3B: Groundwater levels Utrechtse Heuvelrug

RESEARCH REPORT

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Date: June, 2021

UTRECHT UNIVERSITY | REGIONAL INTEGRATION PROJECT (GEO1-2416)

Contents

1. Introduction

Average temperatures in Europe are progressively rising due to climate change which leads to dropping water tables throughout the continent (Teuling, 2018). The access to groundwater, so the fresh water stored in the soil (United States Environmental Protection Agency, 2020), is affected by “the season, climate [and] human impact” (National Geographics Society, 2020). When there is a grave, constant strain on the groundwater table, there is a subsequent risk for droughts. A drought is a period of drier than normal conditions that result in water related problems (Nagarajan, 2010). External factors such as a lower precipitation over time and higher temperatures all lead to a drier system and may cause droughts.

The Netherlands is a relatively wet country with a yearly precipitation mean ranging between 700mm and 900mm (RIVM, 2018). Past hot summers and heat waves however have negatively influenced the groundwater table, as well as the continuously increasing water extraction. This has led to more drought exposure in the Netherlands over the last years (Bakke, 2020) which had severe impacts on ecosystems, agriculture and other sectors (Teuling, 2018). Therefore, it is important to measure the potential for droughts and promote proactive research, especially in sensitive ecosystems.

The Utrechtse Heuvelrug is with an area of 20.000 hectares the second largest National Park of the Netherlands located between Utrecht and Amersfoort (NPUH, Over NPUH, 2021). It is responsible for providing recreation and drinking water to nearby municipalities (NPUH, Over NPUH, 2021). The Netherlands is well known for its water management and systems (van Steen & Pellenbarg, 2004) due to its long history of trying to manage and control the water. To maintain control and knowledge of the water systems, heavy research and management must be implemented (van Steen & Pellenbarg, 2004). An important factor that the country must maintain is its groundwater table. Additionally, research in this specific National Park is relevant, because of its diversity in soil types and land uses. Next to that, it has large elevation differences, which is quite unique in the Netherlands and can influence the water table as well (Heemsbergen, 2021; Actueel Hoogtebestand Nederland, n.d.).

Water tables change depending on the surrounding area and location of the site. Water tables close to a waterbody vary from the inflow to the localized waterbody flow system (Ala-aho, 2013). The aim of this research is to get an overview of how the Utrechtse Heuvelrug, can be maintained so that a conclusion can be drawn to what extent the factors affect the groundwater table to ensure a drought resilient Heuvelrug. Data was collected and correlations between factors were analyzed to answer the question of how site-specific factors influence the groundwater table, near small water bodies in the area of the Henschotermeer and Veenplas of the Utrechtse Heuvelrug.

2. Literature review

2.1 Groundwater tables

The water table and the groundwater are essential concepts with regards to this research. The groundwater is located between the pores of particles in the ground. It can be divided into two sections: saturated and unsaturated zone. The saturated zone is located beneath the unsaturated zone and is characterized by the water filling up all the pores and open spaces in the ground. In the unsaturated zone both water and air make up the pores and open spaces and it is located directly below the ground surface (United States Environmental Protection Agency, 2020). The term water table describes the boundary between the unsaturated and saturated zone (United States Environmental Protection Agency, 2020).

The four main hydrological factors influencing the groundwater and water table are: precipitation, evaporation, storage, runoff to land surfaces (Evaristo, Lecture 5: River basin hydrology, GEO1-2412, slide 5,8,17,18., 2020). Of these factors only precipitation increases the water table (United States Environmental Protection Agency, 2020). In contrast, evaporation and runoff decrease the amount of water in the ground and lower the water table. The amount of storage that is available in the ground defines to what extend the water table changes during precipitation events or droughts (National Geographics Society, 2020).

2.2 Factors influencing the groundwater level of the Heuvelrug

2.2.1. Water bodies

Water bodies are considerable buildups of water such as lakes, the result of waterbodies effects the water table in surrounding areas. The first way that water bodies can be formed is mainly by a collection of precipitation and runoff in a lower elevated area (Surface Water, 2019). Water from these then seep into the ground and raises the water table. However, this does not necessarily mean the water table is close to the surface. Another way water bodies are created is when the elevation drops so much the water table intersects the surface (McConnel, 2010). In these cases, the groundwater creates the water bodies, but if the water table drops it can distribute water back. This results in the water table being close to the surface directly around the lake.

