WATER AND SOIL AS LEADING FACTORS FOR THE FOUNDATION OF A FAMILY HOUSE IN THE NETHERLANDS

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ABSTRACT

Due to global warming causing climate change, extreme conditions like droughts and floods are increasingly happening. Currently buildings in the Netherlands are experiencing the consequences of these extreme conditions, which they are not build for. Especially the foundations are a big problem. Therefore this paper is aiming to find a foundation typology for a family home in a flood prone area which is able to resist the dynamics of this location. Interviewing experts about foundation typologies and floodplain dynamics, analyzing data about the river and soil compositions and using literature to put the paper in context with existing information and academic content, provided information as to what type of foundation this problem needed. Though it would be logical, the technical solution is not the best when also taking into account the social, political and environmental factors. Therefore a combination of typologies is proposed.

KEYWORDS: *Family home, Floodplains, Soil, Water*

I. INTRODUCTION

Currently the Netherlands is experiencing a paradox, where it has to endure extreme dry and extreme wet time periods. The floods in Limburg, the Netherlands are an example of a very wet period. The Maas river flooded due to heavy continues rainfall and high river tides (Schyns, 2022). Droughts are a problem, especially for structural foundations of buildings where the slinking of the ground makes the buildings rise above ground level, and the degeneration of foundations happens faster (NOS nieuws, 2021). These together make a very interesting problem where the foundations of buildings need to be able to withstand the forces of a flood, the slinking of the ground and simultaneously keep the building safe and on its place. A foundation at all times needs to be able to distribute all the forces, in and on the building, into the ground (Oosterhoff, 2013). This calls for a new solution into the structural foundation, to keep the building safe from floods and can survive during multiple transitions from extremely dry to completely wet.

Not only the Netherlands is experiencing this, these problems happen in multiple countries all over the world have to endure river floods (Feyen, Dankers, Bódis, Salamon, & Barredo, 2012; Floodlist, 2022). A study shows that in Europe these floods will occur also more frequently and extremer in the future (Feyen, Dankers, Bódis, Salamon, & Barredo, 2012). Droughts and floods are therefore not a local problem but global problem. It is caused by a commonly spoken about problem, namely climate change (Golz, Schinke, & Naumann, 2015). Which is partially influenced by global warming. The temperature on earth has risen 1,0 degree Celsius since the pre-industrial period and is expected to rise 0,2 degrees Celsius per decade due to human activities like fossil fuel burning (Nasa, 2022). This makes the paper very relevant to current problems around the world. And the result can therefore pose as an example for other locations dealing with completely or partially the same dynamics.

Currently for building flood resilient there are 3 strategies for dealing with floods (Sutherland, 2022). The first one is protect, the building needs external or internal additions to protect itself from floods. Examples could be, building a dike around the property or making the building levels prone to flood risk water tight. The second one is by accommodating for the water to trespass the property. For example when building on piles, the water is able to flow directly underneath the building. And lastly by retreating from the site that will be flooded. The house should not even be built on a flood prone location or it should be possible to relocate in times of floods. This paper will be based on the accommodating strategy, trough collaborative principles between what a floodplain needs and what the homeowner needs, the best solution will be generated.

To do research what type of foundation is able to resist the dynamics of flood prone areas, this research will use the locations of the floodplains. These locations present a good representative model for the dynamics found in a flood prone landscape. As for building type this paper will exclude temporary homes since the problem is about finding the best foundation solution for a house built in the same qualities as it is being built now in the Netherlands. This also means that the house should not be able to move to another location. It should at all times have the same GPS location/address. These parameters together will ensure the quality of the eventual outcome. The possible foundation typologies are based on housing in the Netherlands . The type of housing is selected based on the average housing situation in the Netherlands. See appendix 1.

II. METHODOLOGY

Overall this research paper is structured around involving experts through brainstorm sessions. This literally and figuratively will form the foundation for the paper. To support the gathered knowledge found during conversations with experts, literature review, desk research and data analysis are done. This will give an overview of what the characteristics of the river and soil are. And provide information about existing foundation typologies. A literature review will put this paper in context with already existing information and academic content to ensure reliability. The desk-research is done to find non-academic content relevant for the research trough, newspapers, company and governmental websites and manufacturers. The data analysis will determine the current and past situation regarding to the soil composition and different water levels. Lastly the brainstorm sessions with experts revolve around the connecting fields to architecture and the problem. Previous desk-research, about what companies would be relevant and interested in this type of problem, resulted in a list of possible experts. The idea of the brainstorm sessions is to discuss possible foundation solutions and extra information regarding to their profession. These sessions will be recorded and resulted in an article/summary. See appendix 2.

2.1. Sub questions

For every sub question in this research I will be using a different set of methods to come to an answer. The sub questions are listed below, whereafter the methods per sub question are described with the products they resulted in.

1. What are the dynamics of the soil in floodplains in relation to foundations?

2. What are the characteristics of river floods in relation to foundations?

3. What foundation typologies are there and what are their spatial qualities?

Firstly, for this question the information needed is about the soil compositions, load bearing capacity, soil dynamics, and the effects it has on the foundation. For the soil composition governmental data analysis will be done which will result in maps of what soil type is located where and graphs to show in vertical plane the composition of the soil. The load bearing capacity is also done through analyzing data from the government. For the last two, literature review and brainstorm sessions will help in determining the soil dynamics and its effects of it on the foundation. These will result in graphs that explain these effects.

The second question fill be mainly answered trough data analysis of the government. This will result in graphs and maps relevant to floodplains. And explain the reoccurrence of flooding levels, river water levels and its velocity. In the end trough literature review and brainstorm sessions the effect on the foundations are discussed. This will, like the first question result in graphs that explain these effects.

Together with the graphs created for sub question one, these together will result in 22 booklets representing 22 different locations along the rivers in the Netherlands. See appendix 3.

The third question is mainly answered trough desk research and brainstorm sessions. The information about different foundation typologies and which typology would be fitted for floodplains is gathered by brainstorm sessions and supported by literature review. The spatial characters and loadbearing capacities will be found by looking at manufacturers websites since per manufacturer this can vary a bit. Based on multiple manufacturers an average will be taken to get an understanding of the spatial characteristics. In the end this will result in a list of possible foundations typologies represented in a graph with each of their characteristics. See appendix 4.

III. RESULTS

3.1. The Dutch river landscape

The Netherlands exists out of several types of landscapes. The floodplains are located in the river landscape. This type of landscape formed mostly in the Holocene time era somewhere in the last 1000 years of it (Haring, Wesselingh, & Ahrens, sd). But there have been multiple factors involved in creating this landscape. The rivers, glaciers from the Pleistocene era and the wind were all involved in the development of the river landscape into what it is today (Segeren & Hengeveld, 1984). The Delta of the Rijn and the Maas consists mostly out of transported and disposed materials by the current of the river, otherwise called fluvial deposition (Segeren & Hengeveld, 1984; Doornbos, 2022). In the Pleistocene era the slowly moving ice masses pushed up a series of moraines, otherwise called glacial deposits containing debris material. This was creating the Utrechtse Heuvelrug, the Veluwe, the realm of Nijmegen, the Montferland and formed a wall forcing the Rijn and the Maas to the west of the country. Only later did the Ijssel break through the moraines of Gelderland near Arnhem and has since formed the northern Rijn branch (Haring, Wesselingh, & Ahrens, sd). Pleistocene, otherwise called the Ice Age, consists out of alternating periods of cold- and warmer periods. During the warmer periods when the ice had been melting away the riverbeds ended up drying. The wind was during that time able to blow the upper layers of the soil to another location, otherwise called aeolian deposits (Segeren & Hengeveld, 1984). The strong pole withs where able by this affect to create the river dunes (Haring, Wesselingh, & Ahrens, sd). This also created the effect when a new Ice age came the rivers had a different path as they had the last time. This resulted in meandering rivers throughout the country. And only since about a 1000 years ago, us humans gave it a more fixed path to flow trough. This was done by creating the summer/winter dikes and floodplains. During spring, when higher water levels occurred, because of melting snow and rainwater, the river was able to trespass the summer dike and enter the floodplains to the winter dikes (Haring, Wesselingh, & Ahrens, sd).

There are four big rivers in the Netherlands, the Maas, Neder-Rijn, Waal and Ijssel (Cohen, Amoldussen, Erkens, Popta, & Taal, 2014). As seen in figure 1. The last three of these rivers originate out of the same river, the Rijn. Which has a total length of 1230 km which starts in the Swiss Alpes carrying mostly water of melting snow, but also ground water and rain water (Rijkswaterstaat Ministerie van Infrastructuur en Waterstaat, 2022). The Maas, with a total length of 925 km, originates from France carrying mostly ground and rain water. The Waal has next to its water supply from the Rijn also trough a secondary river water flowing in from the Maas.

Figure 1. Rivers in the Netherlands | image by Renée de Vries 2022

The Waal also does not have any dams in place and neither does the IJssel. The Maas and the Neder-Rijn do have dams. Where the Maas has seven in the Netherlands and the Neder-Rijn has three located in the Netherlands (Rijkswaterstaat Ministerie van Infrastructuur en Waterstaat, 2022). Because of these dams these rivers have a more constant level than the ones without dames. This is seen through the graphs in figure 2 showing the water levels and flow rates. For a full comparison see appendix 3.

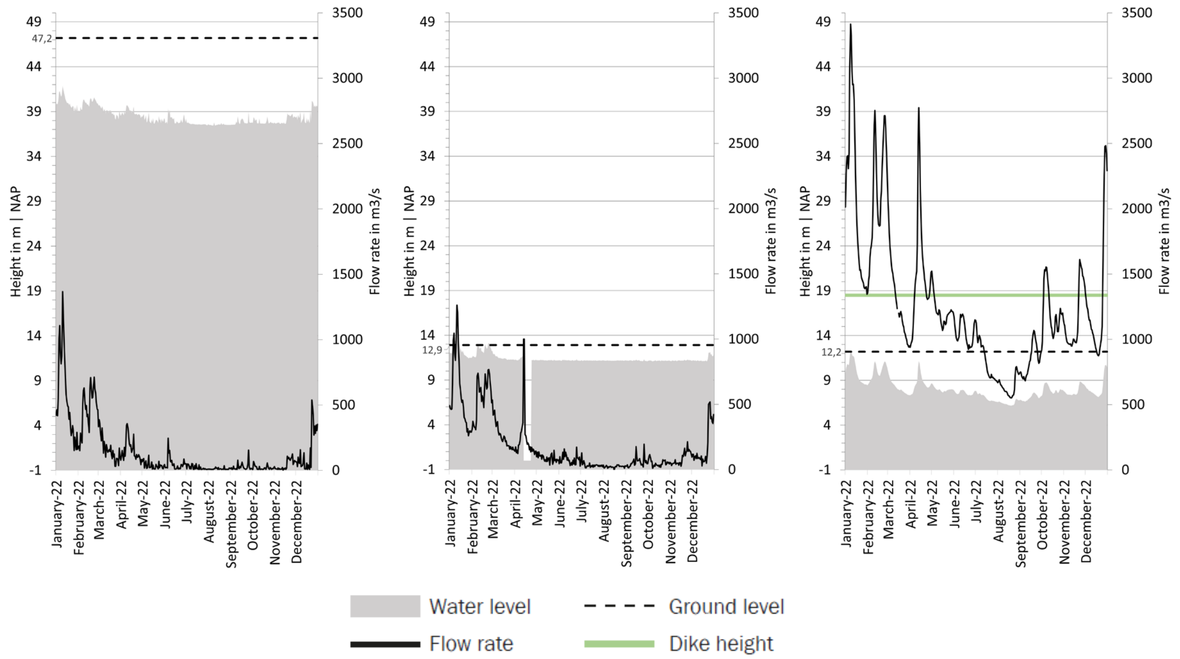

Figure 2. River characteristics, from lef to right: Maastricht(Maas), Gennep(Maas), Millingen a/d Rijn(Waal) | image by Renée de Vries 2022

Overall it has been seen by looking at the graphs, at the beginning of winter time to the start of spring, the water levels are generally higher than over the rest of the year. This is probably due to snow melting over this period of time. The graphs of the Waal and Ijssel show also some peaks in the middle of the year. This would be because these rivers are less controlled by dams and therefore rain fall could have a bigger spontaneous effect on these rivers.

To ensure that floods do not enter the residential areas, dikes and floodplains provide safety from higher river levels. (Kok, Jongejan, Nieuwjaar, & Tánczos, 2016; Hooimeijer, Meyer, & Nienhuis, 2009) The height of the dike is decided by the risk of floodings that are able to happen in the coming time period. These predictions can be different for every location. Therefore some dikes are higher and wider than others. In the area of Limburg there are higher risk numbers for flooding that could happen in a year (Kok, Jongejan, Nieuwjaar, & Tánczos, 2016). There are not a lot of dikes in this region, as Limburg is normally already on a higher level in relation to Normal Amsterdam Level (Normaal Amsterdams Peil, NAP) compared to the landscape in middle and western side of the Netherlands. In 2021 in Limburg it did go wrong when lots of flooding occurred because of long and heavy rainfall. (Schyns, 2022) Though they do have floodplains in many areas, the risk of flooding is higher (Kok, Jongejan, Nieuwjaar, & Tánczos, 2016). This stresses the high importance of designing safety against flooding. The consequences are high when it goes wrong and lives are at risk. Therefore the development of the delta works is a constant project (Sijmons, Feddes, Luiten, & Feddes, 2017). Dikes have been and will be raised multiple times. In the future the storage capacity for water in floodplains will have to be enlarged and has been enlarged in the past. Because of the risks, the amount of extremes and the floods getting higher and higher over time (Feyen, Dankers, Bódis, Salamon, & Barredo, 2012; Blöschl, et al., 2015). It is important in a location like flood prone areas to look at the original problem and what the predictions are for the cause of the problem, being global warming and therefore climate change. And then take actions based on that. Know what the problem is, the occasional flooding, what kind of consequences it can have, material, economical and health dangers, and what a safe way would be to respond the occasional flooding.

The soil of floodplains as discussed has come to existence due to many factors. One of them being the rivers themselves. The rivers during the occasional flooding will dispose several types of soil along the way on the floodplains. A river has not always been in the same place, so it can vary and meander (Bos, Zuidhoff, Kappel, & Gerrets, 2012). Because of this sometimes there is an erratic subsoil where at one part there is sand and the next part there is a gully where there is clay or peat (Veenbergen & Bardoel, 2022). On top of that the floodplains can be fully submerged at multiple times through the year. This creates a spongy like soil. It is expands when it fills itself with water and then it shrinks when the soil dries up again (Bell & Jermy, 2011). Most of the times alongside the river there is washed up sand and when going further backwards to the dike area there are clay soils (Diender, 2022; Dino Loket, 2022). In the northeastern part of the Netherlands and at several places in Limburg the ground is very firm because of the gravel soil layer, but also in some areas in Limburg there are big clay packages like in the middle of the Netherlands. (Doornbos, 2022; Dino Loket, 2022).

Figure 3 shows that Limburg does not completely consists out of a gravel soil layer. The first measurement does show the stronger gravel layer, but the second measurement does show this clay top layer of several meters deep. Furthermore in the most west end of the country in Gorinchem it shows an extremely soft soil that is composed out of clay and peat. But in general it is clear that near the river almost every drilling sample has clay in its composition and at least a few meters of it. For a full comparison of all locations, see appendix 3. When wanting to build on a piece of land these are the graphs and drilling samples that will be used to determine what is needed to build on this location. When talking about a soil type multiple things are looked at, load bearing capacity and accessibility, compressibility, moisture-holding capacity and permeability (Segeren & Hengeveld, 1984; Oosterhoff, 2013). As seen in figure 3 there are a lot of soil types along the rivers.

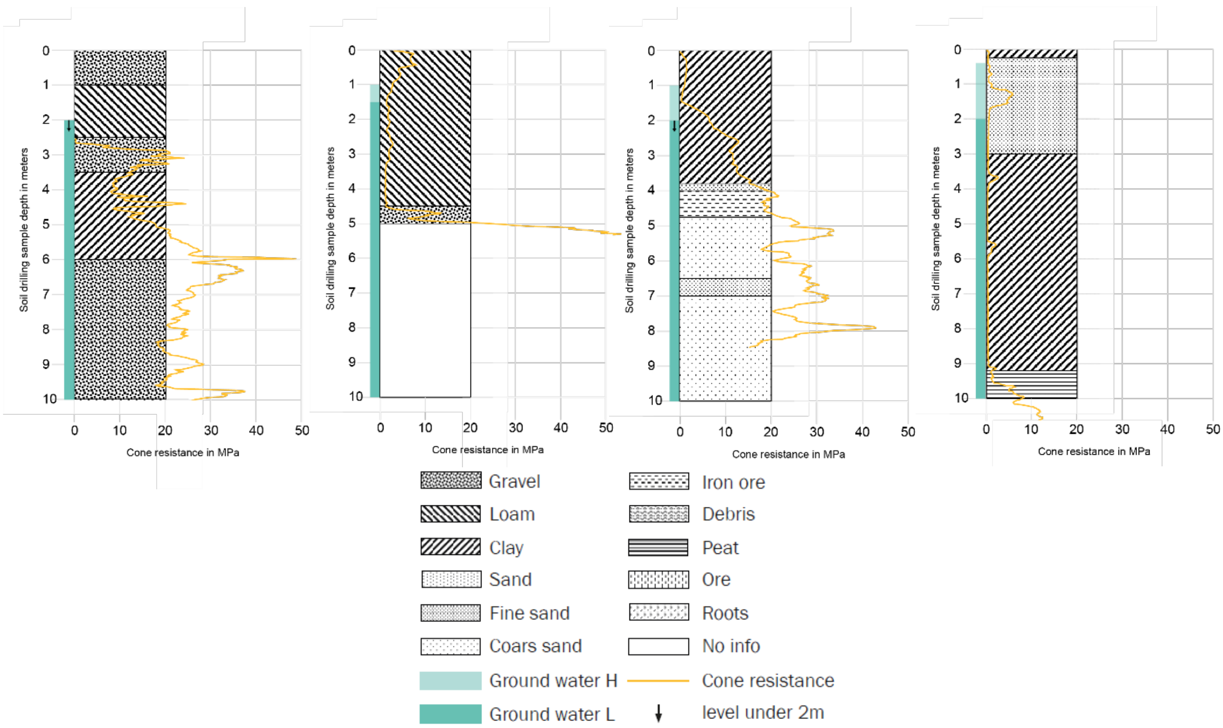

Figure 3. Soil composition, from lef to right: Maastricht(Maas), Maaband(Maas), Overasselt(Maas), Gorinchem (Waal) | image by Renée de Vries 2022

3.2. Foundation typologies

Building houses is something that people have done since the moment we existed. Still to this day the reason for building a house is the same. Protecting ourselves from external dangers like the climate and invaders. And floods have almost always been part of the existence of human kind. "Since ancient times people have settled in flood-prone areas due to favorable geographic conditions which facilitate economic growth, such as accessibility (transportation) and food production (fertile land)." (Bouben, 2006). A house serves as a protection for its users. The people therefore do not have to endure these dangers but the house they live in does. This means to be able to protects its users, first the house itself must be capable of resisting these dangers. This is where the foundation comes in, because as discussed in the previous chapter there are multiple different soil types and water conditions. These soil types all have their own characteristics regarding being more water-containing than the other and/or being able to bear more weight without settling than other soils types. So depending on where the building is being constructed and what the soil characteristics and what flood risks that location has, appropriate measures must be taken. Otherwise a building can settle in multiple directions due to the conditions of that location, causing possibly tears in the walls and an off level floor. In figure 4 a visualization of the different settlements are given. These directions of settlements can also happen simultaneously. For example when a stronger soil at the end of the building and a weaker soil in the front. The building will settle more in the front than in the back. This is the same with the different forces and weights of a building on certain soil type. Even though on the whole plot the soil composition would be the same, the building will settle more on the side where there are heavy weights. Therefore we need a foundation that is able to evenly distribute the forces of a building to a stable enough soil, so it is able to eliminate the disparities and keep the building from settling (Oosterhoff, 2013).

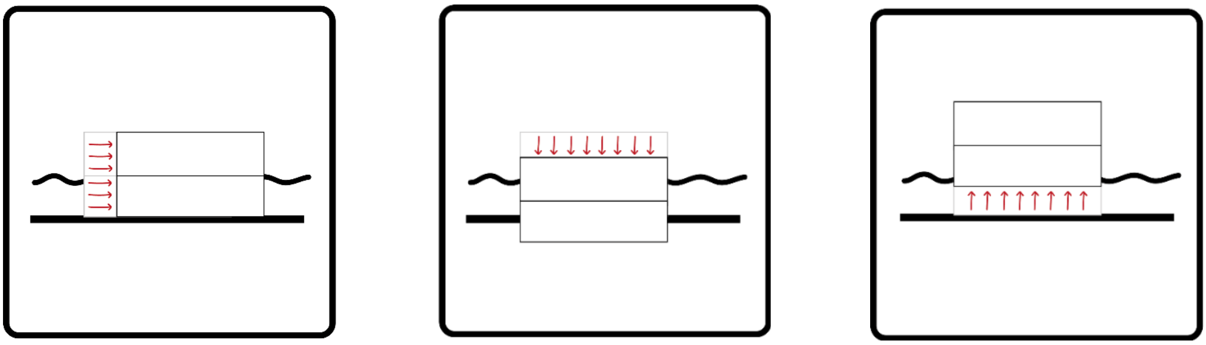

Figure 3. Building settlement directions | image by Renée de Vries 2022

The parameters surrounding the foundation will influence how light or heavy a foundation needs to be and what it needs to handle. Discovering what the parameters are and what their effect on a possible typology will help decide what typology offers a good solution. The involved parameters have to do with everything the foundation physically touches on. The location the foundation will be placed and the building on top that the foundation needs to bear (Blok, 2013). The parameters for the location have to do with the water and soil characteristics. The soil composition and the bearing capacity at the specific location show where the strong-bearing soil layers are. And thus at what depth a foundation needs to be placed inside the ground to offer enough stability (Oosterhoff, 2013). Also the water and ground water levels, relative to the ground level compared to NAP, are influencers for what typology to use. As ground water affects the stability of the soil, water levels relative to the ground levels, determine how high building needs to be placed to be safe from potential flooding. The parameters involving the building are based on the physical dimensions of the building. These are the size is of the connecting floorplan and the weight of the building. Apart from that, the functional requirements can also influence the foundation typology that eventually will be chosen. All these parameters affect the outcome of what typology is best to use at that specific location for that specific type of building. Meaning also that every situation is different.

When the parameters are clear, a foundation can be chosen and the house can be built. Foundations are not difficult and neither is building. There is enough experience and knowledge for this (Doornbos, 2022). But in the case of a floodplain, the problem becomes more interesting and there are extra elements to consider. The repeated alternations between flooding and droughts are responsible for the dynamic soils found in floodplains (Doornbos, 2022; Diender, 2022). Soils in floodplains are in general more saturated than other soils in the Netherlands. Therefore it is also a weaker soil composition, especially when dry periods occur, it is most likely needed to construct a foundation in deeper layers (Veenbergen & Bardoel, 2022).

Flood plains in general serve as a storage area for water when the river level rises, and the dikes are the barriers of this. Without the dikes in the Netherlands many (residential)area's would have flooded multiple times a year. They are the component allowing the river to flow beyond its standard limits (Diender, 2022). The dike therefore needs to be undisturbed in its function. Nothing should effect the dike in any way. Not now and not in the future when reinforcements might be needed. The soil of the floodplains themselves are also considered in the calculation for creating more room for the river. This is due to the topsoil layer often being clay. Clay can store water in itself en therefore prevents the water for some time to flow deeper into the ground and then flowing underneath the dike trough the other side. But when the clay top soil is penetrated by, a pile foundation, the water has a direct highway to the sandy layers where the water is able to flow directly from the floodplain underneath the dike trough the other side. This event is called 'piping' (Veenbergen & Bardoel, 2022; Diender, 2022). Some pile do it more than others. Ground displacing piles have a tight connection between the piles and the displaced soil, contrary to bored piles where the soil is dug out of the ground, the connection between the pile and the soil is less strong and water will penetrate faster deeper into the ground (Veenbergen &

Bardoel, 2022). Because of that and the possibility that the dike needs to be raised in the future, a few meters before and behind the dike it is generally forbidden to build (Diender, 2022).

Pile foundations have already come forward into this paper a little bit. It is also the foundation that is most often used in the Netherlands. But there is another foundation, the strip foundation, that is regularly used besides the pile foundation. If the strong load bearing soil is in the top layers a strip foundation will suffice. But when the strong load bearing soil layer is deeper than two meters into the ground a pile foundation will be used, as this foundation is able to reach down maximally 36 meters deep to the strong load bearing layers of soil. The recommendation for building in floodplains would be to use ground displacing piles that do not have a widened tip (Veenbergen & Bardoel, 2022). Shallow foundation techniques would not be as feasible in a floodplains. Since Load = deformation, on weak soils that means a lot of deformation (Doornbos, 2022), because deformation of the soil is never completely equal in every spot, the house is able to settle on an angle or cracks in the walls will form which cause structural instability. Because this settling of the building is of high importance and should not happen, it would always help in floodplains to use a light and easy construction for the building (Diender, 2022). There are also a two other foundation typologies regularly seen in the floodplains and near the rivers. The mound and the living ark. A mound is made out of sand where on top the building is placed. The top of the mound is high enough so flooding of the house is prevented. But building a mound and using it as an example is not a good solution. Because the mound is completely constructed out of sand, which has become scarce and therefore also expensive (Diender, 2022). Therefore presenting it as a solution and raising everything with it, creates a new problem. The living ark is basically a boat floating on the river, but is not able to sail across the water. It is Anchored to its location through piles or steel cables. But it is able to move with the water level up and down and never has to do with any flooding.

These are not the only foundation typologies. Based on the research done about foundation typologies, displayed in appendix 4., the typologies are grouped together in 6 categories. These are, the strip, the slab, piles, sheet piling, basement and cable foundations. In these categories there are many different typologies displayed. All of these typologies are compared based on how they would react in a flood prone area. Most of them are based on the principle of accommodating for water to trespass the property of the building. Multiple variations of the higher pile foundation especially offer great stability and are able to accommodate for the water to flow directly underneath the building. For example standard higher piles and sheet piles, but also hoisting solutions on piles where through the water level itself, cables or a jack the building is lifted to prevent the building from flooding. This adaptable way of building is an solution that is well-executable, since the high water level in rivers is predictable a few days before these levels arise (Veenbergen & Bardoel, 2022). These are typologies that are able to adapt or are continuously standing on a higher level. On the opposite side of that placing the building inside the ground in the form of a basement, with a small tower to access the building during high and low water levels, shows a solution where the building is able to be fully submerged under the water. The roof of the building is placed at the same level as ground level and has a glass roof to let daylight into the building. For this typology a lot of extra conditions come into play. Especially the pressure of water must be taken into account. When there is no high water this is mainly about the ground water that is trying to push the building upwards. At the time of high water levels it also gives a lot of pressure downwards (Veenbergen & Bardoel, 2022). If there would be three meters of water above ground level it gives 10kPa more pressure downwards. During high and low waters the pressures down and up should be in balance to keep the building in place (Veenbergen & Bardoel, 2022). Thus there are multiple foundation typologies each having their own characteristics. A very important one is the maximum depth into the soil they can have reach for the load bearing layers. Pile foundations and sheet piling go to much deeper lengths, 30 to 36 meters, than the other foundation categories.

Besides the different typologies that are possible, they can all come in different types of materials. The main materials used for foundations currently is concrete. But other regularly used materials are wood, steel and Fibre reinforced polymer. Because of the location for this project being a flood prone area, the element of water makes the choice of materials important. Water has the capability to degenerate some materials faster than they would otherwise do. Especially for wood this is the case. Wood is able to last a very long time if oxygen is not able to touch it. A solution for this is to keep the wood fully submerged at all times. If wood would be used as a material for a pile foundation, the top of the pile will have to be hammered down into the soil to a depth that ground water is always covering the whole pile. To complete the pile to the top of the soil a concrete header is put on the wooden pile. But given the large difference in groundwater levels in floodplains, the use of wooden piles is not recommended (Veenbergen & Bardoel, 2022). And wood is just not able to last as long as other materials in general. Even if it has been submerged under water all the time, it will still degenerate. This is the problem with many wooden foundations in the Netherlands. Not only the top part of the wooden pile that has submerged above ground water level, but all wooden foundations are degenerating. Other materials each have their own problems as well. Steel has for example the consequence that it can rust, and concrete is overall a very strong material, but when it gets damaged through collisions it needs maintenance. Concrete itself is a stone-like material, but it cannot take a tensile load. That's why it has steel in it. Because the steel is covered by concrete it is not affected by oxygen and all kinds of other substances in the air. Just like steel these problems are maintainable. Another material is Fibre reinforced polymer (RFP). It is a relatively new material for structural foundations, but it is slowly emerging. Piles and sheet piling for example are made out of this material or a combination of RFP with concrete and or steel.

IV. DISCUSSION

4.1. Political

On the 25th of November 2022 the minister of infrastructure and waterworks in the Netherlands send a letter to the house of representatives from the government of the Netherlands. The title of it stating, 'water en bodem sturend' (translation: water and soil as guide lines). In general it expresses how important the water and soils are for the Netherlands and that as much as possible needs to be done to preserve the conditions these elements are in now, and even better to try to improve wherever it is possible (Harbers & Heijnen, 2022).

The pile foundation is one of the foundations that would be eminently suitable for a foundation in the flood plains, but one of the remarks Harbers & Heijnen make in their letter is about how crowded our soil already is with foundations, pipes, cables and the extraction of raw materials. They say it should be a principle that we take care of our soil and that it remains suitable for future generations. Any action that is taken, for example constructing a building, must not lead to unintended effects elsewhere or at a later time. This means covering our soils as less as possible, not excavating soil unnecessarily and not contaminating the soil. If a pile foundation is constructed it takes extra space in the soil and next to that, piles are often not extracted after a building as come to the end of its life span and demolished. The piles stay in the ground and therefore pollute the soil even more when keeping in mind future generations.

