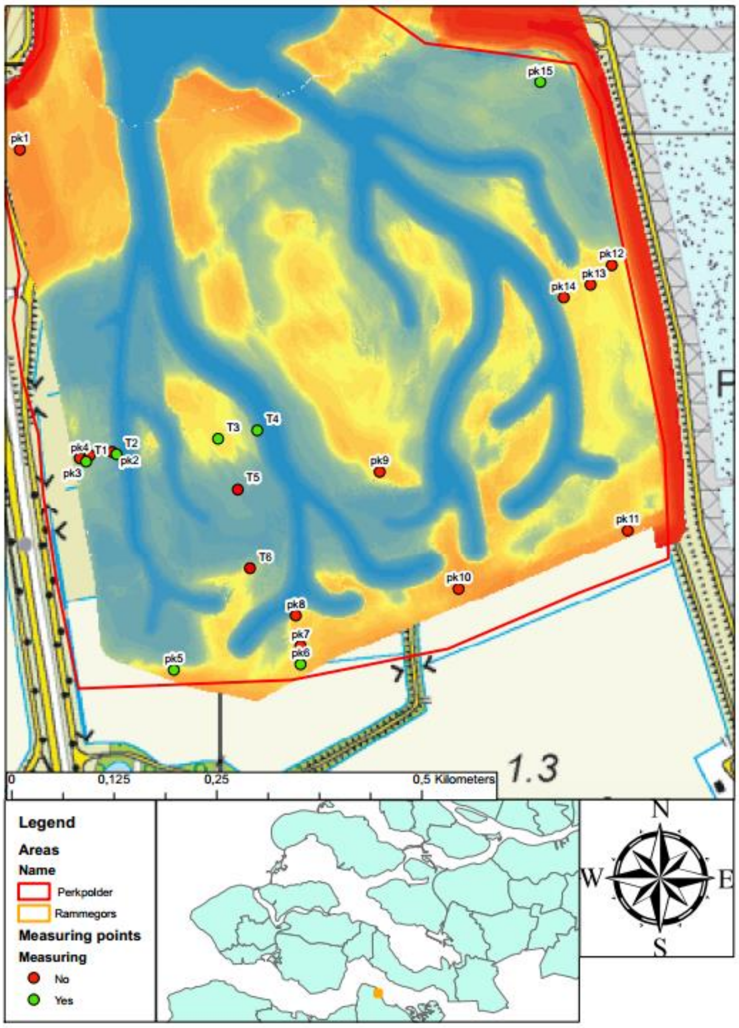

Figure 6 Locations of the measuring points with indication of use in this research.

4 Results

The obtained results consist of the measurements on groundwater quality (the oxygen content, redox potential and salinity), the analysis of the soil samples and data from divers. The measurements on groundwater quality are done by sampling with MacroRhizons.

4.1 Groundwater quality data

Data about the groundwater quality consist of the measurements done in the soil water samples from MacroRhizons. The oxygen content, redox potential and salinity are measured. For each location, a sample is taken at seven depths. On April 12th, the shallowest sample was not taken, because there were not enough Rhizons available at that moment. Per sampling point, the average from the three measurements at low tide is shown in this chapter. All results can be found in the tables in Appendix 5.

In addition to the field measurements, results from the test with the syringes are shown in paragraph 4.2. Paragraph 4.1.1 shows the results of the groundwater measurements of measuring points T1 to T4. These points are located in a line, perpendicular to the dike. The distances vary from 50 to 250 meters.

Gaps in the data are caused by samples which were too small to measure the three parameters. This is caused by a lack of water in the soil, a damaged Rhizon or a too dense soil, from which water could not be extracted. This is the subject of paragraph 5.1.1.

4.1.1 Measuring points T1 until T4

The oxygen, redox potential and salinity profiles from measuring locations T1, T2, T3 and T4 are displayed below. At all locations, a relatively high oxygen content was measured at the shallow samples. In the deeper samples, a lower oxygen content was measured at T1 and T2. The salinity of the samples from T1 increases with depth, while the salinity at T2 is almost constant, varying between 12.8 mg/l and 14.8 mg/l. The redox potential was in general variable over the depths. No clear trend throughout the measuring points was visible.

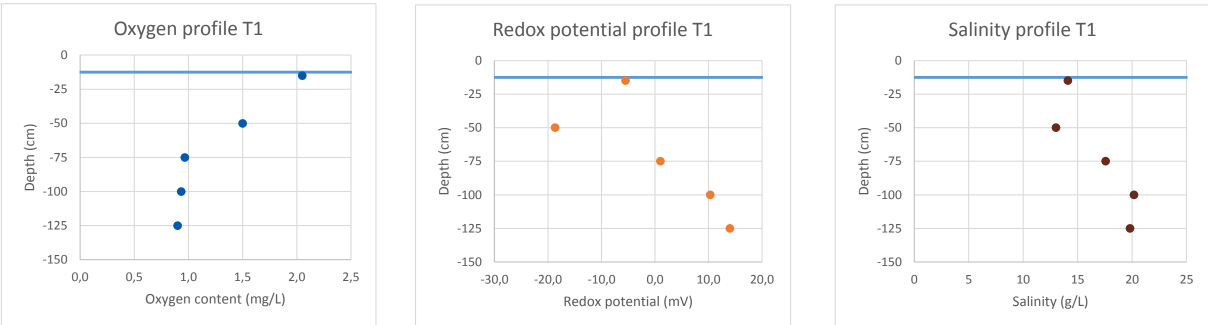

Figure 7 Oxygen level, redox potential and salinity measured in the samples of location T1.

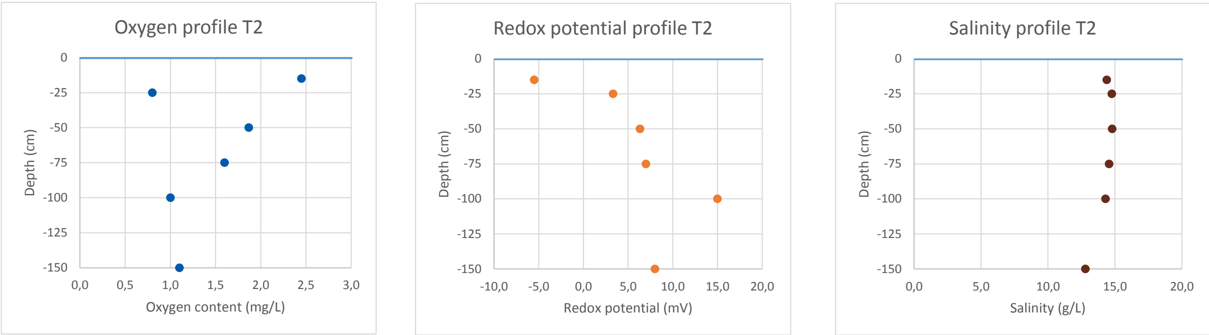

Figure 8 Oxygen level, redox potential and salinity measured in the samples of location T2.

The profiles at location T3 show a different pattern of the oxygen content. This increases with depth, apart from the shallowest sample. This trend was visible on all three sampling dates. The next chapter, the discussion, will also focus on the possible influence of the borehole.

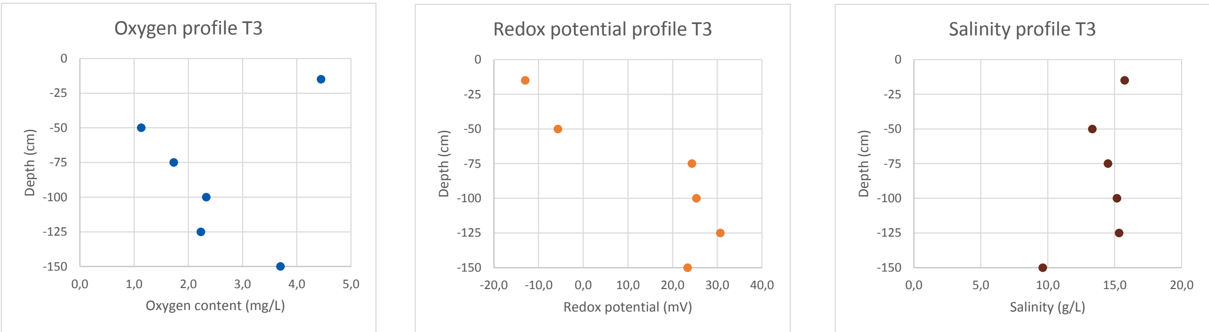

Figure 9 Oxygen level, redox potential and salinity measured in the samples of location T3.

Measuring point T4 shows a relatively constant oxygen content and salinity over the entire depth of the measurements.

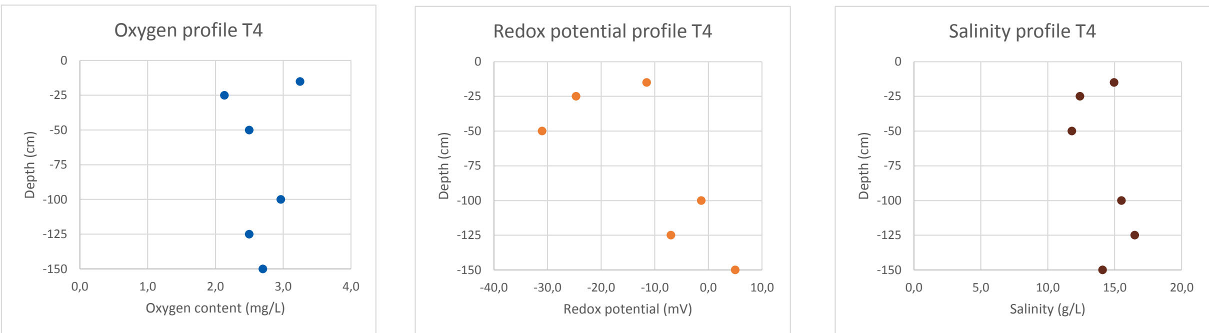

Figure 10 Oxygen level, redox potential and salinity measured in the samples of location T4.

4.1.2 pk5, pk6 and pk15

In the samples from pk5, a higher oxygen content was measured in the 15 cm deep sample. The deeper samples all resulted in a lower oxygen level, but slowly increasing from 1.4 mg/l to 2.1 mg/l. Except for the -125 cm measurement, the redox potential is decreasing with an increase of depth and so is the salinity. The salinity of the -150 cm sample however is higher, most likely this is due to the influence of the borehole, as described in the discussion, chapter 5.

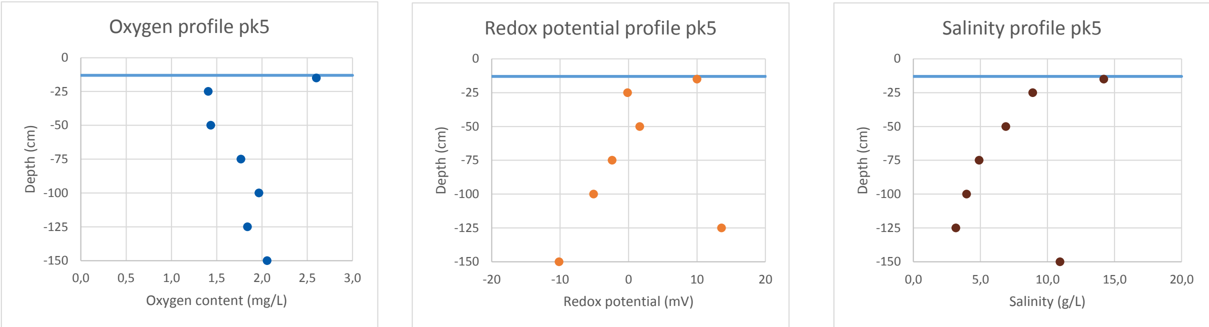

Figure 11 Oxygen level, redox potential and salinity measured in the samples of location pk5.

The salinity and oxygen levels at pk6 are lower at greater depths. The Rhizons at 25 cm and 50 cm depth did not deliver any samples, so there are no data for these depths. Therefore, it's not clear if there is a sharp line or gradual decrease in oxygen and salinity levels.

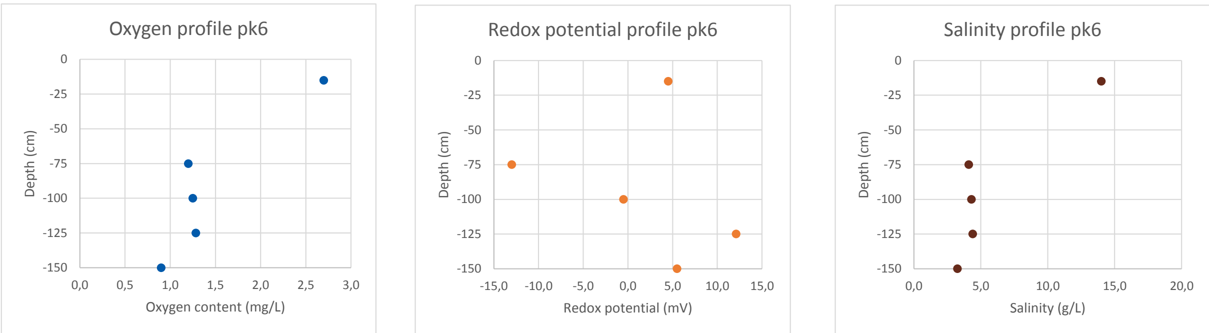

Figure 12 Oxygen level, redox potential and salinity measured in the samples of location pk6.

At pk15, there is also an incomplete dataset, but the measured values give the impression that the salinity is decreasing gradually. The oxygen content gives no clear pattern, comparable to the redox potential.

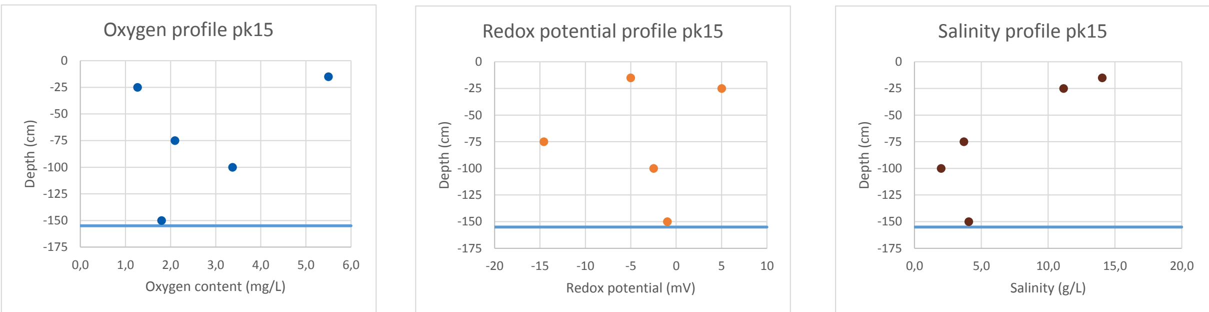

Figure 13 Oxygen level, redox potential and salinity measured in the samples of location pk15.