2.2.2. Vegetation type & cover

In the Utrechtse Heuvelrug, forest is the main vegetation type, but heathland, sand drifts and grasslands can also be found (Stortelder & Hommel, 1990). The main tree species are deciduous Linde, Sycamore, European beech, Common oak, Birch, Black pine and Cots Pine, and the coniferous Japanese larch, Douglas fir and Norway spruce (Stortelder & Hommel, 1990). The water use of plants is determined by their transpiration rate and interception ratio (Nisbet, 2005) and research has shown that conifers use generally more water compared to deciduous trees due to high interception rates (Nisbet, 2005). Heathlands on the other hand use less water than forests because of lower transpiration rates (Nisbet, 2005).

Many experimental studies have found a negative correlation between vegetation cover by phreatophyte vegetation (deep rooting plants) and height of the groundwater table. It has been shown that clear-cutting of forests leads to an increase in groundwater table and even in some cases to waterlogging (Doubé et al, 1995), whereas the planting and growing of trees has been proven to decrease the groundwater table (Han et al., 2020). These observations have been explained by transpiration of the vegetation and rainfall interception.

2.2.2 Elevation change

The name of the research area, Utrechtse Heuvelrug, stems from the elevation that runs from north to south through the region and was formed by glaciers in the ice age (NPUH, Over NPUH, 2021). Differences in surface elevation affect the height of the water table. If the land surface increases in height the water table gets pulled up with it to a certain extent which results in a ‘water table bubble’. That means that the water table is relatively higher than the in the surrounding areas. However, the water table tends to level out due to gravity, which leads to deeper water tables if measured from the top of the hill, despite the relative increase in height, as seen in *Figure 5* (NPUH, 2021). The opposite is true for lower elevated sites in the landscape where the water table is closer to the surface, but lower than the surrounding groundwater.

2.2.3. Soil type

The soils of the Utrechtse Heuvelrug largely consists of sandy soils varying from fine to coarse sand as seen in *Figure 6*. There are also small areas that consists of light clay soils. The permeability of those soils is a major influence on groundwater flow (Gleeson, 2015) and varies between different soil types. Depending on the particle size of the soil, the groundwater can permeate at different rates, with sandy soil being more permeable than clay soil (Bot, 2011). The humus layer is the top layer of soil, abundantly made from organic matter. Low amounts of organic matter increase water retention in sandy soils but reduce the water retention in soils with smaller pore sizes. With high concentrations of organic matter or even a humus layer however the amount of water retention increases regardless of the soil type (Rawlsa et al., 2003).

3. Methods

To collect valuable data, a dynamic sampling strategy was applied. First, 13 sampling points in the north-eastern part of the Utrechtse Heuvelrug with a rather large distance of 980 meters in between them were allocated (see *Figure 1*). The groundwater table was reached at two of these sampling points, which allowed an increase in resolution of the data-collection by allocating another 15 sampling points randomly within a 500-meter radius around those two sampling points (see *Figure 1*). Lastly, resolution was increased further by focusing on two routes leading away from the Veenplas, a water body that was part of the sampled area. The routes were defined by an initial distance to the lake of ten meters and five sampling points at increments of 20-meter distance. The directions were chosen to go through a forested area and a heathland without trees in the immediate proximity to the sampling points, to allow for direct comparisons (see *Figure 1*).

