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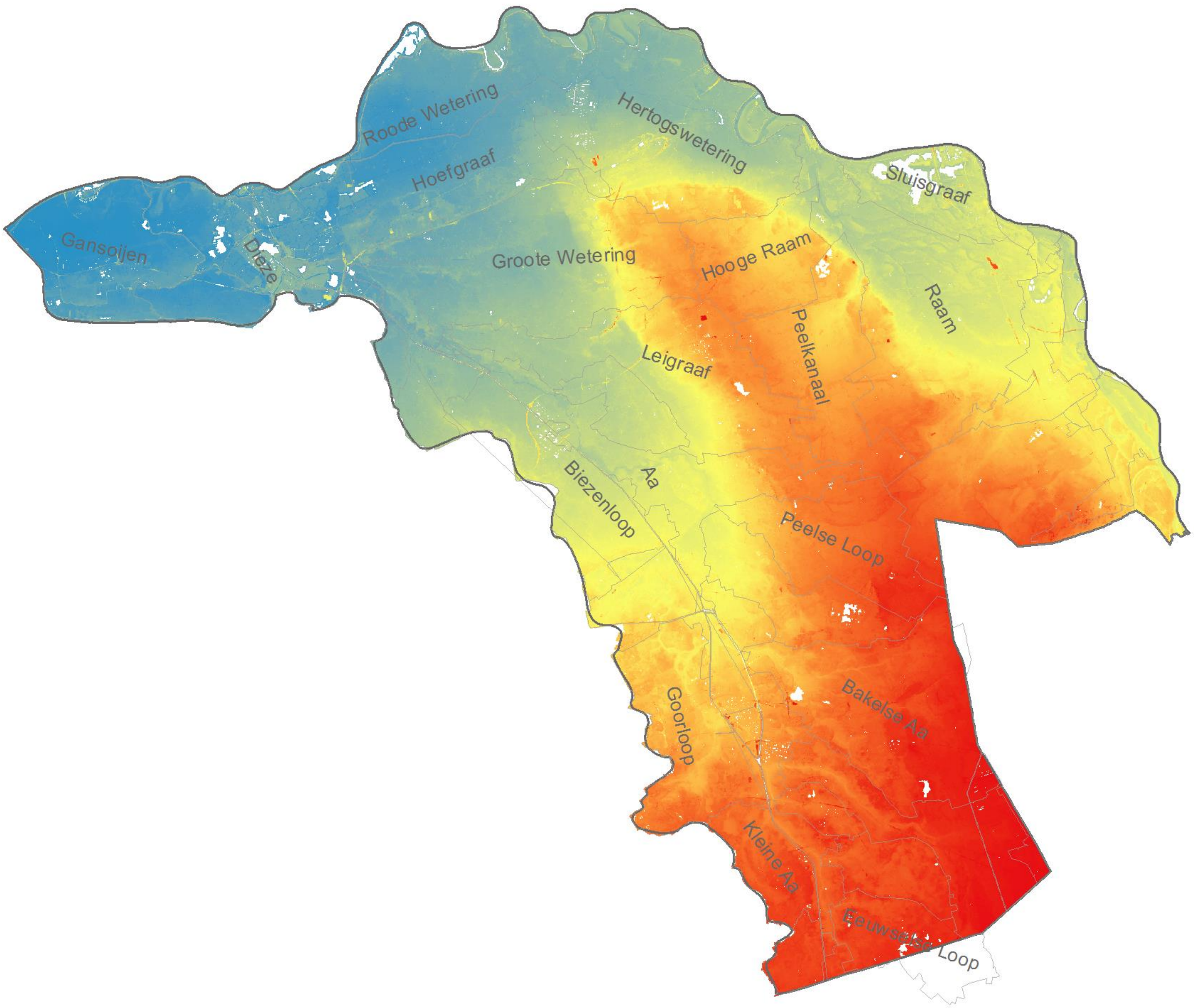
Waterschap Aa en Maas

Water level management Aa and Maas

Examining performance of current weir management based on data analysis



COLOPHON

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Waterschap Aa en Maas

PREFACE

This thesis is the culmination of my Bachelor of Civil Engineering and my internship that I conducted at Waterschap Aa & Maas in 's-Hertogenbosch. Between April and June 2016, I carried out a big data analysis. This analysis focuses on the water level management of Waterschap Aa & Maas, in particular their management of the inland waterways that are controlled through weirs.

This was a subject I had almost no previous knowledge on. Although I worked on hydrological cycles for my minor at the University of Tokyo and flood protection during my BSc at the University of Twente, many of the challenges I had to face during this research process were new to me. Groundwater and surface water interactions and weir management in particular, were subjects that required me to expand my knowledge to gain the necessary expertise to be able to conduct and complete my research. Both my internship and university supervisor, C. van Rens and P. van Denderen, were very supportive in this and I would like to thank them for their help.

From the University of Twente, I would like to thank the professors K. Venner, P. Roos and D. Augustijn for supporting and helping me throughout my BSc. Finally, I would like to thank my parents, my sister, my peer review partner M. Beltman and last but not least, M. Asai. All of them have supported me throughout my BSc and this thesis and I could not have done this without them.

Bas Leijser
July 2016

ABSTRACT

The Netherlands has a unique network of inland waterways that are managed through an extensive system of weirs and pumping stations. Each region is managed by a regional water authority, also called a water board. One such water board, Waterschap Aa & Maas (hereafter called WA&M), is the focus of this research.

Data has been collected from approximately 900 weirs in an area of $1610km^2$, the entire region that is managed by WA&M. Each weir has an adjustable floodgate and a policy margin (that is unique per weir and determined by WA&M). Depending on the floodgate height, it also has a water level and a distribution (percentage over time) of how this water level corresponds to the policy margin. This data has been acquired by the operators of the weirs by the use of a smartphone application. The main goal of this research is to gain an overview of the water management of the entire region, based on this data. This is the first time that a complete database of all the weirs in the management area of WA&M is analysed in such a way. For WA&M, this research is thus a potential foundation for future research and to identify risks and chances in doing so.

As a result, the main research question is:

> ***"How were the weirs in the study area managed in the period of January 2013-2016, what are the chances and risks and how can these be explained or prevented?"***

To answer this question, the data has been converted and modified so it could be analysed through ArcGIS. Human errors and typos were either removed or manually fixed. Weirs that are automatically controlled were added by hand. To each weir, a nearby critical minimum ground level (hereafter called: CMGL) was assigned. This is a single location in an adjacent field. This way, its unique characteristics such as land use (corn, grass, et cetera) could be added to create a single database with data on both the weirs and their corresponding CMGL's. By doing this, not only the weirs could be analysed but a comparison could also be made between the water level (of the waterway in which the weir is located) and the surface height of the subsequent CMGL. This gives insight into the moisture content of the soil.

Results show that the policy margins for the weirs, as set by WA&M, are reached 66% of the time in the period of 2013-2016 for both winter and summer[1]. The initial data collected through the weir operators contained a significant amount of errors, such as typos or no +NAP correction for height values. Most of these errors have been filtered or corrected. Nevertheless, it is recommended to improve this accumulation of data by the weir operators to make future analysis more efficient.

Other results show that the water levels in summer are, on average, at least 20 centimetres higher than in winter for 115 weirs (out of approximately 900). For 315 weirs this difference is at least 10 centimetres. This can be harmful to ecological areas that thrive on constant and natural water levels. Other potential risks are sixteen locations in summer where corn is being cultivated on the CMGL, yet the moisture content of the soil is critically high. For these sixteen CMGL's and their corresponding weirs, the water levels only met the policy margin 45% of the time. For certain locations, it thus seems apparent that new policy margins or a stricter adherence to them are needed.

Since this research is the first attempt to gain an overview of the water management in the entire study area, it was not possible to judge or validate the water management by WA&M. This would require more (reliable) data, expertise and future research. Nevertheless, this research provided an initial overview of the data and identified errors, risks and chances. The results, such as the 66% of the time that the margin is reached, can be further interpreted by WA&M to improve their water level management.

[1] This refers to the hydrological seasons. The transition takes place in April/May and September. There is no spring or autumn.

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List of abbreviations

>10cm OM	More than 10 centimetres outside margin
ABMA	Above margin
BEMA	Below margin
CMGL	Critical Minimum Ground Level
GGOR	Desired ground- and surface water regime
INMA	In margin
LL	Lower limit/level of the margin set for water levels
OL	Optimum level of the margin set for water levels (the centre of the margin)
OM	Outside margin, which refers to the category >10cm deviation compared to the UL or LL
UL	Upper limit/level of the margin set for water levels
WA&M	Water board Aa & Maas

LIST OF FIGURES

1 INTRODUCTION

Water is a vital aspect of our daily lives. Management of water resources affects social welfare, public safety, water supply and the state of ecological systems [1]. It is imperative to control and optimize this operation. Although water management in the Netherlands is typically associated with the Delta Works or river management, the waterways in the mainland hold an integral role. Efficient management of the ditches and streams can prevent local flooding, stimulate ecological growth and aid in efficient crop farming [2]. To regulate the water levels of these streams, weirs are used. Water flows over the weir crest and the head over the weir can be controlled by adjusting the position of the floodgate (see Figure 1-1). Since the water level in the waterways affects and is affected by groundwater levels [3], floodgate control can be used to achieve desired phreatic surfaces depending on the land use. Three categories are distinguished for land use: ecological, agricultural and urban systems [4]. Their conflicting demands create an intricate water balance that is further complicated by the expected effects of climate change.

Figure 1-1: An example of a weir where water flows over the floodgate crest

Due to climate change, in the Netherlands drought in summer is expected to increase and heavy precipitation events in winter will occur more frequently [2][5]. This leads to larger variations between summer and winter seasons[2]. Average precipitation in winter could increase by 14,2% by 2050 and in summer a decrease is predicted of 19,0% [5]. Coupled with a rise of evapotranspiration, this results in a precipitation deficit that could increase from the current average of 144mm to 440mm per year [5][6][7]. Subsequently, this moisture deficit lowers the yield of agriculture [7][8]. These developments further stress the need for efficient water management of the weirs and in particular to conserve water during the winter to compensate for the dry summer season [2]. It is the responsibility of regional water authorities to create, optimize and enforce this operation.

Waterschap Aa & Maas is such an authority. This Dutch water board manages the weirs and pumping stations for category A[3] streams in the area as shown in Figure 1-2. This region spans a total area of 1610 km^2, containing approximately 2200 weirs including water inlets and static thresholds. The main suppliers of water for the various waterways are the Maas river in the northeast and the Aa and Raam streams in the west and centre, respectively. Ws Aa & Maas strategically distributes this water over the various waterways. Then, weirs and pumping stations are used to make further adjustments and, if necessary, to conserve water. Conserving water is one of their main preventive measures for drought and climate change. By keeping the water levels in the various waterways high, starting from April, it will be absorbed by the surrounding soil where it can be contained [9]. If a heavy precipitation event is expected, adaptation is possible by lowering floodgates and thus the water level.

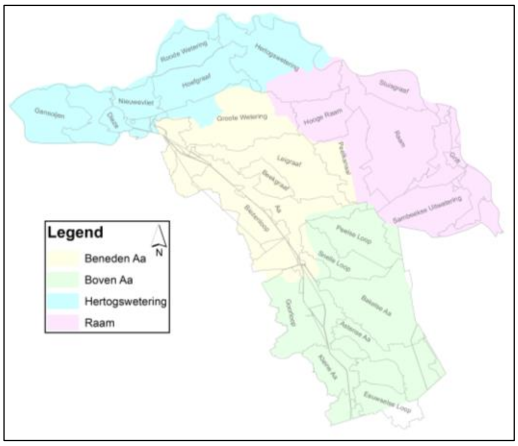

Figure 1-2: The regions managed by Ws Aa & Maas, larger version in Appendix A: Study area (map)Appendix A

The conserving water strategy is relatively new and was introduced in 2001. In fact: most weirs were built in the current century. In the 1960's-80's, the only goal of Ws Aa & Maas was to discharge surplus water. While the *conserve-contain-discharge* strategy is relatively

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[2] Summer and winter in this report refer to the hydrological seasons, with a transition in April and September (so there is no Autumn and Spring season)

[3] Cat. A streams have a minimum discharge of 30 L/s, cat. B of 10-30 L/s and cat. C of <10 L/s [2]

simple, many stakeholders and other factors add complexity to it. In 2000, the *European Water Framework Directive* (WFD) was published [10]. This means Ws Aa & Maas now has certain biological, hydro-morphological and chemical qualities to uphold for their waterways. On a national level, the *National Administrative Agreement Water* contains standards for flooding [11] and the *Nature conservation law* and *Flora & Fauna law* contain additional ecological standards [12][13]. Finally, several regional and local policy documents exist.

In order to gain better insight into this strategy, data has been accumulated since January 2013 for each weir. The floodgate position and corresponding water level (over the crest) is available for the period of January 2013-2016. This data was obtained from the local weir operators, by the use of a smartphone application. Figure 1-3 shows how this works in practice. At random intervals throughout the year, the operator performs the measurements by hand. A tool has been developed by Ws Aa & Maas to convert this data into shape files for the whole area, that can be imported in the program *ArcGIS*. This research study will be the first time this data is used on a larger scale. Through ArcGIS and various other tools, the data will be subjected to a critical analysis. For instance, human error can be a factor, as can be derived from Figure 1-3. The main goal of this research is to gain an overview of the water management in 2013-2016 for the entire region and to find possible chances and weaknesses. The results, conclusions and future recommendations based on this research are presented in this thesis. The process and method on how these results were obtained, are included in the Appendices.

Figure 1-3: Measuring the floodgate height and water over crest

1.1 Research aim

The problem context has largely been defined in the main introduction. It consists of the new challenges introduced by climate change, the intricate balance to meet the wishes of various stakeholders and the lack of any insight into the regional water management of Ws Aa & Maas. It should be noted that the latter is due to the data being accumulated only recently and because the strategy of Ws Aa & Maas changes according to new developments. Therefore, the goal is to gain insight into the water management and use this as a foundation for the identification of potential risks and for future research.

As a result, the main research question can be defined as:

> ***"How were the weirs in the study area managed in the period of January 2013-2016, what are the chances and risks and how can these be explained or prevented?"***

The study area is similar as the one shown in Figure 1-2. From this main question, five research questions can be derived. Answering these questions in turn resolves the main one.

Rq.1 *What are the water levels above the weir crest for the whole area and per region, in both summer and winter?*

Rq.2 *What is the drainage height for the critical minimum ground level per weir, for both summer and winter?*

Rq.3 *What intensive crops are at risk based on their drainage heights and what is the cause?*

Rq.4 *What are the risks for regime 2 areas regarding winter-summer differences and drainage heights?*

Rq.5 *Which areas received complaints and how does this compare to the current water management strategies?*

1.2 Research scope

The research scope is an important aspect because of the broad initial goal (gaining an overview of the water management). Moreover, only 12 weeks are available for this research (from April the 4th, 2016 until the end of June, 2016). For proper time management, a sufficiently focused research scope is thus of vital importance.

First of all, this research will only focus on the hydrological aspects of water management. All other factors such as water quality are neglected. Within the field of hydrology, this study will only focus on two aspects: water levels over the crest and *drainage heights* compared to the minimum nearby ground level. Water discharges, precipitation, evapotranspiration and groundwater fluctuations are not a part of the research scope.

Furthermore, only the period of January 2013-2016 is analysed in ArcGIS. While other tools and programs could be used, such as SOBEK, this research will focus mainly on using ArcGIS to analyse and visualize the data. To analyse this data, it will be compared to other factors such as seepage values and land use. For this, assumptions had to be made. For instance, for seepage values only one year of historical data (2013) is compared to the entire time period (2013-2016). These kinds of abstractions were deemed necessary due to the time constraints. In Appendix B it is clarified how these choices were made and how the database was constructed.

At the start of the ArcGIS analysis of this research (around April 15th, 2016); the database of the weirs as provided by Ws Aa & Maas was not yet complete. The regions *Sambeekse Uitwatering*, *Raam* and *Peelkanaal* were not yet finalized; which means that most weirs in these regions have missing data. Specifically, these weirs have no *margins* assigned to them. These policy margins consist of an upper (UL) and lower limit (LL), in metres +NAP, that denote a recommended range of the floodgate height. These margins differ per weir, are constantly updated and provide the main method of control by Ws Aa & Maas over the water management. In consultation with C. van Rens from Ws Aa & Maas, the choice was made to start with the research before these areas could be finalized to prevent time management problems. Most of the weirs from these regions were filtered from the database (see Appendix B). Apart from that, these regions only resulted in slight errors in one case, see Chapter 2.1 and Figure 2-3. Therefore, these weirs are excluded from the research scope.

Finally, the research scope is limited to a global overview and none or few individual or clustered outliers. For example, after plotting all the weirs based on their drainage height, it would take too much time to analyse all the extreme outliers. Therefore, for each part of the analysis only a limited amount of individual or clustered weirs will be investigated. The main focus here is to gain a global overview and support this with one or two examples; over-analysing individual or clustered cases could lead to time management issues. This also means that the performance of the water level management can be critically assessed, but not judged or evaluated. For example, this research will determine how the margins for each weir are followed in practice but these results cannot be validated because there is no numerical standard or comparison. See also Chapter 8 Discussion.

2 WATER LEVELS OVER CREST

From the shape files in ArcGIS, the water levels for each weir are known. In this chapter, these results are presented and discussed. The process that preceded the obtainment of these results, such as the elimination of unreliable data and human errors, is detailed in Appendix B. The definition "water level" in this report refers to the water level of the stream as measured on top of the floodgate, this is also called the water over crest (see Figure 2-1). This value is equal to the height of the floodgate plus the overflow. The overflow value is a constant for winter and summer. Therefore, when referring to "adjusting the floodgate" or something similar in this report, this essentially means the same as adjusting the water level. The value of both the floodgate height and water level is measured in metres +NAP, which is also called *Amsterdam Ordnance Datum*. This value is roughly equal to the average sea level [15].

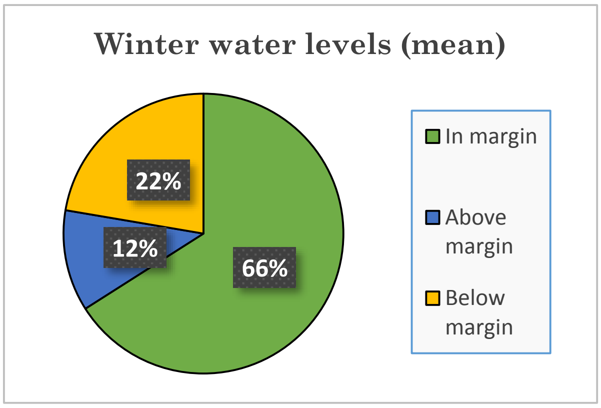
Figure 2-1: Water level over crest of the floodgate, measured in m +NAP

The target water levels for each weir are based on a policy document [9] that was published in June 2015, followed by an extensive local process [16]. For instance, a farmer can call the operator to request a lower water level so his machinery does not get stuck in muddy soil. These local wishes are taken into consideration when a policy is created for each weir. To make the weir operation easier and more efficient, a *margin* is set that denotes an upper and lower limit (UL and LL) for the floodgate height. The centre (mean) of the margin is called the *optimum level* (OL*)* by Ws Aa & Maas. However, it should be noted that achieving this optimum level is not a goal. A better definition would be *centre level*.