4.2 Soil sample data

Soil samples are taken from the locations pk15, pk5 and T2. The results from the samples consist of the particle size measurements with the Malvern Mastersizer 2000. In addition to that, the organic matter content is determined and soil profiles from DINO-loket are collected.

Table 3 Classification of the particle size of the soil samples (given by the Malvern Mastersizer 2000).

Class	Particle size limit (µm)	
	Lower	upper
Silt	0	63
Very fine sand	63	125
Fine sand	125	250
Medium sand	250	500
Coarse sand	500	1000

4.2.1 Location pk15

The results of the particle size analysis are presented in the chart below. The samples from -225, -250 and -275 cm consisted of peat. The analysis was done to see what the results of the Malvern Mastersizer 2000 would be for the peat samples. The discussion explains more on these specific results. A three meter deep piezometer was installed at pk15. The soil samples were taken to 275 cm deep, because the 300 cm sample was mixed too much to be representative for this soil layer.

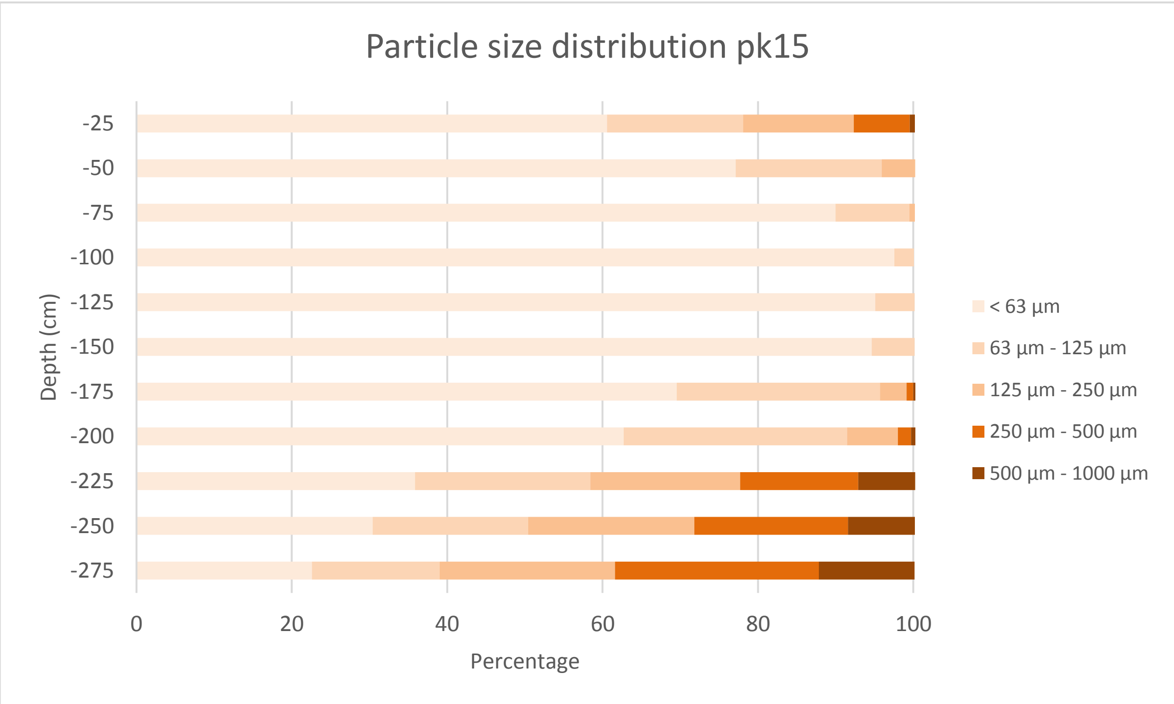

Figure 14 Particle size distribution of the soil samples of location pk15.

The SD10, SD50 and SD90 were also found with this analysis. These are displayed in the chart on the next page (figure 13). This gives an indication of the permeability of the soil.

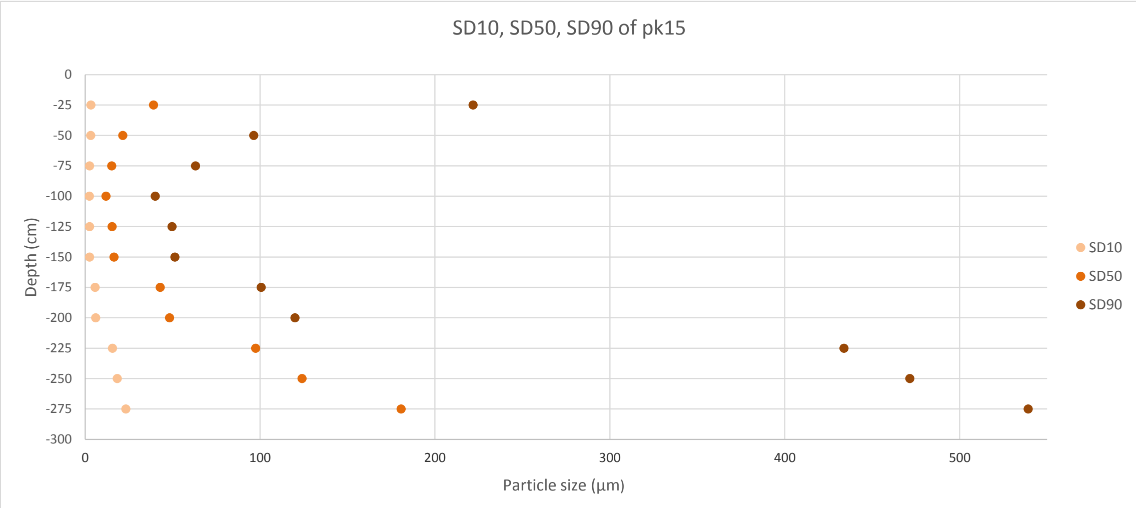

Figure 15 SD10, SD50 and SD90 of the soil samples of location pk15.

4.2.2 Location pk5

Two piezometers are installed at pk5, one with a filter on 2-3 meter deep and one with a filter on 0.8-1.0 m deep. The soil samples were only taken from the shallow borehole. Malvern Mastersizer 2000 results are plotted in the two charts below.

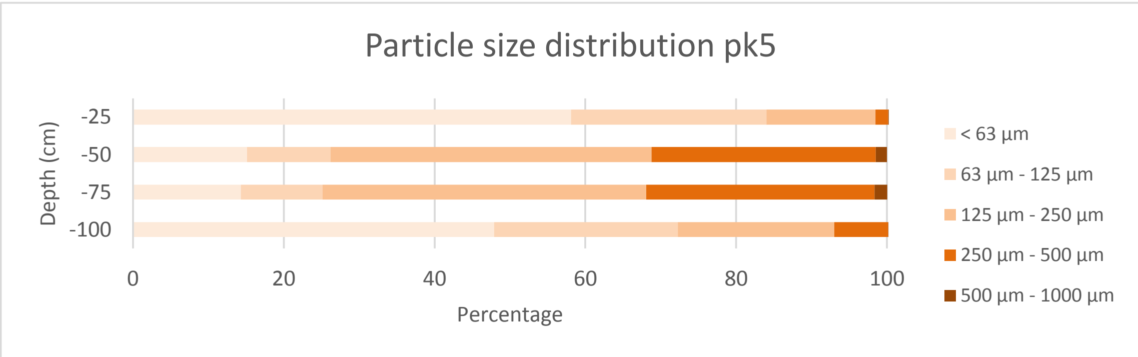

Figure 16 Particle size distribution of the soil samples of location pk5.

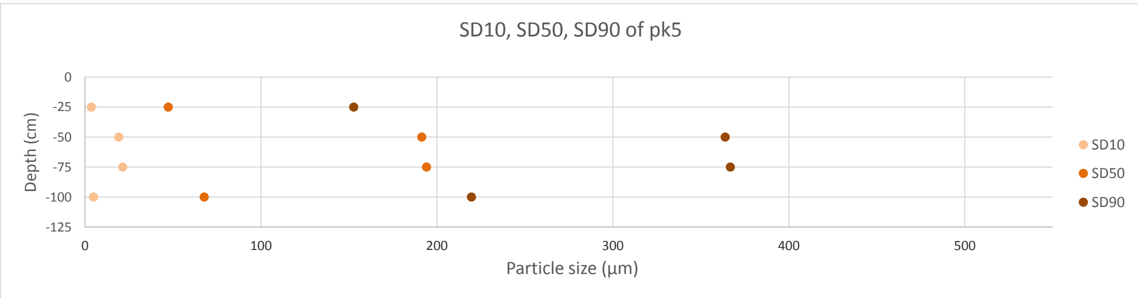

Figure 17 SD10, SD50 and SD90 of the soil samples of location pk5.

4.2.3 Location T2

Deltares already installed deeper piezometers on this location. From these boreholes, no descriptions are available since the method used does not give any samples of indication of the soil properties. The soil samples are taken while placing the piezometer at 80 to 100 cm depth.

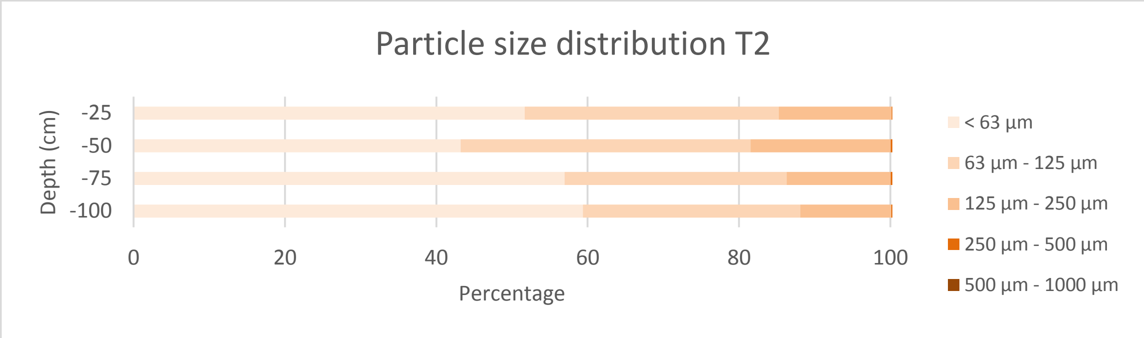

Figure 18 Particle size distribution of the soil samples of location T2.

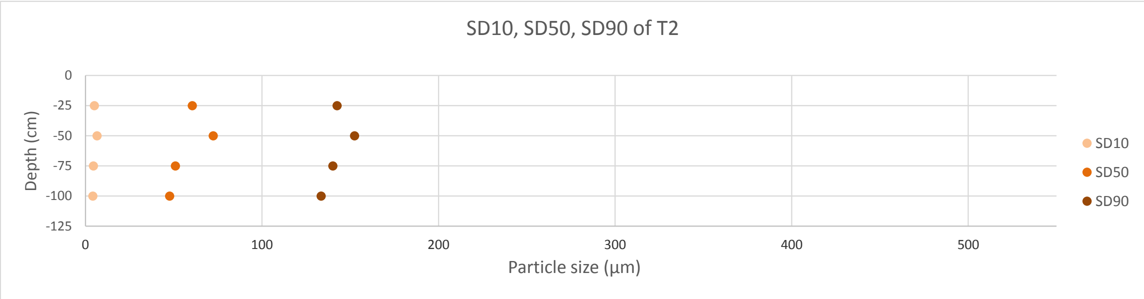

Figure 19 SD10, SD50 and SD90 of the soil samples of location T2.

4.3 Subsurface data from DINO-loket

DINO-loket provides data from the subsurface of the Netherlands. The borehole data are retrieved from the area of Perkpolder, of which three lines across the intertidal basin Perkpolder are made. These indicate the pattern in the soil layers of this are. The results show clearly the depth of the peat layer, which in most places is confined between clay. Sandy soils consist of fine sand according to the borehole descriptions of the DINO-loket data. The following legend is used for all three figures below.

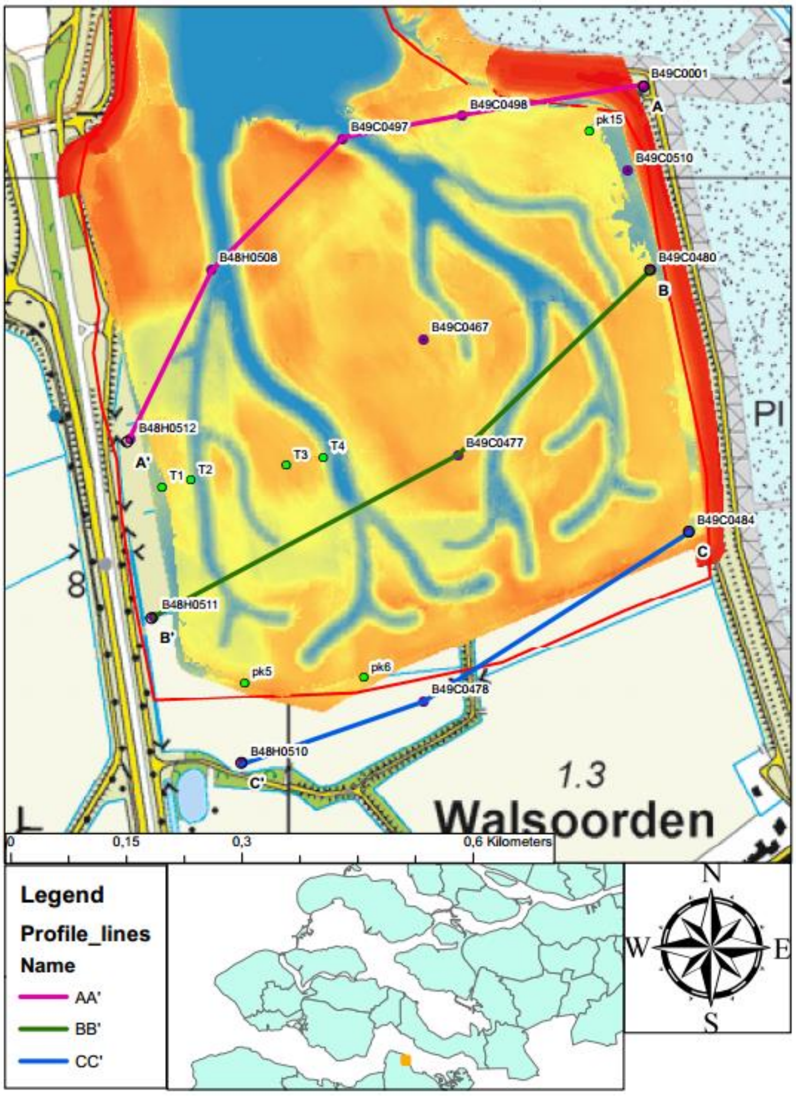

Figure 20 Locations of DINO-drillings and lines of the soil profiles..