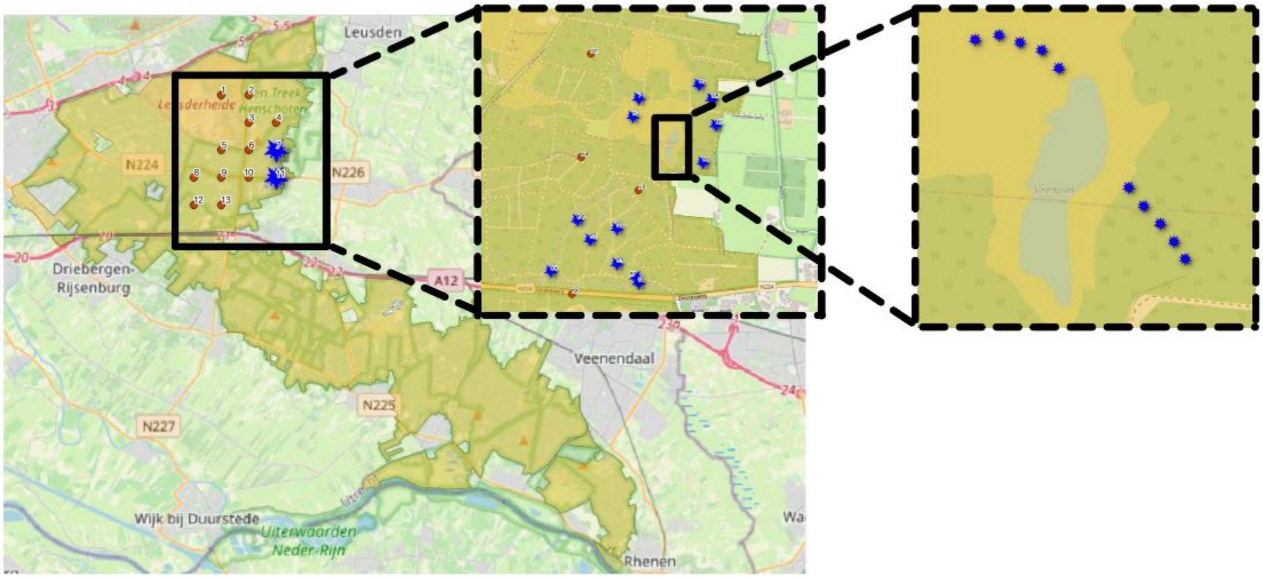

Figure 1: Sampling points in increasing resolution. Blue Stars indicating water table was reached. Red points indicating water levels was not reached

To navigate to the planned sampling point, the GPS-system of a smartphone was used. This method has an uncertainty of maximum 10 meters horizontally. To define the parameter of elevation, the elevation data provided by the “Actueel Hoogtebestand” (AHN, 2021) with a precision of 5 meters was applied. For each location, the reported height was exported with the help of QGIS.

At each location, the depth of the groundwater table was determined with an auger which was defined as the depth at which the soil became saturated with groundwater and thereby largely fluid. The measurement of depth was taken immediately to avoid soils flowing in and altering the water level. This measurement point marked the center from which, in a radius of 10 meters, vegetation cover was estimated, and the number of trees were counted. Canopies of fully-grown trees were not considered as part of vegetation cover, since they were accounted for as individual species, however trees smaller than 3 meters were not counted as trees but were included in the vegetation cover. As rainfall could have caused errors in water depth of sample points, it was noted in each measurement set if precipitation occurred at the time of sampling or in the last 24 hours. All measurements were collected in Survey123.

At each sampling point, a set of variables was collected (see *Table 1* below). These are listed together with the measuring method in the following paragraphs.

No.	Variables collected per sample	Measurement
1	Sample number	Number 1 to 38
2	Group member	Name of the member taking the measuring point
3	Date of extraction	Day and hour of extraction
4	Rainy conditions in last 24h	Yes/No
5	Location of Sampling point	Latitude and Longitude
6	Elevation of Sampling point	Meters above sea-level
7	Depth of Groundwater table	Meters below surface
8	Height of water table above sea level	Meters above surface
9	Closest distance to small lake	Meters from the lake
10	Closest distance to Henschootermeer Lake	Meters from the lake
11	Vegetation Cover	Percentage of bare soil area covered when viewed from above
12	Type of soil	Sand, Clay or a mix

Table 1: overview of the data collection template

The measurements were explored and analyzed in SPSS. First, a normality test on all variables shown in table 1 was carried out (except for variable 1-5 and 12). In this research the focus is on finding correlations between the groundwater table and the other variables with the aim of sustainable water management. Due to the non-normally distributed water table depths solely Spearman's Rho tests were used.

The regression models in the depicted scatterplots, were chosen after a sequential analysis was performed to check if a quadratic or linear regression is more applicable. In the statistical analysis, the variable "distance to lake" was defined as the smaller distance to one of the two lakes. For some analyses the depth of the groundwater was used as a scale value. This only includes the measurements that reached the water table (N=23). For other analyses all measurements (N=38) were converted to ordinal values with the following classification:

1) Water tables shallower than 120cm

2) Depths between 120cm and 220cm

3) Water tables deeper than 220cm

4. Results

4.1 Distance to closest water body

In the scatterplot (*Figure 2*) it can be seen that the further the distance of the sampling point is it to a lake, the deeper the groundwater table is. The line of fit indicates this with a positive slope. This is supported by the results of the Spearman's Rho test which indicated a strong positive statistical correlation (Spearman's rho test, N=23, p=0,009, Rho=0,533) between the two variables. The model's strength did not increase markedly when applying a quadratic regression (R=0,698 p=0.001) instead of the linear regression (R=0,695, p<0.001).

