Enhancing Efficiency in Noorderzijlvest's Freshwater System: Analyzing Freshwater Utilization

BSc Civil Engineering Thesis Assignment

How to deal with the increasing salinization in the northern part of the Netherlands between Lauwersoog and Noordpolderzijl?

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Water Authority Noorderzijlvest
University of Twente
11 April 2023 until 28 June 2023

28th June 2023

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28th June 2023

Preface

Dear reader,

The bachelor thesis assignment titled ’Enhancing Efficiency in Noorderzijlvest’s Freshwater System: Analyzing Freshwater Utilization’ is presented here. This research was performed for the graduation of the bachelor’s degree in Civil Engineering at the University of Twente. The research was carried out between April and June 2023.

During the course of my study, I noticed the limited freedom to explore certain subjects in depth due to strict requirements. Motivated to investigate a challenging and relatively unknown topic near my hometown, aiming to think critically and push the boundaries of my knowledge. Programs, including the integrated Water Analysis Management system, ArcGIS, and Excel, were extensively utilized, providing valuable experience. The primary sources of information were the employees of Noorderzijlvest, from whom I learned significantly on social, analytical, and professional levels.

I would like to express my gratitude to the Water Authority Noorderzijlvest for their thrust and the opportunity to conduct this research. Special thanks go to Marijn Hooghiem and Floris Knot, my supervisors at Noorderzijlvest, for their guidance, expertise, and support throughout this research journey.
I also want to thank Maarten Krol, my supervisor at the University of Twente, for his active participation in thorough discussions, offering valuable feedback, and assisting in maintaining a clear overview of my research.

I wish you a pleasant reading experience.

Jan Marten Hofman
Groningen, 28th June 2023

Executive Summary

This research presents a comprehensive analysis of the freshwater management system on the west side of Water Authority Noorderzijlvest, focusing on the years 2021 and 2022 and the eleven water level compartments between Noordpolderzijl and Lauwersoog. The research aimed to determine water balances on an annual, monthly, and dry season basis (1 April to 31 August) and identify sources and extent of salinization to determine which waterways carry the highest salt load. By integrating both, the effectiveness of pumping stations was assessed and potential solution directions for enhancing efficiency in the freshwater management system were provided.

The water balances were established using the bucket model, which accounted for all possible influxes and outfluxes, including quantification of meteorological data and all possible in- and outflow locations. When examining smaller time frames, 'other values' such as infiltration and net storage of soil become more significant. However, the heterogeneity of soil compositions within the large study area hindered realistic and accurate quantification of 'other values'. Therefore, further research is recommended to investigate specific areas or selected plots in greater detail.
To discover, identify and select waterways with high salt content, all EC measurements conducted in previous years were organized in Excel Tables and analyzed using pivot tables to determine average EC values per month, annually, and during the dry period. These average EC values were spatially distributed and visualized in maps, ranging from green (indicating good EC level) to red (indicating bad EC level). Qualitative proposed solutions were made based on these research findings, literature review, and expert consultations with various employees at Noorderzijlvest.
Further research could be performed for the 'problem areas' that were revealed in this study, such as the area around and in the northern region of Pieterburen. The main proposed solution directions involve maintaining well-dredged ditches with minimal vegetation along the waterways, constructing manual weirs, and conducting a pilot for pumping saltwater over the dike. It is crucial to assess the effectiveness of these solutions and secure stakeholder support for further research.

This research report acknowledges limitations, such as the underestimation of the actual evapotranspiration during wet periods and overestimation during dry periods. This limitation is taken into account qualitatively, but to quantify it significantly further in-depth research is needed, including among other things investigating crop types and irrigation practices. Another limitation that necessitates further research is to investigate the dredging periods and to measure EC at different depths for studying the variations in EC content of the cross-section of a waterway. Quantifying salt seepage from the silt layer through EC measurements is also recommended.
In conclusion, this research contributes to enhancing efficiency in Noorderzijlvest's freshwater management system by providing new insights into freshwater utilization, salinization challenges, and potential solution directions.

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Chapter 1

Introduction

Water is the foremost essential requirement for sustenance, not only for human beings but also for nature and animals.

In the Netherlands, there is a growing concern about the increase of salt concentration in soil, groundwater, and surface water, commonly known as salinization. This issue is particularly dominant in the northern and western regions of the country, along the coastline. Salinization can occur due to a variety of factors, such as salt seepage (upward movement of salt or brackish groundwater), dry deposition, and seawater intrusion through the dikes, rivers, sluices, and spillovers, as well as human activities like drainage implementation and water system modifications for shipping or nature conservation purposes.

The negative consequences of salinization include damage to crops and plants, which makes also irrigation sometimes impossible for farmers. The Dutch government has included the theme of salinization in its policies to minimize problems and create opportunities. It is the task of each Water Authority to effectively manage the growing salinization problems. In the Netherlands, there are 21 Water Authorities, that are responsible for facilitating water supply and drainage, treating sewage water, discharging polluted water, maintaining water defenses such as dikes and dunes, and in some cases, managing roads and waterways.

Water Authority Noorderzijlvest is the party that commissioned the project. They are responsible for a management area in the northern part of the Netherlands, including a large part of the province of Groningen. The west side of Noorderzijlvest's freshwater system management area is experiencing challenges due to the increasing salinization of water and soil. To address this issue, freshwater from the IJsselmeer is pumped through the management area via pumping stations, reducing the salt content, and improving the overall water quality in the water level compartments for purposes such as irrigation and for maintaining target water levels. However, the freshwater construction circuit was designed in the 1990s and has remained largely unchanged. As the demand for freshwater rises and the supply from the IJsselmeer becomes uncertain, there is an urgent need to improve freshwater utilization and optimize the flushing requirements of Noorderzijlvest's freshwater system in a sustainable and efficient manner.

Therefore, the primary objective of this report is to develop water balances in specific time intervals and to map the watercourses that carry the highest salt loads. Once this mapping is completed, the impact of pumping can be analyzed, and potential solutions can be identified and evaluated to improve the efficiency of freshwater management and ensure good water quality in the western part of the freshwater supply system, located between Lauwersoog and Noordpolderzijl. This area is characterized by low-lying polder landscapes, which are protected by dikes from the Waddensea. The land-use is mainly agriculture, where crops such as potatoes are grown in the fertile soil.

The structure of the report is the following. First, in chapter two, additional context surrounding the problem is provided, including background information, involved parties, problem statement, and research objective. Chapter three explains the entire research design, starting with the research questions, research framework, and methodology, and concluding with the research & model assumptions. In chapter four, the results of the water balances are presented. In chapter five, the mapping of salt measurements in different time intervals are provided, and analyzes the effect of pumping on the salt content in the water. Chapter six consists of recommendations that focus on providing potential solution directions to effectively address the salinization issue and promote sustainable freshwater resource management. In chapter seven, a discussion of the thesis project is given followed by the conclusions in chapter eight. Finally, chapter nine ends the project thesis and offers suggestions for further research.

An appendix has been included in this report to provide a comprehensive explanation of the water balance and the detailed results of the network's average EC values, along with relevant additional information. The final page of the report will feature a glossary, where a list of definitions and terms are defined and explained, such as typical Dutch hydrological jargon. Furthermore, two Excel tables titled 'Waterbalance' and 'EC-Values_Measurements' have been provided and attached to this report to access the detailed calculations and necessary values for further research.

Chapter 2

Project Context

In this chapter, the context of the research is explained, whereas the current state of the field is critically examined. First, some background information about the assignment is outlined followed by a description of the various parties involved in the project, which also offers their insight into desires. The third section starts with a general topography, which leads to a specific description of the study area for the thesis. The context chapter concludes with a problem statement, research objective and the research questions.

2.1 Background Information

The assignment involves an evaluation of the flushing requirement as part of the freshwater supply system in the management area of the Noorderzijlvest Water Authority. This supply system extends along the entire Waddensea coast in the Noorderzijlvest management area. The assignment mainly concerns the area between Lauwersoog and Noordpolderzijl. The area is currently affected by the salinization of the ground and fresh water, and the issue is projected to exacerbate in the future, due to climate change, sea level rise and soil subsidence [3]. In fact, the freshwater circulation system was established in the 1990s and has undergone little change since then. However, the demand for freshwater is continuously rising, while the freshwater supply from the primary source, the IJsselmeer, is decreasing, there is a high need for improvement in the flushing system and freshwater utilization. The main focus is to effectively monitor and manage the water level compartments within the study area.

Therefore, a number of pumping stations have been installed in the area to pump freshwater into the area in order to improve water quality and ensure sufficient water of adequate quality in the water level compartments. Additionally, Noorderzijlvest is actively working to restore a more natural transition between fresh and saltwater in the Lauwersmeer, without compromising the interests of agriculture, which seeks to have sufficient freshwater availability (two conflicting interests). The establishment of an extensive and accessible system for measuring salt content will assist in this project, which is currently underway in the Lauwersmeer area.

Although there has always been sufficient water available in the IJsselmeer, it is expected that in the future, the demand for IJsselmeer water will increase while the supply decreases. As a result, sufficient freshwater availability during dry periods cannot be guaranteed in the future.

Water authorities are working with farmers to find ways to use freshwater more efficiently. This is accompanied by research into the salinization of soils, whereby salty seepage rises from the ground. This makes the ”fresh” water increasingly salty, which worsens water quality and sometimes makes it impossible for farmers to irrigate their land, among other things.

