7/7/2022

Assessing the Reliability of Discharge Data

Final Report

Image: (de Harder, 2019)

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Preface

This is my final report of my bachelor thesis '*Assessing the reliability of discharge data*', which I carried out for the hydrologists of the Research & Advise department of Waterschap Drents Overijsselse Delta. This research concludes my bachelor study Civil Engineering at the University of Twente. By analysing four Acoustic Doppler Current Profilers (ADCPs), more insights in the identified anomalies within the time series of these flow meters are provided. Hopefully, this research will contribute to the understandings of the discharge data and the assessments of the other flow meters owned by Waterschap Drents Overijsselse Delta. Despite that the outcomes of the assessment indicates that a large part of the data is not suited for further use, I hope that Waterschap Drents Overijsselse Data can benefit from this research.

Conducting this research made me realize how interesting water-related matters are and how broad the water section of civil engineering is. I am very thankful for the opportunity to conduct this research for the water board to further develop myself on educational and social levels. I really appreciate the kindness, the genuine interest, and willingness to help of the employees of the department. In particular, I would like to thank my external supervisor Guus van den Berg, for his help, support, and comprehension during this period. Despite that it was sometimes difficult to meet due to our mismatching agendas, he always endeavoured to make room in his agenda for me, even though it would confiscate his Saturday afternoon. His knowledge about the flow meters really contributed to this research. Additionally, I would like to thank my internal supervisor Erik Horstman, for his comprehension, tips, and willingness to give feedback whenever needed. The weekly meetings and his insights really assisted me during the conduction of this research and to stay on the right track.

Despite encountering multiple unexpected misfortunes, I genuinely enjoyed conducting this research. Hopefully, you enjoy reading this report as much as I enjoyed writing it, and that you find this research as interesting and equally valuable.

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1 July 2022

Management Summary

Waterschap Drents Overijsselse Delta, one of the Dutch water boards, utilizes flow meters within their field of operation since 2005. These flow meters measure the flow velocity and the water level of a waterway, with which the discharge of the waterway is computed. With the obtained data Waterschap Drents Overijsselse Delta, abbreviated WDOD, desires to cquire knowledge about the water system to enable themselves to further improve their water management. However, the flow meters provide measurement data that are considered to show many anomalies, such as steep jumps with a periodicity of approximately twelve hours. Therefore, Waterschap Drents Overijsselse Delta wants to know what the causes for these anomalous results are and to what extent the time series are suitable for further use.

A global data analysis was conducted to select four flow meters, such that all the identified suspicious patterns were addressed and assessed at the end of the research. A profound data analysis of the data of these four flow meters was conducted to get a clear overview of the identified anomalies. The data obtained by the flow meters consists of discharge data, flow velocity data, and water level data. Data from nearby hydraulic structures, such as weirs and pumping stations, were studied in order to compare the data and identify similarities and differences. Simultaneously with the data analysis, literature research was conducted to gain more knowledge about the technological aspects of the ADCP meters, to get a better understanding of the data.

To determine the background of the problem and discover possible causes for the identified anomalies within the data, multiple interviews with experts were conducted. By conducting interviews with the application manager of Waterschap Drents Overijsselse Delta, two water system managers from Waterschap Noorderzijlvest, a hydrologist from Waterschap Rijn en IJssel, and a representative from Flow Tronic, multiple specific questions about the causes of related anomalies in the flow meter data, either technological or hydrological, were formulated. The specific causes for these anomalies were obtained by interviewing flow meter manufacturer Nortek.

The identified explanations for the, in total eleven, observed anomalies turned out to be technologically based for eight cases. Although a specific cause is not found in most cases, the origin of the problems can be classified in different areas of the process. This revealed that flaws in the formula in the substation, that processes the raw measurement data to the measurement data available in Wiski, are present, while a setting or formula in the data server from WDOD could contain an error as well. The error, that is present in either the substation or the data server from WDOD , may be the cause for several anomalies, such as the missing of time series, or data being visualized with positive values only, including the originally negative values. On top of that, it became clear that data gaps are mostly caused by either defects of the flow meter or errors in the data transfer process from the substation to the data server from WDOD.

Two anomalies turn out to be hydrologically based. The periodic jumps in the discharge data of the flow meter in the Groote Grift are caused by a pumping station. By performing three calibration measurements on the flow meter, it can be verified whether the time series complies with the actual discharges. If not, the time series should be recalculated in order to use them again.

The periodic fluctuations of the water levels in the Overijssels Kanaal occur because the water level is automatically regulated. Within the Overijssels Kanaal, the alternatingly positive and negative discharge and flow velocity values that are present in the data provided by the flow meter, are assumed to be caused by sloshing in the port of Deventer. Literature research and/or field research should confirm or reject this explanation.

Since the flow meters located in the Drentsche Hoofdvaart and the Wold Aa provide data with mostly technology-induced anomalies, nearly fifteen years of data is unreliable and cannot be restored. If it is possible to restore the data since November 2019, from when the discharges have magnitudes with positive values only, it is possible to use at least the data that has been collected since then. However, this only applies if no further anomalies are identified within that restored data and for sections where the water level data does not show large fluctuations.

To conclude this research, it can be stated that the anomalies in the discharge data, flow velocity data, and water level data are in most cases caused by technological issues, often related to adaptations within the formulas of the substation or the data server from Waterschap Drents Overijsselse Delta, that process the raw data into the measurement data that is available in the data analysis program Wiski. Besides that, communication errors between the substation and the data server from WDOD are likely to be the cause of multiple anomalies as well. Since it cannot be verified what happened during these periods, the exact cause of these technological issues cannot be defined. Furthermore, the hydrological related anomalies in this research are related to the characteristics of the water system, hence making it difficult to use the identified causes for water systems with different characteristics.

It is recommended to use the discharge data, provided since November 2019, from the flow meters in the Drentsche Hoofdvaart and the Wold Aa, only if the time series are properly displayed, calibration measurements are performed, and no other anomalies are identified. By performing calibration measurements, the data from the flow meter in the Groote Grift can be restored, after which it is suitable for further use. Unfortunately, the time series from the flow meter in the Overijssels Kanaal are not suitable to use. Nevertheless, by performing calibration measurements on pumping station and weir Ankersmit and optimizing the formula in the substation, proper measurements can be conducted at this location, to get a clear overview of the inflow and outflow at this location. By restoring the available data from Ankersmit, if necessary, data since 2017 is available.

In general, it is recommended to appoint an employee who is responsible for the continuous validation of the collected data, to prevent rejecting large periods of data in the future. As a result, suited measures can be taken on the short term to minimize the quantity of unusable data.

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1. Introduction

1.1. Project Background

Traditionally, the focus of Dutch water management was on protecting the country against the water (van der Brugge et al., 2005). Engineers solely had the purpose to design a system that sufficiently protected the Netherlands while minimizing the expenses for the project. However, this approach turned out to be vulnerable on the long-term, because of severe effects of climate change, such as the global sea level rise (van der Brugge et al., 2005). After the construction of the delta works in the 1970s, awareness rose with respect to the ecological aspect which led to a shift in the paradigm: integral and participatory water management started to substitute the technocratic water engineering approach (van der Brugge et al., 2005). Present-day, this more ecological approach is increasingly pursued to cope with the aggravating impacts of climate change. Besides the important goal of protecting the Netherlands against inundation, a major element of this innovative approach is the improvement of the water quality.

Dutch water management takes place on both a national and regional level. Rijkswaterstaat is responsible for the management on the national level, while twenty-one water boards are responsible for the regional water management (Rijkswaterstaat, 2022b). To clarify, Rijkswaterstaat manages the larger water bodies and warns the authorities involved for storms and high water. On top of that, they are also accountable for coastal protection, making room for the river, and maintaining water related constructions. The water boards are responsible for the water quality, flood protection, the water levels, the fish stock, and the quantity of water required for agriculture, all on a regional scale.

From this it can be stated that it is important to be familiar with the water bodies to forecast where floods can occur, and which water bodies will be polluted due to wastewater discharges in a certain body. It is crucial to know how much water flows through the water bodies and what their capacity is under which circumstances. Therefore, flow meters are deployed. Flow meters are devices that can determine the discharge, which is the quantity of water that flows through a waterway within a certain time frame.

Waterschap Drents Overijsselse Delta, one of the Dutch water boards, utilizes such flow meters within their field of operation since 2005. With the obtained data it is desired to gain knowledge about the water system to enable themselves to further improve their water management. However, the flow meters provide considered to be anomalous measurement data. Therefore, Waterschap Drents Overijsselse Delta wants to know what the causes for these anomalous results are.

Discharges can be determined in several ways. It is possible to determine the discharge by using system constraints, for example the maximum discharge capacity of a pumping station. Incidental calibration measurements are applied as well, where water level and flow velocity data are collected at arbitrary locations and times. Furthermore, flow meters can be installed in the concerning water bodies to monitor discharge variations over time. By multiplying the measured wet cross section of a channel with the measured velocity of the channel flow, the discharge can be calculated by the flow meter and data can be digitally provided. Figure 1 visualises how the discharge can be determined.

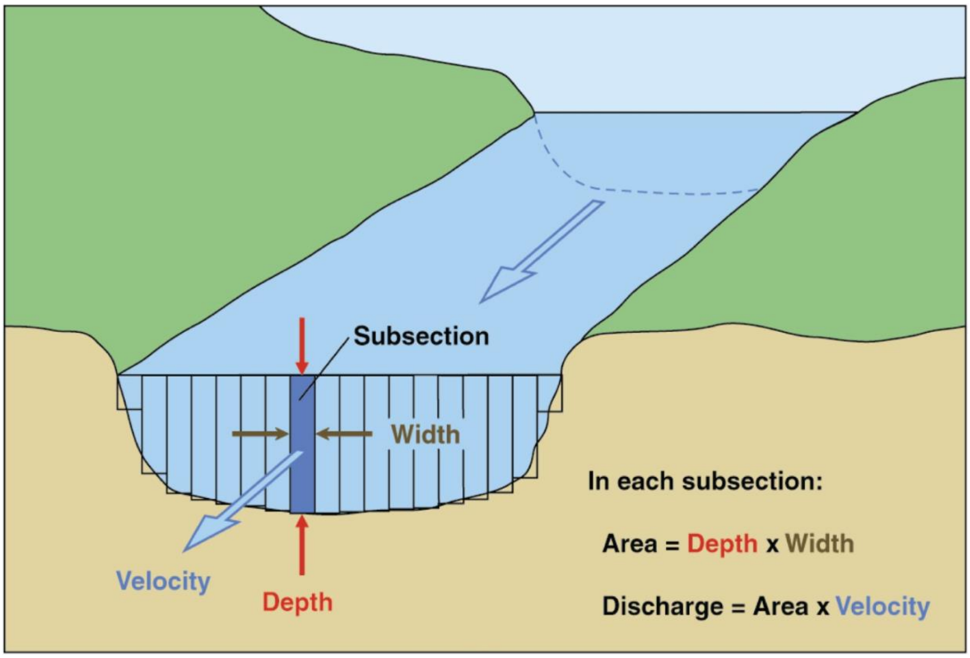


Figure 1 Example of how the discharge can be calculated (Resources, 2011)

With these discharges, the hydrologists of the Research & Advise department within WDOD endeavour to expand their knowledge of the water system. With sufficient insights in how the water system works, which factors influence the water system, and how the water system will react to certain weather conditions, water management can be further developed. For instance, flood protection can be improved. When time-series of discharges are known, the magnitude and flow direction of water flows can be determined and predicted, for example during heavy rain events. As a result, flood protection measures can be taken if necessary, such as heightening the dikes or evacuating residents. Furthermore, dry, and heavy rain periods can be dealt with more efficiently if trustworthy discharges are available, because water levels can then be maintained by adjusting weir heights and pumping capacities, preventing ecological and economic damages.

Within the Research & Advise department, a group that focusses on the harmful substances in the water bodies use the data from flow meters as well. Namely, the quantity of harmful substances flowing through the water bodies could be determined by using the discharges and concentrations of the harmful substances in the water. Within each type of waterbody, concentrations should not exceed the maximum concentrations stated by the European directives for the water bodies due to the severe consequences at both the environmental and societal level (Rijksoverheid, 2022).

1.2. Problem Statement

Currently, several flow meters are installed within the field of operation of WDOD as shown in Figure 2. However, several flow meters are defect and hence are unable to measure the discharges. Although the remaining flow meters are still operating, several flow meters provide results that differ from calibration measurements or system constraints, such as maximum outflows imposed by hydraulic structures. Moreover, during the 2021 period with a lot of rain, just one flow meter delivered data that was found trustworthy by the water board. Additionally, anomalous, and sometimes unrealistic discharges, do emerge from the flow meters. Questions arise around events when the flow meters measure discharges that are larger than the maximum capacity of a pumping station located further downstream, or discharges that are alternating between positive and negative values, thereby indicating a change in the direction of the flow.

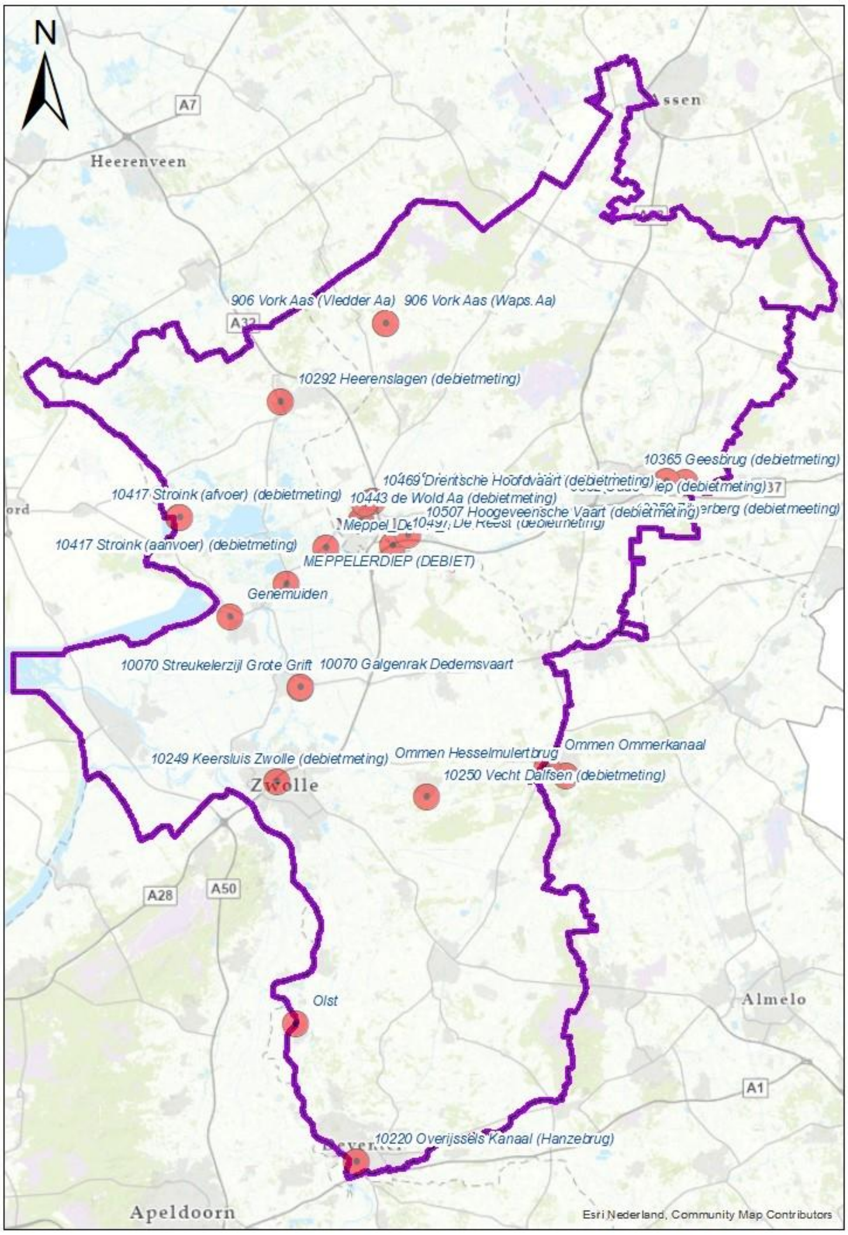


Figure 2 Locations of the flow meters from Waterschap Drents Overijsselse Delta (van den Berg, 2022)

To give a brief and complete description of the problem, a problem statement is provided down below.

Problem Statement:

Predicting the water discharges and managing the water levels in the field of operation of Waterschap Drents Overijsselse Delta is difficult when discharge data provided by flow meters is considered potentially unreliable. In fact, multiple fragments of the data are considered to be anomalous. Since it is not known whether the causes of the data considered to be anomalous can be technically explained or hydrologically justified, the reasons for the suspicious discharge data must be investigated.

1.3. Research Objective and Research Questions

Due to the abovementioned inconveniencies, water board Drents Overijsselse Delta does not trust the data from the flow meters. Therefore, the water board would like to find out what the causes of these considered to be anomalous monitoring data are, which have been collected ever since the first deployment of the meters. It is desired to find out whether the flow meters measure rather inaccurately or that the measurements are in fact correct. Regarding the latter possibility, a hydrologic explanation should be found to clarify these monitoring data. To give a concise description of the objective of this research, the research objective below is formulated.

Research Objective:

The objective of this research is to assess the accuracy of the flow meters in the field of operation of Waterschap Drents Overijsselse Delta by investigating possible causes of the measured considered to be anomalous discharges through establishing technological and/or hydrological clarifications.

Based on the research objective, the research question and three accompanying sub-questions are formulated. These questions are stated below.

Main Research Question

Since Waterschap Drents Overijsselse Delta endeavours to get intelligibility regarding the causes of the suspicious measurement results of their flow meters, the following research question is constructed:

- ❖ What technological or hydrological causes explain the suspicious patterns in the measurement data obtained by flow meters from WDOD and to what extent is the data suitable for further use?

Research Questions

To get completely familiar with the problem at Waterschap Drents Overijsselse Delta, it is important to first obtain more insight into the measurement results and their interpretation. Therefore, the first two sub-questions are:

- ❖ What do the measurement results from the flow meters from WDOD represent and what anomalies can be identified in these obtained data?
- ❖ To what extent do the measurement data obtained by flow meters from WDOD differ from measurement data obtained by WDOD from system constraints?

To answer the main question and thus address potential technological errors or discover possible hydrological phenomena, it is important to investigate both aspects. Hence, the third sub-question is formulated:

❖ To what extent can the suspicious patterns in the measurement data obtained by flow meters from WDOD be hydrologically or technologically explained and to what extent is the data suitable for further use?

1.4. Report Outline

In the following Section, the research methods are addressed. An elaboration of the research methods is provided for each research question, such that it is clear how each question will be tackled and answered. After that, a data analysis is present where four flow meters are discussed. This Chapter consists out of multiple Sections, starting with a brief overview of the selection process of the flow meters. Subsequently, a data analysis of each flow meter is present in Section 3.3 up to and including Section 0. Section 3.7 provides a brief overview of the identified anomalies per flow meter.

After the data analysis, the characteristics of the flow meters and their data are discussed in Chapter 4. First, the technological aspects of the flow meters are addressed in Section 4.1. Subsequently, information acquired during multiple interviews will be used to implement in Section 5.

Now that the information is gathered through an extensive data analysis and by conducting interviews with internal and external experts, sufficient information is present to construct a proper assessment of the time series provided by the four flow meters. This assessment is present in Chapter 0, where each flow meter is discussed in a separate Section.

Next, a discussion is present in Chapter 6. Within this Chapter, an elaboration is given on the points of interest of the research. Strengths and weaknesses will be discussed for the different Section such that a clear overview about the execution of the research is formulated. The information acquired throughout the conducted research will be used to draw conclusions about the reliability of the analysed flow meters in Chapter 7, after which recommendations are given in Chapter 8 about the reliability of the time series of the analysed four flow meters. Furthermore, suggestions are given as well about the usage of other flow meters with similar anomalies.

2. Research Methods

A methodological approach is constructed based on the research sub-questions since these questions contribute to answering the main question. Throughout the research, three different research methods are applied. A data analysis will be conducted to get better understandings of the data and to identify the anomalies in the data. Literature research is done to acquire information about the study areas and technological aspects of the flow meters, while interviews are conducted to gain more knowledge about the flow meters and their data. Figure 3 shows a detailed overview of the steps that are conducted, including the required methods. The methods are displayed at the top of the flowchart, while the corners of each block are marked with the colour belonging to the method(s) that is/are required for this step. During this project, several steps will be executed partly alongside each other since certain information can overlap or information for multiple steps can be obtained within the same method.

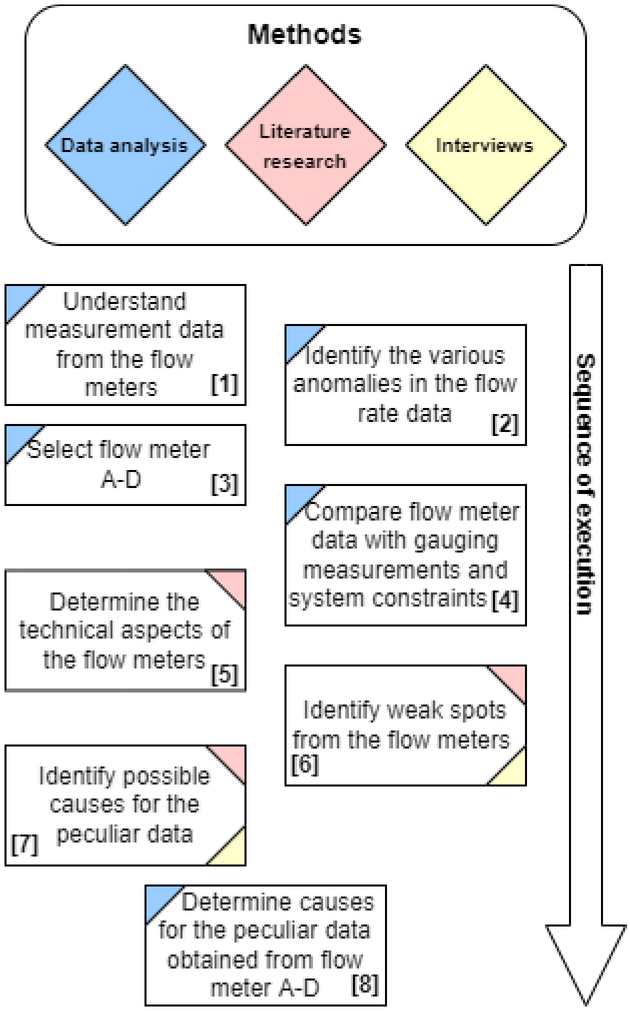


Figure 3 Flow chart for the proposed methodology

After executing the first three blocks from the flow chart, the first research sub-question about the representation of the data and the identification of the anomalies is answered, while the fourth block makes it possible to answer the second sub-question and address the similarities or differences between the discharges obtained by the flow meter versus the discharges obtained by hydraulic structures. Blocks five, six, and seven will contribute to answering the fourth research sub-question.

Finally, the main research objective can be accomplished by answering the main research question through combining the previously gained answers of the research sub-questions.

2.1. Understand Measurement Data and Identify Anomalies

For answering the first research sub-question it is required to understand the time series of the discharge data and the other parameters, after which deviating patterns can be identified in the data. Since the first flow meter from Waterschap Drents Overijsselse Delta was installed in 2006 and multiple flow meters were installed after, over fifteen years of data of discharges is available within the Research & Advise department. A global analysis of these time series data from all flow meters owned by WDOD is conducted by focussing on the magnitude of the discharges, the continuity of the discharge graphs, and possible negative discharge values. Through these observations, a better understanding of the discharge data can be acquired with respect to common patterns for short and long periods. After that, anomalies within these time series should be identified properly. Previously gained knowledge by WDOD can contribute to identifying these anomalies since multiple patterns have been marked during the past years. As a result of the identification of the anomalies, a final selection of four flow meters is selected that covers all types of deviations within the analysed data, such that the assessment of these flow meters can be used for the assessment of other flow meters that encounter similar anomalies. Section 3.2 briefly elaborates on the selection process of the four selected flow meters, after which four Sections are dedicated to the four flow meters.

For each of the flow meters a brief description of the study area is provided. This description is constructed through using literature and having conversations with specialized hydrologists from WDOD who did research about the flow meter or the concerning area before. Then, the total time series are displayed, and an elaboration is given on the global pattern of the time series. An explanation about how to interpret the data is provided, where annual trends will be addressed. Next, the remarkable fragments in the time series will be addressed. Based on this global overview, the remarkable fragments will be studied in detail to develop a better overview of the anomaly regarding its periodicity, magnitude, and frequency. In addition, multiple fragments before and after the anomalous fragments are studied in detail as well, to verify whether the anomaly occurs temporarily or permanently. Furthermore, time series of either water levels or flow velocities are considered in the data analysis as well if the time series are (partly) available. This provides possibilities for a more elaborate data analysis since these parameters are necessary to determine the discharge. Hence, a better picture of the overall problem can be acquired and better insights in what the data represents can be acquired. Similar to the analysis of the discharges only, the analysis will start on the global level and narrow down on the anomalous fragments, after which multiple arbitrary samples are studied as well to verify the dimensions of the present anomalies.

2.2. Compare Flow Meter Data with Data Provided by Hydraulic Structures

Certain patterns observed in the time series from the flow meters could match the patterns from the time series acquired by hydraulic structures that are located nearby. Conversely, possible new anomalies can be identified as well, such as a difference in magnitude of the discharges measured by the hydraulic structure and the flow meter. Again, the elaboration of this data analysis is similar to the previous analyses. This data analysis makes it possible to answer the second research sub-question. In other words, an extensive data analysis covering multiple parameters and nearby hydraulic structures results in the possibility to answer the first two research sub-questions. Therefore, these Sections are merged in Section 3.

2.3. Assessment of the Identified Anomalies

First, information about the technological aspects of the flow meters is required through literature to get a better understanding of how the discharges are measured. Apart from that, strengths and weaknesses of the flow meter come forward that can be used to confirm or reject possible hydrological or technological clarifications for the assessment of the flow meter. Furthermore, this literature research will also investigate what factors may influence the measurements. Hydrological factors could be watercrafts, aquatic plants, or wind. Technological factors could be deviations in measured water levels, measured cross sections, or measured flow velocities.

Next to the fact that the flow meters are ADCP devices and that obvious weak spots can be identified through literature research, more information regarding technology of the flow meters and the identified anomalies can be obtained from experts. Therefore, semi-structured interviews are conducted with one internal party and four external parties. These semi-structured interviews are globally prepared beforehand, leaving room for related questions and questions from the other party as well, making them more interactive than fully structured interviews. This is especially useful for external parties since inputs from these experts are considered important as well to verify whether the identified anomalies are a local problem within WDOD or are in fact a larger problem. Dependent of available time of the experts, several questions can be further elaborated on.

To get a clear overview of this process, a question tree will be constructed in which a route can be followed based on whether a certain question can be answered or not. Based on the results of an interview, certain questions can be adapted or removed for the next interview(s), whereas other relevant questions can be added as well. Every interview is held online via Microsoft Teams and recorded with consent of the other party, such that the interview is available for self-reflection. On top of that, information can be traced back to confirm several statements and prevent possible deviations on certain aspects due to incorrect perceptions of certain knowledge during the interview.

As mentioned before, five parties are selected for these interviews, one internal party and four external parties. An overview of the planned interviews is displayed in Table 1.

Table 1 Schedule of the interviews

Interview number	Organisation	Expert	Function	Date (DD-MM-YYYY)
1	Waterschap Drents Overijsselse Delta	Johan Schadenberg	Application manager	10-05-2022
2	Waterschap Noorderzijlvest	Johan Draaijer & Marijn Hooghiem	Water system managers	24-05-2022
3	Waterschap Rijn en IJssel	Gert van den Houten	Hydrologist	01-06-2022
4	Flow Tronics	Hans ten Kate	Representative	09-06-2022
5	Nortek	Maarten Mulder	Project engineer	17-06-2022

Instead of elaborating each single interview, the acquired information will be combined and supported by information acquired during the data analysis and literature research. It is determined to do it this way to prevent for overlap. The Section that emerges from this approach is the assessment of the flow meters, which will provide an answer to the third research sub-question. The formulated general questions of the interviews can be found in Appendix C1, Appendix C2, and Appendix C3. Since the Figures, that are present in the data analysis in Section 3, are used to show the identified anomalies to the interviewed experts. As a result, no concrete questions are formulated in Appendix C3 since Section 3 already offers a great guideline that can be followed.

First, the identified anomalies from the flow meter in the Overijssels Kanaal will be discussed. Next, the identified anomalies from the flow meter in the Groote Grift will be elaborated on. Finally, the time series from flow meters in the Drentsche Hoofdvaart and the Wold Aa will be addressed simultaneously since a large part of the identified anomalies overlap. With these results, Waterschap Drents Overijsselse Delta can identify the causes for the anomalous data for the other flow meters. Furthermore, they can conscientiously consider whether the time series are sufficient reliable to use for their projects.