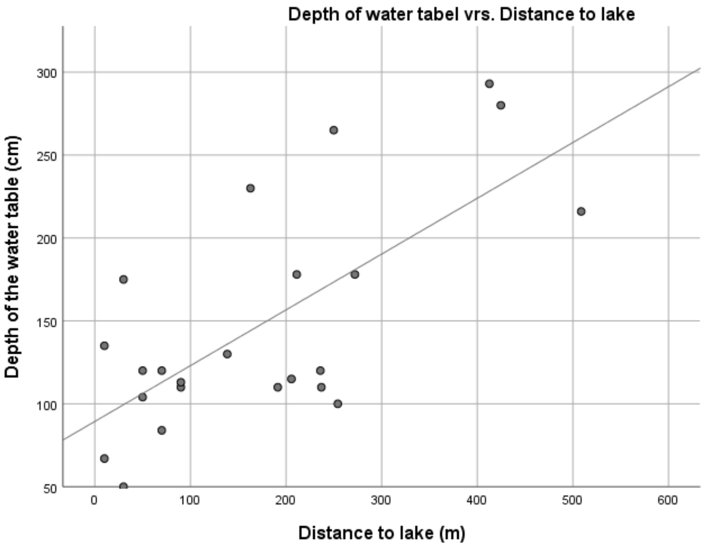

Figure 2 relation of distance to lake (m) and depth of water table (cm)

4.2 Vegetation

As can be seen in the scatter graphs below, if one compares the water table depth with the number of trees, the more trees are at the site, the deeper is the water table (*Figure 3*). The regression line has a positive slope and therefore also indicates this trend. When running the statistical tests among the measurements where the groundwater table was reached, an additional statistically significant positive correlation (N=23, p<0.01 and Rho=0,75) between the total amount of trees present and the depth of the groundwater was found. I.e., more trees correlated with deeper groundwater tables. This finding supports what can be assumes from the graphs and the data.

When plotting the depth of the groundwater against the vegetation cover, the pattern is less distinct (Figure 4). However, a Spearman's Rho test showed that there is also a statistically significant negative correlation between vegetation cover and groundwater table (N=23, p=0,05 and Rho=-0,569). This means that if the ground is covered with more vegetation then the water table is shallower.

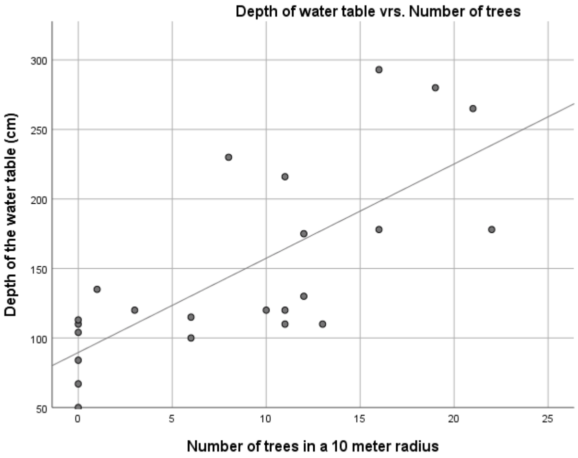

Figure 3 relation of number of trees and depth of water table

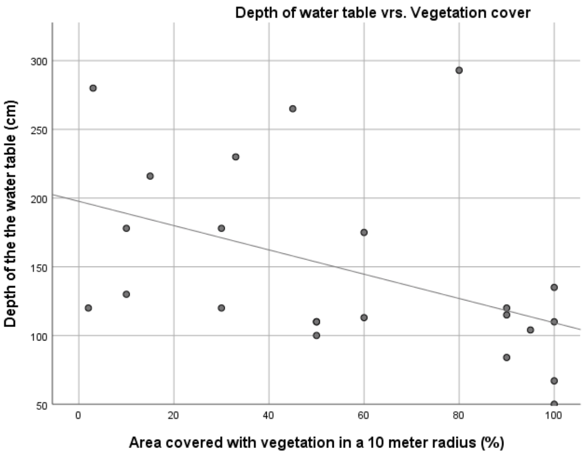

Figure 4 relation of vegetation cover and depth of water table

4.3 Elevation

The effect of elevation on the groundwater was analyzed in two ways: 1) only the samples where ground water was found (around 50cm – 300cm water depth) were considered and 2) the ordinal approach was used to able to include the sampling points where no groundwater was found.

First analysis: When using the Spearman's Rho test, no statistically significant correlation (N=23, p=0,312) between the elevation and the depth of the water table was found. The range of elevation values in this sample was between 5,8 and 12,6 meters.