2.2 Involved Parties

Water Authority Noorderzijlvest is the party that commissioned the project. They are responsible for a management area of 144000 hectares in the northern part of the Netherlands, including a large part of the province of Groningen, visualized in Figure 2.1. In this region, the Water Authority is responsible for ensuring that water is managed sustainably and efficiently, including measures to prevent flooding, manage water quality, and maintain water levels. This is one of the most dangerous areas laying under sea level in the world [4]. So, to keep our feet dry, the Water Authority has to protect ourselves against water. This is a growing concern in the future as climate change is increasing, indicating higher sea levels and fluctuations in the weather. Consequently, Noorderzijlvest must learn to live safely with sometimes too much and sometimes too little water.

Specifically, in Groningen, the Water Authority is working towards improving the freshwater supply system and dealing with the issue of soil salinization, which affects the quality and availability of water for agriculture and other users.

In addition to climate change, there is another unique and dangerous factor that makes the work for Noorderzijlvest even more challenging, namely gas extraction, which causes not only earthquakes but also significant subsidence of the land [3]. Furthermore, there is a growing demand for freshwater due to the increasing population and settlement of more industrial players (data centers, hydrogen production) in the Noorderzijlvest area. To conclude, the sea level rise, growing freshwater demand, and the significant subsidence of the land contributed to a more complex problem for preventing salinization and providing efficient and sustainable enough freshwater for the agriculture, ecologists, and inhabitants of the area.

2.3 Area Description

In this section, the total study area of Water Authority Noorderzijlvest will be explained, with a focus on their main characteristics and water management works inside. Furthermore, Section 2.3.2 is dedicated to explaining the topography of the thesis study area, which will be the main focus during the research.

2.3.1 Management area of Noorderzijlvest with their main functions water system

The Water Authority Noorderzijlvest is part of the sub-basins of the Rhine-North and Ems river basins. The total management area of the Water Authority Noorderzijlvest in visualized in Figure 2.1, which is the red colored part of the Netherlands. Next to this, the main water courses and the pumping stations with the different hydrologically separated catchments are shown. In Figure 2.1, the borders of each shell of the river basin Electraboezem are clearly shown. The original Electraboezem was once a single entity, but has been subdivided due to soil subsidence's caused by natural gas extraction. The northern part of the 3th shell Electra is where the study area is mostly involved. In the majority of this shell, an operational target water level of -0,93 mNAP in summer and winter is aimed for [5]. However, if you would zoom-in into these shells, you are able to distinguish different water level management compartments with each different operational summer- and winter target water levels. In the management area of Noorderzijlvest, there is no difference in the target water level between the water level in the polder drainage system (in Dutch: 'boezemwater systeem') and the water level in the smaller drainage channels within the polder (in Dutch: 'slootwater systeem'). This differs from areas such as Flevoland, where the flower bulb fields are situated in water compartments with lower elevation, while the target water levels in the 'boezemwater' systems are comparatively higher.

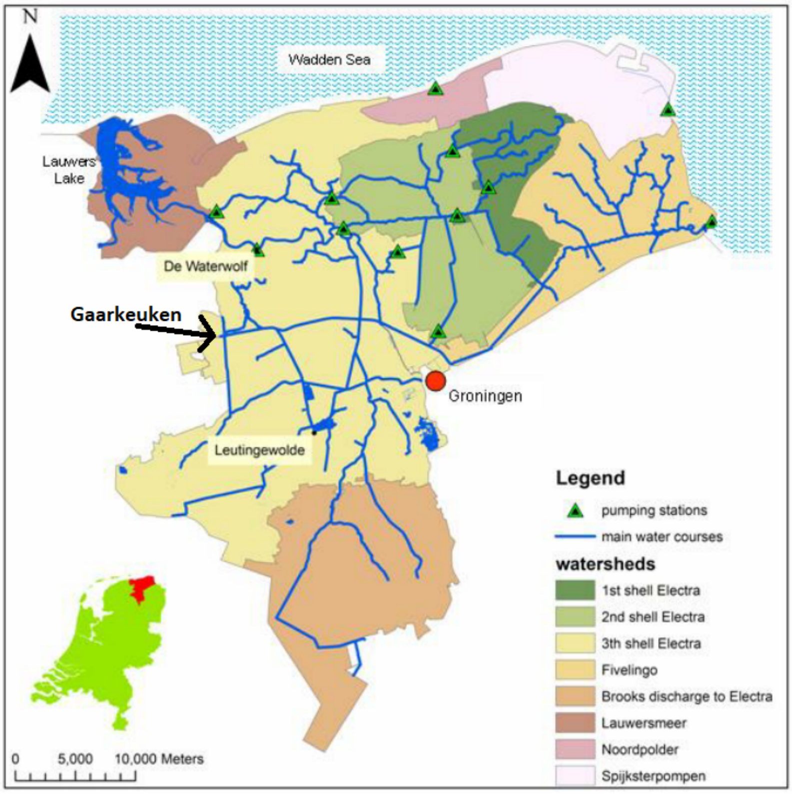


Figure 2.1: Water Authority Noorderzijlvest with the different hydrologically separated catchments, the main water courses and pumping stations. [1]

In Figure 2.1, the most important water inlet is given, namely the water inlet Gaarkeuken. The freshwater could be transited under free decay with a maximum capacity of 24 m^3/sec from the IJsselmeer to the inlands of Groningen. In dry periods, 20 m^3/sec will flow to the pumping station Dorkwerd, which is located slightly north of Groningen and is a transit pumping station and a discharge outlet for Noorderzijlvest to the sluice Oostersluis for the management area of Water Authority Hunze and Aa's [6]. If needed, with help of the so-called 'Booster discharge pumps' at the Oostersluis, water from the Starkenborghkanaal will be pumped to the Damsterdiep, which is a water channel that goes to the Water Authority Hunze en Aa's their management area, which covers the east part of the province Drenthe and Groningen [7]. This happens mainly at dry periods or when the adjacent water level compartments needs to be maintained at the same level. The remaining 4 m^3/sec from the Ijselmeer offers the freshwater supply for e.g. to satisfy the flushing requirement within the study area of this project. The main water discharge outlet for the river basin of Noorderzijlvest is 'De Waterwolf' pumping station with a capacity of 75 m^3/sec + a certain spillway capacity. By using among others the Waterwolf, Noorderzijlvest is able to keep the water level at a constant preferable level. The canal from the Waterwolf connects directly to the Lauwersmeer (Lauwerslake), created on May 23, 1969, through the closure of the Lauwerszee. The Lauwersmeer serves as collection point for all water runoff from the entire management area of the Water Authority Noorderzijlvest. Freshwater is retained unless there is an excess of water, surpassing threshold water level values,in which case it is discharged through discharge pumps, preferably via free fall through the R.J. Cleveringsluizen spillway. These sluices divide the Lauwersmeer from the

Waddensea and are located at the far north side of Lauwersmeer, as visualized in Figure 2.1.

2.3.2 Thesis study area

The research will focus on the 'west-side of the freshwater system', involving the northern part of Groningen located behind the dikes stretching from Lauwersoog to Noordpolderzijl. This region has been selected due to its significant salinization-related challenges. A magnified map of the study area is shown in Figure 2.2, with each water level compartment labeled with its corresponding name. The small map at the bottom-right of Figure 2.2 shows the total management area of Noorderzijlvest bounded with the green line with the square representing the location of the study area, which is an extent of the map frame. Each of the eleven water level compartment has its own operational summer- and winter target water level [m+NAP], presented with its corresponding name and total surface area in Table 2.1. During the summer, the target water level is maintained higher than during the winter to prevent excessive groundwater depletion, prolong the presence of freshwater in the area, mitigate salinization, and meet the rising water demand [8].

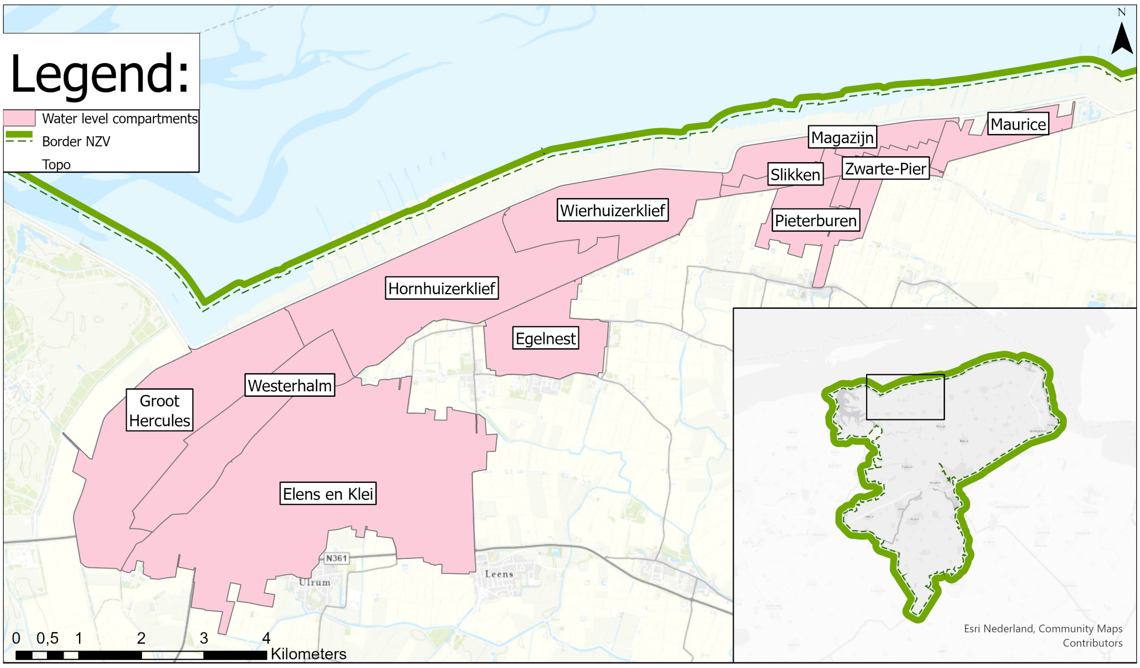


Figure 2.2: The total eleven water level compartments of the study area with its corresponding name and extent of map frame.