3. Data Analysis and Identification of the Anomalies

3.1. Understandings of the discharge data

Before anomalies in the discharge data can be identified and a selection of four flow meters can be chosen, annual trends and season-based trends must be investigated, whereas the visualization of these patterns in Wiski must be clear as well. Usually, water discharges in downstream direction are expressed in positive discharge values, while water discharges in upstream direction are expressed in negative discharge values. Respectively, positive flow velocity values are related to a downstream flow, known as the outflow, while negative flow velocity values imply an upstream flow direction, hence the inflow. Nevertheless, time series from hydraulic structures are practically always displayed in positive values since the flow direction is technically constrained in one direction. In general, water discharge occurs more frequently and with larger magnitudes during the winter periods in controlled waterways, while water is scarcely discharged, or even pumped up, during summer periods to maintain a certain water level and thus prevent a water deficit in the upstream areas. This yearly pattern is often recognizable in time series that display multiple years of data, where positive discharges are observed during the winter based on the characteristics of the waterway, while the negative discharges represent the summer discharges in a waterway-specific pattern. If downstream areas have sufficient water, water can be retained upstream to maintain a required water level during a period with little to no precipitation. This will result in smaller magnitudes in the discharges. If a water deficit tends to occur, water will be pumped upstream. This transition period from the water outflow towards the water inflow is recognizable in the time series, where the positive and negative blocks gradually increase or decrease and smoothly transition into each other. Usually, a high-water period occurs during the winter season between January and March, while it could also occur during the start of the spring season (Rijkswaterstaat, 2022a). This is clearly visible through the large peak that is present in the time series during the winter period. This peak can be distinguished from incidental peaks due to its larger presence, which is shown by a broader peak instead of one large steep line which is present between rather low discharges.

3.2. Selected Flow Meters

As described in the methodology, four flow meters located in the field of operation from Waterschap Drents Overijsselse Delta are selected for further data analysis, after which the various anomalies in their time series will be identified. First, the study area will be addressed in which the flow meter is located. After that, the time series of the discharge will be analysed, and the trends and anomalies will be identified. Next, the measured water levels and flow velocities will be included to get further insights into the data. Finally, data collected by nearby hydraulic structures, such as pumping stations or weirs, will be compared to the flow meter data.

Multiple work meetings regarding the flow meters with Guus van den Berg, a specialized hydrologist at WDOD and external supervisor of this project, led to the initial selection of two flow meters, based on their large variety of anomalies present throughout the over 15-year-old time series and the impact of the two waterbodies on the water system downstream. Anomalies such as large fluctuations, sudden periodic jumps in the magnitude of the discharge data, and the absence of negative discharges are determining factors for selecting these two flow meters. These flow meters are located in canal the Drentsche Hoofdvaart and the canalised river Wold Aa. Both waterbodies flow towards Meppel, a city located in the province of Drenthe, into canal Meppelerdiep. The other two flow meters are selected after further research, based on their deviating anomalies compared to the other selected flow meters. The third flow meter is located in the Overijssels Kanaal in Deventer and provides very fluctuating discharge values laying between -5 m^3/s and +8 m^3/s. The discharges are continuously alternating with a periodicity of 5-60 minutes since the start of the measurements in March 2011. The fourth flow meter is located near Hasselt in stream the Groote Grift. This flow meter provides data since December 2016 and the time series of the discharges show a rather constant noise pattern, except for a large data gap between August 2020 and April 2021. This noise appears to be present in large peaks with a constant periodicity and magnitude, which distinguishes this flow meter from the other flow meters. However, besides investigating this anomalous pattern, the analysis of this flow meter is also aimed to lead to clarifications for data gaps in other flow meters.

3.3. Analysis Flow Meter Overijssels Kanaal Hanzebrug

The Overijssels Kanaal is a canal that consists of three sections all originating in the province of Overijssel. While two sections form a connection between Zwolle and Almelo, the third section makes a connection with Deventer, which is located south of the abovementioned cities (Canon van Nederland, 2022). The very end of the third section is the part where the flow meter is positioned. Figure 4 gives a clear overview of the end of the third section, which flows through Deventer.

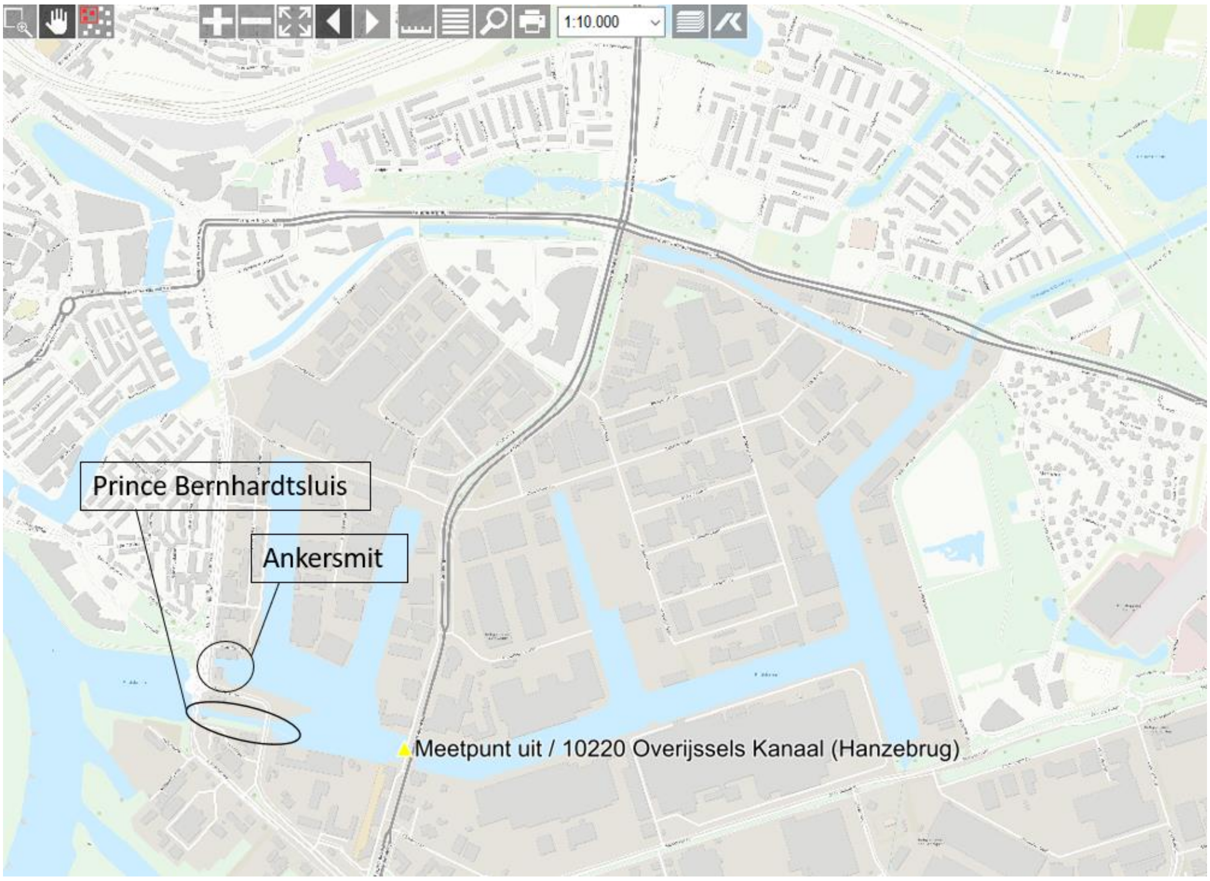


Figure 4 Study area of flow meter Overijsels Kanaal Hanzebrug

The flow meter is installed under the Hanzebrug, a drawbridge that enables the Hanzeweg to cross the water. On the west side of the Hanzebrug the industrial port of Deventer is present. The port of Deventer is a port with two branches and 20 hectares of water surface (Port of Deventer, 2022). Combined with a docking site of 40 hectares directly connected to the port, over one million metric tons of trans-shipment takes place each year. The port of Deventer is connected to the river IJssel by the Prince Bernhardsluis, a sluice that can be utilized by watercrafts with a maximum length and width of respectively 100 and 11.5 meters. The wooden sluice is designed by Witteveen en Bos and constructed in 1951 (HSSN, 2022). The lower sluice threshold on the side of the IJssel is -1.6m NAP, while the upper sluice threshold on the canal side is 2.3m NAP.

Next to the sluice, a pumping station is present. This pumping station is called Ankersmit and consists of four electric pumps with jackscrews. During dry periods, pumping station Ankersmit is utilized to provide sufficient water upstream of the canal. East from the flow meter, the canal flows through the industrial area of Deventer. The three side-branches of the canal, two large branches and one smaller branch, all have a dead end.

The flow meter under the Hanzebrug is an ADCP meter (see Section 4.1). This ADCP meter has been providing data since early 2011. Figure 5 displays the time series of flow meter Overijssels Kanaal. The validated graph, called 'Momentaan V', lays over the unvalidated time series 'Momentaan O' since the unvalidated time series has larger peaks and will still be visible. Unreliable values of the outliers in the unvalidated time series are omitted in the validated time series, hence the latter will be analysed as mentioned in the methodology. The discharge data shows an annual trend of increasing and decreasing discharge magnitudes in both stream directions, indicating that water inflow and outflow both occur. This pattern is very clear between 2015 and 2019 but is also recognizable before and after this period, albeit two large data gaps from August 2012 to November 2012 and June 2013 and September 2013 make it difficult to see the annual pattern in 2012 and 2013. Throughout the whole time series, many minor discharge peaks are present directed in both flow directions, while the largest part of the fluctuating discharges lays between -5 m^3/s and +8 m^3/s.

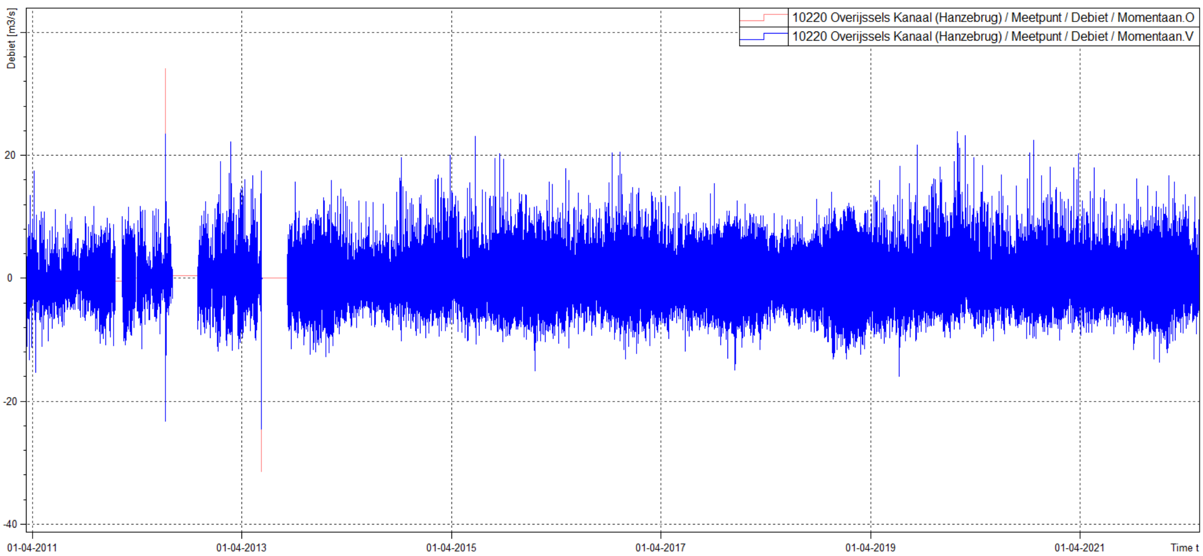


Figure 5 Unvalidated and validated discharge time series of flow meter Overijssels Kanaal

To get better insights into the data, several fragments of the time series are analysed in detail. Figure 6 displays such a small fragment. Discharge values for approximately three days show that the values are alternating between positive and negative values during the day, with a periodicity of about 15 minutes. While the majority of the discharges have values between 1 m^3/s and -1 m^3/s, several larger discharges are measured as well. Multiple fragments are analysed, and the pattern shown in Figure 6 is present throughout the whole time series. The only difference between the fragments is the magnitude of the discharges, although this difference appears to fit the summer and winter season trend.

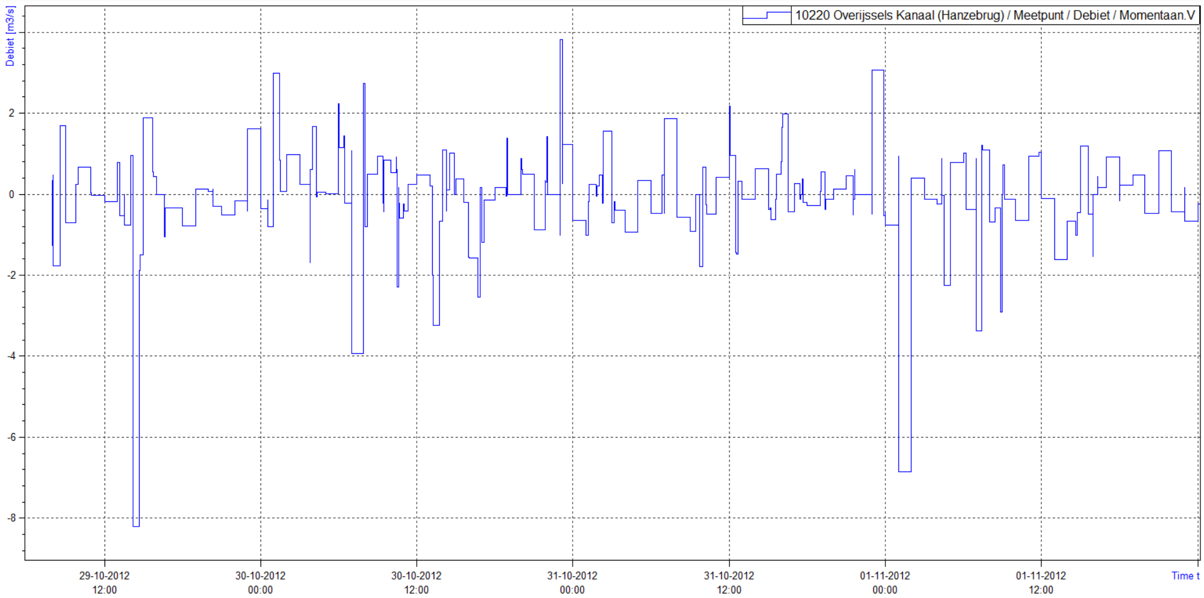


Figure 6 Fragment of the validated discharge time series of flow meter Overijssels Kanaal

Solely based on the discharge time series two main anomalies come forward. First, discharges are alternating between positive and negative values during the day. When a discharge is constantly alternating between positive and negative values, it would mean that the water through the waterway constantly switches its flow direction. Since the water in a canal can only flow into two directions, it would mean that the water repeatedly flows upstream and downstream. Second, several sudden peaks are present in the time series. This anomaly arises for both positive and negative discharges.

To acquire more knowledge about the flow meter data, multiple parameters are analysed besides the discharge. Figure 7 shows the time series of the discharges of flow meter Overijssels Kanaal together with the flow velocity data and the water level data, all three validated. It is remarkable that the water level data are not collected simultaneously with the discharge data and the flow velocity data. Although the flow velocity appears to match the discharge profile on the global overview, its values are unrealistically high with a magnitude of over 100 cm/s in both directions. Subsequently, the water level data graph contains several increases and decreases with an annual periodicity. This means that the water levels are deliberately higher during the summer period, while lower values are persisted during the winter season. The water levels during the summer period vary between 5.73 meters NAP and 5.82 meters NAP, while the water levels during the winter season vary between 5.68 meters NAP and 5.76 meters NAP. This large spread seems like a continuous noise that is present. Therefore, the water level data must be studied in more detail to verify whether this spread can be considered as noise. Finally, several peaks on both the upper and lower part of the graph are present which seem to be caused by noise.

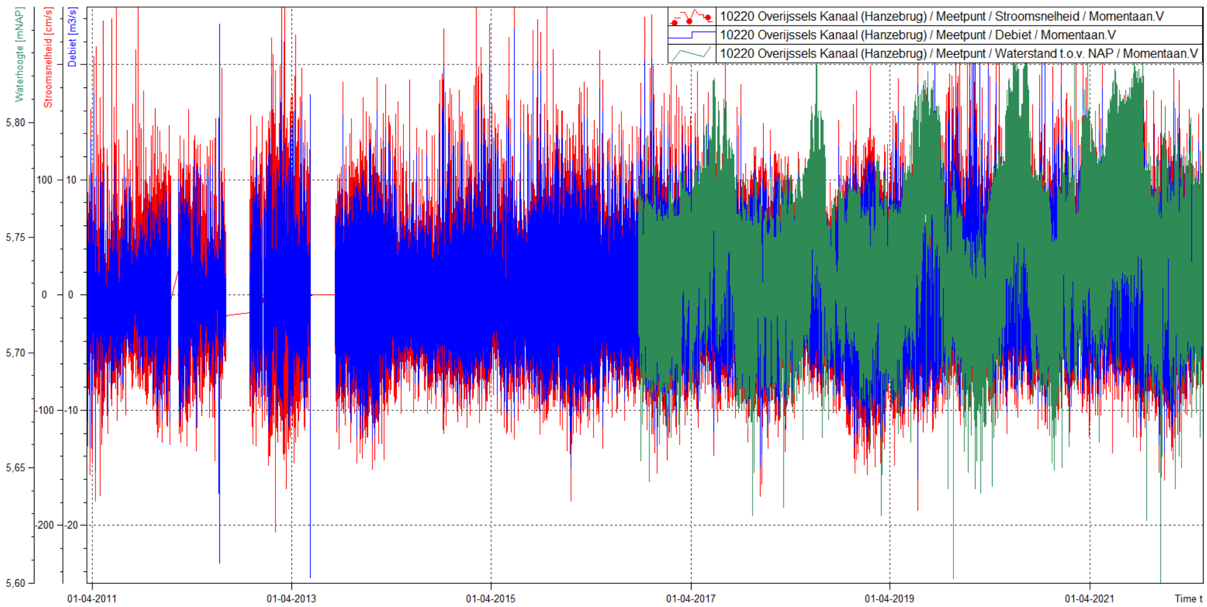


Figure 7 Time series of the discharge, flow velocity, and the water level of flow meter Overijssels Kanaal

A more detailed visualization of multiple fragments shows that the flow velocity graph fits the discharge graph accurately, while the water level pattern does not fit these two graphs. Increases, decreases, and rather constant fragments seem to match in every scenario for the flow velocity and discharge data. Figure 8 gives an overview of this pattern for four weeks during the summer period of 2019. At first, the water level appears to fluctuate frequently as observed above. Within this fragment it fluctuates between 5.72 metres NAP and 5.77 metres NAP, indicating a total water level difference of 5 centimetres. Since the fluctuation occurs constantly for the most part, it can be stated that this trend is not an arbitrary noise. However, the question arises what causes this constant fluctuation. On a 24-hour fragment it is visible that maxima and minima are reached every six hours, meaning that the time difference between a maximum and minimum water level is three hours. This process occurs both adays and overnight. However, the pattern is disturbed in the second half of the visible pattern and higher water levels occur with larger repetition times of approximately 10 hours. This constant water level fluctuation occurs as well with slightly deviating patterns. For example, the periodicity of the fluctuation becomes irregular, or the relation between the duration of the water level rise and water level descent change. Appendix A1 shows an example of such a pattern, where the time differences between maximum and minimum water levels are less constant than the scenario shown in Figure 8. After investigating multiple fragments from the whole time series, it became clear that these periodic trends are present all the time, albeit incidentally disturbed for a short period.

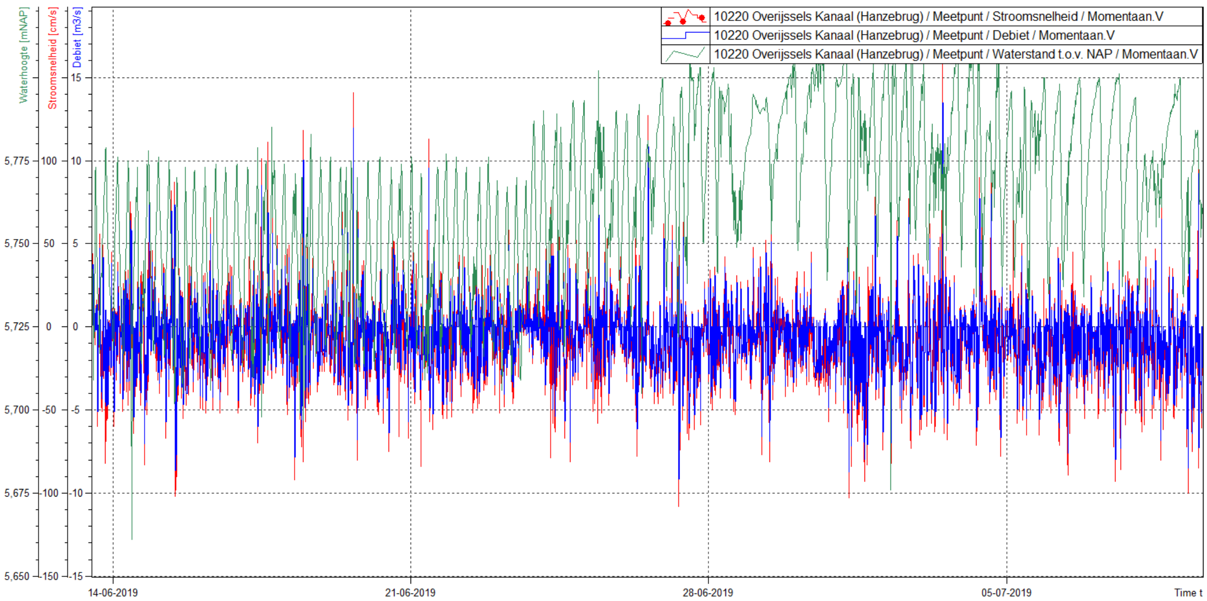


Figure 8 Fragment of the time series of the discharge, flow velocity, and the water level of flow meter Overijssels Kanaal

Another data source that was considered was the data acquired by hydraulic structures within the study area. The time series from pumping station Ankersmit are known since 2017 and are shown in Figure 9. The gravity flow of water into the river IJssel occurs during the same period each year during the winter season, while the water inflow into the Overijssels Kanaal only occurred during one period according to the time series, which seems unlikely. It may be possible that time series were not stored before.

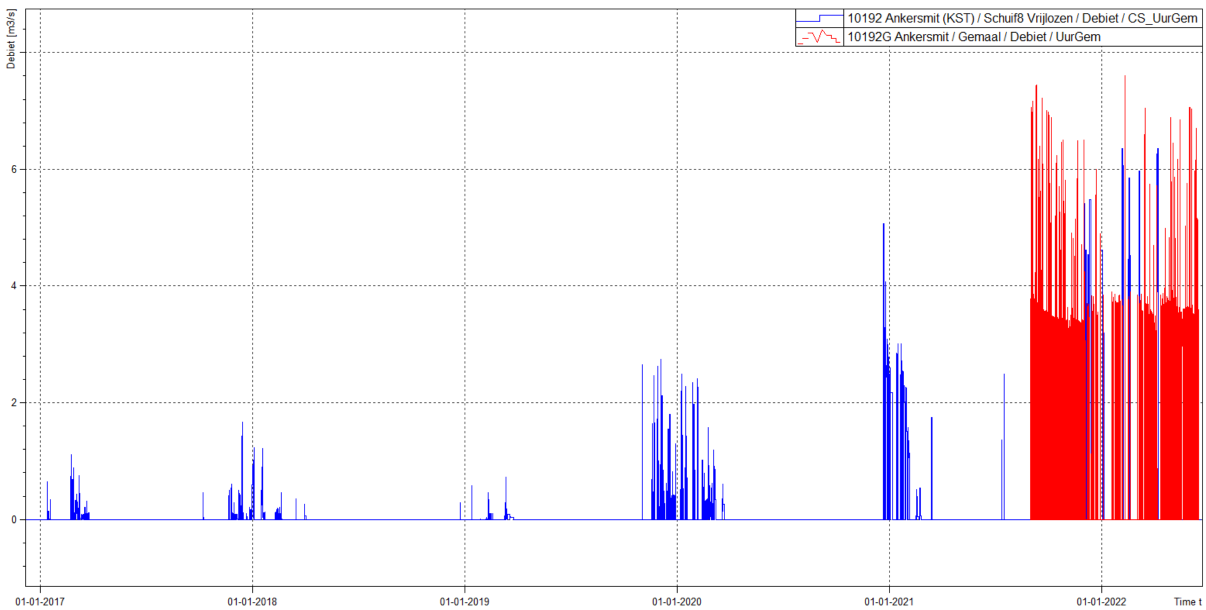


Figure 9 Time series of the discharges from gravity flow and pumping of pumping station Ankersmit

Figure 10 shows that the calculated discharges from the hydraulic structure are often of the same magnitude and only deviate incidentally, where larger and sometimes lower peaks are present in the graph. The Figure also shows that the gravity flow of water into the river IJssel indeed occurs during the winter season, while water was also discharged into the river IJssel during April, which can still be supported by the fact that high water periods can also occur in the beginning of the spring season.

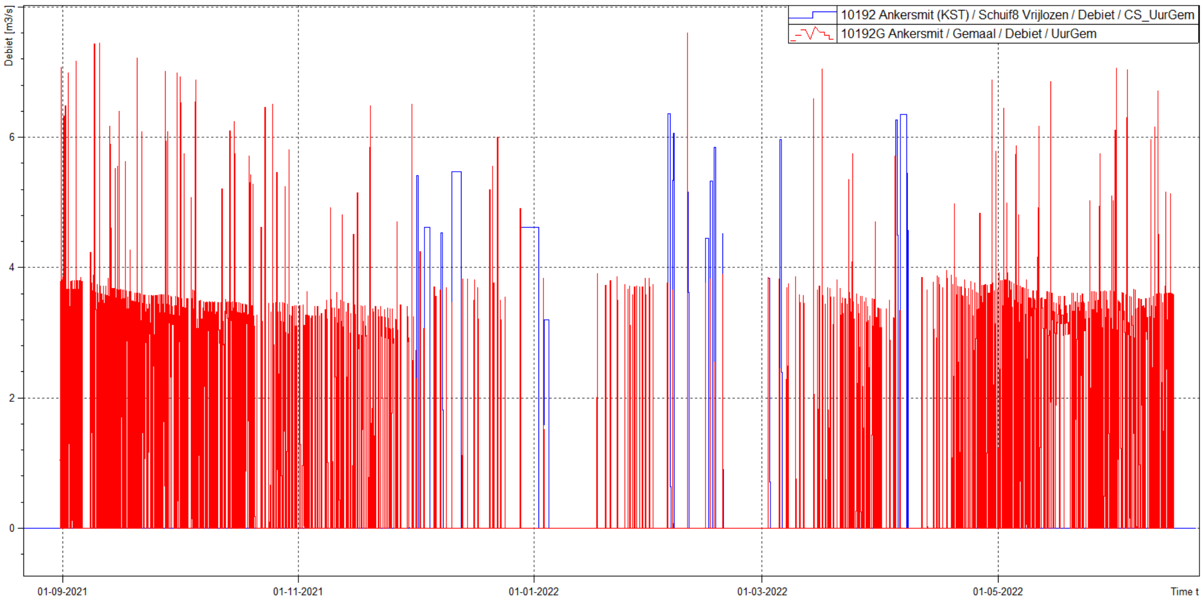


Figure 10 Fragment of the time series of the discharges from gravity flow and pumping of pumping station Ankersmit

Figure 11 gives a detailed fragment of approximately a week of the time series provided by hydraulic structure Ankersmit plotted against the discharge data obtained by the flow meter. In this fragment, no water is discharged into the River IJssel, but water is discharged into the Overijssels Kanaal. On average, the pumping station discharges approximately 3 m^3/s into the river IJssel when it is switched on. Although several of these peaks fit the discharge graph from the flow meter, a large part of the peaks differs from the pattern from the flow meter data.

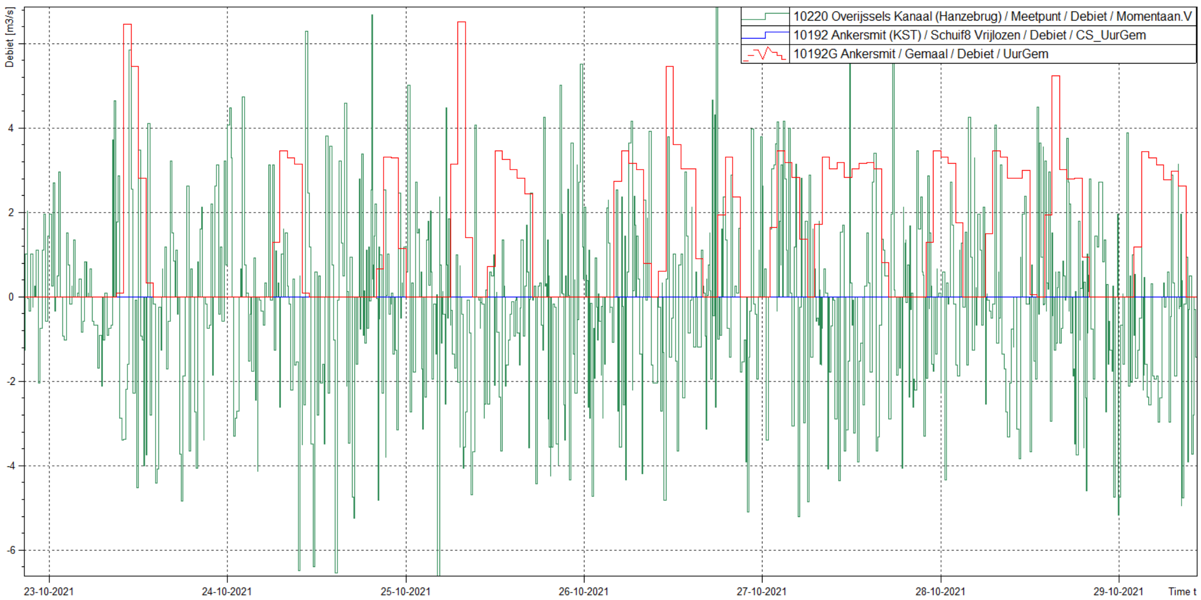


Figure 11 Fragment of the time series of the discharges from gravity flow and pumping of pumping station Ankersmit compared with the discharge time series from the flow meter

3.4. Analysis Flow Meter Streukelerzijl Groote Grift

Located at the east side of Hasselt, a city located in the province of Overijssel, two canals named Dedemsvaart and Groote Grift are located and separated from the river Zwarte Water by respectively pumping station Galgenrak and Streukelerzijl, as shown in Figure 12. Both pumping stations have a weir included as well, which makes it together with the pumping system possible to manage the water flow in both directions. Since the water level in the Dedemsvaart is higher than the water level in the Groote Grift and pumping station Galgenrak cannot manage the water drainage in all cases, weir Fissele can be utilized. Through this weir water from the Dedemsvaart is transported to the Groote Grift and drained by pumping station Streukelerzijl together with the surplus amount of water from the Groote Grift. Throughout the year, water is drained into the Zwarte Water to keep the water levels at a specific height suitable for the adjacent farmland. During dry periods, water is pumped into the area to prevent a water deficit in the area.