Second analysis: When the data was treated as ordinal, a positive statistically significant correlation between the depth categories and elevation (Rho=0.644, N=38, p<0.001) was found. The range of elevation values in this sample was between 5,8 and 44,8 meters.

5. Discussion

The main question this research wants to answer is what site-specific factors influence the water table in the Utrechtse Heuvelrug, especially near small water bodies in the area north to the Henschotermeer.

The results map the depth of the water table in the area north to the Henschotermeer, which gives a direct overview of how deep the water table is at a certain point in this area (see video in Figure 8). Next to that, comparing the measurements with a variety of factors to the respective water table gives an indication of what factors could have an influence on the depth of the water table. Additionally, by running tests about the correlations enables support between the relationships, which can be estimated with the scatter plots. In the following paragraphs, those correlations will be analyzed and viewed in context with existing literature.

5.1 Distance to water body

With the gathered data, it can be said with confidence that the groundwater is higher near a lake and increasingly drops the further the sample is taken from a water body. This adds to previous finding by Ala-aho et al. (2013) who studied how groundwater interacts with surface water in sandy landscapes and while their data concentrated more on the 'how', our data adds the qualitative data of water depth near such lakes. One of the assumptions made in the statistical analysis of distance to water bodies was to only work with the measurements that reached the groundwater. This is reasonable, as most points where water levels turned out to not be detected were also the ones located comparatively far from the lakes. When extrapolating our model to theses distances and comparing the prediction of our model with the actual measurements, they are in accordance in 13 out of 15 cases.

To be sure we ran additional test where we assumed that the water level at the five points where it was not found was respectively one or two meters deeper. Even then, the positive correlation between the distance from the lake and the ground water depth was strong (both N=28, p=0,01).

One aspect that could be interesting to study in the future is to what an extend the size and depth the lakes influence the depth of the groundwater table. For instance, would a bigger lake lead to a higher groundwater level then a similar, but smaller lake?

5.2 Vegetation

The data supports the findings of Han et.al (2020), which concluded that trees, lower the ground water table and shows that the groundwater table is shallower in places where there are less trees. However, drawing the conclusion that as a measure to raise water levels trees should be cut would not be a sustainable management strategy. On the one hand trees do use groundwater, since they are mostly deep rooting and use groundwater as their source of water intake which lowers the water table, but on the other hand they provide protection against run-off and increase water retention. This a crucial ecosystem service, as the Netherlands are facing droughts usually not because of an overall shortage of water but due to poor soil water retention (International Groundwater Resources Assessment Centre, 2020).

Vincent Cotrone (2015) summarized the advantages of trees as: “Forests are the most beneficial land use for protecting water quality, due to their ability to capture, filter, and retain water, as well as air pollution from the air. Forests are also essential to the provision of clean drinking water to […] residents of the watershed and provide valuable ecological services and economic benefits including carbon sequestration, flood control, wildlife habitat, and forest products.” It is therefore important for the management of the Heuvelrug to keep the existing trees and even reforest critical areas, but while keeping in mind that this could lower the water table.

Looking at the data and analysis of the vegetation cover, the negative correlation that was found between vegetation cover and the presence of trees might be misleading, as it entails a hidden variable. The findings in the data showed that the presence of trees and vegetation cover are also strongly negatively correlated, indicating that when there are more trees (such as in the forest) the ground is covered with less plants. Therefore, it can be assumed that trees lower the amount of vegetation cover as well as the water table depth. Moreover, vegetation cover and the depth of the groundwater are not necessarily directly connected but their correlation rather depends on the presence and number of trees.

5.3 Elevation

Two different methods of analysis were used to study the correlation between elevation and water table because firstly it is considered important to discover if there is a correlation between the sampling points where water was found and what the elevation is. Secondly, try to discover if the results change when taking into account all sampling points. This was done through an ordinal approach by assigning three different depth categories to the points with 220cm and more being the highest category. Surprisingly, the results of the first approach did not show a significant correlation between elevation and the water table. Contradicting was the information from NPUH (Heemsbergen, 2021), which stated that the elevation in the Utrechtse Heuvelrug can increase the depth of the water table. However, as seen in *Figure 1*, the blue sampling points where water was found are located around an elevation of 10m ASL. At elevations between 10 and 45 the water table could not be reached with an auger, which could indicate that the first test shows no correlation between elevation and water depth, because there is not enough difference in elevation between the points measured to influence the water table. These points were not considered during the first analysis which is why the ordinal approach was used for the second analysis, assigning categories to points deeper than 220cm a correlation test.