Furthermore the problem with droughts and floods come up in the letter. As made apparent before and again in this letter, climate change makes it much more likely that worst case scenarios actually happen. And it is suggested that we need to prepare ourselves better for these possible situations (Harbers & Heijnen, 2022). Besides preparing ourselves, preventing it these occasions from happening is of course even better. Droughts and floods need a coherent approach, this would be done by creating a vital soil system, which is able to soak up water like a sponge, but by realizing sufficient buffer and drainage capacity (Harbers & Heijnen, 2022). A structuring decision, made by the minister of infrastructure and waterworks, for the future is therefore: 'We no longer allow new construction in the floodplains (which fall under the policy 'grote rivieren'). By doing so, our rivers will be more climate resilient and prevent increasing damage. (Harbers & Heijnen, 2022)' This statement contradicts with the project in this paper, as this project is specifically placed on this location. And in being fully aware of the current proposals the government makes, this project still belongs at this location. The location for this project is not chosen because it is a beautiful natural location with lots of great views. It is chosen because the conditions of this location resemble locations that in the future may flood as frequent as the floodplains. Also besides that if the solutions presents itself as being excellent at resisting floods it would be possible to allow for taking bigger risks in dike reinforcements if all the buildings in the flood zone would be able to resist this event. The paper is not trying to say that building in floodplains is the solution, it is trying to discover a flood resilient solution based off the characteristics found in floodplains today.

4.2. Professional

So when future buildings are constructed the footprint and depth of the building should be as small as possible, and the water of the river at all times needs to be able flow as undisturbed as possible. Making soil and water leading factors in the decisions of future buildings. When looking at the foundation typologies this results in a dilemma. On the other hand the foundation that is chosen should not contaminate the ground as much as possible, therefore a shallow foundation appears to be the solution. This though often means that the footprint of the building is larger than when de building would be when it is built on piles. And if the building is built on piles the ground would be more contaminated due to the foundation going deeper into the soil too strong load bearing layers. But as stated before the pile foundation is recommended because of the low risks it has with settlements and floods. A sheet pile on the other hand is not an ideal option as it would discard both these factors. It would take the entire footprint and leaves no room for the river to flow at that point. And it contaminates the ground like the normal pile foundation.

Technically these foundation typologies have all different characteristics. But also visually they differ a lot. Especially the typologies where the building is statically raised above ground. They are enormous structures because of their height. The height is based off on the height of an dike, as the dikes are calculated based on flood risks. But therefore on ground level these buildings only show a lot of structure and become a big construction in the floodplains. Typologies that would be lower to the ground or have less structural mass propose better solutions visually. As it is not intended to obstruct the view of the floodplain in any way, either walking around in the floodplains or on top of the dike looking over the floodplains.

V. CONCLUSION

What foundation typology, for family housing, is able to offer resilience to the dynamics of flood prone areas in the Netherlands?

Trough the analysis of the dynamics in the floodplains in the Netherlands it has become apparent that in most locations near the river, somewhere in the soil composition, the soil consist out of clay. Overall the soils next to the river are therefore generally very soft, and the load bearing layer finds itself in the deeper parts of the composition. Only in the north-eastern and south-eastern parts of the Netherlands there are a few locations where harder soils like gravel and sand are located in the top layers of the soil. These softer soils combined with the occasional flooding, happening generally during the winter months, an uncontrolled river like the Waal or the Ijssel are able to present as good example locations for designing a flood resilient family home.

Based on the floodplain characteristics in the Netherlands, the most logical conclusion would be building on piles at the height of the dikes at that location. But the technical aspects are not the only parameters the conclusion for the appropriate foundation typology must consider. Based on the social, political and environmental sides of the problem a shallow foundation, with a relatively small footprint, lets the river flow as undisturbed as possible and does not contaminate the view of and on the floodplains would be the most responsible solution. Not any foundation is able to check all these boxes while also offering enough stability. Only in the locations where there are some harder soils, a shallow foundation like the strip foundation and/or the slab foundations are able to suffice. In softer soils the foundations with adaptable building height and the cable foundations offer better compromise. These are often constructed in combination with a secondary structure.

To find right foundation typology this problem needs to be further researched. Especially on the visual and functional part of the foundation the research through design would offer more insights into the effects of certain foundation typologies. Also then a combination of multiple foundation typologies together can be designed which could solve the problem and is able to tick all the boxes to which the solution must meet to represent itself as an exemplary project.

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APPENDIX 1_AVERAGE HOUSING IN THE NETHERLANDS

Soil and water as leading factors for designing a floodreselient family home

Average housing in the Netherlands

TU Delft

Soil and water as leading factors for designing a floodreselient family home

Average housing in the Netherlands

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Date
26-01-2023

Stage
Concept

1. Introduction

◀ **Picture front page**
Floodplains of the Waal river near Deest, the Netherlands.
Own image

In this document the average house in the Netherlands is discussed. Because when designing a family house to be an example for others, this project needs to look at the the average characteristics of one. This document is then able to inform further steps taken when discussing foundation solutions for a family house.

This will be done trough the types of housholds in the Netherlands that live in these houses. Then the average amount of surface area display per housing categorie the differences. After that the average amount of building layers per categorie will put into perspective what this means of the sizes of these buildings. And lastly the diffrent spaces inside a house will be discussed to show what kind of rooms are typically in a house.

The information found is based on literature and governmental websites of the Netherlands.

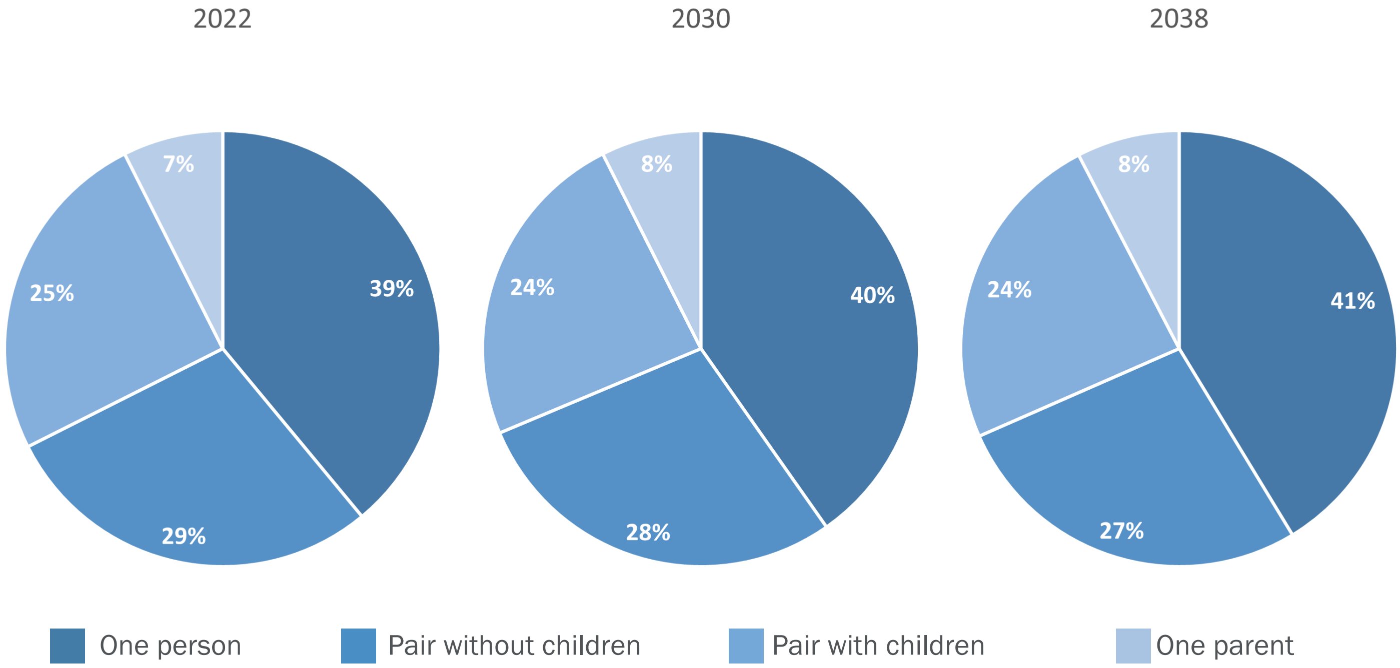
Picture page 2 ▶
Floodplains splitting of Rijn to Waal near Doornenburg, the Netherlands.
Own image

2. Average house in the Netherlands

2.1. Household

In the Netherlands there are currently around 8 milion house holds (CBS, 2021). But not all of them have a houshold with children. If there are children in the houshold it is often that this house hase more rooms, and factually needs more squaremeters to have enough room for everyone. In figure 1 the average households in the Netherlands are displayed.

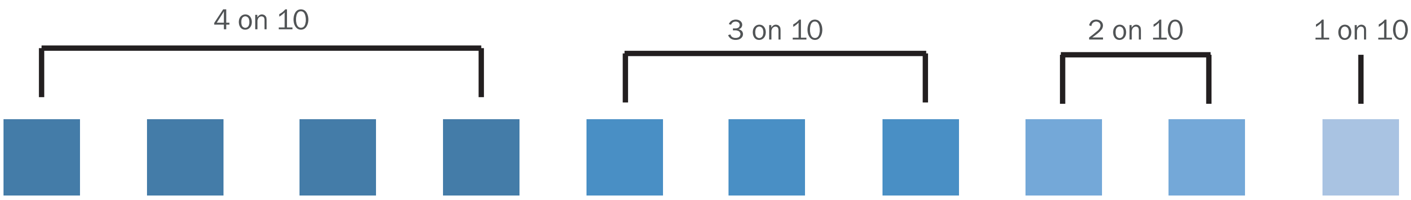
Figure 1
average households in the Netherlands. (CBS, 2021)
▼



As seen in figure 1. the housholds are distinguished between one person, a pair without childer, a pair with childern and one parent. In the future it is expected that the one person housholds wil slightley increas just like the on parent houshold. The Pair with and without children is expected to decrease in the amount of housholds over the next 16 years (CBS, 2021).

If these are the divisions indifferent housholds, then there should be housing fitted for these categories. It is though possible that people change from from houshold type during their course of life. But the divisions will remain roughly the same. So if 10 houses would be designed in a project the division would be as shown in figure 2. 1 house for one parent, 2 for a pair with children, 3 for a pair without children and 4 for people living alone. What this means for the rest of the plan will be discussed in the following chapters.

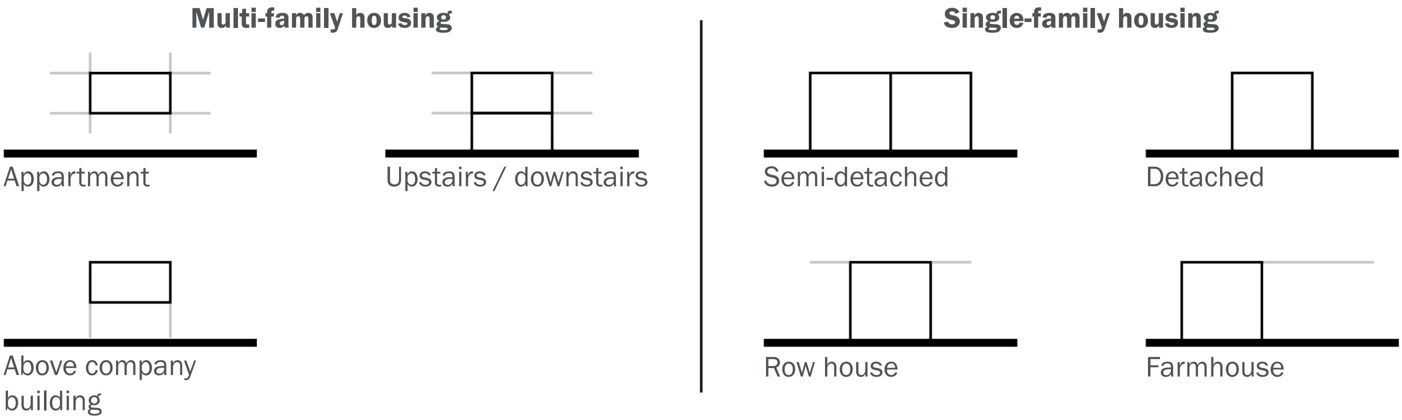
Figure 2
Division 1 on 10 houses based on the numbers from the CBS.
▼



2.2. Surface area

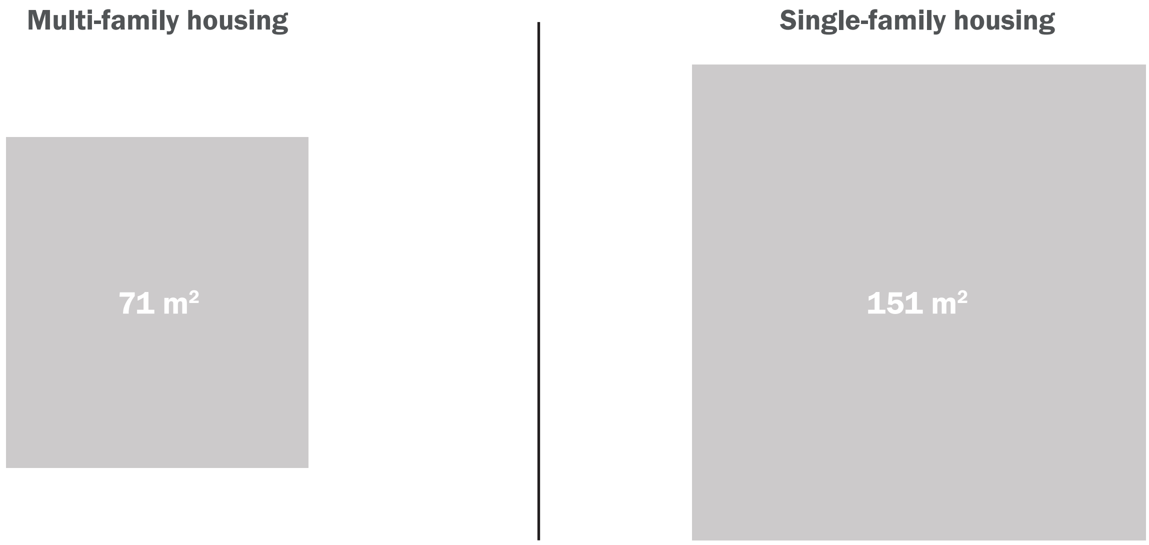
In the Netherlands, there are two gneral categories for housing. These are, a multi-family housing and single-family housing (CBS, 2022). The multi family housing category basicly means that one building houses multiple housholds. And for the single-family housing means that one dwelling forms the entire property. Which types of housings fall under these categories are displayd in figure 3 (Leupen, 2011).

Figure 3
Housing types per category, multi-family housing or single-family housing
▼



These single-family houses are on average more then twice as big as Multi-family housing. According to the CBS a multi-family house in 2022 was on average 71m^2 (CBS, 2022). Where a single-family house had an average in 2022 of 151m^2. In figure 4 the difference in size is displayde on a scale of 1:200.

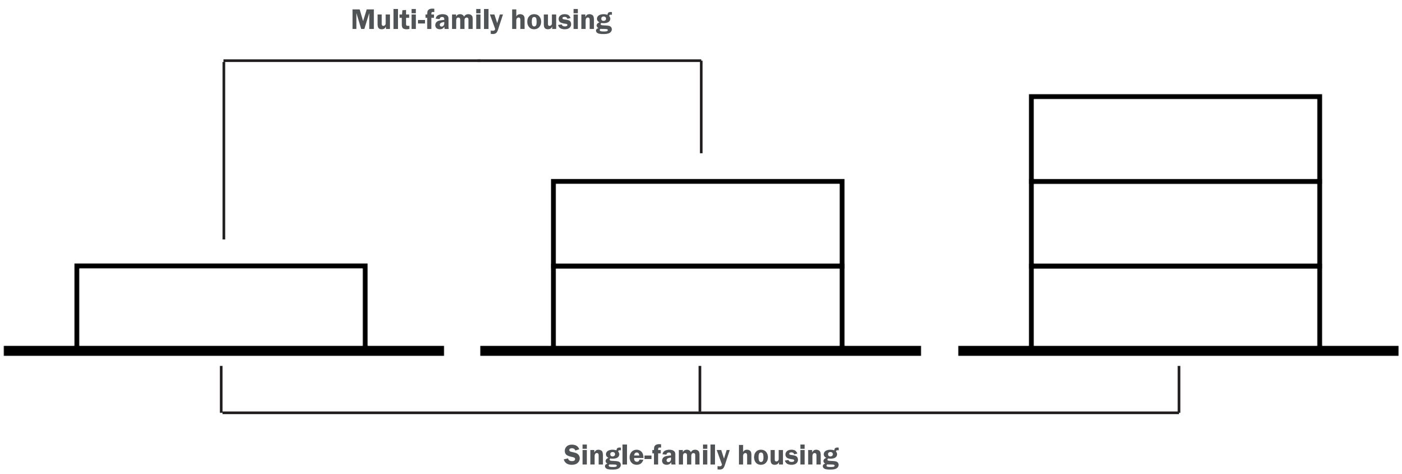
Figure 4
Size diffrence of multi-family home compared to single-family home
▼



2.3. Layers and dimentions

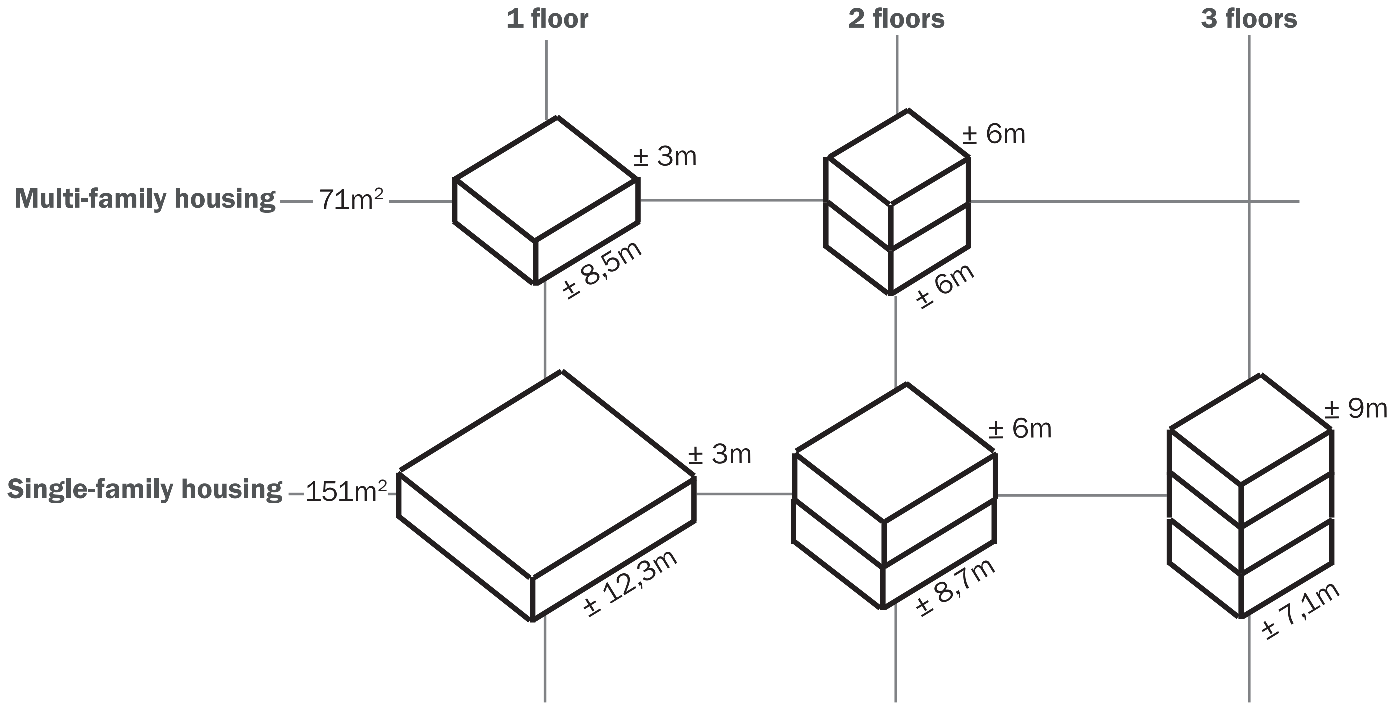
Typically houses in the Netherlands excist out of on 1 to 3 floors (Leupen, 2011). A multi-family housing is a building that houses multiple residences. Most of these residences have 1 floor. Only a maisonettes will are typicaly 2 floor residences. Only a single-family home has a third floor in its residence. This is in the netherlands very common vor single-family houses. It is also possible that they are build with 2 floors or 1 floor, but in general 3 floors is the standard. Figure 5 is a graphical representation of this.

Figure 5
Amount of floors per housing category.
▼



To compare the sizes of each possible combination, in figure 6 the building masses are shown based on a squared floor plan. The masses are in proportionated to each other to distinguish the differences. The measurements give an indication of how big the house could be.

Figure 6
Building mass comparison between housing categories and amount of floors.
▼



2.4. Spaces in houses

Depending on the amount of people living in a house, the amount of rooms might lightly differ. But at the base line for a houshold with multiple people, a kitchen, livingroom, bedroom, bedroom/office, entrance, hallway, bathroom, toilet, outdoor area and technical room will always have a place in a house . And if there are children involved, a third bedroom would become part of this list. For multiple floors a stairs would come in to play and if wanted a storage / utility room is often found in a standard house.

Figure 7
Grouping of different spaces and rooms in a house.
▼

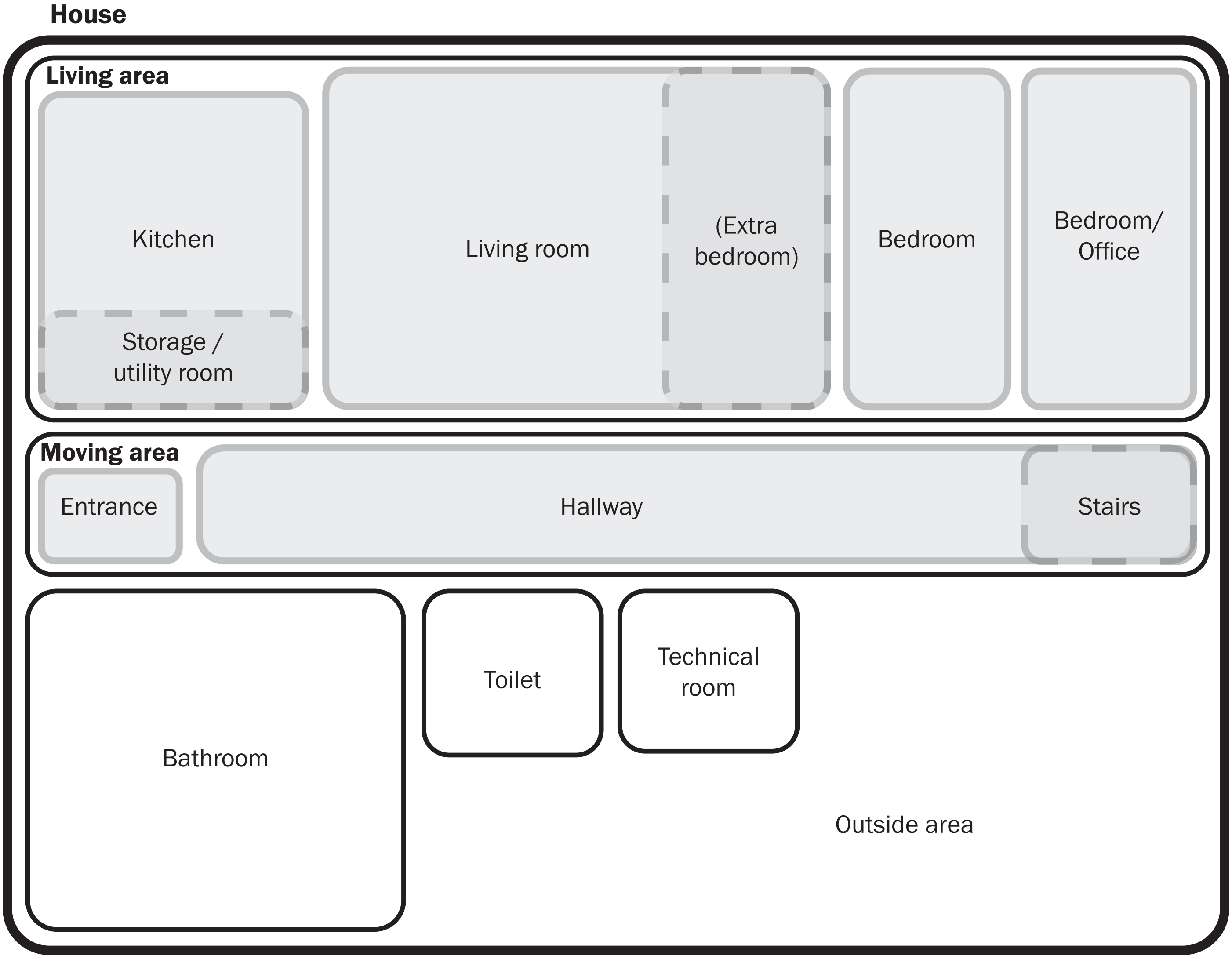


Figure 7 shows a representation of these rooms together. It does not represent a certain composition of a house, it only shows a graphical representation of what types of rooms can be found in a house and how these can be grouped together in terms of their functions. These are the rooms that have to fit in a house to qualify as a livable and functional house in terms of the building code of the Netherlands (Ministry of Domestic Affairs and Kingdom Relations, 2022).

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◀ **Picture page 7**
Floodplains of the Waal river near Druten the Netherlands.
Own image

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Colophon

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Photos: Renée de Vries
Illustrations: Renée de Vries
Text: Renée de Vries

TU Delft

APPENDIX 2_SUMMARY OF BRAINSTORM SESSIONS

Interview summary

Heijmans – Hans Diender

Company: Heijmans
Interviewed: Hans Diender
Interviewer: Renée de Vries
Date: 30-nov-2022
Location: Online

Information interviewed

Hans Diender is a Climate adaptation specialist at Heijmans in the infrastructural department. At Heijmans they have seen the growing importance of climate adaptation. This is also why they more often are asked to advise on property developments, were water and soil are like infra leading factors. We are on the implementation side of projects which gives us a unique position in the problem. We can almost directly implement our solutions by being our own client.

Water and soil as leading factors

The location of choice is the base, the soil and water characteristics that present themselves at that location are the leading factors for any new project. The water department of the government has a "stand still" principle. The water should not change from before versus after an intervention. For example when developing a big green meadow into an residential district with a lot of pavement, an invention should somehow create the possibility for rainwater to enter back into the soil like it did when it was still a meadow.

For floodplains there are extra elements to consider. The effects of recurrent flooding which results in specific the dynamics of the soil that together create a very unique situation. The soil of a flood plain is start at the river bed often washed-up sand and underneath and after that towards the dikes there is clay,. The dikes are a sacred like component for flood protection. This is why a few meters before the dike and behind the dike you are not allowed to do anything with this soil. Because digging too deep can cause "piping" underneath a dike which results in erosion. Therefore it must therefore remain protected. Though it is technically possible to build on or near a dike without safety consequences for the dike, it will cost only more and makes the houses unaffordable. When a dike is reinforced it goes up and then of course its toes get wider and wider if there is room for it. If there is not, then other solutions must be looked at, such as sheet piling.

If the building levels were to change to 20-30 centimetres higher, we would have more margins in times of floods. Water is then allowed to stay on our streets. But this is a piece of acceptance that we are absolutely not ready for. When people see water on the streets, they get scared. While this is something that we have to accept in the coming years.

But important is, that it should not be possible that on a regular basis water is entering a house. In the case of designing a house resilient to flooding, a safe way to do that would mean building 2 meters higher than wat we now do. But that would be very hard for infrastructural components to allow for that. It could tough be more feasible when the houses are autarkies, that it has all its amenities on board. A bit more efficient though would be a collective community not too big. This small community would be able to arrange a number of amenities together. Heat, reuse of rainwater, dirty water and maybe even clean water when putting a purification system in between.

Simultaneously the subsidence of soil because of droughts is a very big problem. Houses located in floodplains currently struggle with settling clay, this results in houses where the pressure is not evenly distributed anymore and causes cracks in walls. But the technical solution for this problem is already there, building on piles and putting them on the right load bearing layer, there wouldn't be any problems at all. What would always help in floodplains is a light and easy construction. And maybe also easy to pick up again. What happens a lot for example, a modular home that is very light and well insulated. And if it sinks, it is easily picked up and it is possible to backfill the ground until everything is straight.

Foundation typology
Building on a mound would also be possible but it has also some big cons to it. A mound takes space away from the river when building in the floodplain. And taking space away from the river is taking away water storage. And there is another problem, we don't have sand for that. Sand is getting expensive, it's getting scarce. Not extremely, but sand is not cheap. Sand is a raw material that is widely used and in high demand. And if raising everything with it, creates a new problem. A large concrete slab could be a solution as well. But it would cover extra soil from the floodplain because it has to be much bigger than the house itself. Though it would be able to absorb the difference of slumping clay. If there were a shallow foundation type that offered the same security as founding on piles I would say do it right away. In relation to contamination of subsoil and that it is already so full. But for now, all other foundation techniques pose risks for us. You can also try to just start founding on the clay and then adjust the whole structure. And then take settlements into account. Overall the main thing is that we want to build riskless. And building on piles comes the closest to that aim.

It is also possible to build a foundation on wooden piles, but then the ground water should at all times be high enough so that it is never possible that air is able to reach the wood. A solution could be to use a wooden pile at the lower part and then put a concrete pile on top of it, to allow for ground water level shifts. It would not be surprising if in the near future a composite material becomes available to use as foundation in terms of sustainability. But a concrete pile can now also be reused and there are also types of concrete that are perfectly circular. Though it is extremely expensive to pull out piles, technically it's all possible. Currently no matter what is built, there must always be an instruction as to how that each material can be processed again when a building has to be demolished.

An option could be to use fewer piles but the beams in between the piles then should be more firmer and stiffer, a sturdier structure with more reinforcement. Or take it a step further and make the house rigid enough. By means of wood construction, for example, then it is possible without poles or with light poles. That it is somehow so stiff that it is allowed to move a little with the subsidence. But in any case the water has enormous forces. What could be a solution is to build the houses as boats that it is a point through which the water runs easily past it, hydraulically sound. That could also be done with piles, they are not square poles but poles in a drop shape.

Interview summary

ABT – Vasco Veenbergen & Jan-Willem Bardoel

Company:	ABT
Interviewed:	Vasco Veenbergen and Jan-Willem Bardoel
Interviewer:	Renée de Vries
Date:	02-dec-2022
Location:	ABT office in delft and online

Information interviewed
Jan-Willem Bardoel works 3 years at abt. Studied TU delft, hydraulic engineering. And is since then working as a water safety consultant, mainly on dike reinforcements. There are occasional detours into other areas such as geotechnical engineering or port developments.