Table 2.1: The name, surface area and operational summer- and winter target water level (TWL) of the eleven water level compartments in the study area.

Name	Surface Area [m^2]	Summer TWL [m+NAP]	Winter TWL [m+NAP]
Westerhalm	2792776	-0,73	-0,88
Groot Hercules	5451845	-0,9	-1
Elens en Klei	12120669	-0,73	-0,93
Maurice	1027934	-0,2	-0,8
Hornhuizerklief	5621562	-0,35	-0,93
Wierhuizerklief	3151647	-0,35	-0,93
Egelnest	2131877	-0,5	-0,93
Pieterburen	1707290	-0,73	-0,93
Zwarte-Pier	700157	-0,5	-0,93
Magazijn	1479643	0,2	0,2
Slikken	568445	-0,3	-0,8

2.3.3 Land-use and soil composition of the study area

The polders in the northern coastal area were formed by land reclamation. Outside the dikes, the salt marshes were gradually accreted through natural sediment deposition. The area rises in time and when it was high enough, it was embanked and cultivated. A deeply cultural dutch principle applies here, namely ”de recht van opstrek” (in English: the right of extension), whereby farmers were allowed to cultivate the extension of their reclaimed plots [9]. Most of the study area was reclaimed in the 18th and 19th centuries, where e.g. the Noordpolderkanaal was excavated for transportation of agricultural goods.

Nowadays, the primary land-use of the study area is agriculture, where crops such as potatoes, onions, and grain being grown in the fertile soil. There are not many livestock farmers located in the study area, this is also visible in that there is almost no land-use for grass. Behind the dikes (in the coastal dunes and salt marshes) and the Lauwersmeer area are so-called Natura-2000 areas, which are nature reserves and protected areas. These protected areas are not playing a role inside our study area. In the study area, the residential land use is low, since the area is sparsely populated and only consists of small villages.

The soil composition in the study area is predominantly called ’poldervaaggronden’, what could be translated in English as ”polder deposits soils”. This is a soil type within the Dutch system of soil classification. It belongs to the sablon / sandy loam (in Dutch: ’Zavel’) and clay soils with periodic high groundwater levels. They do not have peat within 80 cm and no dark topsoil. This is the most common subgroup of soils in the Netherlands. The polder deposits soils are typically in the low-lying areas that were reclaimed from the sea in the Netherlands. In the northern part of the study area, the soil primarily consists of calcareous polder light sablon- and clay soils, depicted in Figure 2.3 as the light green colors. The further South, the soil consists of more calcium-poor polder light sablon- and clay soils, with some small areas of heavy sablon soils, visualized in Figure 2.3 as the darker green/brown colors. In general, the area’s soil composition is shaped by the region’s geological history and the influence of the Wadden Sea on the surrounding landscape.

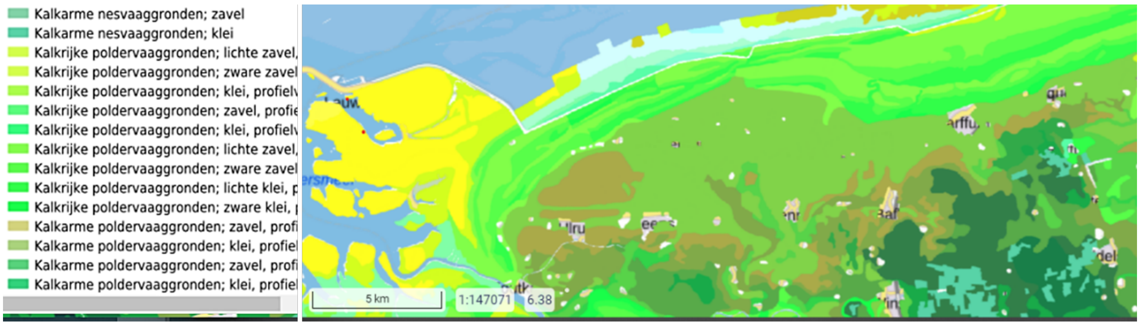


Figure 2.3: The soil composition of the study area.

2.4 The Problem Statement and Research Objective

In this section, the problem statement is explained with the subsequent research objective that describes the goal to be achieved to solve the problem.

Problem statement

The west side of the freshwater system of the management area of Noorderzijlvest is facing problems due to the increasing salinization in both water and soil. To mitigate this, freshwater is pumped through the management area via pumping stations, primarily for irrigation purposes. The spatial distribution of salt content across different waterways and the impact of pumping on the salt content within the study area have never been adequately assessed. The current approach involves activating the pumps during spring based on maintaining the water level or sporadic EC measurements of the water level manager at paper, without systematic recording or analysis of these measurements over time. Moreover, there is limited understanding of the water demand from the IJsselmeer for the purposes of flushing and prevention of salinization. The precise quantities of freshwater required on an annual, monthly, or seasonal basis remain unclear. In fact, the quantification of outflow from the study is also never thoroughly researched, despite its significance in understanding where the pumped freshwater exits the study area. The demand for freshwater is rising, due to the increasing salinization, while the supply from the IJsselmeer cannot be guaranteed. Therefore, there is a high need to promote better freshwater utilization and to use the flushing requirements of Noorderzijlvest's freshwater system more efficiently and sustainably.

Research objective

The study will involve the analysis, mapping, and evaluation of current EC measurements conducted at various locations within the freshwater system, including measurements of both flow rates and salinity. This will enable the identification of the sources and extent of salinization. Important is to determine which waterways carry the highest salt load and where the majority of problems arise. By integrating the salt load data / maps with the water balances and operational duration of the pumping stations, it becomes possible to approximate the effectiveness of the pumping stations. Together with defining criteria for the stakeholders, exploration of various techniques and approaches to better utilize the freshwater to maintain good water quality, while preventing salinization issues. In the end, the best options for lowering the salt content in the water with trying to reduce the current flushing requirement will be recommended to effectively address the salinization issue and promote sustainable freshwater resource management resources along the

coastline.
The objective of this research study is to assess the effects of freshwater management on salinity in the study area between Lauwersoog and Noordpolderzijl by quantifying water balances and mapping salt loads. This assessment will enable the estimation of pumping effects to identify and evaluate solutions that reduce flushing requirements, improve freshwater system efficiency, and promote sustainable utilization of freshwater resources, while effectively managing the increasing salinization of water and soil.

2.5 Research Questions

From the research objective you could define this in three research questions with more in-scope added sub-questions to answer the research aim:
1- What is the water balance for the group water level compartments located on the western side of Noordpolder, and what level of precision is achieved in the estimation?

- What modeling techniques can be used to develop as closed as possible water balance?
- Which time periods and units of representation are most suitable for conducting water balance calculations?
- What are the inlet and outlet fluxes (e.g. evapotranspiration, precipitation) for making a water balance in the study area and how can they be quantified?
- What is the expected range of errors and uncertainties in the water balance calculations?

2- Is it feasible to map the waterways and sources that carry a high salt load and can the water demand be determined for the western side of the freshwater system to maintain a good water quality for preventing salinization?

- What modeling techniques can be used to quantify the major waterways and sources that carry a high salt load?
- What is the relationship between pumping and the reduction in salt content?
- Could the water balances data be integrated with the mapped salt charts to conduct a comprehensive analysis of both outcomes?
- How can the accuracy of past EC measurements be determined?

3- What are the potential solutions in reducing the freshwater requirement in the study area between Lauwersoog and Noordpolderzijl to effectively manage the increasing salinization?

- Which existing technologies, models and approaches are useful for improving freshwater system efficiency and promoting sustainable utilization of freshwater resources in the study area?
- Which criteria should be considered when exploring various techniques and approaches to reduce the flushed freshwater required to maintain good water quality and prevent salinization?
- What are comprehensive recommendations to reduce the freshwater requirement in the freshwater system with an eye on better utilization?

Chapter 3

Research Design

In this section, an explanation of the methodology to answer each research question is described. To clarify this, first, a research framework is made to get a clear overview of all components the project comprises. After that, the methods with their corresponding steps are formulated to be able to perform each box in the research framework. Finally, a small section will be spent emphasizing the research & system assumptions made during the execution of the project.

3.1 Research Framework

The outcome of this project is to analyze the effect of pumping on the salt content of the water to enable identification and evaluation of solutions to decrease the flushing requirement, thereby increasing the efficiency of the freshwater system. In Figure 3.1, a research framework is organized as a scheme to get a clearer overview of all the components that the thesis comprises. With this framework, you are not only getting a better overview of all inputs of the project but also seeing the exact step-wise system and internal logic of the project. This helps to demarcate the project and to prevent a situation of not being able to see the wood for the trees.

Noorderzijlvest will provide a laptop to access each used platform, e.g. looking for the data of water in and outlets. In the research framework of Figure 3.1, the yellow filled-in boxes represent the answering to each research question, where the final research objective could be satisfied by answering the final third question. These three steps with their results are also of the highest importance to the client Noorderzijlvest water authority. Important in this framework is the way how every box is connected with each other, which is done by the arrows. Some research objects could be performed independently of each other, while others need information from different steps.