	Soil type
	Clay
	Fine Sand
	Peat

Figure 21 Legend of the soil profiles from DINO-loket.

The first transect is the most northern one. It shows the soil profile close to locations pk15 and the transect T1 – T4. The figure confirms the soil layers found when making the boreholes in the area.

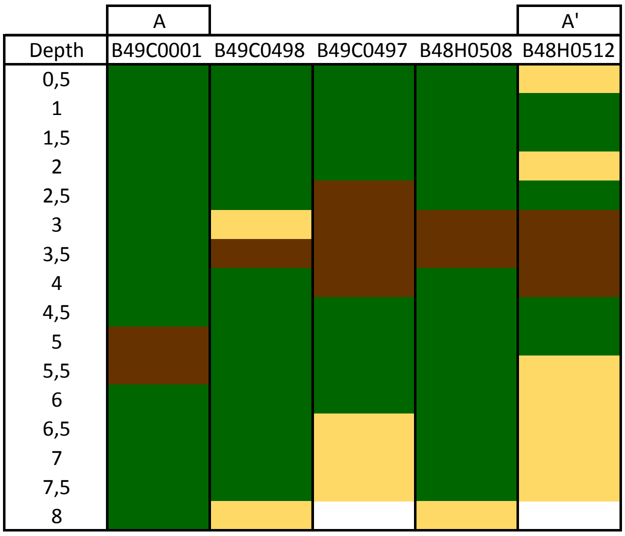

Figure 22 Soil profiles along line AA' (DINO-loket).

The second transect is through the middle of the area. It shows the soil profile at only three locations, at which the depth of the peat layer is about equal to the more northern profiles. The peat layers seem to be continuously present in the area, which is confirmed by the REGIS maps on the following pages.

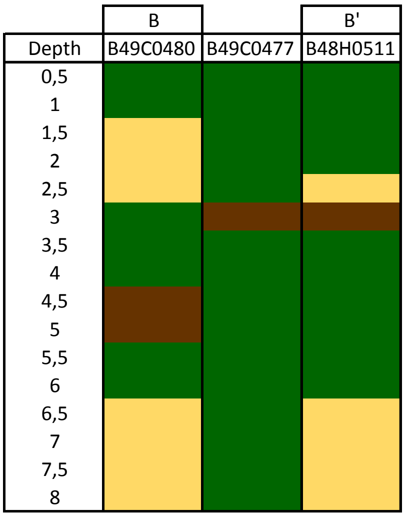

Figure 23 Soil profiles along line BB' (DINO-loket).

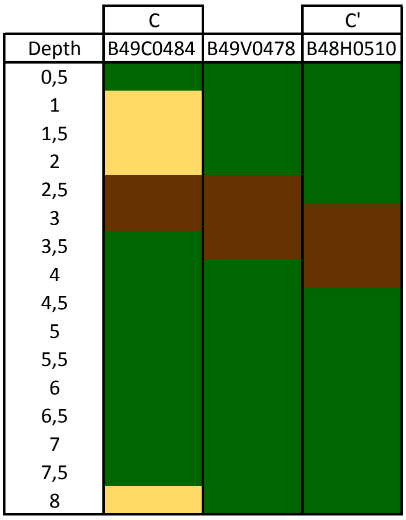

Figure 24 Soil profiles along line CC' (DINO-loket).

The third transect is made along the south side of the intertidal basin. The depth indicates the original depth, not from the top of the dike which is on some of the borehole locations now. The peat layer is slightly more towards the surface and the sand layers become thicker, as the second transect also showed.

4.4 Diver data

Diver pressure data is converted to water levels, referenced to NAP. The results are presented in graphs in Appendix 6. The graph below shows an example of measuring point T2 with a filter depth of 1 m.

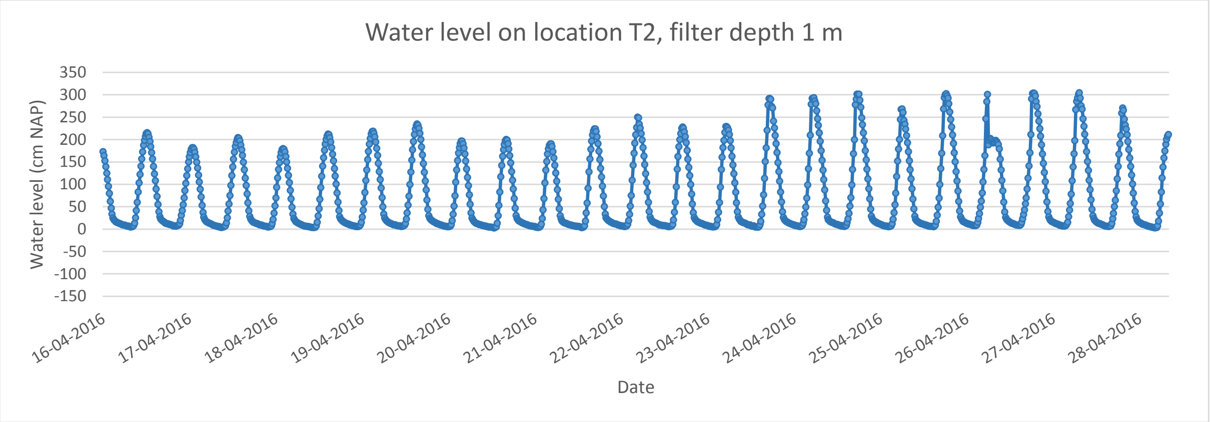

Figure 25 Example of the diver data from location T2 with a filter depth of 1 m.

5 Discussion

The discussion is split into two parts. The first paragraph contains a sharp review of the methods used for this research. The main purpose of this first part of the discussion is to learn more about research methods for intertidal areas, focused on soil and water sampling. The second part of the discussion is focussing on the data itself, related to the way they were obtained.

5.1 Discussion on the research method

5.1.1 MacroRhizons

The methods which were used are described in Appendix 10 Soil water sampling with MacroRhizons was planned for several measuring points in the intertidal area. The Rhizons were placed by making a hole with a stick first, then inserting the Rhizon. If this was not possible due to a hard, compact soil, an auger was used to make the hole. Then, the Rhizon was inserted and pierced into the hard soil layer below.

With both methods, the Rhizon could be damaged during insertion in the soil. The filter is the most sensitive part of the Rhizon and it is not always attached perfectly straight. This means that in case of inserting it in a hole, made with a stick, the filter can hit the wall of the hole and get damaged. When a hole is drilled with an auger, the Rhizon will not hit the wall of the borehole with inserting it, but it can be damaged when it is penetrated into the soil (at the bottom of the borehole). A solution for this is to drill the hole deeper, insert the Rhizon to the bottom of the hole and fill it with sand before adding bentonite pellets. With a few Rhizons, this was done because the soil layer, in which the Rhizons filter should be placed, was too hard.
In hard soils, this can also help taking samples. The soil water can infiltrate into the sand, from which it can be extracted quicker than from the hard soil layer in which it actually is. This hard soil is in Perkpolder usually clay with a low permeability.

The Rhizons from which a sample can be taken easily, are almost certainly placed without damage. Rhizons delivering no samples or very small samples might be damaged, but could also be placed in a soil layer with a too low permeability. These Rhizons could be extracted to inspect this, but since the yield differs from time to time, the choice was made not to do this. After replacement, it would still be unsure if the Rhizon is undamaged in place. In general, per measuring point, a profile was created which gave an impression of the soil water quality. A sample of at least 20 ml is needed to measure the three desired parameters.

5.1.2 Piezometers

The piezometers were placed at two places with a filter at a depth of two to three metres. In addition to this, three piezometers were placed with a filter from 80 to 100 centimetres depth. The deeper piezometers were placed with a casing. This way, it is very difficult to see if the sand added after inserting the piezometer reaches until the top of the filter. Therefore, the amount of sand added might be too much, so water from more soil layers is entering the piezometer. Adding bentonite pellets was always possible in such a way that a closed seal was almost certainly there. There were no water quality measurements performed on the water from the piezometers, only the water level in the pressure head in the soil layer was measured.

Diver water level loggers were placed in the piezometers. These were well below surface level, so they are below the groundwater table all the time. This way, a continuous measurement was ensured. The Baro Diver was also placed in a piezometer. The risk of theft was low, because the piezometers are all in the intertidal flat, which is a protected area and not easily accessible.

5.2 Discussion on the data

Some results do fit in a pattern properly. These will be discussed in this section. Per paragraph is also discussed what the values tell about the processes in the subsurface of the area.

5.2.1 Groundwater quality results

Some of the Rhizons gave a sample which was too small to measure any parameter. Some of the Rhizons did not deliver any water at all. All missing data in the graphs in chapter 5.1 and in the tables in Appendix 5 are caused by this.

The oxygen level seems to decrease slightly in most profiles. Except at T4, where it is quite constant, pk5, where the oxygen level seems to increase with depth and pk15, where there is no trend visible in the measurements.
Redox potentials do not show a general pattern. At T1, T2 and T3, the redox potential is increasing with the depth, while on pk5 it seems to increase. T4, pk6 and pk15 do not show a trend.
Salinity measurements show (with an increasing depth) a decrease in salinity at pk5, pk6 and pk15, an almost constant profile at T2, T3 and T4 and an increase at T1. The constant values could be influenced by boreholes, but since the profile is different on some locations and the method of placement is the same everywhere, this is not expected to be the problem with these measurements. Infiltration through the Rhizons tube is also not possible, because the Rhizon is air- and watertight glued into the bottom of the tube. Rhizons placed by making a borehole are covered with sand and bentonite. The amount of bentonite used should make a decent seal of the borehole. As far as possible, the borehole was filled with the sediment originating from the borehole.

The redox potential measurements have a high risk of inaccuracy according to DeLaune and Reddy (2005). The measurements are sensitive to influences from air and the measurement gives an indication of the electron availability. The measured potential is also a mixed potential which gives the weighted average of all present redox couples. Therefore, the risk of error is very high. The variation in the measurements could be caused by the way of measuring or by pollution of the sample. This can be caused by e.g. an air bubble on the sensor, a drop of water which is transferred from one to another sample or a drop of cleaning water. Discussions of the data resulted in the insight that the data are probably all within the range of measurement errors (McAteer, 2016). The values are all close to 0 to 10 millivolts.

The increase or decrease of the oxygen content of the ground water does not show a clear relation with the groundwater table. The groundwater table at locations pk5, T1 and T2 are above the depth of the measurements. On other locations, it is either below this level or not measured in the cover layer but below. The oxygen could be confined in the soil layer and therefore be measured, but diffusion through the ground water is also possible.

Measurements of the salinity of the water is the least sensitive to changes over time or influences by air. The measurements are done after the oxygen and redox measurements. Saline water can be present already in the subsurface for a longer time, as described in chapter 2.2. This can be diluted by the infiltration or precipitation, after which salinization can take place when sea water is present in the area again. The salinity of the sampled groundwater could give an indication of which process is going on. Location pk5 and pk6 has the freshest groundwater at the deeper samples. This most likely means there is confined fresh water which is very slowly becoming more saline. The top layer has already become more saline. This influence is possible here because of the more sandy soil, in which seawater can infiltrate quicker. Other profiles, like T2, T3 and T4, indicate a higher salinity throughout the profile. The salinity of the ground water is higher than from the Western Scheldt water flowing into the area. The inflow of the Westerns Scheldt has a salinity of 15,7 g/L, measured in the intertidal area. Therefore it seems likely that this salt is captured in the soil in the past and still present today.

At measuring location T1, a different profile can be seen, There, the salt water has not infiltrated that much. The salinity of the top layer is clearly lower, which can be due to the infiltration of rain water.

5.2.2 Syringe test

For the sampling of soil water, Terumo Syringes 50 ml with a luer lock connection were used. This is the standard syringe used for this, though different volumes of this type are available. The syringes are not completely airtight, which was first assumed after the first measurements at pk5. The experiment resulted in two graphs, from two different testing methods. They show a similar trend during the first 90 minutes, so the way of measuring does not make the difference in this case. Time is the most important factor. Measuring as soon as possible after sampling resulted in measuring in the field, in the syringe. This influences the measurement as little as possible, except for the time the syringe has to be connected to the Rhizon to take the sample.

5.2.3 Soil samples

One of the cups containing the samples tilted while putting it in the exsiccator. No spill was visible, but the result is still marked as unreliable.

The borehole descriptions indicate the presence of oxygen. There is no smell of H_2S (hydrogen sulphide), which would indicate anoxic decay. Oxygen required for the decay of organic matter might be present in the soil, but the lack of H_2S smell indicates little decay. Also the little amount of organic matter present could be the cause of this finding. (Cadenas & Packer, 2015)

5.2.4 Diver data

The Baro Diver was placed in a piezometer at location pk15. This diver must be dry all the time, because it has to measure nothing but air pressure. The peak on April 26th is too high to be a measured air pressure. This can be explained by a measuring fault, but this is not likely because of the accuracy of the device and the fact that it is the only faulty measurement. It is more likely that the diver was flooded at this moment. The tide was very high at that day and therefore the diver could be flooded. This is also visible in the compensated water level graphs as a deformation in the regularity of the data series.

The pressure is transferred directly through the soil to deeper layers. Therefore, even in deeper soil layers than the ones measured in this research, the pressure head rises and drops with the tide. This however does not indicate a flow of groundwater. The soil properties and saturation of the soil layers has more influence on this.
The change in water level in the area causes a change in the pressure head in the first aquifer. This rising pressure will diverge to the surrounding area through this first aquifer. Increasing pressure in the first aquifer will reduce the infiltration and potentially decrease the volume of the fresh water lens. Measurements on the pressure head in the shallow aquifers show a change in water level with the tidal cycle, so the tide does influence the ground water system. (De Louw, Visser, Doornenbal, & Pauw, 2016) (De Louw, 2013)

6 Conclusion

The elevation of the intertidal area is higher than it was before the breach in the dike was created. In almost the entire southern half of the area, sedimentation takes place. Therefore the surface level is raised with the thickness of the sediment cover. This layer could influence the depth of the fresh-saline interface of the ground water. The measurements in this research show some patterns in the salinity levels of the ground water, but this is different per location. The source of the present salt can be different per measuring point. Rainwater infiltration created a fresher layer of groundwater. The saline water in the area now causes this to become saline again, starting at the top. This is measured at locations pk5 and pk6.

This can be confirmed by the soil properties. Soil samples from location pk5 have a higher median grain size, so this soil facilitates infiltration better. Therefore, the soil water chemistry can also change the fastest. This is not clearly shown by the measurements of the oxygen content of the soil water or in the redox potential measurements. The distance to the channel shows no clear relation with these profiles, since the profiles at measuring points T1, T3 and pk5 show different patterns in both oxygen levels and salinity.

The current situation of the groundwater levels, fresh-saline interface and soil chemistry properties does not show a clear relation with the distance to the channel. The found soil layers are all older soil layers, present from (mostly) the Holocene. The sediment layer on top will have an influence on the soil properties and groundwater flows, but since the thickness is minimal, this is not proven with this research.