Vasco Veenbergen works already for 20 years with subsoils, and the last 12 years for ABT. The first 10 years my work was more centred around excavation pits, drainage and foundations. A whole other line of work than dikes and water safety which what he has been doing for the last 9 years. Due to his background he prefers reinforcing dikes in a constructive way.

Soil dynamics
Soil in floodplains is more saturated compared to soil outside the floodplain. It's the weaker than soil which is not always under water whereby it is more likely to be necessary to construct foundations in deeper layers. Silt and clay are in the upper layers and so a deeper foundation must be realized, for example on piles. Shallow foundation techniques would not be as feasible in a floodplains. Because shearing can occur in the ground, making the soil less stable and causing cracks in a house. This would only be an option in Limburg, where the subsoil along the Maas consists of gravel. But in the floodplains in the upper river area (east of the country) the subsoil is mostly clay up to several meters deep. In the lower river area (western part of the country), the soil sometimes consists of peat and very weak clay layers, sometimes 10 to 12 meters deep. A river has not always been in the same place, so it can vary and meander. Because of this sometimes there is an erratic subsoil where at one time you can have sand and then the next time a gully where there is clay or peat.

For dike reinforcements, the storage of the floodplain itself is also sometimes considered. This is also included in the calculations. This is because the layer of clay on top also inhibits the water from penetrating underneath the dike. And if you make holes in them with poles that is not always desirable. And that is increasingly being taken into account in the assessment of the dike. In the floodplain you have a layer of clay or silt, and underneath is a layer of sand. Through which water penetrates the dike. And this layer of clay inhibits the water from passing through the dike to fast, and if you make holes in the clay layer with structural foundation piles, the water will be able to run down into the sand more easily. It depends a bit on which type of pile you use, some do it more than others. If you use, say, the classic concrete pile, it pushes the soil away so you generally still have a good connection between soil and concrete. But if you really go with a bored pile and remove all the soil, then you have more chance of water running faster towards the sand layer, or piles that have a widened base then you really create a channel right along your pile. Piles for in the floodplain must therefore be ground displacing without a widened tip

Foundation typology
If you are going to build something in the Netherlands then it must comply with the law. The bearing capacity of the foundation, that it is strong enough and the rigidity of the foundation, which means

that it is allowed to sink if this is limited to a few centimetres. Both must be tested. Especially if the house is leaning, you get cracks and it is not practical for the occupant and the consequences are enormous when a foundation is failing.

A slab of foundation has a huge weight and will push the clay away and thus sinks. But that soil does have enough bearing strength to let the house stand on it. The plate itself is strong enough, but then you might end up with a slanting building and foundation or sinking decimetres in places like peat.

A mound could also be built, but sand will also sink. A high water wave can be 5-6 meters high compared to a river as it flows now. If a house is built on top of that, it will take an enormous amount of sand to make the mound. Which, in the west in particular, will sink hard into the same weak subsoil. And in the floodplain the Department of Public Works also wants to keep room for the water. So if we put a lot of sand there, the river will have less room to flow and it will form an obstacle and elevations will form upstream.

In recent years, space for the rivers has been made with everything removed as much as possible. Of course, a house is also an obstacle when it is land-bound. The concept of a floating pier could be a solution to this and still leave space for the river. Then there will be more serious loads on the building in terms of waves. The dimensioning of such a house will then present the necessary challenges. The waves created when compared to a boat crossing the river is nothing compared to long wind waves over a very long stretch, those are much bigger. But the bigger something is the less sensitive it becomes to waves. A whole complex will be better able to deal with this than a single house.

Building on piles above maximum water level does take a lot of material. In some places the water rises 6 meters above ground level and that means that the piles stick out 6 meters above the ground but also go into the ground to the bearing layer. For river flow, an option would be to look at round piles instead of square or possibly drop-shaped. But 6 meters above ground level also gives view pollution. because the house should actually be equal in height to the dike in terms of safety.

To this day, wooden pile foundations are still used. For light houses or farmers' stables, for example. Wood can really last a long time, but without oxygen. It just has to be permanently submerged. What they do then is to hammer away the wooden pile recessed and then put a concrete overlay on top. In the concrete placement, the ground water level fluctuates and then the wooden pole is always submerged. In this instance, the posts are cheaper, pine and spruce. Hard wood on the other hand is more resistant to water and oxygen. But that gives another impact for environment and sustainability. Given that the there is such a large difference in groundwater levels in the floodplains, this is not considered feasible.

Perhaps a house that is jackable could provide another solution. After all, high water in a river is not a matter of it being there within an hour. It is predictable which gives you several days to do something.

A final solution could be a single-story house whose roof is at ground level, with a glass roof instead of a tile roof to allow for daylight to come in. It would additionally require an above-ground element to exit the house during high water. Then the pressure of water must be taken into account. In daily conditions this is about groundwater and in times of high water the extra pressure upwards this gives. At high water, this is 10kPa more per 3 meters of water above ground level. Tension anchors could be a solution for this or the upper part of the house must compensate for this back pressure a form a vertical balance. With this underground solution there remains room for the river and you have no flow forces on the house only pressure forces.

Interview summary

Royal HaskoningDHV – Hans Doornbos

Company: Royal HaskoningDHV
Interviewed: Hans Doornbos
Interviewer: Renée de Vries
Date: 13-dec-2022
Location: In office

Information interviewed
Hans Doornbos has been working in hydraulic structures for more than 30 years. And currently for Royal Haskoning DHV. Also from different perspectives like from contractor but also from client.

Soil
The Netherlands is a delta country. Soil structure in the Netherlands consists largely of what was brought in by rivers. There are also a few areas that were formed during the ice age and then some that were formed partly after it and partly before it. Western Netherlands for example, lots of peat areas, rows of dunes. Eastern Netherlands the rivers that run here and the barrages and the high grounds, the strong grounds. Friesland Groningen also some small peat areas. Most of the Netherlands is just relatively poor to build on.

The floodplain has dynamic soil, but there are a few other aspects that come with it. For those weak soils, indeed, you're usually going to use a pile foundation. And on the north-eastern part of the Netherlands where you just have those firm soils, there you can go on steel foundations. And there you don't have the whole flood thing, it's just too high there. But there have also been floods in Limburg, where the ground is firm, but not everywhere. That also has to do with the type of river. There you also encounter nice clay packages, especially at the top.

Water
We know what the rivers and water levels in the Netherlands have been like in recent years. We know approximately how fast the sea water is going to rise. Of course, these are all just forecasts. And from those you can extract a kind of frequency of how often a certain water level will occur. And if you extrapolate that, you end up with numbers of 1:1000 years, 1:3000 years. And those kinds of numbers correspond to certain water levels. And that is what the dikes in the Netherlands are designed for. Those are numbers that are in constant motion. There is certainly a chance that these numbers will have to be raised again in the future. But given the theoretical lifespan, actually reference, period of a home is 50 years. That is relative to a levee very short. To choose a height of the crest of a dike is then a good approximation.

The strong current doesn't necessarily mean you have very big waves right away. If you make it a kind of community and so you start connecting the houses together and then you get a lot of stiffness from that as well. And so you can prevent waves from having their effects on those homes. Surely a cluster of homes then makes it easier to do that in a joint way than to provide each home with all kinds of conveniences on its own.

Flow of the river in normal situations can flow quite hard, but the wider it gets the calmer it also gets at some point. So that flow of the water is not even the biggest problem most of the time. And a little foundation should be able to withstand that easily. But the dirt that gets swept along in the river are often the dangers to the structure and the house itself, such as tree trunks and loose ships, which is also very relevant in times of flooding in today's residential areas where there are bicycles, cars, road signs, lampposts, etc. everywhere. That just happens that kind of thing. You have to treat these places with extra care, because it really does create extra risks. And when there has been high water, you shouldn't be surprised if there's a whole layer of mud in that spot. In addition to mud that settles down when you start making pile foundations, what wants to happen then is that not only the bike that's up against this washes away, but also the soil that's there is going to happen to that. If you stand on the edge of the beach by the sea, you can see exactly what happens to the soil and how it is washed away. There will be leaching. Before and after high tide, the subsoil will look completely different.

Foundations
Foundations are not difficult, building is not difficult, making a house is not difficult. But all those things at the same time and floods and water that does make it interesting. For foundations in the Netherlands there are several things already thought out. Like the strip foundation and the pile foundation. If you have good ground you can use steel foundations and if you have poor ground you have to find a bearing layer by means of a pile foundation. There is also a third type of foundation, and that is just the boat. Foundations are really not that much more than ensuring that the structure can remain on the ground. You can make a foundation as light or heavy as you want. Only the principles you follow, they can be slightly different each time. So it's a matter of choosing good starting points and then coming up with something at a certain point.

You can start building for a fixed place. And you can start building things that they can just be moved temporarily. Looking at things that stay in place. Then you're talking about a pile foundation. And a strip foundation. And those are actually the two most common structures. Most people will say you just need a pile foundation there. And whether you're going to take a pile or a sheet pile that would be another question. It's going to be something that you're going to have to put in the ground to a greater depth.

A strip foundation, in itself, is fine even in weak soils. But you have to put certain requirements on that house. For example, imagine building a house on a very large rigid slab of concrete on very weak soil. Then that house is going to sag a little bit. Load = deformation. Only load on weak soil means a lot of deformation. And in the Netherlands this deformation is never completely equal.

And then you have another foundation possibility, and that is simply using cables. These are then laid in a certain place, whether it's a houseboat or 10, it doesn't matter. And then at each corner there is a cable which ensures that it is pulled tight in four directions and held in place. But you can make the cables so that they allow the house to go up and down slightly. Those cables are anchored in the ground, just compare it to a ferry.

There are 3 materials that you could do reasonably well here. Steel, which can rust so you have to maintain that, or give it stitches. Concrete is a very hard material. And that can take a little bit of flow of water, but it gets damaged over time. But that's just fixable. Concrete itself is a stone-like material, but it cannot take a tensile load. That's why it has steel in it. And concrete is so alkaline that the steel is not affected by oxygen and all kinds of other substances in the air. To make sure that that alkalinity around that reinforcing steel just stays, that outer piece of concrete does have a function, it always has to be there. And needs a certain thickness. And when you start talking about these conditions, you just have to choose that thickness a little bigger. It might be a little bit harder to make and you need a little bit more material. The third material, is not yet so widely used in the Netherlands, but you can see it slowly emerging a bit. This is fibre reinforced plastic. Epoxy for repairing cars, for short, but made for special constructions. It's also used in televisions, and bridges are even being built out of it these days. It's little fibres of carbon, fiberglass whatever. And they are held together with resin. And you can make very strong things out of it. Sheet piles used to be made mainly of steel, but today they are also made of fibre reinforced plastic. Pipes can also be made of fibre reinforced plastic. Much more can actually be done and I expect that many more tests will soon be carried out to apply it to this kind of construction. It is not very common yet, but it will come.

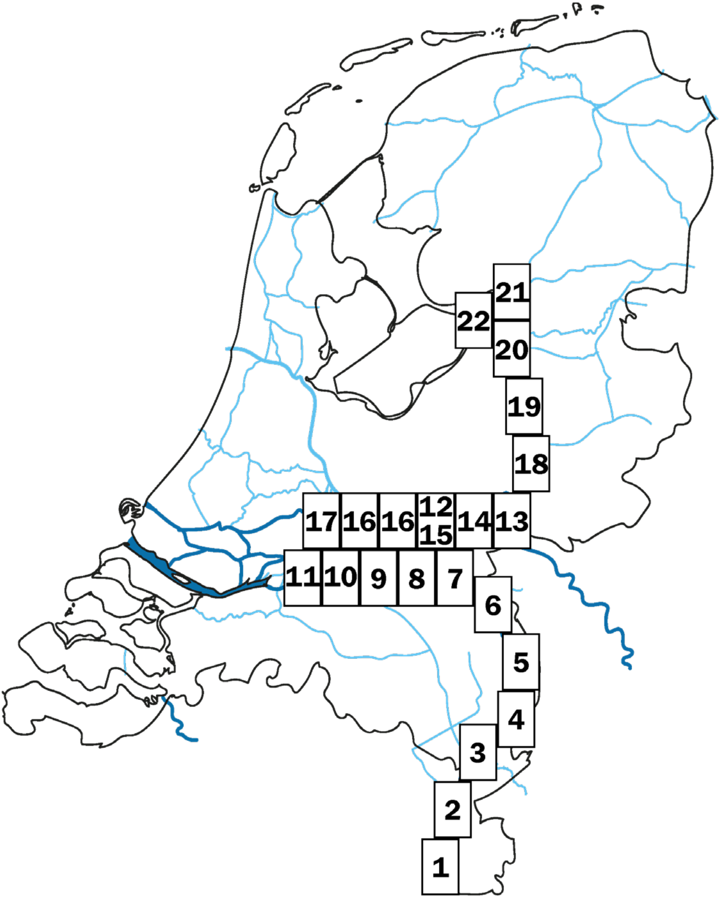
Wood as a foundation material is of course a lot less, but when it comes to flotation joints, wood can be very ideal. But then what are you going to use it for and how are you going to use it. It is not always the case that wood will weather very quickly when it changes from wet to dry. Even wood underwater can run out. It is not for nothing that we have a lot of problems with wooden pole foundations in the Netherlands. This is not only because of the top piece that now sticks out of the water all at once. It's also the rest of the pile these days. So that's going to be a much bigger problem than it is right now. So wood doesn't last our whole life, it does last the whole life of a home on the other hand. It is also almost 100% sure that at the boundary between water and air that wood will be eaten first. But that also means that it's just a relatively narrow zone that is very sensitive. And if you apply the right materials to that zone, a good type of wood and good protection, I don't see the problem. Then maybe it can last 30, 40 years or even longer. And, of course, you can start combining wood with other materials. For example, what you also see are those concrete floats. And those consist of a thin layer of concrete and then a very large pack of pur foam or whatever is in there and then you have another thin layer of concrete. But it works ideally. And you can apply wood that way, of course. It still has a certain look to it.

Other notions

If you have a house that's just on the ground. And it gets high water, it remains to be seen whether tie is going to come up then. It will not always come up. It will only do so when there is actually water coming under it. It will be held in a vacuum and then it will stay on the ground. And of course it will come free at some point, but the question is how controlled that is. What such a shape is only going to do more than prevent your load from increasing is purely the leaching, runoff of material and soil at ground level there is a lot that shape can do about that. The strength will not be a problem.

APPENDIX 3_SOIL AND WATER BOOKLETS

0. Introduction



<u>What is this:</u>
This is a supporting product for the research thesis 'Soil and water as leading factors for designing a floodreselient family home'.
This product explains the dynamics of floodprone soils and river characteristics in the Netherlands.

<u>How does it work:</u>
This product exists out of:
a. 1 introduction booklet nr. 0
b. 22 location based booklets nr. 1 to 22
c. case.

a. Introduction booklet
On the front of this booklet is a map with the numbers 1 trough 22. These represent the 22 different locations and the corresponding booklets. The selected locations are related to the big rivers in the Netherlands: The Waal, Maas, Neder-Rijn and the IJssel. If the front pages of each bookled are connected, as shown on the front page of this booklet, a whole map of these rivers occure.

Other information found in this introduction booklet: Explenation of this product, vocabullary list, a ledgend and an overall conclusion.

b. Location based booklets
The composition of every booklet is the same. Front page with map, soil page, water page and then last pages with conclusions per location.

The map on the front page shows by a symbol where the water and soil measurements have been taken per location. is for water, is for soil.

The soil page shows a graph of the soil composition, the cone resistance and the ground water level. In the vocabulary list a description for these parameters is given.

The water page describes the flow rate, water level, ground level and dike height in relation to each other. In the vocabulary list a description for these parameters is given.

c. Case
The case has on the front a map with the names of main locations in the netherlands and the names of the main rivers. On the back of the case is a colophone.

Soil graph:

Cone resistance: ,point resistance, is the quotient of the force required to move the cone downward when probing and the area of the base of the cone.

Ground water: Is the water found between solid particles in the subsurface (sand, clay, silt, peat, loam). These spaces between soil particles are called pores. When pores are filled with water, this is called groundwater. The highest level of groundwater is called the water table. Above the water table, water also occurs. At this depth, however, not all pores are filled with water; this water is called soil moisture.

Soil drilling sample: Is the description of the samples from the penetrated part of the soil in terms of contiguous layers of soil types.

Gravel: Consists of at least thirty percent of rock fragments whose diameter is larger than 2 millimeters and smaller than 63 millimeters. When the fragments are smaller, it is sand. When they are larger, they are boulders.

Loam: earth that is a mixture of sand, clay, and decaying plant material

Clay: thick, heavy soil that is soft when wet, and hard when dry or baked, used for making bricks

Sand: a substance that consists of very small grains of rock.

Iron ore: a substance formed naturally in the ground and from which iron can be obtained.

Debris: broken stone and bricks, etc

Peat: a dark brown, soft soil that was formed by plants dying and becoming buried.

Ore: a substance formed naturally in the ground and from which metal can be obtained.

Roots: the part of a plant that grows down into the earth to get water and food and holds the plant firm in the ground and leves leftovers in the ground

Water graph:

NAP: Normal Amsterdam Level, The NAP level is a horizontal plane (roughly corresponding to mean sea level) relative to which it is possible to indicate the height of land and water in the Netherlands

Flow rate: Is the term for water that a river discharges and is expressed in cubic meters per second. The average discharge of the Rhine is about 2200 m3/s The discharge, however, can range from 600 to 16000 m3/s. The discharge of the Meuse is about 200 m3/s with a spread of 20 - 3500 m3/s

Water level: Calculated surface water level relative to Normal Amsterdam Level

Dam: Distribute water from major rivers and lakes to all water users as best as possible.

Ground level: Is the height of the top of the ground of the site.

Dike height: Is the height of the dike vs. NAP.

Map:

Soil measurements
Water measurements

Soil:

Gravel	Iron ore
Loam	Debris
Clay	Peat
Sand	Ore
Fine sand	Roots
Coars sand	No info
Ground water H	Cone resistance
Ground water L	level under 2m

Water:

Water level	Ground level
Flow rate	Dike height

Soil:

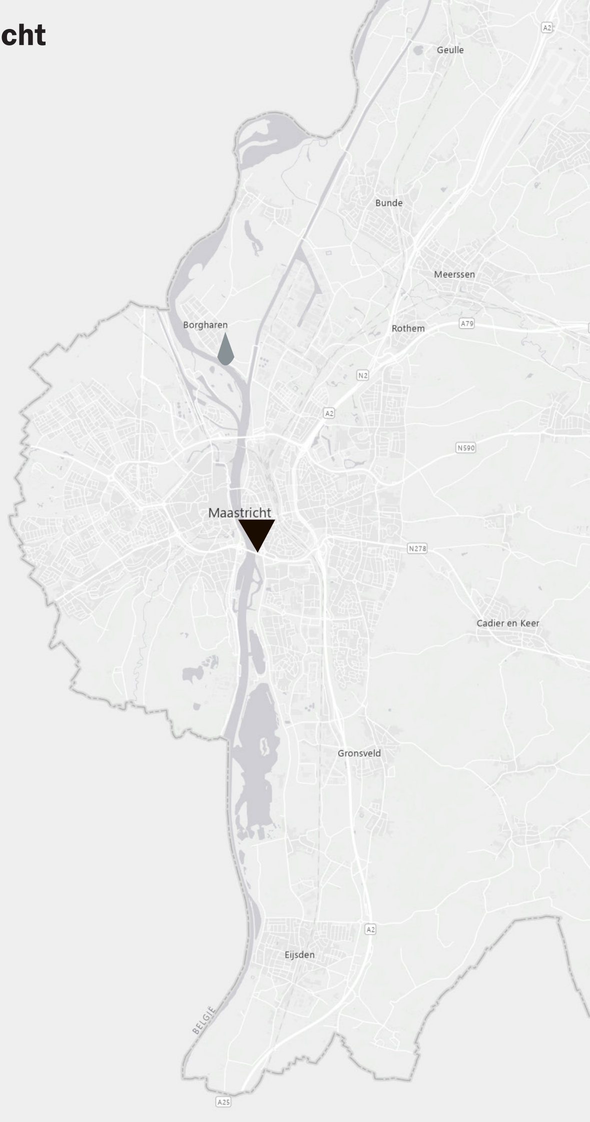
- In the North-eastern part and South-eastern part of the Netherlands there are in general harder soils like gravel and sand.
- In the middel of the Netherlands and mid-eastern part the soil in general consists out of clay.
- In the more Western directions and at the end of the IJssel river, the soil gets weaker and weak. Consisting out of clay and peat.
- In general allong the rivers there is always some part of the soil that is clay. Therfore soils allong the rivers are in general relatively weak.

Water:

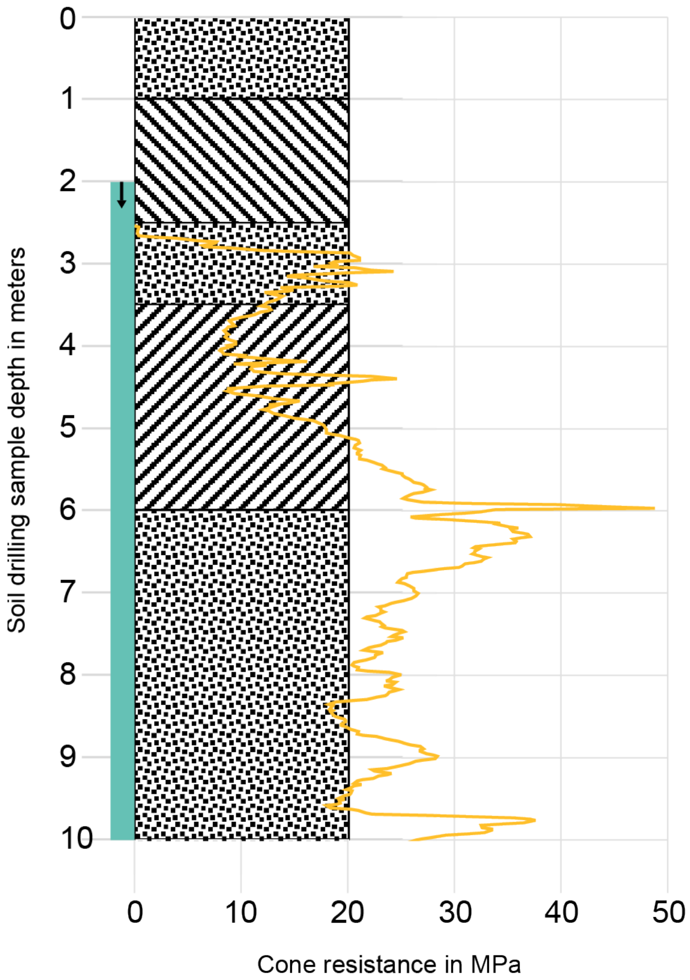
- Flow rate impacts the water level. High flow rate is often higher water levels if there are no dams involved.
- During winter period water levels are in general higher and more erratic.
- The Waal and IJssel are uncontrolled rivers
- The Maas and Neder-Rijn are controlled rivers.

sources:
www.geologievannederland.nl - www.madhavuniversity.edu.in/soil-types - www. basisregistratieondergrond.nl - www. dictionary.cambridge.org - www. rivm.nl/landelijk-meetnet-grondwaterkwaliteit/grondwatersysteem - www. rijkswaterstaat.nl/en/water/water-safety - www.rijkswaterstaat.nl/water/waterbeheer/bescherming-tegen-het-water/waterkeringen/dammen-sluizen-en-stuwen - www.dinoloket.nl - www.ahn.nl/ahn-viewer

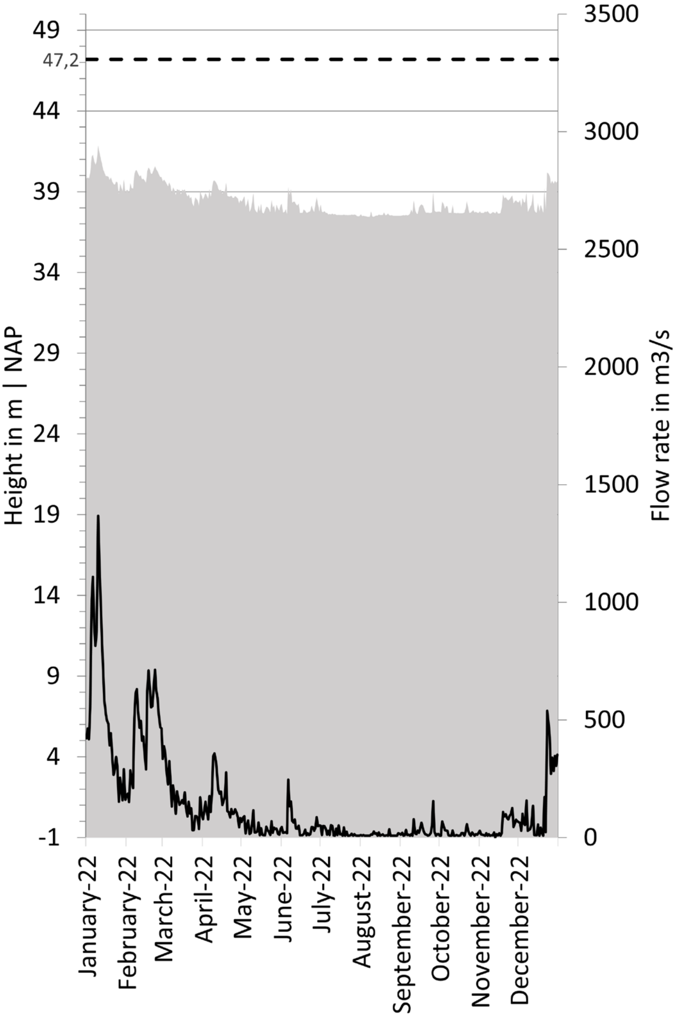
1. Maastricht



1. Maastricht | Soil graph



1. Maastricht | Water graph



1. Maastricht | Conclusions

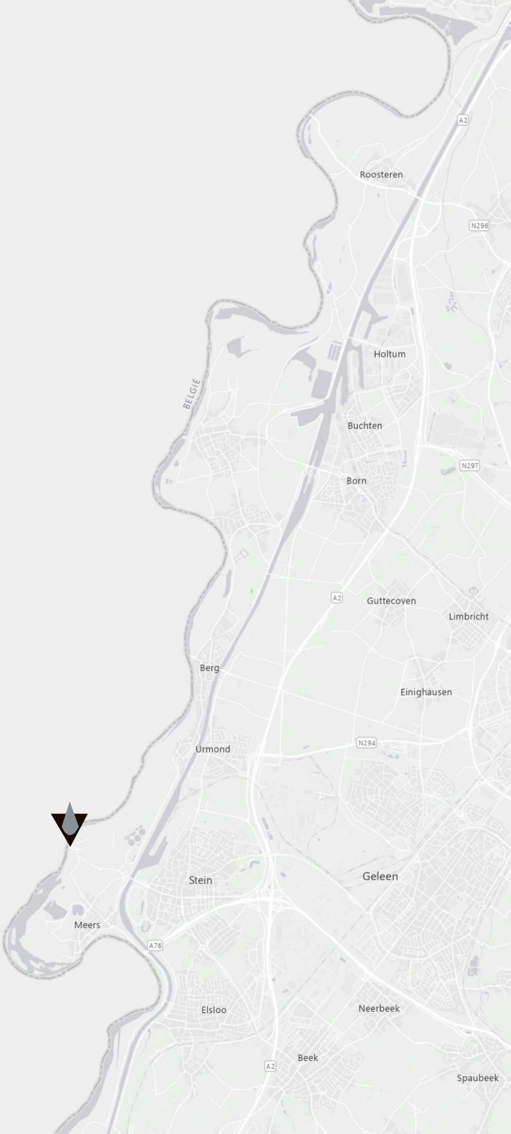
Map:
The map shows that the measurements are taken at seperate locations but close to each other:
Soil, Maastricht
Water, Borgharen dorp

Soil:
The soil composition is relatively strong at a depth of 6 meters. This is probalby due to the big gravel layer that starts at this point. But the upperpart shows that the ground is very unstable untill a depth of 2,5 meters, this is likely a result of the clay.

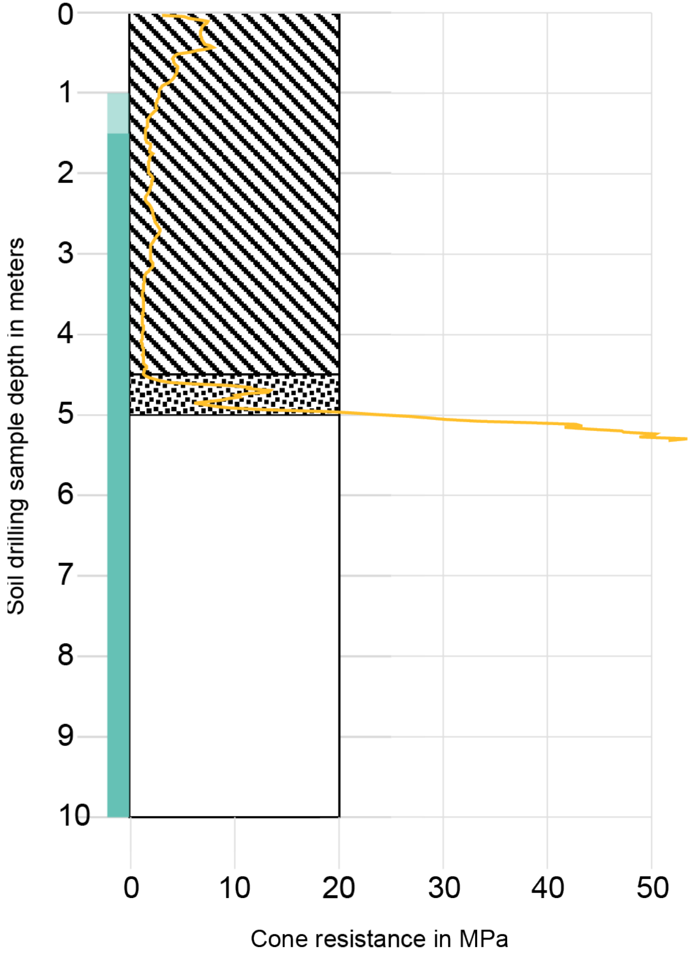
Water:
This location in the river does not have a very big flow rate. There is a connection visible between the fast flow and the shift of heigher and lower water levels. At this location the water is less likely to enter ground level as there is no dike.