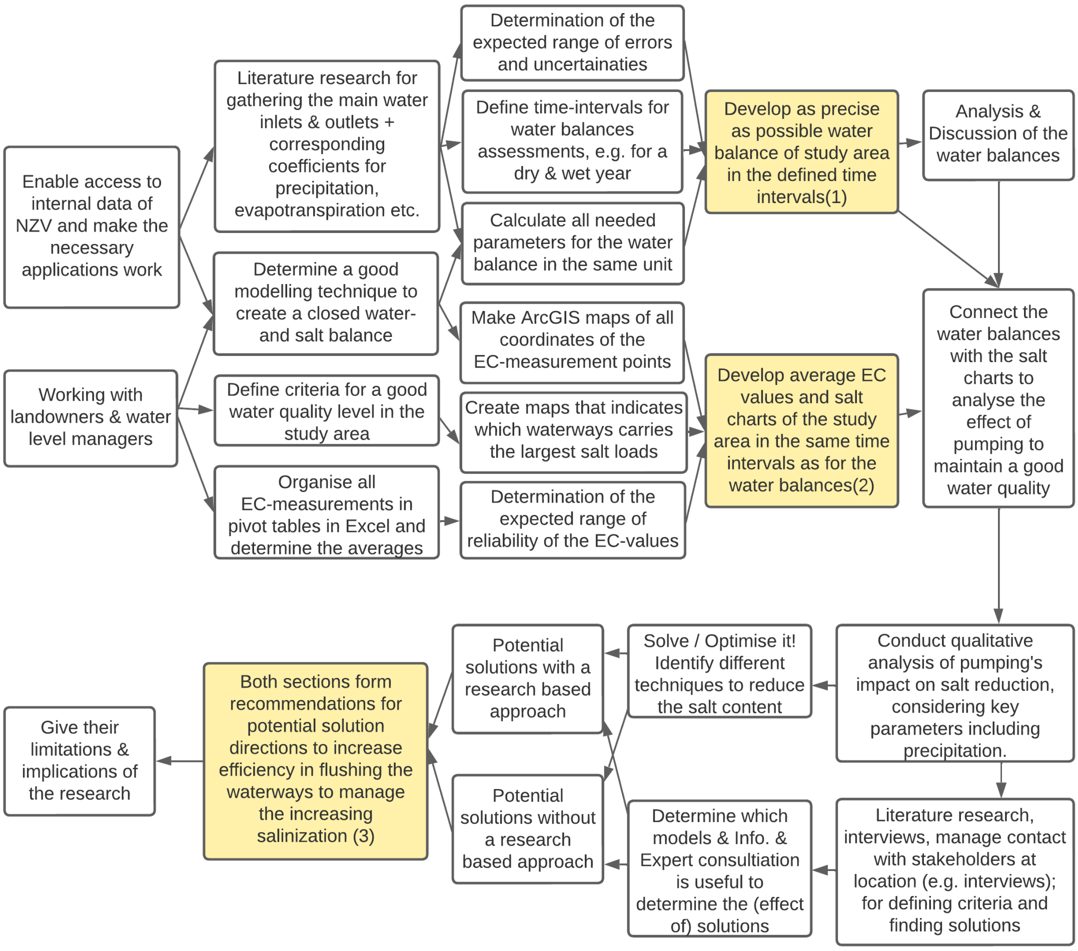


Figure 3.1: Research Framework; an overview of all the components that the thesis comprises.

3.2 Research Methods

The goal is to get insight in possible solutions to decrease the flushing requirement. In the end, recommendations will be made with identifying measures that can be taken to manage the increasing salinization problem to optimize the freshwater plan. By doing so, freshwater resources are utilized more effectively both in the present and in the future. The main focus is maintaining a good water quality of the water level compartments inside the study area.

In Figure 3.1, the focus is on answering the 'what' questions, where all steps are defined in a specific order and how they are connected with each other. In contrast, this section on 'Research method' is crucial for clarifying the 'how' questions, which detail how each step/question will be approached and solved. This will save time in the execution of the project and provides a kind of step-by-step plan for carrying out the research. Additionally, it is important to clearly outline how the sub-questions are linked to the three main questions. Finally, in this section, how the first two questions will lead to a resolution of the third question is explained, thereby achieving the research objective.

3.2.1 Determination of an accurate water balance of the study area

This subsection focuses on the answering on consecutively the first, second and third sub-question of Research Question One, in which the fourth sub-question will be answered in the Discussion Section 7.2 and in the Assumptions Section 3.4. A water balance could be set up to determine the primary sources and locations of water in- and outflow and assess the impact of precipitation and evapotranspiration on the flushing requirements. By knowing these fluxes, a more precise estimation of salt seepage can be achieved, specifically considering the influence of various factors such as the amount of pumping on the reduction on the salt content. The data for the fluxes could be obtained through various ways, such as the NHI and FEWS WAM Portal of Noorderzijlvest, which will be further explained in this section.

Simplification of the water balance

Water balances will be established for the study area during the years 2021 and 2022, with the choice for these specific years explained in Subsection 3.2.1. Equation 3.1, will be used as a guideline for the determination of the water balances, addressing the first sub-question of Research Question One [10]. Precipitation and inlet discharge inside the study area (from pumping stations) are the two main input fluxes, while evapotranspiration and outlet discharge (from the pumping stations and weirs) are the two main output fluxes. Evapotranspiration can be calculated based on the potential evapotranspiration which is based on meteorological variables such as temperature, humidity, wind and net radiation [10]. Evapotranspiration is the evaporation of the soil and the transpiration from plants combined. Other important hydrological fluxes are infiltration, surface runoff and groundwater discharge, but these are fluxes that contribute to internal water movement between the topsoil and subsoil. However, these fluxes focuses primarily on surface water and influence the net storage of water. While the individual internal fluxes are not directly relevant to the water balance of the entire study area, the overall change in net storage of water does play a role. Over longer time horizons, significance of water storage diminishes as it tends to balance out over time. Equation 3.1 describes this relation, which is basically the law of conservation of mass applied to the hydrological cycle. The change in storage needs to be included in Equation 3.1, but its importance depends a lot in which time horizon you look at.

$$P + Q_{inlet} = Q_{oulet} + ET + \Delta S \tag{3.1}$$

Where:
P = Precipitation
Q_{inlet} = Inlet discharge through pumping stations (stream flow)
Q_{outlet} = Outlet discharge through pumping stations and weirs (stream flow)
ET = Evapotranspiration
Δ S = Net / change in storage

Thereby, the water balance calculation, $\sum$ inflow - $\sum$ outflow, for the region is most likely not equal to zero, since it is a dynamic system that can change over time due to changes in weather, land use and water management practices. During the supply season in summer, the water balance will probably become negative, because more water is leaving the study area than entering it, as the soil is drying out. According to the Water Authority Noorderzijlvest EC measurement data, salt seepage flux chart of the management area could be made to identify which water ways carries the

highest salt load. If the salt seepage is constant in time, you can calculate the flushing requirement over time by using the water balance.
However, the challenging part will be to investigate the effectiveness of how the water flows through the canals, ditches etc. The water inlet through the pumping station will not lower the salt content throughout the whole management area by the same amount. In fact, there are probably ditches where the freshwater from the pumping station will not even reach because the freshwater flows through main and faster canals. Therefore, it will be important to determine the feasibility of calculating the flushing rate and duration, to look how long it takes when the desired reduction in salt content is achieved.

NHI - hydrological models of the Netherlands

The Netherlands Hydrological Instrument (NHI) is an innovative program that aims to simulate the movements of water in rivers, streams, lakes, and other water bodies. With this, you can look for how water management authorities and various influences are related to each other. The program enables the prediction of water movement and distribution after implementing certain measures. NHI promotes consistent and effective water management by providing access to high-quality data and knowledge throughout the Netherlands. Furthermore, they ensure that the data is properly accessed, interpreted, and of good quality by using reliable tools to extract meaningful information from the data and continuously performing quality checks to ensure the accuracy of the results. In Figure 3.2, all the measurement locations for chloride in the groundwater are visualized. Chloride measurements in mg/L and electrical conductivity (EC) measurements serve as indicators of water salinity. Both units could be converted to each other, but for simplification high EC values correlate with high chloride measurements, indicating increased salinity. NHI models and charts might be useful for identifying where the biggest salt fluxes are coming from, as it is measured at -10m NAP. However, for determining the effect of pumping on the reduction of the salt content, this source is not really useful, because it is only measured once in the groundwater and not in the surface water at various times. In 2020, a national fresh-salt groundwater modeling framework was developed to visualize the impacts of climate change and human activities on the internal salinization of fresh groundwater reserves [2].

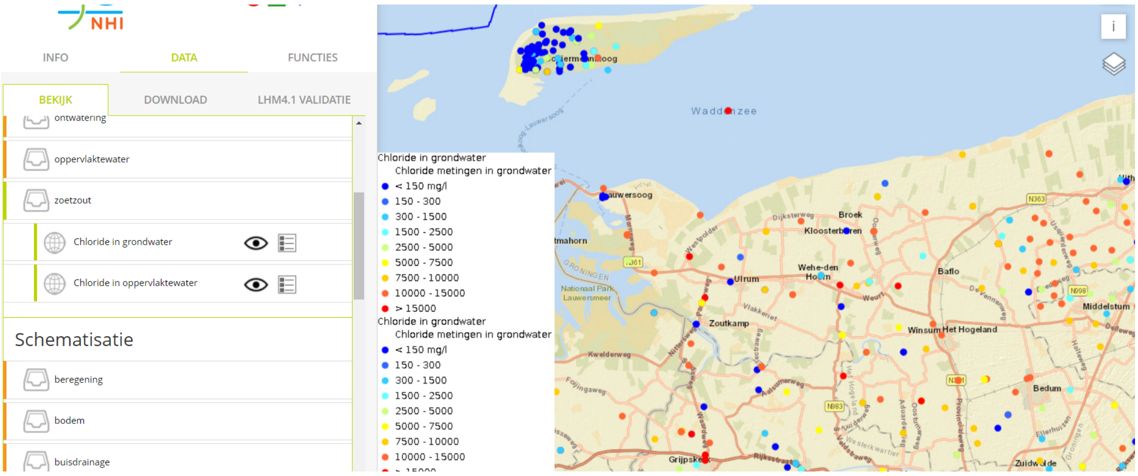


Figure 3.2: NHI chloride measurements in groundwater in the study area [2].