The margin was created specifically to allow free adjustment of the weir (with a phone call from a farmer as one exemplary use of it). Therefore, this chapter will focus on how often the water level of a weir falls inside or outside the margin; the optimum level will not be taken into consideration.

2.1 Region totals

Figure 2-2 plots the distribution of the water levels for both summer and winter for the entire study area. The (left) graph should be read as: for winter, during the period of January 2013-2016, the mean water level of the roughly 900 weirs was 66% of the time in margin, 12% above margin and 22% below margin. These percentages are based on the mean values for the entire study area.



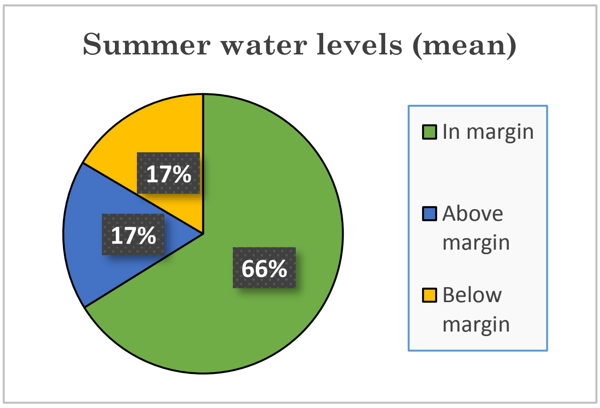
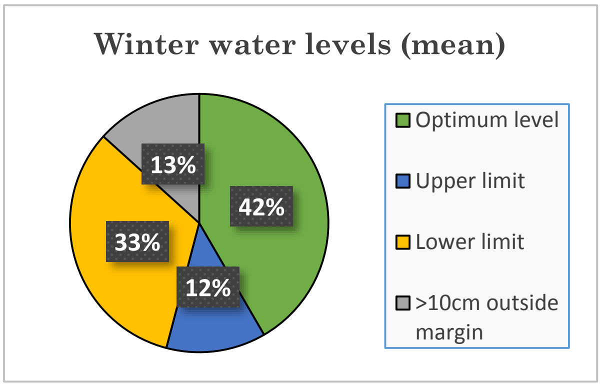


Figure 2-2: Mean values of the water levels in the study area, for both winter and summer

It can be derived from this figure that the differences between summer and winter are small, especially the "in margin" values. Water levels in summer are typically higher than in winter (17% above margin compared to 12%), which was anticipated based on the policy document [9]. After all, water levels in summer are raised purposefully to prevent drought. What these figures don't show, is the relative deviation of the water level compared to the margin. Therefore, a distinction was made between four categories: optimum, upper limit, lower limit and >10cm outside margin (OM). This is plotted in Figure 2-3. Again, this is the mean value over time for all the weirs in the study area. However, this time a water level that is, for example, eight centimetres above the upper limit will be assigned the UL category (in Figure 2-2 it would be in the "above margin" category). When the deviation compared to the UL or LL is greater than 10 centimetres, the ">10cm outside margin" category is assigned. Finally, the distinction between OL and the UL or LL is based on proximity. If the water level is exactly halfway between the optimum and one of the limits, the OL is chosen. It should again be noted that the OL is purely the centre of the margin and not always the most ideal water level.



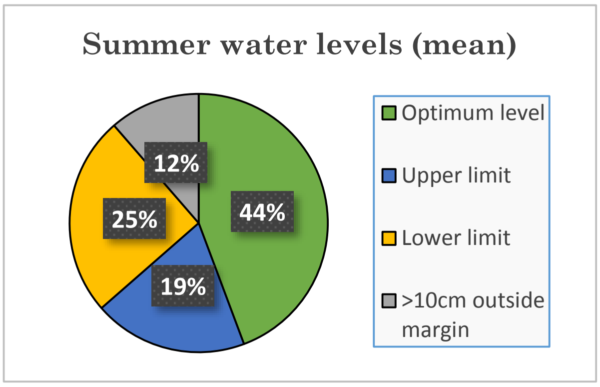


Figure 2-3: Mean values of the water levels in the study area, for both winter and summer

By taking the sum of the OL, UL and LL values, this can be compared to the "in margin" category from Figure 2-2 to see the actual distribution of the water levels. This results in a value of 87% in winter and 88% in summer (so, from Figure 2-3, the green, blue and yellow areas combined). So, most values that are assigned the "above margin" or "below margin" category in Figure 2-2, have a deviation of less than 10 centimetres compared to their respective nearby limit. The grey area from Figure 2-3 thus represents the actual outliers and require more thorough analysis.

The grey category in winter consists of the mean value of 367 (out of 971) weirs. These weirs fall in this category more than 0% of the time, leading to the mean value of 13%. 167 out of these 367 weirs have a >10cm OM value of 100%. It turns out that most of those (128) have no margin values assigned to them in the ArcGIS database. In other words: these weirs have no margin which causes the water level to fall 100% in the >10cm OM category. However, these weirs are all located in the regions *Sambeekse Uitwatering*, *Raam* and *Peelkanaal*. These areas, as described in Chapter 1.2 in the research scope, were not yet completed at the start of this research process; which explains the lack of any data. The same is true for summer where 145 weirs have a >10cm OM value of 100%. Since these incomplete weirs have no drainage height values, they do not affect the analysis and results of the drainage height in a negative way.

The weirs that do have a margin assigned to them, yet still return a 100% value of >10cm OM, have other causes. These can be found in the descriptions of the weirs and range from "high constant level because of ecology" to "this weir isn't being used". A list of these weirs was reported to Ws Aa & Maas and it shows how adjusting the margins is a constant process. Since margin adjustment is not a part of the research aim or questions, this will not be further analysed in this report.

2.2 Water level per region

The same pie chart from Figure 2-3 has also been plotted per region on a map of the entire study area (see Figure 2-4). A larger version of this map and one for the winter situation can be found in Appendix D.

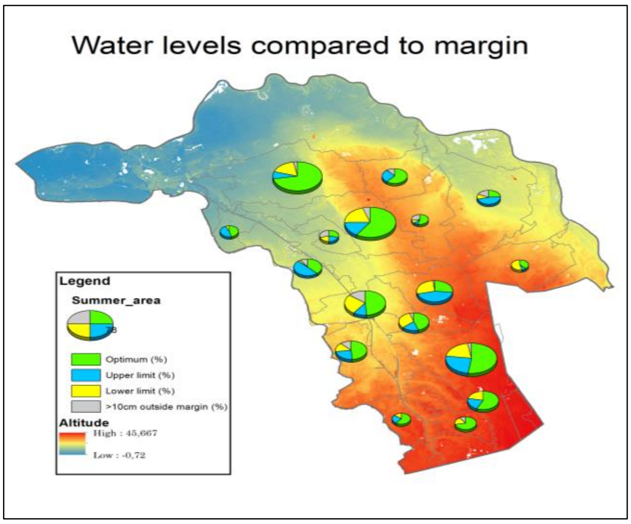


Figure 2-4: Water levels plotted per region in summer, larger version in Appendix D

The observation from chapter 2.1, that the grey category (>10cm OM) is mostly taken up by weirs where the database is not complete, can also be seen in Figure 2-4. For instance, near the eastern side of the map, the pie chart next to *Boxmeer* scores almost 50% in the grey category

An altitude map is shown as an overlay for this map, however, there seems to be no correlation between the altitude and the water levels. Both downstream and upstream areas have high scores for UL (blue, indicating high moisture content) or LL (yellow, indicating possible drought). It should be noted that the map plots all the regions but the amount of weirs differs per region. Some regions only contain ±10 weirs while others contain up to 100 weirs. This, combined with the incomplete database makes a more in-detail analysis ineffective. Instead, this analysis will focus on the drainage heights, see Chapter 3.

2.3 Strategy according to policy document

In Figure 2-5, the past, present and desired future water level strategy by Ws Aa & Maas is plotted [9].

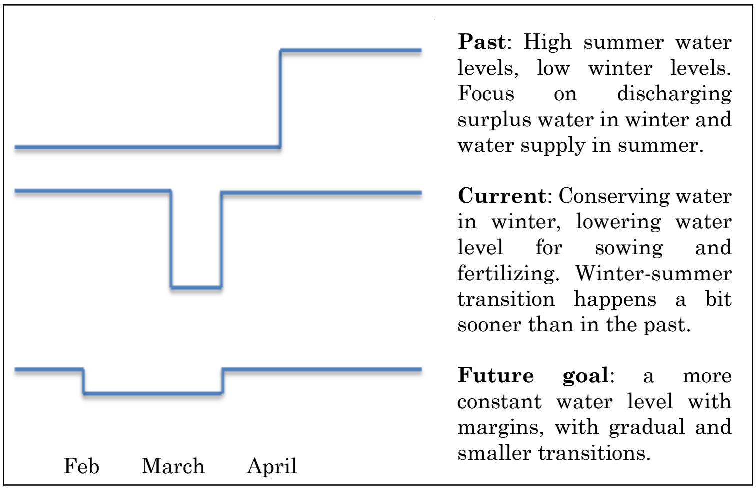


Figure 2-5: Past, present and desired future water level operation by Ws Aa & Maas [9]

The current situation in practice seems to be a mix between the upper and centre graph. As Figure 2-2 showed, water levels in summer are still generally higher than in winter. The current strategy, where water levels are lowered for sowing and fertilizing, is a harmful strategy to ecology and water conservation. Lowering the floodgate (around March-April) will discharge the built-up surplus of water in winter. For example, if during a dry year there is not much precipitation in April and May, then this can cause droughts. Therefore, Ws Aa & Maas gives priority to the primary function of water supply rather than local interests from landowners [9]. The common interest is deemed more important than that of a local stakeholder. Hence, water levels upstream can be higher than would be ideal based on local interests. Solving these local problems should occur through precise allocation of the water but it should not affect the larger water level policy.

This is reflected in the future goal strategy. Maintaining more constant water levels is not just beneficial for water conservation, but also for ecology. Ecological zones and shoreline vegetation require mostly constant water levels to thrive, especially during the transition from winter to summer. Near the end of summer, lowering the water levels does not affect the ecology much since the germination of fish eggs and growing of vegetation starts around April and is then already completed [9]. This strategy of conserving water upstream is visualized in Figure 2-6. The goal is to conserve as much water as possible upstream. Downstream, a balance is established between water conservation and meeting desires from local stakeholders, which is called *optimum conservation*.

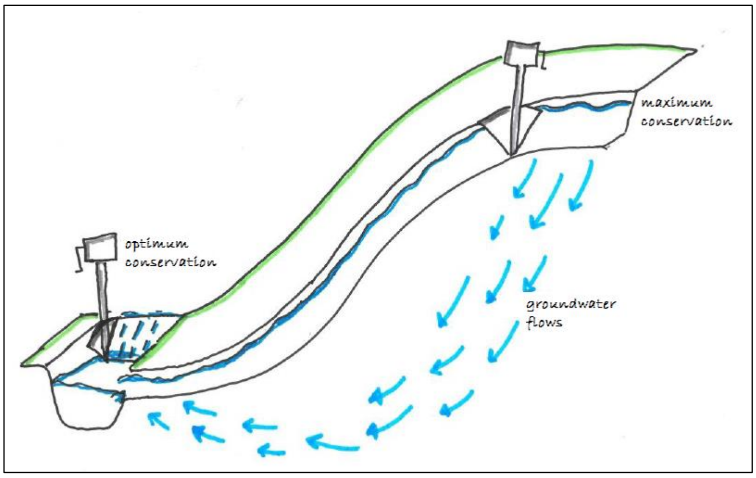


Figure 2-6: Strategy conducted by Ws Aa & Maas, maximum conservation upstream, optimum conservation downstream, picture shows a cross section of two weirs and a waterway (blue line)

To evaluate the situation in practice, the water levels in winter have been subtracted from those in summer. The result of the entire region can be seen in Figure 2-7. On average, the summer water level is 6,6cm higher than in winter (median of 4 cm). This seems closer to the strategy of the past then the "current" or future one according to the policy document. This is especially true for individual weirs and certain clusters, as can be seen in Figure 2-7. 115 weirs have a water level in summer that is more than 20 centimetres higher than in winter. By adding an altitude overlay (see Figure 11-8 in Appendix E), it can be concluded that this mostly applies to downstream weirs but several weirs in higher areas also have highly fluctuating water levels.

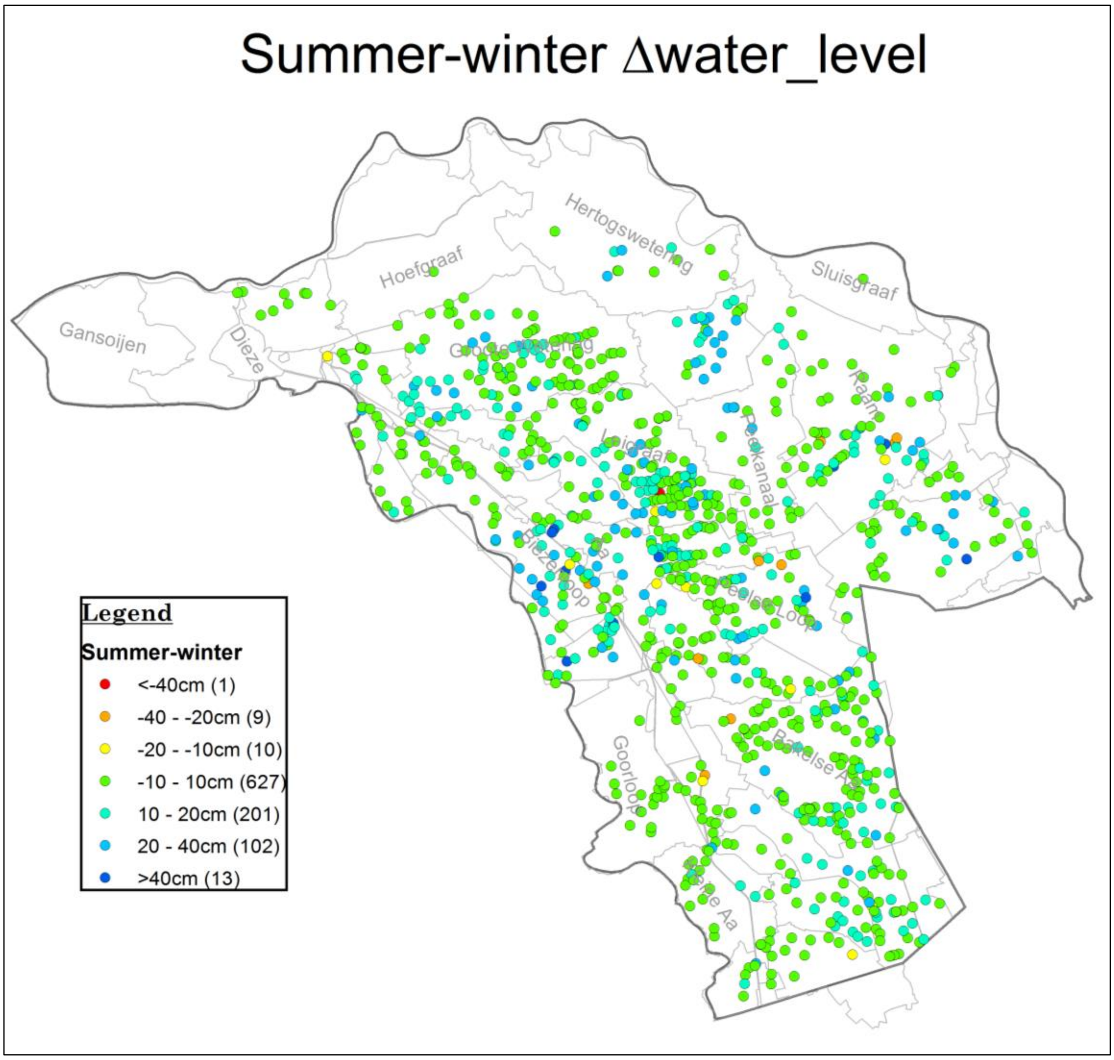


Figure 2-7: Difference between summer and winter water levels for the entire study area

3 DRAINAGE HEIGHT TOTALS

The main part of this research is focused on drainage heights. This definition should not be confused with drain depth, even though they seem similar. "Drainage height" in this report is meant as a translation of the definition *drooglegging* in Dutch. In Figure 3-1 this is visualised. The drainage height refers to the height difference between the ground level and the water surface of the nearby waterway. For the ground level the critical minima are used in this report. Each weir has one or multiple critical ground levels associated with it. This is the nearby location (like an adjacent crop farm) that is critically vulnerable to either flooding or drought. Only the minimum level will be used for the analysis in this report, so that means one critical minimum ground level (CMGL) per weir.

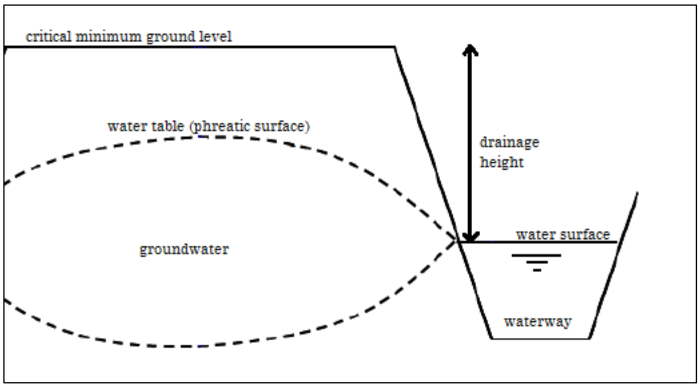


Figure 3-1: Drainage height explained

The drainage height is a representation of the dry- or wetness of the soil. However, the value cannot be interpreted directly due to the phreatic surface of the groundwater, which could be higher than the water surface. Nevertheless, the drainage height allows an analysis to be conducted for dry and wet areas. Phreatic surfaces were not added due to the lack of available data and because this is outside of the project scope. Chapter 4, 5 and 6 use drainage heights for their analysis but in a more focused way (for example, only locations with complaints are analysed). In this chapter, the drainage height for the entire study area, with no selection by any factor is evaluated.

3.1 Drainage height summer & winter

Figure 3-2 shows a box plot of the drainage height in summer, winter and winter minus summer (named "delta" and coloured red in the figure). An explanation on how box plots work and why they are used in this report can be found in Appendix C.

The box plot is based on data for all the weirs, which equals 900+ entries for both summer and winter. It can be derived from the figure that the drainage height in summer and winter are roughly equal and slightly higher in winter. At first, this might seem surprising because drought occurs more frequently in summer rather than winter [23]. However, as Figure 3-1 showed, a larger drainage height does not necessarily mean the soil is relatively dry. In summer, evapotranspiration is much higher than in winter and there is less precipitation, which leads to less infiltration of water in the soil [5][6][7].