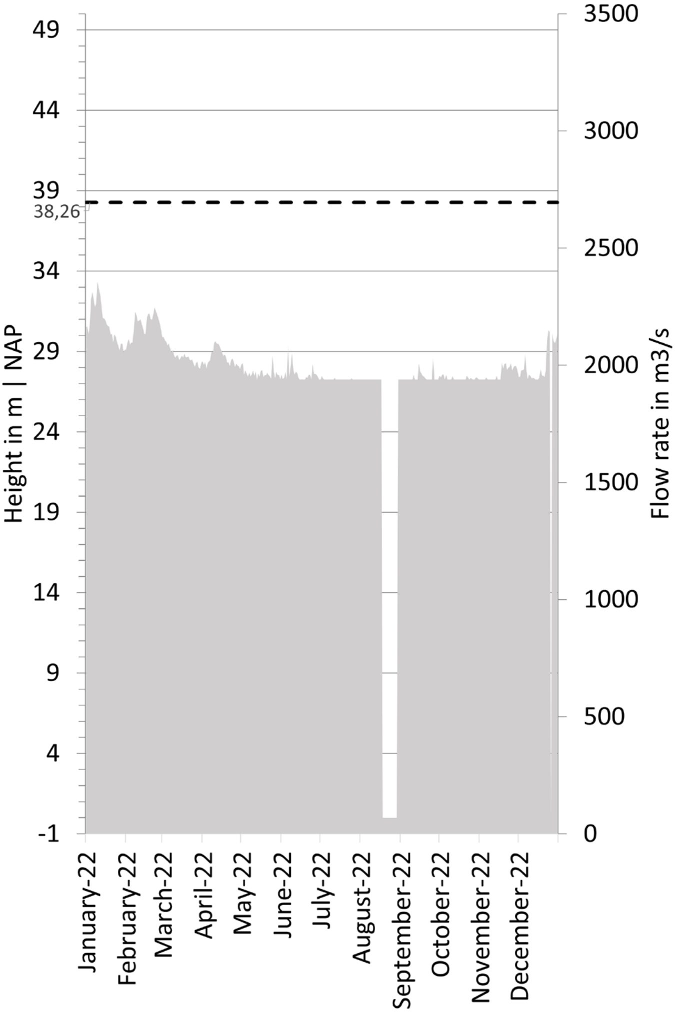
Overall:
The Maastricht location is a high location with a relatively stable river and a stirdy soil

2. Maasband


A2
Roosteren
N296
Holtum
BELGIË
Buchten
N297
Born
A2
Guttecoven
Limbricht
Berg
Einighausen
Urmond
N294
Stein
Geleen
Meers
A76
Elsloo
Neerbeek
Beek
A2
Spaubeek

2. Maasband | Soil graph

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Height in m | NAP
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Flow rate in m3/s
January-22
February-22
March-22
April-22
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June-22
July-22
August-22
September-22
October-22
November-22
December-22

2. Maasband | Conclusions

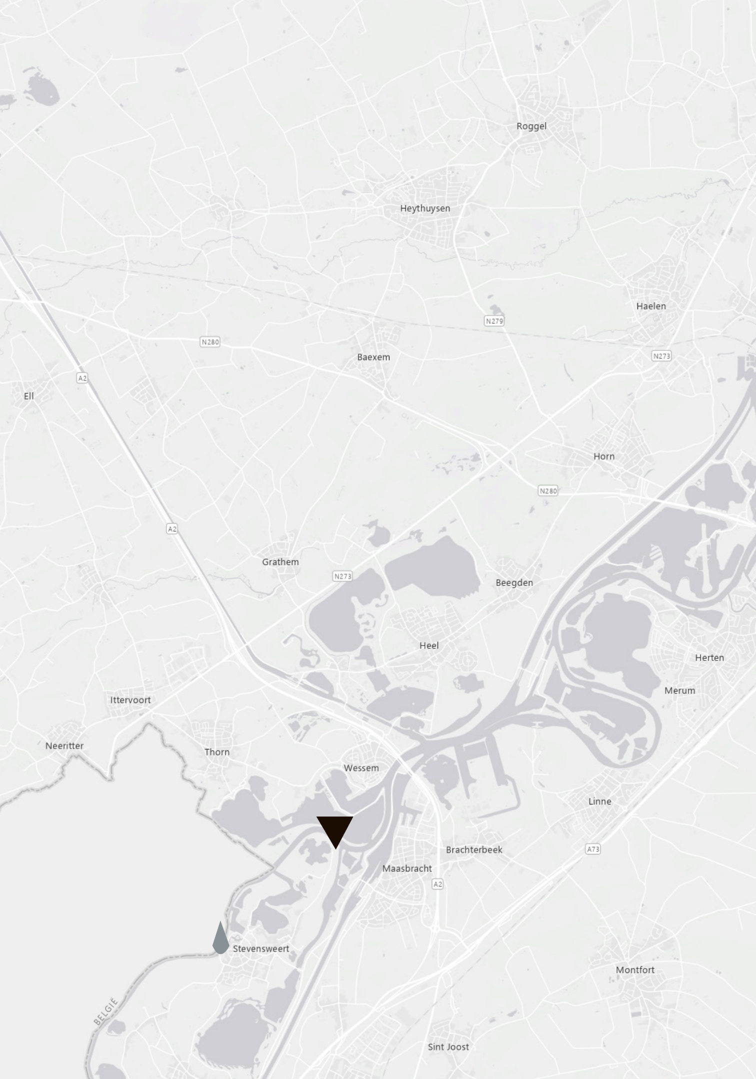
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Maasband
Water, Eisden Mazenhove

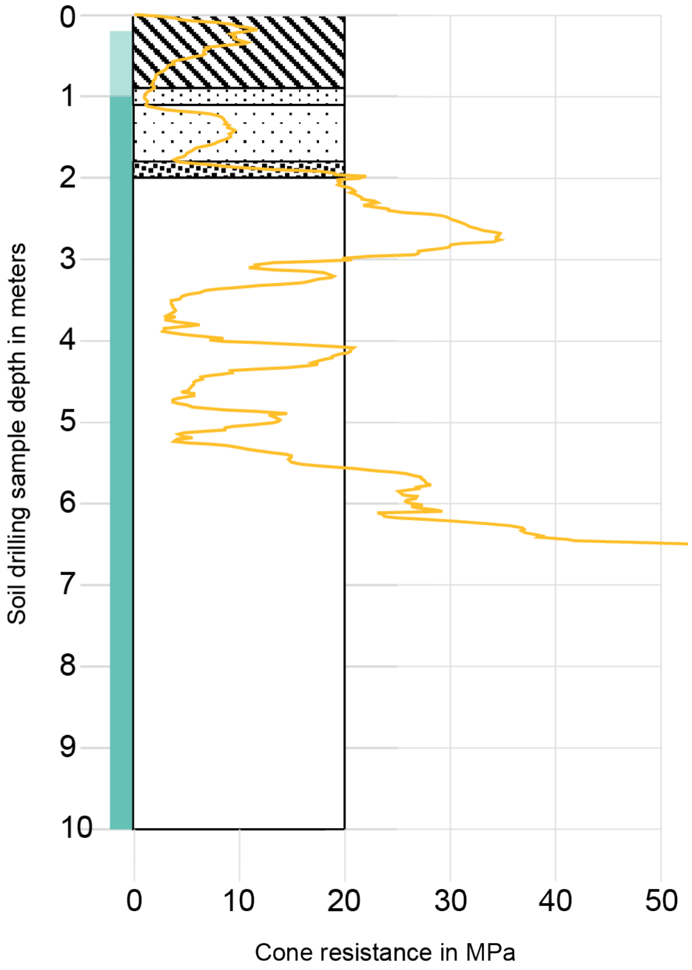
Soil:
Untill a depth of 4,5 meters the composition mainly excists out of clay therfore the resistance of this part is very low. After that, the gravel starts and the soil is stronger at that depth.

Water:
At this location the water will not go over ground level that often, as there is no dike. Only in the winter months a higher water level is visible.

Overall:
At 5 meters the soil is very strong. The river it self at this location is relatively stable.

3. Maasbracht

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Soil drilling sample depth in meters
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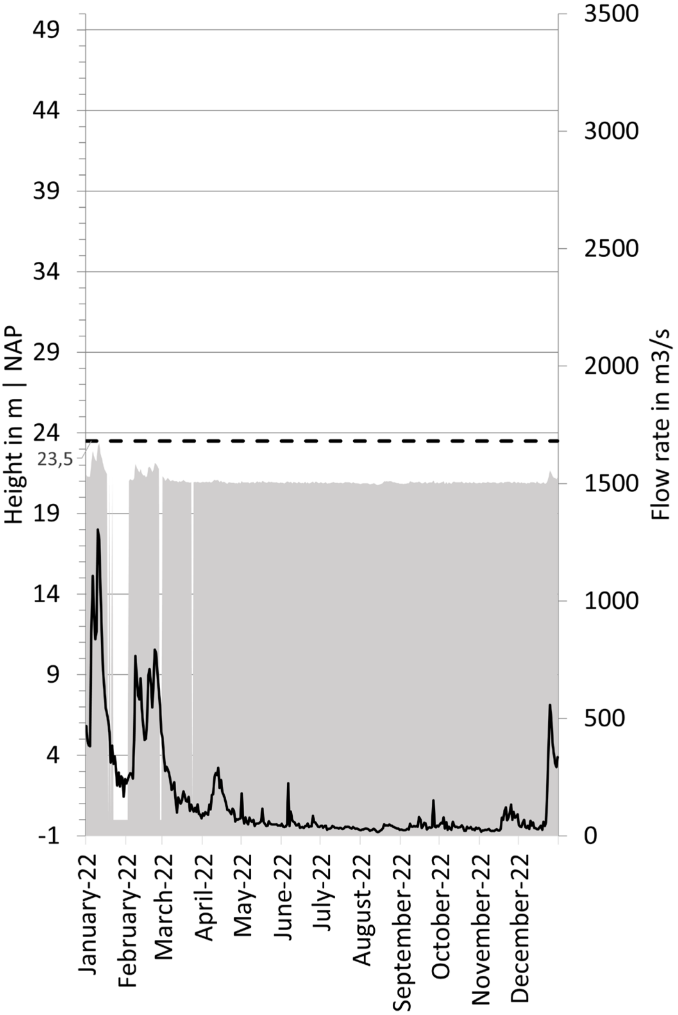
50
Cone resistance in MPa



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Flow rate in m3/s
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September-22
October-22
November-22
December-22

3. Maasbracht | Conclusions

<u>Map:</u>
The map shows that the measurements are taken close to each other. The locations are:
Soil, Maasbracht
Water, Stevensweert en Maaseik

<u>Soil:</u>
At a depth of 2 and 5,5 meters the soil has a stirdy composition. The upper layers and in between sow great variaty in stability.

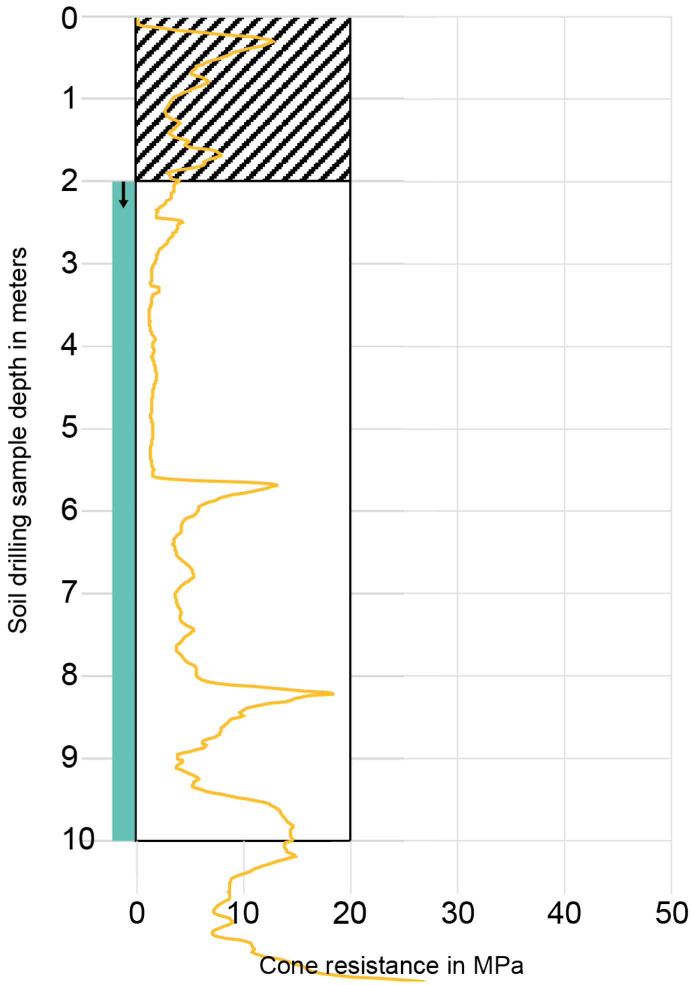
<u>Water:</u>
The water level during winter time almost reaches ground level. This could result in flooding of the area. Since there is no dike in this location it is a very high risk vor people living in de surroundings. Here the flow rate also shows a connection with the water level shift.

<u>Overall:</u>
This is a relatively strong soil. The water level reaches big heights compared to ground water level.

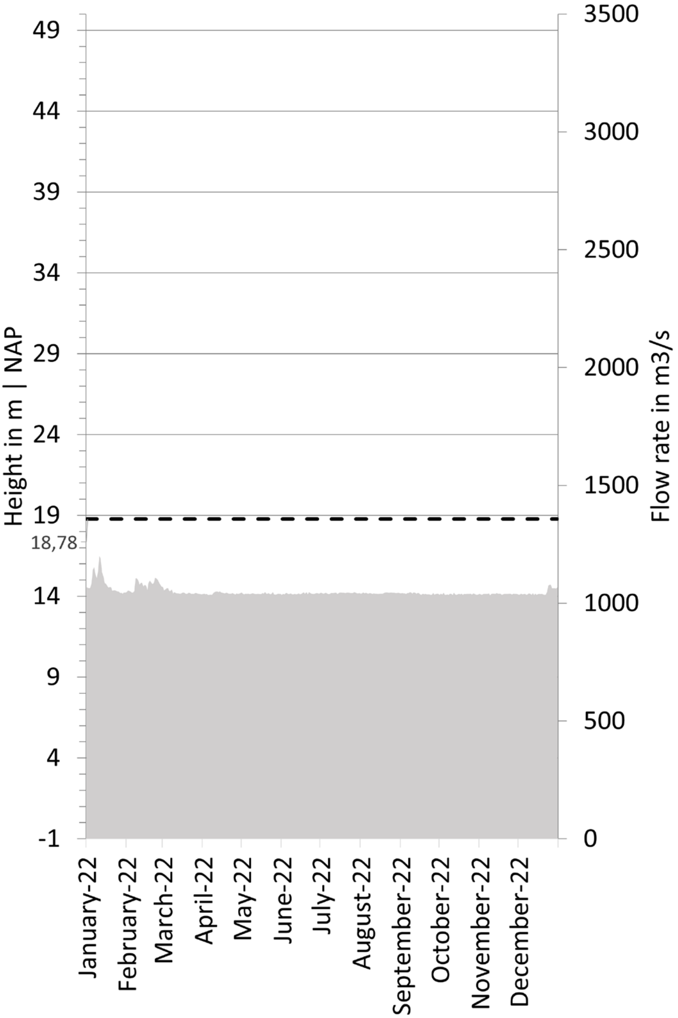
4. Buggenum


A67
A67
Blerick
N275
Maasbree
Hout-Blerick
A73
Tegelen
A61
Steyl
N273
Baarlo
N277
ngen
Helden
Belfeld
Kessel
A73
Reuver
N273
Beesel
Neer
DUITSLAND
A73
Swalmen

4. Buggenum | Soil graph



4. Buggenum | Water graph



Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Buggenum
Water, Buggenum

Soil:
For so far is known the soil composition exists mainly of clay and as seen by the cone resistance it runs probably trough to a dept of 5,5 or even further. This is relatively weak soil.

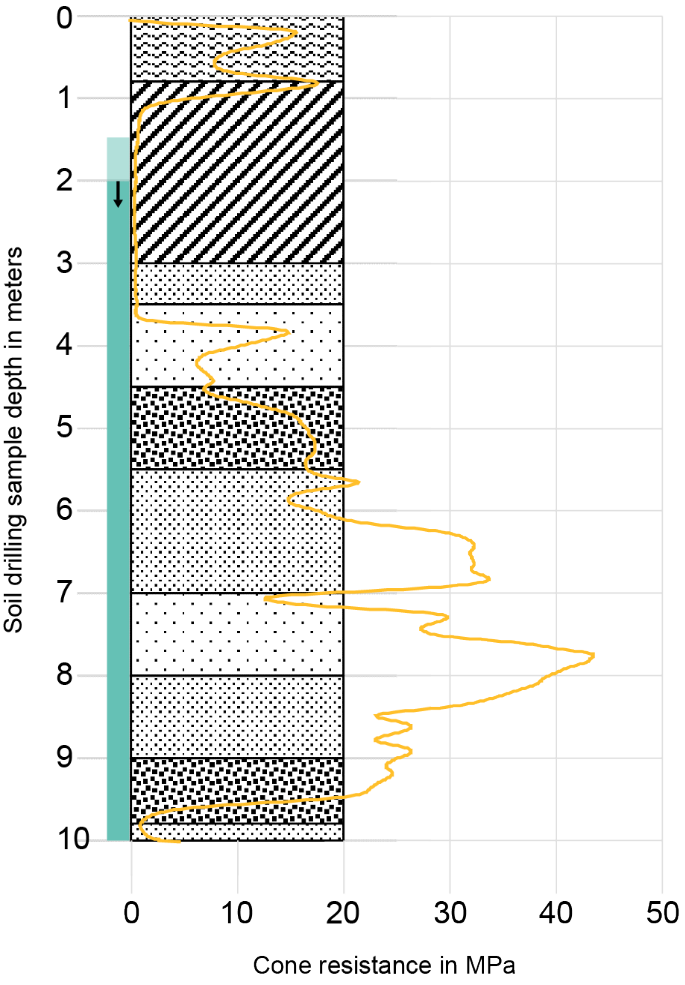
Water:
The water level at this location is very stable. It has a few higher peaks but in this graph never go close to ground level.

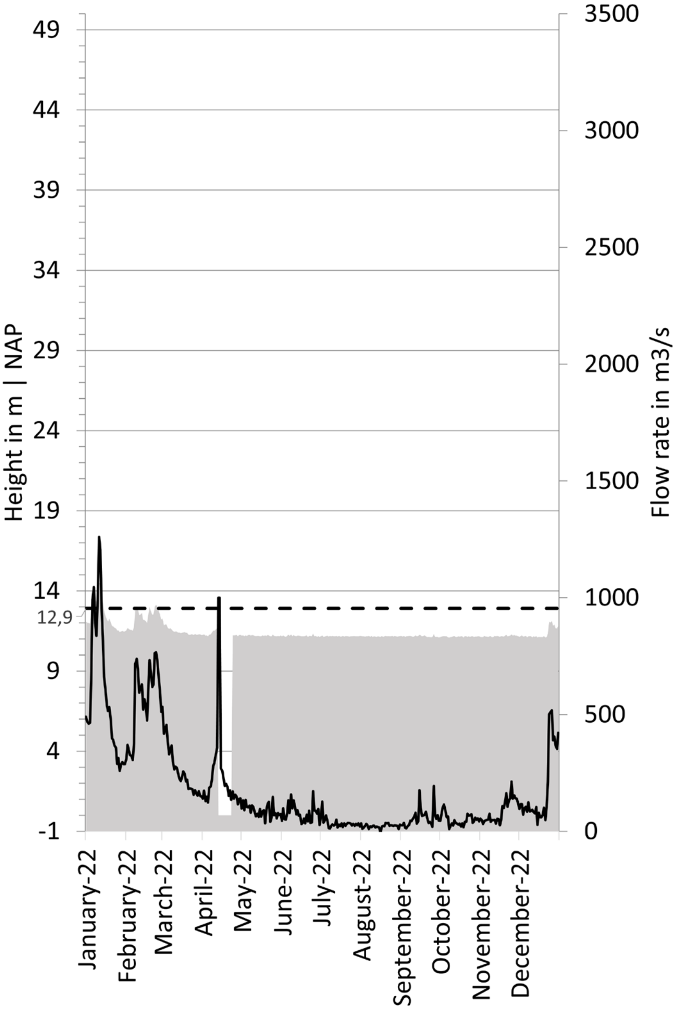
Overall:
This location present a weak soil composition and has a stable water level.

5. Arcen


Well
Wanssum
N271
N270
Oostrum
Meerlo
A73
Tienray
Arcen
Melderslo
N271
Horst
Hegelsom
A73
N271
A73
Grubbenvorst
Velden
Sevenum

5. Arcen | Soil graph





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Height in m | NAP
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Flow rate in m3/s
January-22
February-22
March-22
April-22
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August-22
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October-22
November-22
December-22

5. Arcen | Conclusions

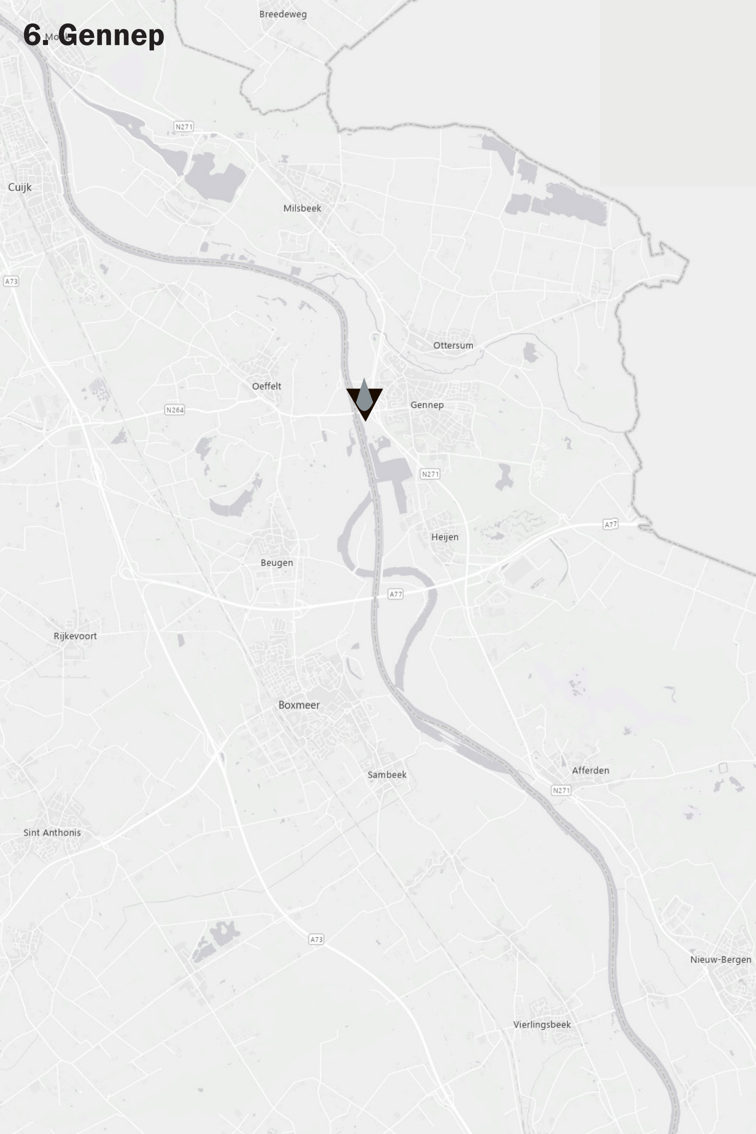
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Arcen
Water, Venlo (seen on map 4. Buggenum)

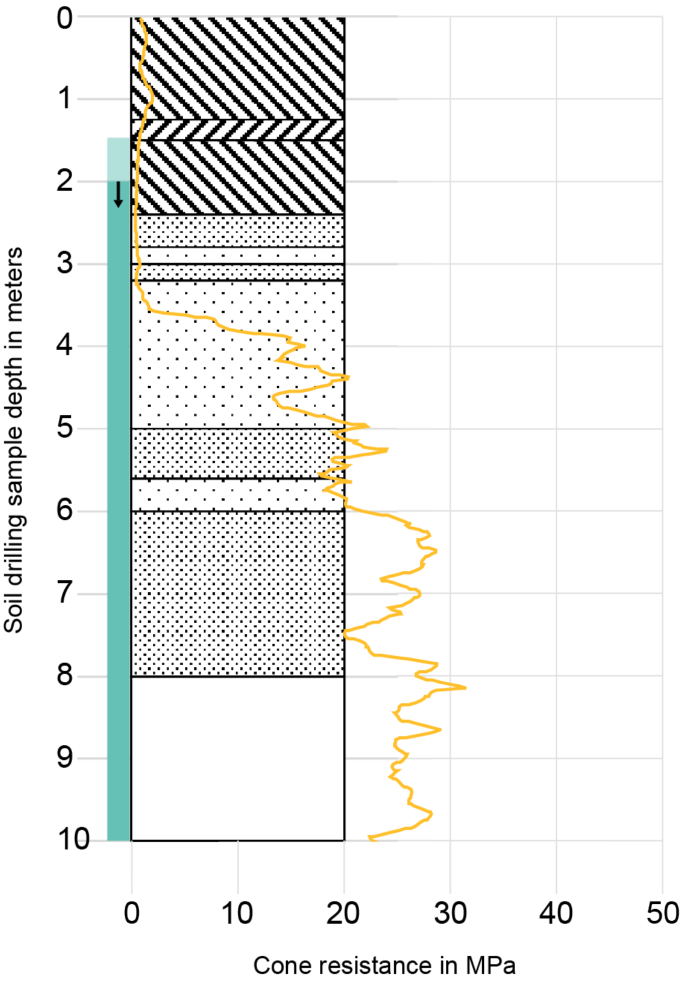
Soil:
This location has a very divers soil composition but at a depth of 6 meters it shows stronger layers that concist out of gravel and sand.

Water:
The flow rate with the water height shows a connection here as well. Also the ground level can in some periods of the year be flooded.

Overall:
The stronger soils are located at a depth of 6 meters. The water levels are relatively concistand and have some peaks where the can rise above ground level.

6. Gennep


Breedeweg
N271
Cuijk
Milsbeek
A73
Ottersum
Oeffelt
Gennep
N264
N271
A77
Heijen
Beugen
A77
Rijkevoort
Boxmeer
Afferden
Sambeek
N271
Sint Anthonis
A73
Nieuw-Bergen
Vierlingsbeek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Soil drilling sample depth in meters
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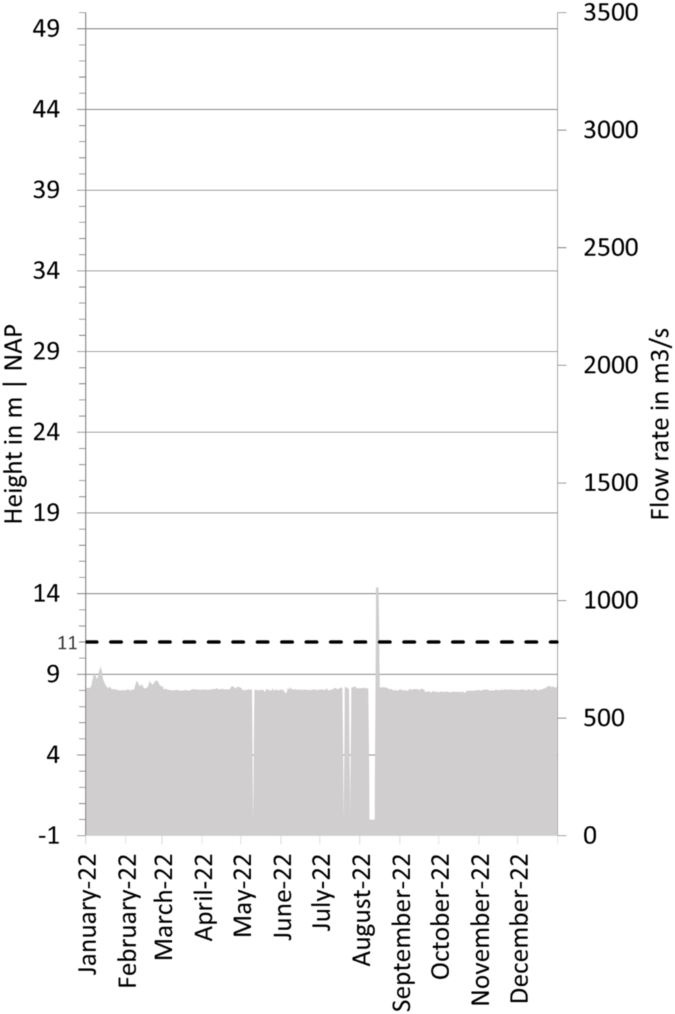
Cone resistance in MPa

6. Gennep | Water graph



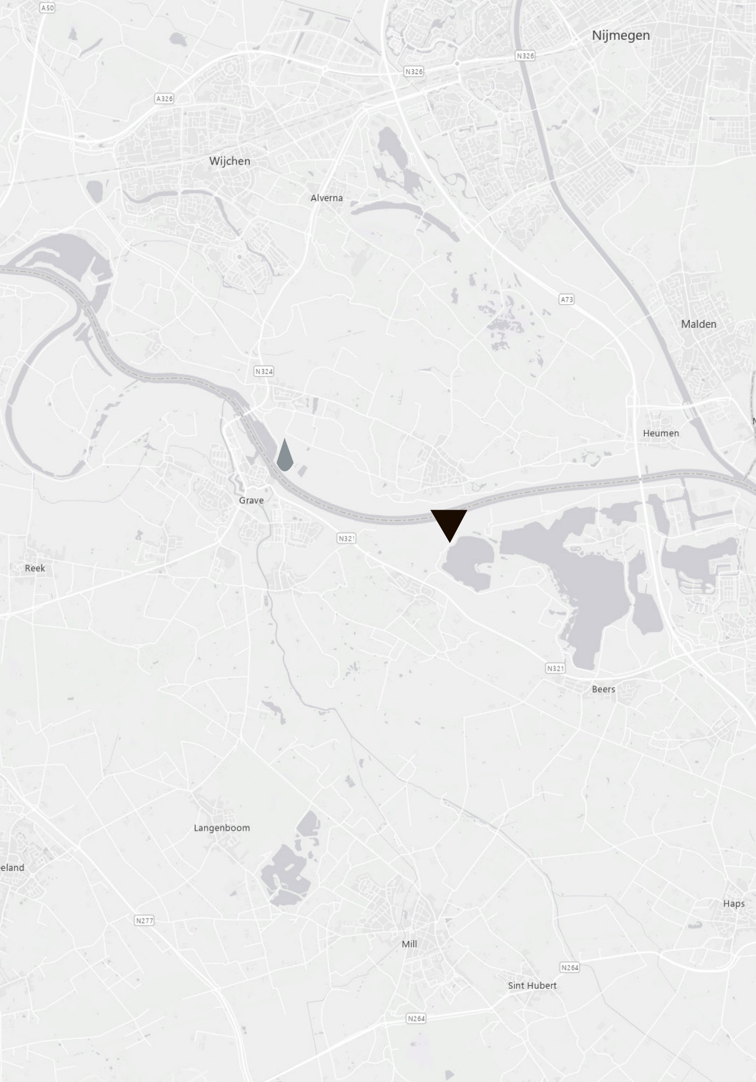
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Gennep
Water, Gennep

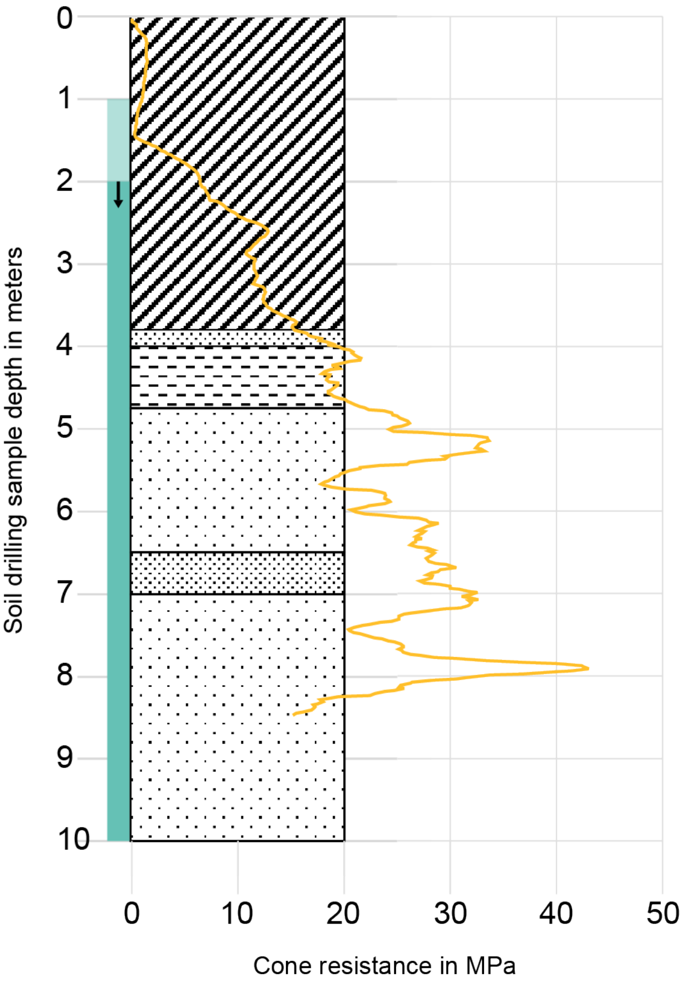
Soil:
The upper part of the soil composition untill a depth of 3.5 meters is very weak, but at a depth of 6 meters it shows stronger layers that concist out of gravel and sand.