FEWS WAM Noorderzijlvest

Since approximately four years, Noorderzijlvest developed an integrated Water Analysis Management system (WAM), where you can quickly and effectively extract data and use it to create models or to do calculations. This system enables the integration of various data parameters, such as running time, flow rate and pump start/stop counts. A downside of being a relatively new program, the accuracy and availability of the data are not always optimal. In Figure 3.3, symbols (e.g. pumping stations or sluices) marked with a red cross indicate the absence of information or data. Additionally, certain water management structures may have fluctuating availability of data. For example, one pumping station may provide data on flow rate and pumping hours per day, while another station may only have data on pumping hours. Moreover, there are gaps for specific time periods. These discrepancies, make it challenging to effectively combine and analyze the data. Unfortunately, for determining inlet flow rates inside the study area you cannot simply summing up the flow rates at the pumps, due to missing or invalidated data, resulting in inaccurate inlet discharges, as it would have been much higher in reality. Furthermore, some of the measured or calculated data is not validated, which may introduce errors or inconsistencies. This is also the case for the precipitation data, where not all stations have undergone full validation over time. Figure 3.3 depicts the program's interface, which offers four filters (meteorology, water quantity, water quality and projects) with multiple layers for investigating specific aspects of interest. For the project, the water quantity layer, particularly the surface water sub-layer with its measurement points, would be the most relevant as it relates to flushing requirements. Finally, it is important to note that the data within the FEWS WAM Noorderzijlvest primarily rely on model simulations rather than real-time measurements.

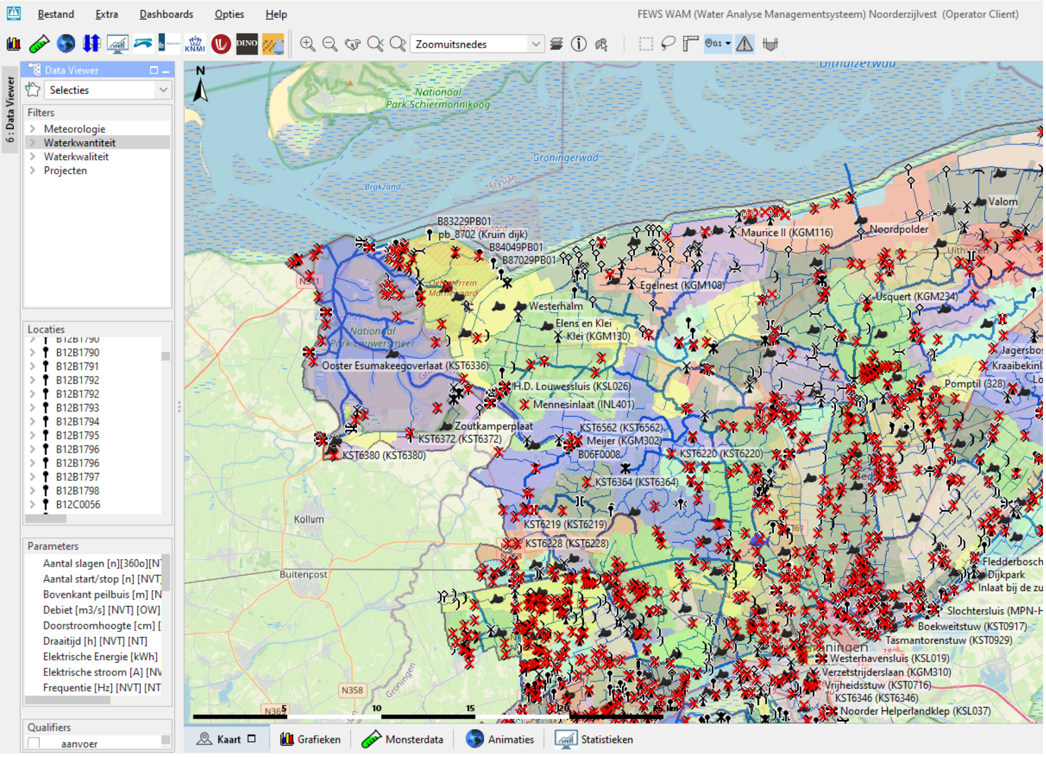


Figure 3.3: FEWS Water Analysis Management system Noorderzijlvest.

Investigation of the years 2021 and 2022

The water balances will be made on the years 2021 and 2022 due to several reasons, primarily due by data availability and the lack of information at certain water structures. The year 2022 was chosen to investigate in depth as it possesses the most complete and up-to-date data, obtained from the FEWS WAM Portal of Noorderzijlvest. As explained in Subsection 3.2.1, there are data gaps in some years, making predictions of flow rates challenging and prone to errors. Conversely, the data for all in- and outlet water system structures in 2022 is complete, with the graphs for pump operating hours and corresponding flow rates included. Furthermore, the precipitation and evapotranspiration data in FEWS have undergone validation.

Next to this, it is interesting to explore differences in the water balances between 2022 and another year, considering that 2022 represents an average year in terms of rainfall. In Lauwersoog, the total precipitation in 2022 was 833mm, while the average precipitation from 1991 to 2020 amounted to 863mm. These results are also available in the attached Excel file titled 'Waterbalance' within 'P_ET_KNMI' sheet. Moreover, March 2022 recorded exceptionally low rainfall of only 5mm, making it interesting to investigate the corresponding impact on salt content and flushing requirement.

In contrast, 2021 was a relatively wet year, with a total rainfall of 926mm in Lauwersoog. Especially during the dry period (1st April to 31st August), an average of 420mm of rain was fallen in the study area, compared to 291mm in 2022. It would have been valuable to compare these results with the exceptionally dry year of 2018, with a total rainfall of 632mm in Lauwersoog. However, the available EC salt content measurement data in the study area primarily dates from 2019 onwards. Furthermore, not all flow rate data from year 2018 is available, e.g. the measurement data from the pumping station of Maurice I and II is only available from 2020 onwards. Consequently, making accurate assumptions regarding the flow of water into or out of the study area at these locations becomes challenging.

To summarize, the decision to compare an average precipitation year, 2022, with a wet year, 2021, was primarily influenced by the availability of data. Water balances will be constructed on a monthly, annual, and dry period (1st April to 31st August) basis for the years 2021 and 2022.

Unit of the water balances $[m^3/sec]$

The conventional unit for water balances is typically cubic meters $[m^3]$, representing the volumes of water that enter or leave a specific area. In the FEWS WAM system, the volumes of each water structure are known, but sometimes only the net volume is displayed. However, relying solely on net volumes can lead to misinterpretation when diving deeper into results. For example, a net volume of -10m^3 of a certain location could be interpreted in different ways. It could signify that 40m^3 was pumped through a pumping station in the study area, while 50m^3 represents the volume of rainfall that flowed back out of the study area over the weir. Alternatively, it could indicate that the pumping station was switched off and only 10m^3 was flowing over the weir out of the study area. To avoid such ambiguities, it is essential to examine the flow rates (measured in m^3/sec) provided in the FEWS WAM System. In here, the flow rates are labeled by PMP for pumps, KST for weirs and KWK the summed total average flow rate. Therefore, it is deemed appropriate to use flow rates as the unit of measurement for the water balance analysis.

Estimation of water balance components: Q_{inlet} & Q_{outlet}

To establish an accurate water balance, it is crucial to identify all potential in- and outflow locations within the study area. This necessitates a thorough investigation of the study area, with particular attention to the water flow direction. Especially, determining whether these is a opposite flow direction during the water supply season as compared to the discharge season, during high rainfall. While some ArcGIS shape files have been made by employees of the Water Authority Noorderzijlvest, it is important to exercise caution and not solely rely on these charts, as they are sometimes a bit outdated. Therefore, a trip with the water level manager Martin van de Maar will be organized to locate all hydraulic structures along the border of the eleven water compartments within the study area, such as weirs and pumping stations. The pumping stations can be observed in Figure 3.4, while the weirs are displayed in Figure 3.5. These charts will be printed and brought along during the field trip to identify any potential errors.