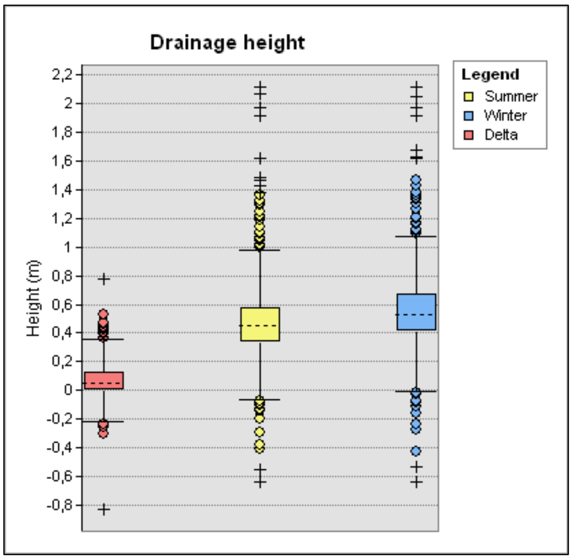


Figure 3-2: Box plot of the drainage height in summer, winter and winter-summer (Delta) for the entire study area

The difference between both seasons (winter minus summer) is plotted as "delta" (the red box). It is notable that (extreme) outliers exist between the summer and winter values. For some locations, the drainage height between winter and summer can differ up to 80 centimetres (both positive and negative). These two locations are further investigated in Appendix F to find the cause for their extreme values.

3.2 Drainage height by land use

For the land use, optimum values exist for the drainage height:

	Optimum drainage height (m)	
	Summer	Winter
Grass	0,40	0,70
Crops	0,60	0,90
Urban	1,10	1,10

Table 3-1: Optimum drainage heights per land use category, for summer & winter [17][18]

These values are all for sand as the underlying soil and the study area also consist of clay and turf. While values based on soil-composition were found [25], this is from an old source and the differences with sand are small (10-20 centimetres). Moreover, there is no reliable data for the soil composition of the study area. The only available shape file contains over 50 categories of different soil types and this would take guesswork to convert to just three categories (sand, clay or turf). Therefore, for this analysis the values for sand will be assumed and a margin of 20 centimetres is used as a "safe factor" to compensate for other types of soil. In other words: if a location has a drainage height 0-20 centimetres larger than the optimum for sand, this is not necessarily problematic.

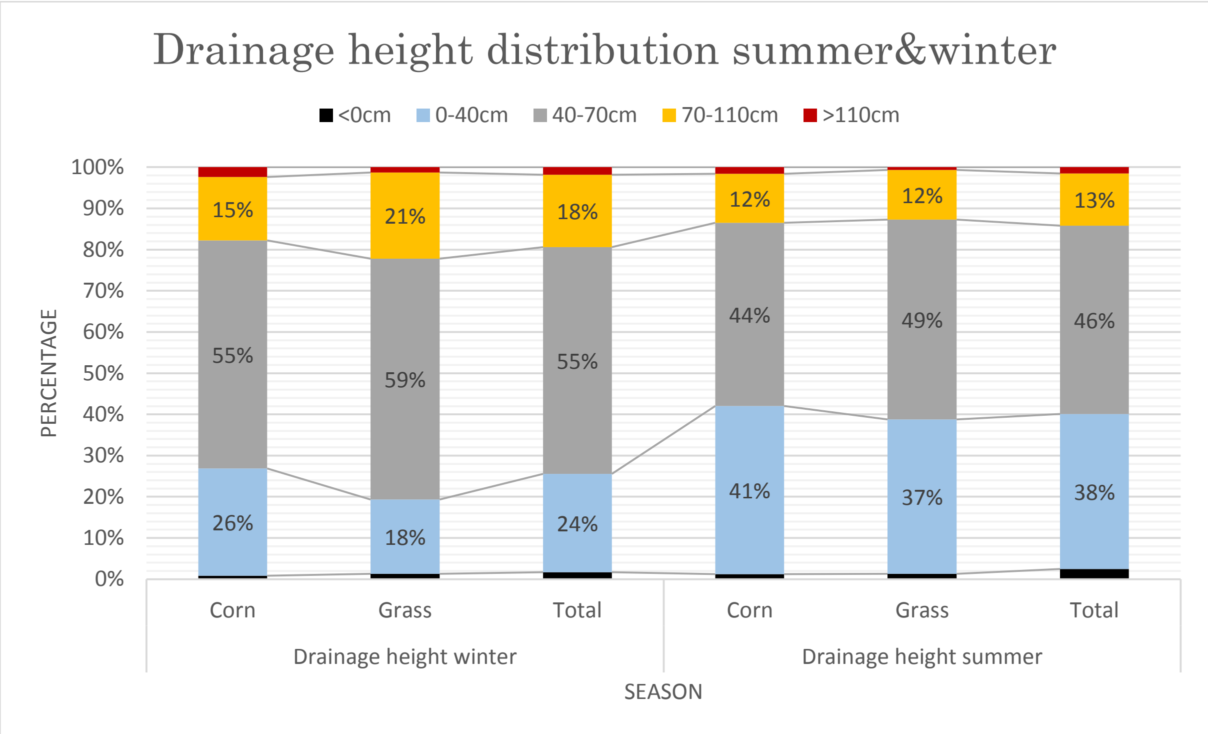


Figure 3-3: Drainage height distribution summer and winter, based on land use

In Figure 3-3, the results can be seen for three categories for the study area: corn, grass and total. Corn is chosen because this is an intensive crop and more susceptible to drought [17]. The category "Total" includes all weirs in the study area (the figure shows the mean values). Further analysis into crops can be found in Chapter 4. Based on Table 3-1, it would be expected that the drainage height for corn is larger than for grass. For Figure 3-3, this would mean that the two categories <40cm are smaller and the part >40cm is bigger. This does not seem to be the case. In summer, 41% is below 40cm for corn compared to 38% for grass. In winter this is 26% for corn compared to 18% for grass. This is an indication of the drainage heights being suboptimal. Although the value for winter can be explained due to the fact that corn (and most other agricultural practices) isn't cultivated in winter and the water levels (and consequently: drainage heights) are only adapted based on conserving strategies and not for local stakeholders. A further analysis of clusters and individual cases can be found in Chapter 4.

3.3 Drainage height by seepage/infiltration

In this subchapter, a potential causal relation between seepage/infiltration and drainage heights will be investigated. Seepage is water that “climbs up” vertically in soil. This process happens frequently around *geographical fault lines*. See Chapter 4.2 for a more detailed description.

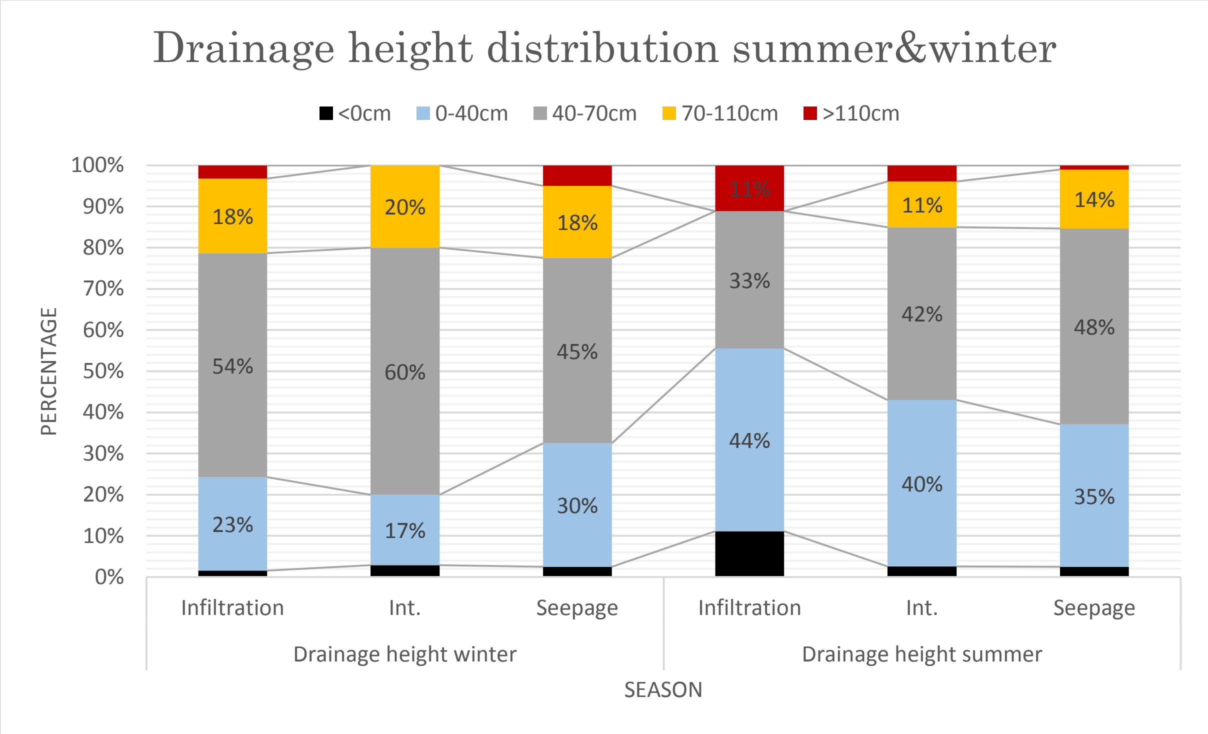


Figure 3-4: Drainage height distribution summer and winter, based on seepage and infiltration values

In Figure 3-4, the drainage height distribution for both summer and winter is shown, based on seepage and infiltration values. “Int.” stands for “Intermediary”, which is a chosen margin. Seepage and infiltration values have a unit of mm/day and are available as raster data in ArcGIS, with both positive values (infiltration) and negative values (seepage). A margin was chosen (as an estimated guess) of 0,5 mm/day, therefore the “Int.” category ranges from -0,5mm/day to +0,5mm/day. In other words, the figure can be read as: locations (CMGL’s) with relatively high seepage values, with average seepage or infiltration (Intermediary) or with relatively high infiltration.

It can be derived from the figure that the locations with relatively large seepage values have a smaller moisture content than the intermediary category in summer. There seems to be no correlation between seepage and drainage height. What was anticipated, is that seepage would lead to smaller drainage heights. Although this may seem counterintuitive, since drainage height is the height difference to the waterway instead of the phreatic surface (Figure 3-1), ultimately a higher phreatic surface will discharge into the waterway and cause that water level to rise as well.

Although there seems to be a large effect from infiltration in summer, only seven locations actually had more than 0,5mm/day infiltration (while the seepage and intermediary categories consist of 300-400+ locations); which makes a comparison unreliable. This seems logical due to the lack of (heavy) precipitation events in summer. Nevertheless, the results show that the infiltration causes the drainage height to be smaller (56% <40cm) which implies a correlation between infiltration and drainage height.

In winter, a similar small correlation seems to exist. For both seepage and infiltration, drainage heights are slightly larger than for the intermediary category (23% <40cm for infiltration, 31% for seepage, 18% for intermediary).

4 CROPS ANALYSIS

This chapter continues from Chapter 3.2 and provides a more in-depth analysis of locations with a critically high or low drainage height where crop farming occurs. As mentioned in the introduction, the water management conducted by Ws Aa & Maas is an intricate balance between the wishes of various stakeholders. This is mostly evident in areas where agriculture and ecological areas are relatively close to each other and where the water level affects both. In winter, this is less problematic because no agricultural activities take place. Therefore, upholding high water levels in winter (for conservation purposes) is typically met with minimal opposition from farmers [9]. However, starting from March or April, problems start to arise. If the water level of the waterway is too high, then this will in turn increase the moisture content of the soil. This can be hazardous to crops but mostly hinders farmers when they are sowing or fertilizing their fields, because the machines can get stuck in the muddy soil.

On the other hand, by lowering the water levels to accumulate to the farmers' needs, part of the conservation strategy is lost which is especially harmful to ecological areas. For the germination of plants and shoreline vegetation, a more constant water level is preferred [9]. In practice, this means that the wishes of the farmers cannot always be met which logically results in various complaints (these will be discussed in Chapter 6). To compensate for this, Ws Aa & Maas holds the policy that on the critically low surface levels, no intensive crop farming should take place [9]. Grass fields (for example, grass meant for livestock) are preferred here, since a smaller drainage height (in other words: a higher moisture content of the soil) is less problematic for this type of land use (see also chapter 3.2, Table 3-1). This chapter will check how this policy is brought into practice.

4.1 Crops with suboptimal drainage height

For crops, the optimum drainage height is 0,60m in summer. Since no crop farming takes place in winter, this analysis will only focus on the summer season. An assumption has to be made for when the actual drainage height is considered "suboptimal". For this, a margin of 40 centimetres was chosen as an estimated guess [23]. In other words: a drainage height of <0,20m or >1,0m in summer is considered suboptimal for crop farming. In Figure 4-1, the locations of all the crops with a suboptimal drainage height are plotted. 29 locations are critically wet and 6 locations are critically dry. Table 4-1 contains a summary of the mean values for several factors at these locations. For both critically dry and wet locations, water levels are 35-37% in the margin, compared to a global median of 65% (see Figure 2-2). Water levels for the dry locations are typically below margin (42%) and for the wet locations above margin (54%). Therefore, for both critically dry and wet locations, there seems to be a correlation between the margin for water levels and drainage heights. Both types are also affected by seepage effects, 0,54mm/day for dry locations (which is close to the intermediary margin as set in Chapter 3.3) and 1,2mm/day for wet areas.

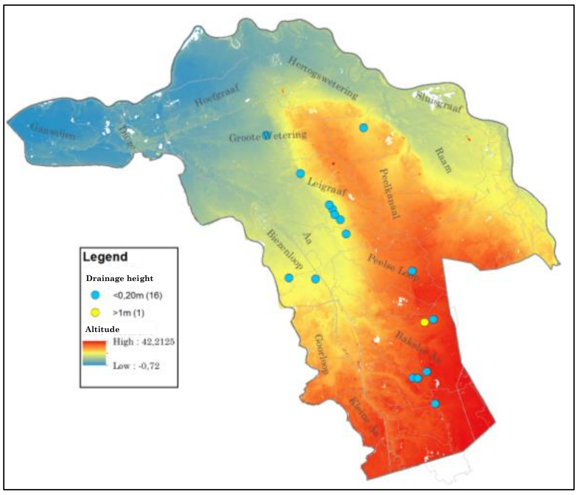


Figure 4-1: Locations of crops with relatively large or small drainage heights

	Crit. dry	Crit. wet
Seepage (mean)	0,54 mm/day	1,2 mm/day
Altitude (mean)	17,5 m +NAP	16,4 m +NAP
% in margin (mean)	37%	35%
% above margin (mean)	5%	54%
% below margin (mean)	42%	7%
% >10cm outside margin (mean)	32%	23%

Table 4-1: Summary results for critically wet and dry locations

For both types, water levels are often more than 10cm outside the margin, 32% for dry and 23% for wet locations; compared to a 6% global median (Figure 2-3). Finally, there seems to be no correlation between altitude and dryness or wetness, since both locations have a mean altitude of roughly 16-17 metres +NAP. Therefore, no general conclusions or clear correlations can be found, apart from the fact that the water levels for these locations generally do not follow the set margin which could be the cause of the high or low moisture content of the soil.

4.2 Cluster study: Boekel area

A cluster of relatively near locations can be found in the *Boekel* area (Figure 4-1). After plotting a *seepage raster* over this area, it turns out that five nearby locations are located in high-seepage spots. This is visualised in Figure 4-2. Unlike the results from Table 4-1, these locations score well on water levels compared to the margin, as can be seen in Table 4-2.

	Value
Seepage (mean)	2,2 mm/day
Altitude (mean)	13,7 m +NAP
% in margin (mean)	86%
% above margin (mean)	0%
% below margin (mean)	14%
% >10cm outside margin (mean)	1%

Table 4-2: Summary of the results for five critically wet locations near Leigraaf

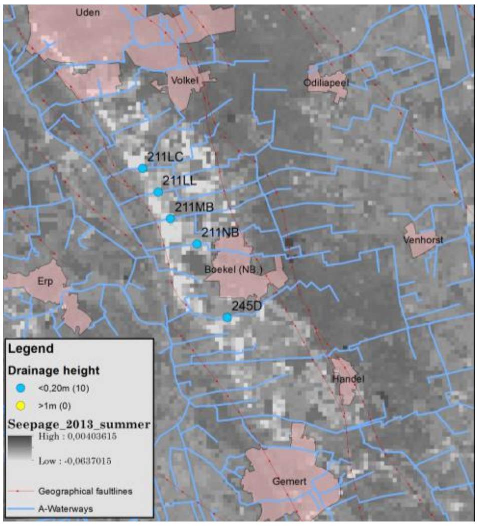


Figure 4-2: Cluster of critically wet locations around Boekel, with a seepage/infiltration raster (black = high seepage value)

The water levels of the weirs corresponding to these CMGL locations, fall 86% of the time in their margin. Yet, they are still critically wet. This could be caused by seepage. From all 900 weir locations, a seepage value of 2,2 mm/day is in the top 20 of highest scores. Seepage can be expressed as a quantity of water flowing through a certain area of soil, per unit time [19]. The corresponding equation for seepage is *Darcy's Law* [19][20].

Darcy's law:

$v = ki = -k * \frac{dh}{ds}$ (1)

In this formula, k is the coefficient of permeability while i is the hydraulic gradient. The gradient is dimensionless and this law assumes a linear dependency between the gradient and discharge velocity (v). These five locations are located on *gooreerd* soil, which hardly contains clay and mostly consist of fine sand. The corresponding k-factor is 0,05-0,001 cm/sec [19].

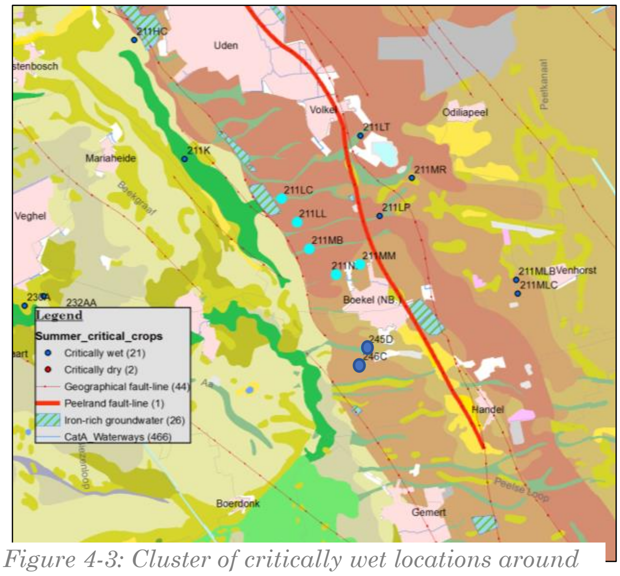


Figure 4-3: Cluster of critically wet locations around Boekel, with an overlay of geomorphological conditions

From the geomorphology of the area (see Figure 4-3), all five CMGL's are located on the west side of a plateau. The direction of the water flow is from east to west (see Figure 4-5 for a large altitude map). All spots are also located close to the *Peelrand* fault-line. The *Peelrand* is a fault-line located between the *Peelhorst* and the western plateau of Brabant, called the *Roerdalslenk*. This is a shear fault-line, the western part (the plateau) slowly sinks while the eastern side slowly rises. By these movements of the planetary crust, tectonic plates and fractures originate. If a tectonic plate is pushed upwards, this is called a *horst*, while a downward pressed plate is called a *slenk*. All five locations are located on an upward *horst* (dark brown in Figure 4-3), which typically have a higher moisture content of the soil [21]. This seems contradictory, higher areas are wet while low areas are dry. However, this is caused by groundwater rising along the fault-lines (seepage). The fault-line itself, as well as the deep soil layers, consist of clay (deposits from the Maas river). Clay has a very low water permeability (k = <0,000001 cm/sec). Therefore, horizontal groundwater flow through the fault-line is difficult. This causes the groundwater to rise up and creates *wijst* areas that have a typical rusty appearance due to the iron in the water that oxidizes when it reaches the surface, see Figure 4-4. This iron is present in deep soil layers underneath the fault and further decreases its water permeability. Based on these findings, it seems likely that seepage along the Peelrand fracture-line is the cause of the small drainage height in these locations. Although the existing margins are closely followed in practice, the locations are still critically wet. Adjustment of the margins may thus be necessary to compensate for this seepage effect.