This second test a positive statistically significant correlation between the depth categories and elevation was found, indicating that the water table is lower, the higher the elevation is. This is in line with the information from the National Park and supports the theory of a ‘water table bubble’ under the hill ridge (Heemsbergen, 2021).

One aspect that would strengthen this theory is utilizing longer augers or similar tools that are able to reach the groundwater when it is deeper than 320cm. Those findings could refine the accuracy of the statistical tests since then a scale measure could be used.

6. Conclusion

Groundwater, the saturated zone within the soil, is vital for multiple factors such as: vegetation and drinking water. The depth of the groundwater, which is determined by but not limited to the climate, human impacts, is an essential indicator for a sustainable water management (National Geographics Society, 2020).

The research showed many correlations within the ground water system in the Utrechtse Heuvelrug. Most important factor found was that the smaller the distance was to a water body the shallower the ground water tables. The research was done in order to reduce the risk of drought through the National Park as well as making the Utrechtse Heuvelrug drought resilience. Low groundwater may lead to droughts, which further negatively impact the vegetation, especially deep-rooting plants and crops, which use the groundwater as their water supply.

Further research could analyze the interactions of the groundwater table and water bodies as this accounts for water availability. It is also valuable to do more research about the extent of the influence of the size of water bodies on ground water tables. For example, does the width of the water body has a larger impact than the depth and how are they related to groundwater?

As water availability is vital for an ecosystem and the correct management is important in order to maintain the area. Cooperation between Staatsbosbeheer (national forest management), inhabitants in the area and other stakeholders can contribute to sustainable management and agreements such as maximum amounts of water taken from the Utrechtse Heuvelrug. Cooperation between the stakeholders can allow clarity regarding the water reserves and groundwater depths, preventing overuse of the groundwater.

7. Relevance and integration possibilities

The general research question of the topic 'Water management' is "How can we organize our use of several water bodies sustainably along the surroundings of the UH?" The findings of this research give an insight into the site-specific factors which influence the water table around water bodies in the UH and their correlations to the depth of the groundwater. From these correlations an analysis could be performed to provide sustainable management advise for the water bodies around the Utrechtse Heuvelrug with regards to groundwater and droughts. Other groups will provide findings that concern other water bodies and together a holistic strategy can be developed.

In the light of accelerating climate change, it is crucial to develop a drought-resilient management system for the Utrechtse Heuvelrug. Correlations between high groundwater and site-specific factors can be used to help other topics surrounding water management, topics with a strong emphasis on social science. The data in our research can help farmers in the Utrechtse Heuvelrug that are struggling with drought prevention as farming and droughts create a vicious circle. When the soil is dry the farmers need to irrigate the fields more frequently and this heightens the pressure on the groundwater systems, which in turn worsens the drought (Boesvelt, 2021). For vegetation, enough moisture is vital. This is not only true for the forest and heathland found in the Heuvelrug but also for the crop production in the surrounding area. It will result in lower yields and can led to a 18% reduction in forests' function as carbon sinks as happened with the summer drought in 2018 (ICOS, 2021). This is another feedback loop which is caused by climate change but also worsens climate change at the same time. Through this collaboration we hope that we can get better insight into the social and governance aspects of this topic and design a holistic management advise for the Utrechtse Heuvelrug's water system and answer the overarching research question.

This research also provides future water management proposals that can be implemented outside the UH**.** The research sites around water bodies have a low groundwater depth and as stated previously this has many benefits. A proposal could be to implement artificial water bodies to dry areas. This would positively influence the land. There are some difficulties with this, firstly the making of a manmade lake in a nature area could have some ethical critics such as human beings not supposed to be superior to nature, thus controlling and unsettling it. Also, building the lake would in turn damage the ecosystem around temporary. The positives and negatives must be weighed and seen if the positive effects outweigh the harm in the ecosystem.

Further the relevance of groundwater levels in the UH are vital for the connection to climate change. Europe's temperatures are increasing, fresh water is getting scarce. Depleting water availability and increasing drought resilience, risk the integrity of whole ecosystems and our drinking water supply, which is why intensive research must be done in order manage a sustainable groundwater level.