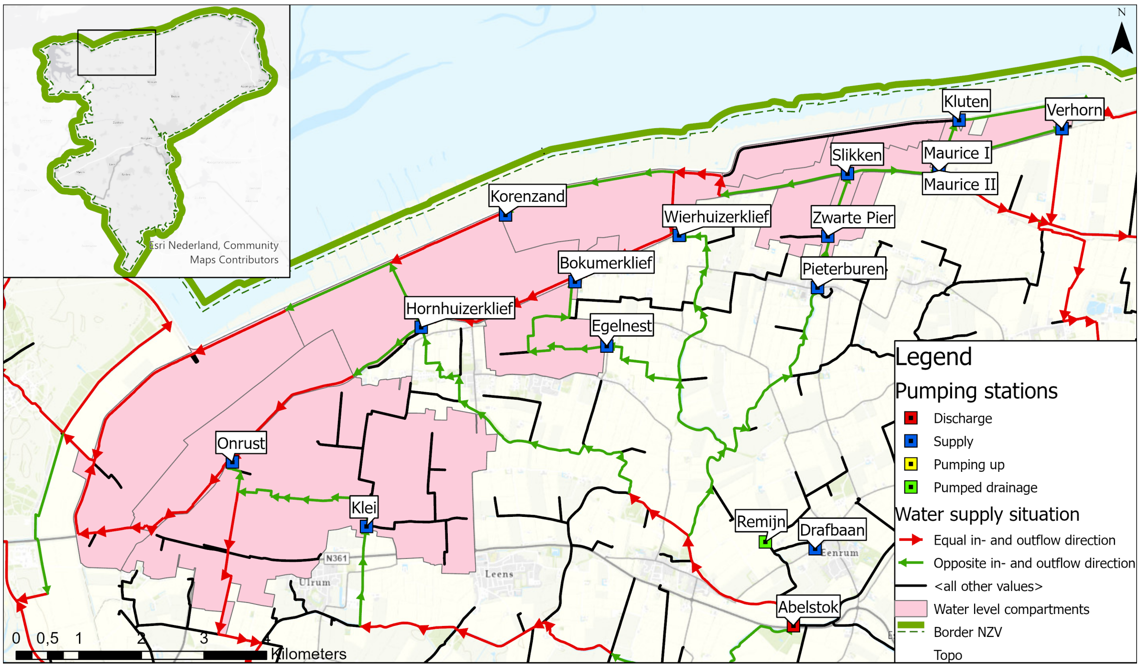


Figure 3.4: Spatial distribution of the pumping stations in the study area with the direction of flow rate during water supply situation included.

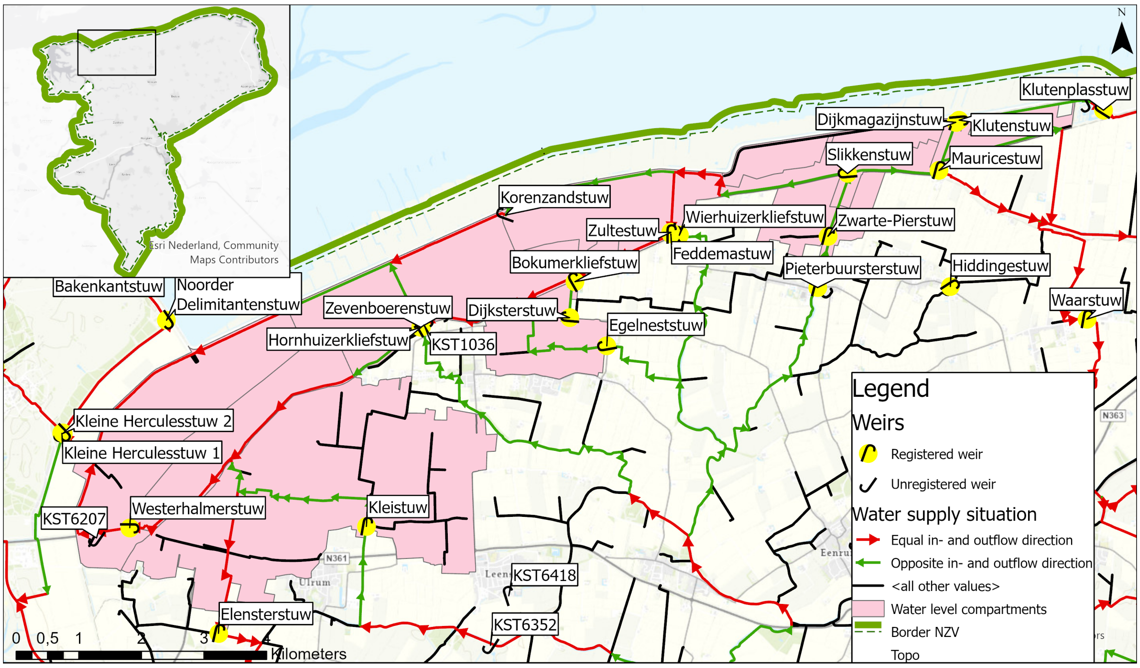


Figure 3.5: Spatial distribution of the weirs in the study area with the direction of flow rate during water supply situation included.

In most of these hydraulic structures, flow rates are determined by using FEWS WAM Portal, for the unknown flow rates assumptions are made, which will be further explained in Section 3.4. Initially, it was tried to identify the best and most efficient method for calculating the inflow and outflow discharge of pumping stations and weirs at the border of the study area. It was decided to directly use the corresponding flow rates from the FEWS WAM Portal instead of calculating them based on average daily pumping hours and maximum capacity of each pump. Several reasons supported this decision:

- Directly using the flow rates from the FEWS WAM Portal saves time compared to manual calculations.
- Consistency in using the same method for both weirs (KST) and pumps (PMP) facilitates a more accurate comparison between these hydraulic structures, since the flow rates are only known for the weirs in FEWS WAM.
- Consultations with experts of Noorderzijlvest revealed that the method of calculating the flow rates based on pumping hours and max. capacity is not accurate, as pumping station may not always be able to operate at maximum capacity due to factors such as high water levels inside the study area. Furthermore, several pumping stations are equipped with a frequency switch, implying that the maximum capacity cannot be uniformly assumed for calculations, as it may vary and could be lower. Therefore, flow rates from the FEWS WAM Portal provide a more realistic representation of average flow rates compared with manual calculations.

It is important to note that for the water balances, the known information at each location of the pumping stations should be considered separately, rather than using the total flow rate (KWK $= \sum PMP - KST$). This will allow distinction between the amount of water being pumped into the study area (PMP = supply: Q_{inlet}) and the amount of water flowing back over the weir out of the study area (KST = discharge: Q_{outlet}). Therefore, three tables with the Q_inflow and Q_outflow flow rates will be created to account for the in- and outlet locations in water balances:

1. Inlet Locations at Pumping Stations: This table will provide the flow rates at each location where pumping stations introduce freshwater into the study area of each month in year 2021 and 2022.
2. Outlet Locations at Pumping Stations: This table will include the flow rates at weirs located near the pumping stations. During periods of high rainfall, water will flow out of the study area in the opposite direction of the water being pumped during the water supply season.
3. Single Outlet Locations: This table will include the measured flow rates at locations situated at the border of the study area, which function as 'drainage' points for the study area.

These flow rates will be provided of the years 2021 and 2022; Annual, dry season and per month. By organizing the water balance data in this manner, a more comprehensive analysis can be conducted. The results will be presented in Subsection 4.1.2 and further details can be found in the attached Excel file titled 'Waterbalance'.

Estimation of water balance components: Precipitation

There are three precipitation measurement stations nearby the study area, which involves Zoutkamp, Eenrum and Warffum. The daily validated precipitation data could be obtained from FEWS WAM from the years 2021 and 2022. The next step will be to calculate the sum of precipitation on a monthly, annual, and dry period (1st April to 31st August) basis. With this you can calculate the average precipitation fallen in each period by summing up all three locations and divide by three. The final crucial step will be to change the unit of precipitation from 'mm' to 'm^3/sec', which can be done by Equation 3.2.

$$P_{AVG}[m^3/sec] = \frac{P_{AVG}[mm] \times A}{\sum T \times 1000} \tag{3.2}$$

Where:
$P_{AVG}[m^3/sec]$ = The average precipitation in the desired unit 'm^3/sec'
$P_{AVG}[mm]$ = The average precipitation in 'mm'
A = Total area of the ten water compartments in 'm^2'
$\sum T$ = Total amount of seconds in the corresponding time-frame of water balance, e.g. month or year

In this study, the meteorological part of the water balances will consider a total area of ten water compartments, **excluding** the water level compartment of Maurice. This is done, because of insufficient data on pumping station Verhorn and the open nature of the water level compartment Maurice, which allows water to flow along the dike in the north of the water level compartment without knowing any adequate flow rates in that waterway, what is visualized as the green line north of Verhorn in Figure 4.2 in Section 4.1 of Chapter 4. Therefore, in such situation, is not feasible to completely enclose the study area, which is solved and avoided when excluding the water level compartment Maurice, as further elaborated Section 3.4.

Estimation of water balance components: Evapotranspiration

Lauwersoog is the only evapotranspiration (ET) measurement station located near the study area. Various methods exist to determine ET, in which KNMI primarily uses the Penman method for potential evapotranspiration and the Makkink method for determining the basis for reference crop evapotranspiration (in Dutch: 'referentiegewasverdamping'). The validated reference evapotranspiration obtained from the FEWS WAM Portal, based on the Makkink method from KNMI, will be used for the water balances as it is the only available and reliable method/source. This represents the evapotranspiration from a short grass surface that is optimally supplied with water, so no evapotranspiration reduction to soil moisture deficit [11]. These reference crop evapotranspiration will be calculated on a monthly, annual, and dry period (1st April to 31st August) basis for the years 2021 and 2022, with the unit of measurement being cubic meters per second [m^3/sec], following the same approach used for precipitation calculations.

It is possible to convert the reference crop evapotranspiration (ETc) to potential crop evapotranspiration (ETp), by multiplying the ETc by a crop factor [12]. With this, the effects of weather on ET from the effects of crop properties and growth stages could be separated. Those crop factors are determined through measurements and are specific to methods and regions [13]. In the Netherlands, the crop factors of Feddes (1987) are used in combination with ETc according to Makkink to get ETp [14]. Potential evapotranspiration is the maximum ET under ideal circumstances, while actual evapotranspiration (ETa) is the real amount of water that evaporates, which depends on water availability and evapotranspiration-limiting factors.