Figure 12 Study area of flow meter Streukelerzijl Groote Grift

Flow meter Groote Grift was installed by Aqua Vision, an independent hydro- and oceanographic consultancy (Aqua Vision, 2022). The time series from the discharges are available since the end of 2016 and are displayed in Figure 13 below. Again, the pink coloured 'Momentaan O' time series represents the unvalidated data, while the blue 'Momentaan V' time series are validated. Until mid-2020, the time series appears to have a rather stable pattern. However, the discharges fluctuate between just below 0 m^3/s and 4 m^3/s. From this Figure it is unclear whether this is caused by noise or that a periodic event is occurring. After this trend, a data gap between September 2020 and April 2021 is present, after which the pattern slightly deviates from the pattern before the data gap. Furthermore, multiple outliers are visible in the time series. However, certain peaks consist out of more data points. These peaks are mostly present during the winter, where a high-water period normally takes place. Appendix A2 Appendix shows an example of these described peaks. Based on this pattern and the period where these high discharges occur, it can be assumed that these large peaks during the winter season are caused by high water events.

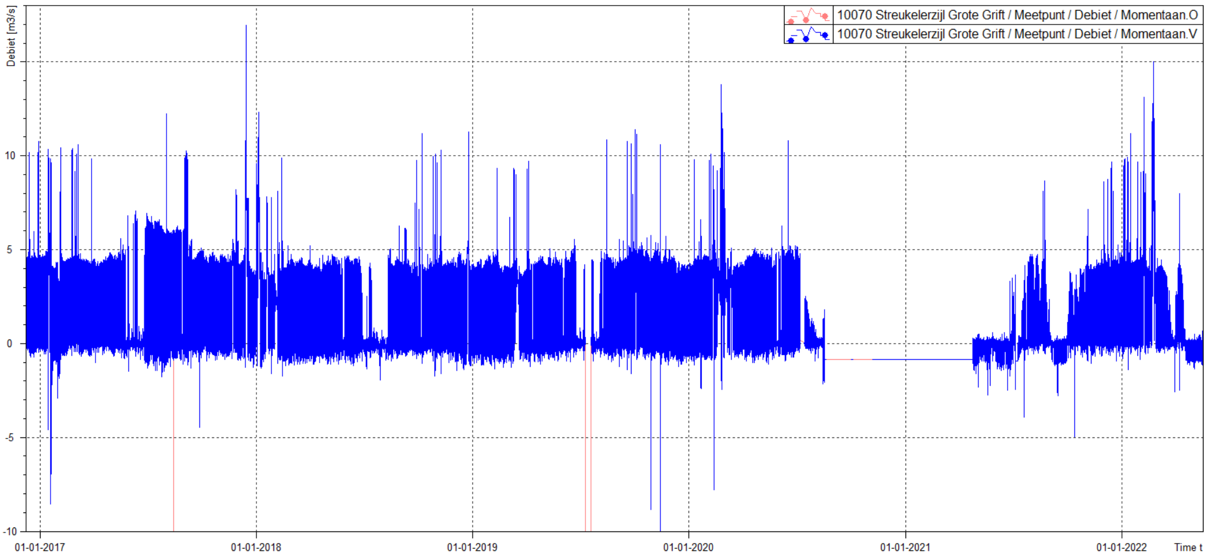


Figure 13 Unvalidated and validated discharge time series of flow meter Groote Grift

A closer look at the time series shows that the fluctuation of the discharges has a periodic pattern for a large period of the time. In Figure 14 it is clearly visible that the discharge increases to approximately 4 m^3/s for a short period of about 45 minutes, after which it rapidly decreases to values around 0 m^3/s. The frequency of this event is approximately six hours. During summer periods, this phenomenon is interrupted, and discharge fluctuations occur occasionally if water is discharged to the Zwarte Water. Besides the discharges, Figure 14 displays the flow velocity as well. Over the whole time series, the patterns of both graphs fit each other conscientiously, while the magnitudes are constant within the time series as well. Unfortunately, the time series of the water level is not available.

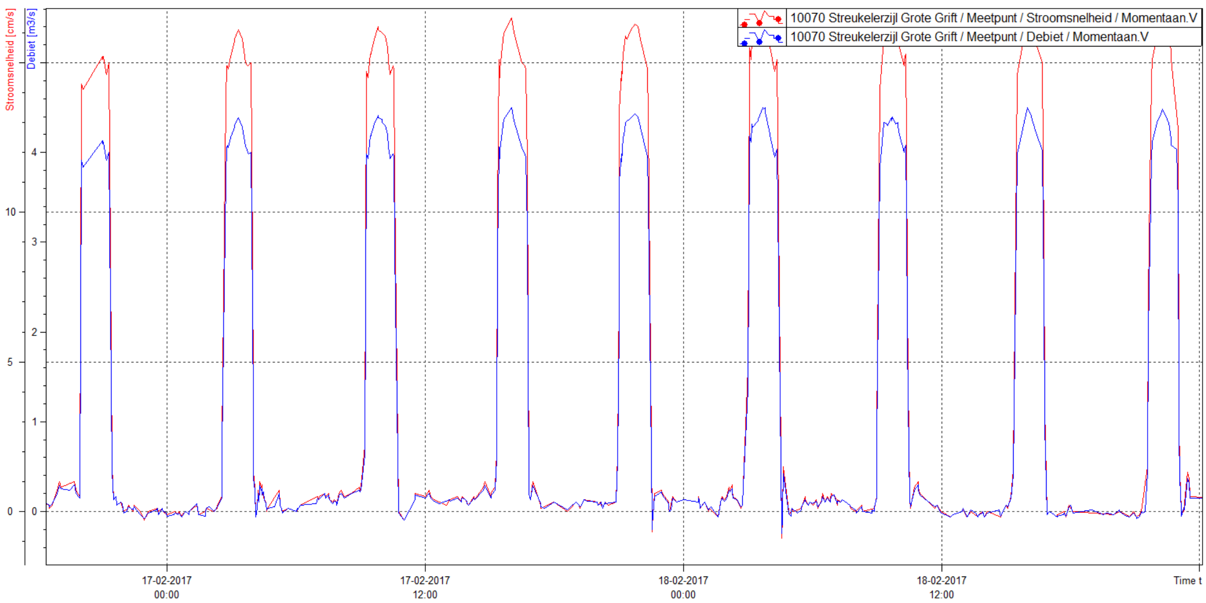


Figure 14 Fragment of the time series of the validated discharge and flow velocity of flow meter Groote Grift

Furthermore, data collected by artefacts is examined to get more acquainted with the study area. The discharges measured by pumping station Streukelerzijl are marked in red in Figure 15, while the accompanying weir indicates the discharges in black. Weir Fissele is included in green and provides the exact same pattern provided by the weir component of Streukelerzijl, which is remarkable since weir Fissele is rarely active, since water from the Dedemsvaart is usually discharged directly into the Zwarte Water by pumping station Galgenrak.

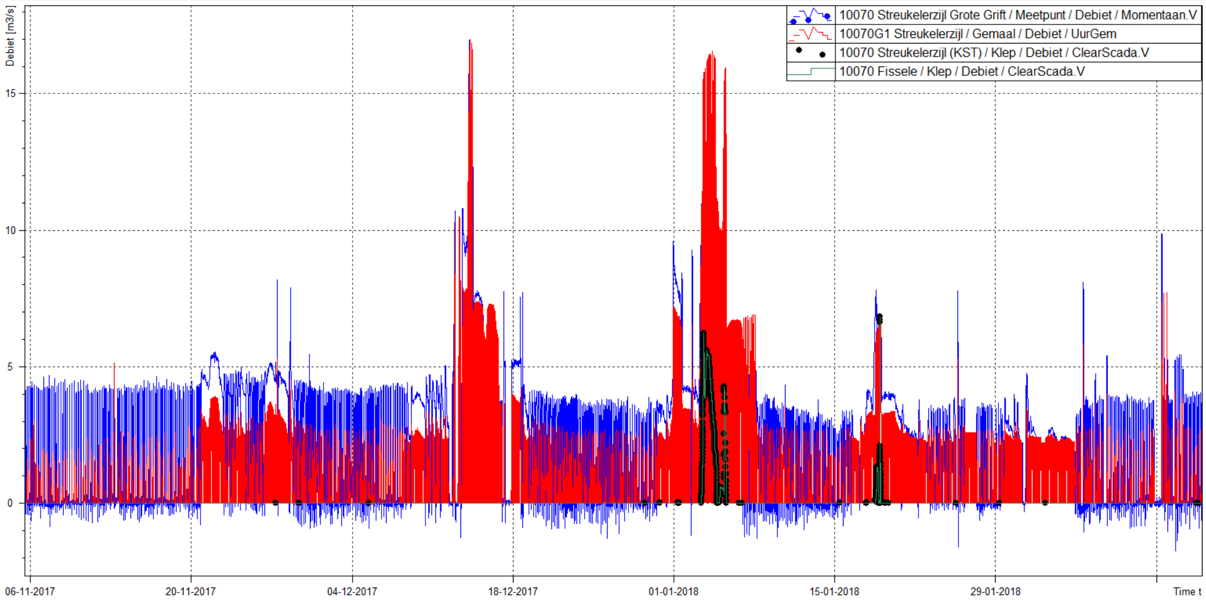


Figure 15 Time series of the validated discharges of flow meter Groote Grift, pumping station and weir Streukelerzijl, and weir Fissele

Although the graph from pumping station Streukelerzijl fits the graph from flow meter Streukelerzijl based on the shape, the magnitude deviates. Figure 16 shows a more detailed fragment where it is clearly displayed that the discharges measured by the pumping station have a magnitude of approximately 2 m^3/s, while the discharges measured by the flow meter are twice as high. However, the pumping station measures higher discharges than the flow meter during high water periods.

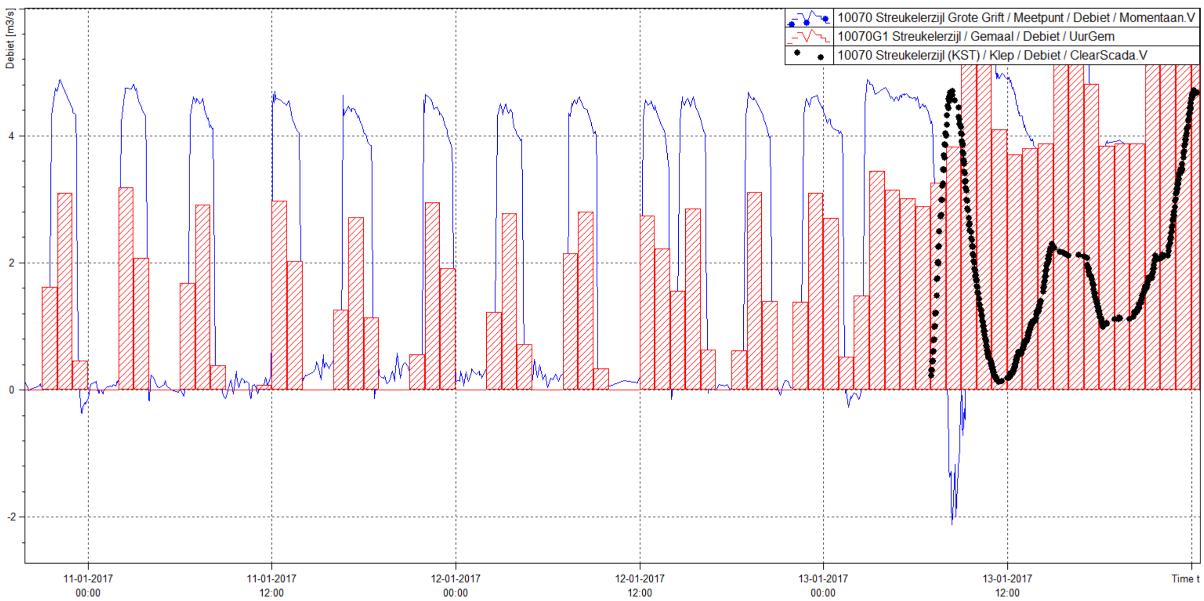


Figure 16 Fragment of the time series of the validated discharges of flow meter Groote Grift, pumping station and weir Streukelerzijl

3.5. Analysis Flow Meter Drentsche Hoofdvaart

Within the city of Meppel, located in the province of Drenthe, many waterways stream and converge. One of these waterways is the Drentsche Hoofdvaart, a 230-year-old canal that flows from the province's capital Assen towards Meppel. Although the canal was utilized for commercial purposes, one of them being the exploitation and transport of peat, it is now utilized for recreational navigation (Geheugen van Drenthe, 2022). The canal has a length of approximately 47 kilometres and six sluices are present (Werkgroep Drentsche Hoofdvaart, 2022). The end of the canal merges with canal the Oude Vaart in the northern part of Meppel, after which they merge with canal Meppelerdiep. Just above this intersection a flow meter is located. Figure 17 shows the waterways including the location of the flow meter. Furthermore, an artefact is visible as well, the Paradijssluis. This artefact consists of a sluice on the east-side and a pumping station with weir on the west-side. Generally, water is flowing southwards towards the Meppelerdiep. However, water is pumped northwards during dry periods to provide the upstream areas of sufficient water for functions such as agriculture. Downstream of the flow meter, a relatively small pumping station is present called Haveltermade. Due to the minor quantities of water that the pumping station drains into the canal and based on its location, this pumping station is neglected in the analysis. However, its water level data will be addressed as well.

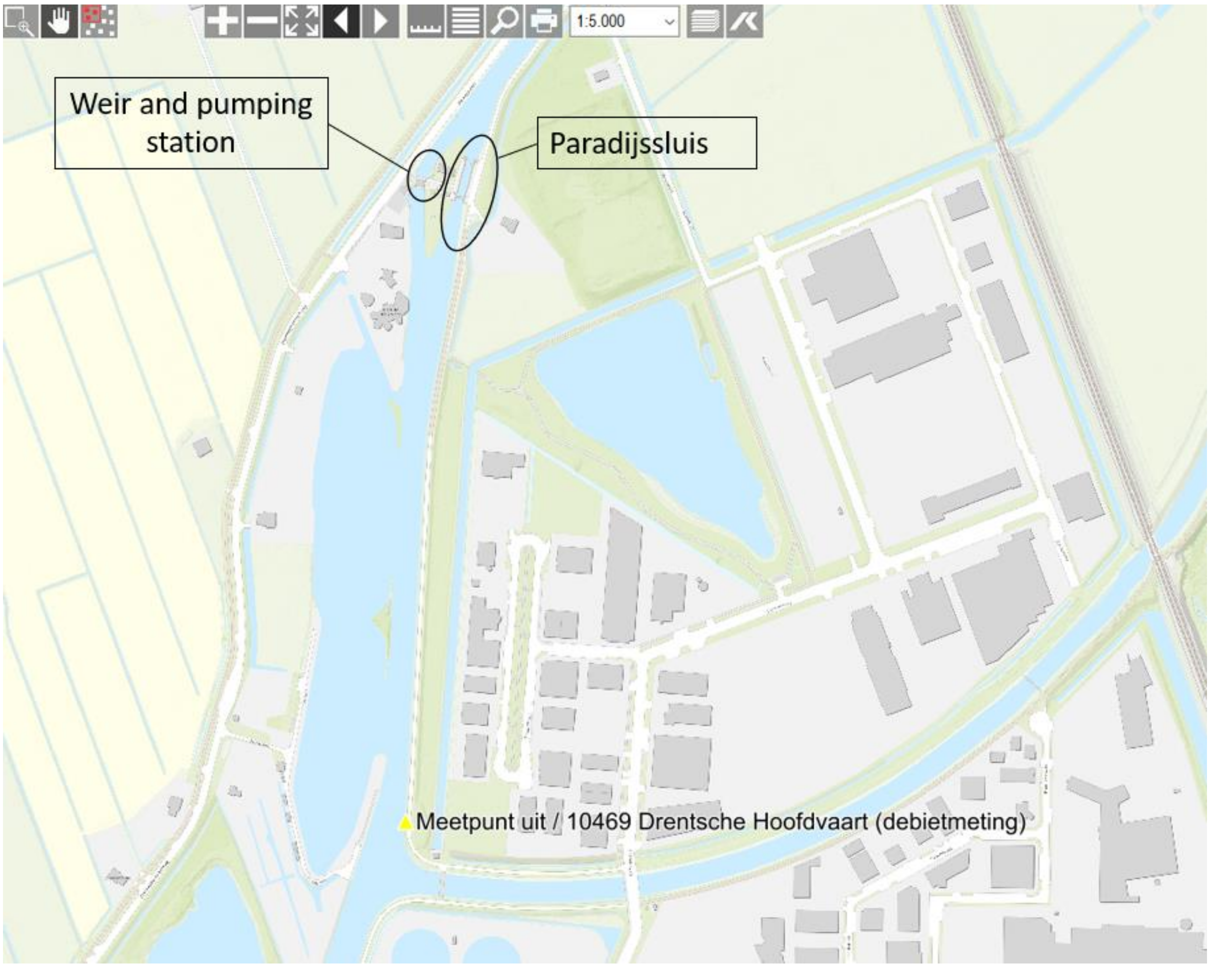


Figure 17 Study area of flow meter Drentsche Hoofdvaart

The abovementioned process with water discharge and provision is also recognizable in the flow rata data collected by the flow meter for a large part of the time series that is shown in Figure 18. Until 2019, an annual pattern can be recognized where discharge magnitudes on the global level appear to be rather similar within these annual patterns. However, the disturbed pattern from 2006 until mid-2009 is remarkable, as it seems like this period contains less discharge data due to its low density. Subsequently, after a minor data gap from 30 October until 13 November in 2019 (see Appendix A3 for detailed visualization), all discharges are positive, implying a constant water outflow, which is unrealistic based on the annual trends from 2006 up to and including 2019. Besides that, the magnitude of the discharges does not correspond with the previous pattern, although the high water period from February 2022 seems to be detected by the flow meter (Appendix A2), which follows a similar pattern in comparison with other high discharge periods occurring during the winter season. It could be possible that only the water outflow data is stored.

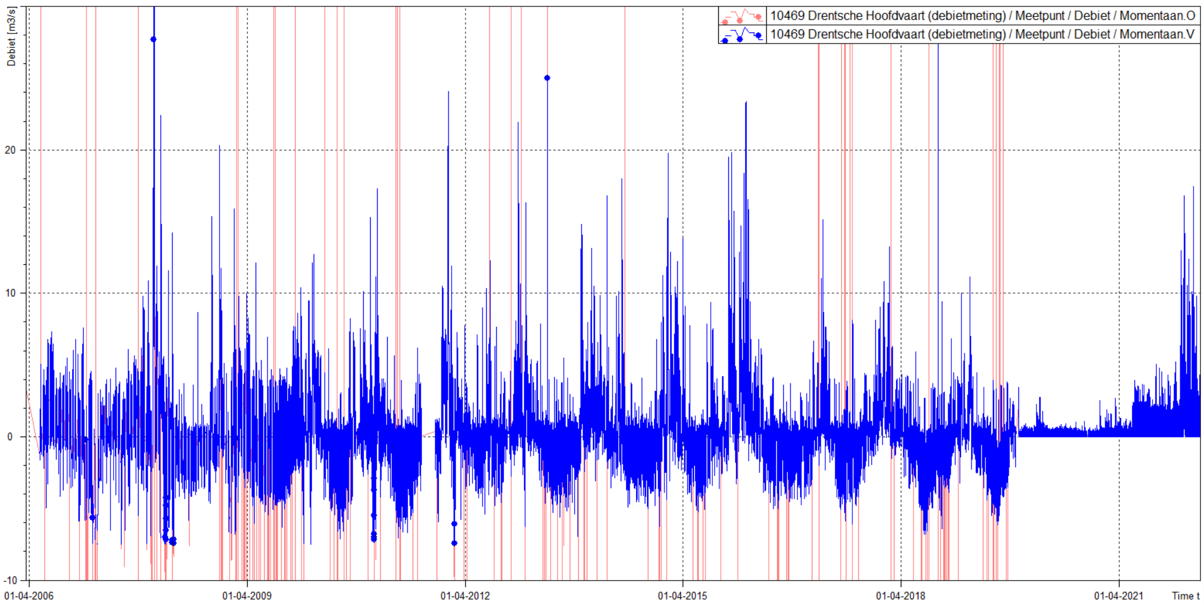


Figure 18 Unvalidated and validated discharge time series of flow meter Drentsche Hoofdvaart

The time series are also compared with the time series from the neighbouring flow meter in the Oude Vaart which is shown in Figure 19. Despite that the Oude Vaart only has a water outflow and does not supply water upstream, the drainage pattern appears to be slightly similar based on the annual water discharges during the winter season. Obviously, the discharges are not exactly similar since the flow meters are installed in different waterways, but the parabolic shapes for the water discharge in downstream direction is rather similar, indicating that both flow meters measure the discharges simultaneously.

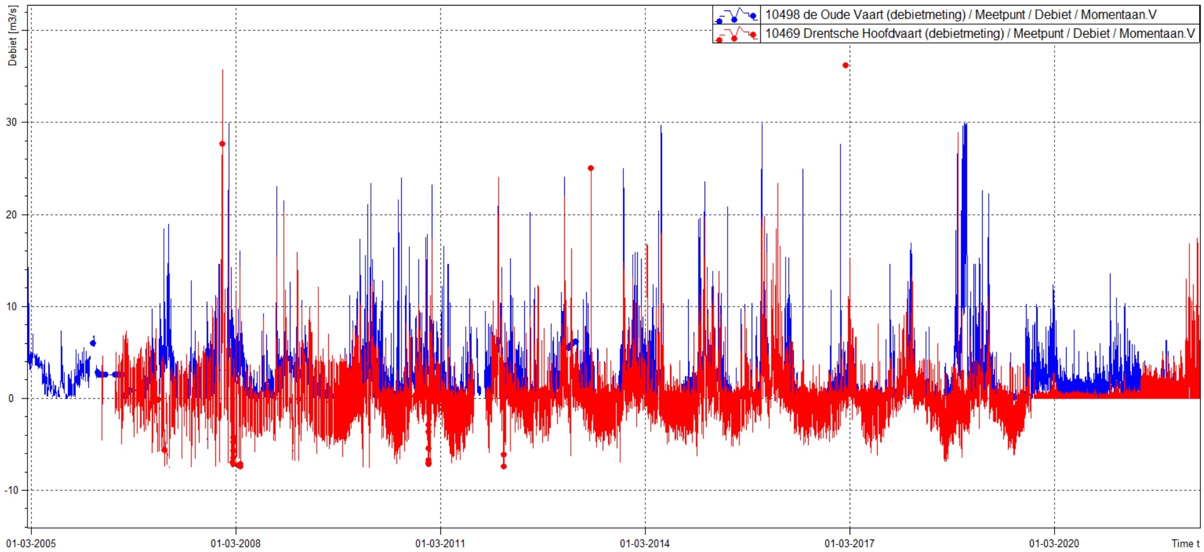


Figure 19 Validated discharge time series of flow meter Drentsche Hoofdvaart and flow meter Oude Vaart

A closer view on the time series reveals that the first years of the time series indeed contain multiple data gaps, which is shown in Appendix A4, while a certain pattern is also present during the whole period until the data gap in November 2019, apart from the year 2009. This pattern is present in three variations. Figure 20 shows the first variation. It is clearly visible that flow meter measures jumps, which only occur at 12.00 and 0.00 hours. After that, the discharge remains constant until the next jump. Appendix A5 and Appendix A6 show the other two alternatives that have the same type of anomaly, where one variant has a lot of noise between the upper peaks, while the third variant appears to have jumps for positive discharges only.

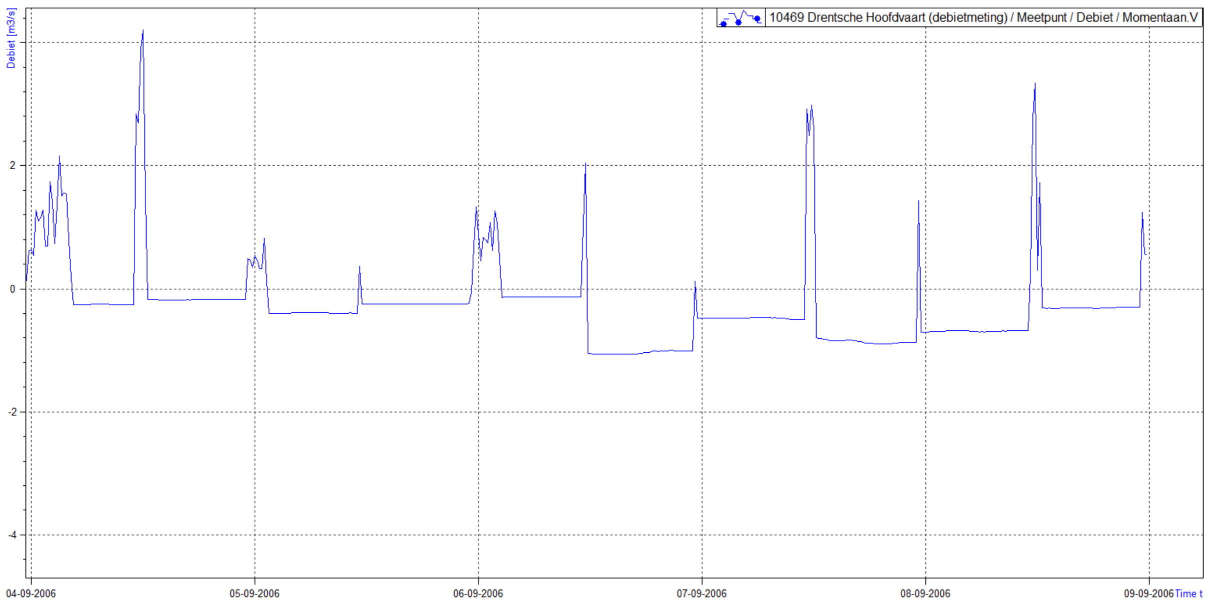


Figure 20 Fragment of the validated discharge time series of flow meter Drentsche Hoofdvaart

Besides the unusual pattern with positive discharges another anomaly comes forward in this flow meter. Figure 21 shows a sudden increase in the discharge by a factor of four, after which the discharge continues with the same fluctuating pattern. It is visible that the fluctuation of the discharges between 0 m^3/s and 0.5 m^3/s go abruptly to a fluctuation between 0 m^3/s and 2 m^3/s. Nevertheless, discharges are rarely exact zero, which would indicate that a continuously water outflow occurs. However, no negative discharges are present in the time series after the data gap in 2019, which is not realistic compared to the annual patterns from previous years. Since the discharges are never exactly zero, the probability that the water inflow values are omitted is also very small. In that case, it is expected that the values are cut off at zero and not above zero.