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9. Annexes

Literature review:

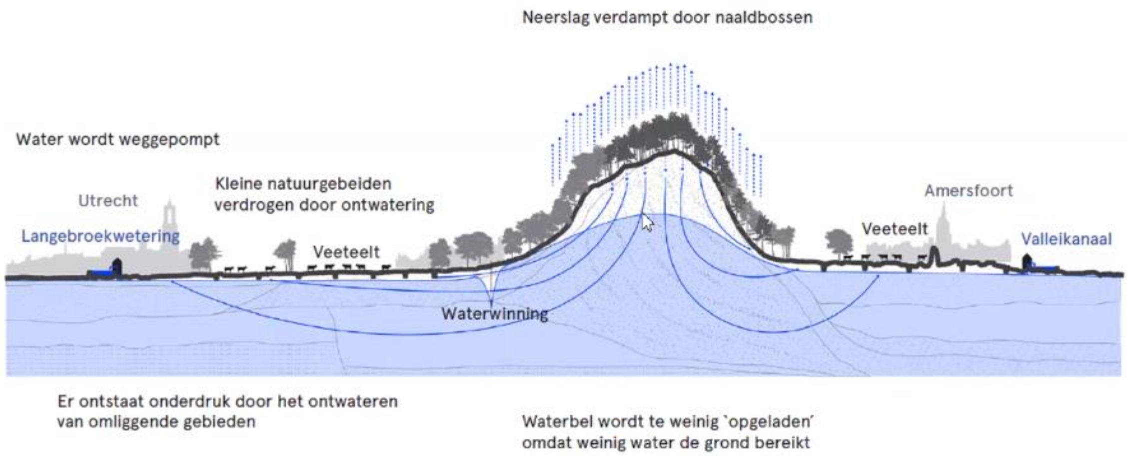

Figure 5: RIP Lecture 3 by Jeroen Heemsbergen (Heemsbergen (NPUH), 2021)

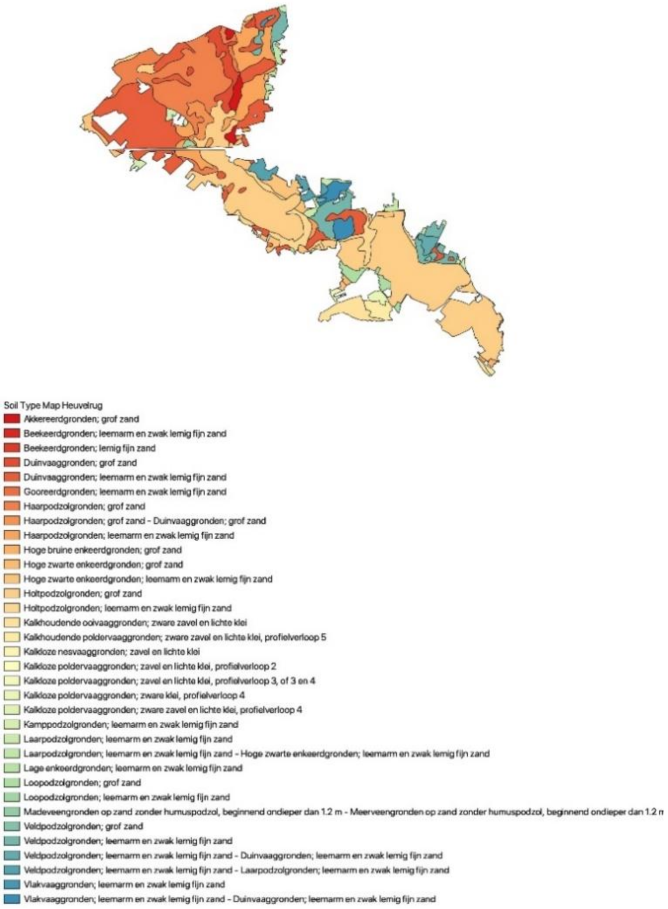

Figure 6: Soil types UH (Rijksoverheid, n.d.)