ETp is commonly used to determine the amount of water needed for irrigating crops, while ETa is used to determine the actual amount of water that evaporates from a specific location [15]. For the water balances, it would be interesting to calculate the the ETa, to know the actual amount of water that leaves the study area. However, to estimate the ETa is really complex. In fact, on an annual basis, the use of Penman method results in an average 10% higher potential evapotranspiration compared to the Makkink method, which indicates already a high error margin in the early stage [16]. Direct measurements at different locations in the Netherlands revealed that the ETa on annual basis could decrease on average to 88% of the ETc according to Makkink, with an error margin of ± 11% [17]. This is most likely due to moisture limitations during a large parts of the summer period, in which in some months this ratio will decreases further. The underestimation of the actual evapotranspiration during wet periods and overestimation during dry periods makes it even more uncertain, which will be further discussed in the water balance analysis in Section 4.2 and in the discussion in Section 7.2.

Hence, the water balances will incorporate the actual evapotranspiration, determined multiplying the calculated ETc averages by 0,88. Important to note, that the estimation of ETa entails a relatively high margin of error, which will be discussed in more detail in Chapter 7.2.

Comparing FEWS WAM with KNMI data

The precipitation and evapotranspiration data in FEWS WAM will be cross-referenced with the KNMI data to ensure validation. The data of FEWS WAM is connected to the KNMI stations, which means that the data should be the same. Therefore, the monthly precipitation records for the Eenrum station in 2022 will be compared between FEWS WAM and the KNMI online monthly precipitation reports to ensure their alignment [18]. Additionally, the reference crop evapotranspiration in Lauwersoog will be assessed for each month in 2022 [19].

3.2.2 Mapping of EC measurements for salt content charts

This subsection focuses on discovering, identifying and selecting the water ways which contains high levels of salt content within the study area, implying the answering of the first sub-question of Research Question two. The main source of salt include salt seepage from the soil and ground. Additionally, the freshwater that will be pumped inside the study area contains sometimes already a high salt content, which makes it more difficult to flush the waterways to reduce the salt content. Another source contributing to the increase in salt content in watercourses is land fertilization. When farmers heavily fertilize their land and subsequent heavy rainfall occurs, significant increases in salt concentrations can be observed in the watercourses. As an example, in April and early May 2023, the salt content in some ditches increased from 1,5 EC to 2,7 EC within a two weeks, because of intense rainfall after land fertilization [20]. Finally, in the northern part of the study area, salt could be blown over the dikes during extreme weather conditions or rainwater could contain high salinity levels coming from the sea. However, these sources of salt is considered to be negligible according to the water level managers and hydrologists at Noorderzijlvest.

Although chloride measurements are not available in the FEWS system, manual measurements have been conducted by the rat catchers, as well as by Martin van der Maar, who is the water level manager of the North-West region of the management area of Noorderzijlvest. An observation day will be also scheduled to shadow the water level manager 'Martin van der Maar' in performing measurements in the study area for soil and water quality research. This will provide an opportunity to gain a firsthand understanding of the measurement techniques used on-site, complementing the laptop-based knowledge. Those measurement points from Martin van der Maar are only located in the storage basin (main watercourses), excluding measurements in the intermediate ditches, which are mainly the locations where the rat catchers have measured. All the measurement data for the past few years are stored in a comprehensive, cluttered and complex database maintained by Noorderzijlvest, covering lots of measurement points across the management area and distributed throughout different polders and regions. Each measurement point is identified by a unique code/identity.

First, all EC-measurement points that are relevant to the research will be determined from the Excel-sheets of the rat catchers. Therefore, all x/y coordinates from the various Excel files and folders were compiled and integrated within ArcGIS. This compilation resulted in an EC-Measurement Network, encompassing all measurement points where the rat catchers have measured the EC-values in canals, ditches, and water bodies. Subsequently, the entire EC-Measurement Network was clipped based on an intersect within a 100-meter buffer of the study area's boundaries, which consist of the eleven water level compartments. By doing this, the inclusion of all important measurement locations will be ensured, since some EC measurements are taken near pumping stations, weirs, and other waterways which lays outside the study area (within 100m), while it provides valuable information. In total, there are 49 measurement points inside and within 100 meters of the study area, each accompanied by their corresponding identity code (MPNIDENT/CODE), name (MPNOMSCH), and x/y coordinates, as presented in Table B.1 of Appendix B.

The next step will be to locate and document every measurement point in clear Excel sheets. These measurement points will be divided into five groups: Pieterburen (3 points), Linthorst Homanpolder (18 points), Negenboerenpolder (15 points), Westpolder + Other (13 points), such as the 'Kleine Herculesstuw 2' and the 'Grote Herculusstuw', which are classified based on their names as stated in Table B.1 of Appendix B.

In the group of Pieterburen, all three locations of EC measuring could be used, while in the Linthorst Homanpolder, there are four out of the eighteen locations where the measurements were only taken in 2019, which are MO-LHP7, MO-LHP8, MO-LHP13, and MO-LHP14. These points are marked with an orange background in Table B.1 of Appendix B and will not be included in calculating the average EC-values. These points are removed, due to insufficient information and measurements, which will make it inaccurate to make reliable statements about them. In the Negenboerenpolder group and Westpolder + Other group, there are two more locations which will not be used for any average EC-value calculation, due to the lack of adequate data.

Consequently, it will be crucial to thoroughly check all measurements taken, as sometimes decimal points are misplaced, resulting in, for example, an EC measurement of 1127 instead of 11.27 EC. If this is not taken into account, it will significantly affects the calculated averages. The rat catchers did these these measurements in addition to their main duties. Some of them were not aware that when the EC device displays a value below 1 mS/cm, it will be displayed e.g. as 789 µS/cm, which is equivalent to 0.789 mS/cm = 0,789 EC. However, they simply recorded it as 789 in the Excel sheets, while it needed to be recorded as 0,789. Next to this, various other rules are also applied to the Excel sheets, such as an exclamation-mark indicating EC measurements higher than 3 and a check-mark indicating measurements lower than 3. It is important to remove all accompanying text and rules from the numbers and delete any rows or columns that do not contain EC values, because otherwise it is not possible to calculate the averages by functions used in Excel, as it think you will divide by zero.

The ultimate goal will be to create pivot tables from all available measurements. To achieve this, it will be also necessary to remove some rows, where measurements were only taken at a single date. Otherwise, there may be outcomes where only a single measurement was taken in e.g. January, resulting in table row with solitary average EC-value for that specific location, with no other averages showed for all other measurement locations, as all those boxes will be empty. This limited data representation is not comprehensive or accurate enough to include in the overall analysis.

Proper organization of the Excel sheets is necessary to maintain a clear overview of all available and required data. It is also crucial to set up the tables correctly, convert all the dates to the number format 'date notations' in Excel, and verify the accuracy and consistency of the dates. All incorrect dates and typographical errors should be removed, and peaks in EC measurements should be validated. Once this is done, the focus shifts to determining the sources of the highest salt loads and the areas with the greatest salt seepage. Therefore, pivot tables in Excel could be used to analyze, summarize, and organize data from the large source Excel files containing all the EC measurements. This powerful feature allows you to view and present data in different ways, such as creating summary reports, performing analysis, and discovering trends and patterns. In this study, the pivot tables will enable to easily rearrange and summarize the data by taking the averages of all EC measurements in each year and in each month. Other functions of pivot tables could be chosen by selecting a layout and aggregate functions, such as generating sum, count, maximum, minimum and so on. The pivot table could also provide interactive features, such as data filtering, adding slicers for quick filtering, and grouping data based on specific criteria. This will allow you to quickly explore different views of your data and customize the analysis to suit your needs.

The next step, will be the actual calculation of the average EC values for each month, year, and all measurements for all four groups by using pivot tables. Additionally, it will be interesting to determine the average EC value for the dry period (April 1 to August 31) and the wet period (January 1 to March 31 + September 1 to December 31) for the years 2021 and 2022. To ensure the reliability of the measurements, it will be crucial to examine the number of measurements conducted during each time period. Therefore, a limit of five measurements will be set, which means that when the amount of measurements taken is below five, the average EC-values will be considered less reliable. This boundary will ensure that data is not skewed due to, for example, all five measurements being taken in April, which would present an unreliable representation of the entire dry period. These average EC values could be compared with the water balances outcomes, to analyze and evaluate the effectiveness of pumping. For instance, the impact of notable high flow rate values from pumps or precipitation in specific months will be analyzed in relation to their influence on potential EC reduction during those or subsequent months.

The EC measurements conducted by Martin van der Maar, a total of 21 measurements, will undergo the same procedure as will be done for the EC measurement network conducted by the rat catchers, as explained in Subsection 3.2.2. So, this will also result in Excel tables displaying the total, annual, and monthly EC-value averages, as well as for the dry- and wet periods for the years 2021 and 2022. To ensure clarity and avoid data overlap, these measurements will be presented in separate Excel-Sheets. Martin's measurement network is abbreviated as 'SB', which stands for Storage Basin, where the EC measurements were taken mainly near pumping stations and weirs. The rat catcher measurement network will be abbreviated at each Excel-Sheet with 'RC'. In the identification codes, it is worth noting that some codes share similarities but differ in the use of 'HWZ' (high water side) or 'LWZ' (low water side), indicating that measurements are taken on both sides of the pumping station or weir, which represents the boundary between the water level compartments.