Figure 26 Impression of the dike built around Perkpolder, seen from the intertidal mudflat (Edwin Paree).

7 Recommendations

7.1 Field work

The field work was executed in an intertidal area in which a lot of sedimentation takes place. This causes a layer on top of the hard agricultural soil. The system is still not approaching its equilibrium, so sedimentation will continue for a longer time. The sediment layer will become thicker, which makes field work more difficult. Walking on the mudflat means sinking into it until one stands on the hard soil below. It is likely that at some point, walking with a wading suit or boots becomes impossible, so at that point, field work and sampling locations have to be adapted to what is possible at the site. Another way to solve this problem is to change the way of transport in the area. A mud sled could be a solution or (if monitoring at high tide is possible) going into the area by boat could be better.

Figure 27 Mud sled built by the Research Group Building with Nature (Edwin Paree).

The method for placing MacroRhizons in intertidal areas with hard soils is described in both appendix 9 and the discussion (chapter 5.1.1). This method is optimized during the research and fieldwork. The manual for placing piezometers was computed from different manuals which were discussed with colleagues trained in this. Then the manuals were summarized and optimized for this research. These manuals can be used if any more piezometers have to be placed in this or comparable areas.

The methods do work for the area, but to ensure the consistency of the sampling and measurements it might be better to place all Rhizons as small piezometers. This means installing them with an auger, put sand around the filter and seal the hole with bentonite pellets. The way of placing the Rhizons does not influence the quality of the samples, but it does increase the chance of placing them without damage.

7.2 Research

In further research, the methods and results from this study could be used as reference. Using the same methods would most likely result in comparable outcomes, but some remarks have to be made regarding further research.

First of all, the MacroRhzions are installed at a certain depth at the start of this research. Sedimentation will cause the Rhizons to stay at the same level above or below the NAP reference, but the depth from the surface will vary over time. This means that the analysis of the soil water samples is from the same soil layer, but from a different depth.
Sedimentation creates a new soil layer, with its own hydraulic properties. It could influence the infiltration and impact of the saline water on the soil below. Analysis of this sediment layer is therefore recommended as this layer grows. With the analysis of the soil samples, in further research the bulk density and soil moisture content can be determined to get a better picture of the soil properties.

Figure 28 Drilling with an auger and casing for placing piezometers (Edwin Paree).

Secondly, the sampling techniques might be improved. Airtight syringes would ensure a better measurement, since the inflow of oxygen into the syringe is now relatively high, especially during the first hours. Airtight syringes may not have this problem and therefore cause a smaller error in the measurement. If this is not possible, investigating a way of enclosing the syringes in an airtight bag or box might work. This was not possible within the timeframe of this research and is expected to be difficult in the field, but with the current results in mind, this method is worth investigating.

More research on the sediment can be done in the near future. If this layer thickens, the influence on the ground water system will increase. The hydraulic properties of this layer are then more determining for the properties of the shallow subsurface and the response of the groundwater system on the presence of saline water. The soil will set and be compacted by the sediment load on top, more benthic organisms can colonise the area and this can change the conditions which could be important for vegetation. This will however take a long time. The vegetation will probably not be present in the few following years, as other research from the research group Building with Nature shows.

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Appendix 1, Measuring points Perkpolder

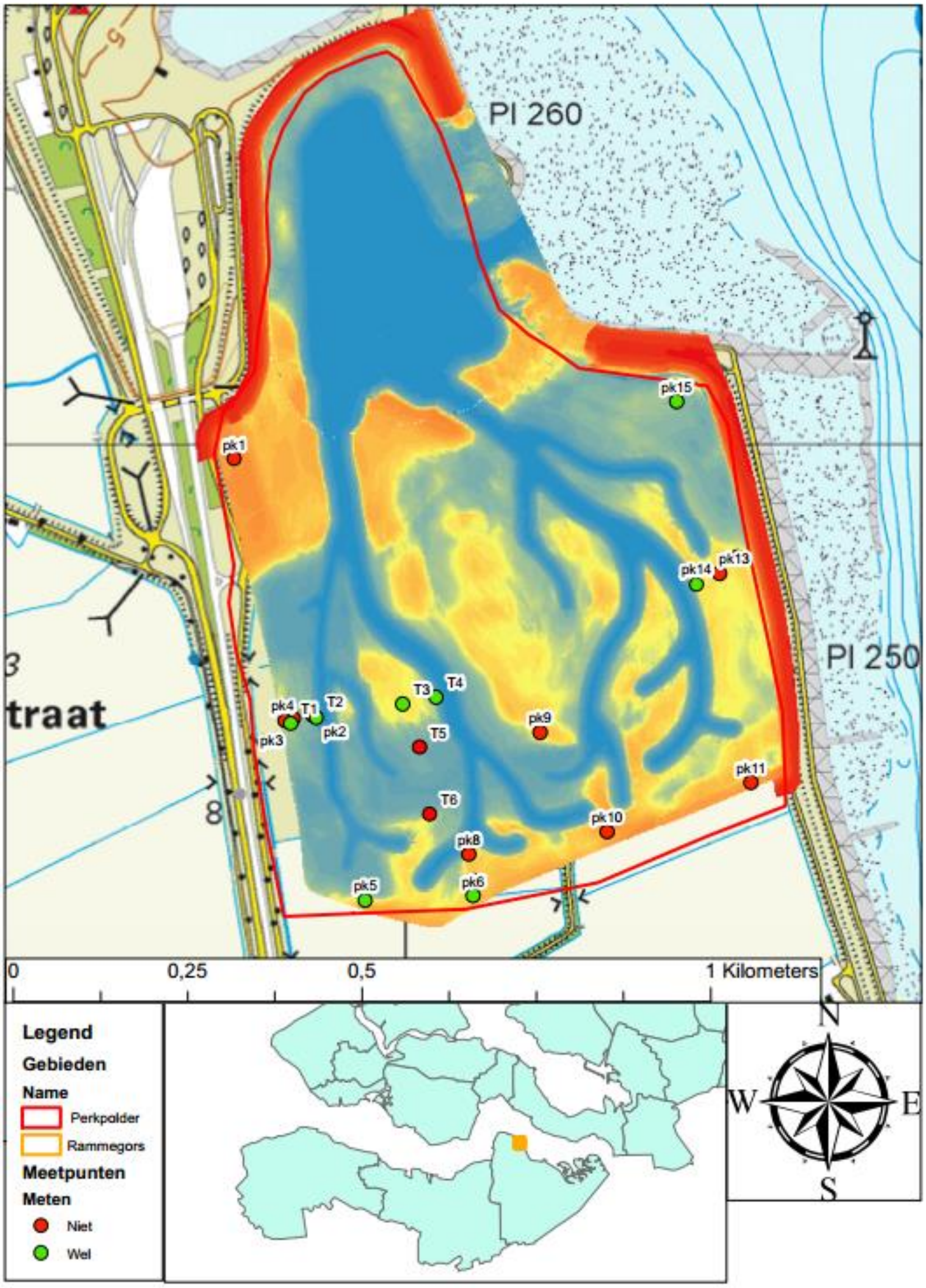

Figure 29 Map with the measuring locations and their numbers.

Appendix 2, Test results syringes

The syringes were tested, since the measured values from the first test samples were much higher than expected. The oxygen level was around 4 mg/l in all samples at pk5. To test the syringes, tap water was de-oxygenated with nitrogen gas. The water was 'sampled' with the syringes while the nitrogen gas was still bubbling through the water. Each syringe contained 40 ml to 50 ml sample.

The oxygen content was measured in 2 ways. During the first test, this was done in a glass cylinder, continuously flushed with nitrogen gas. The water was put into this tube by a small hose attached to the syringe. The second way was by pulling the plunger out of the syringe and measuring in the syringe itself. The time interval for both methods was different, as the following table shows. The methods did however show a similar curve. The measurement on -5 minutes was done in the beaker in which the water was degassed.

Table 4 Results of the measurements on the oxygen content of a deoxygenated sample in a Terumo Luer Lock Syringe.

Time (min)	Oxygen (mg/l)	
	Method 1	method 2
-5	0,14	0,2
0	0,38	0,6
15	0,85	0,8
30	1,04	0,9
45		1
60	1,10	1,2
75		1,2
90	1,09	
120	1,49	
180	1,80	
240	1,92	
1380	3,58	

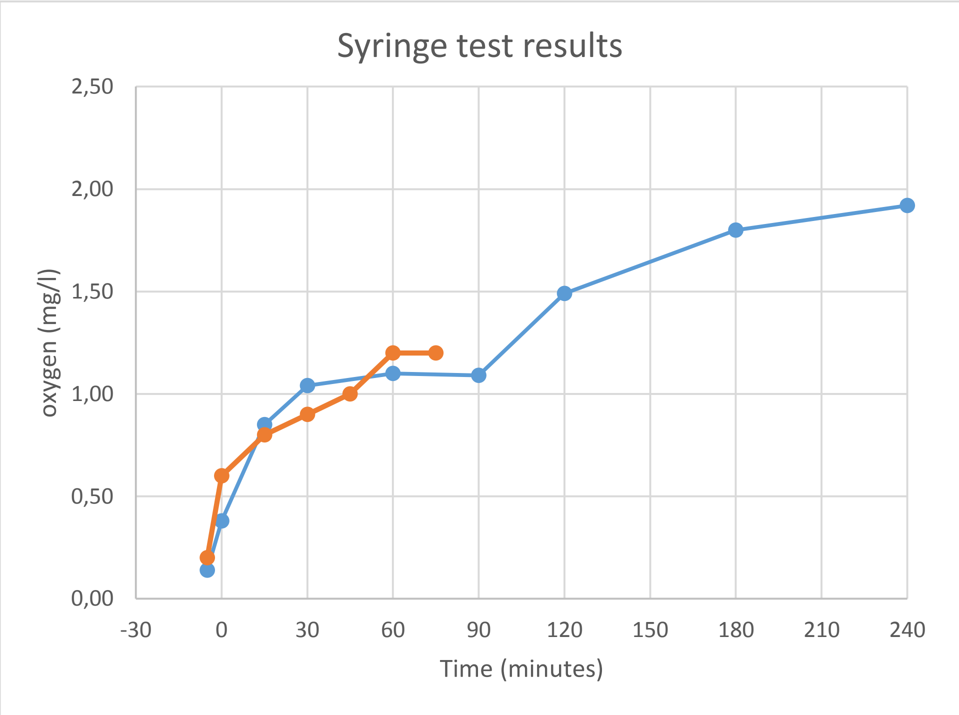

Figure 30 Results of the syringe test with both series plotted in one graph.

Appendix 3, Borehole description form

The form below is used to make borehole descriptions. The content was chosen to have a log of the sampling which is clear and accurate. This form is composed in consultation with borehole

Measuring point (number)		
Filter depth (cm below surface)		
Filter length (cm)		
Depth of filter sand (cm below surface)		
Amount of water used on site (L)		
Soil layer 1		**Example key words/questions**
Smell		Rotten/anoxic/no smell
Texture		sandy/clay/wet/dry
Color		grey/brown/black
Anthopogenic components		rocks/debris
Gley / oxidation / 'corrosion'		e.g. brown rust spots
Extra information		can you form a ball?
Soil layer 2		
Smell		
Texture		
Color		
Anthopogenic components		
Gley / oxidation / 'corrosion'		
Extra information		
Soil layer 3		
Smell		
Texture		
Color		
Anthopogenic components		
Gley / oxidation / 'corrosion'		
Extra information		
Soil layer 4		
Smell		
Texture		
Color		
Anthopogenic components		
Gley / oxidation / 'corrosion'		
Extra information		
Soil layer 5		
Smell		
Texture		
Color		
Anthopogenic components		
Gley / oxidation / 'corrosion'		
Extra information		

Figure 31 Borehole description form as used in the field.

Appendix 4, Malvern Mastersizer 2000 protocol from Royal NIOZ

This is the standard Malvern Mastersizer 2000 protocol used by the Royal NIOZ institute for doing analysis of soil samples.

1. Determination of particle size in sediment by laserdiffraction (Malvern Mastersizer)

2. Application:

This method is applicable for sediment. Detection range: 0,02 – 2000 µm.

3. Background [1]:

Particles in a light beam will scatter light into space, with angels and intensities which depend on the size, the optical properties of the particles, the light and their suspending medium. These effects are known as light diffraction. Following fysical properties are used for calculation Particle Size:

- Rayleigh scattering; for very small particles compared to the wavelength of light (< 1/10 λ)
- Forward scattering; for larger particles (> 1/10 λ)

Calculation is based upon Mie-theory.

4. Principal:

The Mastersizer uses two light sources:

1) 632.6 nm red Helium Neon laser; for “big” particles (> 63 nm to 2000 µm)
2) LED blue; for small particles up to 20 nm

To avoid interference, one light source is shut of when measuring the other.

5. Apparatus:

- Malvern Instruments, Worcestershire, United Kingdom
  - Mastersizer 2000, serial number 34403/139, model APA 2000 with Hydro G 2000 introduction unit and Autosampler 2000

6. Calibration:

Laserdiffraction is an elementary fysical technique, therefore apparatus needs no calibration with a standard.

7. Sample:

Samples can be analysed with or without pretreatment. Pretreatment consists of treatment of the sediment with H_2O_2 and HCl to remove organic matter, prevent clogging and to remove salts. At NIOZ samples are analyzed directly from 2001.

N.B. Samples should always be freeze-dried and sieved over 1 mm-sieve.

8. Quality control:

Every batch of samples, the measurement results are checked with two internal control samples (real sediment)
At least two times per year an external quality control sample (quartz) from Malvern Instruments is analyzed.

9. Literature

1. Malvern Particle Sizer; Manual version 6.0 en 6.02. 1987
2. Operators guide, Mastersizer 2000
3. Theory of light scattering. Applicable for Laser diffraction instruments like Malvern Mastersizer 2000. Goffin Meyvis, H. Vink, 2004.
4. Afstemming deeltjesgroottebepaling tbv MONEOS, RWS report, 2012.

10. Reporting variable

Variable:	Parameter:
SD(0.1)_2	10% grens (10% smaller then…µm)
SD(0.9)_2	90% grens (90% smaller then …µm)
SD50MUM_2	Median grainsize D50 from Malvern in µm
SD50PHIM_2	Median grainsize D50 from Malvern in PHI
SSILT63_2	Silt % <63 µm
SVFINES%_2	Very Fine sand fraction PHI 3–4, 62.5-125 µm
SFINES%_2	Fine sand fraction PHI 2-3, 125-250 µm
SMEDIUM%_2	Medium sand fraction PHI 1-2, 250-500 µm
SCOARSE%_2	Coarse sand fraction PHI 0-1, 500-1000 µm
SMODE_2	Modus grainsize in µm

Appendix 5, Groundwater quality data

This appendix contains all data from the measurements of the groundwater quality. The samples are taken from the Rhizons. If there is no data for a certain location and depth, the reason for this is described in the table. In most cases, the sample was too small.
For each sampling location, four tables are shown. The first one is the average measured value at low tide. The following three tables contain the data from the three measurements done at low tide. The time of low tide was different, but always during daytime with a limited amount of precipitation.