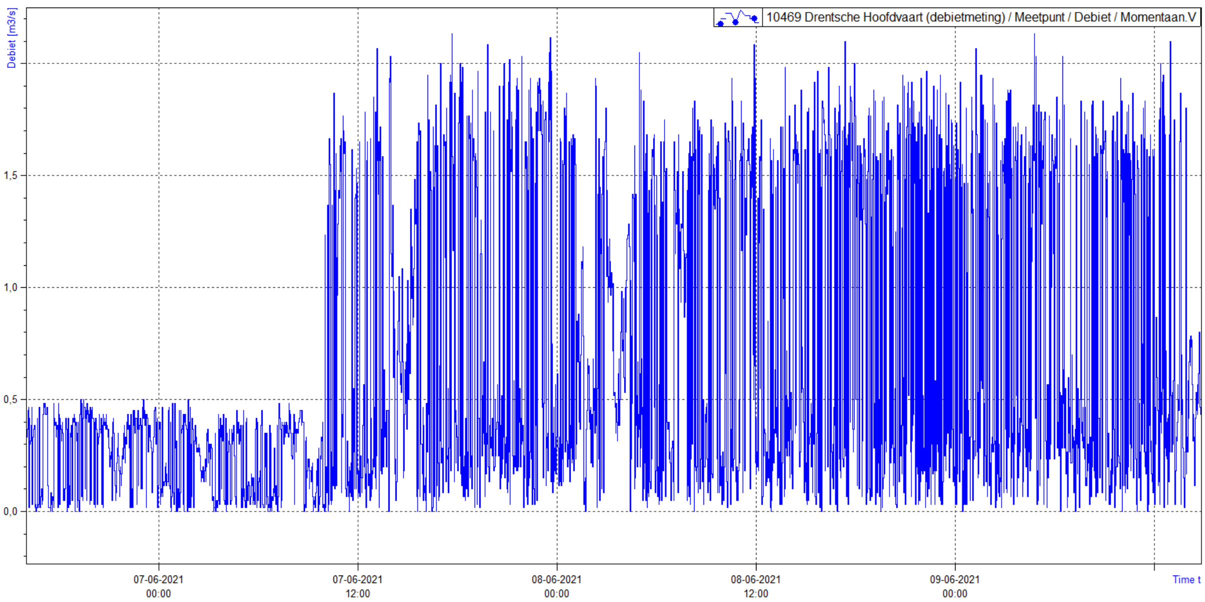


Figure 21 Fragment of the validated discharge time series of flow meter Drentsche Hoofdvaart after the data gap in 2019

Before the data gap in 2019, only the time series of the water level was collected as shown in Figure 22. After that, only the flow velocity was available in Wiski. Because of the large fluctuation in the water level data, the water level data from pumping station Haveltermade is included. The water levels measured by pumping station have smaller differences in magnitudes but measures higher water levels. On top of that, it appears that both graphs are rather similar based on their water level decreases and increases during winter and summer periods. On a closer level it is also visible that both the water level data measure equally increases and decreases during certain periods, while other periods deviate. Appendix A7 shows a fragment where both the matching periods and deviating periods are visible. However, a stable pattern over the years is not recognizable. Regarding the flow velocity it is visible that increasingly negative flow velocities, usually inflow, correspond with increasingly positive discharges, usually outflow. However, since water outflow occurs during a high-water period, it appears that the flow velocity data is reversed. On top of that, such a peak for water inflow would not be possible, since the pumping station has a maximum capacity of 8 m^3/s to provide water upstream, and this peak exceeds that capacity. Altogether, the discharge data is difficult to relate to these time series.

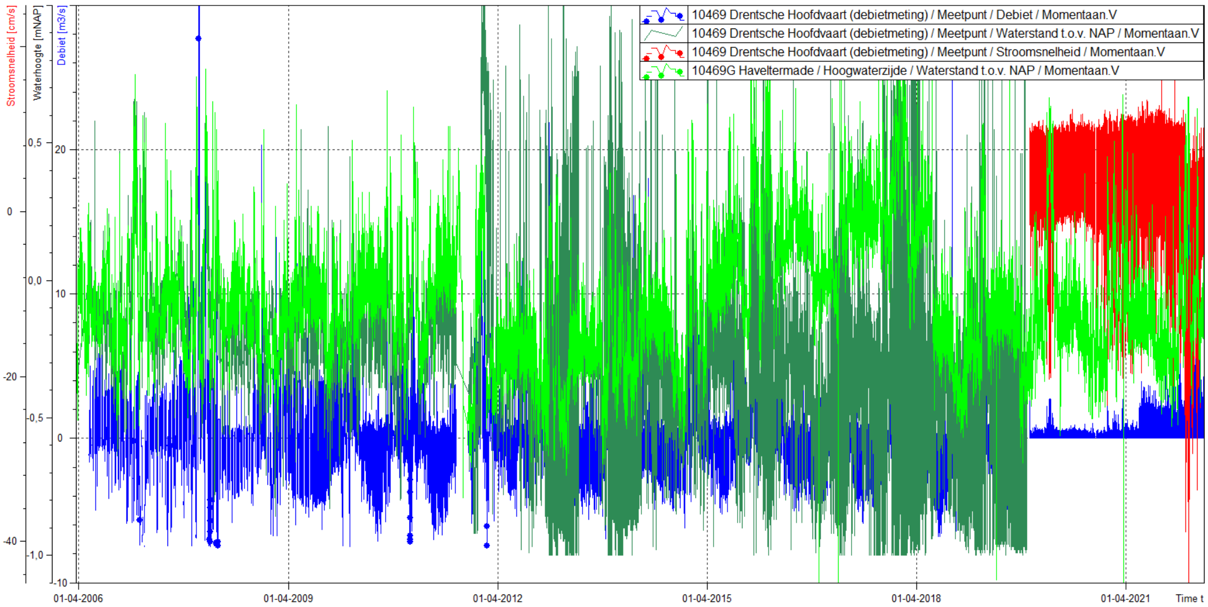


Figure 22 Time series of the discharge, flow velocity, and the water level of flow meter Drentsche Hoofdvaart and pumping station Haveltermade

Figure 23 shows the time series of the discharges measured by the pumping station and the weir in respectively red and green. Since these measurements are available since 2020, only the positive discharge pattern can be compared with these data, because no negative discharge values are present after 2019. First, it is remarkable that the pumping station a larger inflow than the flow meter, while it is also unknown whether the positive discharges from the flow meter indicate a water outflow or water inflow. Furthermore, the discharges measured by the weir are significantly higher than the discharges measured by the flow meter. This could however be possible since weirs could measure the discharges higher than they theoretically are when the weir drowns.

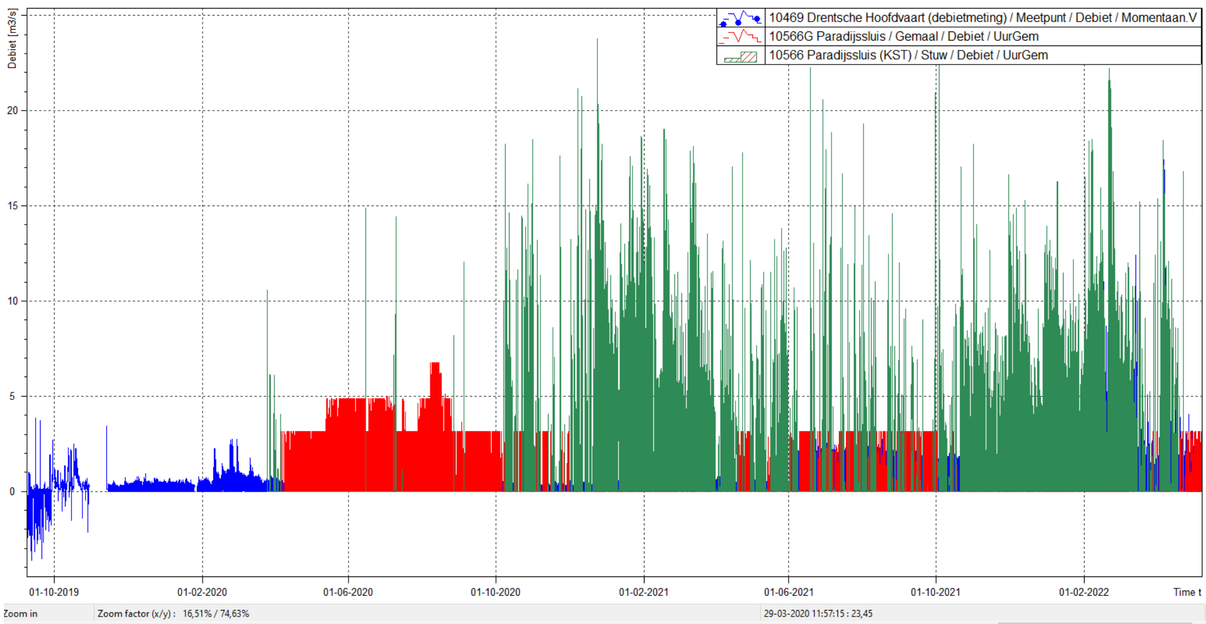


Figure 23 Fragment of the validated time series of the discharges from flow meter Drentsche Hoofdvaart and validated time series from the Paradijssluis

During the first three years of the time series, it is noticeable that the water level data contains multiple data gaps as well. Moreover, when data gaps in the water level time series are present, discharge data is present during that period, which is visible in Figure 24. This is theoretically not possible since the water level data is required to determine the discharge.

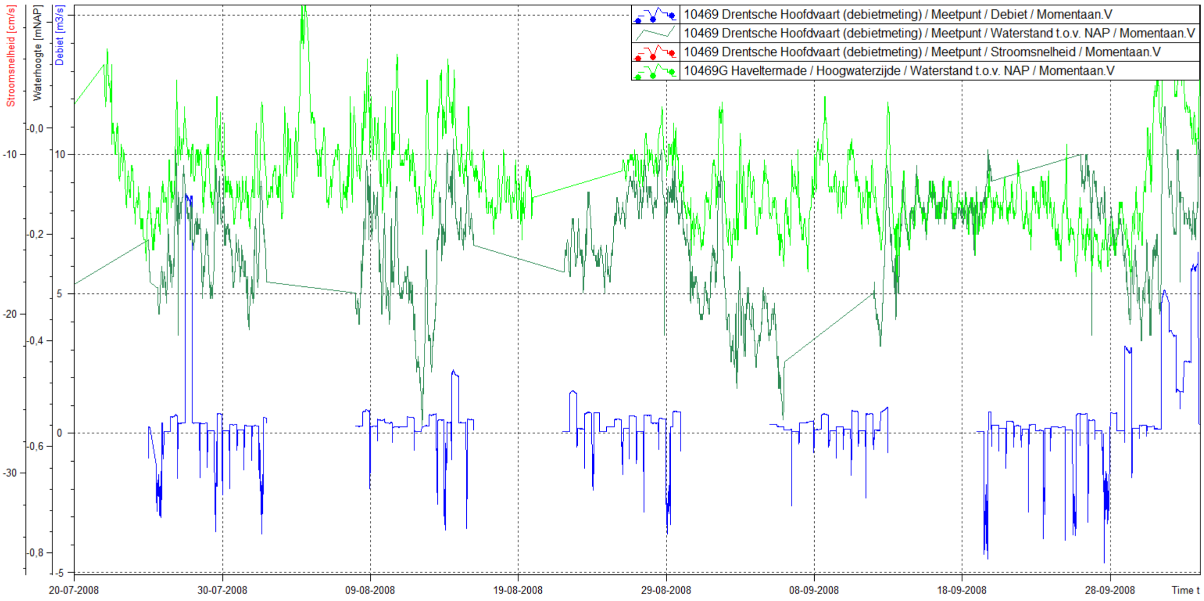


Figure 24 Fragment of the water level data and the discharge data from the flow meter in the Drentsche Hoofdvaart

Next, Figure 25 shows that the weir appears to be alternately active with the pumping station, indicating that water is flowing downstream and being pumped up alternately, which is questionable.

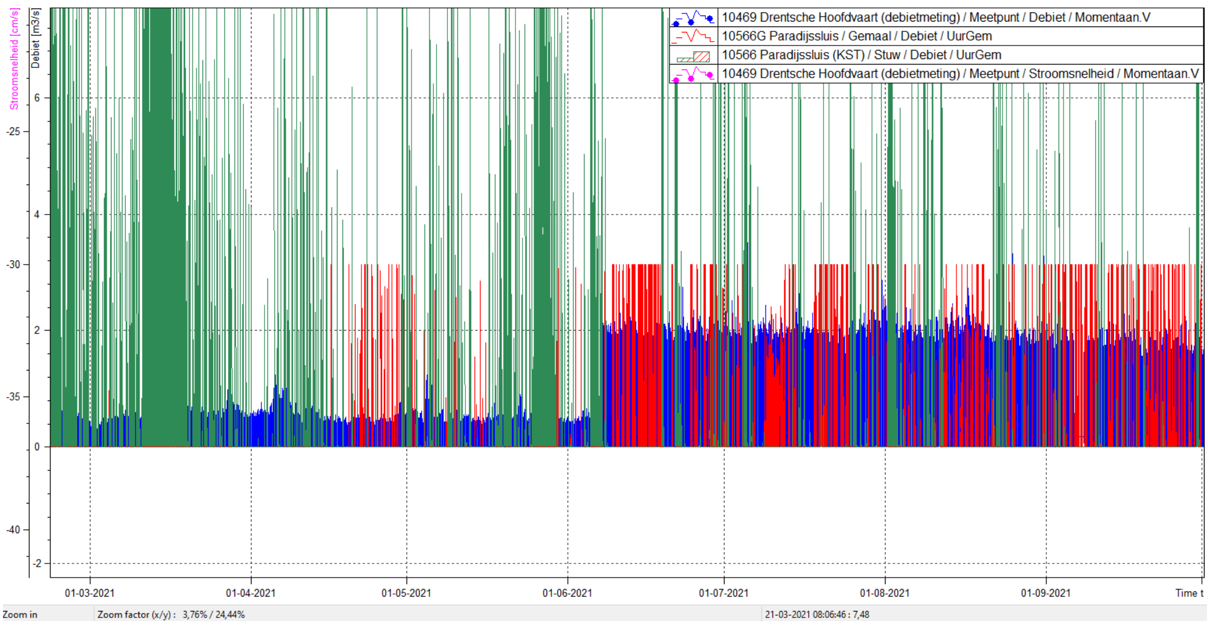


Figure 25 Validated time series from the Paradijssluis where the weir and the pumping station are alternatingly active

3.6. Analysis Flow Meter the Wold Aa

The Wold Aa is a canalised river that ends in the city of Meppel as well and flows into the Meppelerdiep, shortly after it merges with creek De Reest. Including the upper reaches of this slowly flowing stream has a total length of 31 kilometres, where multiple weirs are located (WDOD, 2021). The catchment of the Wold Aa is approximately 13,000 hectares. The main purpose of the Wold Aa is to supply the agricultural needs. Figure 26 shows the downstream end of the Wold Aa that merges with the merged waterway that consists out of the Drenstche Hoofdvaart and the Oude Vaart. These waterways together discharge in canal Meppelerdiep southwards from Meppel. The Figure also shows the location of the flow meter and the locations of two nearby pumping stations that discharge water from the adjacent areas and the location of weir Blijdenstein upstream.

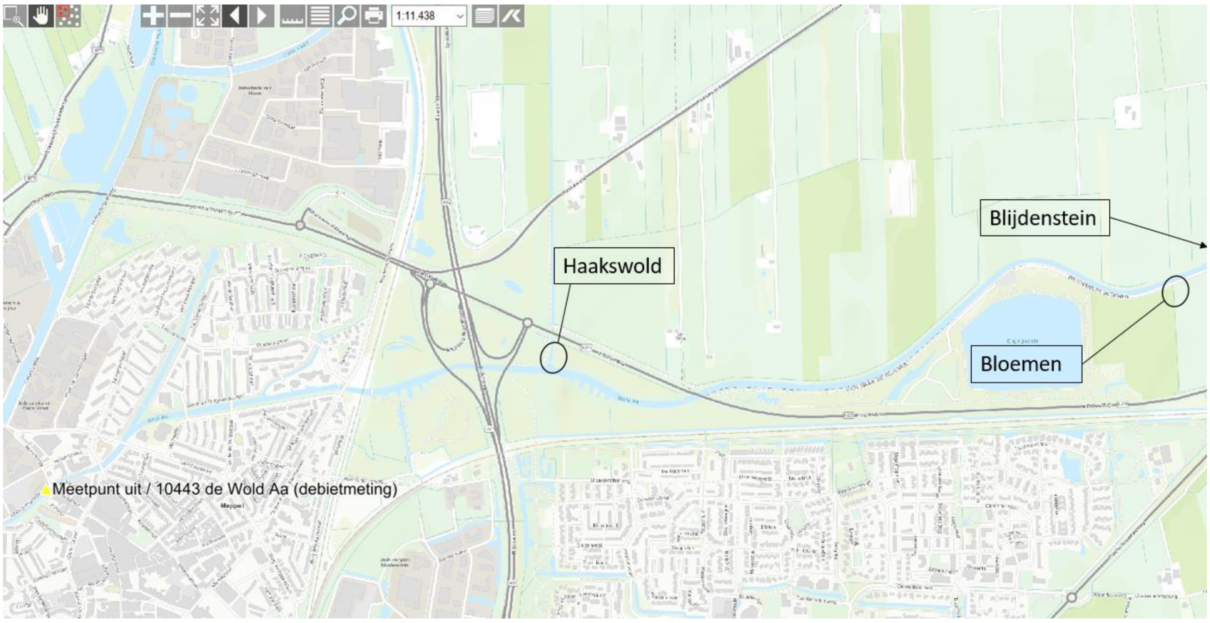


Figure 26 Study area of flow meter Wold Aa

The discharges measured by flow meter the Wold Aa shown in Figure 27 are similar to the discharges gathered by flow meter Drentsche Hoofdvaart which are shown in Figure 18. Similar to the discharges in the Drentsche Hoofdvaart, an annual pattern can be recognized with water water inflow during the summer and water outflow during the winter. Another similarity with the Drentsche Hoofdvaart is that the discharge data pattern from flow meter the Wold Aa is also less dense compared to the data obtained since 2009. Furthermore, the positive discharges after the data gap in 2019 is present in both time series as well. Nevertheless, the disturbed pattern during the first years of the time series seems more realistic than the positive discharges acquired after the data gap in 2019.

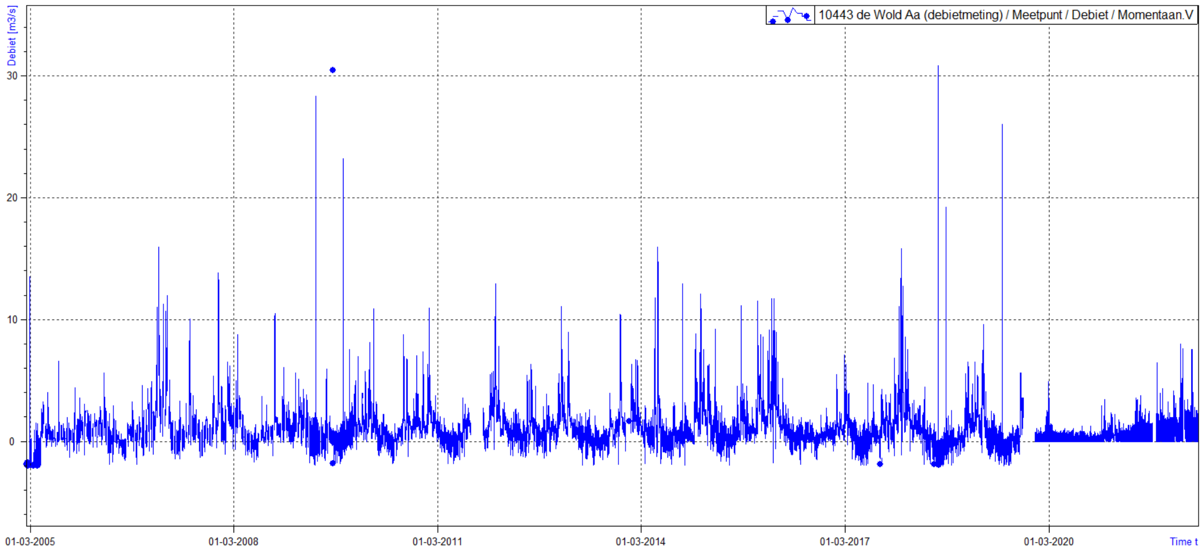


Figure 27 Validated time series of the discharges from flow meter the Wold Aa

The discharges have a fluctuating pattern during the first two months between 0 m^3/s and -2 m^3/s that is shown in Figure 28. Although the pattern appears to look properly, it is remarkable that a water inflow occurs during the winter period, while multiple data gaps are present as well. Besides that, the discharges suddenly increase at the start of May and the pattern changes.

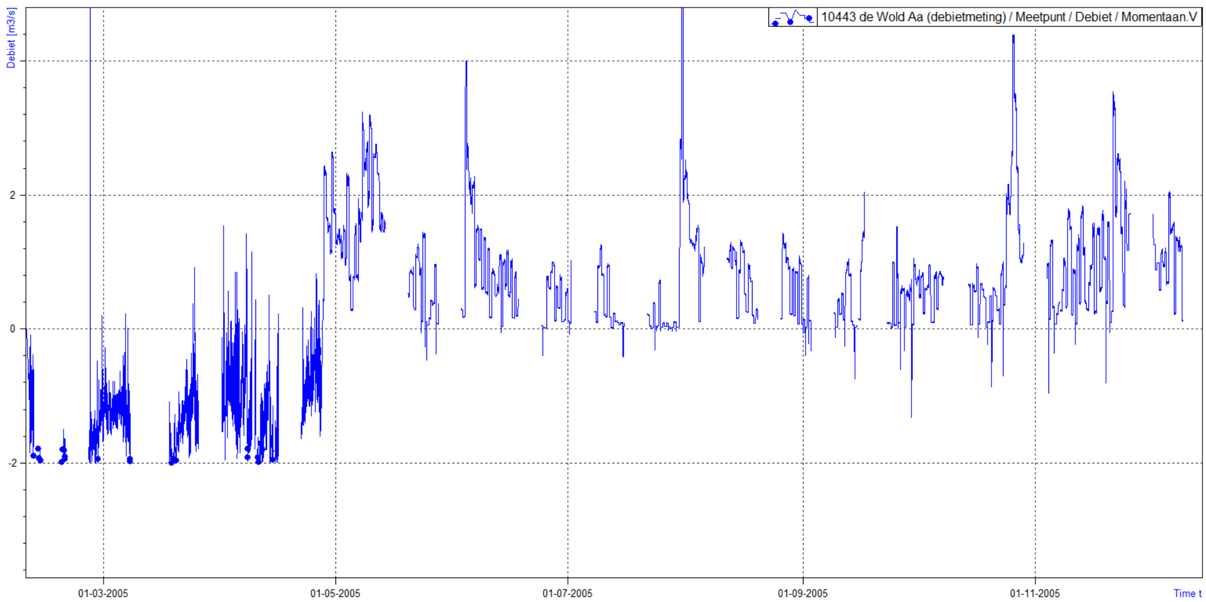


Figure 28 Fragment of the validated time series of the discharges from flow meter the Wold Aa

A closer look on the new pattern reveals that the jumps in the discharges as shown in Figure 20 for the Drentsche Hoofdvaart are present together with many data gaps in this fragment of the time series, which is shown in Figure 29. However, Appendix A8 shows that this step trend only occurs for water outflow values. For water inflow, only steep peaks are present. After multiple fragments were analysed, it became clear that this step trend disappeared in October 2008 but returned in December 2009 until the data gap in November 2019.

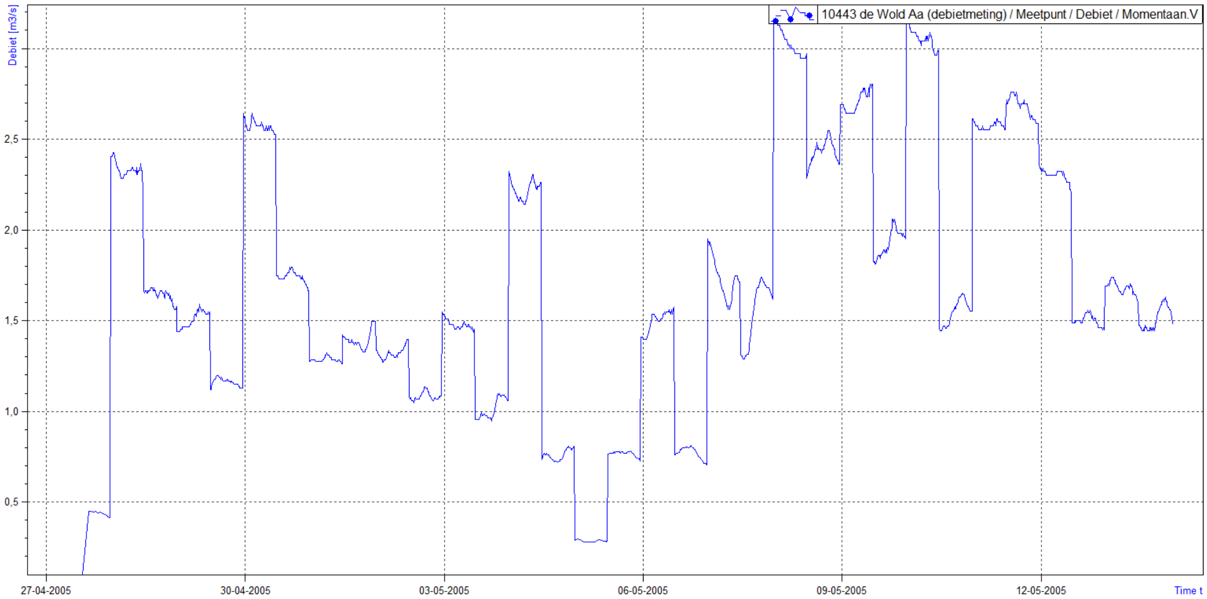


Figure 29 Fragment of the validated time series of the discharges from flow meter the Wold Aa where the step trend is visible

Again, a rather similar pattern comes forward which is shown in Figure 30. Within the water outflow, a sudden jump occurs, just like in Figure 21 for the Drentsche Hoofdvaart. The lower limits of the discharges rise from values just above 0 m^3/s towards 0.5 m^3/s. Despite this minor difference, it is still remarkable that such a rough transition occurs.

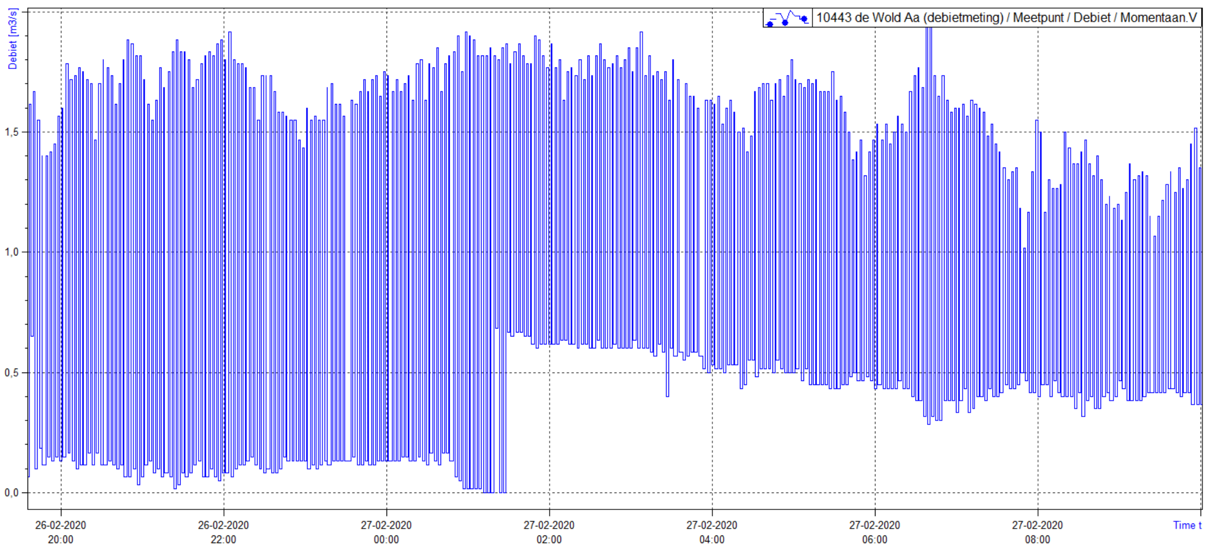


Figure 30 Fragment of the validated discharge time series of flow meter the Wold Aa after the data gap in 2019

Figure 31 shows the time series for the discharge data together with the time series from the flow velocity and water level. Again, flow velocity measurements are stored after the data gap in 2019, albeit the water level data is also available after the data gap, as opposed to the water level data from the Drentsche Hoofdvaart. For a large part of the water level time series the annual patterns are recognizable. While the water level reaches values just below 0 meters NAP during summer periods, water levels descent towards -0.5 meters NAP during the winter. Nonetheless, the water level data contains a lot of noise, where the fluctuation is certain scenarios has a nett difference of over 2 meters, for example in 2018 and 2019 where the values fluctuate between -0.75 meters NAP and +1.5 meters NAP. This net difference of 1.25 meters is very noticeable and is not physically possible, especially not when the water level bridges this difference within an hour. After such a rapid decrease, the water levels immediately increase to the water levels that were previously measured. This trend occurs for both sudden increases and decreases, although the sudden lower peaks occur with a periodicity of less than an hour. Next to these trends, the water level data appears to be rather constant with a natural shaped trend, where fluent minor ascents and descent are present.

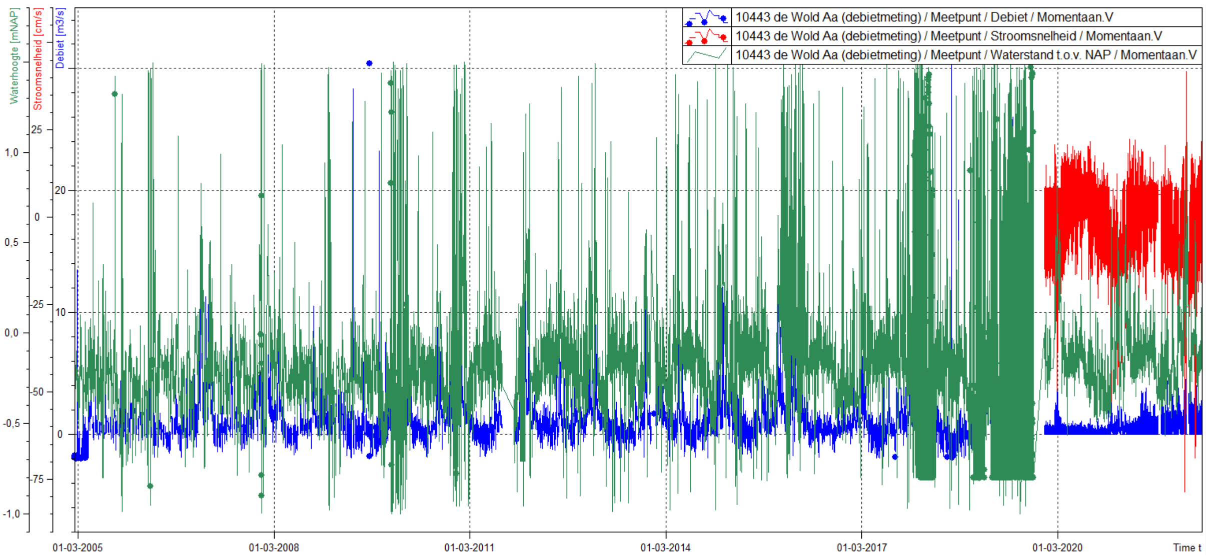


Figure 31 Validated time series of the discharges, flow velocities, and water levels of flow meter the Wold Aa

During the noise present in the first years of the time series, water level measurements are frequently missing. However, these data gaps do not match the data gaps in the time series of the discharge, which is shown in Figure 32. Considered from a theoretical perspective this would be impossible, since a discharge cannot be determined without the water level being known. Here, an example of a large fluctuation phase of approximately one week is also visible with a nett fluctuation of over 2 meters, which is physically not possible.