Water:
There is one high peak in the water graph but overall it is a very stable water level. But it shows the possibility that sometimes it can reach ground level.

Overall:
At this location at a depth of 3.5 meters the stronger sandy layers start. And this location normaly has a very stable water level.

7. Overasselt




Soil drilling sample depth in meters
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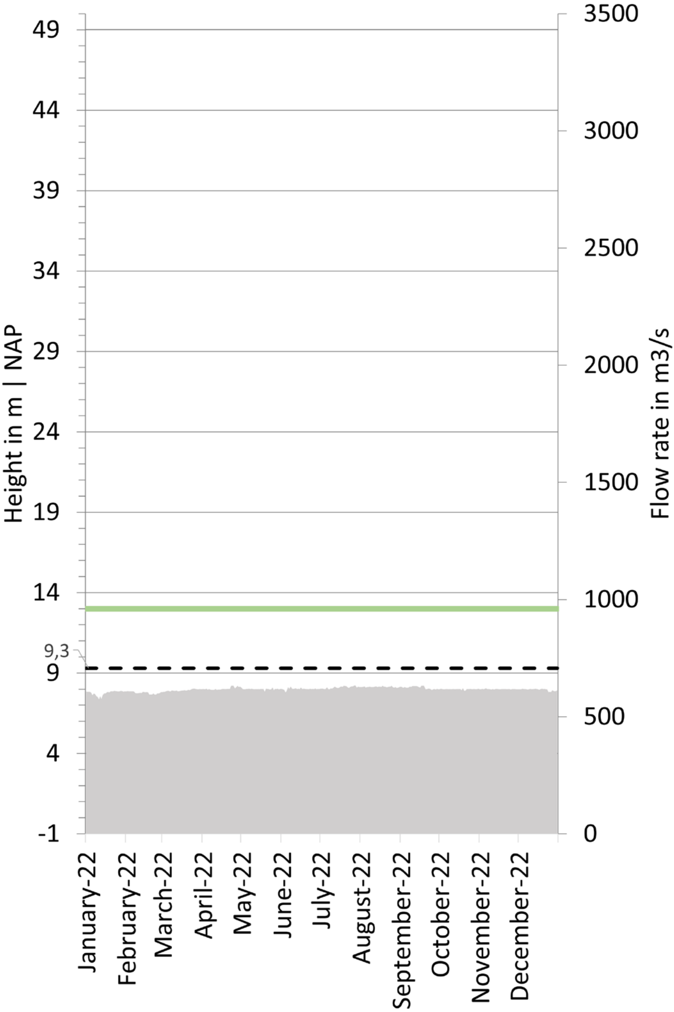
Cone resistance in MPa



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Height in m | NAP
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Flow rate in m3/s
January-22
February-22
March-22
April-22
May-22
June-22
July-22
August-22
September-22
October-22
November-22
December-22

7. Overasselt | Conclusions

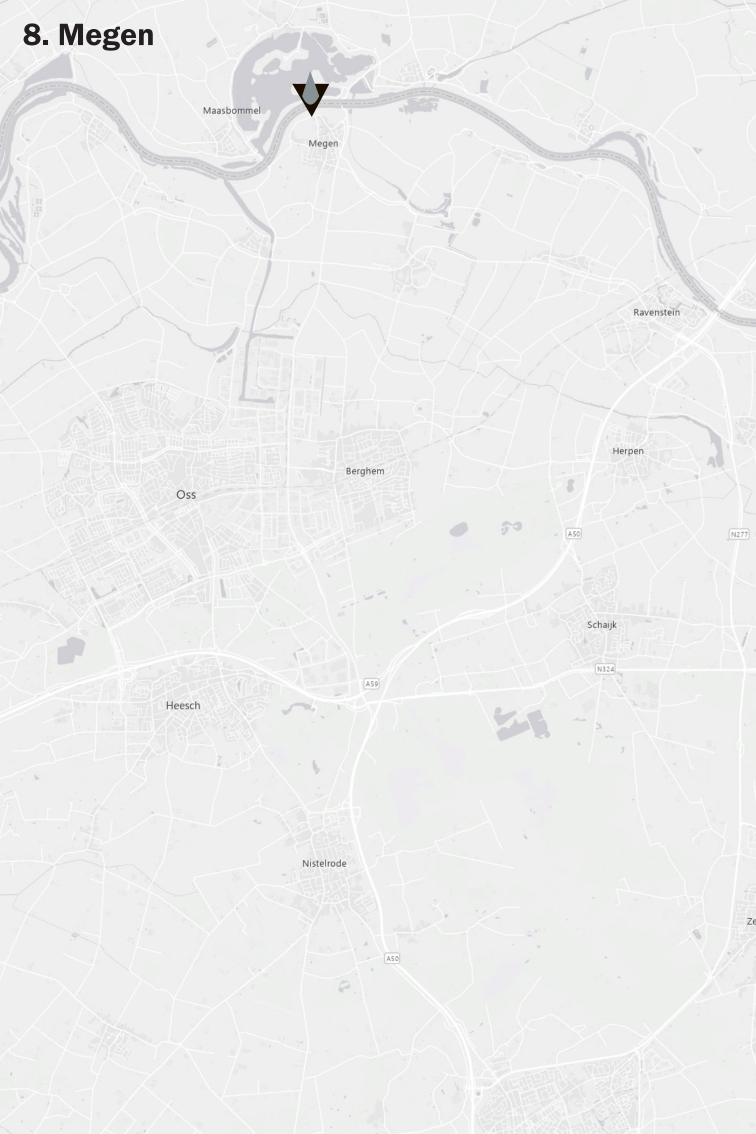
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Overasselt
Water, Grave boven

Soil:
The upper part of the soil composition untill a depth of 4 meters is relatively weak due to the clay composition but afther that it shows stronger layers that concist out of multiple sandy layers

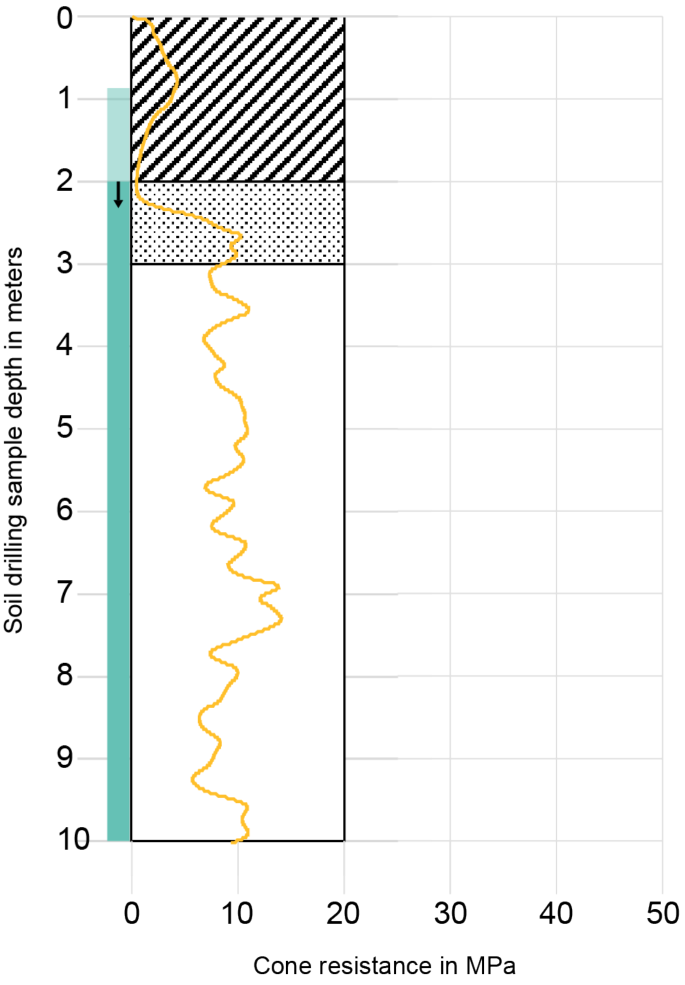
Water:
This location has a very consistant water level. But as seen by the dike located at 13 meters it shows the height of the river that is taken into account to preserve the residential areas behind it.

Overall:
At this location the soil is relatively strong after 4 meters and water level has been very stable for the last year.

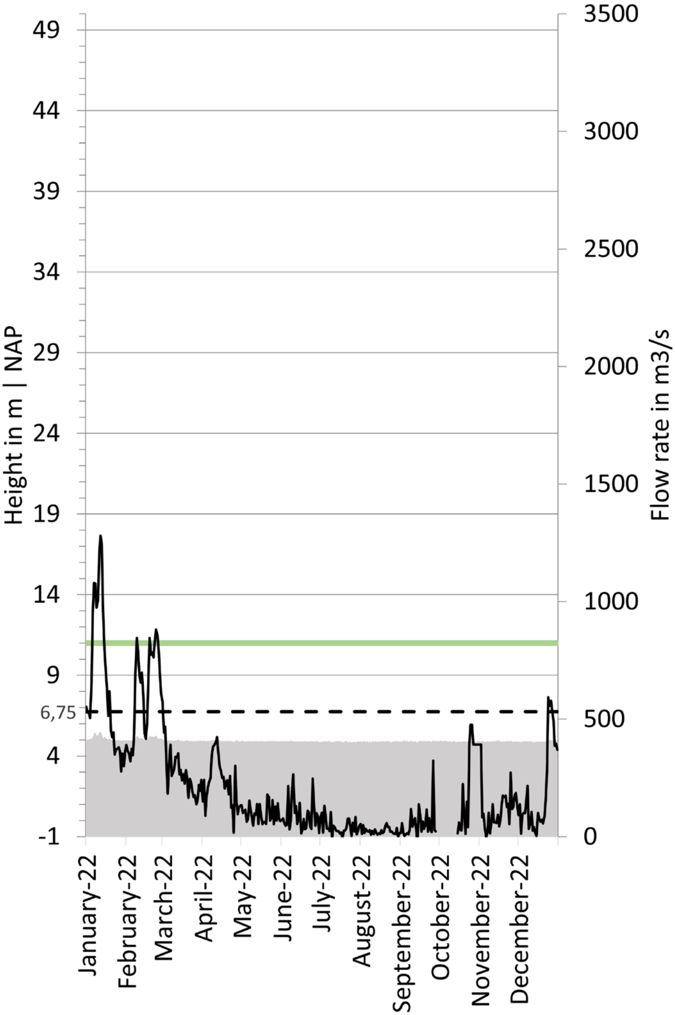
8. Megen


Maasbommel
Megen
Ravenstein
Herpen
Berghem
Oss
A50
N277
Schaijk
N324
A59
Heesch
Nistelrode
A50

8. Megen | Soil graph



8. Megen | Water graph



8. Megen | Conclusions

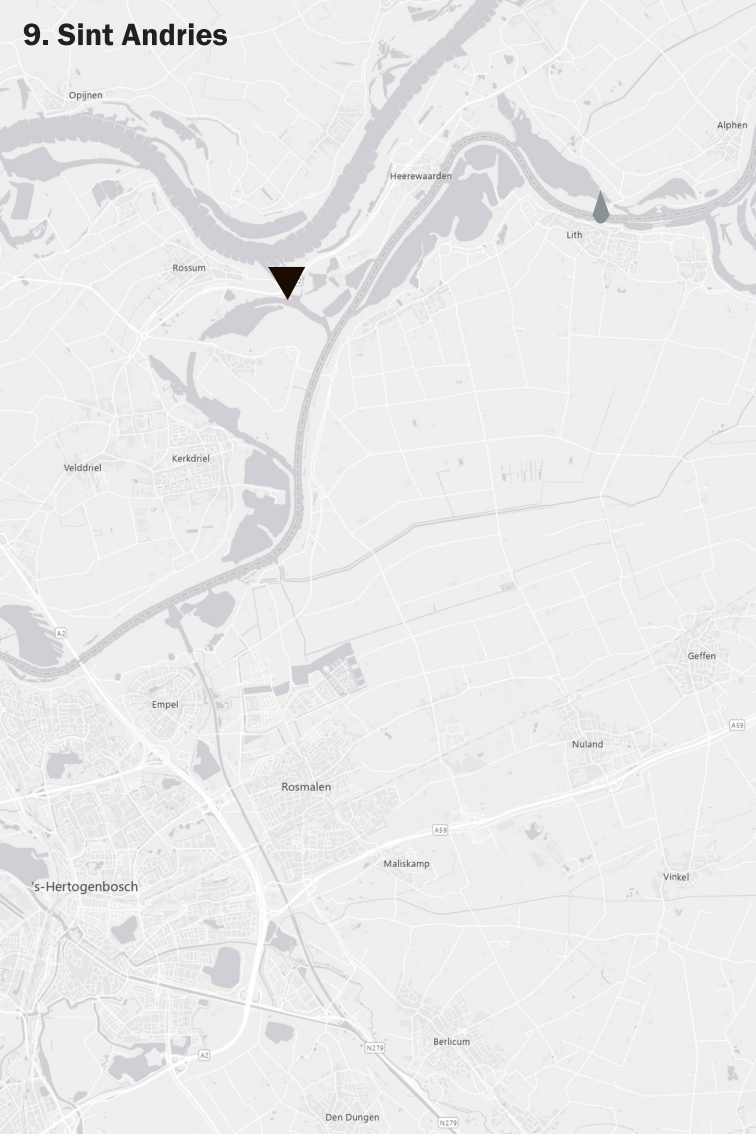
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Megen
Water, Megen

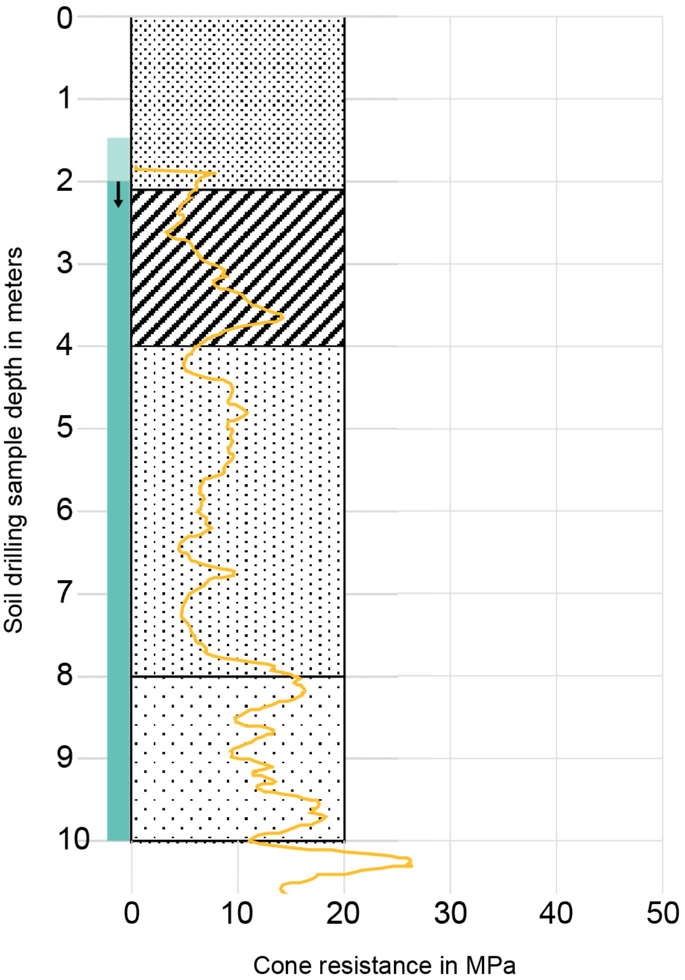
Soil:
The soil composition in this location is relatively soft compared to others. A big part of the composition is unknown, but trough the cone resistance graph it is visable that the fine sand runs probably deeper trough since it is almost the same resistance level all troughout a depth of 10 meters.

Water:
This location has a very consistant water level. But the flow rate is much more erratic. This means to keep the waterlevel consistant it must be a very controlled part of the river trough dams.

Overall:
There is a very consistand soil composition and the same for the water levels, though a very erratic flow rate it is kept stable by dams.

9. Sint Andries

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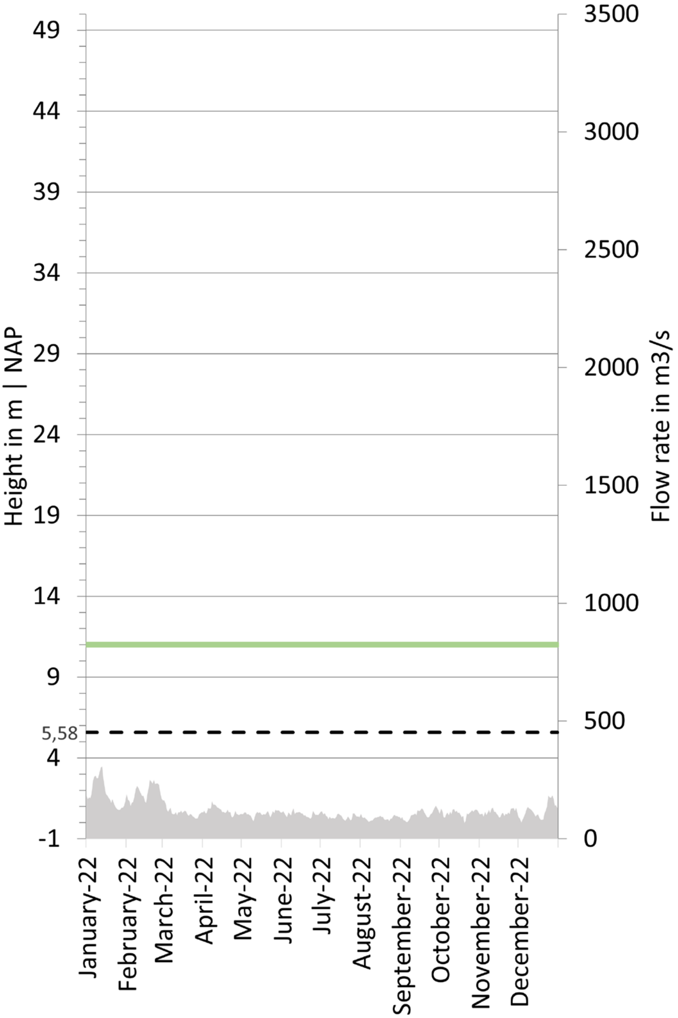
10
Soil drilling sample depth in meters
0
10
20
30
40
50
Cone resistance in MPa

9. Sint Andries | Water graph



9. Sint Andries | Conclusions

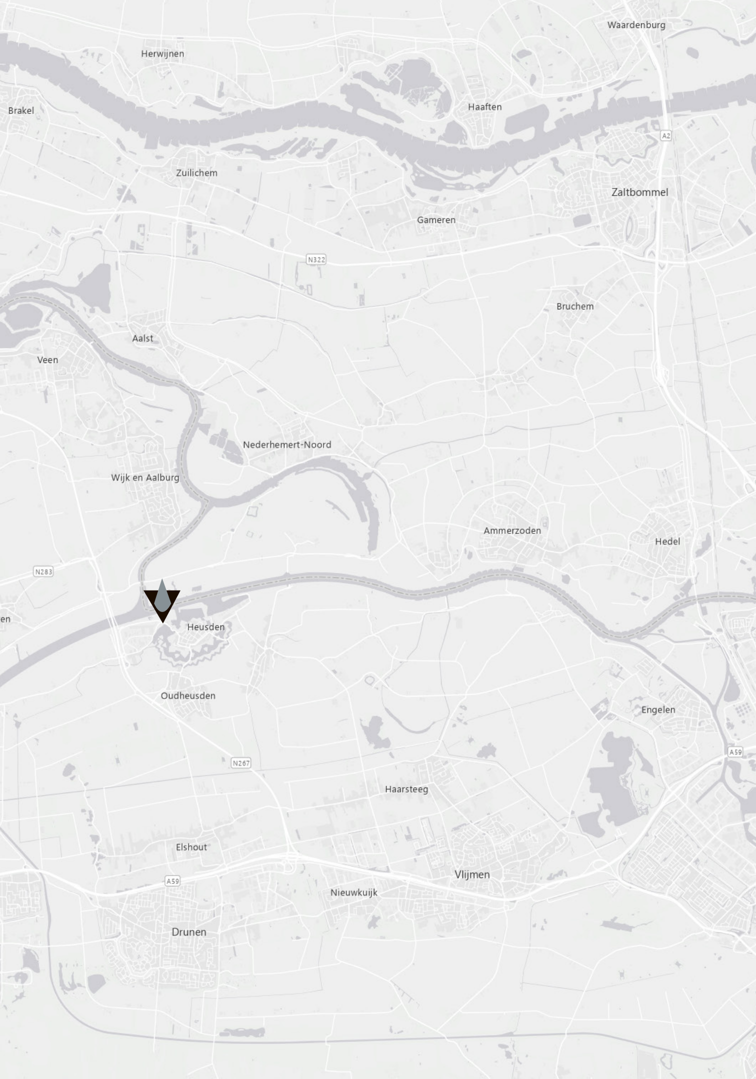
<u>Map:</u>
The map shows that the measurements are taken close to each other. The locations are:
Soil, Sint Andries
Water, Lith dorp

<u>Soil:</u>
This soil composition shows very clearly that coarser sand has a higher cone resistance. And tough there is clay in the compostion the shallow layer of it does not seem to make a very big difference in resistance.

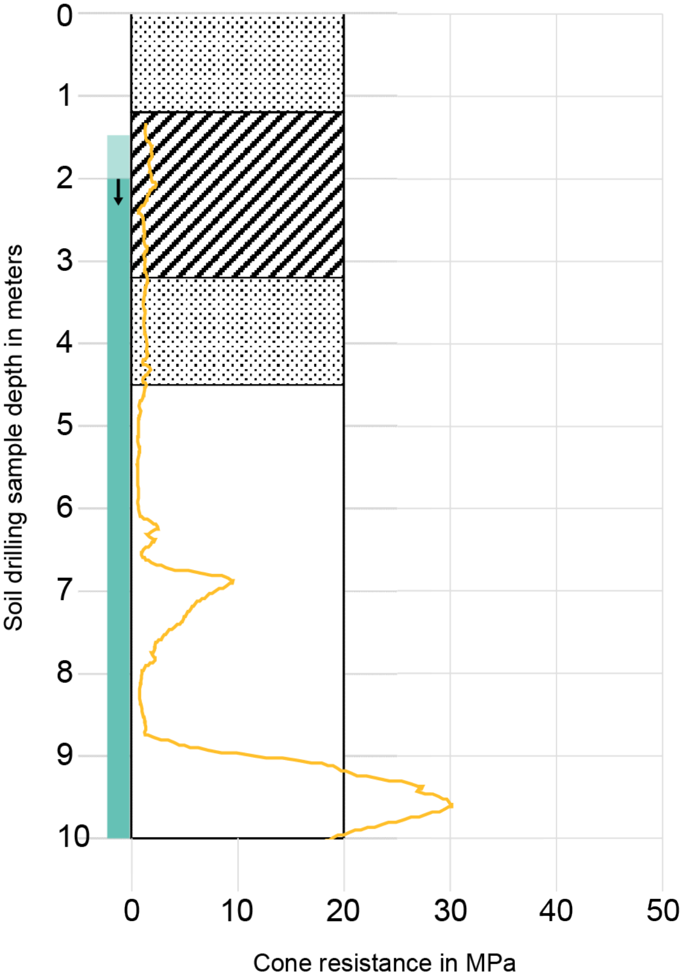
<u>Water:</u>
The water level here shows relatively bigger differences and almost has a rythm to it. Further more again in winter period there is a higher water level experienced than in other seasons. Probably due to snowmelt.

<u>Overall:</u>
This location has a relatively consistand soil composition. And the water level here experiences more height differences.

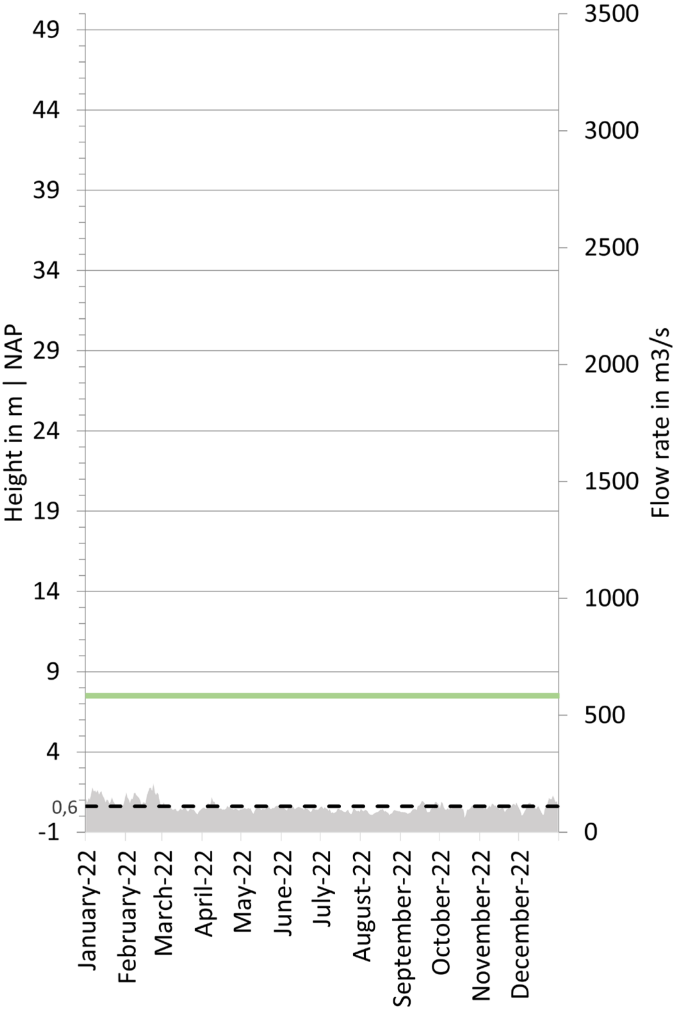
10. Heusden


Waardenburg
Herwijnen
Brakel
Haaften
A2
Zuilichem
Zaltbommel
Gameren
N322
Bruchem
Aalst
Veen
Nederhemert-Noord
Wijk en Aalburg
Ammerzoden
Hedel
N283
Heusden
Oudheusden
Engelen
A59
N267
Haarsteeg
Elshout
A59
Vlijmen
Nieuwkuijk
Drunen

10. Heusden | Soil graph



10. Heusden | Water graph



Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Heusden
Water, Heesbeen

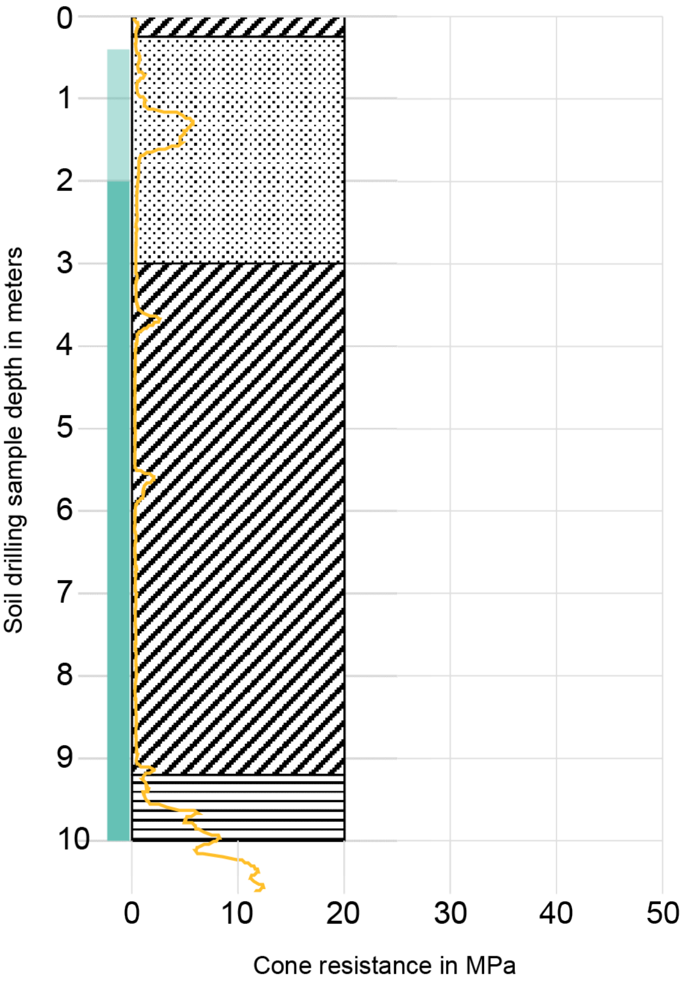
Soil:
This location has a very week soil, only in the deeper parts at 9 meters, there seems to be more stable soils.