Figure 4-4: "Rusty" water, due to the high iron content that oxidizes when it reaches the surface [22]

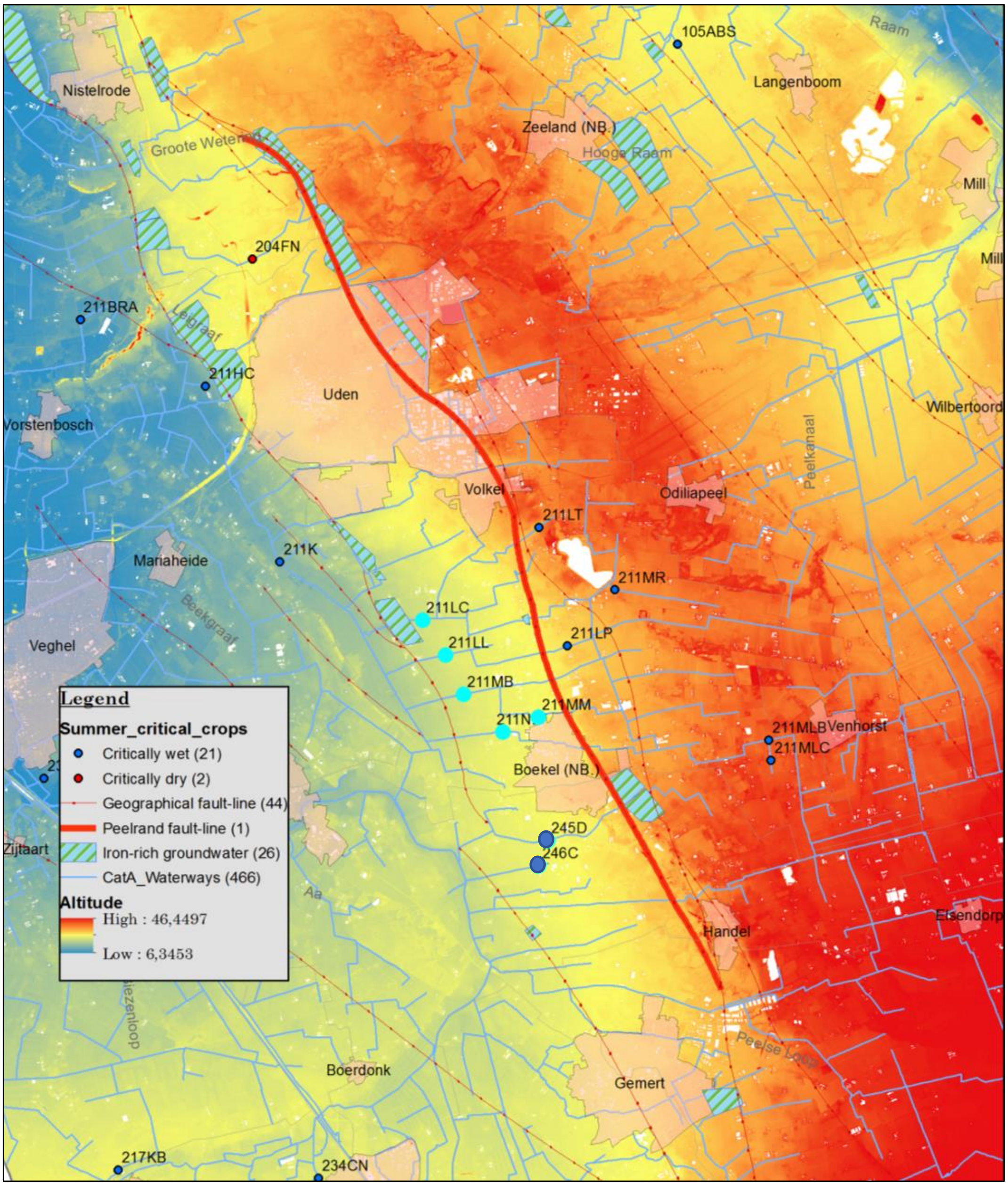


Figure 4-5: Altitude map of the five critically wet locations in summer around Boekel

5 REGIME 2 ANALYSIS

In this chapter, only weirs that fall in the regime-2 category will be analysed. Ws Aa & Maas distinguishes seven different regimes, based on the land-use [9]. Regime-2 areas are a combination of agriculture and ecology. These have conflicting stakes on the water levels, as stated in Chapter 4. Since ecological areas require constant water levels, both in the waterway (for riverbed vegetation) and for groundwater (for forests and other vegetation), this chapter will focus on the differences between winter and summer season.

5.1 Drainage height difference summer-winter

Figure 5-1 shows the locations of all regime 2 weirs with their corresponding drainage height differences as a result from subtracting the summer from the winter values. A positive value means that the drainage height in summer is lower and vice versa. It should be noted that although drainage heights are typically lower in summer, droughts are more of a problem in summer than in winter. As stated in Chapter 3.2, higher evaporation and different groundwater levels are the cause for this.

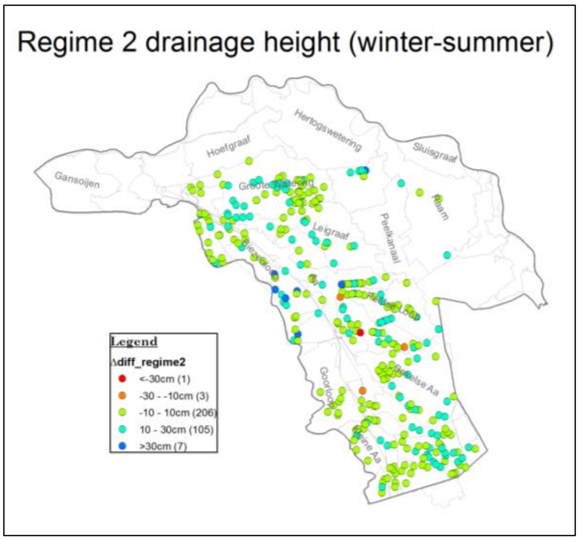


Figure 5-1: Drainage height difference between winter and summer for regime 2 locations

Out of all the 337 regime-2 locations, 44 have complaints. Since there are only 92 locations with complaints in total, this means that approximately 50% of all complaints originate from regime-2 locations. The mean, absolute value of the drainage height difference between winter and summer is 8,9 centimetres. Both critical differences are +44,5cm and -30,6cm. Therefore, the outliers of regime-2 areas are not extreme outliers for the total study area, see Figure 3-2. The possible correlation between complaints and (extreme) outliers will be further analysed in Chapter 6.

Of the seven locations with a >+30cm difference, two have received some complaints. Some comments for these weirs, from the database:

- *"Very wet, that's why floodgate isn't raised"*
- *"During heavy precipitation, water can reach the CMGL"*

It is possible that for these locations, too much water is conserved in winter which causes a high moisture content of the soil in summer. An analysis of the water levels may provide more insight.

5.2 Water level difference summer-winter

Evaluating the water level for the whole area would give similar results as for the drainage height, since the drainage height is the water level plus the CMGL height. For the differences between winter and summer, these results are thus negligible.
Evaluating the water levels compared to the margin, leads to similar results as the global average from Figure 2-2 and Figure 2-3. These results can be found in the table below:

	Summer (mean, %)	Winter (mean, %)
% in margin	65,6	65,8
% above margin	17,7	15,2
% below margin	13,5	20,0
% >10cm outside margin	10,1	12,8

Table 5-1: Mean values for summer and winter regime-2 locations, based on water levels compared to the margin

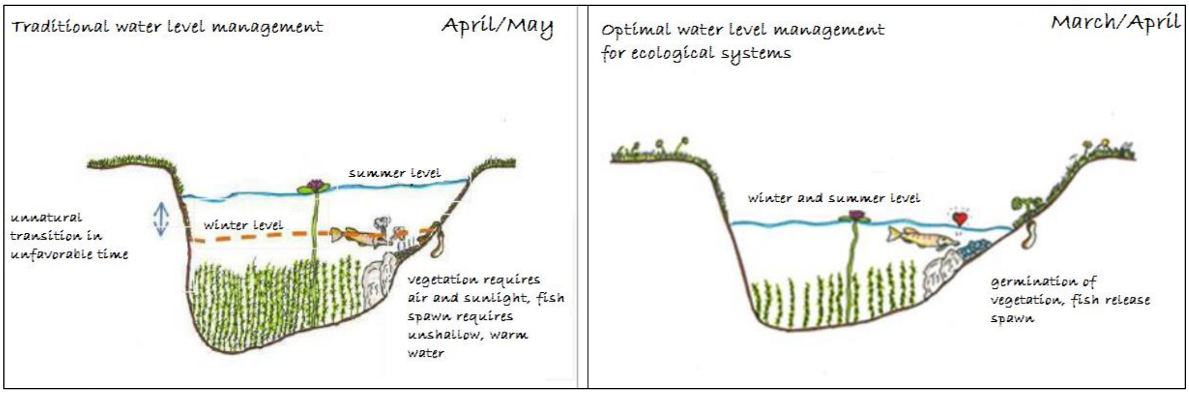


Figure 5-2: Traditional vs optimal water level management and its effects on ecological systems [9]

In Figure 5-2, the effects of traditional versus optimal water level management on ecological systems is shown. If the summer water level is (much) higher than that in winter, then insufficient sunlight and air reaches the vegetation and the water level will be too high for the fish eggs. As mentioned in the introduction (Chapter 1), Ws Aa & Maas has several ecological standards to uphold to as described in the Water Framework Directive, WFD [10]. The current more traditional water level management is one of the reasons why the WFD standards are not met [9].

Therefore, all locations with a higher summer water level are potentially harmful to ecology. According to Figure 5-1, 112 locations have a water level in summer that is at least 10 centimetres higher than in winter. Since the CMGL height does not change, a smaller drainage height in summer equals a higher water level of the waterway. Figure 5-3 is essentially the same as Figure 5-1, but now more intervals and a different colour scheme are used.

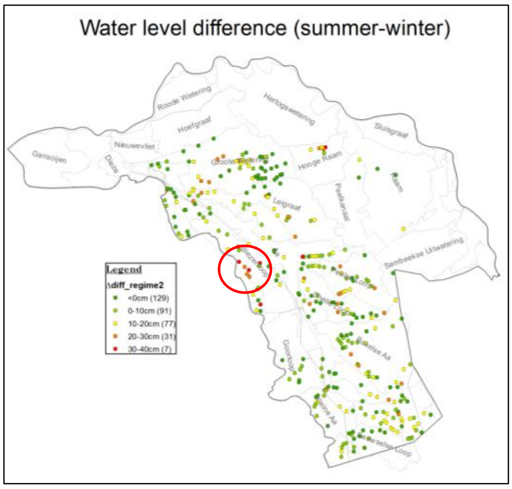


Figure 5-3: Water level difference between winter and summer for regime 2 locations

A cluster of five weirs with a difference of >20cm can be seen in Figure 5-5 and is encircled in Figure 5-3. No correlations could be found between the high water level difference and any other factor. The floodgate fluctuations for these weirs were individually analysed, the graph for weir 217-J can be seen in Figure 5-4. The graph has a comment on April 4th, 2014: "*New margin needed*". The dive of the graph in December 2014 is only temporarily (due to dredging) and no new margin or floodgate height has been incorporated since 2014. It seems that for these five weirs – and possibly other weirs with a higher summer water level as well – a new margin is needed with lower floodgate heights and thus water levels in (early) summer.

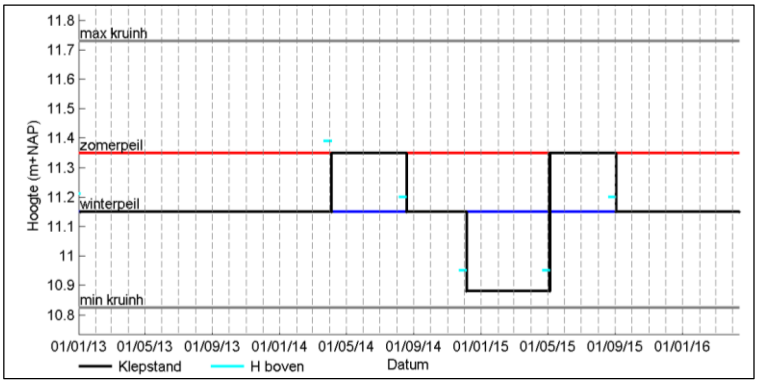


Figure 5-4: Floodgate fluctuations of weir 217-J

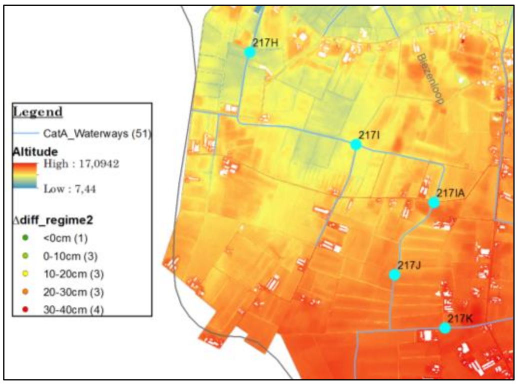


Figure 5-5: Cluster of five weirs with large water level difference (winter-summer)

6 COMPLAINTS ANALYSIS

Of the 900+ weirs that are analysed in this study, 92 received complaints in the period of January 2013-2016. Typically, a complaint means that a farmer who is facing some kind of problem calls the local weir operator. Since the cause for making the complaint and the urgency of the complaint differs for each weir, the information of the complaint is added as a non-uniform text field in the administration of Ws Aa & Maas (the ArcGIS weir database). Therefore, to make further analysis possible, this qualitative data has to be quantified first. For this, two categories are distinguished in this chapter: “some complaints” and “many complaints”. The allocation of the complaints to these categories was done subjectively. One or “a few” phone calls are included in the first category, while frequent complaints are assigned to the second one. With this simple quantification, it is now possible to conduct a further analysis of the complaints.

First of all, the locations of the complaints can be identified. This map can be seen in Appendix H. Secondly, the complaints can be compared to previously obtained results from this research to see if the data shows that there is in fact an actual problem; and thus a valid reason to complain. Consequently, possible causes for complaints can be identified which can be used for future prevention.

6.1 Comparison to totals

The box plot in Figure 6-1 shows a comparison between locations where complaints were made (blue and red) and a total of all locations (cyan and yellow). The y-axis is the difference between the actual and the optimum drainage height while the box plot represents the frequency per interval.

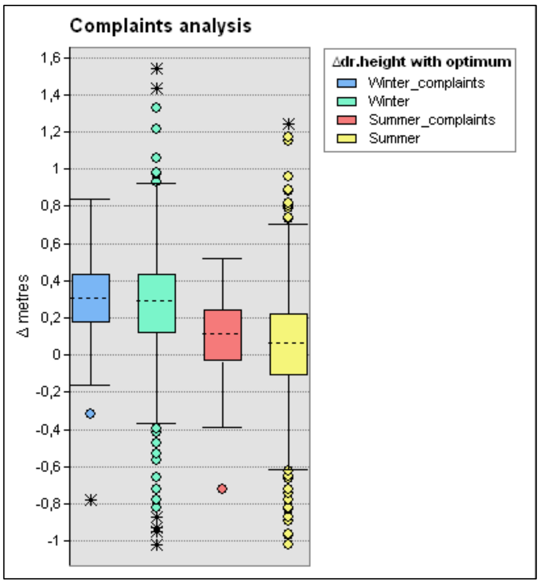
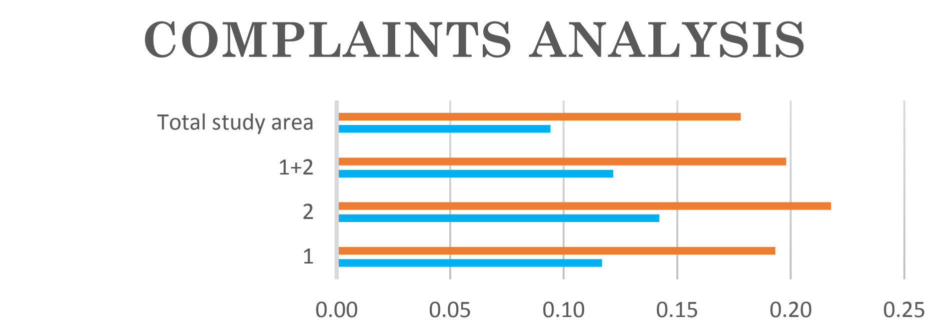


Figure 6-1: Box plot of the complaints compared with all the weirs, showing the difference between optimum and actual drainage height

Based on the figure, the drainage height for locations with complaints does not seem to be any more suboptimal than for the total study area. There are less outliers but this is expected since there is less data as well. The median value and 2nd and 3rd quartile (50% of the data, around the median) are largely comparable to the total situation. Ergo, there seems to be no correlation between suboptimal drainage heights and complaints.