Table 5 Data from sampling point T1.

Average			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	2,1	-5,5	14,1
-25			
-50	1,5	-18,7	13,0
-75	1,0	1,0	17,6
-100	0,9	10,3	20,2
-125	0,9	14,0	19,8
-150			

12-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	No Sample (no Rhizons available)		
-25	Sample too small		
-50	1,2	-24	12,9
-75	1	0	17
-100	0,8	5	20,3
-125	0,8	13	19,7
-150	Sample too small		
22-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	1,5	0	13,1
-25	Sample too small		
-50	1,1	-14	13
-75	1,2	3	17,9
-100	0,8	14	20,3
-125	1,1	16	19,8
-150	Sample too small		
28-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	2,6	-11	15,1
-25	Sample too small		
-50	2,2	-18	13,1
-75	0,7	0	17,8
-100	1,2	12	19,9
-125	0,8	13	19,9
-150	Sample too small		

Table 6 Data from sampling point T2.

Average			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	2,5	-5,5	14,4
-25	0,8	3,3	14,8
-50	1,9	6,3	14,8
-75	1,6	7,0	14,6
-100	1,0	15,0	14,3
-125			
-150	1,1	8,0	12,8

12-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	No Sample (no Rhizons available)		
-25	1	5	15,1
-50	1,7	-12	14,7
-75	3,1	-1	14,4
-100	Sample too small		
-125	Sample too small		
-150	1,2	2	12
22-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	2,6	-13	14
-25	0,8	0	14,7
-50	2,8	17	14,9
-75	0,9	9	14,9
-100	0,9	15	14,5
-125	Sample too small		
-150	1	10	13,3
28-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	2,3	2	14,8
-25	0,6	5	14,5
-50	1,1	14	14,8
-75	0,8	13	14,4
-100	1,1	15	14,1
-125	Sample too small		
-150	1,1	12	13,1

Table 7 Data from sampling point T3.

Average			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	4,5	-13,0	15,8
-25			
-50	1,1	-5,7	13,3
-75	1,7	24,3	14,5
-100	2,3	25,3	15,2
-125	2,2	30,7	15,3
-150	3,7	23,3	9,6

12-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	No Sample (no Rhizons available)		
-25	Sample too small		
-50	1,1	-8	13
-75	2	27	14,6
-100	1,9	24	15,2
-125	2	27	15,2
-150	2,4	22	8,9
22-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	5,9	-15	16,2
-25	Sample too small		
-50	1,2	-6	13,6
-75	1,7	26	14,7
-100	3,5	26	15,6
-125	2,8	34	15,5
-150	2,7	29	9,7
28-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	3	-11	15,3
-25	Sample too small		
-50	1,1	-3	13,4
-75	1,5	20	14,2
-100	1,6	26	14,7
-125	1,9	31	15,3
-150	6	19	10,3

Table 8 Data from sampling point T4.

Average			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	3,3	-11,5	15,0
-25	2,1	-24,7	12,4
-50	2,5	-31,0	11,8
-75			
-100	3,0	-1,3	15,5
-125	2,5	-7,0	16,5
-150	2,7	5,0	14,1

12-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	No Sample (no Rhizons available)		
-25	3,2	-29	10
-50	Sample too small		
-75	Sample too small		
-100	2,7	5	14,8
-125	Sample too small		
-150	2,7	5	14,1
22-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	2,7	-4	14,6
-25	1,5	-22	13,4
-50	Sample too small		
-75	Sample too small		
-100	3,5	-4	16,1
-125	Sample too small		
-150	Sample too small		
28-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	3,8	-19	15,3
-25	1,7	-23	13,8
-50	2,5	-31	11,8
-75	Sample too small		
-100	2,7	-5	15,6
-125	2,5	-7	16,5
-150	Sample too small		

Table 9 Data from sampling point pk5.

Average			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	2,6	10,0	14,2
-25	1,4	-0,1	8,9
-50	1,4	1,6	6,9
-75	1,8	-2,4	4,9
-100	2,0	-5,1	4,0
-125	1,8	13,6	3,2
-150	2,1	-10,1	10,9

12-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	No Sample (no Rhizons available)		
-25	1,22	-15,4	7,2
-50	1	-7,1	5,3
-75	1,5	-2,2	4,5
-100	2,2	-21,3	4,3
-125	2,12	-2,2	2,7
-150	1,57	-22,4	9,9
22-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	2,6	10	14,2
-25	0,8	11	8,2
-50	2	6	6,7
-75	1,8	-8	4,8
-100	1,1	13	3,8
-125	2,4	32	3,3
-150	1,5	-20	11,4
28-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	Sample too small		
-25	2,2	4	11,3
-50	1,3	6	8,7
-75	2	3	5,4
-100	2,6	-7	3,8
-125	1	11	3,5
-150	3,1	12	11,5

Table 10 Data from sampling point pk6.

Average			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	2,7	4,5	14,0
-25			
-50			
-75	1,2	-13,0	4,1
-100	1,3	-0,5	4,3
-125	1,3	12,1	4,4
-150	0,9	5,5	3,3

12-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	No Sample (no Rhizons available)		
-25	Sample too small		
-50	Sample too small		
-75	Sample too small		
-100	Sample too small		
-125	2,65	-5,7	4,4
-150	Sample too small		
22-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	3,1	3	14,3
-25	Sample too small		
-50	Sample too small		
-75	1,2	-13	4,1
-100	1,1	0	4,3
-125	0,5	23	4,4
-150	1	3	3,2
28-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	2,3	6	13,7
-25	Sample too small		
-50	Sample too small		
-75	Sample too small		
-100	1,4	-1	4,3
-125	0,7	19	
-150	0,8	8	3,3

Table 11 Data from sampling point pk15.

Average			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	5,5	-5,0	14,1
-25	1,3	5,0	11,2
-50			
-75	2,1	-14,6	3,7
-100	3,4	-2,5	2,0
-125			
-150	1,8	-1,0	4,1

12-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	No Sample (no Rhizons available)		
-25	1,9	-5,9	11,3
-50	Sample too small		
-75	2,09	-21,7	4,4
-100	1,72	-3,4	2,2
-125	Sample too small		
-150	1,6	-10,9	4,1
22-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	5	-4	13,8
-25	0,9	13	10,9
-50	Sample too small		
-75	2,2	-7	3,3
-100	4,3	3	1,9
-125	Sample too small		
-150	2	9	4,1
28-apr			
Depth (cm)	Oxygen (mg/L)	Redox (mV)	Salinity (g/L)
-15	6	-6	14,3
-25	1	8	11,3
-50	Sample too small		
-75	2	-15	3,4
-100	4,1	-7	1,9
-125	Sample too small		
-150	1,8	-1	4

On April 12th one measurement was done 3 hours before low tide. Because of the wind direction and tide, only pk5 was accessible. Only three Rhizons delivered a sample at this moment. The data are shown in the graphs below, but are not used for further analysis, since they don't show a pattern and are not validated with a second or third measurement.

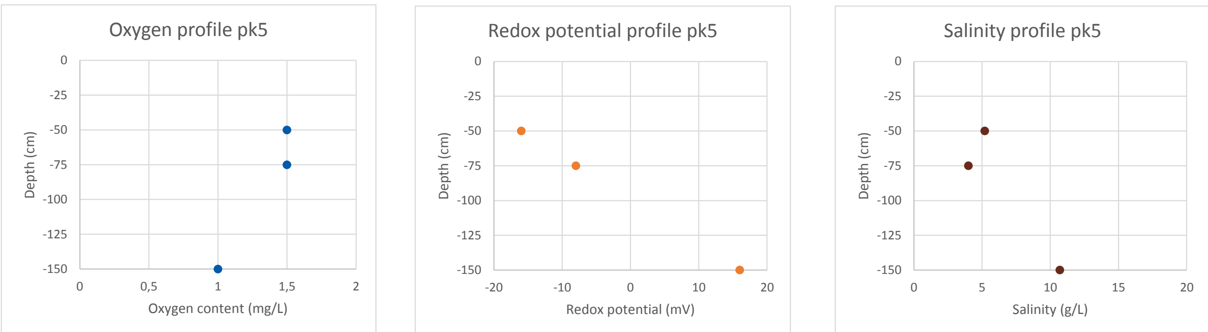

Figure 32 Oxygen level, redox potential and salinity of the sampling three hours before low tide on pk5.

Appendix 6, Diver data

The divers have been measuring the water level in the piezometers installed in the area. Piezometers on T1, T2, T3 and T4 were placed by Deltares. On these locations are piezometers at various depths installed. It was not always possible to use the shallowest (1-3 m deep) filter, so therefore the 5 and 6 meter deep piezometers were used. The data are corrected for the air pressure, so the graphs show the water level measured from the NAP reference. The main purpose is to show the pressure fluctuation in the groundwater. This might not indicate groundwater flow, but the conclusion explains more on this.

The diver data was converted to a water level by the Diver Office program. This requires the cable length, piezometer height and barometric data. The barometric data source is the Baro Diver, measuring the air pressure. It was placed inside a piezometer, but above the water table. The data from this Baro Diver is retrieved with Diver Office and the graph in figure 33 shows the data.

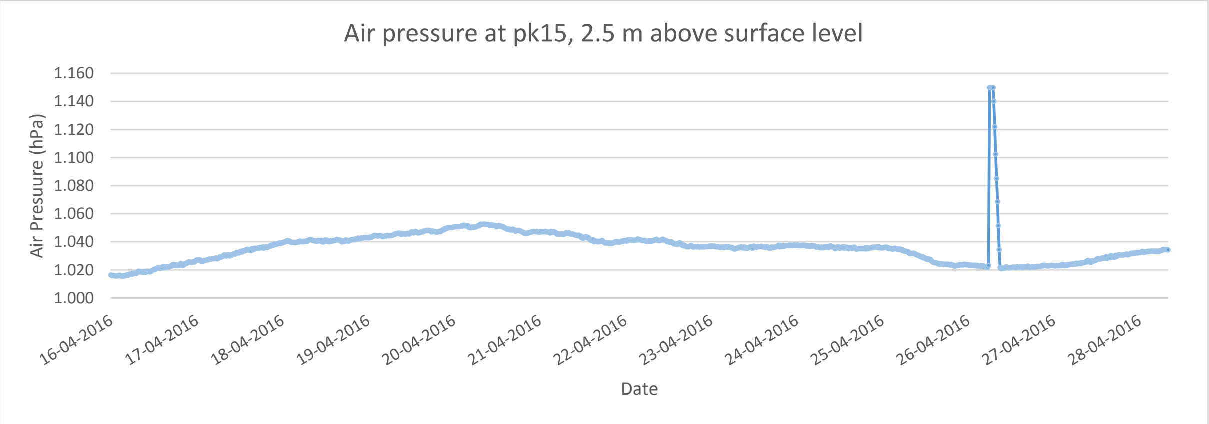

Figure 33 Air pressure measured by the Baro Diver on pk15.

Diver data from deeper piezometers

The diver data from the piezometers with the deeper filters are in the three graphs below. These piezometers are all installed by Deltares.

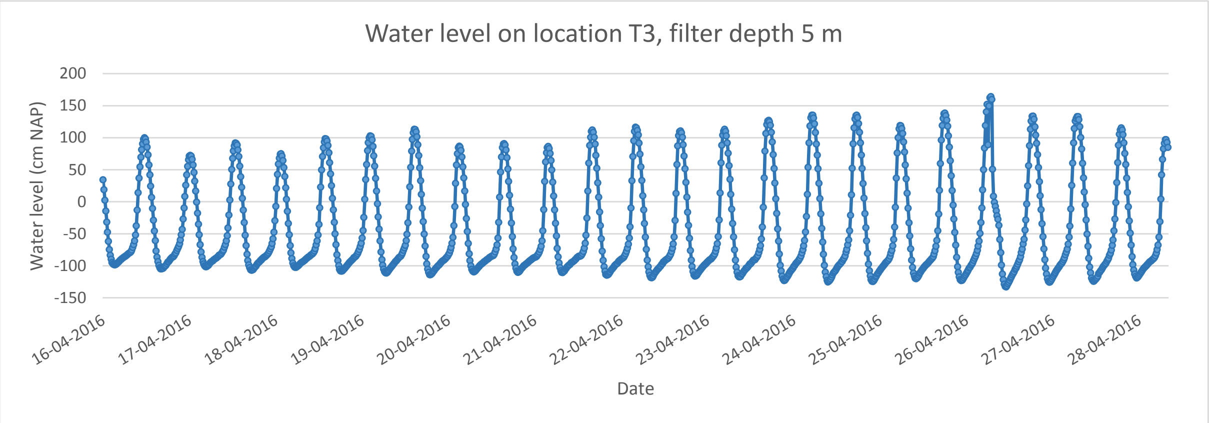

Figure 342 Water level in the piezometer with a filter at 5 m depth on location T3.

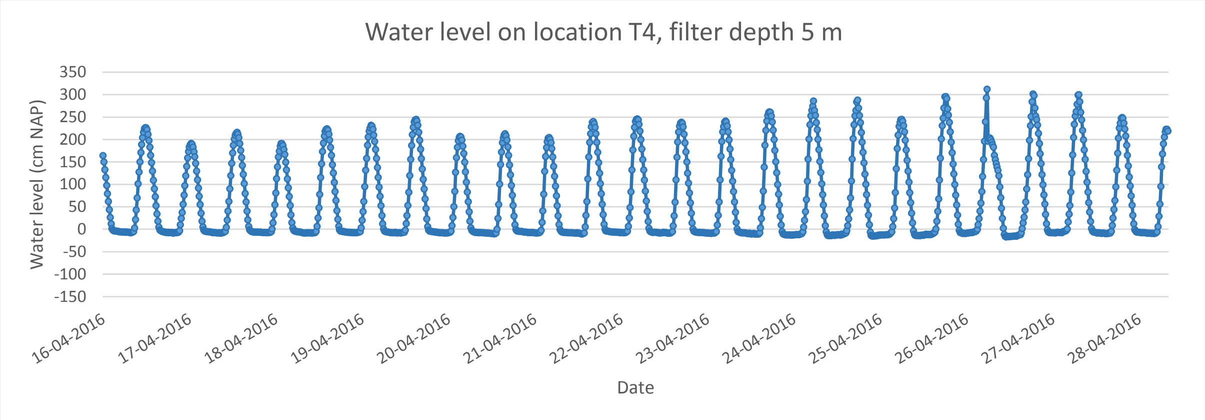

Figure 35 Water level in the piezometer with a filter at 5 m depth on location T4

Diver data from shallower piezometers

This paragraph contains the data from the shallower piezometers. These are, except for the one on T1, installed in March and April 2016. Data from the shallowest piezometer at pk15 (at 1 m depth) is unfortunately missing, since it was not possible to read the data.