Water:
The water graph shows that the water level compared tot the ground level regulary rises above ground level. This is probably also because of the base of the waterlevel allready being almost identical to the ground level.

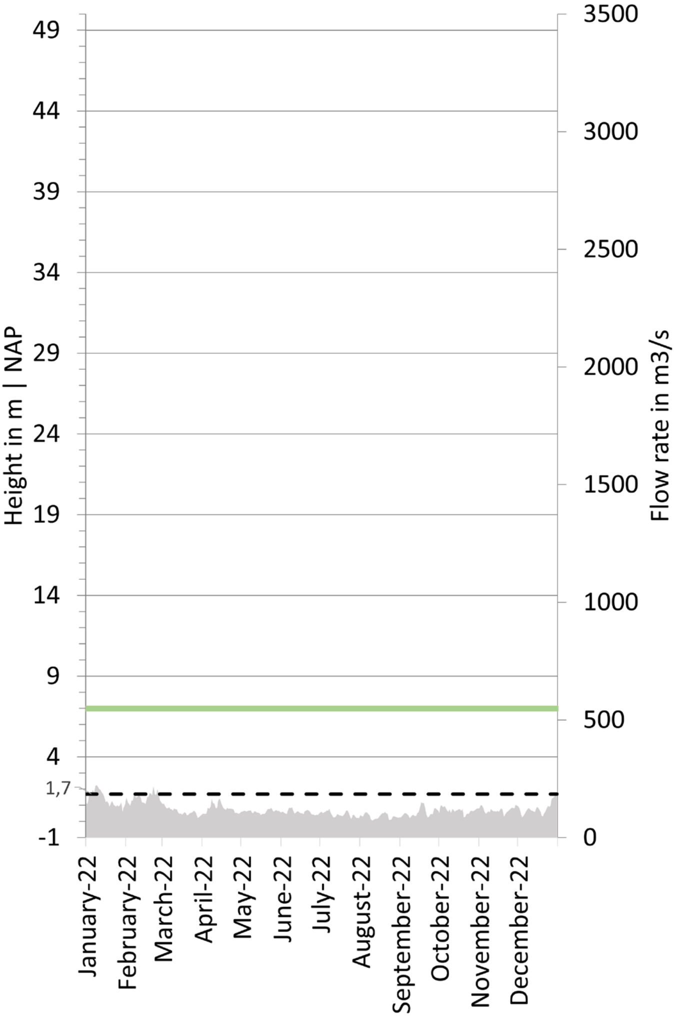
Overall:
This location has a very weak soil composition in the first few meters deep, and it is a location with a high chance of regular flooding.

11. Gorinchem

11. Gorinchem | Soil graph



11. Gorinchem | Water graph



11. Gorinchem | Conclusions

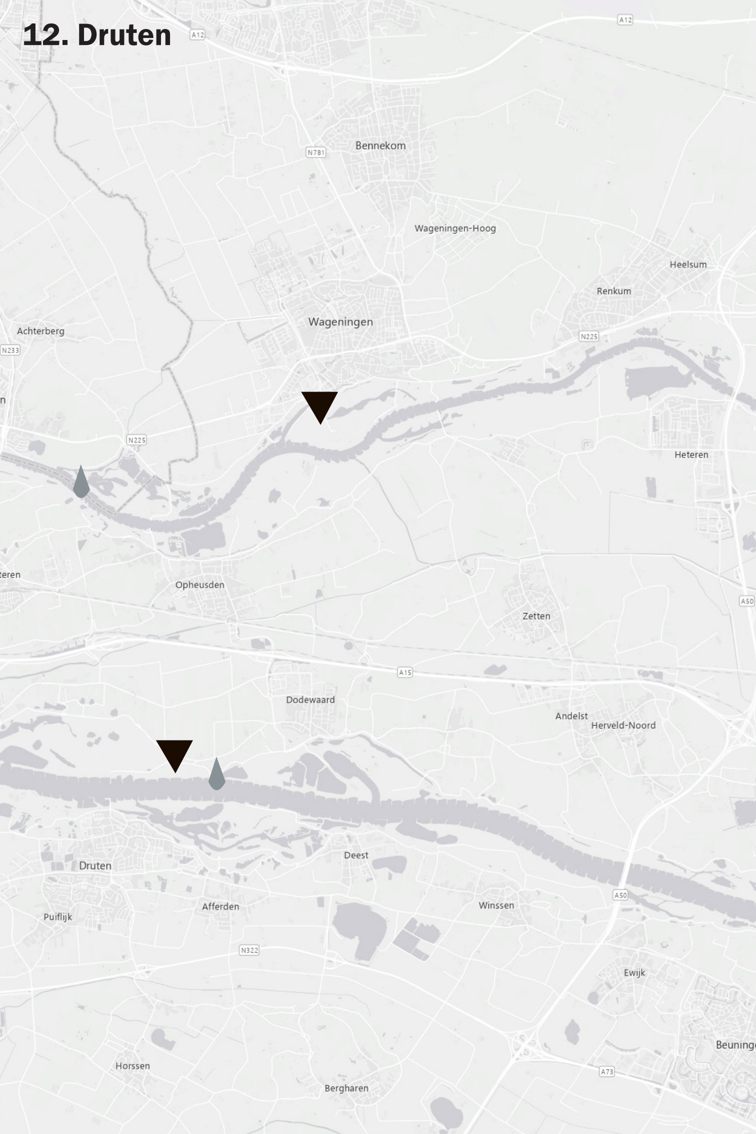
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Gorinchem
Water, Vuren

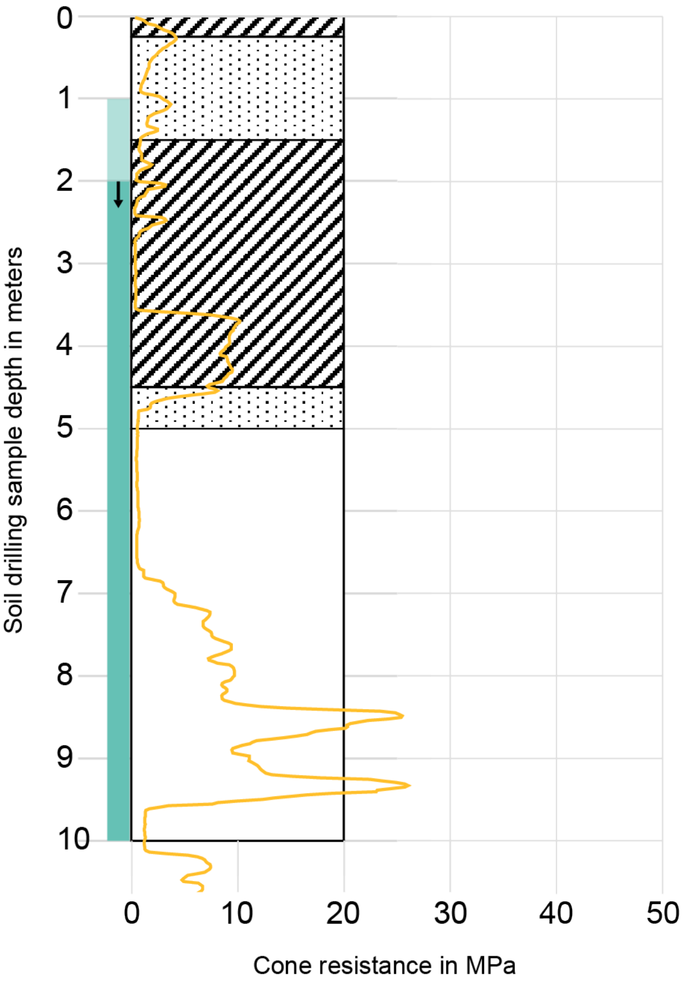
Soil:
The soil composition at this location is extremely weak, this is probably due to very long and deep layers of clay and peat.

Water:
The water level at this location shows relatively often differences in the height. And in the winter season it shows even higher differences which would be able to cause the occasional flooding.

Overall:
This location has an extremely weak soil composition and this combined with the occasional flooding that might happen creates a very dynamic location.

12. Druten


A12
A12
Bennekom
N781
Wagenigen-Hoog
Heelsum
Renkum
Wageningen
Achterberg
N233
N225
N225
Heteren
Opheusden
Zetten
A50
A15
Dodewaard
Andelst
Herveld-Noord
Deest
Druten
Afferden
Winssen
A50
Puiflijk
N322
Ewijk
Horssen
Bergharen
A73



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Soil drilling sample depth in meters
0
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20
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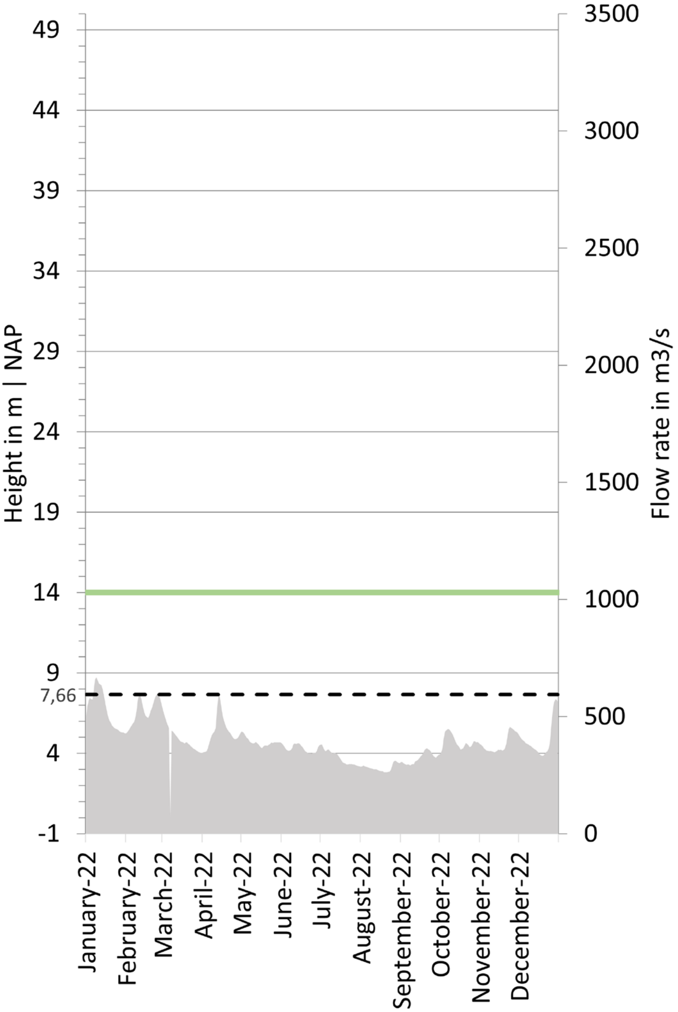
40
50
Cone resistance in MPa

12. Druten | Water graph



12. Druten | Conclusions

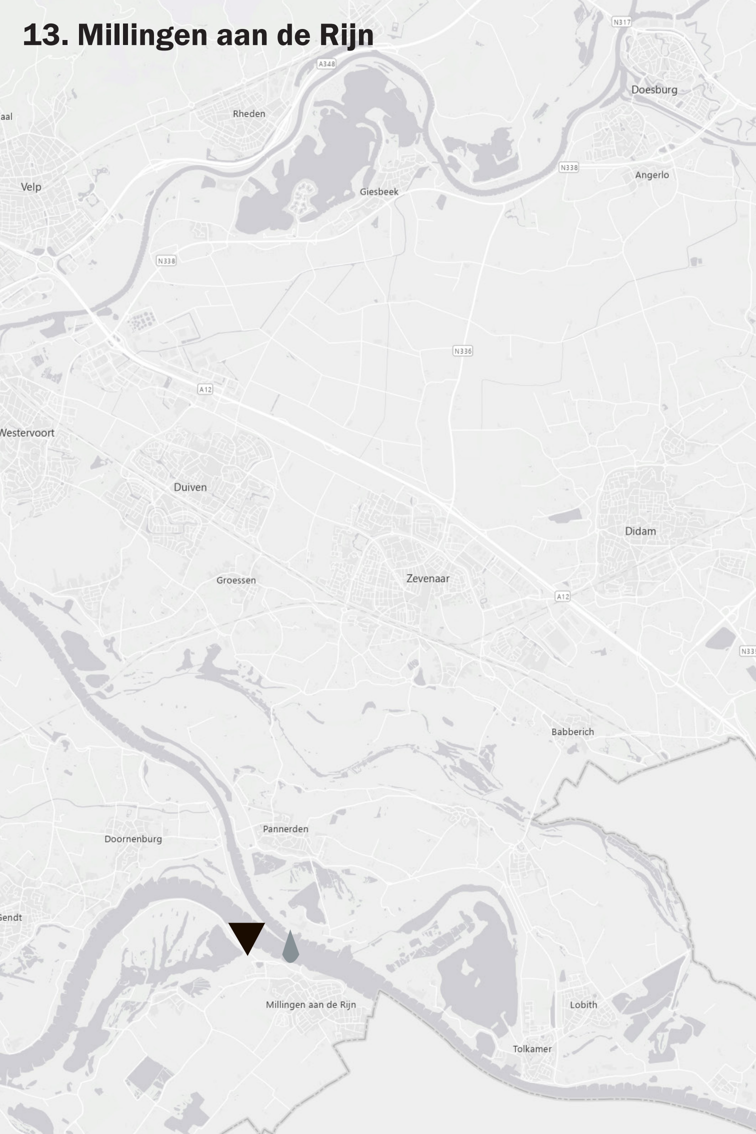
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Dodewaard
Water, Dodewaard

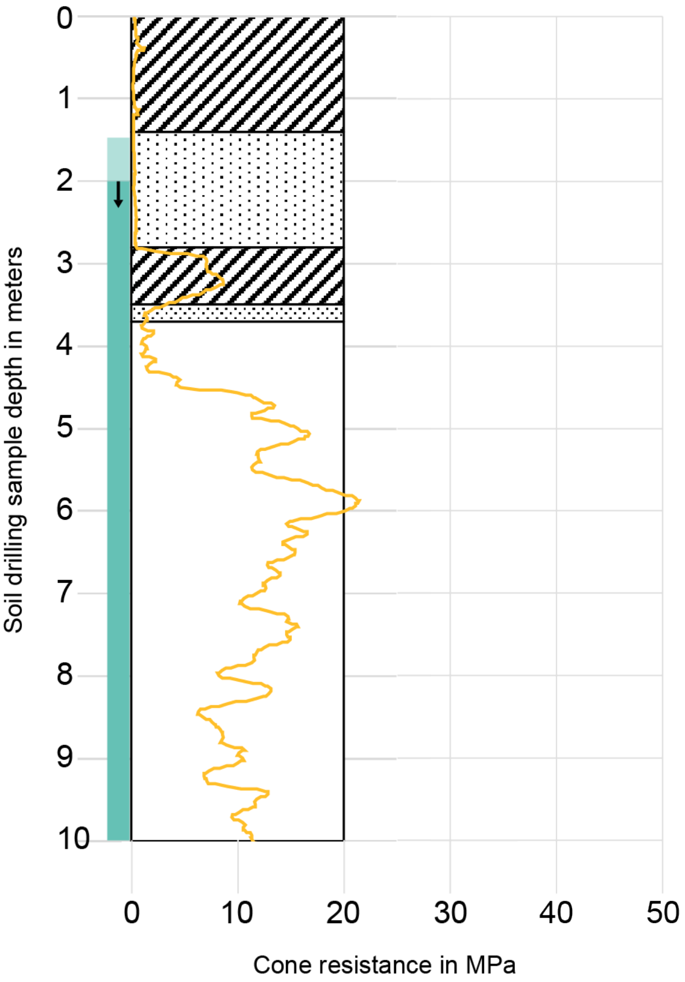
Soil:
This soil composition has extreem weak parts consisting out of clay, alternating with some shallow harder soil types like sand.

Water:
The water level at this location of the Waal is very erratic. Though there are higher differences in the winter period during summer the waterlevel still shifts a lot. This shows therfore a very uncontrolled part of our rivers. As there are also no dams in the Waal.

Overall:
This poses as a very dynamic location as there is a possiblility of the occasional flooding due to the high fluctuation of water levels and the combination of extremely weak and some harder soils together.

13. Millingen aan de Rijn

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Soil drilling sample depth in meters
0
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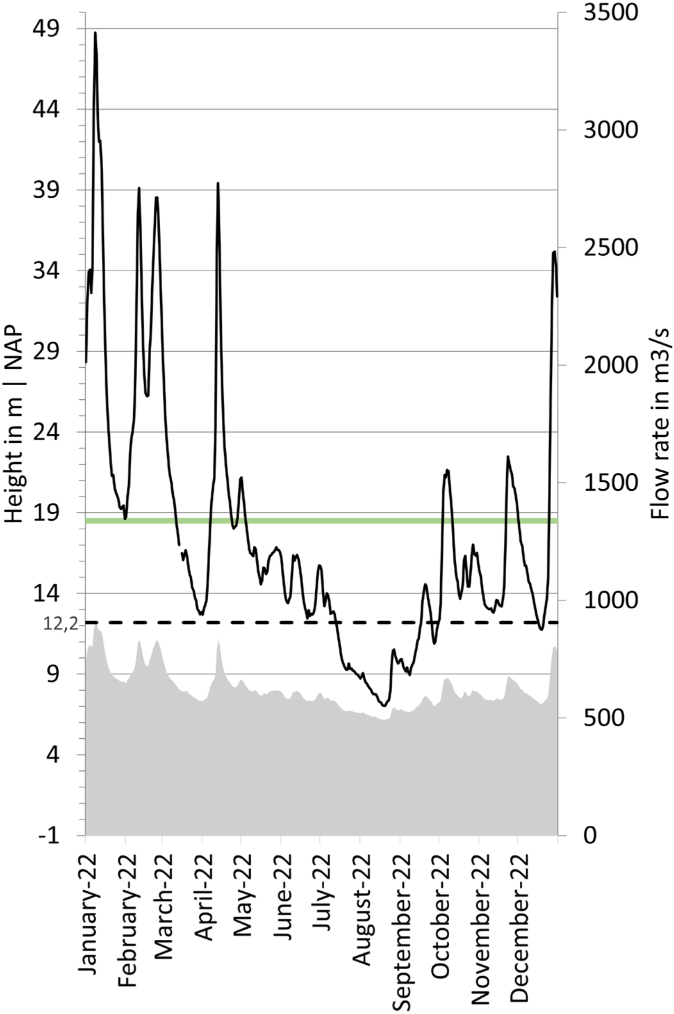
Cone resistance in MPa

13. Millingen aan de Rijn | Water graph



13. Millingen aan de Rijn | Conclusions

Map:

The map shows that the measurements are taken close to each other. The locations are:
Soil, Millingen aan de RIjn
Water, Pannerdense Kop

Soil:

The top layers of the soil untill a depth of 4,5 meters a very weak due to the clay layers in that part. But after that there is a bit more stronger soil wich will probably consist out of sandy layers.

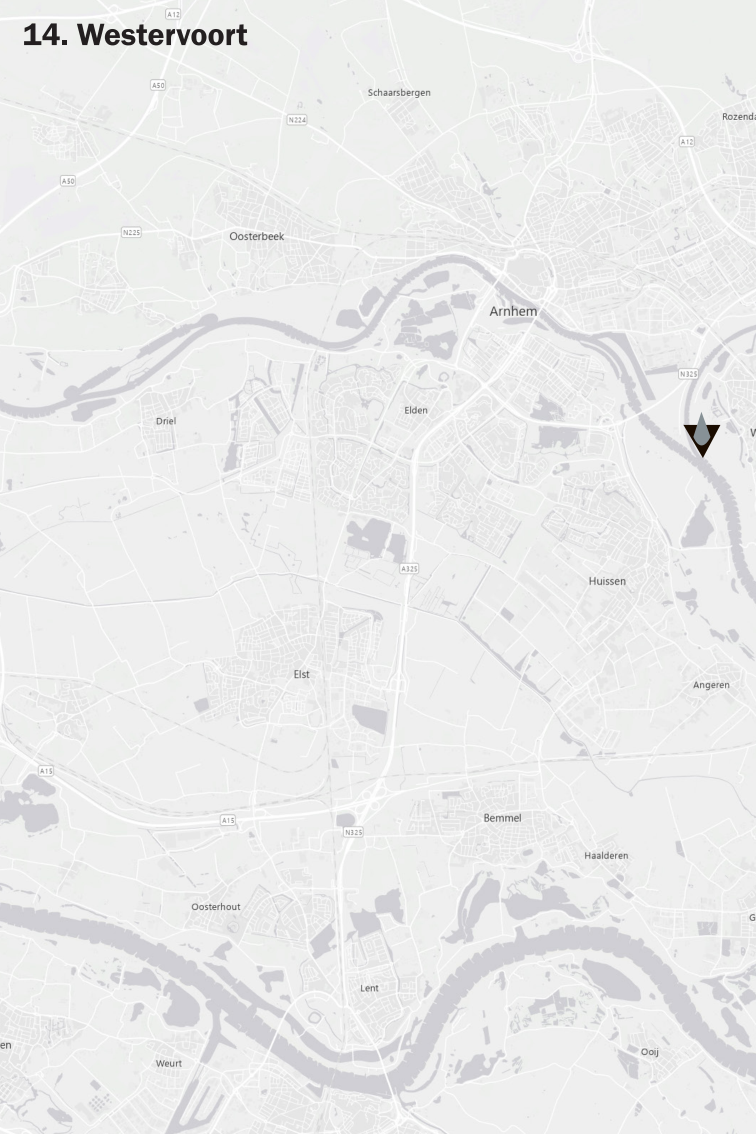
Water:

The water level at this location of the Waal is also very erratic. This is also seen in the flow rate of the Waal. It has a very high flow rate and is therfore able to dispose of more water in a shorter time. At this location there is also the possibility of the occasional flooding.

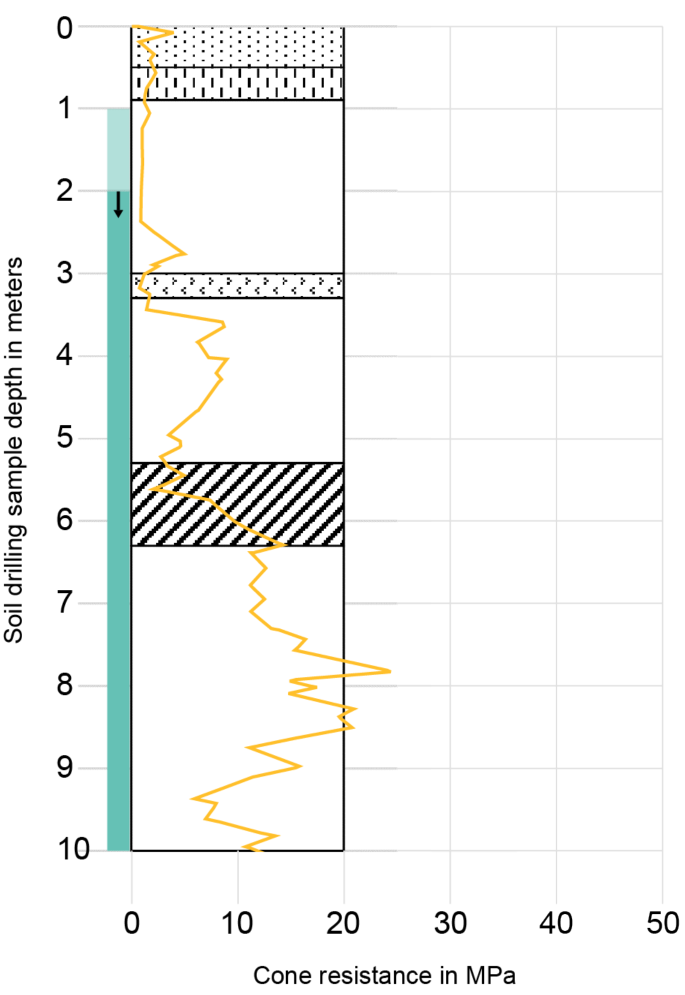
Overall:

This is a very variable location due to the high differences in the water level and the relatively soft top layers in the soil composition.

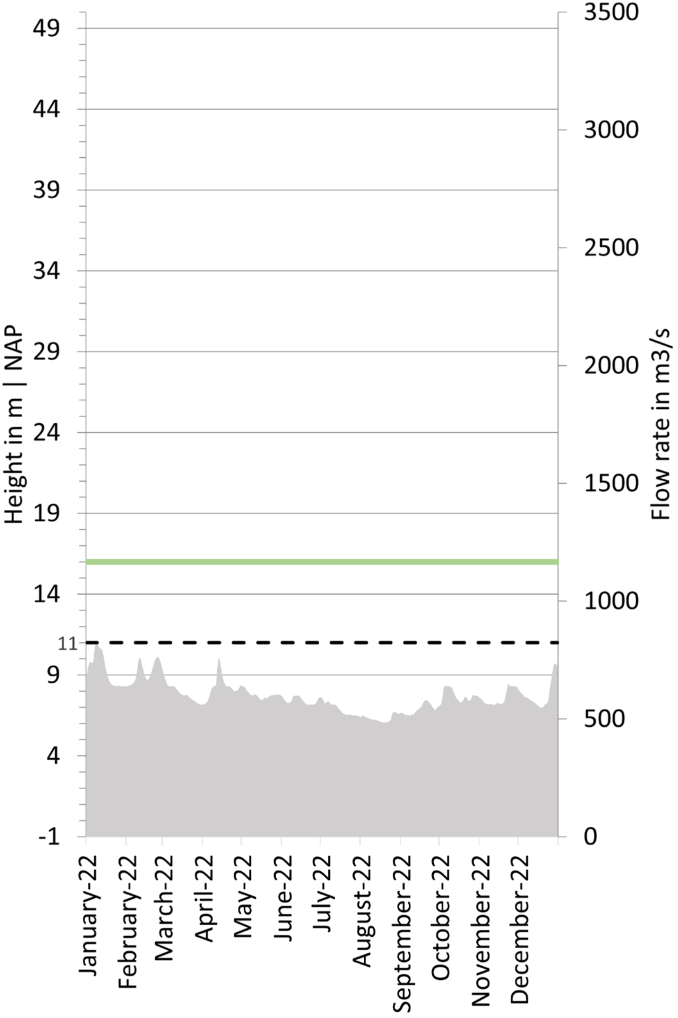
14. Westervoort



14. Westervoort | Soil graph



14. Westervoort | Water graph



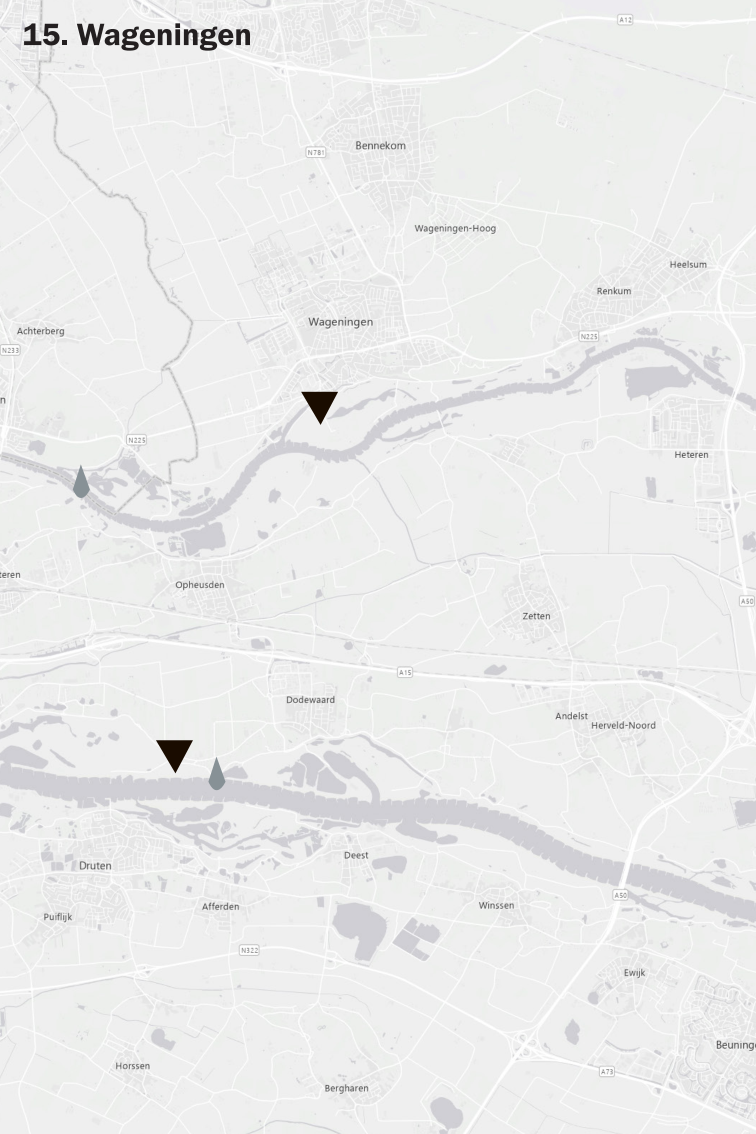
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Westervoort
Water, Ijssel kop

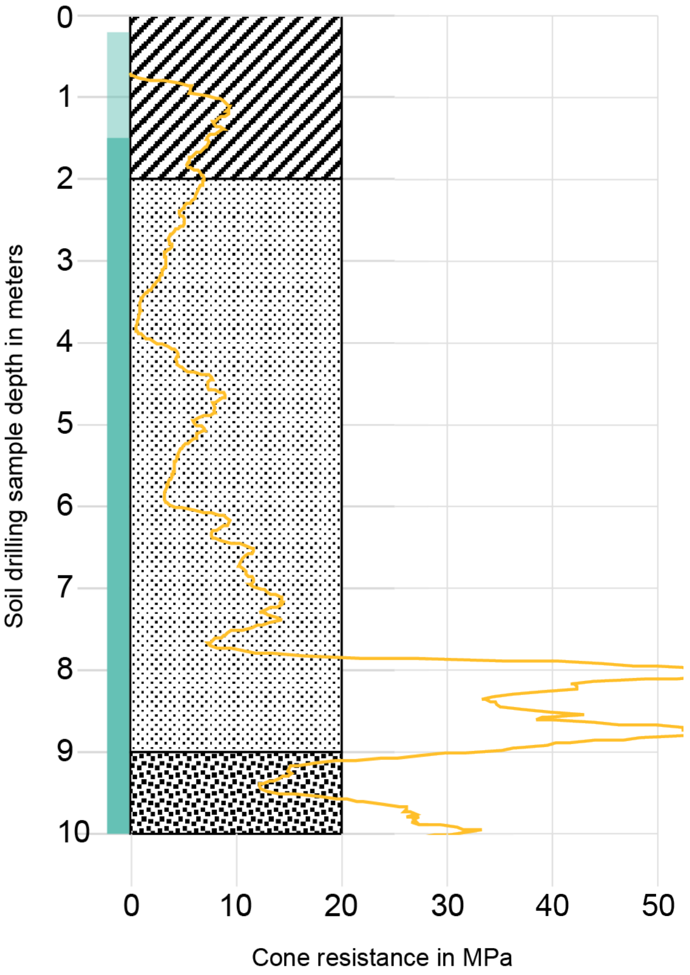
Soil:
This is a very diverse soil composition. Though there is a lot unknown after a depth of 6 meters there are soils that show a higher cone resistence and therfore a stronger soil layer.