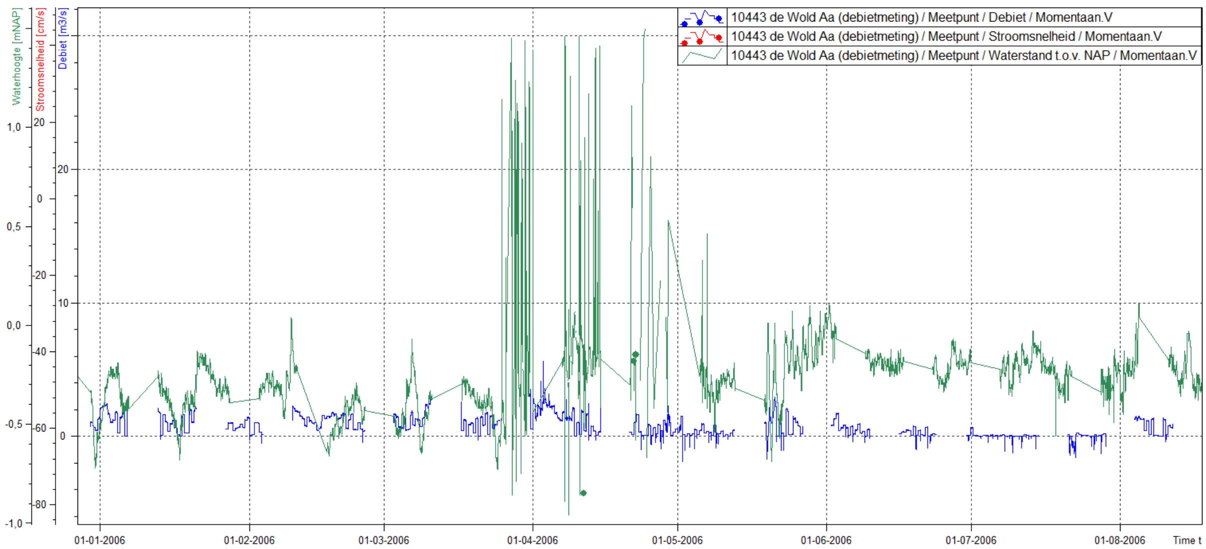


Figure 32 Fragment of the time series of the discharge and water level of flow meter the Wold Aa

Figure 33 shows that the water level graph does tend to match the discharge graph in certain periods. However, the water level graph contains periodic rapid drops with values that are between 0.5 and 1 meter lower, which is not realistic. Besides that, the sudden rise in the discharge graph on the 26th of December 2017 is not recognizable in the water level graph, although the discharges are determined using the water level and the flow velocity. Nevertheless, it is possible that the flow velocity increased. Unfortunately, no flow velocity data is available up to and including 2019.

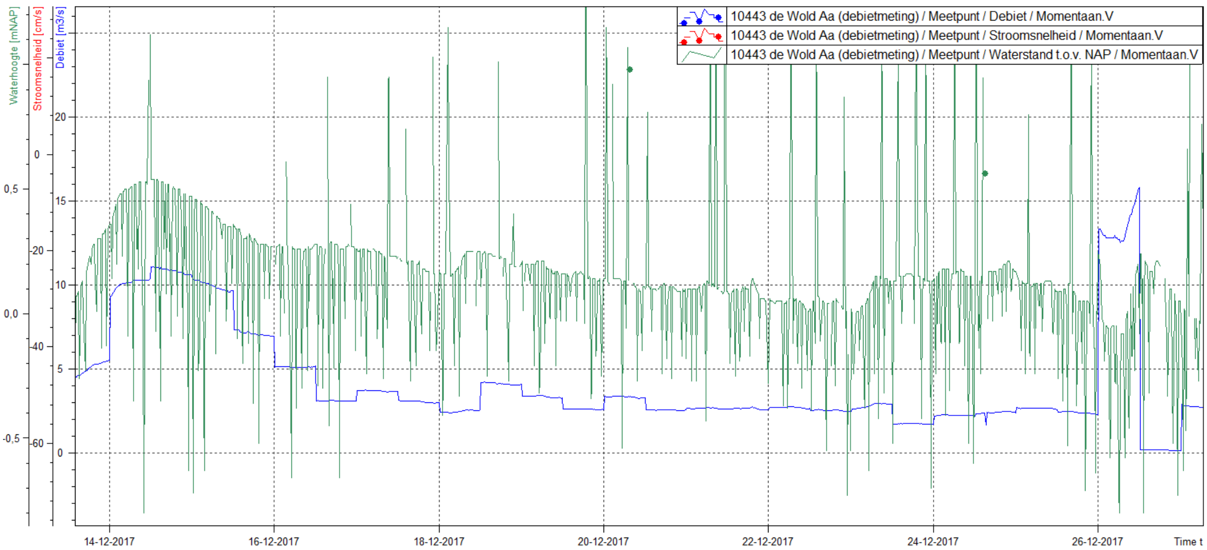


Figure 33 Fragment of the time series of the discharge and water level of flow meter the Wold Aa

Comparable to Figure 22, Figure 34 shows that the flow velocity appears to have a direct effect on the discharge values, while the direction of the flow velocity appears to be directed in the opposite way since greater negative flow velocities would imply an increasing water inflow, which is visualized by discharges with a negative value. It is also visible that no discharge values are available when the flow velocity is missing as well, while the water level data is still available. Again, the water level graph roughly matches the discharge graph, although it seems that certain fluctuations in the water level do not influence the discharge values, such as the peak at the end of March 2022.

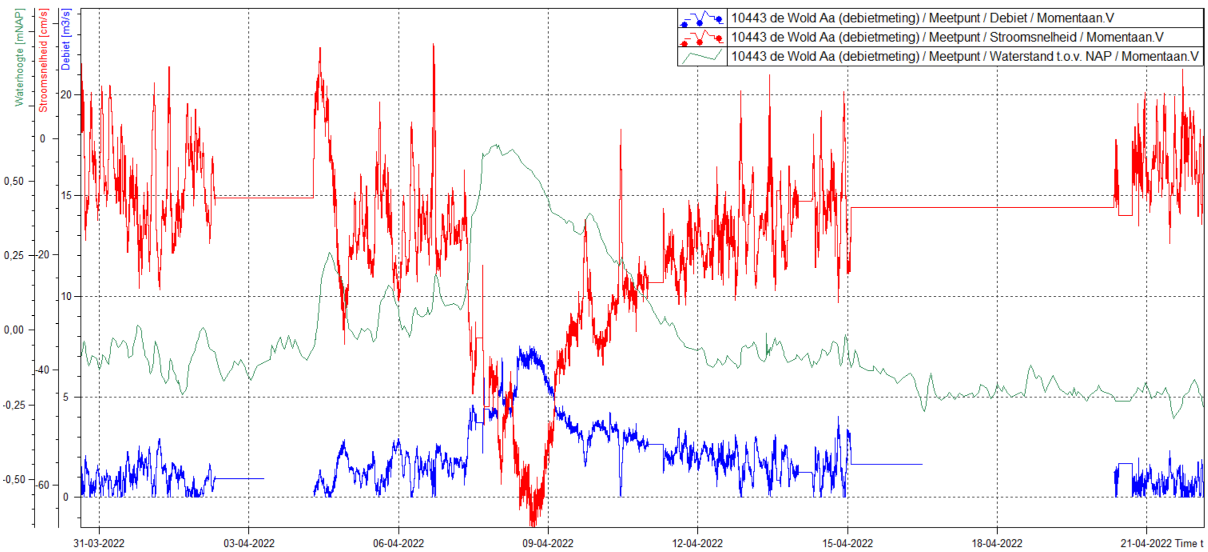


Figure 34 Fragment of the validated time series of the discharges, flow velocities, and water levels of flow meter the Wold Aa

To get further insights into the pattern and values of analysed time series from flow meter the Wold Aa, weir and pumping station Blijdenstein is included in the analysis as well. But, due to the rather low and scarcely measured discharges from the pumping station shown in Figure 35, it is decided to ignore these values and focus on the discharges from the weir in the comparison. A relation between the time series from the hydraulic structure and the flow meter appears to be present. If the pumping station is active, discharges of approximately the same magnitude are present and displayed in the correct direction, while the high-water periods are detected by both the weir and flow meter as well. However, the weir provides discharge data with higher magnitudes than the flow meter for the 2020 and 2021 period. On top of that, it is remarkable that the pumping station is alternatingly active with the weir during the summer period of 2020, which would indicate that water inflow and water outflow occurs within this period. Nevertheless, the pattern of the time series from Blijdenstein appears to match with the graph of the discharges provided by the flow meter before all discharges are expressed in positive values after the data gap in 2019, implying a constant water outflow.

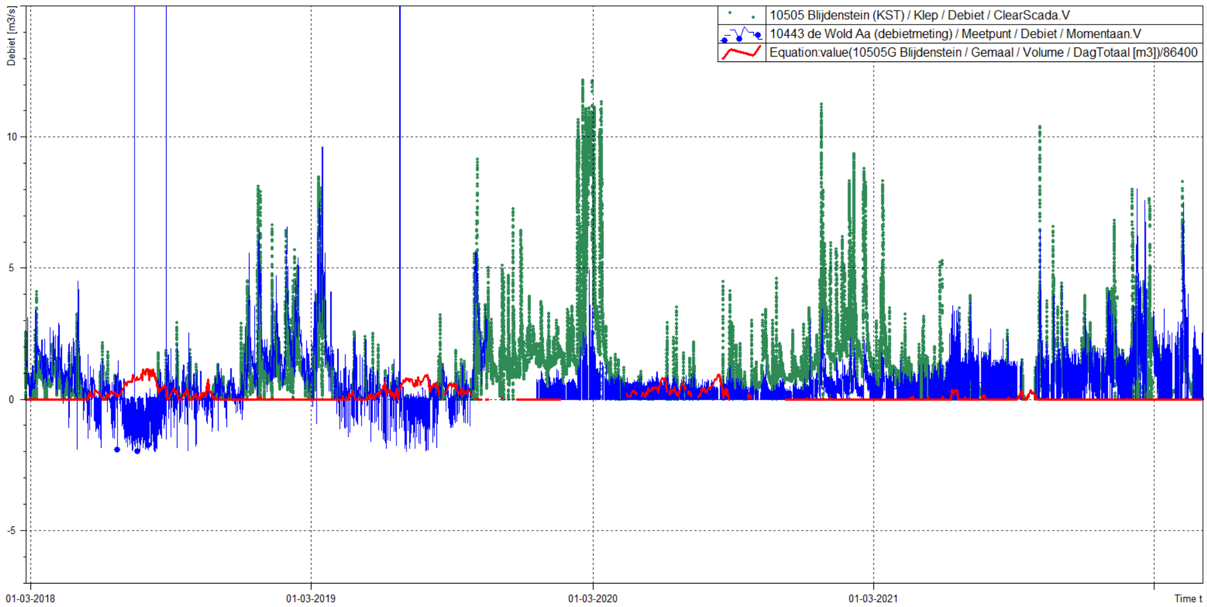


Figure 35 Discharges from the weir and pumping station Blijdenstein

Discharges from hydraulic structures Haakswold and Bloemen are studied as well, since these weir and pumping station combinations are located between Blijdenstein and flow meter the Wold Aa. These hydraulic structures discharge and obtain water from the Wold Aa or from their adjacent areas. However, Appendix A9 shows that the discharges discharged or extracted by hydraulic structure Bloemen are neglectable compared to the total measured discharges by both the flow meter and weir Blijdenstein. However, the discharges from the pumping station part of Haakswold are included since these discharges reach magnitudes of approximately 0.5 m^3/s on several occasions, although multiple data gaps are present within data peaks, as shown in Figure 36. In the analysis these time series will be combined with the discharges time series from the flow meter, to balance the inflow and outflow data to verify whether the water outflow downstream is equal to the water outflow upstream. The discharges from the weir construction of Haakswold are excluded, since the weir is generally not active for a large continuous period.

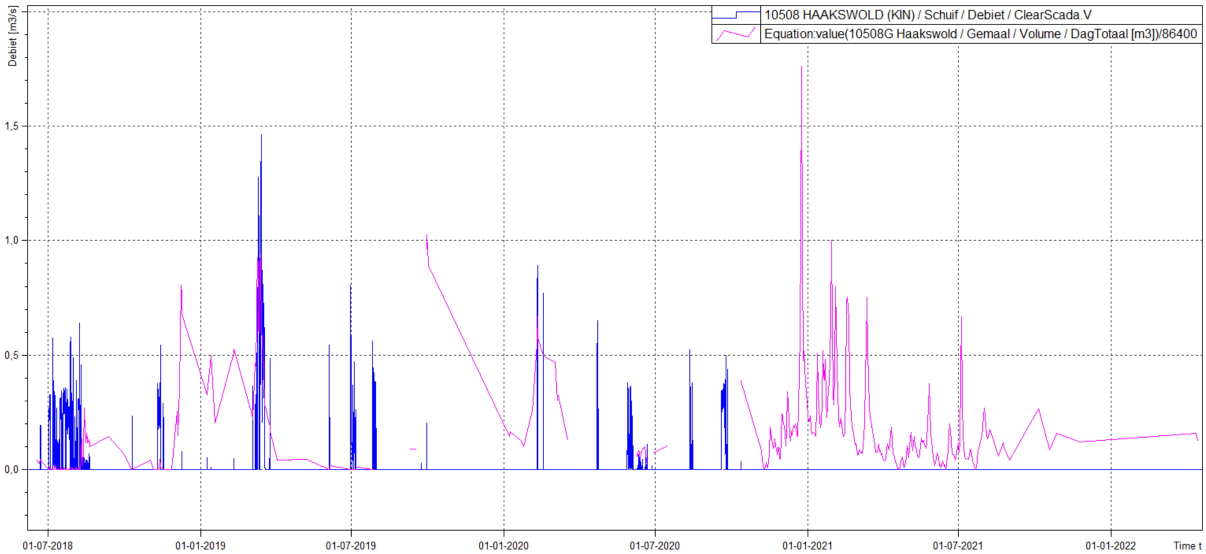


Figure 36 Discharges provided by hydraulic structure Haakswold

Figure 37 shows the time series from pumping station Haakswold together with the time series of the flow meter plotted against the time series from weir Blijdenstein. For water outflows, the shape of the graphs appears to follow the same pattern, but the magnitudes of the discharges do differ. On the left side it is visible that the weir measures slightly lower discharges, while the middle section shows that the weir measures slightly higher discharges. Near the end of the time series, the graph from the Wold Aa and Haakswold have a large noise pattern, which makes it difficult to determine the actual discharges. Finally, both graphs contain multiple data gaps. Appendix A10 shows a fragment that shows these addressed anomalies in detail.

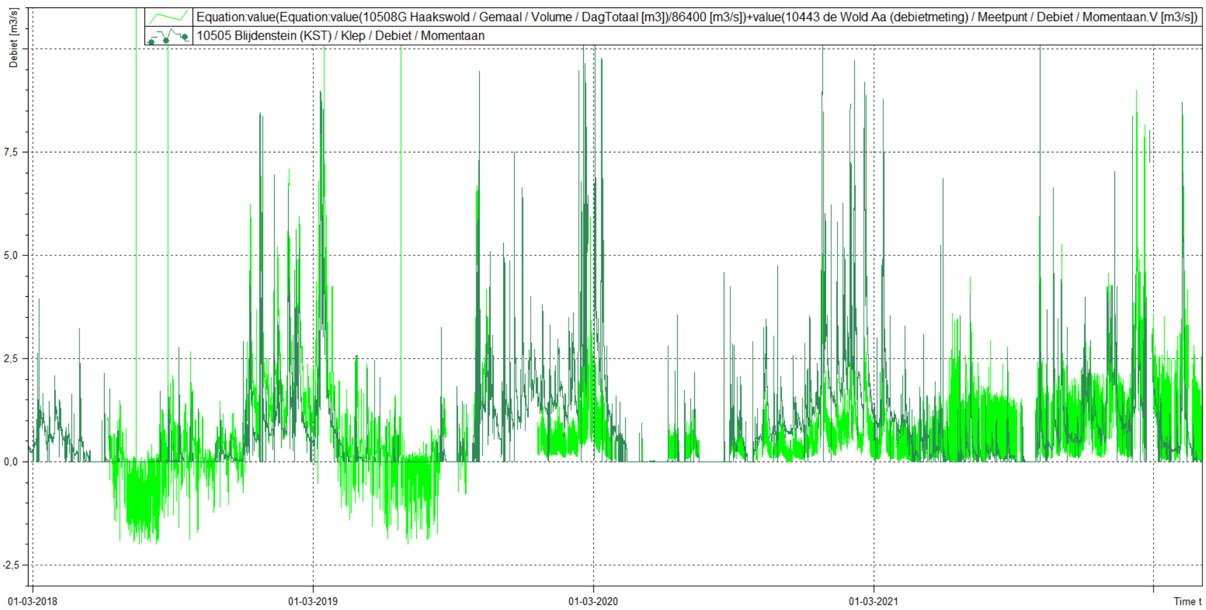


Figure 37 Discharge time series of weir Bleidenstijn compared with the sum of the discharge time series from pumping station Haakswold and flow meter the Wold Aa

A closer look on a fragment of the time series reveals that the measured noise by the flow meter and the pumping station occurs with a rather small periodicity of about a day. Besides that, it is visible that the time series of weir Blijdenstein has multiple fragments where no discharge is detected during these spring periods, while discharges are measured downstream, although these discharges fluctuate between positive and negative values.

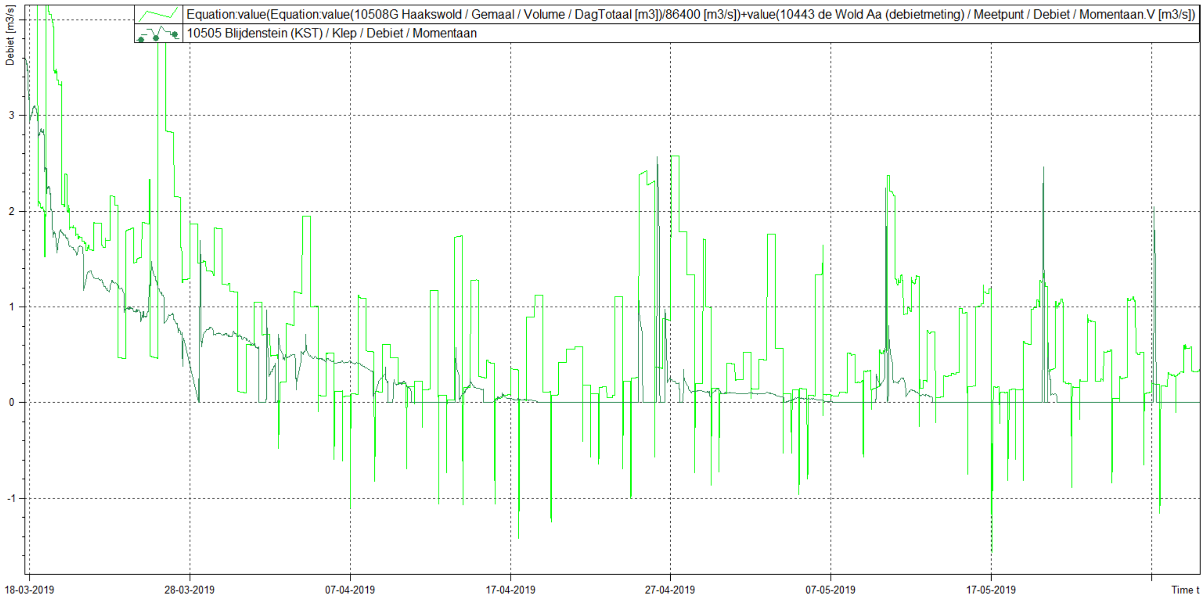


Figure 38 Fragment of the compared discharge time series of weir Blijdenstein and the combined flow meter and pumping station Haakswold time series

3.7. Brief Overview of the Identified Anomalies

In order to get a clear overview of all the anomalies per flow meter, all the identified anomalies are listed under the concerning flow meters.

Flow meter Overijssels Kanaal Hanzebrug

- Fluctuating positive and negative discharges with a periodicity of about 15 minutes
- Alternating flow velocities with a magnitude of above 100 cm/s in both directions
- Generally constant pattern in alternating water level heights with an average periodicity of approximately six hours
- Measurement data from Ankersmit is available since 2017

Flow meter Streukelerzijl Groote Grift

- Continuous pattern with peaks in the discharge time series between 0 m^3/s and 5 m^3/s
- A large data gap is present between mid-2020 and mid-2021
- Time series of the water levels are not available
- The measured discharge values by pumping station Streukelerzijl are twice as low as the measured discharges provided by flow meter Groote Grift

Flow meter Drentsche Hoofdvaart

- A lot of fluctuation and data gaps are present in the discharge time series from the flow meter during first years
- From 2006-2009 and 2009-2019 sudden jumps are present every 12 hours
- After the data gap in November 2019, only positive discharges are provided by the flow meter
- After the data gap in November 2019, no water levels are available. Instead, the time series of the flow velocity are now available
- A sudden jump in the discharge time series from the flow meter is present, where the discharge rises from 0.5 m^3/s to 2 m^3/s
- The time series of the water level contain large fluctuations and noise and do not match the data from the discharges
- The flow velocity appears to be displayed in the reversed direction
- The weir and pumping station measure higher discharges than the flow meter
- The pumping station and weir are alternatingly active within a short period of time

Flow meter Wold Aa

- A lot of fluctuation and data gaps are present in the discharge time series from the flow meter
- From 2006-2008 and 2009-2019 sudden jumps are present every 12 hours, but only for discharges with a positive magnitude
- After the data gap in November 2019, only positive discharges are provided by the flow meter
- After the data gap in November 2019, time series of the flow velocity are suddenly available
- Before the data gap in November 2019, a lot of the data contains jumps every 12 hours
- A sudden jump in the discharge time series from the flow meter is present in February 2020
- The time series of the water level contain large fluctuations and noise
- The flow velocity appears to be displayed in the reversed direction
- Weir Blijdenstein measures larger discharges than the flow meter
- Several high-water periods are detected by the weir but not by the flow meter

4. Characteristics of the Flow Meters

4.1. Technical Aspects of the Flow Meters

Now that the flow meters are selected and the anomalies are identified, it is important to acquire more knowledge regarding the technical aspects of the flow meters. To measure the discharge, various measuring methods can be applied. These measuring methods can be either classified as incidental measurements or continuous measurements (Hartong & Termes, 2009). When the discharge at a certain location is measured during a limited period, the measurements are categorized as incidental measurements. These types of methods are applied to acquire discharge data in that area for one single time, for example to determine the capacity of a waterway or to calibrate a measurement setup for continuous measurements. Incidental measurements commonly have a measuring frequency of several times a month or several times a year. When it is desired to gain knowledge of the discharge for a longer period, but with a high measuring frequency, continuous measurements must be conducted. However, continuous measurements are in fact semi-continuous since measurements are still performed using time steps, for example every 15 minutes, every hour, or every 12 hours. The flow meters from Waterschap Drents Overijsselse Delta provide continuous measurement data. Information about incidental measurement methods can be found in Appendix B. Since each of the four selected flow meters makes use of the same technology, only that technology will be elaborated within this Section. The other continuous measurement methods can be found within the same Appendix where the incidental measurement methods are described.

The selected flow meters are all Acoustic Doppler Current Profilers (ADCPs). These flow meters monitor the flow velocity using sound pulses. The flow meter emits two pulses under an angle with a certain frequency. These pulses are reflected by the particles that are present in the water. Since the water flows, the particles in the water move with respect to the flow meter. Because of this movement, the frequency of the reflected pulses will differ from the frequency of the emitted pulses, which is called a Doppler-shift. As a result of this movement, the two reflected pulses have a different frequency. This Doppler-shift can then be used to compute the flow velocity of the particles in the water and thereby determining the flow velocity of the water itself (Hartong & Hermes, 2009). The pulses of the ADCP meter can be emitted horizontally, thus from either side of the waterway, or vertically, which means it is directed upwards from the bottom of the waterway. For both situations, the strength of the reflected pulses is measured with fixed intervals, thereby measuring the reflected pulses over equally increasing distances. These units of time cover a fixed distance in the waterway called cells (Nortek, 2022b). Increasing the measuring time results in larger cells, while decreasing the measurement time results in larger cells.

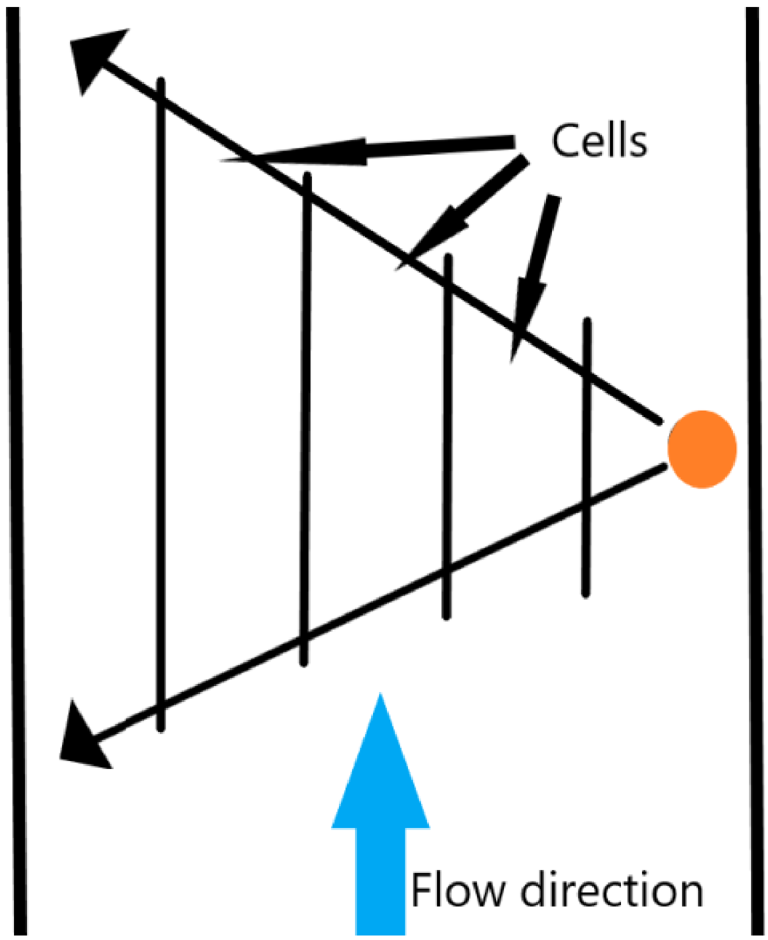


Figure 39 Schematic aerial view of the flow velocity measured by a horizontally located ADCP meter that emits two pulses

The selected flow meters make use of the horizontally aimed beams. A schematic overview of a horizontally orientated ADCP meter is displayed in Figure 39. However, the ADCP meters are most likely not identical due to their differences with respect to age and manufacturer. Flow meters in the Drentsche Hoofdvaart and the Wold Aa are installed by Nortek, a company that designs, develops, and produces scientific instruments, including ADCP flow meters (Nortek, 2022a). Flow meter Groote Grift was installed by Aqua Vision, an independent hydro- and oceanographic consultancy (Aqua Vision, 2022). However, the manufacturer is unknown of this flow meter. The installer and manufacturer of flow meter Overijssels Kanaal Hanzebrug are unknown as well.

5. Assessment of the Flow Meters

5.1. Assessment Flow Meter Overijssels Kanaal Hanzebrug

Assessment of the Discharge Data

Starting with the flow meter from Overijssels Kanaal Hanzebrug, the largest identified anomaly is the presence of the large discharges that are alternatingly positive and negative. With the high flow velocities of approximately 100 cm/s, the question arises how the flow direction keeps switching. One main clarification that may clarify the strongly fluctuating discharges in both directions is mentioned by all four parties to which these time series are shown: because the canal comes to a dead end in the port, the water sloshes back and forth since it cannot flow further. However, this phenomenon is not confirmed with either literature research or field research and cannot be stated with certainty yet.

Assessment of the Water Level Data

Despite the fact that the water levels appear to be reliable, it is desired to investigate why the water levels are constantly decreasing and increasing by approximately five centimetres, which occurs in multiple variations with a constant periodicity of between 12 and 24 hours for a full cycle. Maarten Mulder (Nortek) notices that this must be an automated system where the water level is regulated to maintain a minimum level. The constant water outflow can be caused by many aspects such as the pumping station, the weir, or the sluice. However, Maarten Mulder mentions that it is strange that the flow velocity does not appear to be affected by the water outflow, indicating that the water inflow and outflow would not occur near the sluice or hydraulic structure Ankersmit.