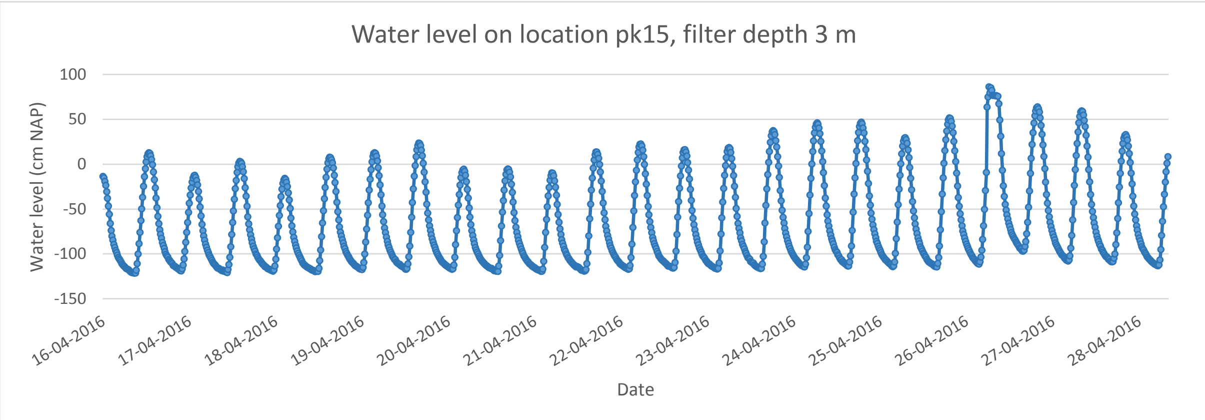

Figure 36 Water level in the piezometer with a filter at 3 m depth on location pk15.

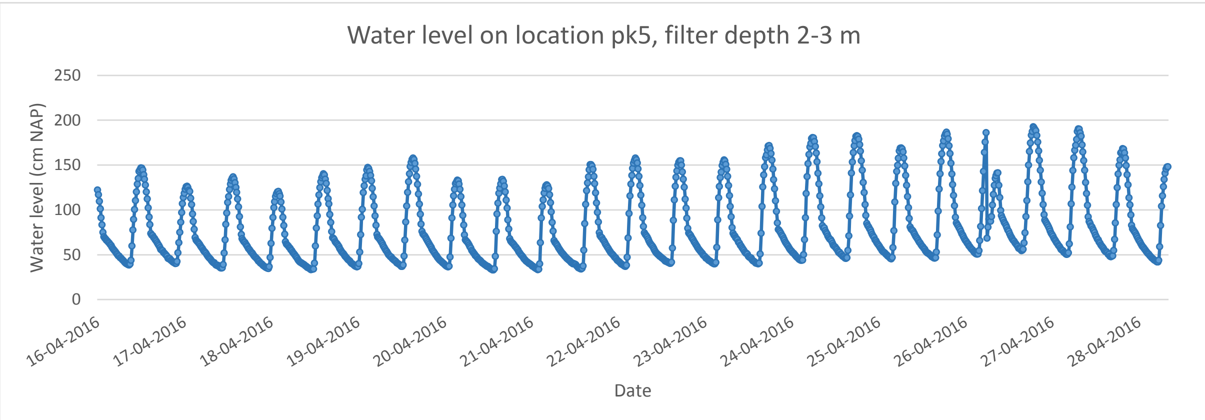

Figure 37 Water level in the piezometer with a filter at 3 m depth on location pk5

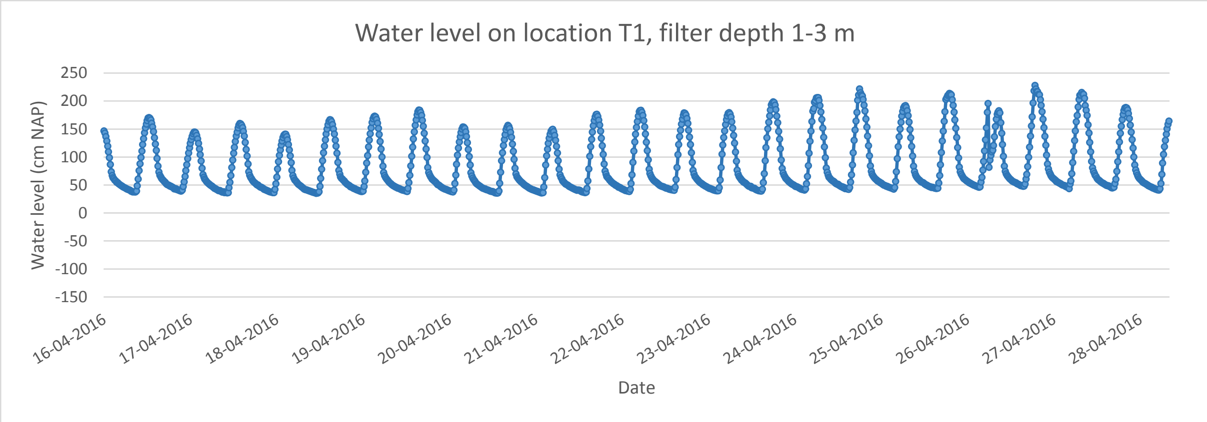

Figure 38 Water level in the piezometer with a filter at 1-3 m depth on location T1

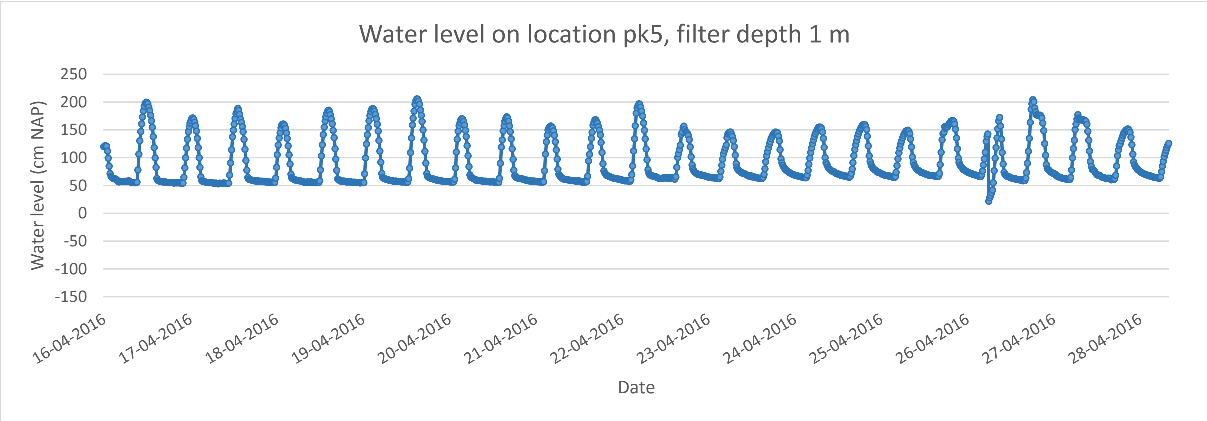

Figure 39 Water level in the piezometer with a filter at 1 m depth on location pk5.

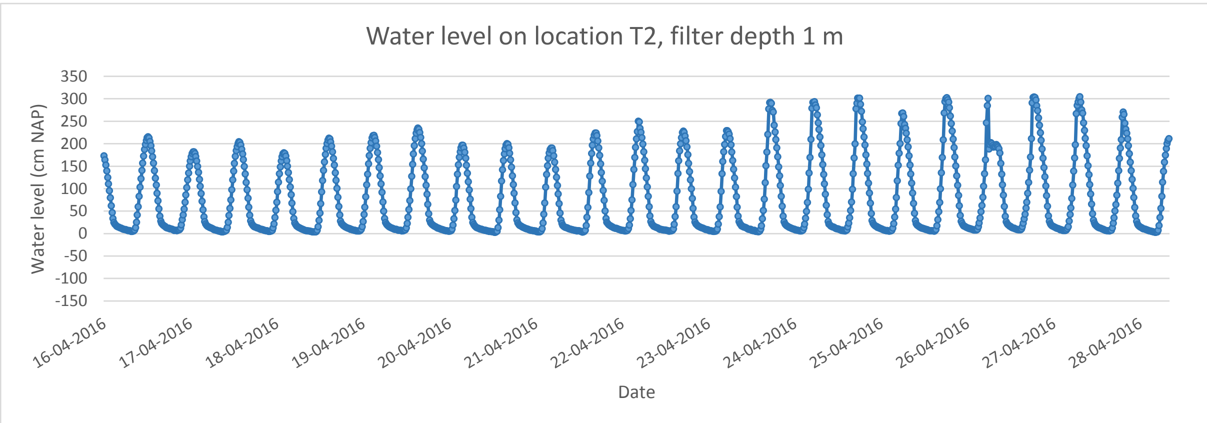

Figure 40 Water level in the piezometer with a filter at 1 m depth on location T2.

Appendix 7, Soil sample data

Malvern Mastersizer 2000

The first table in this appendix is the calculation of the fraction larger than 1 mm. This is done by weighing the sample, sieving it and weighing it again. The Malvern analyser cannot process particles larger than 1 mm, so therefore this is separated before.

Table 12 Soil samples of the three locations (T2, pk5 and pk15), with the weighing results and calculated percentage larger than 1 mm.

Location	Latitude	Longitude	Depth (cm)	Total weight (g)	Weight <1mm (g)	Weight >1mm (g)	Percentage <1 mm	Percentage >1mm
pk5	51.38625	4.02159	25	51,681	51,338	0,343	99,34	0,66
pk5	51.38625	4.02159	50	65,369	64,918	0,451	99,31	0,69
pk5	51.38625	4.02159	75	36,166	34,47	1,696	95,31	4,69
pk5	51.38625	4.02159	100	33,652	33,221	0,431	98,72	1,28
pk15	51.39277	4.02782	25	49,166	49,024	0,142	99,71	0,29
pk15	51.39277	4.02782	50	50,241	50,235	0,006	99,99	0,01
pk15	51.39277	4.02782	75	38,812	38,624	0,188	99,52	0,48
pk15	51.39277	4.02782	100	33,881	33,672	0,209	99,38	0,62
pk15	51.39277	4.02782	125	35,414	35,306	0,108	99,70	0,30
pk15	51.39277	4.02782	150	38,248	37,913	0,335	99,12	0,88
pk15	51.39277	4.02782	175	44,824	44,733	0,091	99,80	0,20
pk15	51.39277	4.02782	200	47,625	47,435	0,19	99,60	0,40
pk15	51.39277	4.02782	225	4,405	3,474	0,931	78,86	21,14
pk15	51.39277	4.02782	250	5,281	3,851	1,43	72,92	27,08
pk15	51.39277	4.02782	275	4,919	2,835	2,084	57,63	42,37
T2	51.38861	4.02051	25	30,984	30,596	0,388	98,75	1,25
T2	51.38861	4.02051	50	53,101	52,621	0,48	99,10	0,90
T2	51.38861	4.02051	75	40,859	40,536	0,323	99,21	0,79
T2	51.38861	4.02051	100	54,855	54,23	0,625	98,86	1,14

As the table shows, most samples have a very small percentage larger than 1 mm. Most of the soil found was sand, silt or clay. The deepest three samples from pk15 have a clearly higher fraction larger than 1 mm. These samples consisted of peat. In the peat, many large parts of organic material are still present. If dried, some of these fall apart so the true number could be even higher. The question remains if the measured particle size is correct and relevant, which can also be seen in the chart (Figure 15) in chapter 4.2. This chart shows for all samples the grain size distribution of the particles smaller than 1 mm. The classification is based on grain size, the table below the graph shows what this grain size means in words. The table before explains the classes used in this chart.

The table on the next page, Table 13, shows the determination of the organic matter in the soil samples. The darker marked lines indicate the sample which was tilted during the time in the exsiccator (pk15_50) and the peat samples (pk15_225, pk15_250 and pk15_275). The analysis of the organic matter content was only done with the fraction smaller than 1 mm. This means that especially from the peat samples, a major part was lost during sieving.

Table 13 Results of determining the organic matter in the soil samples. pk15_50 has tilted in the oven, pk15_225, pk15_250 and pk15_275 are peat samples.

Location	Depth (cm)	Cup weight (g)	Cup + sample before (g)	Cup + sample after (g)	Organic matter (g)	Organic matter (% <1mm)
pk5	25	65,3307	115,5946	113,9357	1,66	3,30
pk5	50	27,0646	75,4306	74,6559	0,77	1,60
pk5	75	36,3236	69,7736	69,2471	0,53	1,57
pk5	100	33,6645	66,1999	65,2053	0,99	3,06
pk15	25	65,333	113,913	112,7500	1,16	2,39
pk15	50	20,6481	70,1463	64,1513	5,99	12,11
pk15	75	36,8298	74,8764	73,6199	1,26	3,30
pk15	100	34,1091	67,4262	65,0953	2,33	7,00
pk15	125	36,3313	71,3147	69,7720	1,54	4,41
pk15	150	25,1542	62,7774	61,0722	1,71	4,53
pk15	175	51,2709	95,4758	93,3852	2,09	4,73
pk15	200	36,4673	80,2882	78,4604	1,83	4,17
pk15	225	20,8895	24,1921	21,8016	2,39	72,38
pk15	250	21,3737	25,0442	22,5653	2,48	67,54
pk15	275	27,0654	29,7164	28,2066	1,51	56,95
T2	25	36,8289	66,9178	66,0115	0,91	3,01
T2	50	25,1552	77,1869	75,5519	1,63	3,14
T2	75	51,2712	90,8158	89,4854	1,33	3,36
T2	100	36,0458	89,5975	87,8905	1,71	3,19

Borehole descriptions

This section contains the full borehole descriptions of the boreholes made for placing piezometers.

Table 14 Borehole description of the piezometer hole on location T2.

Measuring point (number)	T2	
Filter depth (cm below surface)	80 cm	
Filter length (cm)	20 cm	
Depth of filter sand (cm below surface)	75 cm	
Amount of water used on site (L)	None	
25		**Example key words/questions**
Smell	None	Rotten/anoxic/no smell
Texture	Sandy clay	sandy/clay/wet/dry
Color	Brown	grey/brown/black
Anthopogenic components	None	rocks/debris
Gley / oxidation / 'corrosion'	Few dark spots	e.g. brown rust spots
Extra information	Ball can be formed, not very dense	can you form a ball?
50		
Smell	None	
Texture	Sandy clay	
Color	Brown with black and rust spots	
Anthopogenic components	Little debris, small pieces	
Gley / oxidation / 'corrosion'	Dark spots + gley	
Extra information	None	
75		
Smell	None	
Texture	Sandy clay, more clay	
Color	Dark brown	
Anthopogenic components	none	
Gley / oxidation / 'corrosion'	none	
Extra information	none	
100		
Smell	None	
Texture	Sandy clay	
Color	Dark brown/rust spots	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	Rust spots	
Extra information	None	

Table 15 Borehole description of the piezometer hole on location pk5.