Water:
In this location the water level has high diffrences. in the winter period these differences are more erratic then in summertime. And will therfore in the winter period cause the occational flooding.

Overall:
This location has a very variable soil and the water level is able to reach sometimes above ground level and cause the occational flooding of the floodplain.

15. Wageningen

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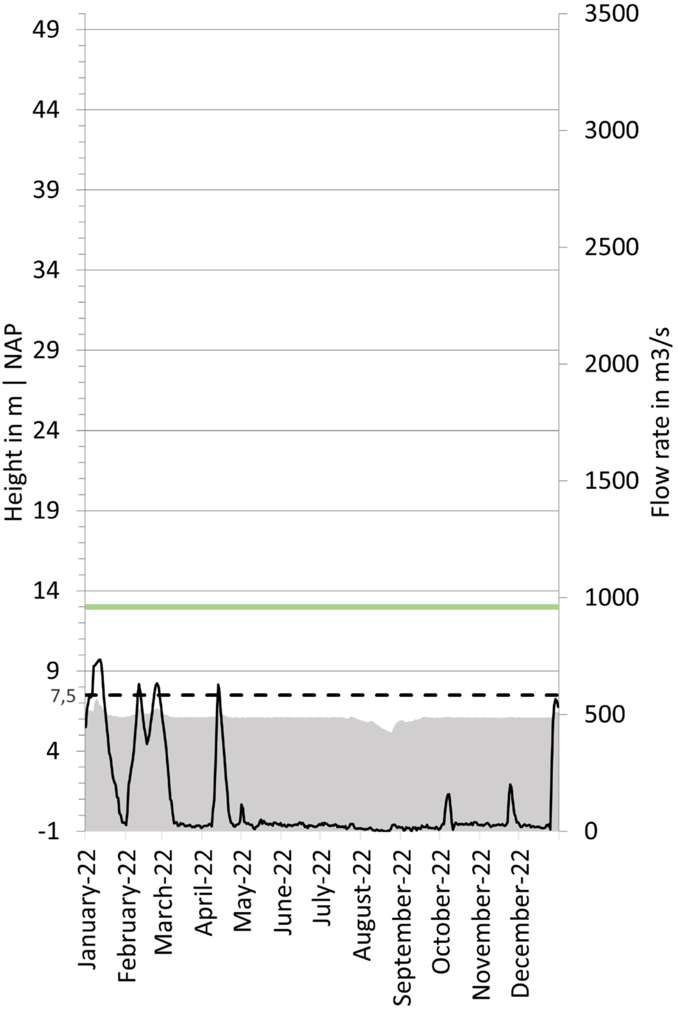
Soil drilling sample depth in meters
0
10
20
30
40
50
Cone resistance in MPa

15. Wageningen | Water graph



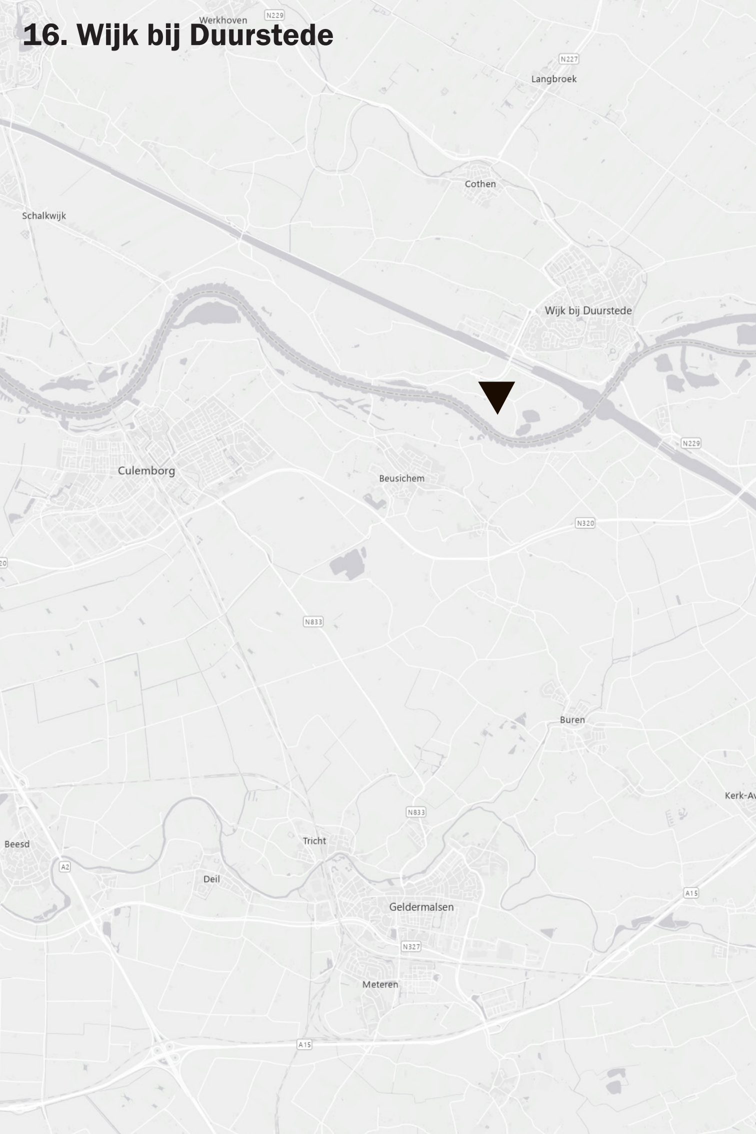
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Wageningen
Water, Grebbe

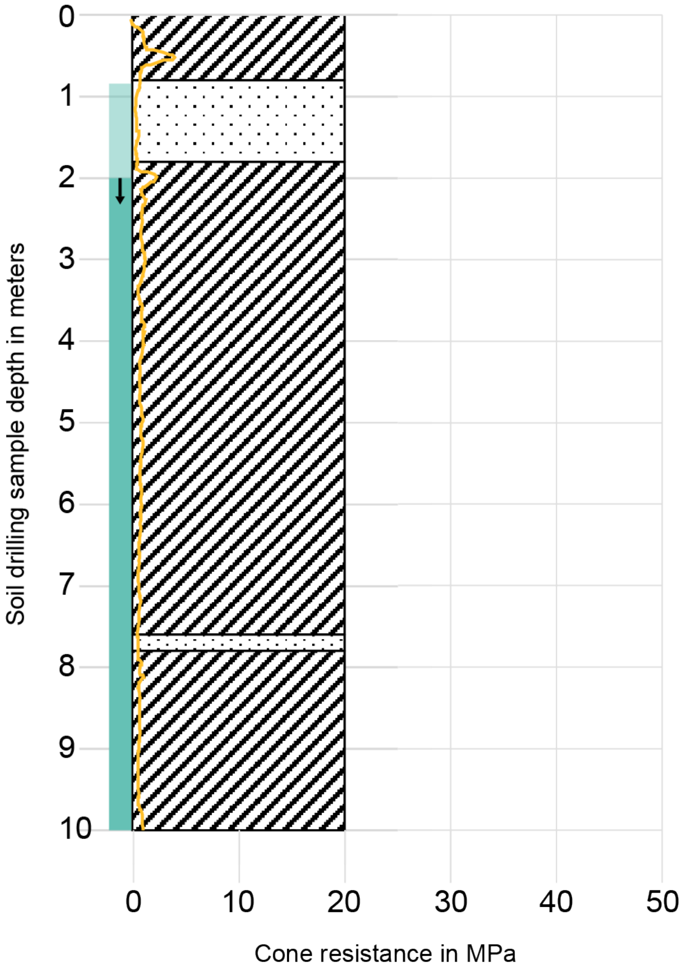
Soil:
This soil composition exists mostly out of fine sand but due to it being fine sand it is not extremely strong. When going to a depth of 8 meters the effect of the gravel layer is visibel in the cone resistance. And shows a very strong layer.

Water:
Eventhough the flow rate has very erratic movements the water level remains extremely consistand. This suggest that this is a controlled part of the river.

Overall:
Overall is this a very stable location with a controlled river system trough dams and has large sandy layers in the soil.

16. Wijk bij Duurstede




0
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Soil drilling sample depth in meters
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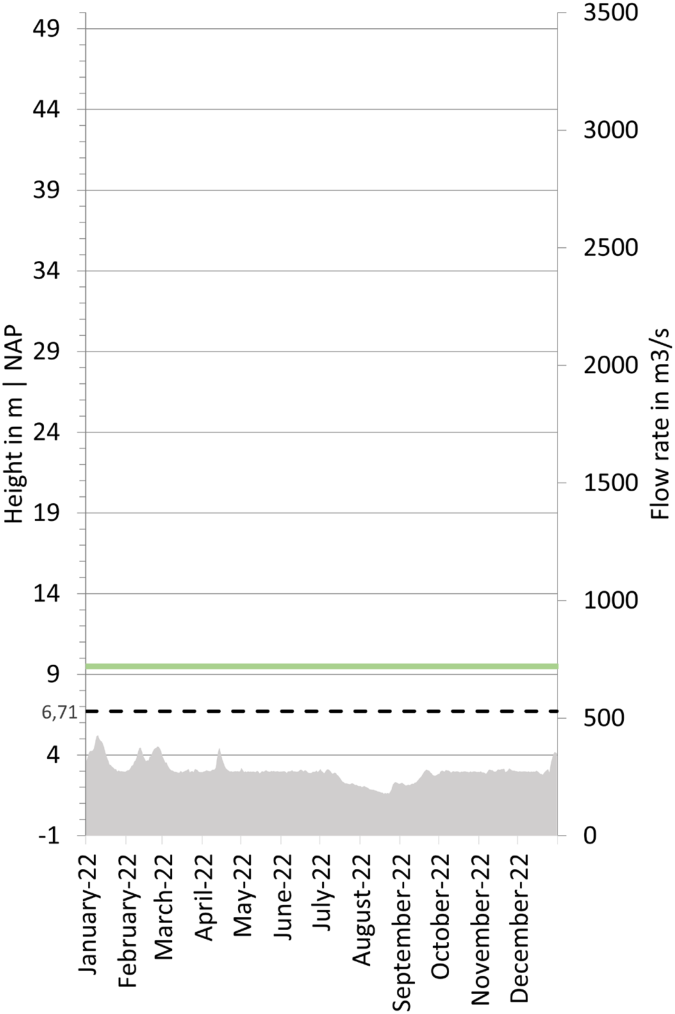
Cone resistance in MPa



49
44
39
34
29
24
19
14
9
6,71
4
-1
Height in m | NAP
3500
3000
2500
2000
1500
1000
500
0
Flow rate in m3/s
January-22
February-22
March-22
April-22
May-22
June-22
July-22
August-22
September-22
October-22
November-22
December-22

16. Wijk bij Duurstede | Conclusions

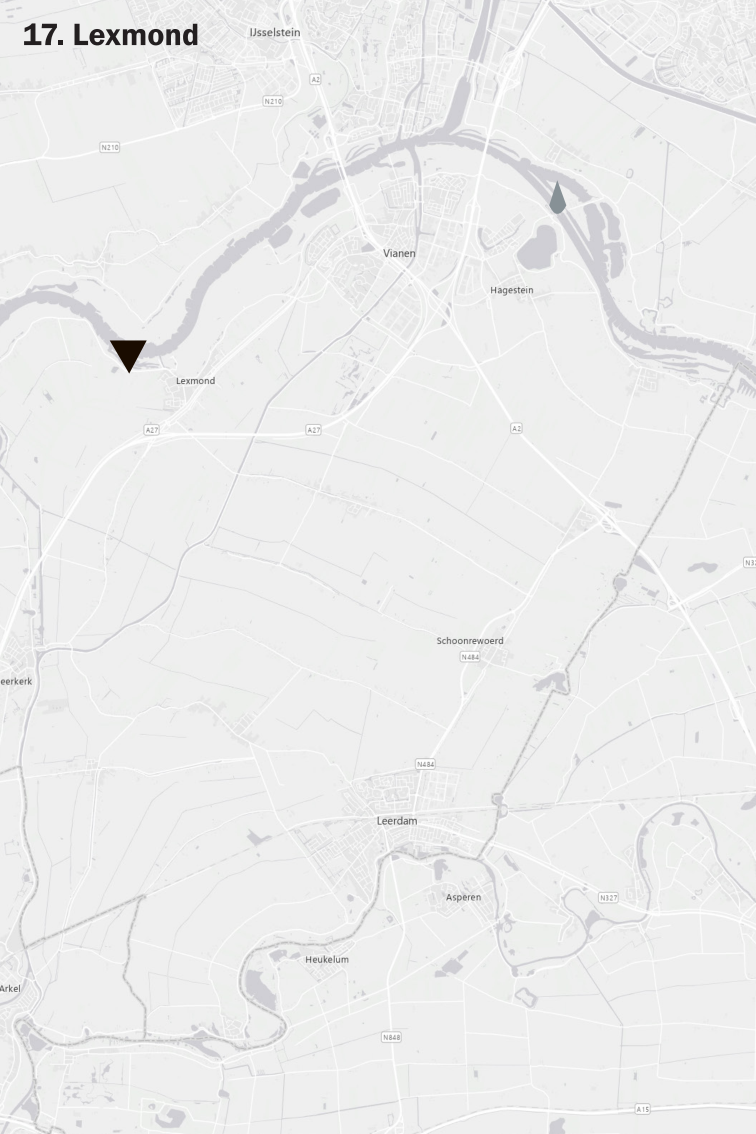
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Wijk bij Duurstede
Water, Amerongen beneden

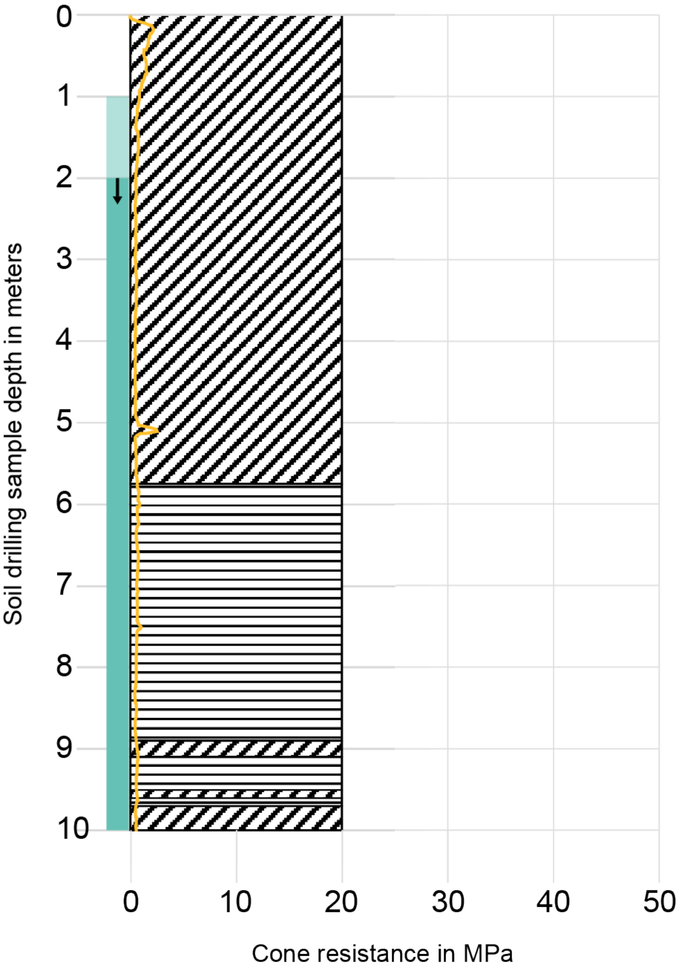
Soil:
This location as a very extremely weak soil as it cosists mostly for the first 10 meters deep out of clay. The cone resistance does for the most part not even move a little.

Water:
During the winter period the water graph shows more differences in water level height. But what is also seen is a low dip during the summer months. This is probably due to the very dry periods last year.

Overall:
Overall this location has a very weak soil. The water level is fairly consistand appart from the winter period.

17. Lexmond


IJsselstein
A2
N210
N210
Vianen
Hagestein
Lexmond
A27
A27
A2
N3
Schoonrewoerd
N484
eerkerk
N484
Leerdam
Asperen
N327
Heukelum
Arkel
N848
A15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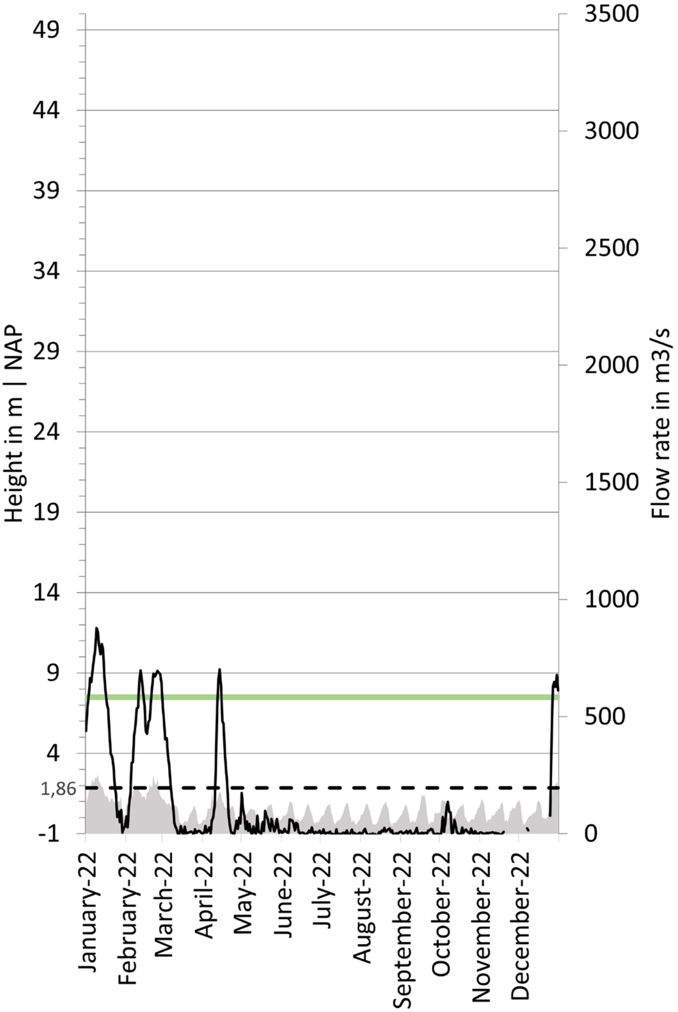
10
Soil drilling sample depth in meters
0
10
20
30
40
50
Cone resistance in MPa

17. Lexmond | Water graph



17. Lexmond | Conclusions

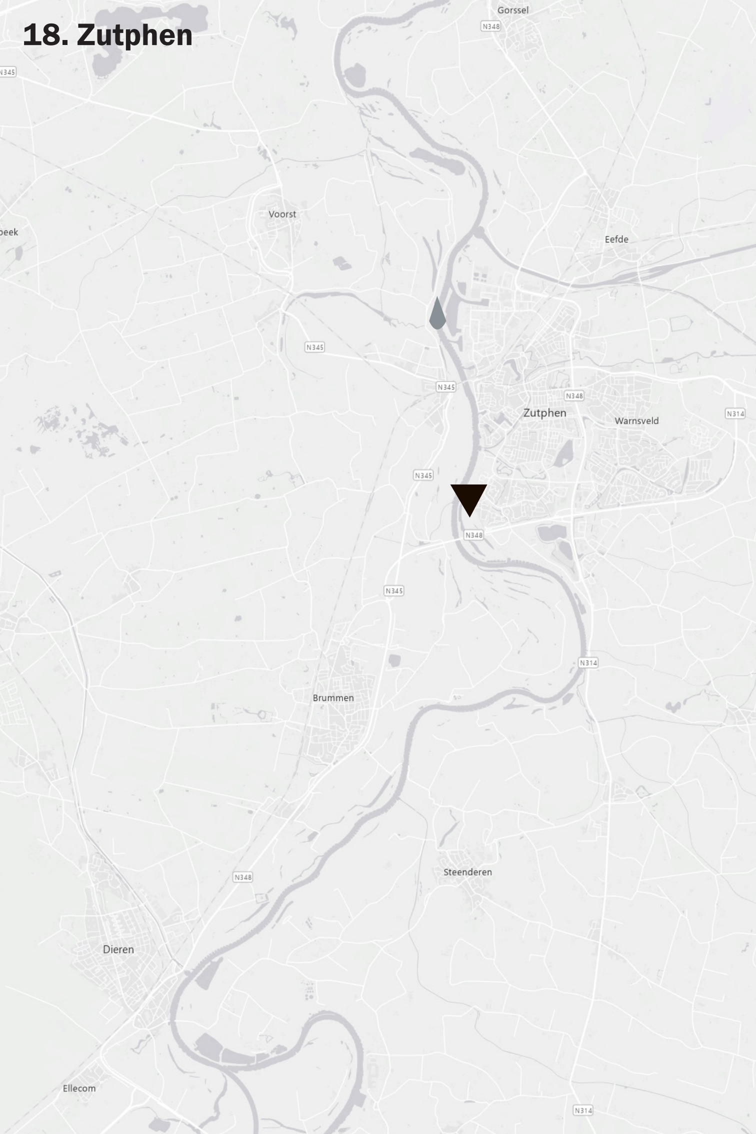
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Lexmond
Water, Hagestijn beneden

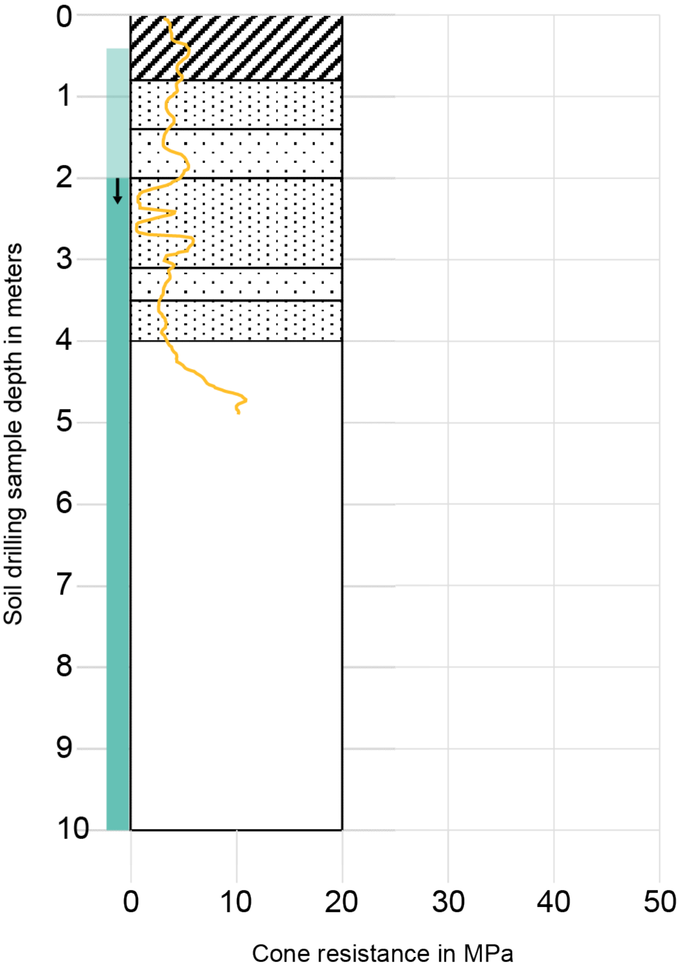
Soil:
This location as a very extremely weak soil as it cosists mostly for the first 10 meters deep out of clay and peat. The cone resistance does for the most part not even slightley move a bit.

Water:
The water level here does have an interesting movement. This is probably due to the measurements being taken right after a dam. The flow rate also show a clear relation when the water levels rise and lower.

Overall:
Overall this location has a very weak soil. The water level is fairly consistandly erratic appart from the winter period. And the occasional flooding is possible.

18. Zutphen


Gorssel
N348
N345
Voorst
beek
Eefde
N345
N345
N348
Zutphen
Warnsveld
N314
N345
N348
N345
N314
Brummen
Steenderen
N348
Dieren
Ellecom
N314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10
Soil drilling sample depth in meters
0
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20
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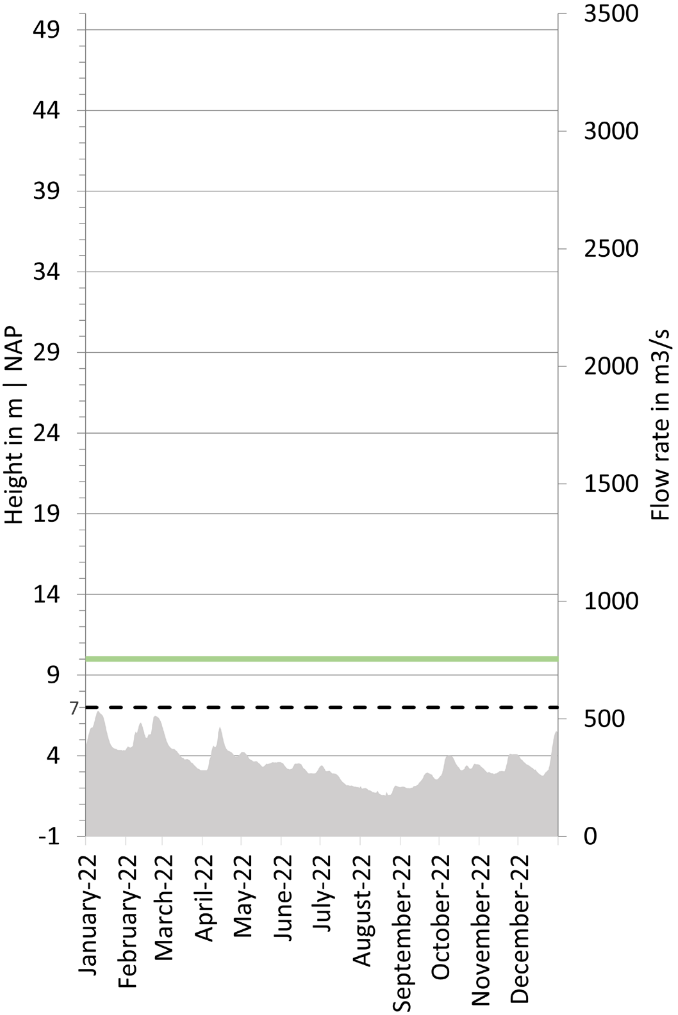
40
50
Cone resistance in MPa

18. Zutphen | Water graph



18. Zutphen | Conclusions

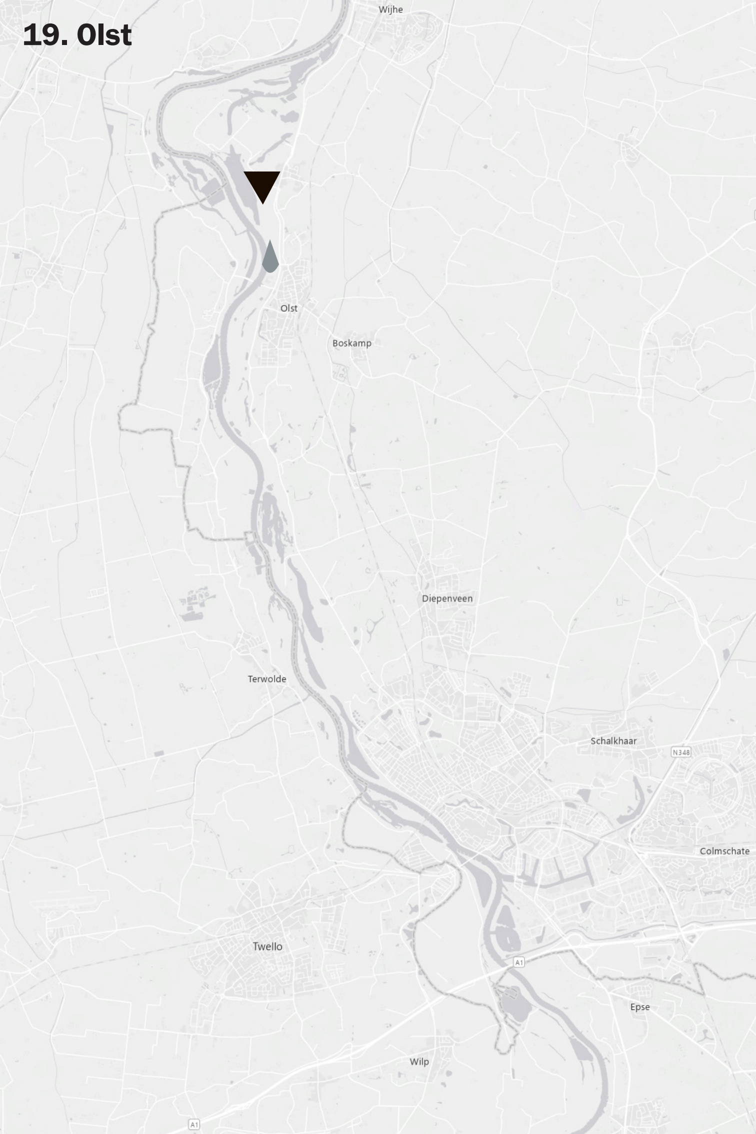
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Zutpen
Water, Zutpen Noord

Soil:
The soil composition of this location is largely unknown after a depth of 5 meters. The top layer is clay and after that untill a depth of 4 meters it consists out of sandy layers.