Assessment of the Flow Velocity Data

Johan Draaijer (Waterschap Noorderzijlvest) advises to do further research into the locking times of the sluice since the water transportation in the sluice might influence the flow velocity and direction at the flow meter. However, since on average less than 4 boats enter the port via the sluice, this clarification seems implausible since the flow direction changes multiple times an hour, also during the night.
Besides that, Gert van den Houten (Waterschap Rijn en IJssel) mentions that the wind could impact the flow direction if the flow velocities are very low.

However, the discharges with magnitudes that are sometimes larger than 100 cm/s are considered unrealistic by Hans ten Kate (Flow Tronic). He indicates that it is likely that an error is present regarding the unit of the parameter. Instead of centimetres per second as displayed, the measurements could be conducted in centimetres per minute. Another clarification that he proposes is that an error regarding the factor of a parameter is present. For example, the axis may be multiplied by a factor 10 or 100.

Maarten Mulder (Nortek) supports this claim that such high flow velocities are unlikely to occur, except when loaded freighters navigate into the port. Nevertheless, such events may occur for fifteen minutes, but not for periods of half an hour. Therefore, a recommendation is made to further investigate the larger peaks in the discharge data and compare these with the locking times of the sluice, if possible, to confirm or deny this possible clarification. From this further research it is observed that these peaks may be caused by freighters since the flow velocities drop back to values around 40 cm/s within 15 minutes of the occurrence of the peak.
To verify whether the flow velocities and water levels are correct, a sample will be verified by a manual calculation. The canal has a width of 37 meters according to the database from WDOD. Hans ten Kate mentions that the water height of the canal is approximately 2.5 meters. Figure 40 shows a fragment of the time series from the morning on 15 January 2022.

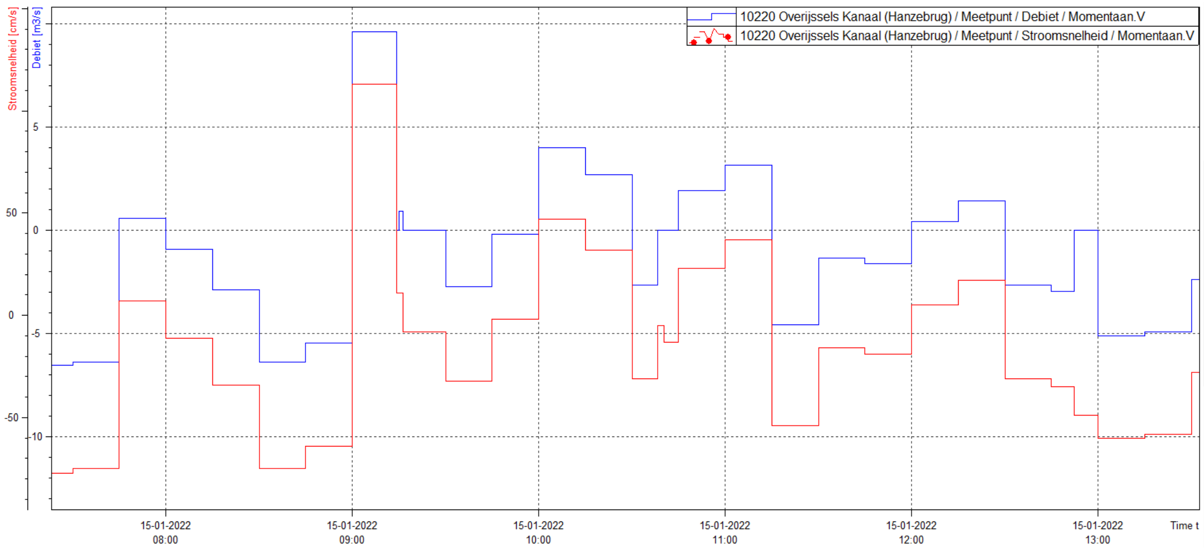


Figure 40: Fragment of the flow velocity and discharge data from the flow meter in the Overijssels Kanaal

At 9.00 AM, the flow velocity is 113 cm/s, equal to 1.13 m/s, while the discharge is 9.62 m^3/s. The simplified formula is as followed:

$$Discharge\ (m^3/s) = Width\ (m) \times Water\ height(m) \times Flow\ velocity(m/s)\ (1)$$

Multiplying the flow velocity with the wet cross section results in the following answer:

$$Discharge = 37 \times 2.5 \times 1.13 = 94\ m^3/s \neq 9.62\ m^3/s\ \ (2)$$

The above stated result shows that the computed discharge is about ten times larger than the observed discharge. This anomaly can be solved by dividing the flow velocities by ten and adapting the formula in either the substation or in ClearScada. It is unknown which of these two locations is the actual cause of this problem.

Based on the constantly changing flow direction, the question arises by Gert van den Houten and Maarten Mulder why the flow meter is installed at that location. Because of the changing flow direction expected to be caused by the water that sloshes in the port, it is hard, if not impossible, to obtain accurate data about the water outflow and the water inflow into the Overijssels Kanaal. Gert van den Houten proposes to remove the flow meter continue measuring at hydraulic structure Ankersmit. By measuring the water outflow and the water inflow from the Overijssels Kanaal and the sluice during every locking, a better quantification of the water flow should be obtained. However, it is important to verify whether the discharges measured by Ankersmit comply with the actual discharges.

5.2. Assessment Flow Meter Streukelerzijl Groote Grift

When discussing the periodic peaks present in the time series of flow meter Streukelerzijl Groot Grift, all parties first mentioned that it was possibly noise. However, a closer look on the time series omitted that idea. Now, it is visible that the discharge is approximately zero with peaks in between that have discharges of approximately 5 m^3/s with a periodicity of approximately six hours, which is shown in Figure 14 in the data analysis. All parties pointed that pumping station Streukelerzijl directly affects the discharges measured by the flow meter. Possible clarifications are mentioned for the difference in magnitude. First, a difference in magnitude due to a deviating formula for the computation of the discharge is likely to be the case according to the four external parties. Hans ten Kate mentions that the flow meter could be located in the middle of the canal, because it is possible that vegetation is present at the shores. As a result, the flow velocity is practically zero in those areas. If this would be the case, the whole wet cross-section implemented in the formula should exclude these vegetation zones, otherwise the computed cross section is larger than the cross section in which the flow meter measures the flow velocity. By redetermining the cross section utilized by the flow meter, this clarification can either be confirmed or rejected. Another clarification could be an error in the scaling process according to Maarten Mulder.

The difference in magnitudes of the measured discharges can easily be solved by executing a calibration measurement on either the pumping station or the flow meter, while calibration measurements on both the pumping station and flow meter can be performed as well. After that, the data can be suitable to use when the existing discharge time series are recalculated.

It occasionally happens that weir Fissele is active to discharge water from the Dedemsvaart into the Groote Grift. Marloes ter Haar, hydrology advisor at WDOD, mentions that the flow meter is less accurate due to turbulence that arises near the weir when water is being discharged in the Groote Grift. Since the flow meter is located close to the weir, it is directly affected by this turbulence.

5.3. Assessment Flow Meter Drentsche Hoofdvaart

For the flow meter in the Drentsche Hoofdvaart, multiple anomalies are identified during the data analysis and the interviews. First, the discharge data will be addressed, supported by data obtained by the pumping station and weir next to the Paradijssluis when necessary. After that, the water level data will be discussed. Finally, the flow velocity is elaborated on.

Assessment of the Discharge Data

During the first three years, multiple data gaps are present between 2006 and 2009, as shown in Appendix A4. Two possible clarifications come forward for this anomaly. First, it is likely that there are problems with collecting the data, according to project engineer Maarten Mulder from Nortek. Another possibility that is brought forward is that the flow meter occasionally provides data and is defect. However, Maarten Mulder mentions that this phenomenon rarely occurs and mentions that the problem probably is caused by an error in collecting the data. Nevertheless, it is difficult to firmly state what exactly went wrong in collecting the data, since it is not possible to investigate what happened exactly during that period, since it happened fifteen years ago.

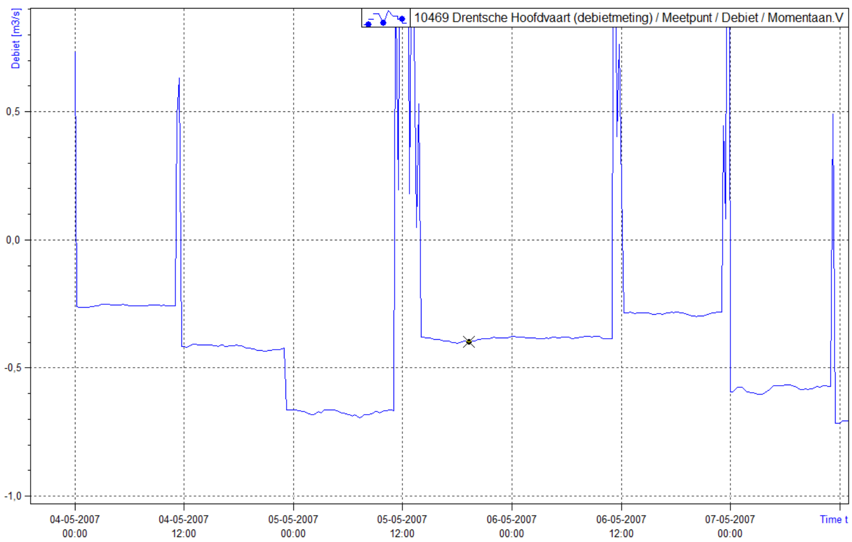
During these first three years, periodic sudden jumps are present in the data. From January 2009 up to and including December 2009, these jumps disappeared. After that, the jumps appeared again until the data gap in 2019, but only for water outflow data. Water system managers Johan Draaijer and Marijn Hooghiem from Waterschap Noorderzijlvest once had an issue where an optimized parameter was used for the calculations. However, this parameter arrived late in the system. Because of that, the optimized parameter from the previous measurement was applied in the calculations. This might be the issue for the sudden periodic jumps, although Johan Draaijer addresses that he is not sure about that. Another possible clarification is that at 12.00 and 0.00 the largest data export takes place. This data export would then include information to fill the data gaps that were present during the last twelve hours. He expects that the substation manager ought to know more about this anomaly. The substation is the device that processes the raw data into the desired outputs, which is send to the server at WDOD. To verify the data, Johan suggests that discharges can be verified by manually calculating them in excel using the flow velocity and water level data. He would not utilize the time series when such jumps are present.

Gert van den Houten mentions that an error in the data communication could cause the flatliners in the sudden jumps, since it appears that data is alternatingly missing for 12 hours and is then temporarily available. This means that there may be some issues when transferring the data that has been read out in the substation towards the data server from WDOD.

Figure 41 shows a detailed overview of the 12-hour jump pattern together with a part of the discharge values in the accompanying table, on 5 May 2007 from 15.00 up to and including 23.45. During this time span the discharge varies between -0.831 m^3/s to -0.403 m^3/s, interjected with short-lived peaks of discharges up to 1 m^3/s. Even in a controlled water system, such small discharge differences are unrealistic, especially when it appears in a pattern with constant intervals separated by steep peaks. It may be clarified by the fact that the pumping station next to the Paradijssluis is active, thereby maintaining a constant water inflow, hence the negative discharges. However, next to the fact that the time series of the pumping station are only available after the data gap in November 2019, this trend is present throughout the whole year. Since the pumping station is mainly active during summer periods, it is not plausible that the pumping station is the reason for the constant discharge values between the jumps. Just as Johan Draaijer, Gert van den Houten advises to investigate the flow velocity data to verify whether there are similar patterns. However, this data is unavailable up to and including October 2019, through which it is not possible to compare the data with the discharge data from the flow meter that did contain annual trends.

Maarten Mulder mentions that events that take place around 12.00 and 0.00 are always suspicious and do unfortunately occur regularly due to the systems that reset on these moments. Fragments with fluctuating data that are temporarily present, for example on 5 May 2007 around 12.00 or the water inflow data in Appendix A6, have a valid pattern according to him. However, the flat lines are suspicious. Maarten Mulder mentions that the fluctuating discharge pattern for the discharges with negative values, shown in Appendix A6, may be correct. However, the parts of the data that contains these patterns should not be trusted since difference in discharges after a jump sometimes have a magnitude of over 2 m^3/s in fragments where the discharges vary between 0 m^3/s and 3 m^3/s.

To conclude, the first three years with the many data gaps present and the sudden periodic peaks are considered untrustworthy. Furthermore, it can be stated that the remaining data with this jumping pattern with the flatliners in between is unreliable as well, because even when the average discharges over such periods are taken, the observed deviations are way too large.



05-05-2007	15:00:00	-0,383	80 (Autovalid)
05-05-2007	15:15:00	-0,387	80 (Autovalid)
05-05-2007	15:30:00	-0,390	80 (Autovalid)
05-05-2007	15:45:00	-0,390	80 (Autovalid)
05-05-2007	16:00:00	-0,390	80 (Autovalid)
05-05-2007	16:15:00	-0,392	80 (Autovalid)
05-05-2007	16:30:00	-0,394	80 (Autovalid)
05-05-2007	16:45:00	-0,396	80 (Autovalid)
05-05-2007	17:00:00	-0,396	80 (Autovalid)
05-05-2007	17:15:00	-0,398	80 (Autovalid)
05-05-2007	17:30:00	-0,401	80 (Autovalid)
05-05-2007	17:45:00	-0,401	80 (Autovalid)
05-05-2007	18:00:00	-0,403	80 (Autovalid)
05-05-2007	18:15:00	-0,401	80 (Autovalid)
05-05-2007	18:30:00	-0,398	80 (Autovalid)
05-05-2007	18:45:00	-0,396	80 (Autovalid)
05-05-2007	19:00:00	-0,396	80 (Autovalid)
05-05-2007	19:15:00	-0,398	80 (Autovalid)
05-05-2007	19:30:00	-0,396	80 (Autovalid)
05-05-2007	19:45:00	-0,396	80 (Autovalid)
05-05-2007	20:00:00	-0,394	80 (Autovalid)
05-05-2007	20:15:00	-0,390	80 (Autovalid)
05-05-2007	20:30:00	-0,390	80 (Autovalid)
05-05-2007	20:45:00	-0,387	80 (Autovalid)
05-05-2007	21:00:00	-0,387	80 (Autovalid)
05-05-2007	21:15:00	-0,387	80 (Autovalid)
05-05-2007	21:30:00	-0,387	80 (Autovalid)
05-05-2007	21:45:00	-0,383	80 (Autovalid)
05-05-2007	22:00:00	-0,381	80 (Autovalid)
05-05-2007	22:15:00	-0,383	80 (Autovalid)
05-05-2007	22:30:00	-0,383	80 (Autovalid)
05-05-2007	22:45:00	-0,383	80 (Autovalid)
05-05-2007	23:00:00	-0,383	80 (Autovalid)
05-05-2007	23:15:00	-0,383	80 (Autovalid)
05-05-2007	23:30:00	-0,383	80 (Autovalid)
05-05-2007	23:45:00	-0,381	80 (Autovalid)

Figure 41 Fragment of the 12-hour jump pattern from discharge time series Drentsche Hoofdvaart

The third identified anomaly is present in 2019, after the sudden periodic jumps disappeared when a 14-day during data gap occurs from 30 October 2019 up to and including 13 November 2019. After that, all the discharges have positive values. Discharges with positive values are used to indicate a water outflow, while discharges with negative values indicate a water inflow. Since the discharge data is all positive for the last three years, it would mean that a constant water inflow is present, which is implausible considering the wet periods during the winter.

Gert van den Houten notices that the annual trend with the summer and winter period disappeared. This practically horizontal graph is just a noise pattern according to the hydrologist from Waterschap Rijn en IJssel, something is either not correct or data is missing. Hans ten Kate does also address that this pattern is unusual. He firmly states that this problem is caused due to changes in the formulas in the substation. Maarten Mulder backs the claim of Hans ten Kate that a change in the formula is the probable cause of this problem since it is improbable that there are no discharges with negative values present for the last three years. He rules out the possibility that water inflow data is missing. First, there are no data gaps present, which should have been present in case data was missing. Furthermore, the discharges that have values near zero are rarely exactly zero, rejecting the idea that discharges are cut off when they have negative magnitudes. Therefore, he concludes that the formula must turn al the discharges with negative values into discharges with a positive value by considering the magnitude of the discharge only and omitting the flow direction. Nevertheless, the project engineer cannot clarify why the annual trend disappeared after the data gap.

However, Maarten Mulder can explain the peak that is present in February 2022. The project engineer from Nortek mentions that he provided a new formula in February 2022, which appears to be more accurate than the previous formula. Maarten Mulder also addresses that he observed that on 12 June 2022 around 12.00 there was a water inflow when he was working in the field of operation. This physical observation combined with Figure 42 confirms that water inflow is measured in February 2022 but is displayed as water outflow.

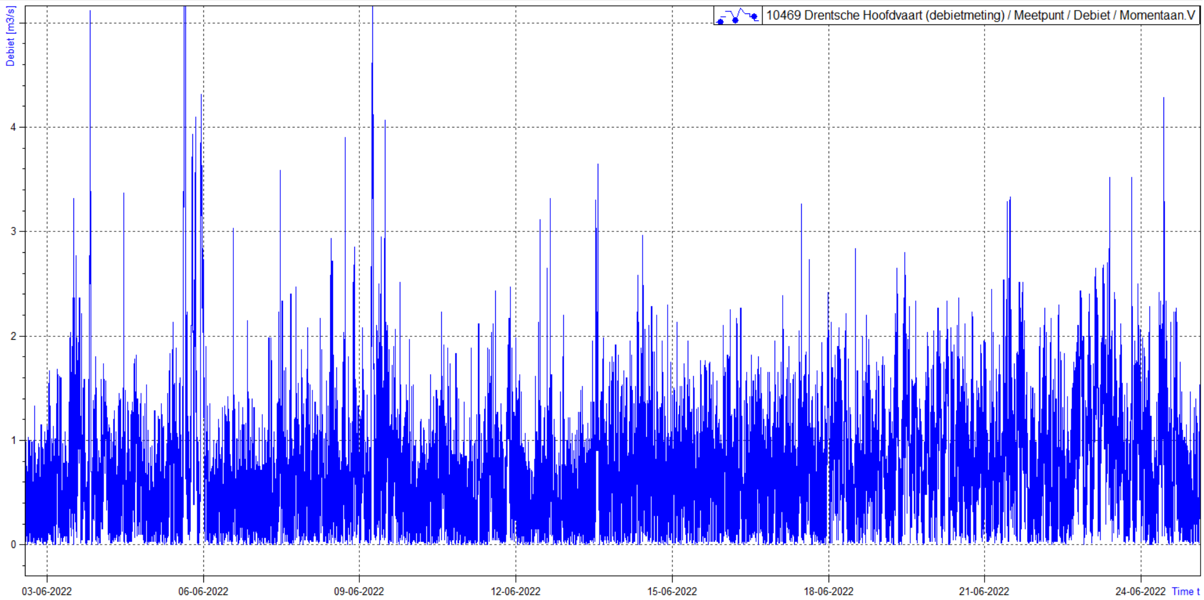


Figure 42: Fragment of June 2022 from the discharges provided by flow meter Drentsche Hoofdvaart

The reliability of the new formula is supported by the fact that the shape of the graph from the discharges measured by the weir next to the Paradijssluis is of the same shape as the graph from the discharges provided by the flow meter since February 2022, which is shown in Figure 43. Furthermore, the rather constant magnitudes of the discharges provided by the flow meter now differ less from the magnitudes of the discharges measured by the pumping station, compared to the data between November 2019 up to and including January 2022. Nevertheless, the discharge data during the high-water period at the end of February 2022 differs 5 m^3/s between the flow meter and the Paradijssluis. This may be caused by the fact that the weir could have been drowned during that period, thereby measuring the discharges higher than they theoretically are.

Apart from the matching shapes and better matching magnitudes from the discharge data, it remains a problem that the discharges measured by the flow meter are all still displayed as water outflow, which makes it impossible to determine the actual flow direction over a certain period. Therefore, the time series are unreliable since November 2019 when visualized like this.

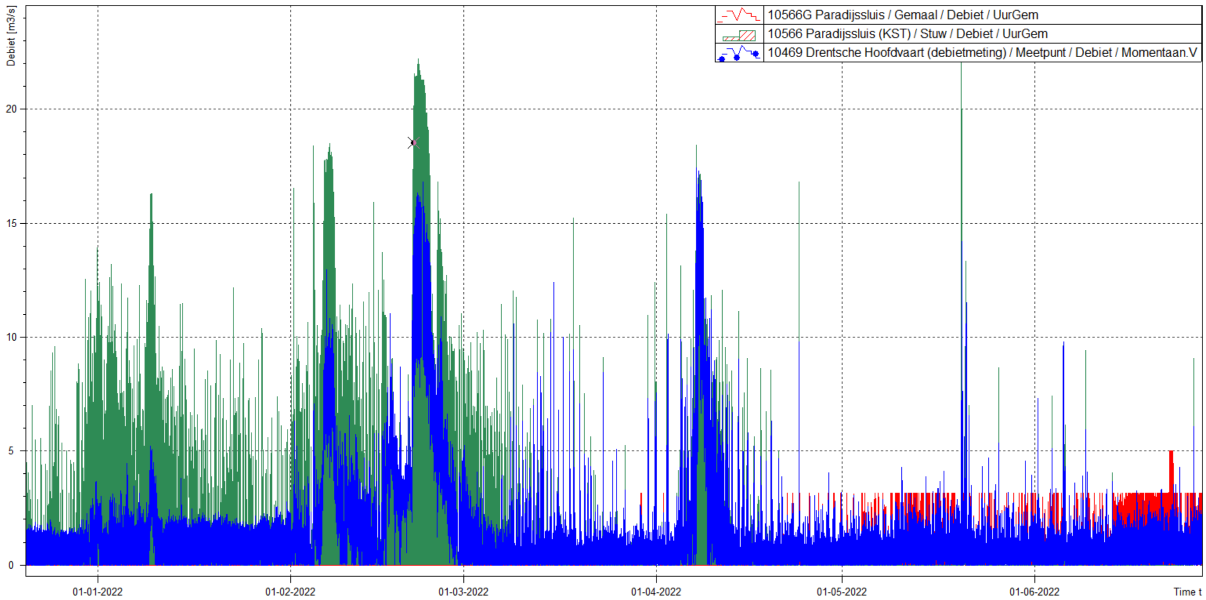


Figure 43 Fragment of 2022 from the time series from the hydraulic structures and the flow meter in the Drentsche Hoofdvaart

Within the data obtained after November 2019, another anomaly is detected. On 7 June 2021, the discharge pattern with fluctuations of the discharge values between 0 m^3/s and 0.5 m^3/s abruptly changes to a pattern where the fluctuation of the discharges lays between 0 m^3/s and 2 m^3/s. This anomaly where the upper values of the discharges appear to be multiplied by a factor of four is probably caused by an adaptation in the formula according to Johan Draaijer. He elucidates that adaptations over time in the wet cross-section may cause deviating discharges, which is mentioned by Maarten Mulder as well. Mowing the vegetation could result in higher discharges. However, both addressed that this process is always displayed with a smooth curve instead of an abrupt jump. Gert van den Houten also believes that this anomaly is caused by a problem of technological nature, which is supported by Hans ten Kate, who thinks the origin of the problem may originate in the substation.

The possible clarifications given that the cause of the problem could be a change in the discharges upstream caused by the pumping station can be ruled out, since the magnitudes of the discharges measured by the pumping station remained identical before and after the sudden jump. Such a sudden jump usually makes it difficult to determine whether the data before or after the jump is more accurate. Therefore, the complete fragment of the discharge data is considered unreliable, until it is determined which side of the discharge data is correct.

Assessment of the Water Level Data

The time series of the water levels are available until the data gap in November 2019, while the time series of the flow velocity are available after the data gap. All four external parties mentioned that the data should be available since they are required for determining the discharge. Johan Schadenberg, application manager of Waterschap Drents Overijsselse Delta, mentioned that it may be caused by the change from the previous data server ATIS to the current data server called ClearScada, which was implemented during the data gap in November 2019. This clarification is supported by Roel Ekkelenkamp, one of the two industrial data processing managers of Waterschap Drents Overijsselse Delta.

Maarten Mulder mentions that Waterschap Drents Overijsselse Delta obtained their data via Aqua Data Systems, a company that develops, sells, and manages telemetry systems. They managed the substation and revised the accompanying data before it was transferred to WDOD. However, after the contract expired WDOD continued to manage the data on their own. It may be possible that the other party programmed the substation such that only the discharges and the water levels were provided during that period, although further research is necessary to confirm or reject this statement. This means that all the unvalidated data including the measured flow velocities from the cells are used as input in the formula in the substation but are not stored. Therefore, it is difficult to analyse the data properly to identify the roots of the anomalies mentioned in this Section since the only available parameter is the water level.

However, the available water level data contains a lot of noise. Until 2009, several data gaps are present, sometimes during periods where discharge data is available. This is theoretically not possible. It is possible that the collection of the water level data failed occasionally. Furthermore, other water level time series might be used to determine the discharge. However, none of these clarifications can be confirmed since it is not possible to investigate what happened during that period since it took place over twelve years ago.

The presence of the noise increased since the data gap in the summer of 2011. After that, there are multiple periods where the water levels vary between -1 meter NAP and +1 meter NAP. Maarten Mulder addresses that the water levels should vary between -0.2 meters NAP and +0.5 meters NAP, according to a colleague of him who conducted field research in February 2022 at the flow meter. A possible clarification for the large differences in magnitude could be that the sensor that determines the water level is wrongly calibrated. For example, if the implemented sensor is calibrated for water levels between 0 and 4 meters instead of being calibrated for water levels between 0 and 2 meters, the fluctuations will become twice as high. However, this does not clarify why the net difference goes up to values of 2 meters, since a net difference of 1 meter is already unrealistic. Another possible clarification is that the wiring of the sensor received water damage, while sand may have damaged the wiring construction as well. As a result of that, incorrect measurements can be provided from the start. Again, this phenomenon does not explain the large fluctuations in the water level data during multiple periods. The discharges do not match the noise pattern of the water levels during these periods, despite the water levels are used to determine the outcome of the discharges. As mentioned earlier, it may be possible that the water level data available in Wiski is not the same water level data that is used in the substation to determine the discharge. It is possible that the raw water level data, first expressed in electric pulses, is used to determine the discharge. Then an error might be present in the transfer process from the water level expressed as an electric pulse towards a water level expressed in a number.

Based on the data gaps during the first years, the repetitive noise patterns, and the possible clarifications mentioned above, it can be stated that the time series of the water level from the flow meter in the Drentsche Hoofdvaart are unreliable.

Assessment of the Flow Velocity Data

Besides the water levels, the flow velocities are utilized as well to determine the discharges. Since these time series are only available after the data gap in 2019, a proper comparison with the discharge trends cannot be made. All discharges are displayed with positive magnitudes, while the flow velocity data contains both positive and negative values, implying a water inflow and water outflow in the system. Furthermore, the flow velocity data fluctuates mainly between -1 cm/s and 9 cm/s with a periodicity of approximately five minutes. Apart from that, the high-water period in February 2022 is related to large flow velocities with a negative magnitude, implying that a water inflow occurs, which is not the case during periods with excessive precipitation. Hans ten Kate mentions that this problem is caused in the formula from the substation.

This claim is strengthened by the clarification from Maarten Mulder. The project engineer mentions that a number in the formula might be either positive instead or negative or vice versa. He mentions that the ADCP meters from Nortek do not measure positive or negative flow velocities but do make a distinction between the two sides. If the formula is in fact correct, it may be possible that the ADCP meter is installed upside down, which causes the graph of the flow velocity time series to be mirrored. Nonetheless, none of these clarifications can be confirmed with certainty. Therefore, the flow velocity data is not suitable to apply as long as the positive and negative values are reversed. This can be realised by either adapting the formula in the substation, or by adapting the settings for the visualization of the data in ClearScada. Further research is required to confirm which of these two aspects is the definite cause of the problem.

5.4. Assessment Flow Meter de Wold Aa

Within the time series of the discharges provided by the ADCP meter in the Wold Aa, multiple anomalies are identified. Many of those anomalies are also identified and discussed in the assessment of the flow meter in the Drentsche Hoofdvaart in Section 0. Therefore, a reference to the same anomaly in the Drentsche Hoofdvaart is made and the anomalies are briefly addressed here. Similar to the structure of Section 0, the anomalies in the discharges are first discussed. After that, the water level data is addressed. Finally, an elaboration of the time series of the flow velocity is present.

Assessment of the Discharge Data

Similar to the Drentsche Hoofdvaart, the first three years of the time series contain many data gaps. The possible clarifications for this irregular availability of the data are equal to the clarifications given for this trend in the discharge data provided by the ADCP meter in the Drentsche Hoofdvaart. First, it is possible that there are issues with collecting the data as mentioned by Maarten Mulder. Besides that, these data gaps can be caused by a semi-defect sensor that occasionally detects the flow velocity or water level, after which it does not measure either one of these parameters or does not measure both at all. As stated in the assessment of the Drentsche Hoofdvaart, it is not possible to discover the true cause of this problem since it occurred over twelve years ago. Due to the lack of continuous data, this part of the time series is considered unreliable by the four external parties, even though small fragments with discharge data appear to be correct.