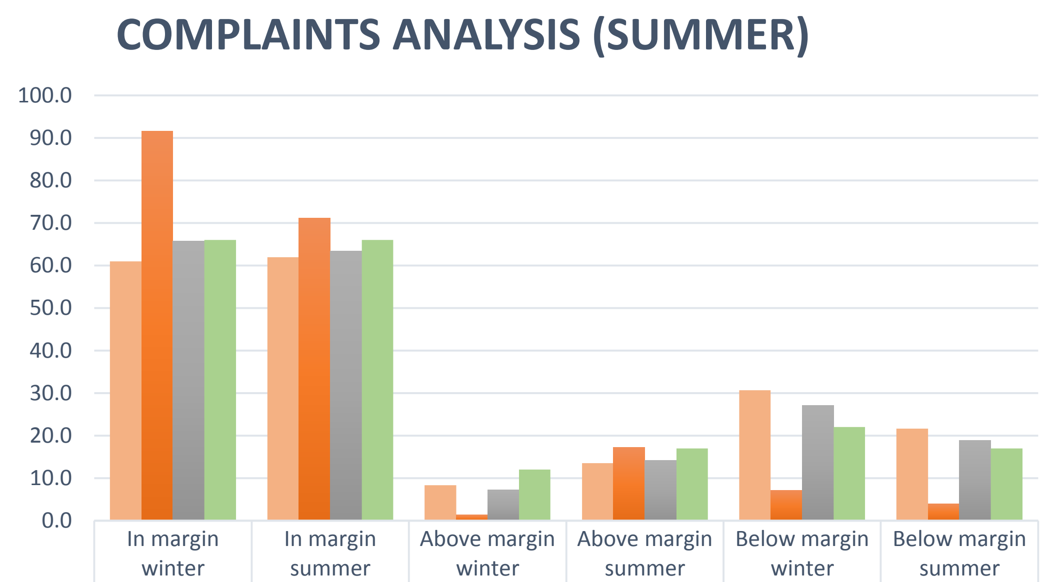
From the plotted figure with complaint locations (Appendix H), it seems that complaints are mostly clustered in the areas *Leigraaf* and *Groote Wetering* and are located mostly in downstream locations (altitude <15 metres). Figure 6-2Table 3-1 shows a comparison between the weirs that received complaints and all the weirs in the study area. These weirs have been tested for the drainage height compared to the optimum (as shown in Figure 6-1), as well as the water level difference between summer and winter. On both factors, the locations with complaints have almost the same results as the total of all the weirs.

The water levels compared to the margins have also been tested for locations that received complaints as well as all the weirs. The results are listed in Figure 6-3. In this case, larger differences can be seen. On average, locations with complaints follow the policy margins more closely in both winter and summer. In both summer and winter, complaints locations are 10% more often in margin. For locations with many complaints, this is 15% (in summer) to 40% (in winter). However, it should be noted that most complaints are from farmers and therefore more applicable to summer. Winter values should be given less value.



	1	2	1+2	Total study area
Δdrainage height summer to optimum	0.19	0.22	0.20	0.18
Waterlevel summer-winter	0.12	0.14	0.12	0.09

Figure 6-2: Complaints analysis, mean values in metres



	In margin winter	In margin summer	Above margin winter	Above margin summer	Below margin winter	Below margin summer
1	61.0	62.0	8.3	13.5	30.7	21.7
2	91.6	71.1	1.3	17.2	7.1	4.0
1+2	65.7	63.4	7.2	14.1	27.1	18.9
Total study area	66.0	66.0	12.0	17.0	22.0	17.0

Figure 6-3: Complaints analysis, mean values in %, "1" and "2" represent locations with a few and many complaints respectively, "total study area" is the mean value for all the 700 weirs

6.2 Cause for complaints

Based on the previous figures and tables, there seems to be no clear correlation between complaints and the policy margins or drainage heights. The information on the complaints itself is written as non-uniform data so quantitative analysis of the exact cause is difficult. Especially since the information is often insufficient in detail, *"receives a lot of phone calls"* does not include the reason for calling. From observation, it seems that many complaints are these so-called phone calls where a local resident or farmer calls the weir operator to request a change in the water level (e.g.: to sow/fertilize his fields). It seems counterintuitive then that the complaints locations so closely follow the policy margins. Either the request from the person who makes the complaint is not granted or the margins might need adjustment.

One other factor to consider as a possible cause is the drainage height itself. Although the difference between the drainage height and the optimum did not give a clear result, the drainage heights on average could still be lower. A box plot with this analysis is plotted in Figure 6-4. Based on the figure, it can be concluded that locations with complaints indeed have lower drainage heights (and thus higher water levels). The mean values are listed in Table 6-1.

	Drainage height (metres)
2 (many complaints)	0,36
1+2 (all complaints)	0,45
Mean of all weirs	0,48

Table 6-1: Mean value in metres, complaints analysis

It seems that a causal relation exists between a smaller drainage height – which means a higher water level – and complaints. This fits with the nature of many complaints, namely that the soil is too wet and machines can get stuck.

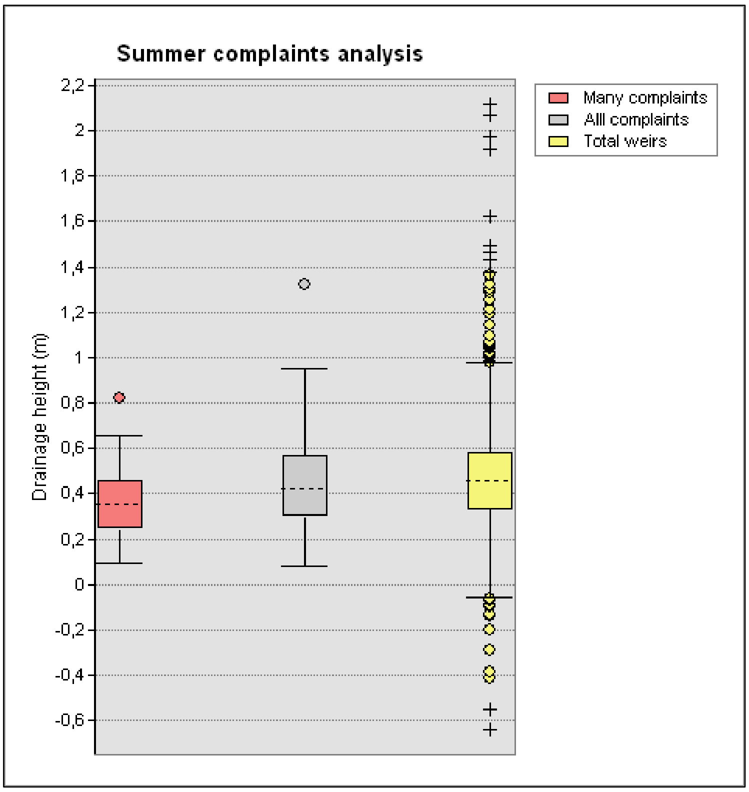


Figure 6-4: Box plot of the locations with many complaints (red), all locations with complaints (grey) and all the weirs in the study area (yellow); comparison of drainage heights

In order to prevent future complaints, not only should the margins for these 92 complaint locations be analysed, but it is also useful to define where most complaints are coming from. In Chapter 5.1, 50% of the complaints occurred in regime-2 areas. *Leigraaf* and *Groote Wetering* are the two regions with the most complaints. The top five of regions with most complaints can be seen in Table 6-2.

	2 (many complaints)	1+ 2 (total complaints)
Leigraaf	10	31
Groote Wetering	5	12
Aa	0	9
Snelle Loop	0	8
Astense Aa	0	5
Total for entire study region	18	92

Table 6-2: Top five of regions with the most complaints

Of the 92 total complaints, 8 are located on unspecified land, 26 are grass fields, 40 contain corn and 18 are other crop types. No matching factor based on geomorphological conditions, altitude or soil composition could be found. Finally, the most common floodgate position is unknown for 8 of the locations, upper limit for 16, more than 10 centimetres outside margin for 4, lower limit for 12 and optimum level for 52. Despite the complaints, this means that 52 out of 92 locations generally have its floodgate height set to the optimum (centre) level of the margin. This could mean that the margins need to be altered, if the goal is to adhere to the cause of the complaint.

7 Score quantification

Since the aim of this thesis is to gain an overview of the water level management, as an extra part of this research an attempt will be made to quantify the management in practice. This will be done by assigning scores to regions based on a certain parameter and corresponding limit. This score system can be used for any parameter and minimum “acceptable” limit; as long as it is a series of data. It is based on the following formula:

$$Score = \frac{100 - \frac{\left(\frac{100 * \sum|\Delta dr.|}{n}\right)}{\Delta dr_{max}}}{10} = \frac{100 - \frac{\left(\frac{100 * \sum|dataset|}{n}\right)}{factor}}{10} \quad (2)$$

With:
n: amount of entries in the dataset
$\Delta dr.$ or $dataset$: each entry of the dataset, for example the drainage height difference between summer and winter
Δdr_{max} or $factor$: either the maximum value of the dataset or a custom chosen maximum factor to compare the dataset to

This formula is a linear approach to give the region a score, based on mean values. By using a virtual scale from 0 (0%) to Δdr_{max} (100%), a score is assigned on a scale of 0-10. This is done by comparing the mean of a data set ($\sum|\Delta dr.|$) to this factor. For example, the drainage height difference between winter and summer can be assessed. Δdr_{max}, the maximum difference, is then 83 centimetres. However, using this as the factor leads to generally high scores since all regions perform well compared to this limit. See Figure 11-13 in Appendix I. Choosing a lower limiting factor results in generally lower scores, see Figure 11-14 in Appendix I for a factor of 40 centimetres. Figure 7-1 shows the performance of each region compared to a maximum acceptable Δdr of 30 centimetres. The more locations in a region that score close to this value, the lower the score. If a location surpasses the limit, this could theoretically lead to a negative score unless this is compensated by other locations.

The scores themselves should not be interpreted in a literal way. As these three figures show, the scores are highly dependent on the chosen factor. This method is a way to compare regions and identify problems, it should not be used to actually assign value to the resulting scores. The formula also does not account for the amount of weirs. Some regions contain 100+ weirs while others contain only 10, which makes for an inaccurate comparison. Nevertheless, this method can be used for a more quantitative approach to identify problems on a large scale. Instead of drainage heights, it can also be used to grade water levels, adherence to the policy margins, amount of complaints et cetera. The formula can also be used multiple times to get one score based on multiple factors. This has been done for the drainage height compared to the optimum level for both winter and summer, as well as the drainage height difference between winter and summer (as in Figure 7-1). As limiting factors, 80 centimetres was chosen for the first two scores and 40 centimetres for the winter-summer difference (which is similar to Figure 11-14). This leads to three scores per region, the resulting mean values can be seen in Figure 11-15. For this score analysis, only regions with at least 10 weirs were included.

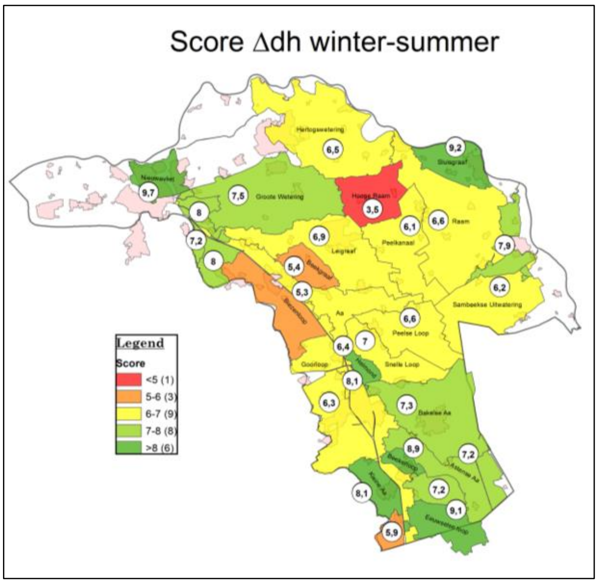


Figure 7-1: Scores per region based on drainage height difference between winter and summer and a limiting factor of 30 centimetres

To conclude, while this formula and score method could use further improvements, it has the potential to be a quick evaluation tool to assess the performance of regions compared for a certain factor.

8 DISCUSSION

In this chapter, first the data will be discussed and then the final results as presented in Chapter 2-7. This discussion chapter is meant as a critical reflection that precedes the conclusion (Chapter 9) and future recommendations (Chapter 10).

8.1 Discussion of the data

In the previous chapters, the water level management has been critically assessed from multiple point-of-views. Each analysis started from the same input: the database as provided by Ws Aa & Maas with water levels and other data for 900+ weirs in winter and summer. Since this input is critical to every part of the analysis, it is important to consider the reliability and robustness of it.

The initial process of this research, as described in Appendix B, was focused on completing and evaluating this weir database. During this process, certain fixes to the database were necessary. The following observations were made:

- Human errors were present in the database, such as typos or height values without the +NAP correction
- The database was incomplete since regions around *Raam* weren't finalized, see also Chapter 2.2.
- Automatic weirs had to be added to the database manually; since this was done by hand only water levels and drainage heights could be added but not the margin distributions
- Extreme outliers had to be removed, such as water levels of 999 metres. These could be human errors as well.

Most errors were either fixed by hand or removed from the database. No truly extreme outliers (such as the 999m water level) are left so mean values should not be too affected. Nevertheless, the fact that different types of errors existed, shows the potential that some have been missed. One possible cause for these problems is that the database was mostly constructed manually by Ws Aa & Maas. Floodgate heights are derived from a smartphone application that each weir operator updates whenever he adjusts the floodgate. The error where no correction for +NAP was made, shows that there is potential for human errors here. Although due to the filtering of extreme values, the effect on mean values should be minimal, this brings the validity of the database into question.

The database is also hindered by its lack of quantitative data. A lot of information, such as complaints or a description of the weirs, is only available as qualitative (text) data. This information is often non-uniform, there is no consistency between similar descriptions. For instance, for one weir the description reads "receives a lot of calls" while another says "quite a few complaints". This is a deliberate design choice by Ws Aa & Maas. Each weir has its own characteristics, problems and effects. Optimal management is always a local process and quantitative data could lead to simplifications or abstractions. On the other hand, for research like in this thesis or a more large-scale analysis, quantitative data could be added separately and still provide a use. In this research process, an attempt has been made to turn the complaints into quantitative data, by assigning it one of three values (0 = no complaints, 1 = some complaints, 2 = many complaints). The same could be done with, for example, information on whether a weir is a threshold or not.

8.2 Discussion of the results

Apart from the reliability of the database, the results and conclusions should also be critically assessed. As previously mentioned, weir management is often a local process. Conclusions on a large-scale go beyond this principle which reduces their validity. This is mostly evident in catering to different stakeholders. The water level management is such an intricate balance that it seems impossible to get one optimal outcome. This is partly the reason why Ws Aa & Maas introduced margins for the weirs, so a certain degree of freedom is possible in altering the water levels. Water levels can be adjusted based on land-use (such as intensive crop farming), or to meet the standards from the Water Framework Directive [10] or somewhere in between. Subsequently, being forced to limit the water level management to one or two factors also affects the results from this research. For example, Ws Aa & Maas mostly bases their management on ecology and water supply [9]. Because of this, no correlation could be found between land-use and drainage heights (Chapter 3.2).

A complication is the fact that the current strategy of Ws Aa & Maas is not entirely clear. Although the policy nota details a current and desired future strategy (see Figure 2-5), this does not seem to match with the water level fluctuations that result from the analysis (Chapter 2.3). This is also evident from the fluctuations of the drainage heights between winter and summer (Chapter 3.1). A possible explanation could be the fact that the policy document was only published one year ago [9]. Since this research provides an analysis of the time period of January 2013-2016, it is possible that the policy note only starts to take effect in the last year. Future research is necessary here, this will be expanded on in Chapter 10.

Another problem with the results is the discrepancy between different sets of data, such as regions. In Chapter 2.2 and Chapter 7, the different regions in the study area are compared. First the water levels according to the margins are compared and then a score is given to each region based on its performance with respect to a pre-defined factor. However, the amount of weirs differs per region and this can range from 10 weirs up to more than one hundred. This is especially evident in Figure 2-4 where certain regions have very different distribution results of the water levels. From a statistical point-of-view, a limited amount of data is undesirable because it causes the data to be less representative for a larger population. However, for this research, these exceptional cases can be useful information. Weir operation is conducted per region, so the analysis should be treated similarly. Moreover, if a cluster of weirs has “extreme” results, then this warrants further, more detailed analysis. Finding exceptional cases can be a goal of the analysis too, instead of just providing a global average. In this thesis, this led to results such as Chapter 4.2 where a specific cluster is the focus of the study.

Finally, a point of discussion is the lack of any validation methods for the results of this thesis. Since the policy nota does not contain any quantitative guidelines and only a general desired strategy, the resulting water levels, adherence to margins and drainage heights from this research could not be compared to any exterior source. A comparison to the management of other water boards in the Netherlands is also inefficient, due to the unique characteristics of the study area and its geographical position. For example, the clay- and peat-layers in the soil, as well as the unique *Peelrandbreuk* and characteristics of the Maas (whose discharge is mostly affected by precipitation), all hinder a comparison to other locations in- or outside the Netherlands. Therefore, it is questionable to what extent the performance of the water level management on different factors can be critically evaluated or assessed. For this aspect, the final conclusions and recommendations should adhere mostly to the research aim. The goal should be to provide an overview of the management in practice, instead of attempting to actually judge its performance.

9 CONCLUSIONS

This chapter lists the conclusions in chronological order of each research question, one paragraph each. The sixth paragraph is a final conclusion.

The water levels for all the weirs in the study area follow the policy margin 66% of the time in winter and summer (mean values, Figure 2-2). Figure 2-3 shows that although the water level falls outside the margin 34% of the time, the offshoot is usually less than 10 centimetres. Water levels in summer are on average 6,6 centimetres higher than in winter. 115 weirs (out of 900+) have a water level in summer that is at least 20 centimetres higher than in winter and for 315 weirs the water level is at least 10 centimetres higher. This does not seem to correspond with the “current strategy” that Ws Aa & Maas describes in the policy note (Figure 2-5); although the value of 6,6cm could not be validated for this research (see Chapter 8).

Apart from water levels, drainage heights were also analysed. For the entire study area, no clear correlation was found between seepage/infiltration and drainage heights (Figure 3-4). However, in the case study of the *Boekel* area (Figure 4-2), seepage occurs due to the nearby *Peelrand* fault-line yet these locations are still critically wet and the water levels follow the margins closely (86% of the time). Thus, for the entire region seepage does not seem to affect the drainage heights but on a smaller scale, like the Boekel area, it does. As for infiltration, one of the strategies by WA&M is to conduct maximum conservation in areas with high infiltration [9], yet the results seem to contradict this (Figure 3-4). Finally, no clear correlation was found based on land-use (Figure 3-3) which corresponds with the fact that WA&M does not adapt their water management to this [9][23].

The land-use was analysed in more detail for the third research question where all the intensive crops (corn) were evaluated. Part of these results were already discussed in the previous paragraph (Boekel area). Apart from this cluster, 12 other locations were found with a drainage height of less than 20 centimetres (11) or more than 100 centimetres (1). For the 16 locations <20cm, the mean water level is in the margin 47% of the time and above the margin 45% of the time. For the Boekel area the water level is in the margin 86% of the time so the other 11 locations significantly reduce the total mean value.

Apart from intensive crops, all locations in a *regime-2* area were analysed as well. 112 of these have a water level that is at least 10 centimetres higher in summer compared to winter. A relatively large fluctuation in the water level between winter and summer is harmful to ecological zones such as riverbed vegetation (Figure 5-2). It seems apparent that this is one of the reasons why the WFD-standards are not met [9][10]. Closer inspection of some of these 112 weirs revealed that new policy margins, especially for summer, may be needed. It should be noted though that regime-2 areas have multiple conflicting stakes and catering purely to the ecological aspect could lead to complaints from the agricultural sector.

Finally, a complaints analysis was conducted. This analysis showed that locations with complaints have a slightly larger fluctuation between the summer and winter water levels. For locations with many complaints (category 2, red in Figure 6-3) the water level frequently falls inside the margin (92%), compared to the global study area (66%). The locations of the complaints have also been determined, although individual analysis is something to be conducted by WA&M.