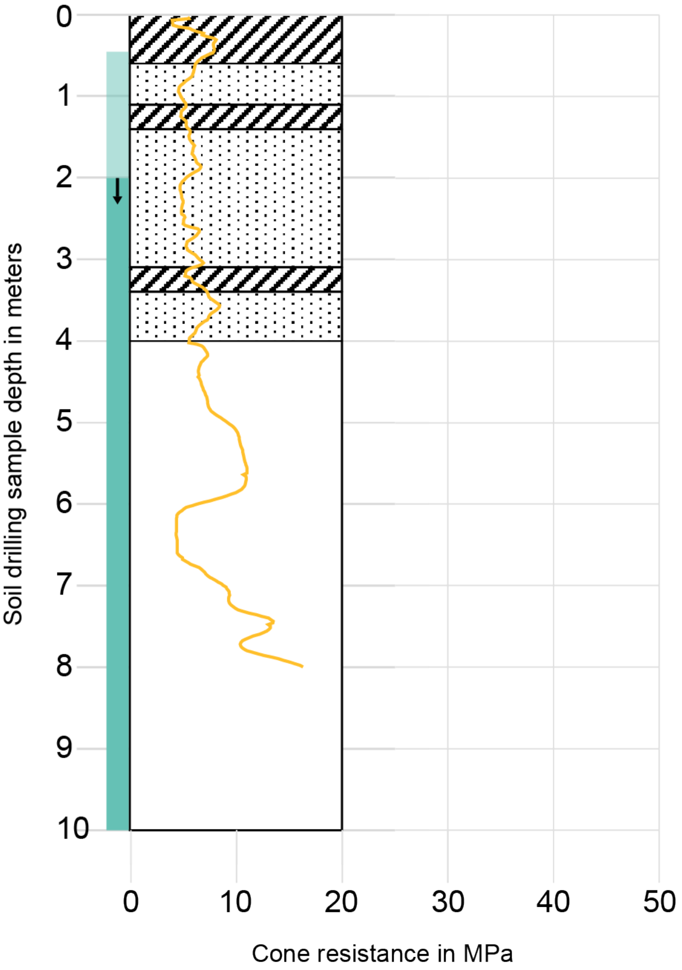
Water:
The water level at this location is very erratic and during winter times it is possible that the floodplains will flood. The erratic water level shows that this is an uncontrolled part of the river the IJssel.

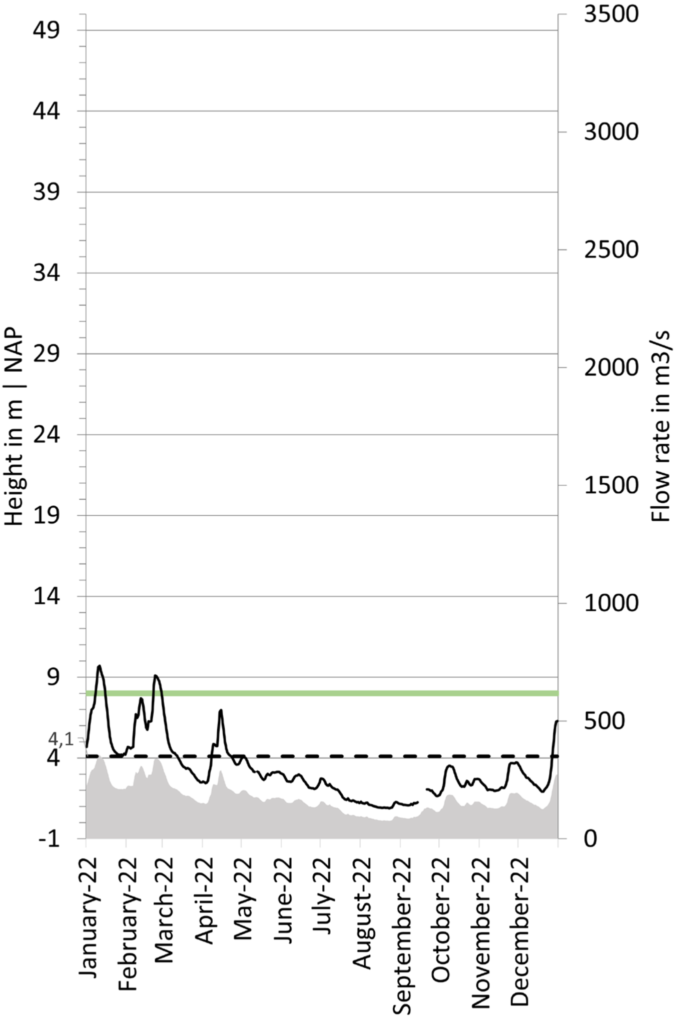
Overall:
Overal for the soil composition further investigation needs to be done. And it is an flood prone location especially during winter period.

19. Olst


Wijhe
Olst
Boskamp
Diepenveen
Terwolde
Schalkhaar
N348
Colmschate
Twello
A1
Epse
Wilp
A1

19. Olst | Soil graph




49
44
39
34
29
24
19
14
9
4,1
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-1
Height in m | NAP
3500
3000
2500
2000
1500
1000
500
0
Flow rate in m3/s
January-22
February-22
March-22
April-22
May-22
June-22
July-22
August-22
September-22
October-22
November-22
December-22

19. Olst | **Conclusions**

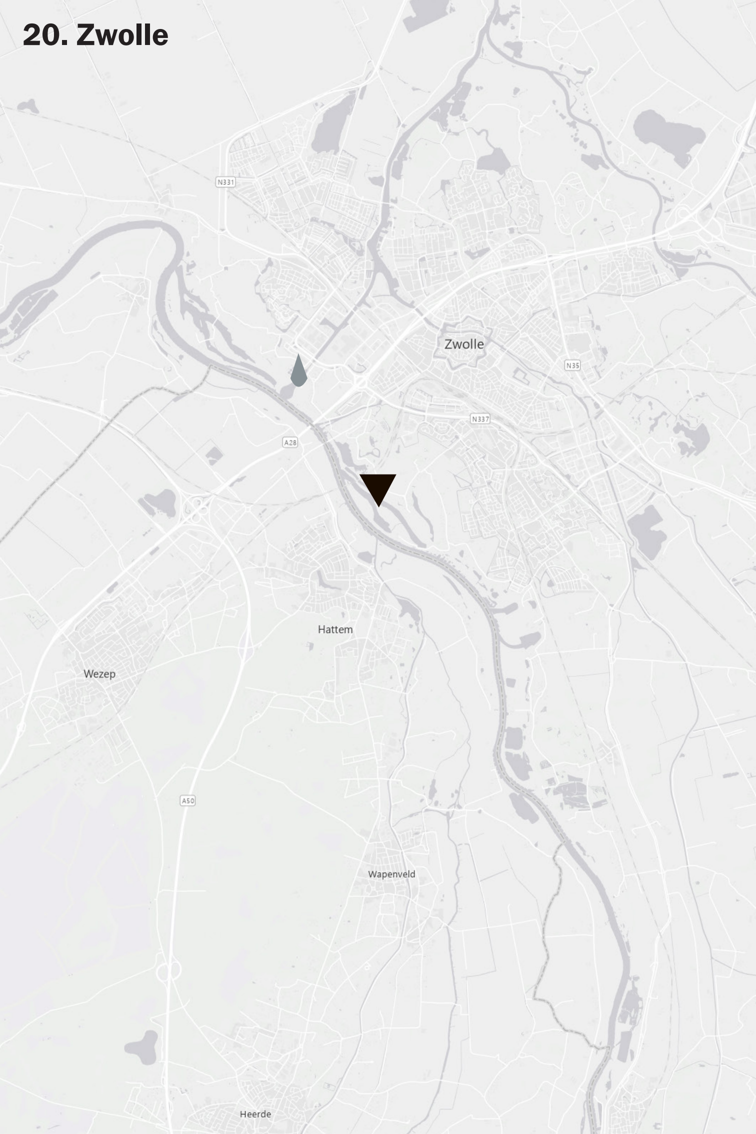
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Olst
Water, Olst

Soil:
The composition of this location alternates between sandy layers and clay layers. After 4 meters deep the composition is unknown. but looking at the cone resistance graph there are no exctremely weak layers in a max. depth of 8 meters.

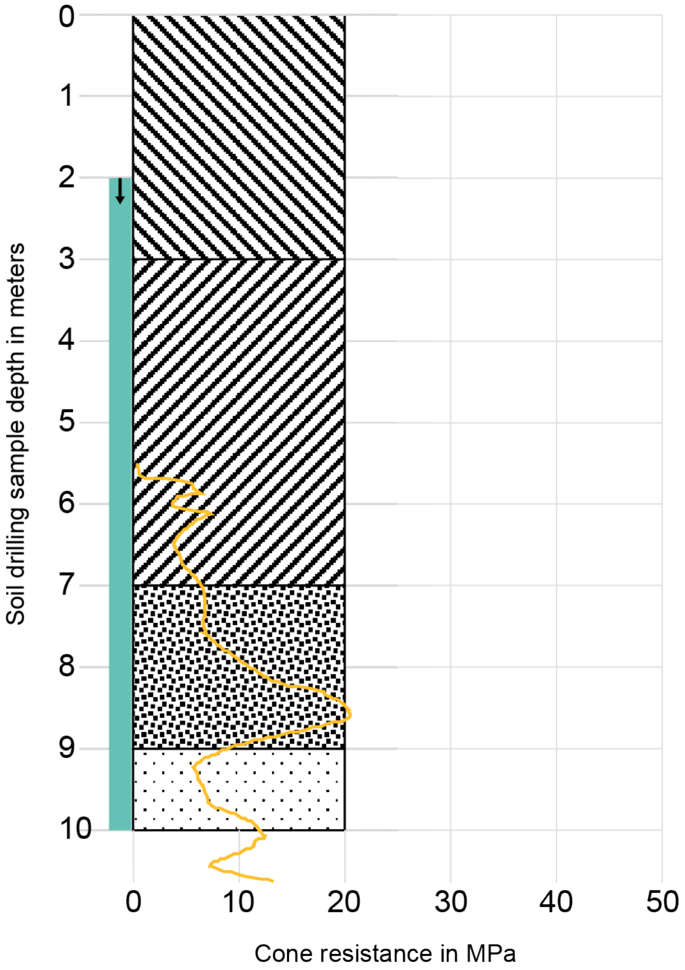
Water:
Here the flow rate and the water level show extreme simalarities. Therefore relate perfectly to each other, during high flow rates there is a higher water level.

Overall:
The soil composition is relatively weak but not extremely, furthermore the water level is in the winter high enough the be able to flood the floodplains occasionally.

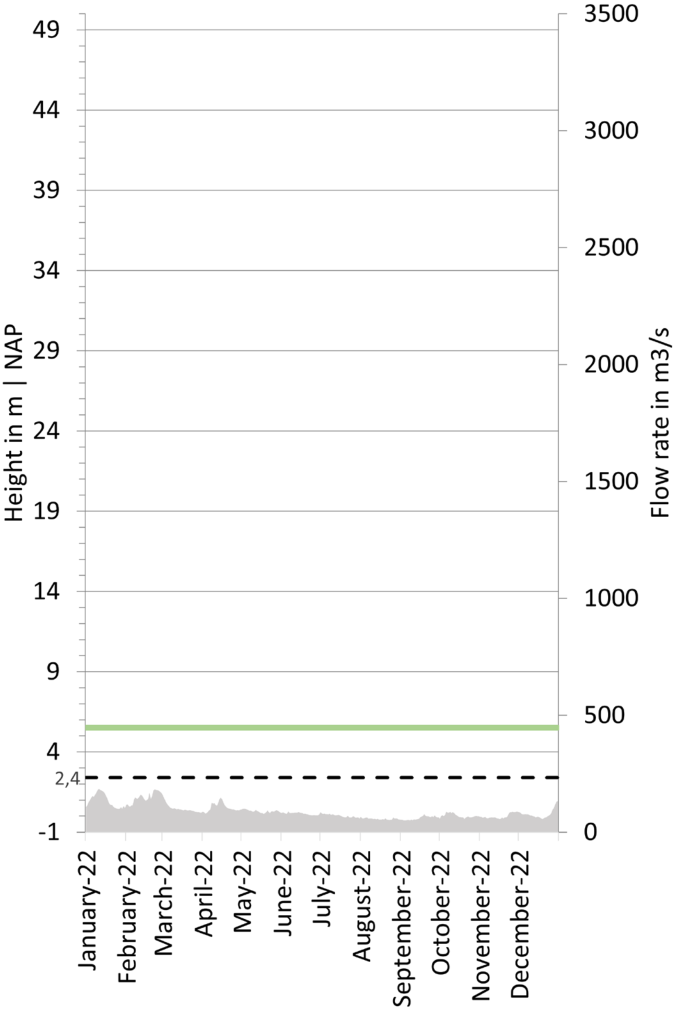
20. Zwolle



20. Zwolle | Soil graph



20. Zwolle | Water graph



20. Zwolle | Conclusions

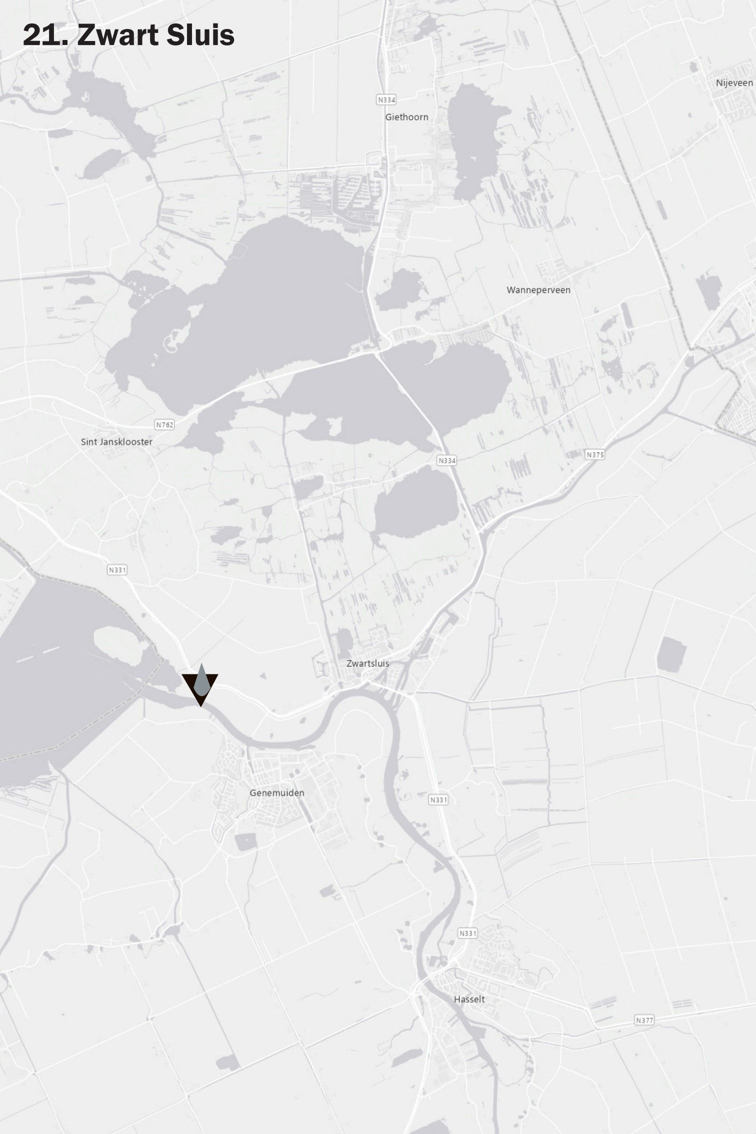
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Zwolle
Water, Katerveer

Soil:
The soil composition is very soft for the first 6 meters. after that a gravel and a sand layer create stronger layers.

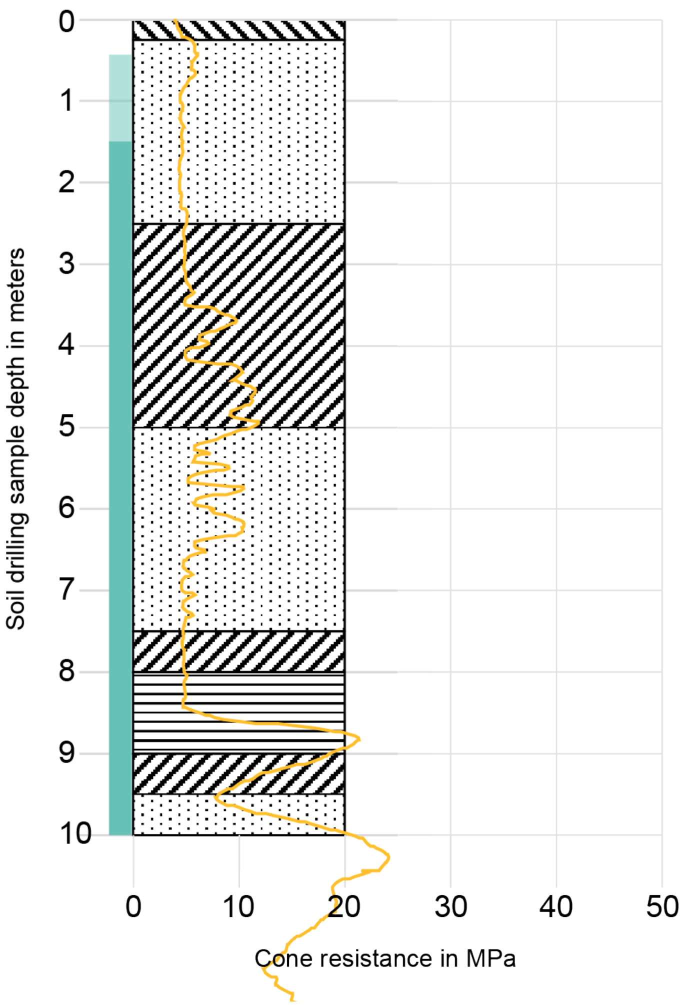
Water:
This is a very stable part of the river, only in the winter period the water level rises more. This is probably due to the melting snow.

Overall:
This location has in its top layers very weak soil. The water levels are relatively stable during summer period but during winter it can cause flooding.

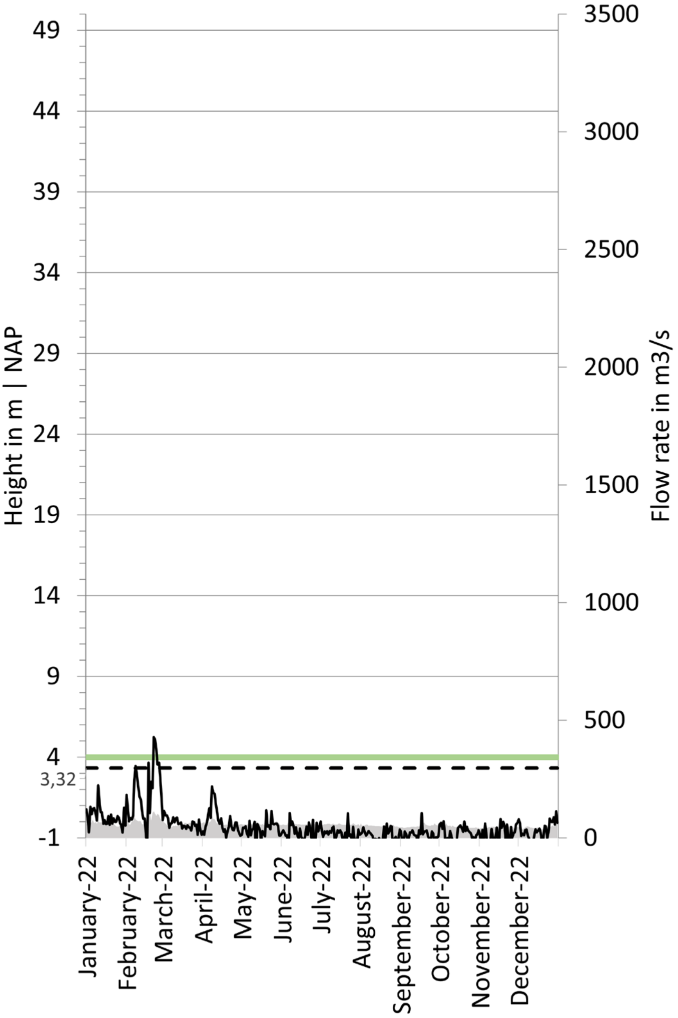
21. Zwart Sluis



21. Zwart sluis | Soil graph



21. Zwart sluis | Water graph



21. Zwart sluis | Conclusions

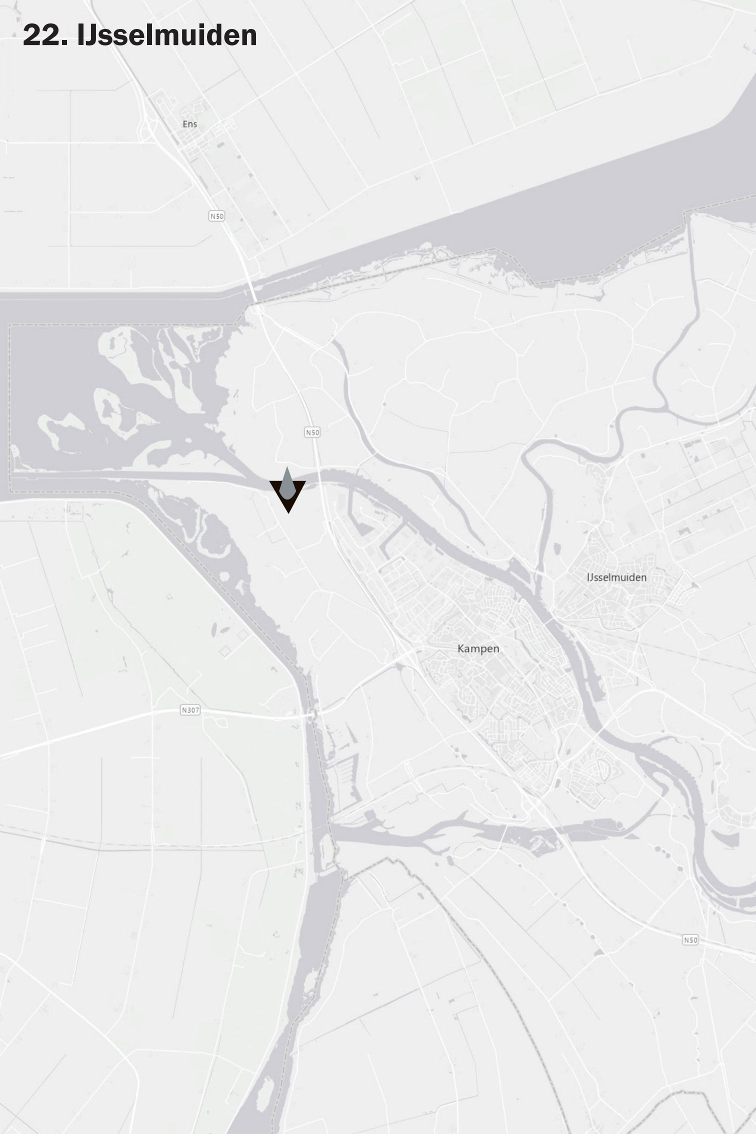
Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, Zwart sluis
Water, Genemuiden

Soil:
At this location the soil is relatively weak as it consist for big parts out of clay. Only after a depth of 8.5 meter the cone resistance shows stronger layers.

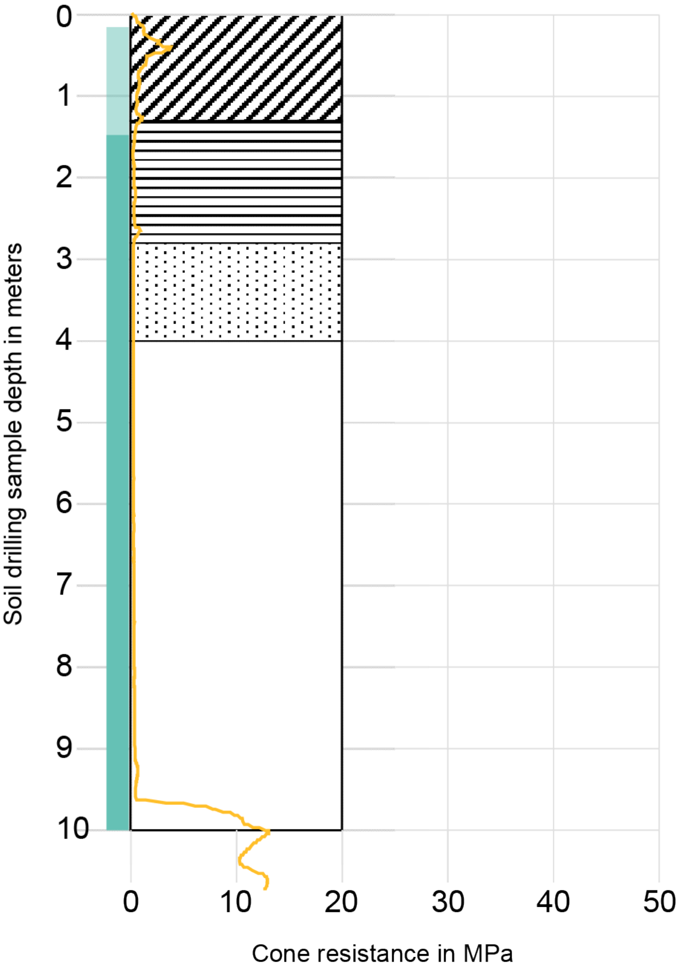
Water:
This is a very stable part of the river, as well as the water level as the flow rate show this. Only in february and march it shows peaks, this is probably due to the melting snow.

Overall:
This location has a relatively weak soil with a very consistand part of the river. This is also the location where the river the IJssel flows into the IJsselmeer.

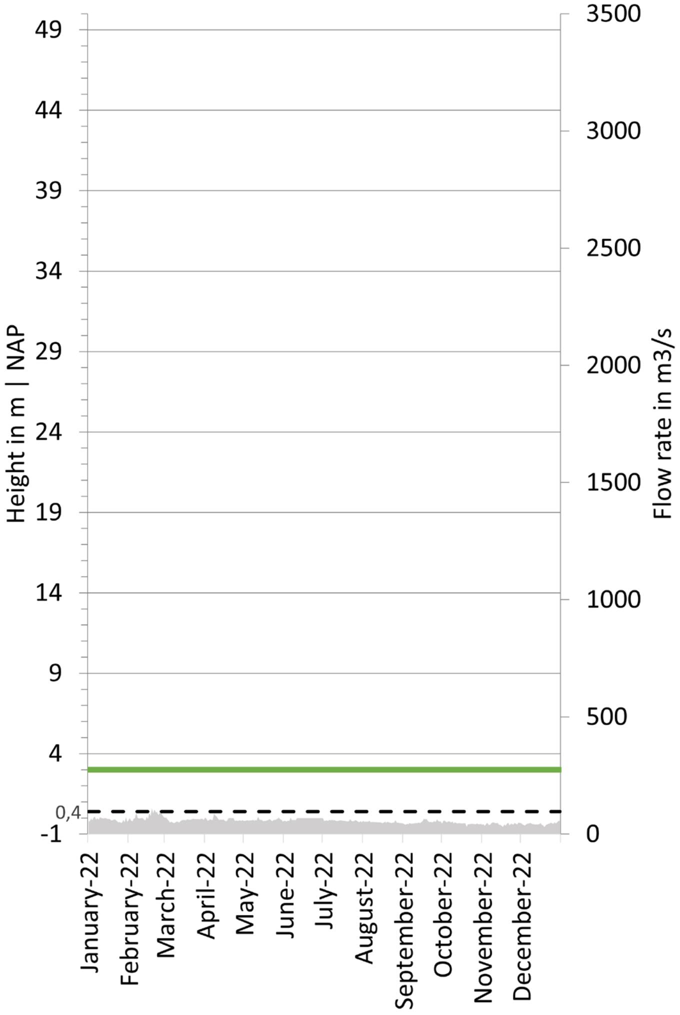
22. IJsselmuiden



22. IJsselmuiden | Soil graph



22. IJsselmuiden | Water graph



22. IJsselmuiden | Conclusions

Map:
The map shows that the measurements are taken close to each other. The locations are:
Soil, IJsselmuiden
Water, Ketel Diep

Soil:
Untill a depth of 10 meters this locations shows an extremely weak soil composition. Though from a depth of 4 meters it is uknown, it is probabely consisting out of clay and/or peat.

Water:
The river here also is very consistand. The ground level is also almost the same as the water level. It is therfore likely that the occational flooding can happen.

Overall:
This location has a extremely weak soil with a very consistand part of the river. This is also the location where the river the IJssel flows into the IJsselmeer.

APPENDIX 4_FOUNDATION TYPOLOGIES

Foundation typology

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