Two months after installing the flow meter, the trend with the jumps occurring every day at 12.00 and 0.00 hours starts to occur. Like for the Drentsche Hoofdvaart, this trend is present until the data gap in November 2019. The trend temporarily disappeared in October 2008 but was present again since December 2009. For this trend, the external parties mentioned the same clarifications as they mentioned for this trend in the discharge data of the Drentsche Hoofdvaart. Johan Draaijer mentions that the problem may be caused by larger data exports at 12.00 and 0.00, while values from the previous measurement could be used to determine the discharge as well. Gert van den Houten defines that a communication error for the data transportation can cause this trend. Maarten Mulder adds that it might be caused by the systems that reset on these times. Nevertheless, even though it is sure that this trend is caused by a technological flaw, meaning that one of the abovementioned clarifications may be true, this data is not considered trustworthy due to the large deviations between the lower and upper values of the discharges, which lay mostly between 0 m^3/s and 3 m^3/s. Even when an average is calculated of the discharges, differences between the magnitudes lay around 1 m^3/s, providing the smallest deviation to be over thirty percent, which is not accurate enough to be reliable for use, according to the four external parties.

From 15 October 2019 until 18 December 2019, a large data gap is present. After that data gap, all the discharges have positive values, indicating a constant water outflow for the last three years. This trend is also present in the discharge time series of the Drentsche Hoofdvaart and the same clarifications for this trend are defined. Gert van den Houten mentions that this is just a noise pattern, which means that the actual discharges cannot be computed from this data. Hans ten Kate firmly states that this is problem is caused due to adaptations in the formulas in the substation, which is supported by Maarten Mulder. The project engineer rejects the possibility that inflow data is missing since the data is constantly provided, since periodic minor gaps where data is missing are not present. As long as this part of the time series remain like this, it is not trustworthy. If the data can be rearranged in positive and negative discharge values, it may be useful, dependent of the pattern. If summer and winter periods are not recognizable and the magnitudes differ such that it is not similar to the magnitudes of the discharges between 2009 and 2019, it is still not trustworthy.

Assessment of the Water Level Data

The first remarkable aspect that is visible in the water level data is that large periods of noise are present. Within this noise, the water level varies between 0.50 meters NAP and -0.75 meters NAP. This net difference of 1.25 is bridged within an hour. Gert van den Houten defines that the periods with the large noise are unusual and not trustworthy, which is supported by Hans ten Kate. Hans ten Kate mentions that water levels from nearby measurement locations such as pumping stations can be used to compare the water level data. If the graph of those time series fits the graph of the time series from the flow meter, that time series can be used instead. As a result, the periods with the large noise patterns can be analysed more accurate, although it is likely that these time series are not fully representative for the water levels on the location of the flow meter.

According to Maarten Mulder, a possible clarification for the large differences in magnitude could be that the sensor that determines the water level is wrongly calibrated. However, that should be visible within the whole time series instead of only in the periods with large water level differences. Besides that, this clarification does not explain the periodic peaks which cause the noise pattern.
Due to this noise pattern, it is unclear which values are correct and incorrect. Independent on whether a maximum, minimum, or average value is selected, the deviation from the actual value is probably too large. Therefore, it can be conducted that the water level time series is not reliable.

Assessment of the Flow Velocity Data

The flow velocity data of the flow meter in the Wold Aa is available since the data gap in 2019. However, the flow velocity values are fluctuating rapidly, most of the times between 9 cm/s and -15 cm/s. Since the periodicity of this pattern is less than 5 minutes, it can be stated that this can be considered as noise. Maarten Mulder confirms this and defines that this is very likely to be caused by an obstacle that blocks the pulses. For example, dense vegetation of aquatic plants in the waterway could impede the beam. By analysing the raw flow velocity data per cell, it can be verified whether an object is blocking the pulse or not. Since these raw data is not available at WDOD, field research must be conducted to determine the roots of the problem. With such a large difference in the magnitudes of the flow velocity, the measurement data is unreliable.

6. Discussion

6.1. Meanings of the Data

The main objective of this research is to determine the technological and hydrological explanations that cause the suspicious patterns in the measurement data obtained by the flow meters deployed by Waterschap Drents Overijsselse Data. An elaborate data analysis is performed, literature research is done, and interviews are conducted. These methods are used to acquire knowledge about the discharge data, the study area, the flow meter, and the data transferring process. All these insights are then combined and assessed for each single flow meter. Now this research is completed, it is clear that a large part of the identified anomalies are caused by technological aspects, such as flaws in the formula in either the substation or in the data server of WDOD. Apart from that, transferring the data from the substation towards the data server appears to contain flaws as well. Based on the patterns in the graph from the identified anomalies and the provided explanations by the experts, it can be stated with confidence that technological issues are the cause of many identified anomalies.

Despite the fact that the stage of the data collection and transfer process where the technological problems occur have mostly been localized, a specific cause for these problems cannot be indicated. Although these outcomes are considered to be reliable, it is unsatisfactory that the exact cause of the anomalies has not been found in most cases, since it is rather impossible to solve this issue now. Nevertheless, the provided explanations about the possible causes of these anomalies are rather loose and ungrounded with either hydrological or technological facts and phenomena. On top of that, it is rather impossible to restore these data fragments to make them reliable and suitable for further use. As a result of that, it is expected that many other discharge time series from other flow meters will be rejected as well.

However, there are identified anomalies for which it is possible to identify the cause with certainty. The alternating positive and negative discharge data and flow velocity data from the flow meter in the Overijssels Kanaal are expected to be caused by the sloshing that is assumed to be present. Based on the characteristics of the study area and the provided arguments by the experts, this explanation seems to be realistic. By actually proving if the water sloshes in the port through literature research or by conducting field research, the clarification can be either confirmed or rejected. In this way, the reliability of the discharge data can be verified, even though the time series is rather unusable since there is no clear overview of the inflow and outflow of the water system. The pattern is also closely related to the water system. Therefore, the outcome of this anomaly for this flow meter is unsuitable to use for other flow meters that contain the same anomaly in their data, but have are located in a waterway with different characteristics.

Furthermore, it is noted that the discharges provided by the meter in the Groote Grift are approximately twice as large as the discharges measured by pumping station Streukelerzijl. Since the discharge cannot differ that much over such a small distance with just one minor side-ditch present between the two measurement locations, as shown in Figure 12, it is important to further investigate the accuracy of at least the flow meter by performing preferably three calibration measurements: one during a low-water period, one during a normal water period, and one during a high-water period, in order to accurately calibrate the formula in the substation for the flow meter, that processes the raw data to the available discharge data in Wiski.

Since this pattern is continuously present under regular circumstances and the observed discharges from the flow meter also correspond with the discharges provided by the weir, this outcome of the analysis is considered to be reliable.

6.2. Limitations

Due to the elapsed time since several anomalies occurred, it is not possible to acquire more knowledge about those identified anomalies. Nevertheless, it may be possible to gain further insights in these patterns if they were to occur again nowadays and will be noted within several days or weeks. The possible clarifications that are then proposed are easier to verify since it is likely that other involved parties may have useful information about that specific moment.

Due to the many technological related different solutions that are brought forward by the experts, the statement that the anomalies are caused by technological issues is considered to be realistic. Because of the many identified technological related anomalies in the data of the flow meters in the Drentsche Hoofdvaart and the Wold Aa, the reliability of these time series cannot be assured. Nevertheless, it may be possible to restore the data acquired after the data gap in 2019, where all the discharges have been visualized as water outflow. If the discharges can be restored to values with positive and negative values, hence showing a water inflow and water outflow in the system, the volume of water flowing in downstream and upstream direction can be determined. This can be done by adapting the formula in either the substation or in ClearScada.

Regarding the selection of the flow meters, it is experienced that the lack of data from the water levels or flow velocities leads to difficulties in the data analysis, since multiple possible explanations cannot be fully verified due to the lack of this data. As a result, several anomalies could not be investigated in detail, which led to the lack of concrete explanations that may have given answers for the occurrence of the anomalies. Therefore, it is advised to always store both the flow velocity and water level data along with the discharge data.

Another point of interest is that all four flow meters are ADCP meters. Since almost all flow meters owned by WDOD are ADCP meters, these results can be used for the analysis of those flow meters as well. However, it is unknown whether the causes for the anomalies related to the characteristics of the water system are relevant for other flow meters as well, since it is likely that the characteristics of other waterways differ from the analysed waterways in this research. Besides, it is estimated that two out of the sixteen flow meters might not be ADCP meters. If WDOD would like to acquire more information about these flow meters and their accompanying data, it is advised to analyse these meters in the future, instead of utilizing the technological explanations provided in this research.

Regarding the interviews, it is experienced that the sequence of the conducted interviews was selected properly, although the interview with Johan Schadenberg should have taken place sooner. However, it might be possible that the given explanations for the identified anomalies are bounded to the expertise of the interviewed experts. This means that the different proposes solutions given may be caused by the fact that for example Johan Draaijer or Gert van den Houten does not possess the required knowledge regarding a technological related anomaly. As a result, the given answers may not be that valuable compared to the answers provided by Maarten Mulder, who possesses more knowledge about the technological aspects of the flow meter. Therefore, a larger separation between hydrological related questions and technological related questions can be made for further research, to acquire more reliable information.

Next to that, an interview with Waterschap Brabanste Delta could have been conducted as well. It is perceived that they are relatively far ahead in the development and use of flow meters compared to other water boards. Therefore, it is possible that other insights could have been obtained that could clarify the identified anomalies. Additionally, an interview with Aqua Vision, the installer of the flow meter in the Groote Grift, could have been conducted as well. This would have resulted in a more complete overview of the flow meter data, resulting in a more complete assessment of the flow meters.

Even though interviews with Aqua Vision or Waterschap Brabantse Delta would likely not have provided new insights but have given similar xplanations as the other parties, possible clarifications can be backed by multiple parties, thereby strengthening the reliability of the findings.

7. Conclusions

The objective of this research is to assess the accuracy of the flow meters in the field of operation of Waterschap Drents Overijsselse Delta, by investigating possible causes of the anomalies in the measured discharge data through establishing technological and/or hydrological explanations.

The main information acquired in the global data analysis is that vertical lines in the graph represent sudden increases, while horizontal lines in the graph indicate that the values remain constant over time. Within a waterway, it is unlikely that such events occur. Therefore, these patterns are not desired to be present in the time series and are practically always incorrect. Fragments in the time series with large fluctuations within a short period of time are also suspicious, since the parameters cannot fluctuate that much in such water systems. During the extensive data analysis, multiple anomalies have been identified in the discharge data, flow velocity data, and water level data using the abovementioned principle.

Among the four flow meters, eleven different types of anomalies are identified. These anomalies are caused either by hydrological phenomena of the water system in which the flow meter operates, or technological phenomena of the flow meter itself or its accompanying system. Out of the eleven different anomalies, two anomalies are caused by hydrological phenomena and one anomaly is expected to be caused by a hydrological phenomenon. The periodic peaks in the discharge data from the flow meter in the Groote Grift are caused by the water outflow, managed by pumping station Streukelerzijl, while the periodic fluctuating water levels in the Overijssels Kanaal occur because the water levels are automatically regulated by one or more hydraulic structures, although it cannot be stated which hydraulic structure(s) is(/are) utilized for that. For the flow meter in the Overijssels Kanaal, the fluctuating positive and negative discharges and flow velocities with a periodicity of about 15 minutes are expected to be caused by a hydrological related phenomena. Although not proven, the interviewed experts indicate that the water sloshes in the port of Deventer causes the fluctuations.

The other eight different types of anomalies are caused by technological related issues. Multiple issues are located in the formula of either the substation or the data server ClearScada, that processes the raw data into the measurement data available in Wiski. The computed flow velocity that is ten times larger than the observed flow velocity is caused by this technical flaw. Besides that, it can be assumed that the pattern, which contains discharges with a positive magnitude only since 2019, is caused by either an error in the formula in the substation or in ClearScada as well. On top of that, the inverted flow velocity data is caused by a mistake in the formula as well, although it is also possible that the flow meter is either installed on the wrong side of the waterway or installed upside down. Finally, sudden jumps that are present in the discharge time series are possibly caused by an adaptation in the formula. However, this cannot be verified in the particular cases for the flow meters in the Drentsche Hoofdvaart and the Wold Aa, as such changes have not been registered.

The (un)availability of time series after the data gap in November 2019, where the transition from ATIS to ClearScada took place, is also likely to be caused by a technological flaw in either the substation or ClearScada. It is unclear whether that data is accessible. By contacting the managers of the substation and ClearScada, it can be verified whether these time series are available or not.

The presence of large data gaps can be caused by a defect in the flow meter or a defect in the substation, while smaller data gaps might be caused by technological flaws in the data transport from the substation to the data server from Waterschap Drents Overijsselse Delta. The sudden jumps that occur every 12 hours are caused by multiple technological errors as well. It is likely that this problem is caused by system resets that take place at 12.00 and 0.00 hours, although this cannot be stated with certainty.

Lastly, the time series of the water level contain large fluctuations and noise with net differences over 1 meter that are reached within an hour. On top of that, the water level data does not match the data from the discharges regarding the shape of the graph and the spread of the data. The exact cause of this technologically natured issue has not been determined, due to lack of the advanced knowledge of the technical aspects of the flow meter.

To conclude this research, it can be said that the anomalies in the discharge data, flow velocity data, and water level data are in most cases caused by technological issues. These technological issues are often related to adaptations within the formulas of the substation or the data server from Waterschap Drents Overijsselse Delta, that process the raw data into the measurement data that is available in the data analysis program Wiski. Besides that, it is expected that communication errors between the substation and the data server from WDOD result in data gaps that are present in the time series. Since it cannot be verified what happened during these periods, the exact cause of these technological issues cannot be determined with certainty.

It is difficult to draw general conclusions regarding the hydrological related anomalies, since water systems are rarely identical to each other. Nevertheless, when the discharge data of a flow meter matches with the discharge data obtained by a nearby hydraulic structure regarding the shape, it can be assumed that the hydraulic station affects the discharge on the location of the flow meter. By performing calibration measurements, it can be verified whether the discharge data provided by the flow meter and hydraulic structure correspond with the actual discharges.

The anomalies that are caused by technological issues are not suitable for further use, except for the anomaly with the discharge data where all the discharges have positive values. If it is possible to locate this problem, which is either caused in the substation or in ClearScada, the formula can be adapted and the discharge data can be recalculated. The investigated discharge data that contains anomalies that are caused by hydrological issues are suitable for further use, after calibration measurements are performed to verify whether the measured discharges correspond with the actual discharges. If not, the time series must be redetermined using the new formula in order to make the time series suitable for use.

8. Recommendations

Within this Section, specific recommendations are given about the further use of the data provided by the flow meters. Recommendations about restoring the data are provided as well if that could contribute to the reliability of the data. Additionally, general recommendations are provided as well for the future. Following these recommendations will decrease the probability that large periods of time series will become unusable due to technological issues.

8.1. Recommendations for the Current Data

Since it is thought that the water in the port of Deventer sloshes, literature research or field research must be conducted to verify whether this observation is in fact true or not. If it turns out to be true, it can be stated that the sloshing causes a constant change of the flow direction, hence it is then recommended to remove the flow meter. However, it is possible to measure the quantity of water that enters and leaves the system by continuing conducting measurements at hydraulic structure Ankersmit. To make sure that these measurements are correct and have been correct for the last years, calibration measurements must be performed to calibrate the formulas for the weir and pumping station. It is advised to perform three calibration measurements. One before a high-water period, one during the high-water period, and one after the high-water period. As a result of that, the formula in the substation can be adapted such that the graph of the discharge data from the hydraulic structure matches the three calibration measurement points accurately. The water inflow and water outflow via the sluice can be determined as well, thereby obtaining an even more accurate view of the total inflow and outflow of the system. However, it is important to investigate where water is able to leave or enter the port of Deventer through other hydraulic structures or sewerage.

To restore the discharge data from the flow meter in the Groote Grift, calibration measurements must be performed for the flow meter and the hydraulic structure Streukelerzijl. It is advised to perform three calibration measurements. One before a high-water period, one during the high-water period, and one after the high-water period. As a result of that, the formula in the substation can be adapted such that the graph of the discharge data from the hydraulic structure matches the three calibration measurement points accurately. If possible, the discharge data can be recalculated from the current time series, which would make the time series reliable for use. However, when weir Fissele is active, a lot of turbulence is present near the outlet of the weir into the Groote Grift. Since the flow meter is located closely to the weir, measured discharges could be inaccurate during that period, which should be taken into account. Fortunately, weir Fissele was scarcely active, hence nearly all the discharge data is still suitable for use after the recalculation. To prevent this in the future, the flow meter can be reinstalled further away from the weir.

Since the discharge data and the water level data from the flow meter in the Drentsche Hoofdvaart contain so many flaws, it is advised to stop using this data. The possibility that the discharge data and the water level data contain deviations and errors is very high. The flow velocity data from the Drentsche Hoofdvaart can be used if it is kept in mind that the flow direction is reversed. If that issue can be resolved, the flow velocity can be safely used. Next to that, it is advised to resolve the problem where all discharges have positive values. This can be done by adapting the formula in either the substation or in ClearScada. Then, it should be verified whether the data still contains suspicious patterns. If not, this part of the discharge time series could be used again. Based on the acquired information during this research, this can be done by examining the formula in the substation or by investigating the data in ClearScada.

Because the time series provided by the flow meter in the Wold Aa also contain many flaws, it is recommended to stop utilizing the discharge data, the flow velocity data, and the water level data, since it is very plausible that the provided values severely differ from the actual values. Again, it is advised to resolve the problem where all discharges have positive values, implying a constant outflow. Then, it should be verified whether the data still contains suspicious patterns. If not, this part of the discharge time series could be used again. Based on the acquired information during this research, this can be done by examining the formula in the substation or by investigating the data in ClearScada.

8.2. General Recommendations

To prevent rejecting large periods of data in the future, several measures can be taken. It is strongly advised to appoint an employee who is responsible for the continuous validation of the collected data. If any suspicious events start to occur, it is important to report this as soon as possible. In that way, it can be verified where to problem originates. For example, construction work might be executed, the flow meter can be damaged, or an obstacle blocks the signal from the flow meter. Then, appropriate measures can be taken, and a marginal comment can be placed in the time series that indicates what the exact problem was and which part of the data is unreliable for usage.

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Werkgroep Drentsche Hoofdvaart. (2022). *Drentschehoofdvaart.nl, met informatie voor de recreatievaart door Zuidwest Drenthe.* http://www.drentschehoofdvaart.nl/

10. Appendices

Appendix A1

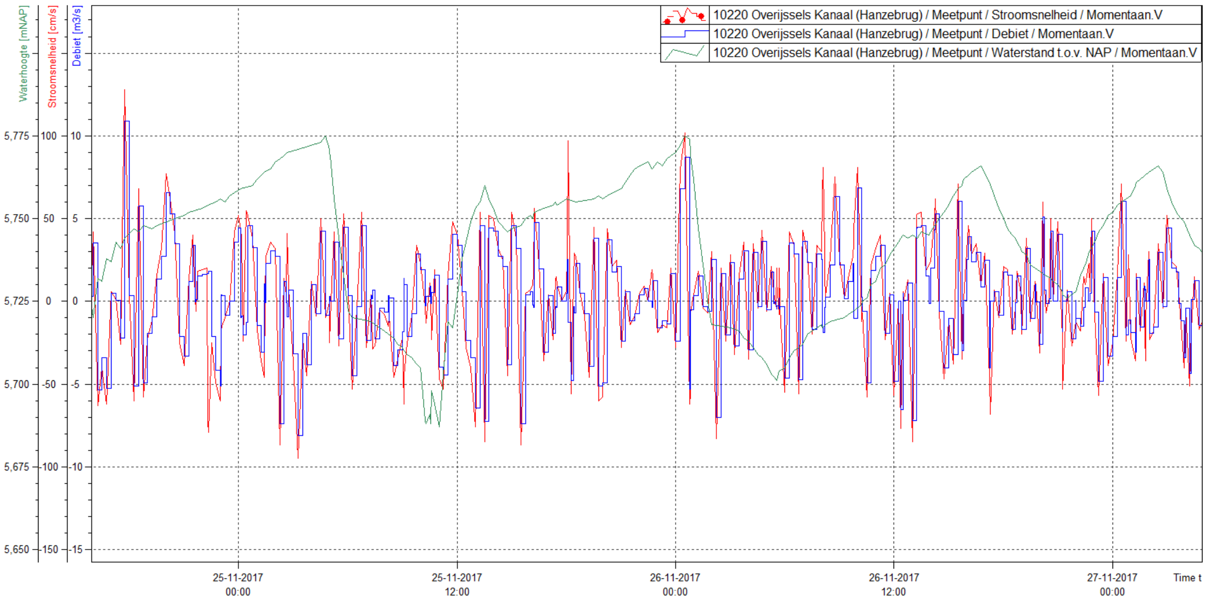

Figure 44 The periodic water level fluctuation in the Overijssels Kanaal present in a deviating pattern

Appendix A2

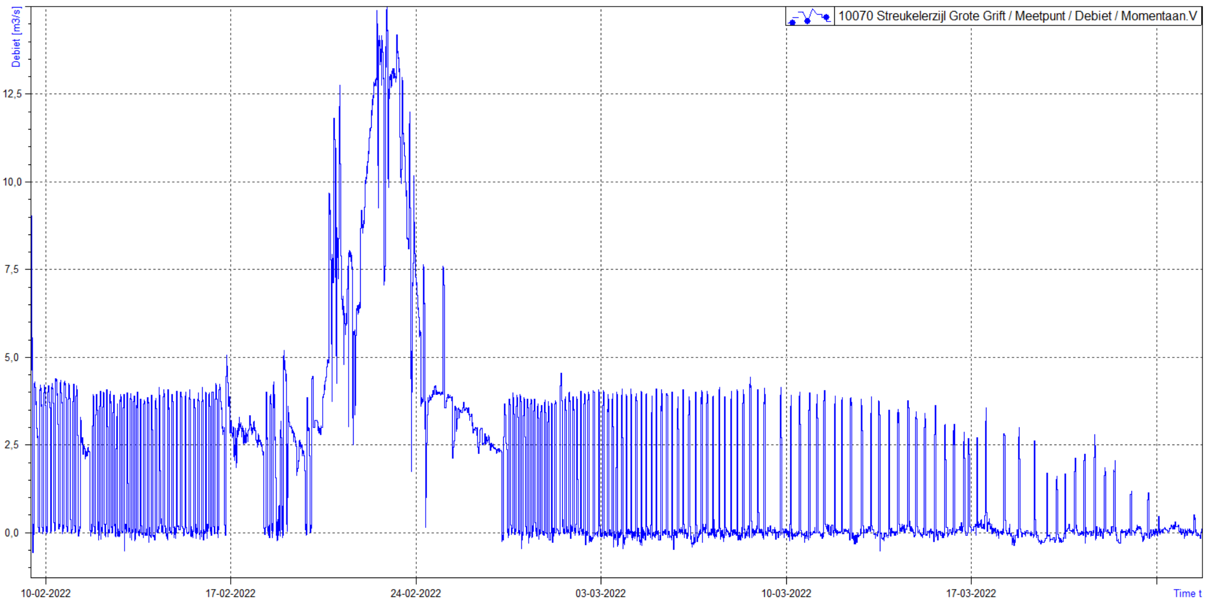

Figure 45 Example of a high-water event in the discharge data from flow meter Streukelerzijl Groote Grift

Appendix A3

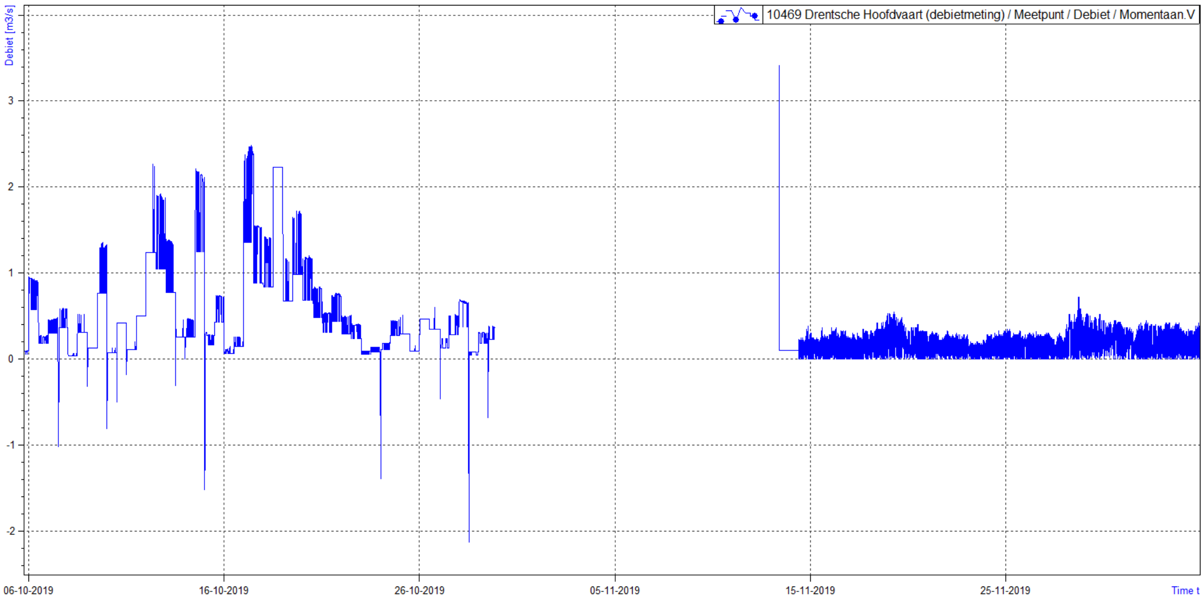

Figure 46 Detailed overview of the data gap from 30 October until 13 November in 2019, followed by the positive discharge data

Appendix A4

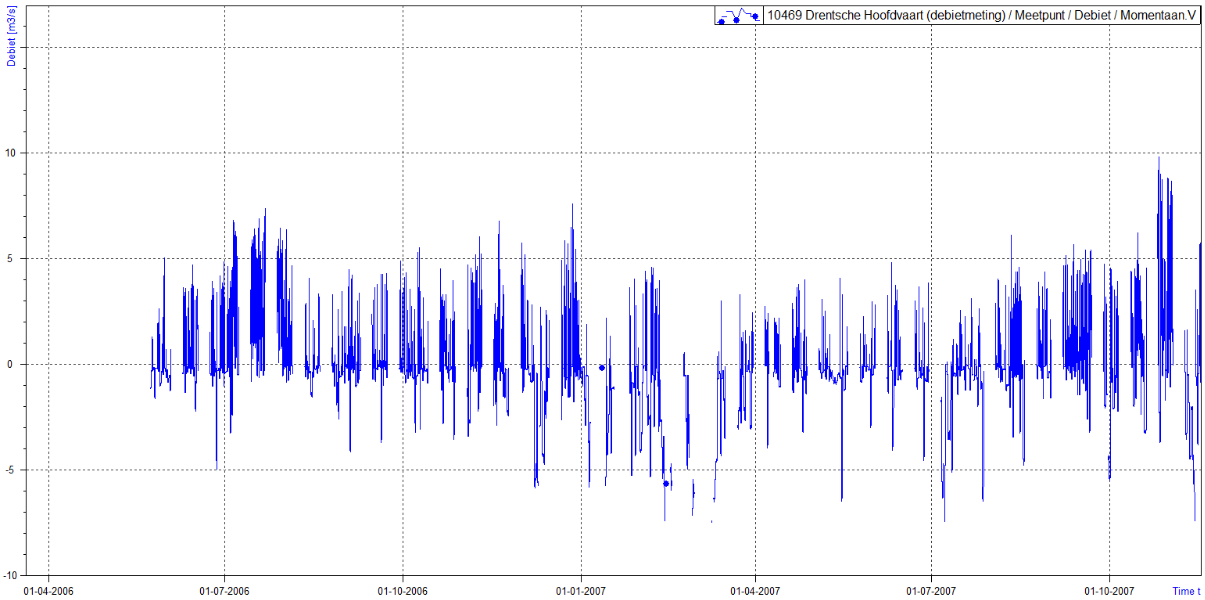

Figure 47 First period of the discharge time series from flow meter Drentsche Hoofdvaart, which contains multiple minor data gaps

Appendix A5

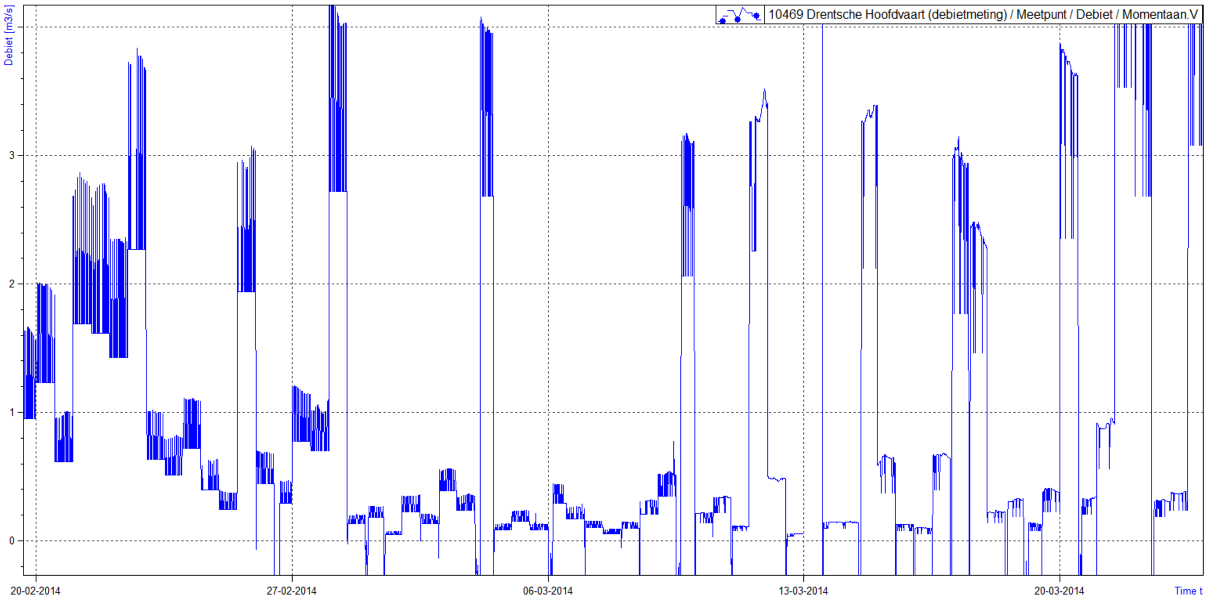

Figure 48 Second variant of the step trend present in the discharge data from flow meter Drentsche Hoofdvaart