Measuring point (number)	pk5	
Filter depth (cm below surface)	80 cm	
Filter length (cm)	20 cm	
Depth of filter sand (cm below surface)	75 cm	
Amount of water used on site (L)	None	
25		**Example key words/questions**
Smell	None	Rotten/anoxic/no smell
Texture	Sandy clay	sandy/clay/wet/dry
Color	Brown	grey/brown/black
Anthopogenic components	None	rocks/debris
Gley / oxidation / 'corrosion'	Gley spots	e.g. brown rust spots
Extra information	Ball can be formed	can you form a ball?
50		
Smell	None	
Texture	Sandy clay, more sandy	
Color	Brown with black and rust spots	
Anthopogenic components	Little debris, small pieces	
Gley / oxidation / 'corrosion'	Dark spots + gley	
Extra information	Ball can be formed	
75		
Smell	None	
Texture	Sandy clay, more sandy	
Color	Dark brown	
Anthopogenic components	none	
Gley / oxidation / 'corrosion'	none	
Extra information	none	
100		
Smell	None	
Texture	Clay	
Color	Dark brown/rust spots	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	Rust spots	
Extra information	Dense ball can be made	

Table 16 Borehole description of the borehole for the piezometer of three meters deep at location pk15 until a depth of 150 cm.

Measuring point (number)	pk15	
Filter depth (cm below surface)	200 cm	
Filter length (cm)	100 cm	
Depth of filter sand (cm below surface)	200 cm	
Amount of water used on site (L)	None	
25		**Example key words/questions**
Smell	None	Rotten/anoxic/no smell
Texture	Dense clay, wet	sandy/clay/wet/dry
Color	Grey/brown	grey/brown/black
Anthopogenic components	None	rocks/debris
Gley / oxidation / 'corrosion'	None	e.g. brown rust spots
Extra information	Dense ball	can you form a ball?
50		
Smell	None	
Texture	Dense clay, moist	
Color	Grey/brown	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	None	
Extra information	Dense ball	
75		
Smell	None	
Texture	Dense clay, moist	
Color	Grey	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	None	
Extra information	Dense ball	
100		
Smell	None	
Texture	Dense clay, dry	
Color	Grey	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	None	
Extra information	Dense ball	
125		
Smell	None	
Texture	Dense clay, moist	
Color	Grey with spots	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	Gley	
Extra information	Ball, less dense	
150		
Smell	None	
Texture	Dense clay, wet	
Color	Grey/brown with spots	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	Gley	
Extra information	Ball, less dense	

Table 17 Borehole description of the borehole for the piezometer of three meters deep at location pk15 of 175 cm and deeper.

175		
Smell	Organic material	
Texture	Mixture clay. Peat	
Color	Grey, light brown	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	None	
Extra information	Ball, less dense	
200		
Smell	None	
Texture	Sandy clay	
Color	dark grey	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	None	
Extra information	None	
225		
Smell	Organic material, not rotten	
Texture	Coarse, moist, peat	
Color	Light brown	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	None	
Extra information	Peat	
250		
Smell	Organic material, not rotten	
Texture	Coarse, moist, peat	
Color	Light brown	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	None	
Extra information	Peat	
275		
Smell	Organic material, not rotten	
Texture	Coarse, moist, peat	
Color	Light brown	
Anthopogenic components	None	
Gley / oxidation / 'corrosion'	None	
Extra information	Peat	
300		
Smell	**No Sample (too much mixing of layers)**	
Texture		
Color		
Anthopogenic components		
Gley / oxidation / 'corrosion'		
Extra information		

Appendix 8, Weather data

Especially the shallow samples can be influenced by precipitation during the sampling time or just before this. To have an impact, the soil has to be permeable and the precipitation has to be enough to dilute the present groundwater. The KNMI data show 0 to 1 mm precipitation on the days of sampling (KNMI, 2016). Assumed is that precipitation has not influenced the data in this dataset.

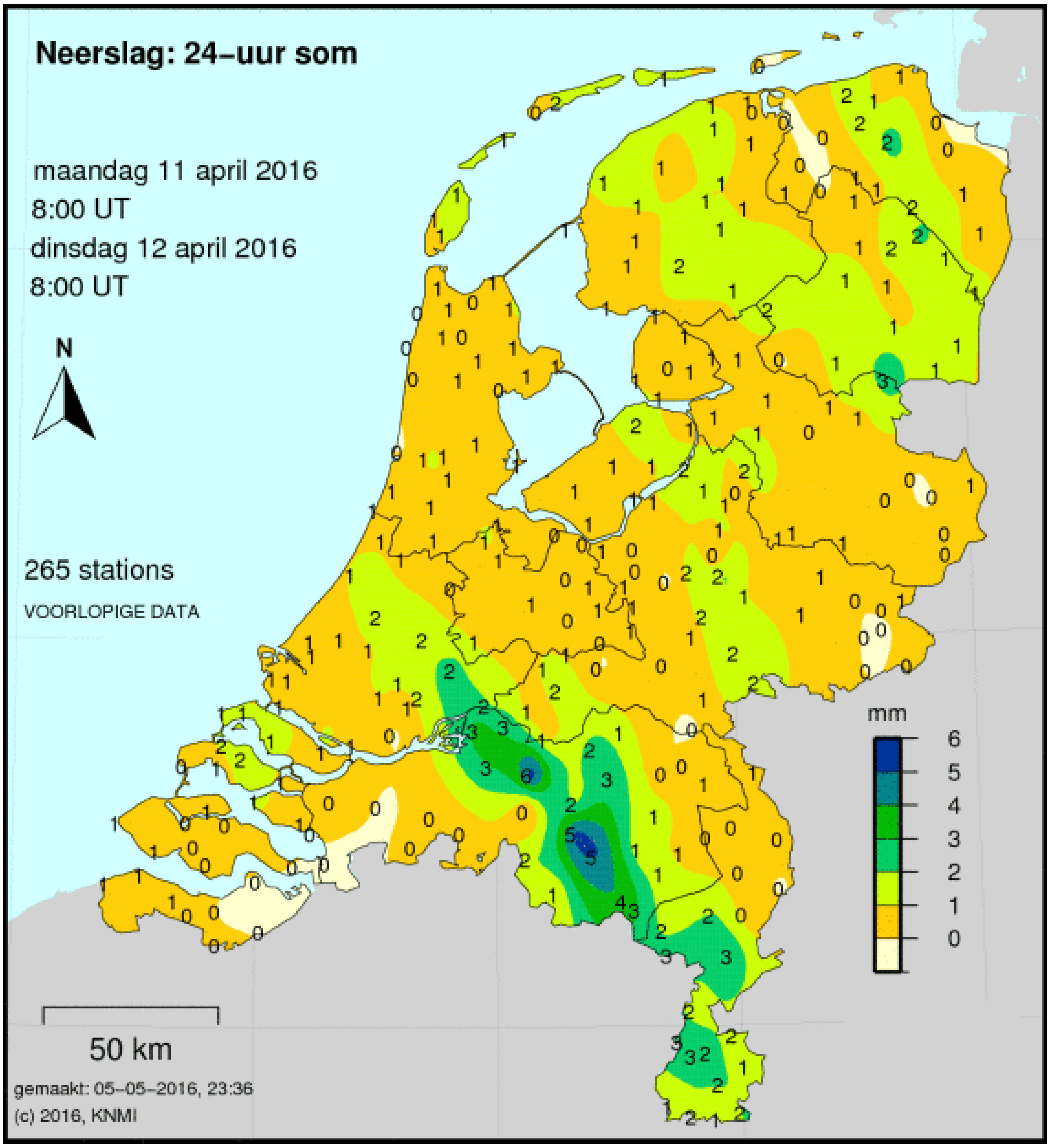

Figure 41 Precipitation over 24 hours on April 12th, 2016 (KNMI, 2016).

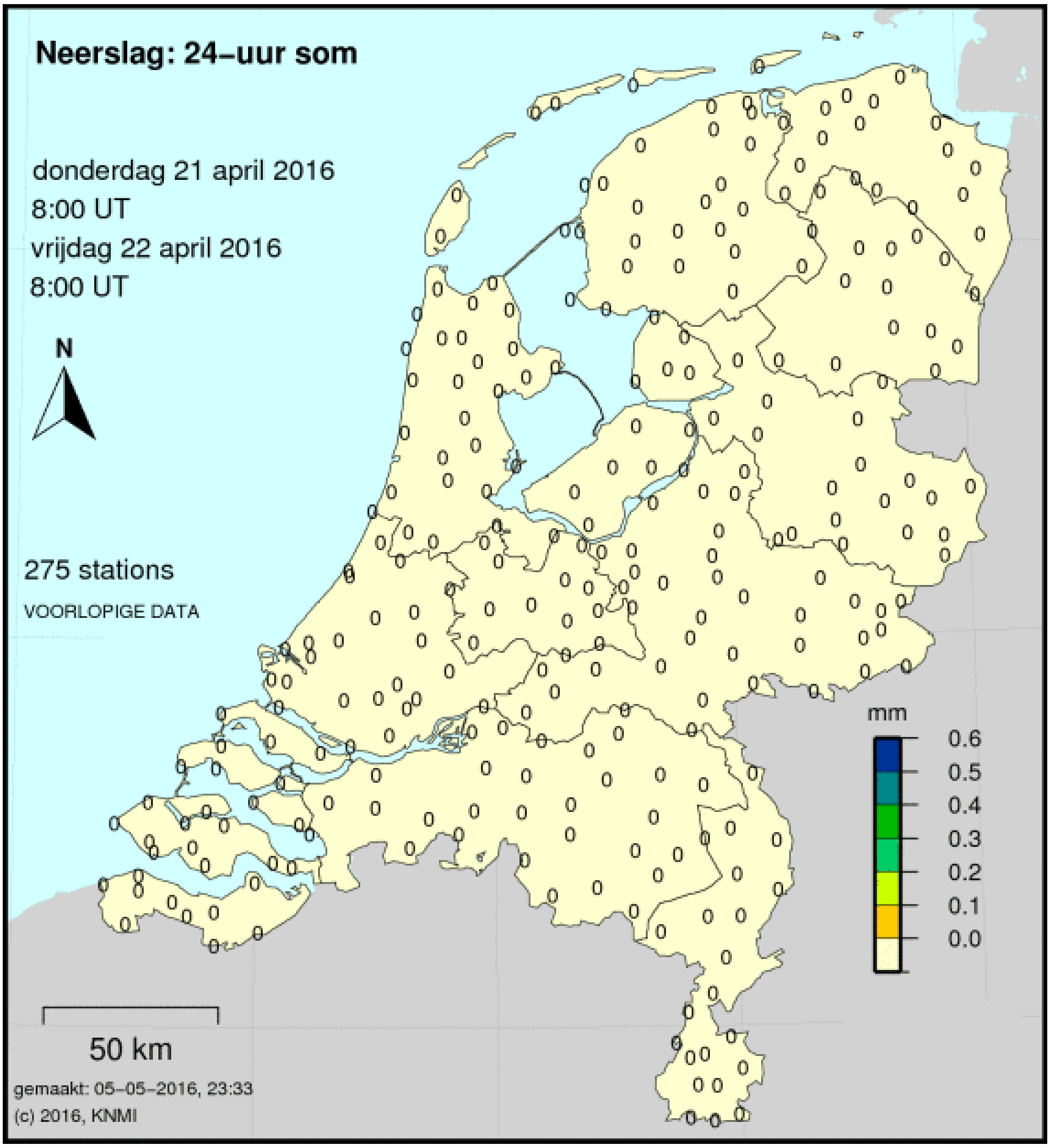

Figure 42 Precipitation over 24 hours on April 22nd, 2016 (KNMI, 2016).

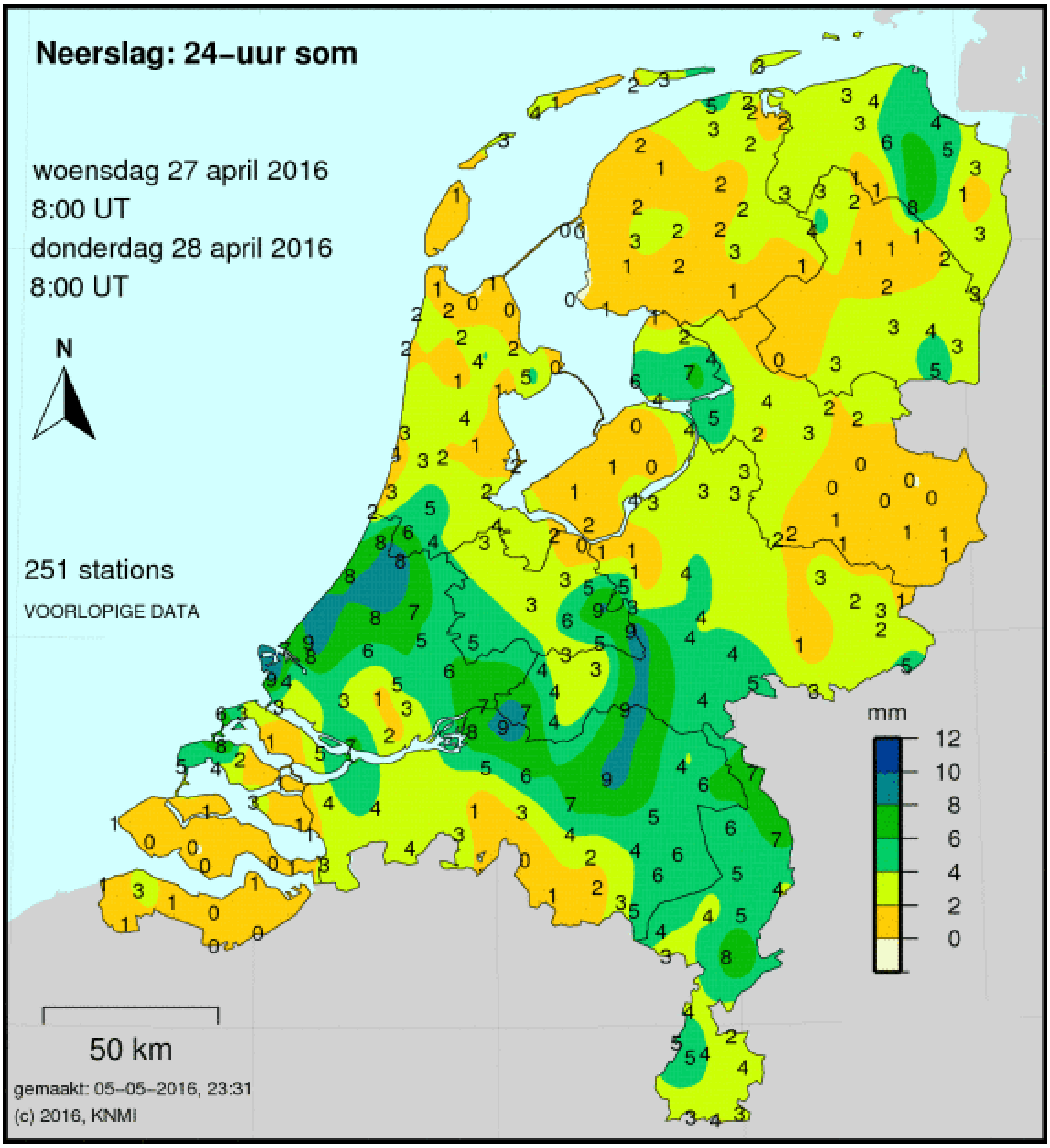

Figure 43 Precipitation over 24 hours on April 28th, 2016 (KNMI, 2016).