To conclude, an overview has been acquired of the water level management by WA&M in the period of 2013-2016. The strategy in 2013-2016 seems more similar to the “past strategy”, rather than the current or desired future one (Figure 2-5), although this could be caused by the policy note only being published one year ago [9]. Although the water levels are typically inside the margin (66%), for 50 of the 93 complaints and the cluster of weirs in Chapter 5.2, it seems that these margins still lead to problems. However, the management of each weir is an intricate balance between local stakes and interests, which makes both margins and water levels highly situational. Therefore, it is impossible to judge or validate these results. Nevertheless, this thesis could potentially aid to identify problems. Based on this, WA&M could start a local process to find an optimal solution for the margins that fits with their desired strategy and a stakeholder analysis.

10 Future recommendations

The database that was constructed and modified for this thesis, will be submitted to Ws Aa & Maas for further use. In this way, the shape-files and modifications that were used for the analysis in this report, can be used in the future by Ws Aa & Maas. Apart from that, there are several other recommendations, some of them for future research.

In the initial proposal stage of this research, there were plans to also analyse water discharges in the area. Ultimately, this was dropped and given to an employee of Ws Aa & Maas, since it would take too much time. This project is expected to be completed at the end of 2016. It could be combined with the results from this thesis to provide a more in-depth analysis of the conservation strategy. With the discharge analysis, it is possible to check how much water is discharged to which areas and how much water conservation is lost in early summer by catering to the interests of local stakeholders. This could then be linked to the complaints and crop analysis from this thesis.

Furthermore, the analysis in this thesis could be expanded now that the database is completed. These extra 100-200 weirs could lead to new observations and possible clusters of areas at risk. A few years from now, the time period of this research could also be extended. By analysing data from 2015-2018 instead of 2013-2016, the effects of the policy document should be more notable. Apart from this extension, the time period could also be more *focused*. Now, only whole seasons are compared to each other, but the results per month could lead to interesting results. How do the water levels fluctuate from February to June? When does the sowing and fertilization start? How does this compare to downstream discharges?

Another possible addition to the analysis could be done by including phreatic surfaces. Now, only the drainage height was analysed which isn't the most convenient method for identifying dry or wet areas. This is evident from the fact that drainage heights in winter are bigger than in summer, even though summer suffers more from droughts. The actual dryness or wetness of the soil depends on the phreatic surface and by combining this with the drainage height data; the reliability and robustness of the final results could improve.

Finally, as mentioned in Chapter 8, more data from the database could be quantified to allow for a more efficient analysis. In this report, this has already been done for complaints but this is also possible for many other factors. For instance, some weirs have qualitative descriptions like "hasn't been used for a few years" or "static threshold". It could potentially be useful to quantify this data so it can be plotted easily on a map for further evaluation. In line with this, a scoring system similar to the one proposed in Chapter 7 could be used as a quick assessment tool to evaluate the performance of a region in comparison to a certain factor. This could be beneficial to the development of long-term strategies.

REFERENCES

[1] H. Savenije, P. Zaag (2008). “Integrated water resources management: Concepts and issues”, Physics and Chemistry of the Earth, Vol. 33, pp.290-297
[2] De Wit, M., "Van regen tot Maas – Grensoverschrijdend waterbeheer in droge en natte tijden", Diemen, 2008
[3] Linsley, K., Franzini, J., Freyberg, D. & Tchobanoglous, G., "Water-resources engineering", Fourth Edition, 1992, printed in Singapore, ISBN 0-07-112689-9
[4] Oomen, E. & Schaafsma, R., Waterschap Aa en Maas, "Waterbeheerplan 2016-2021", oktober 2015, 's Hertogenbosch
[5] Hurk, B., Tank, A., Lenderink, G., Van Ulden, A., Van Oldenborgh, G., Katsman, C., Van den Brink, H., Keller, F., Bessembinder, J., Burgers, G., Komen, G., Hazeleger, W., Drijfhout, S., "KNMI Climate Change Scenarios 2006 for the Netherlands", KNMI Scientific Report WR 2006-01, published on 30 May 2006, De Bilt
[6] Franken, R., Van Minnen, J., Ligtvoet, W., "The effects of Climate Change in the Netherlands: 2012", The Hague, 2013
[7] Van Beek, E., Haasnoot, M., Meijer, K., Delsman, J., Snepvangers, J., Baarse, G., Van Ek, R., Prinsen, G., Kwadijk, J., Van Zetten, J., "Verkenning kosteneffectiviteit van grootschalige maatregelen tegen droogteschade als gevolg van de G+ en W+ klimaatscenario's", 2008, Deltaresrapport T2498, Delft
[8] Klijn F., Kwadijk, J., De Buijn, K., Hunink, J., "Overstromingsrisico's en droogterisico's in een verandered klimaat", Deltares rapport 1002565, Delft, 2010
[9] Ws Aa & Maas, “Nota peilbeheer in vrij afwaterende gebieden”, June 5th 2015, ’s Hertogenbosch
[10] European Parliament, “Water Framework Directive 2000/60/EC”, Official Journal of the European Communities, December 22nd, 2000
[11] Rijksoverheid, “Nationaal Bestuursakkoord Water”, http://www.helpdeskwater.nl/?ActItmIdt=1280, 2003
[12] Overheid, “Natuurbeschermingswet”, http://wetten.overheid.nl/BWBR0009641/2016-04-14, 25 mei 1998
[13] Overheid, “Flora en faunawet”, http://wetten.overheid.nl/BWBR0009640/2016-04-14, 25 mei 1998
[14] Ws Aa & Maas, “Aa en Maas in cijfers”, http://www.aaenmaas.nl/pagina/over-aa-en-maas/aa-en-maas-in-cijfers.html, Juni 2016
[15] Rijkswaterstaat, “Normaal Amsterdams Peil”, https://www.rijkswaterstaat.nl/zakelijk/open-data/normaal-amsterdams-peil, consulted on June 5th 2016
[16] Ws Aa & Maas, “Waterschap Aa en Maas stelt nieuw peilbeheer vast”, http://www.aaenmaas.nl/nieuws/2015/06/waterschap-stelt-nieuw-peilbeheer-vast.html, consulted on June 5th 2016
[17] F. van Dreven, R. van der Gugten, F. de Jong, R. van Lammeren, J. Loedeman, G. Mostert, R. Naudin-Ten Cate, M. Nooren, H. Siemes, R. van der Velden, M. Vergouwen (2000). “Cultuurtechnisch vademecum: handboek voor inrichting en beheer van het landelijk gebied”, Doetinchem: Elsevier bedrijfsinformatie bv, ISBN: 90-5439-089-1 [18] T. Smit, “Memo t.b.v. GGOR Pilot Landhorst op Peil – Uitgangspunten peilbeheer”, e-mail, 20 Feb 2013, via Ws Aa & Maas
[19] M. Harr, “Groundwater and Seepage”, Purdue University, Dover Publications, New York, 1991
[20] Fox, R., McDonald, A., Pritchard, P., “Fluid Mechanics Eigth Edition”, John Wiley & Sons, 2012
[21] Van Balen, R., “Aardkundig excursiepunt 28”, Vrije Universiteit Amsterdam, Grondboor & Hamer nr 6., 2009
[22] Peelrandbreuk, http://www.aardkundigewaarden.nl/aardkundigemonumenten/detailpagina.php?tuin_ID=340, consulted on: June 12th 2016
[23] C. van Rens, Waterschap Aa & Maas, internship supervisor, personal communication
[24] Box plot graphs, http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Box_plot_graphs, consulted on: June 2016

Appendices

This chapter lists all the appendices. References to the appendices are found in the main report.

Appendix A: Study area (map)

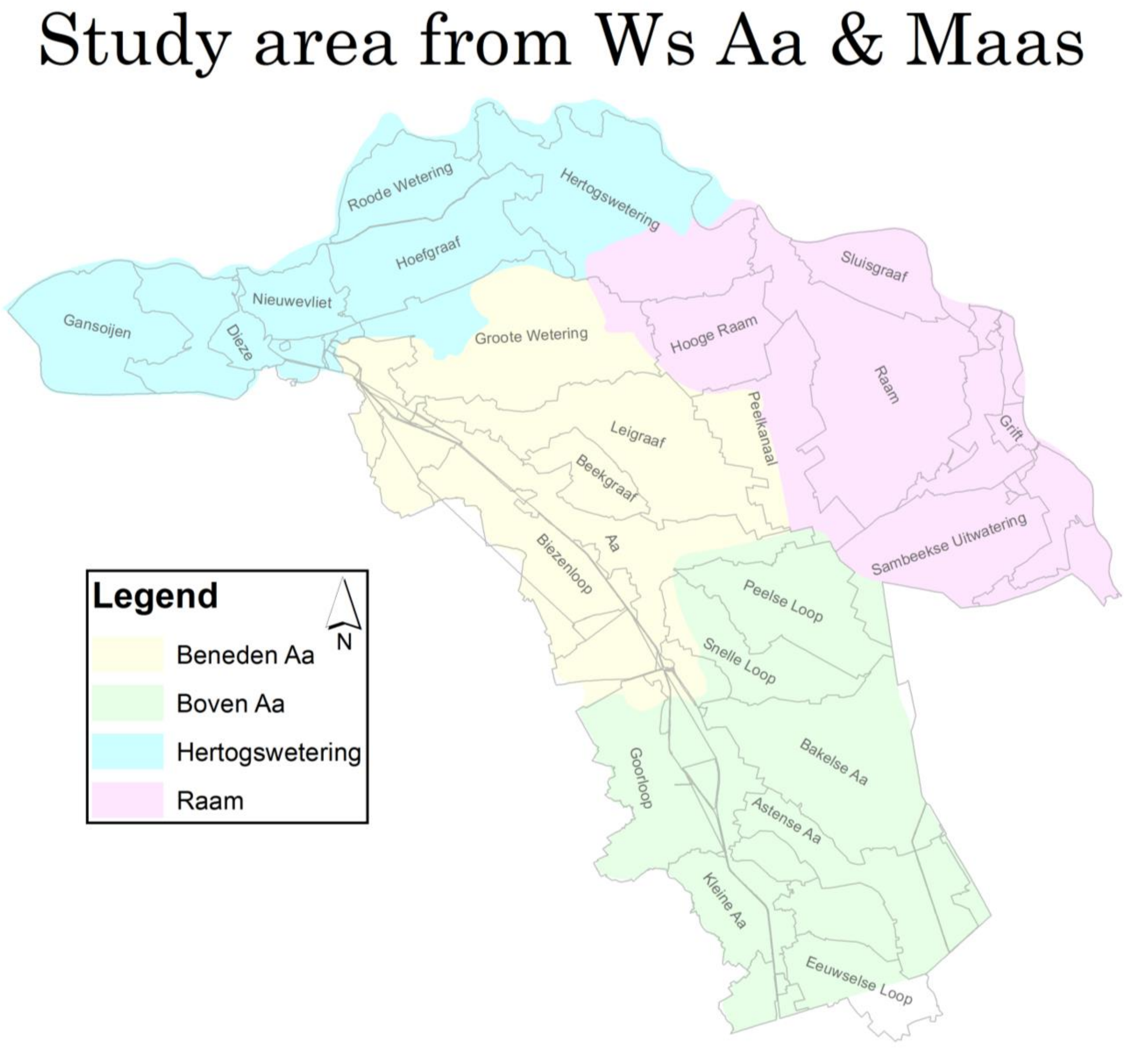


Figure 0-1: Study area of Ws Aa & Maas, with all the regions and the four main districts (colours)

Study area with the names of all the regions. The city of ‘s-Hertogenbosch is located around the *Nieuwevliet* region (upper left corner). The colours indicate the four districts that Ws Aa & Maas uses as a division for their water management.

Appendix B: Database construction & modifications

At the start of this research, four shape files were available as the outcome of the tool, provided by Ws Aa & Maas. Two files consisted of *point data* with a point location for each of the 900+ weirs, for both the hydrological winter and summer (hence the two files). The other two files were *regional data* where the same data (from the point data files) was already summarized with mean values for each region (see Appendix A for the regions). Both the point data and regional data consists of seven values (%) for the water levels compared to the policy margins. For example, a value of 40% for "in margin" means that 40% of the time (2013-2016) this weir or this region has a water level that fits within the policy margin.

Since the regional files are already mean values of a large set of data, they cannot be modified to eliminate individual errors or extreme outliers. Therefore, the regional files were only used for a quick assessment of the water levels compared to the margin but the rest of this research and thesis report is only based on the point data. This point data file was combined with several other files available from the Ws Aa & Maas database (useable for all employees who conduct an ArcGIS analysis). This process is summarized below:

1. Each point data for a weir is joined with its adjacent *critical minimum ground level (CMGL)*. This is a single location in a nearby field where the ground level is at a critical minimum. This spot is useful for further analysis of the moisture content of the soil.
2. Using the coordinates of this CMGL (not the weir!), other factors can be assigned to each weir. For example: land use (what kind of crops are located on the CMGL?), seepage/infiltration values (in mm/day), geomorphological characteristics et cetera. Sometimes a choice had to be made to select this data (for example, seepage values were available from 2010-2013 and one exemplary year was chosen).
3. The resulting database now contains data for 900 weirs with its adjacent CMGL and corresponding characteristics. As a final step, this database needs to be critically evaluated to remove unreliable data and potential human errors, to increase its reliability.

In the paragraphs below, the several data sets that are linked to each weir (based on the CMGL coordinates) are discussed.

<u>Seepage values</u>

For the seepage value, maps for four periods are available: 2010, 2011, 2012 and 2013. Each period, excluding 2013, includes both a summer and winter map. Since the weir database spans the period of 2013-2016, a proper year needs to be selected to ensure an accurate comparison. The meteorological data of all four years, measured in Volkel, can be seen in Figure 11-2 (on the next page). The y-axis is the cumulative increase in precipitation. A negative value thus means that the evapotranspiration is larger than the precipitation rate. It can be derived from this figure that the winter of 2013 was especially dry while the summer and winter of 2012 were especially wet. Precipitation rates in the future are expected to increase due to climate change [5] and this makes scenarios with similar (or larger) precipitation rates as in 2012 more likely. On the other hand, the goal is to link weir data with possible factors that explain the data. Choosing extreme values for seepage can lead to subjective bias. Therefore, for seepage values four values will be selected. The summer and winter of 2012 for an extreme scenario and the winter and summer of 2010 for an average scenario.

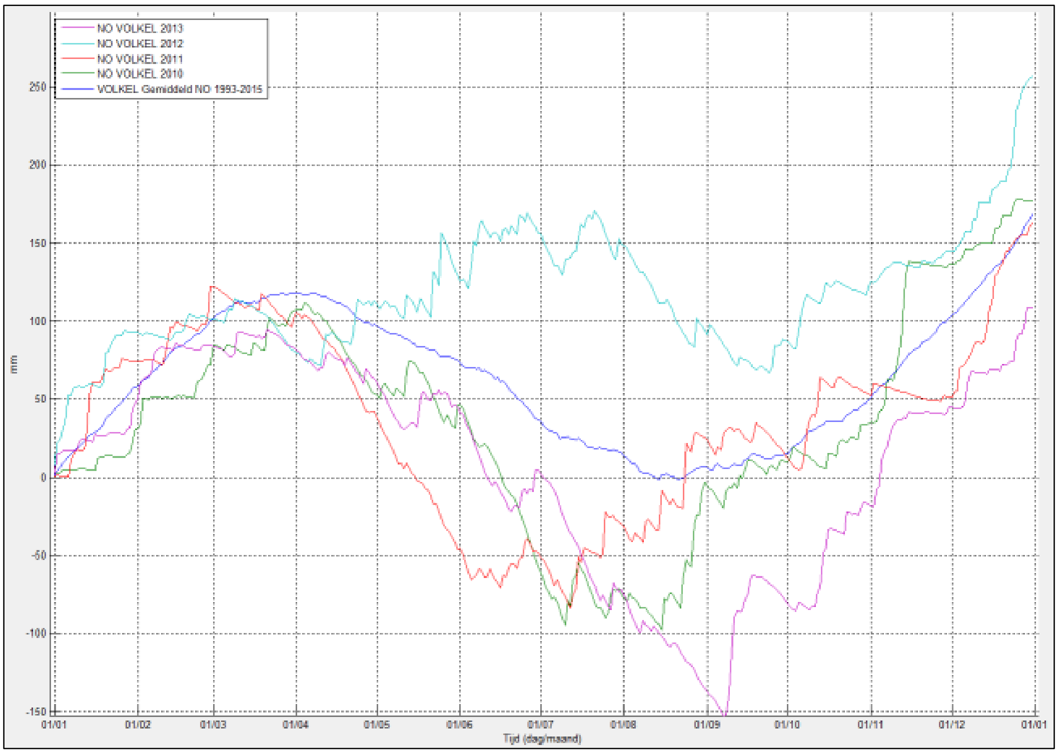


Figure 0-2: Meteorological data for 2010, 2011, 2012 and 2013 in Volkel [23]

Land use
For the land use, the most recent map available in the WA&M database will be used. This map was last updated in April 2014 and includes polygons for the land use in the entire study area at that time, excluding urban areas. The categories of land use were slightly abstracted for this research. For instance, the original map had four subcategories for potatoes, based on the soil (clay, sand). These are now all assigned the category “potatoes”. This leads to seventeen categories in total, including grass, forest and several types of crops. These will be used for the analysis.

Soil composition
For the soil composition, again a map from the WA&M database is used. The year of this version is unknown but since soil composition can hardly be changed by human interference, this should be sufficient. This layer includes data on the groundwater table (GWT) and the soil composition. For the latter, a main category and subcategory are assigned to polygons to distinguish several dozen categories in the study area, such as different types of podzols.

Geomorphological map
In addition to the soil composition map, a geomorphological map will also be used. This map divides the study area into polygons based on their geomorphology. For instance: sand-drift dikes, peat plain and limestone plateaus.

Testing of the tool & database modifications
In this paragraph, a summary is given of how the tool/output was tested and evaluated to make it more reliable. This mostly applies to the two *point shapefiles*, see the introduction of Appendix B.

A straightforward way to test the tool is to look for extreme values for certain weirs and check if these results are caused by the tool. The tool provides data for 1024 weirs (out of 2328 entries in the control register file, which is WA&M’s default database on all weirs). However, since the control register file not only contains weirs but also valves and static thresholds, this difference was anticipated.

After sorting the outputs on water level, several extreme values stand out. Weir 114P17 has a water level of 25233,56 metres and weir 107GHC and 107HEE both have water levels of 999 metres.

What these weirs have in common is an UL and LL of 0 metres. After selecting all entries that share this phenomenon, it turns out that 272 out of 1024 weirs (in summer and winter) all have a value of 0 for these factors. Consequently, the water level and all other values are also 0. However, since these weirs are excluded from the research scope (see Chapter 1.2) and are part of the regions with incomplete data, this is a logical outcome and these weirs can be “safely” removed from the database to prevent these zero-values from influencing the main analysis.