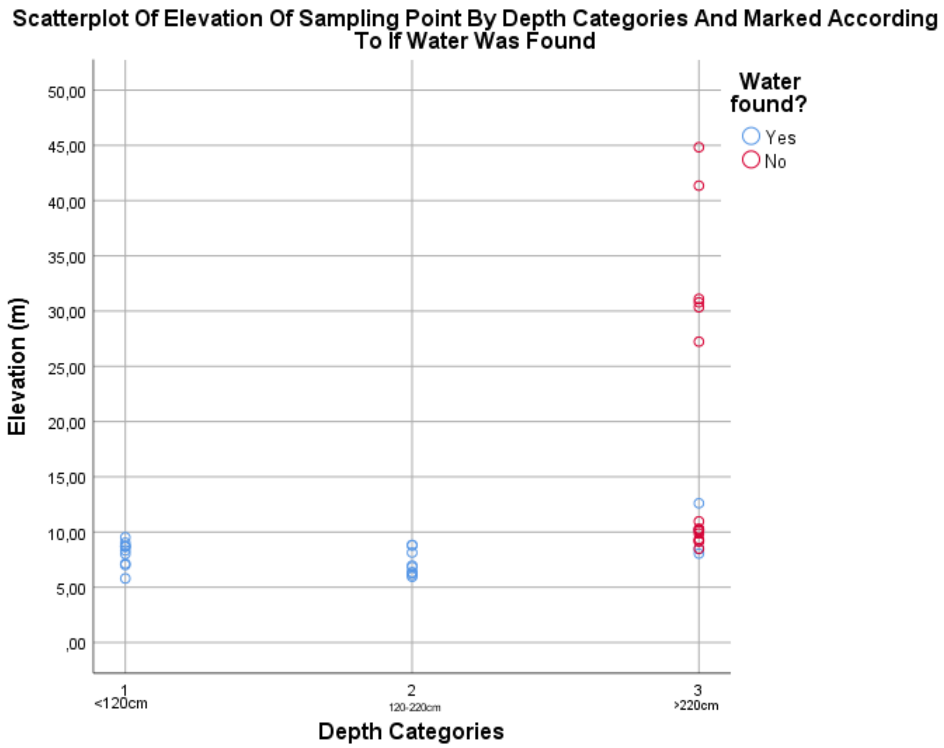

Figure 7: Scatterplot of election of sampling point by depth categories and marked according to if water was found

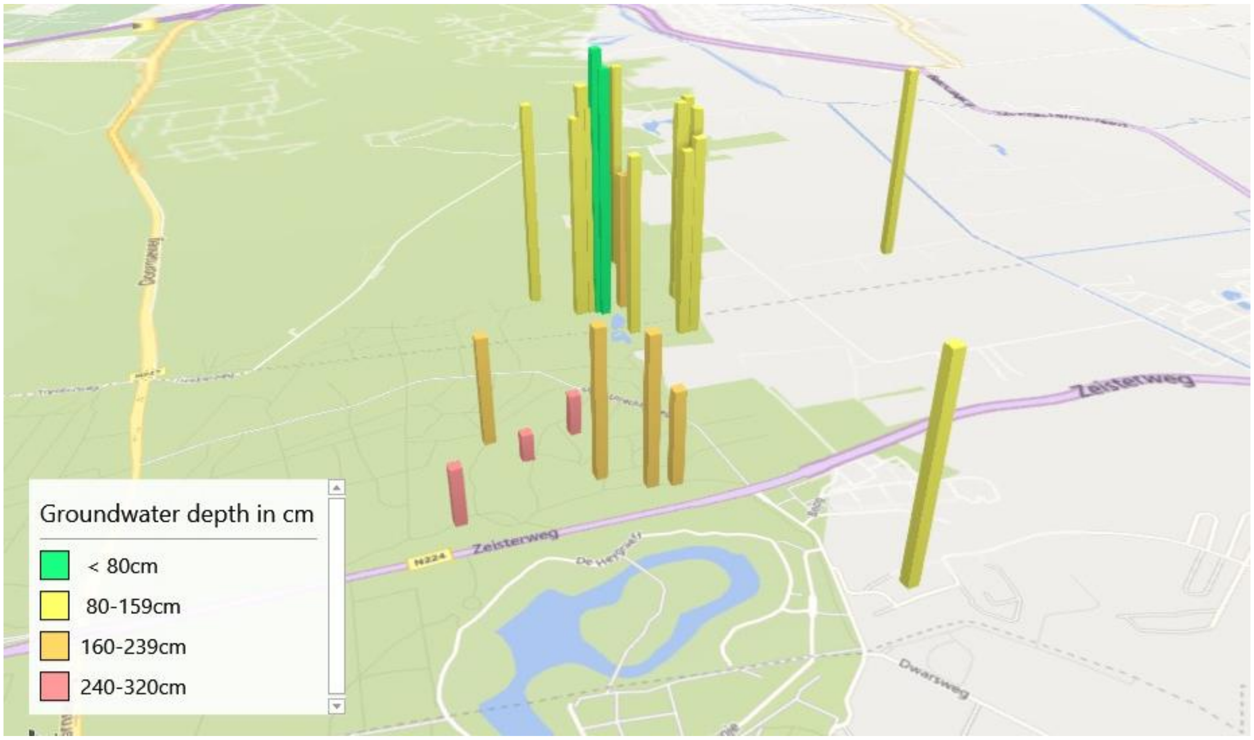

Figure 8: 3D Video of the water depth of the different sampling points
Control+Click on the picture to start the video