Appendix A6

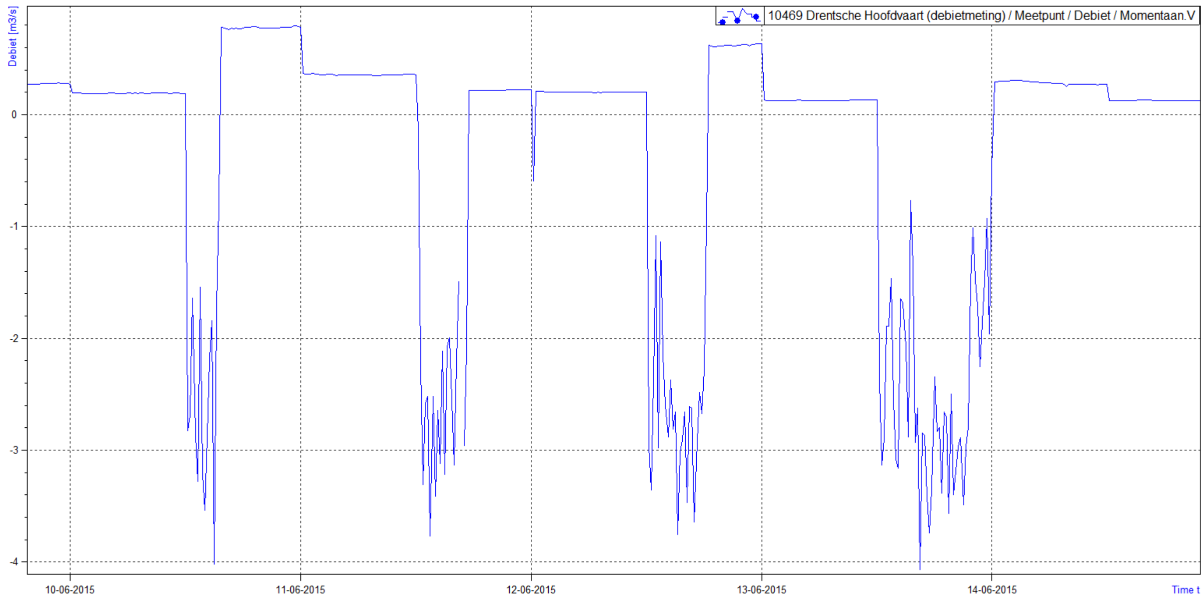

Figure 49 Third variant of the step trend present in the discharge data from flow meter Drentsche Hoofdvaart

Appendix A7

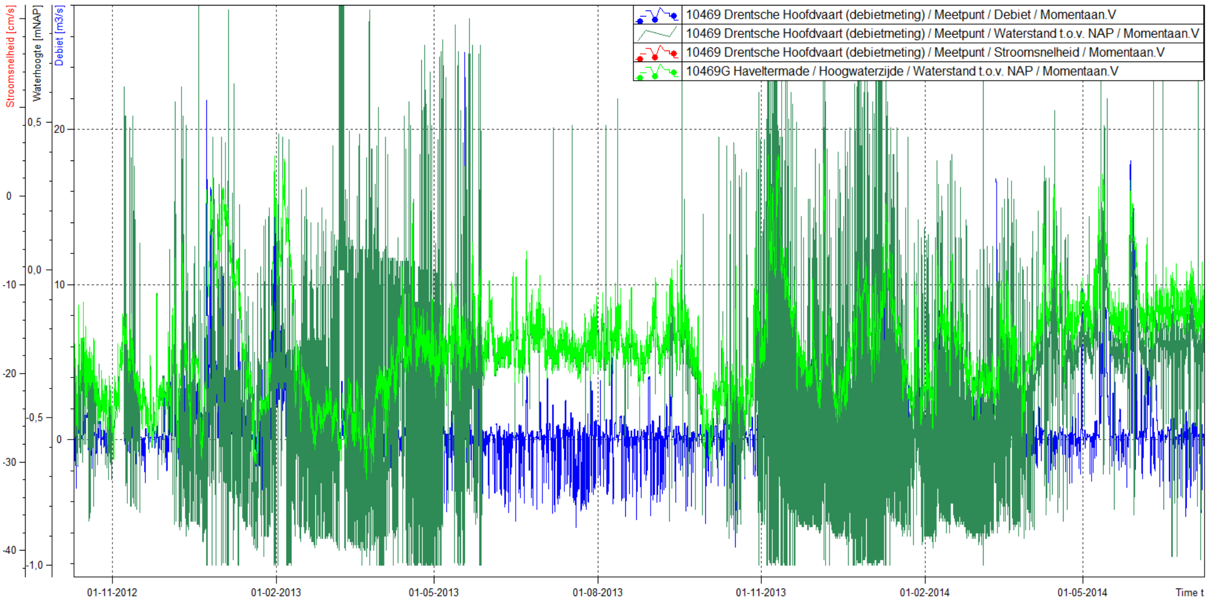

Figure 50 Fragment of the comparison of the water levels measured by flow meter Drentsche Hoofdvaart and pumping station Haveltermade

Appendix A8

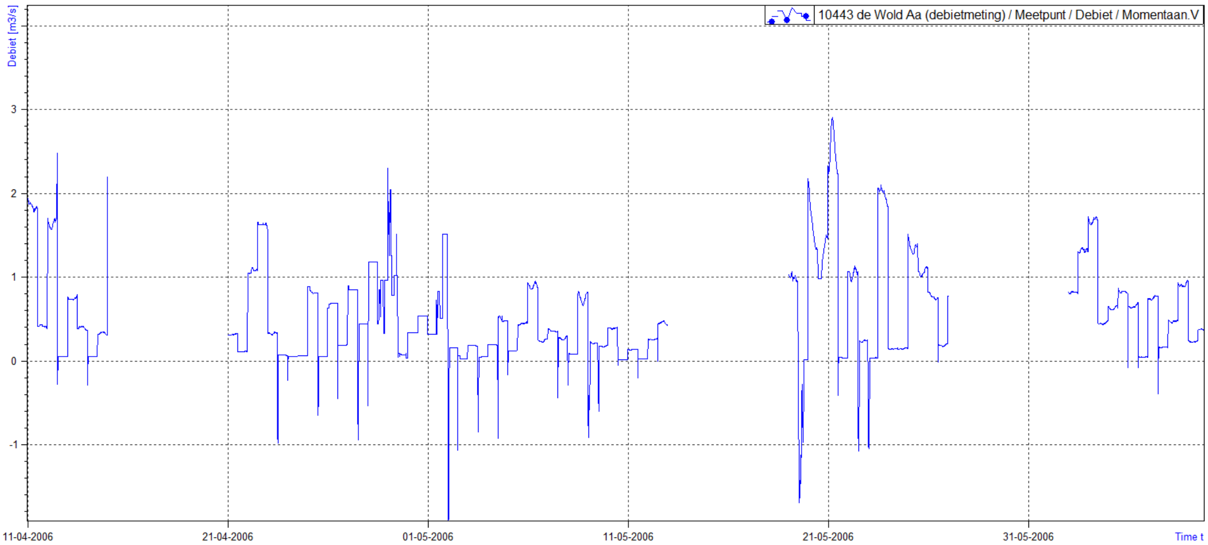

Figure 51 Fragment of the discharge time series from flow meter the Wold Aa where it is visible that the step trend occurs for positive discharges

Appendix A9

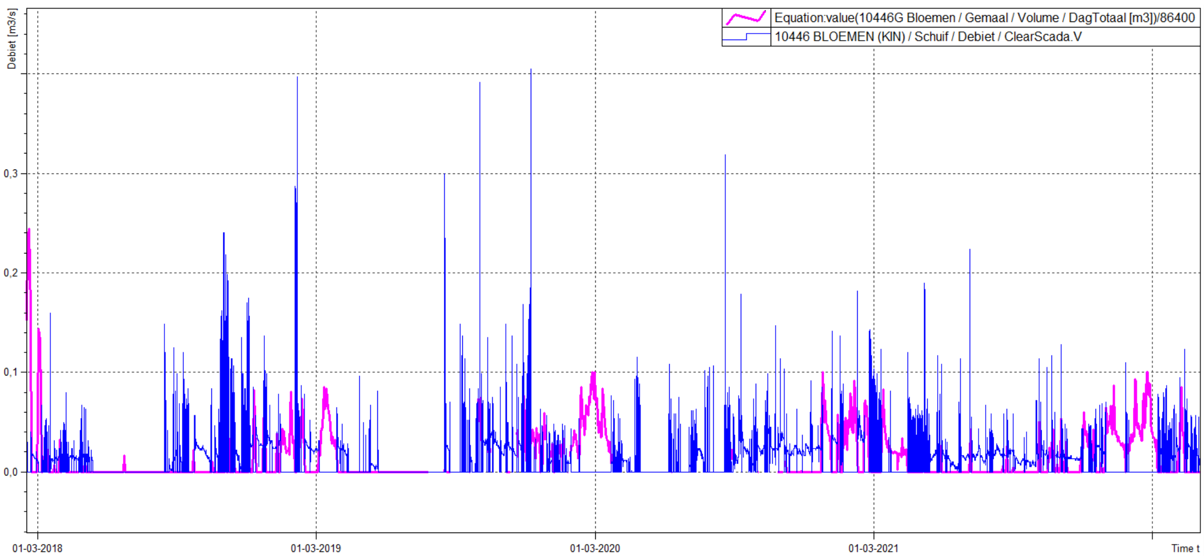

Figure 52 Time series of the discharges from weir and pumping station Bloemen

Appendix A10

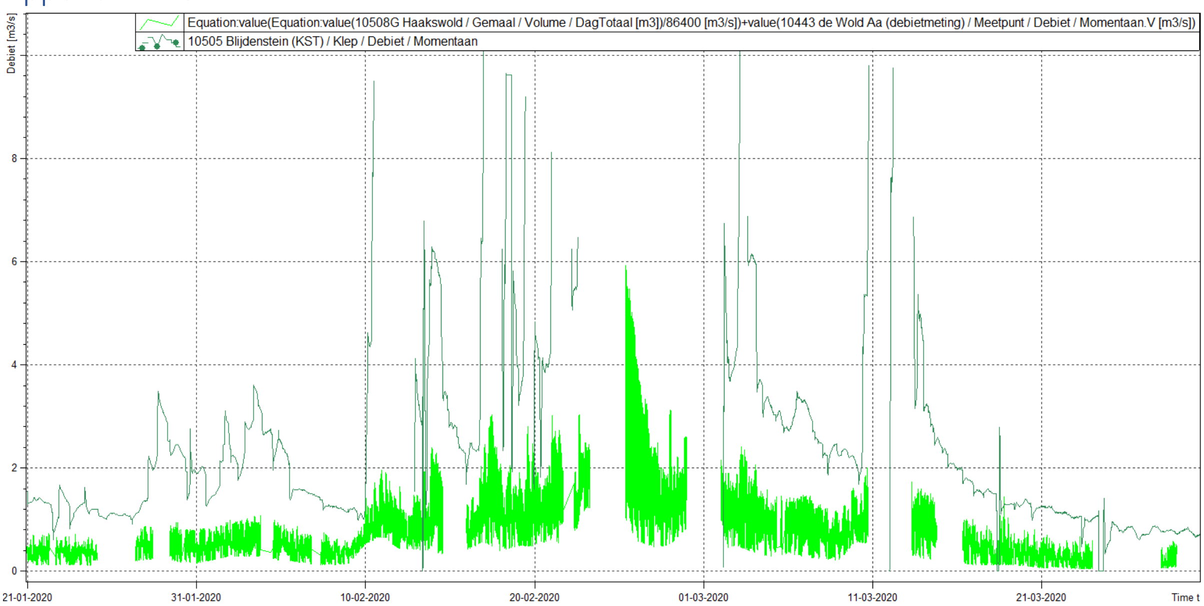

Figure 53 Fragment of the comparison of the discharges from the Wold Aa and Haakswold against Blijdenstein

Appendix B

Type of measurement

To measure the discharge, various measuring methods can be applied. These measuring methods can be either classified as incidental measurements or continuous measurements (Hartong & Termes, 2009b). When the discharge at a certain location is measured during a limited period, the measurements are categorized as incidental measurements. These type of methods are applied to acquire discharge data in that area for one single time, for example to determine the capacity of a waterway or to calibrate a measurement setup for continuous measurements. Incidental measurements commonly have a measuring frequency of several times a month or several times a year. When it is desired to gain knowledge of the discharge for a long period of time, but with a high measuring frequency, continuous measurements must be conducted. However, continuous measurements are in fact semi-continuous since measurements are still performed using time intervals, for example every 15 minutes, every hour, or every 12 hours. To perform proper discharge measurements, several norms apply to give guidance for the measurement methods. These norms originate from the International Organization for Standardisation, abbreviated ISO. In the Netherlands, the norms from ISO are published by NEN alongside with European norms and national norms (NEN, 2022).

Incidental measurement methods

In this section, five different incidental methods from Hartong & Termes (2009a) are addressed.

Velocity-area method

The velocity-area method is a method that can be applied in almost every waterway with a considerable level of accuracy. By multiplying the measured cross section of a channel with the measured velocity of the water in the channel flow, the discharge can be calculated. The area of the cross section can be determined by either measuring the width and depth of the cross section at one point or by measuring the width and depth of the cross section at multiple locations, thereby creating preferably equal subsections in the cross section, which is visualized Figure 54. For each waterway a restricted number of subsections must be determined using the ISO norms. In general, the width of a subsection must be below twenty percent of the total width of a constant waterway or a small waterway, while the width of a subsection must be below five percent of the total width of an irregular waterway or large waterway.

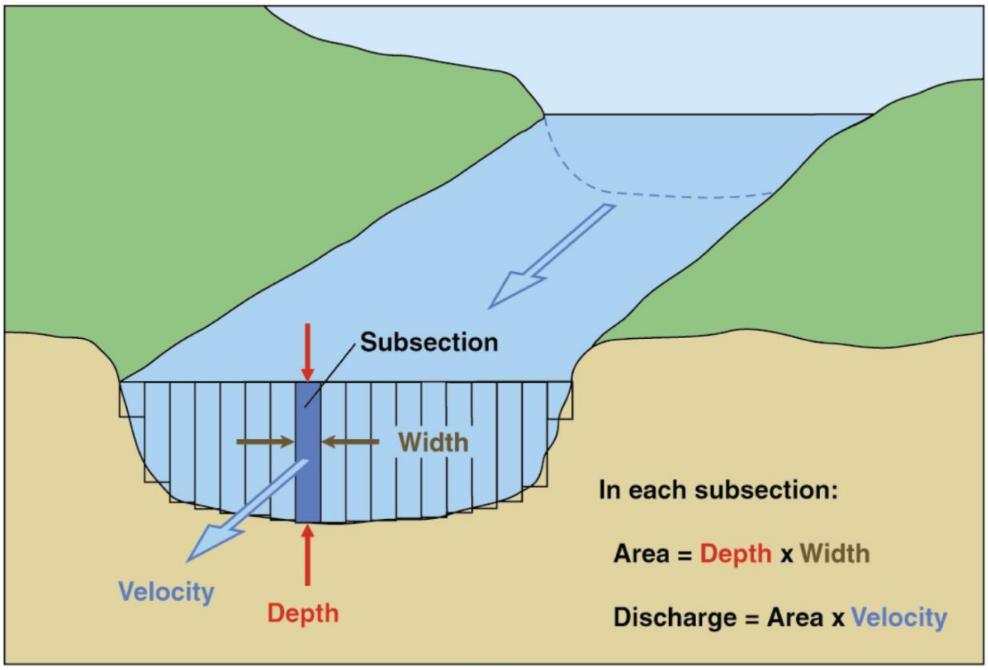

Figure 54 Example of how the discharge can be calculated using the velocity-area method (Resources, 2011)

For each subsection, the average flow velocity must be determined. For the determination of the flow velocity a stationary flow is considered, meaning the discharge is constant over time. Since a turbulent flow is present in most waterways, the velocity-area method presumes a turbulent flow for its calculations. Because the flow velocity is not equal over the cross section due to friction at the bottom and embankments of the waterway and bends and obstacles in the areas upstream of the selected cross section, a velocity distribution must be created. Two frequently used approaches are the power approach and the logarithm approach. After the velocity distribution is created for the specific cross section, known as 'meetraai', the average velocity for each subsection can be determined. At last, the discharge can be determined using either the mean-section method or mid-section method. The mean-section method calculates the discharge of a subsection using its two vertical borders. However, the mid-section method calculates the discharge of a section with a vertical border as central point, thus including two half subsections instead of using one complete subsection. After the discharges for the sections are determined, the total discharge can be determined for both methods by adding the calculated values.

The velocity-area method is in general suited for stationary flows and less suitable for non-stationary flows, quick changing discharges, and waterways that deal with a backwater curve. When the velocity-area is not suited, for example due to differing waterway conditions, time pressure, or economic issues, an adapted velocity-area method can be applied. The moving-boat method is the most applied adapted velocity-area method in the Netherlands. For this method, a boat navigates with a constant velocity from one embankment towards the other embankment, following a trajectory established in advance. During this cross, several depth measurements are conducted using an echosounder, which is installed on a frame together with flow velocity meters that measure the flow velocity. This frame is held at a fixed location beneath the boat. Nowadays, an Acoustic Doppler Current Profiler, abbreviated ADCP, is often deployed for the moving-boat method. This device does not make use of the velocity-area method and determines the discharge during the navigation of the boat. This device is further explained in the continuous measurement methods Section.

Slope method

The discharge of a waterway can also be determined based on the water surface slope and the average area of the meetraaien. First, two segments of a waterway must be selected. It is important that the length of the trajectory is in accordance with the guidelines for this method and that the height difference between the two segments is larger than 0.15 meters. Then, the slope is calculated, the roughness of the waterway bottom is estimated, and the average area of the cross sections is determined. Considering a small waterway with a width smaller than 30 meters, the equation of Manning must be applied to determine the average velocity. By applying the basic discharge equation, stating that the discharge is equal to the area of the cross section multiplied by the flow velocity, the discharge or discharge can be determined. This method is rarely applied in the Netherlands due to its inaccuracies on different aspects, such as the determination of the roughness or the Manning coefficient.

Dilution method

If the cross section of a waterway is difficult to establish, or the flow velocities are too high to implement regular flow velocity meters, it is possible to apply the dilution method. These conditions are often present in creeks located in the mountains. Obviously, these conditions do not apply for the Dutch waterways, resulting in a limited use of this method in the Netherlands. The dilution method is based on the perception that the quantity of water that passes point A should also pass point B further downstream, as long as the waterway does not have branches. A known concentration of a certain substance is constantly discharged for several minutes in the flow at location A, which is presumed to be stationary. The substance is administered using a Mariotte bottle, which is able to discharge a constant flow. At location B, the concentration of the substance is measured. When the measured concentration downstream reaches a constant value, the measurement is finished. Based on the difference in concentrations at location A and B, the discharge can be calculated.

Field calibration

Discharge artefacts, such as pumping stations or weirs, have a discharge relation which is in general identified during the construction phase with calibration measurements or guarantee measurements, although it is theoretically determined in certain cases. Nonetheless, these discharge relations do not correspond with the actual values due to deviations in the shape of the weirs compared to the theoretical shapes. Therefore, calibration measurements must be conducted. Regarding the pumping stations, the operating conditions can differ from the conditions acquired from the calibration measurements. Erosion of the pumping station also affects the actual discharge values. Field calibration can be conducted using several devices and is actually based on existing methods, of whom a few mentioned above such as the velocity-area method. It is favourable that a field calibration can be conducted under all possible conditions, including extreme weather conditions, such as highwater or periods of drought. However, large waves are neglected in this method, together with modifications in the waterway bed due to sedimentation or vegetation.

Continuous measurement methods

Five continuous measurement methods are discussed in this section.

Measurement weirs

Weirs are generally deployed to manage a certain difference in water level, to maintain the upstream water level, or to arrange the discharge downstream. Apart from that, weirs can also be deployed to assess the discharge using a theoretical approach. To get more accurate discharge data, measurement weirs are constructed. In a measurement weir, the cross section of the waterway is narrowed, resulting in a rectangular passage which simplifies the determination of the discharge. When the water flows through the measuring weir and falls in the downstream waterway, the water level will increase just downstream of the falling water. This height difference is caused by the kinetic energy or the velocity from the water particles (Fox et al., 2016). Based on this property and the cross section of the measuring weir, the discharge can be determined. Measuring weirs are classified as standardized or non-standardized measurement weirs. If the shape and design of the measuring weir complies with the ISO norms, it is classified as a standardized measurement weir. If the properties of the measurement weirs deviate from the ISO norms, the measurement weir is classified as non-standardized. Both types of measurement weirs are present in the Netherlands, although the quantity of these constructions declines. Because the construction hampers the passage for water creatures such as fish, more ecological constructions are preferred.

Measurement gutters

Comparable to measurement weirs, measurement gutters narrow the waterway as well, while at certain measurement gutters the waterway bed is also heightened if the sediment transport is not severely hampered. It is desired to minimize the energy loss in a measurement gutter. Within the Dutch water system, trapezium and rectangular shaped measurement gutters are present. It is desired to have a uniform flow at the location of the measurement gutter. It is favourable to have an as low as possible elevation height in the area of the waterway and sediment must be transported in the area.

Transit-time method

The transit-time method is based on the crossing time of acoustic pulses over a waterway. Two pulses are emitted diagonally over the water way: one pulse from point A to point B and one pulse from point B to point A. Due to the fact that one pulse is emitted in the flow direction and one pulse is emitted against the flow direction, the crossing time of the two pulses differ. Based on this difference, the flow velocity can be determined. By emitting another two pulses in a diagonal, such that there is measured in a cross, the direction of the flow velocity can be determined as well. This method is suited for waterways with a dominant flow direction as well as for waterways with alternating flow directions. Using the flow velocity, the area of the wet cross section, and a correction factor K, determined for the location, the discharge can be determined. Inaccuracies in the determination of the discharge may occur due to errors in the determination of the correction factor, ships, aquatic plants, and other obstacles.

Discharge and water level relation

The method that is based on the relation between the discharge and the water level. For a certain water level, a certain discharge is expected. The water level is continuously measured, while the discharge is occasionally measured over the whole outflow length. This measurement is in fact based on the principle of the Chézy equation. However, the discharges are often determined using a different method, such as the velocity-area method. Changes in vegetation, cross section, or water levels, are examples of factors that may cause the discharge-water level relation to be affected. This method is difficult to use for waterways with low flow velocities. Besides that, calibration measurements along the whole trajectory are required.

Discharge and slope relation

The discharge and slope relation method is based on the pump capacity and the travel time of the water to go through the hydraulic structure in the upstream direction. By using these values and measuring the time that the hydraulic structure is active, the water inflow of a system can be calculated. Although these hydraulic structures, such as pumping stations, are not meant for discharge measurements, it is desired to use them for conducting measurements.

Appendix C1

Voor nu wordt met name Drentsche hoofdvaart besproken, aangezien deze veel verschillende verschijnselen heeft die bij de Wold Aa ook terug te vinden is. Op basis van dit resultaat zullen de andere debietmeters beter geanalyseerd en uitgewerkt worden.

Momentaan O en momentaan V → Hoe wordt deze data verkregen en toegepast?

Hoe komen de O en V reeksen in Wiski terecht?

Worden deze reeksen bewerkt? Zo ja, waar en door wie worden ze bewerkt?

Hoe worden de maximale en minimale waardes bepaald voor de momentaan V?

Hoe weet je dat de juiste data gevalideerd wordt in de V reeks?

In beide reeksen incidenteel komen uiterst hoge pieken voor, hoe kan dat?

Ontbreken data → beschikbaar of niet beschikbaar?

Soms zitten er gaten in de meetreeks, wat betekent dat?

Soms is er een gat van een paar dagen of een week aanwezig, soms van een paar maanden. Hoe kan de spreiding zo groot zijn?

Soms geeft de O reeks waardes maar geeft de V reeks een gat, hoe kan dat?

Drentsche Hoofdvaart (figuren uit de data analyse worden getoond)

Hoe kan het dat de data de eerste paar jaar vrij inconsistent is met veel gaten?

Meet een debietmeter vanaf dag 1 goed? Zo nee, hoe lang duurt het voor de meter 'goed' meet?

Is dat voor elke ADCP meter het geval?

Debiet lijkt positief en negatief te zijn, wisselt relatief snel af, hoe moet ik dat interpreteren?

Rond 12u springt het debiet omhoog of omlaag, wat gebeurt daar? Hoe kan dit verschijnsel plaatsvinden?

Voor positieve debieten lijken de waardes snel te zakken, terwijl bij een negatief debiet de waarde constant blijft tot de volgende sprong, hoe kan dat?

Waterstand schommelt ook vrij erg, hoe wordt deze gemeten?

Wat kan de meetresultaten van de waterstand beïnvloeden?

Bijv. in 2014 is er een sprong rond 12u, gevolgd door een schommelend debiet, wat gebeurt daar?

Eind 2019 zijn er even geen metingen, waarna alles positief is. Wat heeft daar plaatsgevonden?

Worden de reeksen bewerkt voor ze in Wiski komen?

Waarom waren er voor het gat in november 2019 wel positieve en negatieve debieten?

Ook hier zijn schommelende waarden van het debiet tussen 0 en 0.2 kuub/s aanwezig, hoe kan dat?

Gebeurt het vaker dat een meter buiten zijn optimale bereik moet meten?

Zijn er geen andere oplossingen/vervangers voor deze meters?

Aparte sprong in juni, wat gebeurt daar?

Waarom is de waterhoogte niet beschikbaar maar ineens wel de stroomsnelheid na het gat, wanneer alleen positieve debieten weergegeven worden?

Hoe wordt de waterstand gemeten, aangezien deze wel data levert als er een gat is in de debiet reeks?

Waardoor worden deze grote sprongen in de stroomsnelheid veroorzaakt?

Waardoor springt de stroomsnelheid zo snel op en neer?

Klopt het dat een negatieve stroomsnelheid hier ineens wordt weergegeven voor afvoer, terwijl het andersom hoort te zijn?

Kunnen boten de metingen van de debietmeter beïnvloeden?

Gemaal en stuw

Waarom lijkt het zo dat he gemaal en de stuw afwisselend actief zijn op zo'n korte termijn?

Hier 1 piek debiet gemeten door gemaal en daarna data van de stuw weer beschikbaar, wat gebeurt hier?

Gemaal meet hoger dan debietmeter, hoe kan dat?

Stuw laat veel door, maar debietmeter geeft lagere waardes?

Appendix C2

Algemene kennis over debietmeters

Met wat voor soort debietmeters meten jullie het debiet?

Hoe ervaren jullie de data die jullie binnenkrijgen?

Achten jullie deze data betrouwbaar?

Valideren jullie deze data ook?

Gebruiken jullie ook data gemeten door kunstwerken?

Hoe ervaren jullie de data die jullie binnenkrijgen?

Achten jullie deze data betrouwbaar?

Wat achten jullie betrouwbaarder, data van debietmeters of data van kunstwerken?

Voeren jullie ook onderhoud uit? (Bij ja, hoe ziet dit onderhoudsplan eruit?)

IJken jullie de debietmeters wel eens? (Bij ja, is dat incidenteel of volgens een procedure/planning?)

Meet een debietmeter vanaf dag 1 goed? (Zo nee, hoe lang duurt het voor de meter 'goed' meet?)

Ontbreken data → Geen data of eruit gevalideerd

Soms een gat van een paar dagen of een week, soms van een paar maanden, hoe kan de spreiding zo groot zijn?

Vragen data aan de hand van grafieken

Vergelijkbaar met de vragen gesteld aan Johan Schadenberg, alleen worden nu ook de patronen aangekaart van de debietmeters in de Wold Aa, de Groote Grift en het Overijssels Kanaal

Appendix C3

Hoeveel secties worden er gebruikt voor het bepalen van de stroomsnelheid?

Was dat bij de eerste meters ook zo of kwam deze technologie later?

Hoe zijn deze secties bepaald?

Wat voor sensor voor waterhoogte? Druk sensor,…??

Hoe wordt de stroomsnelheid gemeten, is dat een gemiddelde of directe waarde?

Gemiddeld? Zo ja, over welke periode

Hoe wordt het waterpeil gemeten, is dat een gemiddelde of directe waarde?

Gemiddeld? Zo ja, over welke periode

Vragen data aan de hand van grafieken

Vergelijkbaar met de vragen gesteld aan de voorgaande partijen. Er is genoeg tijd voor dit interview gepland om uitgebreid in te gaan op de relatie tussen de patronen en de technische aspecten van de debietmeter, aangezien veel patronen waarschijnlijk door technische mankementen veroorzaakt worden.