After removing all these weirs, only (approximately) 700-750 weirs were left. *Automatic weirs* were still missing from this data set because these are automatically controlled and are not used by the tool. Therefore, these automatic weirs were added by hand. The water levels compared to the margin (seven values of % in time) are unknown for the automatic weirs since the tool could not run this data (due to the different data output and source because they are automatic). Thus, only the water level itself (in metres +NAP) and the resulting drainage height could be added and these automatic weirs are only used for that part (drainage height and water level analysis) of the main research.

In total, there are 93 automatic weirs and their respective mean water level in 2013-2016 was derived manually and then added to the database. Only 73 of these weirs had a corresponding CMGL so as an end result, only these 73 were added to the final database.

Finally, a summary of other problems or errors with the database that were either modified or the corresponding weir was removed entirely:

- Several weirs had a relatively low water level compared to a high CMGL (e.g., a water level of 2 metres and a CMGL of 20 metres). This resulted in very high values for the drainage height. By sorting the drainage height for extreme outliers (standard deviation larger than 3), these could be identified. It turned out that for most of these weirs, the B&O operator who entered the information in the smartphone application, forgot to a +NAP correction. This was manually fixed in the database so these weirs could still be used for the analysis.
- In consultation with C. van Rens [23], all weirs with extreme values for certain values (such as water levels or policy margins) were either modified by hand with the correct values or removed from the database.
- All weirs with no policy margin in either winter or summer was removed from the database *only for the water level compared to margin analysis*. The fact that a policy margin was missing doesn’t affect the water level and drainage height values so these weirs were still used for that part of the analysis. Around 100-150 weirs were thus removed for the water level compared to margin analysis, resulting in approximately 650 weirs.
- All weirs that are static thresholds or cannot be controlled (and thus have no influence on the water management) were removed (approximately 10).

Appendix C: Statistics method

In this report, large data (900+ entries) has to be analysed to obtain a global overview and to identify (extreme) outliers. To accomplish this, statistical analysis was chosen as a method for two reasons. Firstly, because this method was used during the BSc of Civil Engineering, particularly in module 3 “Traffic and transport” and module 8 “Modelling and analysis of stochastic processes”. Therefore, this knowledge has already been obtained. Secondly, statistical analysis is a useful method to analyse large quantities of data. The median is not as sensitive as the mean to extreme outliers and thus the preferred way of expressing an “average” value in this study. For instance, if the dataset contains a human error with a water level of 9999 metres, this would hardly affect the median but greatly change the mean value.

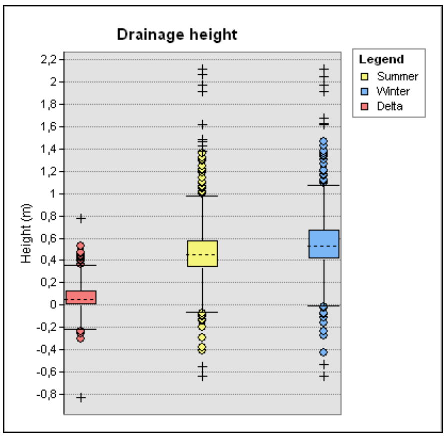


Figure 0-3: Drainage heights for the entire study area for winter (blue), summer and winter-summer (red)

Apart from the median, standard deviations and box plots are also used. One example of a box plot is plotted in Figure 11-3. A box plot is a visual graph that can be seen as an alternative to a histogram (see Figure 11-4). In a box plot, the “box” itself is the second quartile, or in other words: the middle 50% of all the data. For example, if the numeric values 1-8 are the full data set, then the box spans from number 3 to number 6 and the median would be 4,5. The length of the box is therefore a good way to visually check the dispersion of the data.

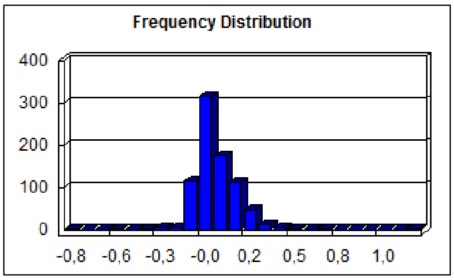


Figure 0-4: Histogram by frequency distribution of the drainage height data, x-axis is in metres

The whisker (T-line) represents all the data within 1.5 inter-quartile range (IQR) from the lower and upper quartile of the box. In the previous example, the IQR would be 3 (6 minus 3) and the whisker length would be 4,5; on both sides of the box. For this dataset, all the data would be included in the whisker. In case of data falling outside of the whisker, this is considered an *outlier* (visualized by a dot symbol in the box plot) or an *extreme outlier* (cross symbol). Mild outliers fall within 3 IQR from the upper and lower quartile, extreme outliers fall outside this range. This is illustrated in Figure 11-5.

Compared to selecting equal intervals by hand; this method ensures that it can be statistically proven what the (extreme) outliers are. Whereas with equal intervals, outliers could be missed or too much data could be included in the outer intervals. Box plots are also useful to compare several sets of data. These can be plotted in one graph while with a histogram, multiple plots would be necessary. In Figure 11-3, the drainage height data sets of both summer and winter can be visually compared because of the box plot. It can be derived from the figure that the median value of both data sets are almost equal and so is the second quartile (box length).

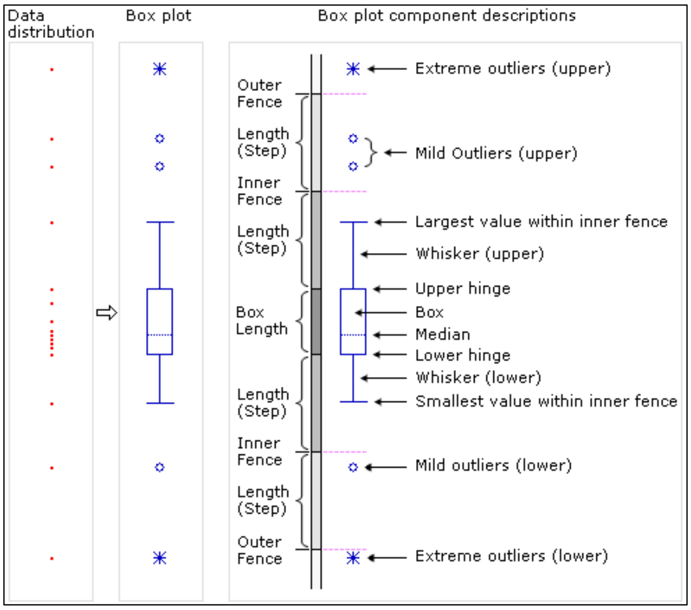


Figure 0-5: Description of box plots [24]

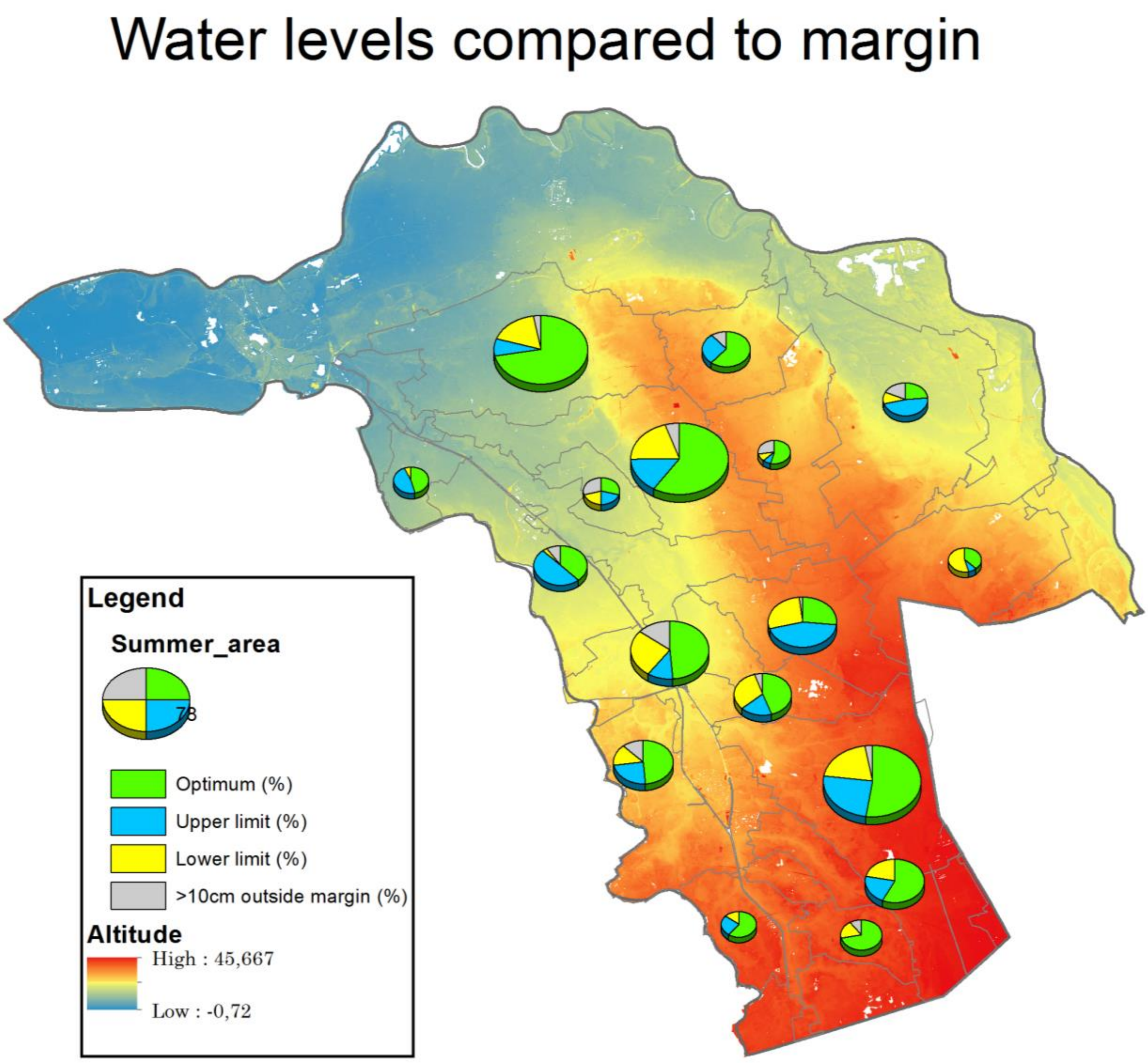


Figure 0-6: Water levels compared to margin per region, for regions with at least 10 weirs, for the summer season

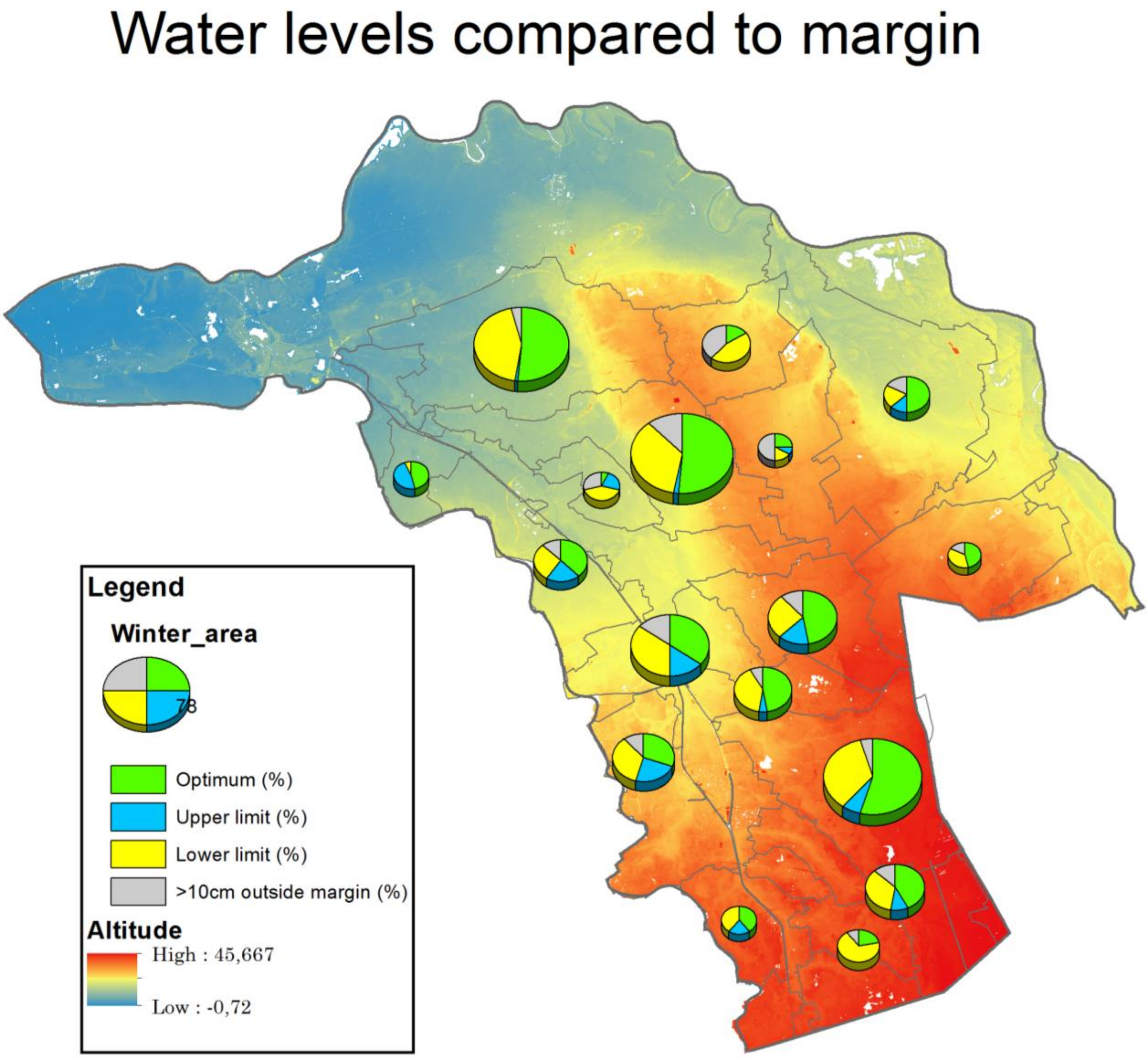


Figure 0-7: Water levels compared to margin per region, for regions with at least 10 weirs, for the winter season

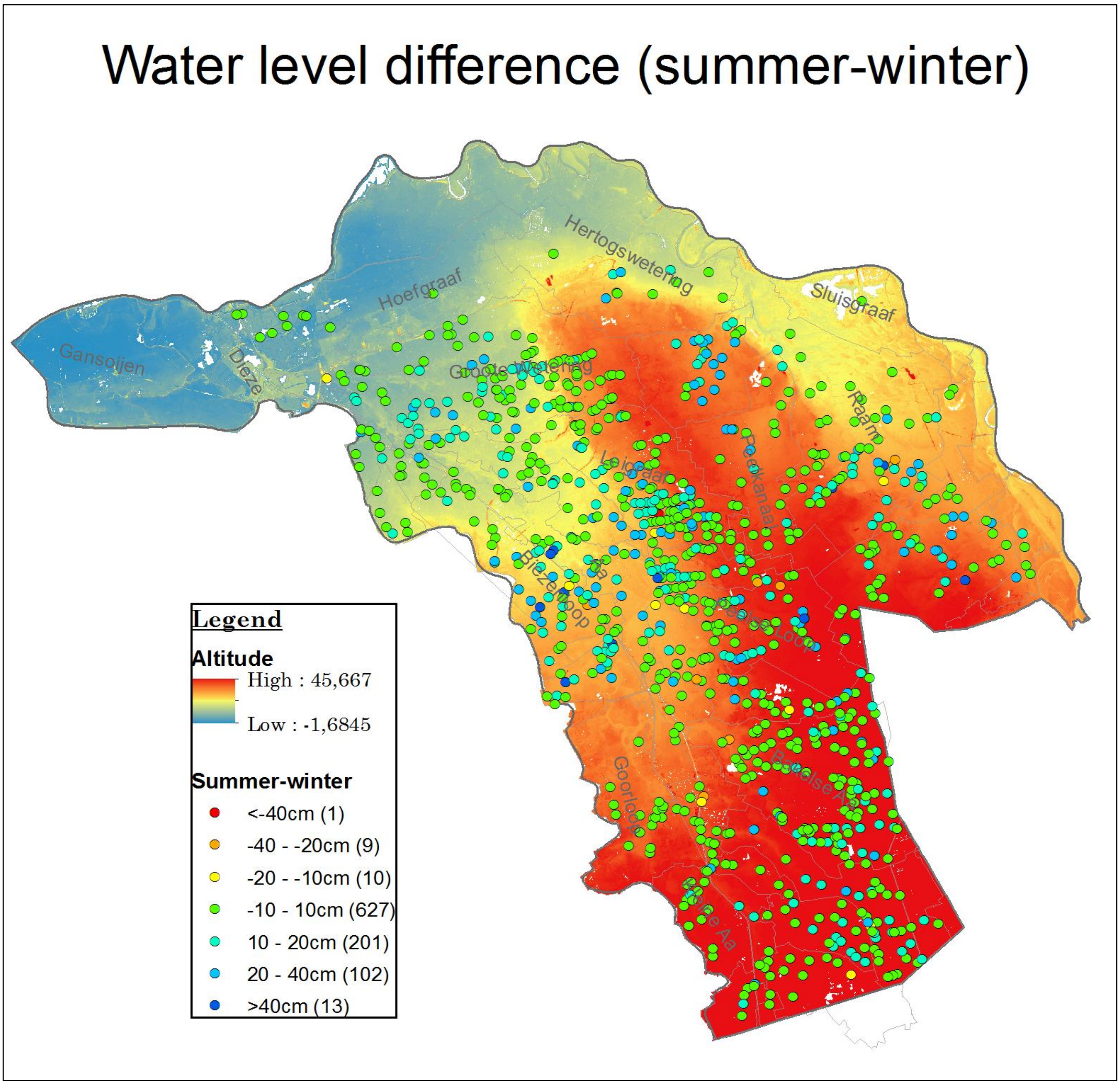


Figure 0-8: Water level difference (summer-winter) for the entire study area, with an altitude overlay