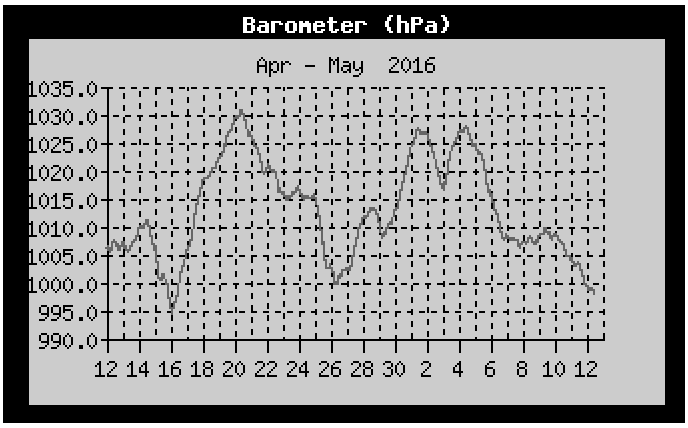

Figure 44 Barometric data from Waterschap Scheldestromen (Hertogh, 2016).

Appendix 9, Method for placing piezometers with Divers

Piezometers are placed on three measuring points where there wasn't one from Deltares already. The piezometers are used for monitoring phreatic groundwater levels and measuring the salinity of this layer. The piezometer can be placed by following the next procedure while filling out the borehole description form (Similar to the filled out ones in appendix).

1. Put the lower casing tube vertically into the ground, push it thought the sediment layer
2. Start drilling the hole, push the casing tube down when possible.
3. Put all drilled material in a line next to the borehole. Make sure the distance/length of the strip of soil matches the depth of the hole.
4. Take 1 sample of each soil layer (about 50 ml).
5. Insert the piezometer. Attach a cap to the bottom of the filter and attach enough riser tubes so the tube reaches above the casing when placed.
6. If the well has the desired depth, fill the borehole with sand until the top of the filter. Extract the casing slowly while filling with sand. Don't extract it completely, only until the height to which the borehole is filled.
7. Add Bentonite pellets, approximately a layer of 15 cm on top of the filter.
8. Extract the casing and let the hole collapse. Make sure it does not fill up with sediment completely, so try to fill it with the extracted soil if it doesn't collapse by itself.
9. Add riser tubes so the tube reaches above the mean high water (in this case 3 m above surface level).

When the piezometer is in place, a Diver water level logger can be placed in the tube. It has to be below the water table to do its measurements. The Diver is hanging on a rope in the piezometer, of which the length must be measured. Also, the height of the top of the piezometer must be measured from a reference (in this case NAP). This is explained by the drawing from Diver Office 2016, figure 45. The cable length and referenced height of the piezometer are needed for the water level calculation, since the Diver only measures pressure.
Apart from that, a barometric compensation is needed, so a barometer has to be placed as well. For this, a Baro Diver is used, which is a Diver which measures air pressure. The Baro Diver is also placed inside a piezometer, but above the water table so it only measures air pressure.

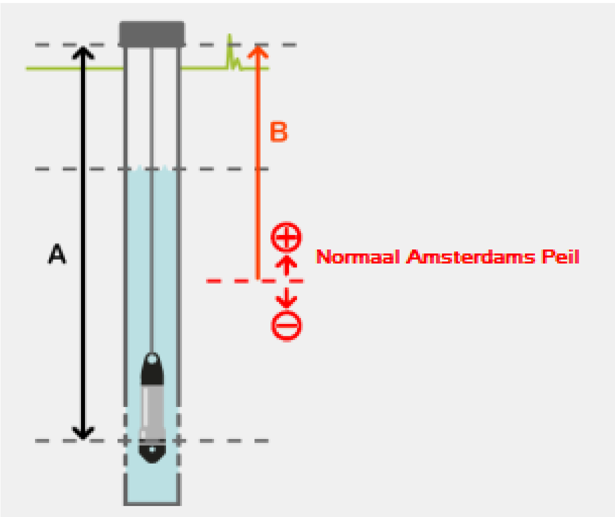

Figure 45 Screenshot from Diver Office 2016 with the drawing to clarify the cable length and piezometer height.

Appendix 10, Method for placing MacroRhizons

MacroRhizons are filters to sample soil water and groundwater. The filter has a length of 10 cm, a diameter of 4,5 mm and a pore size op 15 µm. The filter is placed in the soil at the depth of which a sample has to be taken. Extraction of the water can be done by following the procedure in Appendix 9.

The Rhizons will be placed at depths of 25, 50, 75, 100, 125 and 150 cm. This depth indicates the middle of the MacroRhizon filter. Installing a MacroRhizon at the correct depth was done by following this procedure:

1. Make a hole in the soil with a metal pin or auger. The depth should be about 5 cm less than the depth of the MacroRhizon.
2. Take the cap of the MacroRhizon, connect the syringe and fill the filter and hose with water from a bottle. Close the tap, remove the syringe.
3. Place the MacroRhizon in the hole. Fill the hole with a little bit sand and bentonite pellets to seal the hole. Top the hole off with soil taken out of it, if a hole was drilled.
4. Place a stick next to the MacroRhizons which are 25, 50 and 75 cm in the ground. Secure the MacroRhizons to the stick.

If the MacroRhizon is placed with an auger (or even with a casing), it is in the soil as a small piezometer. The main differences is that in a piezometer, the water gets in contact with air and in a Rhizon it doesn't.

For sampling at 15 cm deep, a Rhizon was brought to the field each time. It cannot be placed steady enough in the soil to leave it in place permanently. In some soils, it's also better to place it at an angle to ensure good contact with the soil it is placed in.

Appendix 11, Method for sampling with MacroRhzions

To take a sample from a Rhizon, follow the next steps:

1) Take the cap off the syringe
2) Take the cap from the Rhizon
3) Attach the syringe to the Rhizon
4) Open the tap on the Rhizon
5) Create a vacuum and wait until about 5 -10 ml is in the syringe.
6) Close the tap, remove the syringe and discard the water from it.
7) Re-attach the syringe, open the tap again
8) Create a vacuum, place the spacer (pvc tube) in the syringe as demonstrated
9) Wait until 40-50 ml is in the syringe. If this takes over 45 minutes, you can stop at at least 30 ml)
10) Remove the spacer, close the tap, unscrew the syringe.
11) Remove the air from the syringe and place a cap on it.
12) Place the cap on the Rhizon.
13) Take the samples to the car to measure oxygen and salinity.

To measure the oxygen and salinity of the water, follow these steps:

1) Hold the syringe vertically with the opening to the top.
2) Remove the cap
3) Pull out the plunger up to 60 ml
4) Screw the cap back on and turn the syringe around carefully and slowly
5) Remove the plunger
6) Measure first oxygen, then then salinity with as little stirring as possible
7) Put the plunger back in, remove the air and close the syringe again.

Appendix 12, Rammegors

Measuring points

From the measuring points of Royal NIOZ and Deltares, a choice has been made to reduce the number of points for this research. This is done mainly because of the limited timeframe in which the research had to be completed. The locations in both Perkpolder and Rammegors were chosen in such a way that between one set of points, only the distance to the channel was variable. The points in one set have the same elevation and are within the same area. The general elevation of Rammegors is higher than Perkpolder.

The locations chosen in Rammegors are visible on the map on the following page and in the table below (Table 18). The locations are chosen to get a diversity in elevation, to relate the soil waters salinity profile to both the elevation and distance to the channel. The distance to the channel is determined in ArcGIS.

Table 18 Measuring points Rammegors.

Measuring point	Elevation (mNAP)	Distance to channel (m)
RG2	0,92	5
RG4	0,94	130
RG8	1,26	62
RG13	1,33	150
RG9	1,18	210
RG12	1,48	15
RG6	1,52	200
RG5	1,52	410

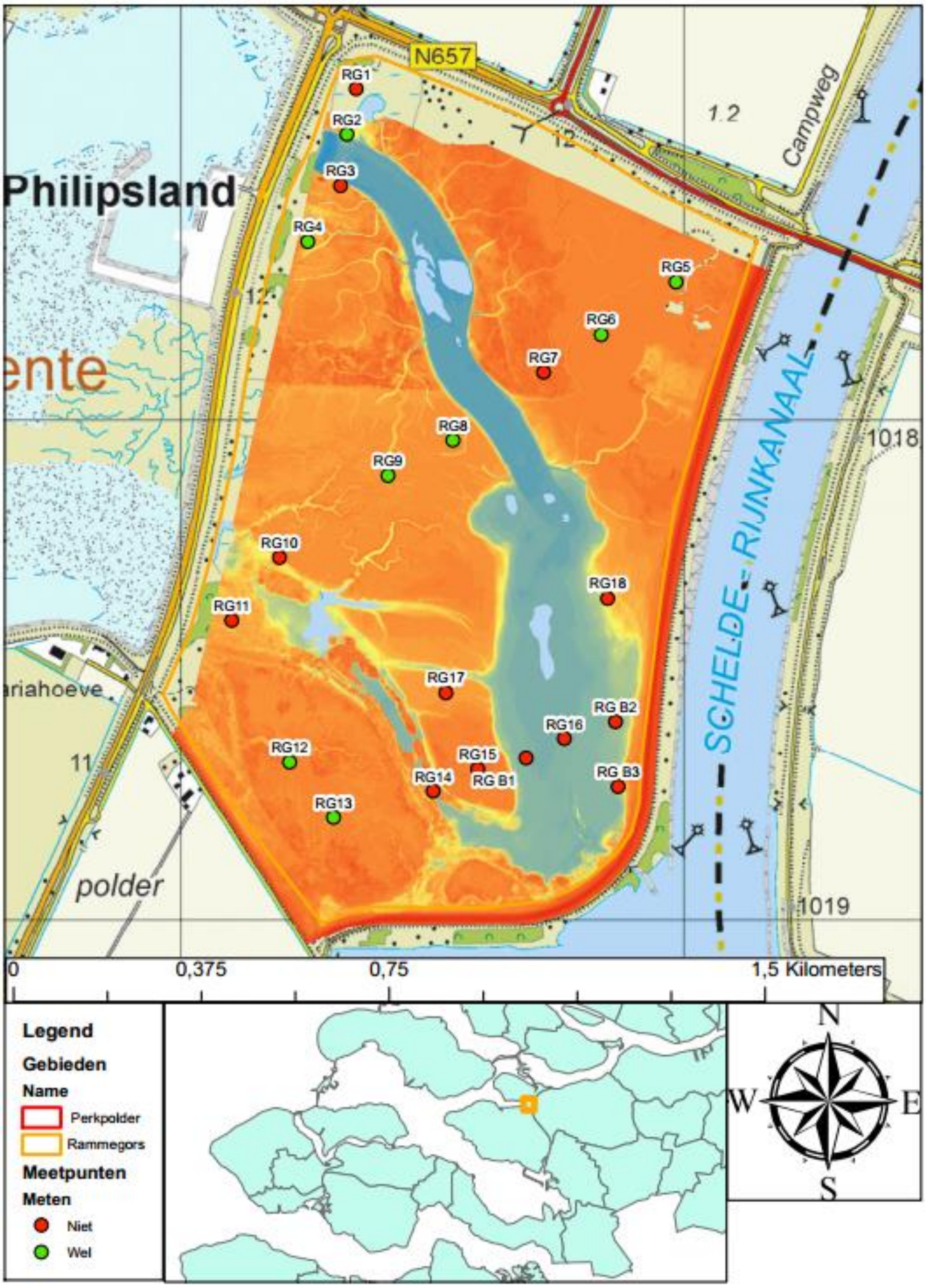

Figure 46 Map with the selected measuring points at Rammegors.

Area description of Rammegors

Various interceptions in the Southwestern Delta made the acreage of intertidal area and salt marshes decrease considerably. These intertidal areas had a great ecological value. In addition to that, the storm surge barrier in the Eastern Scheldt caused a lack of sediment transport into the estuary, known as sand hunger. This is caused by the changing currents, flow velocities and tidal influence. The tidal influence decreased by the storm surge barrier which brought sedimentation and erosion out of balance. (Provincie Zeeland, 2009)

Until 1971, Rammegors was connected to the Krabbenkreek, a tidal channel in the Eastern Scheldt. The area was closed off by the Krabbenkreekdam and it turned into a natural area used for depositing dredged soil. It was a fresh water system, without any tidal influence. The connection with the Eastern Scheldt is restored since December 2014. The tides should be able to influence the area again, part of the Natura 2000 plan. There were however some problems with erosion around the culvert because of high flow velocities and erosion. The culvert was closed again (from February 2016 until probably August 2016) to reinforce the base of the culvert without the water passing through it. The image below shows the desired situation for Rammegors. Rijkswaterstaat expects this situation to be reality in 2018.

Figure 47 Desired situation for Rammegors for 2018 (Arcadis Landschapsarchitectuur, 2014).

Natura 2000 is a European network of national parks in which specific target species can live. These areas are chosen to realise a network servicing these species and keeping their populations healthy. In The Netherlands, there are 166 Natura 2000 areas, for each of which a management plan is composed. This plan contains information about the goals of the area and the different tasks related to that. (Regiegroep Natura 2000, 2015)

One of these national parks is the Eastern Scheldt. The acreage of tidal flats and salt marshes decreased strongly because of the storm surge barrier. The barrier disturbed the balance between sedimentation and erosion, in favour of erosion. Estimated is that around 10 per cent of the intertidal natural areas are lost already. The lack of sediment supply made the Eastern Scheldt more clear. This also means there is less transport of sediment to the intertidal areas, so intertidal flats cannot grow into salt marshes anymore. The sediment transport is now not going towards the mudflats, but away from those towards the channels. (Ministerie van Economische Zaken, sd)
The development of Rammegors will contribute to increasing the acreage of estuarine nature and enlarge the habitat of halophytes and various animals.