Appendix F: Drainage height totals

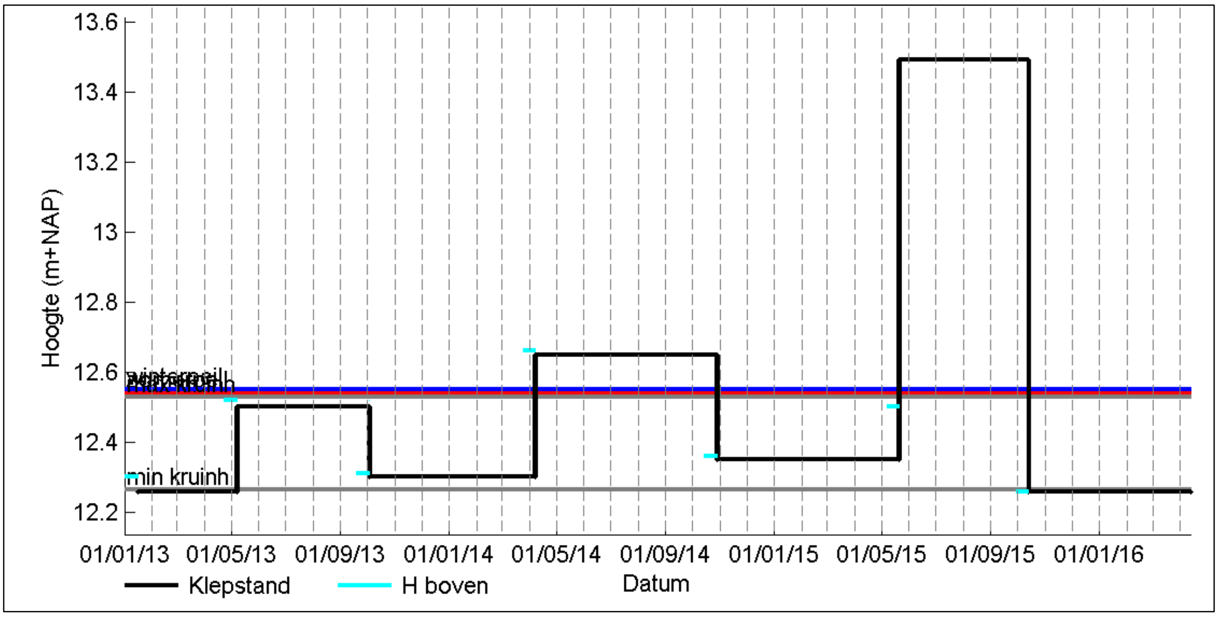


Figure 0-10: Floodgate fluctuations of weir 234CK

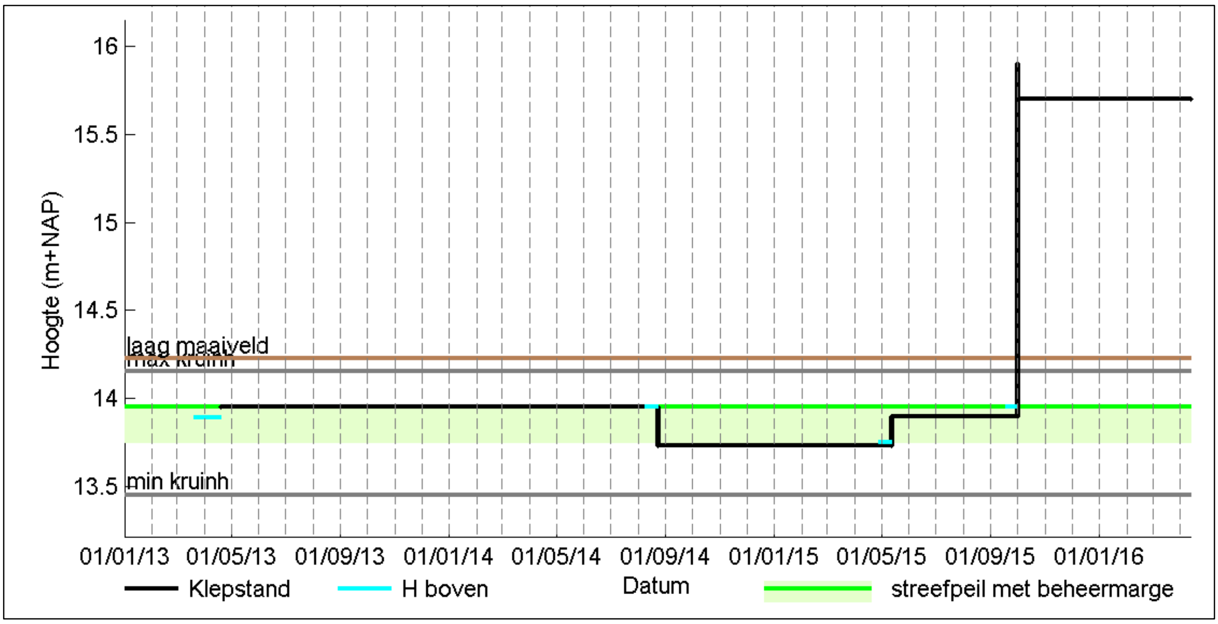


Figure 0-9: Floodgate fluctuations of weir 211LN

Weir 234CK has a drainage height of +77,5cm (winter-summer), while weir 211LN has a drainage height of -83cm. In other words, in summer, weir 234CK has a 77,5cm higher water level while weir 211LN has an 83cm lower water level. On average, weir 234CK is set to *optimum level* in winter and *>10cm OM* in summer; for weir 211LN this is the exact opposite. In both situations, this seems to be the cause of the high drainage height differences.

Weir 234CK has a drainage height in summer of -0,29m and for weir 211LN this is 0,295m. Both have a corresponding CMGL where crop farming takes place, so the optimum drainage height is 0,60meters. Thus, both locations are critically wet in summer. Both weir graphs (Figure 11-10 and Figure 11-9) have no corresponding comments that list the reason for the raised floodgate in 2015. Both weirs should be critically assessed for why this floodgate was raised, although there currently are no complaints or other comments in the database on these weirs.

Appendix G: Crops analysis

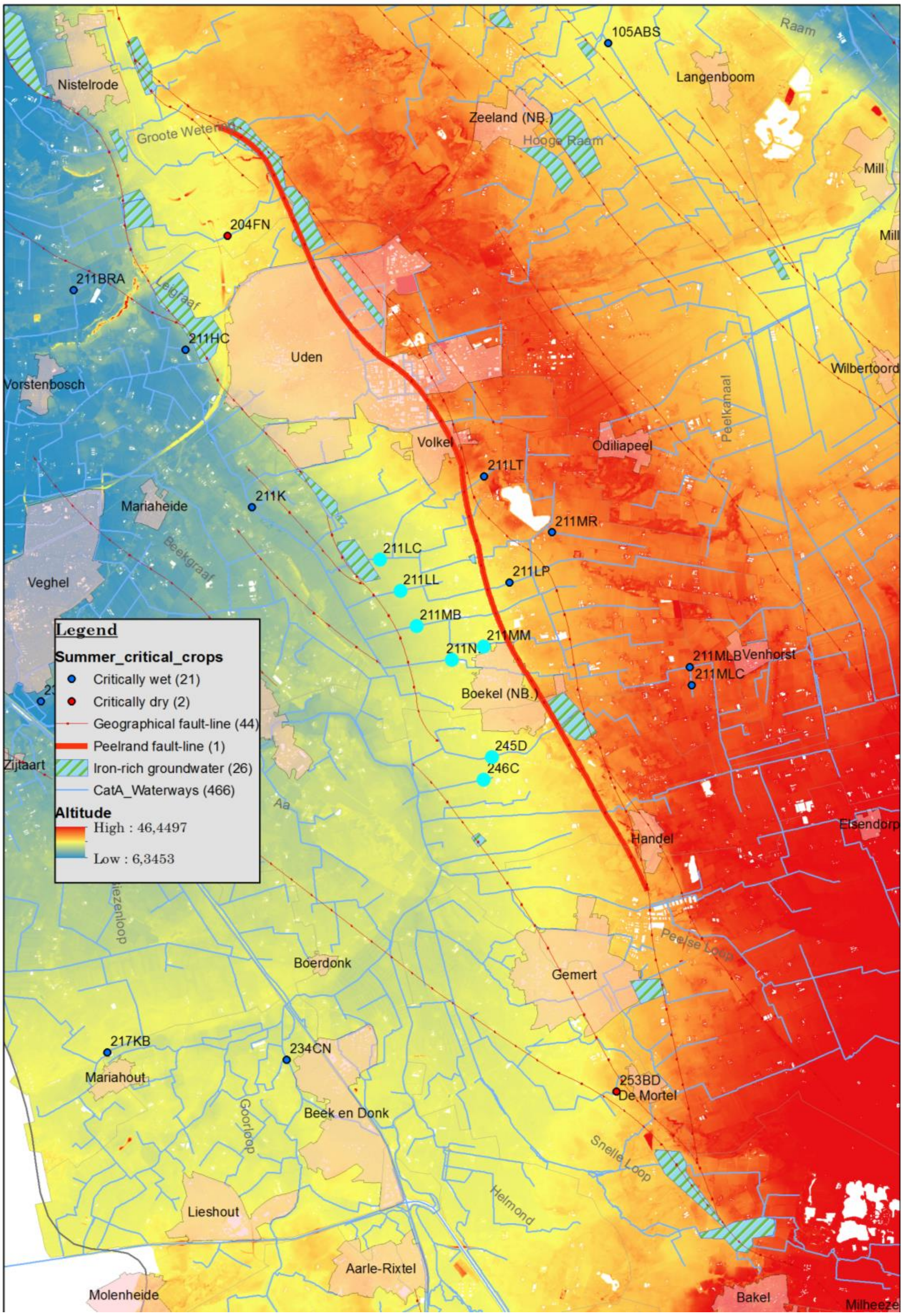


Figure 0-11: Five critically wet locations around Boekel, with the peelrand fault-line, iron-rich groundwater spots, the waterways and the altitude overlay plotted.

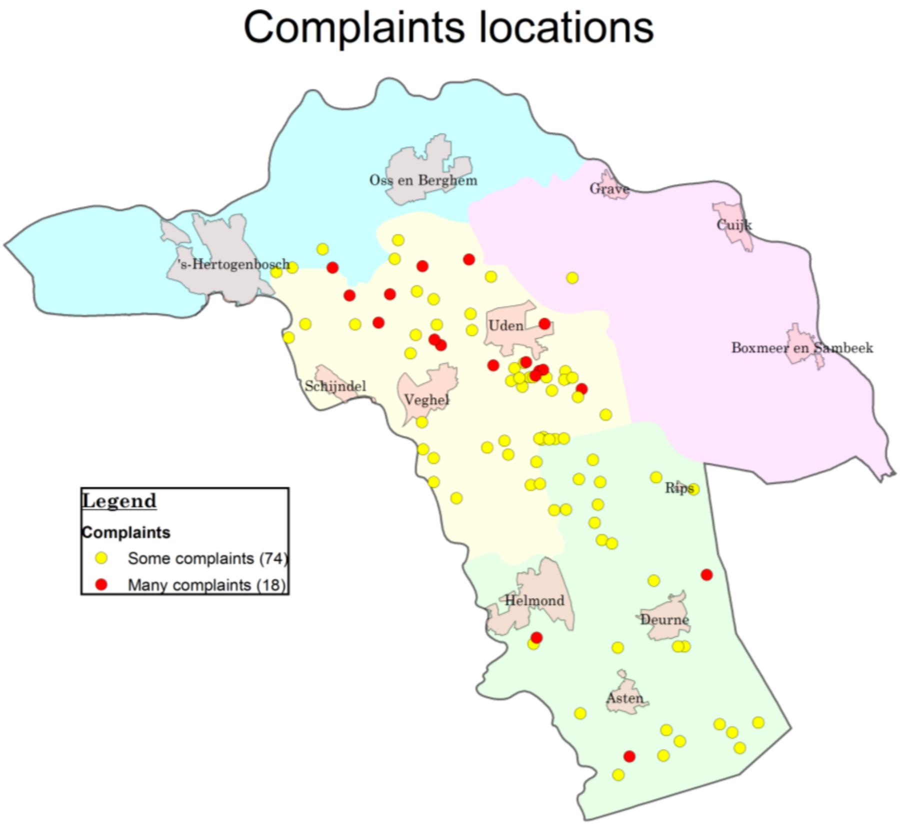


Figure 0-12: Locations of the weirs with complaints in the period of January 2013-2016

Appendix I: Score quantification

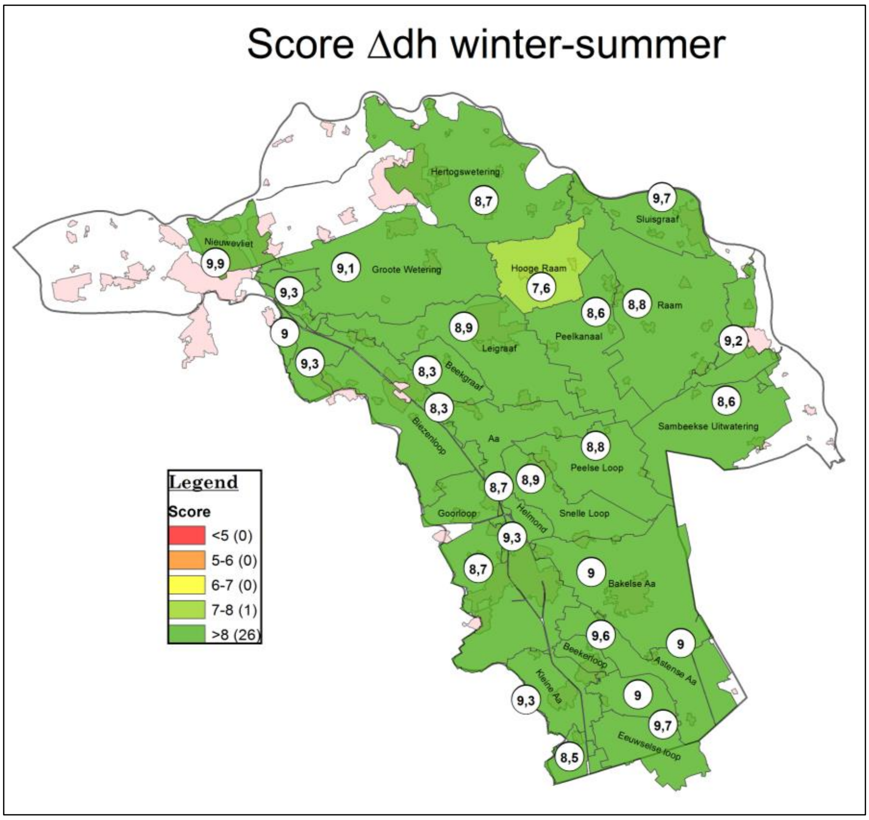


Figure 0-13: Scores per region, based on a Δdr_{max} of 0,83 metres and the difference in drainage height between winter and summer.

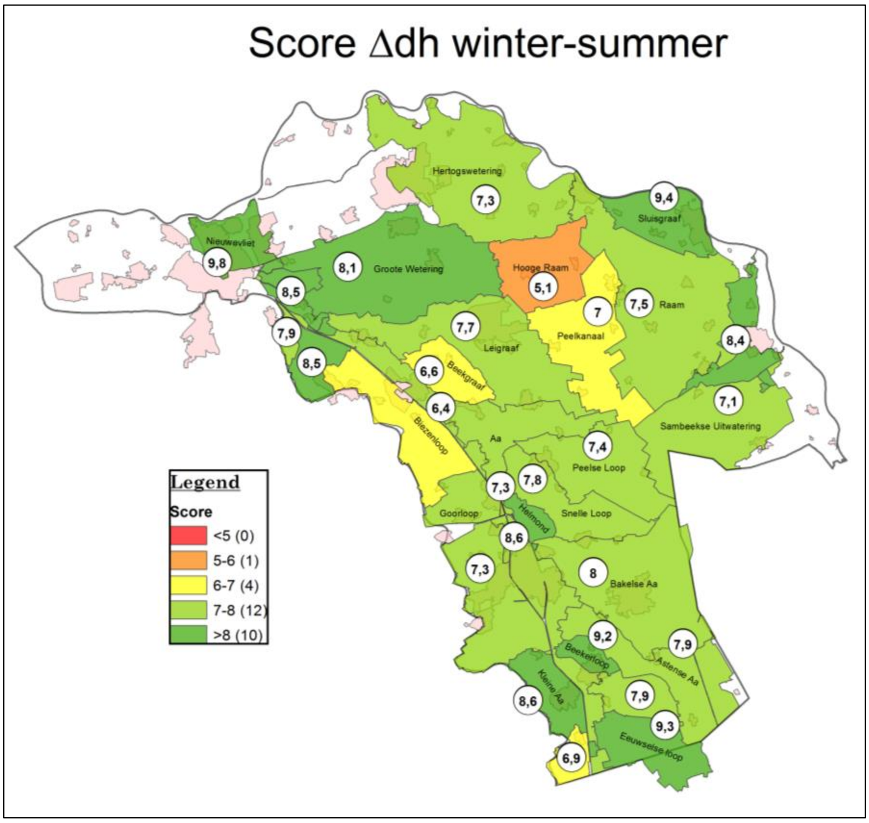


Figure 0-14: Scores per region, based on a Δdr_{max} of 0,40 metres and the difference in drainage height between winter and summer

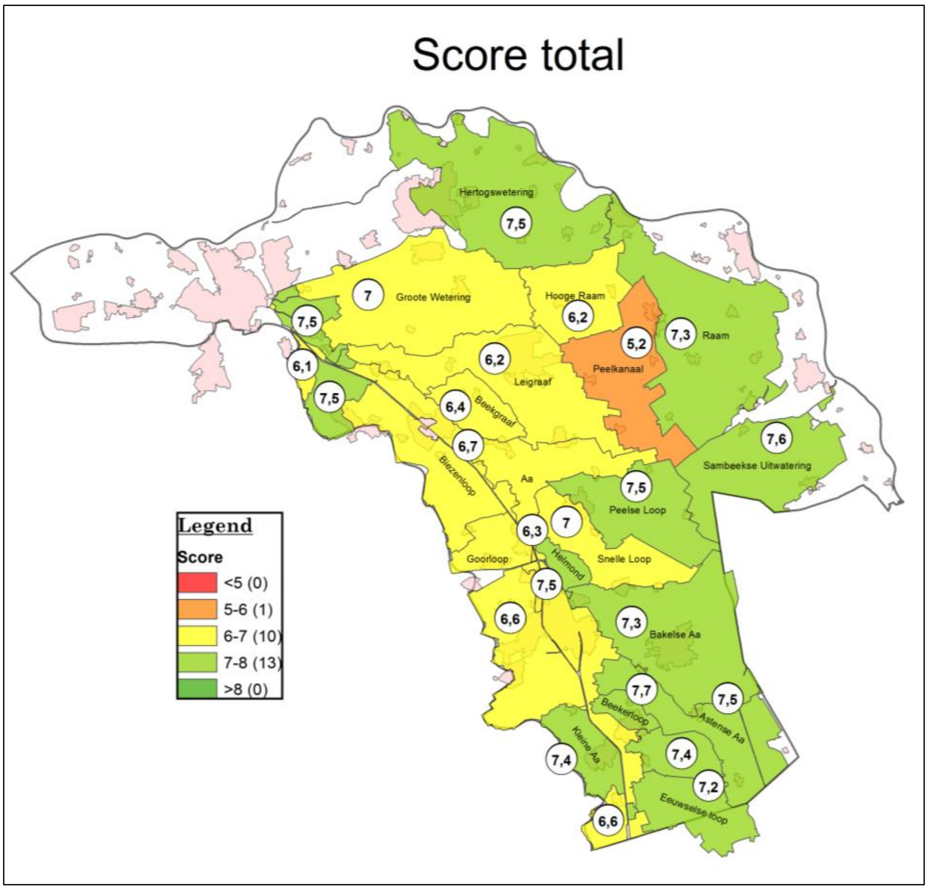


Figure 0-15: Scores per region based on three factors (drainage height compared to optimum for summer and winter; and drainage height difference between winter and summer).