The final step, will be presenting the results in a clear and concise manner for the client. ArcGIS maps could be created for this purpose, with different maps indicating the watercourses with the highest salinity using dot color classification. In ArcGIS, distribution charts can be created from the average EC values to display valuable statistics such as mean, minimum, and maximum values. The distribution charts can than be generated using the symbology button in ArcGIS, selecting graduated colors as the primary symbology with a manual interval method. This allows you to select a number of classes with custom symbols and intervals or upper values. With this, four classes will be made, in which water with an EC value up to 3 will be designated and visualized with a green dot on the map, indicating good water quality for e.g. irrigation. An EC-value of 3 mS/cm corresponds approximately with a chloride content of 1000 mg/L, which is broadly used by the water level managers as a striving value for the salt content in water. According to the remaining color ranking within the four classes, when the EC value exceeds 3 and reaches up to 6, the color changes to yellow, indicating that the water quality might be usable for some crops but far from optimal for irrigation. In between 6 and 12 EC, the water quality becomes too poor for practical use, and the color assigned is orange. When the EC value exceeds 12, the color of the dot turns red, indicating that the water quality is severely compromised and unsuitable for almost any kind of use. Properly labeling each measurement location on the ArcGIS maps holds utmost importance. Ideally, using their corresponding identical MPNIDENT/CODE would be preferred, but due to the extensive network of the rat catchers, consisting of 42 visible points, not all names can be accommodated clearly. Therefore, numbers called 'FID' will be assigned to each MPNIDENT/CODE. This FID can also be found in Table B.1 of Appendix B.3.

In the end, the goal will be to create ten maps, for both the rat catchers and storage basin network, one map that shows the average EC values of all years of data, and four maps showing the average EC values of the dry- and wet periods in the years 2021 and 2022.

3.2.3 Determination of (the feasibility of) the current flushing requirement in the study area

In this subsection, the ultimate goal is to determine how much freshwater you require to maintain good water quality. The water level managers use an EC of 3 mS/m as the target value concerning the EC content. Thereby, the farmers use a desirable EC of a maximum of 1.5 mS/m for irrigation, with an extreme maximum of 2.5 mS/m [9]. Nowadays, water level managers in the study area aim for an electrical conductivity (EC) level of 3 mS/m = 3 dS/m for irrigated locations, which correspond with approximately with 1000mg/L. Setting up a water balance is a useful tool to determine the flushing requirement. The general simplified calculation can be done as follows:

1. First, the total amount of salt in the study area needs to be calculated at the start of the flushing period (supply season). This can be done by multiplying the salt concentration, when you take the average of a lot of measurements, by the volume of water in the system.

2. Determination of the desired salt concentration throughout the supply season, which is known.

3. With these two factors known, you could calculate the total amount of salt that needs to be removed from the system by subtracting the desired total amount of salt from the initial total amount of salt.

4. The flushing requirement could be calculated, by the following formula:

$$V = \frac{(C3 - C2) \times V1}{(C2 - C1)} \tag{3.3}$$

where:
V = the flushing requirement, the volume of water that is required for flushing(in L)
C1 = the salt content of the required flushed pumped water (in mg/L)
V1 = the volume of water to be flushed within the study area = volume of water body (in L)
C2 = the desired salt content (in mg/L)
C3 = the initial salt content of the water inside the study area (in mg/L)

However, Equation 3.3 assumes a uniform distribution of salt content in the water body during flushing. In reality, the salt concentration is uneven, as it depends on water flow rates and amount of salt seepage. Flushing using the pumping stations does not result in uniform flow through ditches. Moreover, the flushing requirement depends on various factors, such as irrigation, actual evapotranspiration, open surface water evaporation, precipitation, salt seepage from the soil. Therefore, this formula is purely hypothetical, to provide a rough estimation of the flushing requirement at a specific pumping station location.

To summarize, this complex problem of determining the flushing requirement could be solved with assistance of employees of Noorderzijlvest. They already monitor various parameters, such as flow rates and salinity levels, at different locations in the study area, which could be used for 2021 and 2022. This involves taking into account all eleven water level compartments on the western side of Noordpolderzijl. Together with literature review and modelling techniques, the major waterways and sources that carry a high salt load will be identified. By mapping this out, the flow of water in specific directions and the impact of pumping on the salt content reduction in various waterways could be assessed for year 2021 and 2022. This will provide insights into potential solutions as recommendation for more efficient utilization of pumped freshwater.

3.3 Expert interviews; For Proposing Potential Solutions

To address the methodology to answer the (final) third research question, potential solutions will be identified and presented in two sections, in which the distinction will be based on with and without a research based approach / specific substantiation from this research findings. The first section will propose potential solutions based on literature review, expert consultations with employees at Noorderzijlvest and results & analysis from this report.

Within the organization of Noorderzijlvest, there was a weekly meeting called the 'Standby Consultation Watersystem Management' (in Dutch: 'piketoverleg Watersysteembeheer'), held every Monday from 9am to 10am. This meeting involved 23 employees (e.g. water level % hydraulic structure managers, and hydrologists) and focused on discussing for example; alarms, water level changes, applies for freshwater / irrigation, emergency situations, issues with pumping stations. Two half-hour sessions during these meetings was arranged to present and discuss the intermediate and final results of the water balance analysis, salt mapping charts, and corresponding analysis. The main objective of these meetings was to exchange knowledge and insights regarding potential solutions, including their (dis-)advantages. These sessions were scheduled for the two meetings on May 8th and 29th.

Additionally, there was a weekly meeting called the 'Meeting Team Management Watersystems and Watersafety' (in Dutch: 'Overleg Team Beheer Watersystemen en Waterveiligheid') held every Tuesday from 9am to 10am. This meeting involved 14 employees (e.g. water quality researchers, hydrologists, policy officer, groundwater researcher), which was also the team overseeing my internship and the thesis assignment. The meeting at 6 June was used to discuss the results and findings of this thesis assignment, with the aim of gaining knowledge for proposing various solutions.

At Water Authority Noorderzijlvest, there are flexible workplaces available, allowing employees to work in different rooms each day and fostering an open and relaxed atmosphere. Furthermore, each door was almost always open, further facilitated easy communication and interaction among colleagues, enabling discussions related to the research or any encountered problems. Dialogues, meetings, and conversations in formal settings (planned meetings, email, Linked-In) as well as informal settings (coffee and lunch breaks, working hours, corridors) formed the foundation of this report, especially for proposing potential solutions.

The second section will present qualitative solutions that are of a general nature and will require further research. These proposed solutions are not directly linked to the findings of this study, but are based on 'common-sense' and general knowledge derived from literature review and expert consultations with employees at Noorderzijlvest, as described in the previous paragraph. While these recommendations, including potential next steps or actions, can be useful, especially for the answering of research question three, it will be important to clearly distinguish them from the main research-based recommendations presented in the first section. The potential solutions of section two, will be qualitatively analyzed to determine if they effectively address the research question three. The feasibility and relevance of these solutions will be taken into account and assessed to ensure they are adequately aligning the other research questions and goal of this report. Therefore, these solutions are of high importance for further research in optimizing the freshwater plan, but they are not extensively discussed in this report as they do not directly support the reported findings, but rather address the general problem at hand.

Both sections, will present an enumeration of potential solutions, with and without evidence-based support from the report findings. Together, they will successfully answer the final research question by identifying potential solutions to effectively manage the increasing salinization problem with an eye on improving freshwater utilization.

3.4 Research & System Assumptions

This section is crucial for identifying potential research method failures and devising strategies to prevent them, ensuring the feasibility and reliability of the research questions. Assumptions are necessary due to limited data availability and the need to maintain a 10-week project timeline. Additionally, this section addresses potential project-related issues, including model application challenges, time allocation, the level of stakeholder communication, and the significance placed on the evaluation of various solution options.

Inflow and outflow locations of surface water

- There was a pilot implementation at the Verhorn pumping station in 2022, caused inaccurate flow rate values in FEWS WAM Portal. To ensure a fully closed study area for the water balances, the Maurice-I, Maurice-II and Kluten pumping stations were taken into account. First of all, Maurice-I and II will be included in the Output Single Locations table. The total flow rates (KWK = PMP1/2/3+KST) of Maurice-I will be used, since the water is pumped out of the study area by the three pumps in the same direction as the water flowing over the weir during the discharge season. The flow rate at Maurice-II has an opposite flow direction during the water supply season. In summer, the flow rate consists of water being pumped out of the system (PMP), while during rainfall, it represents water entering the study area over the weir (KST). The water pumped from Maurice-II will flow towards Verhorn and thus the total flow rate (KWK) will be considered, calculated as PMP-KST. Finally, the water being pumped through Kluten is outflow, while the flow rate at the weir is inlet, as during high rainfall the water is flowing inside the study area. However, the flow rates at Kluten, although small and negligible, will be taken into account for completeness.
- The Elensterstuw (weir) is located at the border of the study area and primarily functions as discharge outlet during rainy season, as is visualised in Figure 3.5. However, there are no nearby flow rate measurement points, which causes potential errors in the water balance. Nevertheless, the impact of this small waterway on the overall water balance is minimal as

this are small flow rates. The flow rates at Kleistuw are multiplied by 0.25 to estimate the flow rates at Elensterstuw, considering the difference in the relative drainage / discharge areas.

- Pumping station Egelnest has a manual weir and one pump, in which only the flow rates at the pump are known. When the pump is activated, the weir is adjusted to prevent water flowing over it, ensuring that only water is pumped inside the study area. The drainage area of Egelneststuw (weir) is similar to that of Elensterstuw, and therefore the same flow rates are considered. Next to this, the flow rates in March 2022 will be also multiplied by 1/3, August 2022 by 1/2, and March 2021 by 3/4 to account for the periods when the pump was active.
- For Kleine Herculusstuw 2, flow rate measurements were conducted from mid-May until to mid-November 2022, as no water was flowing over the weir during the remaining period. No water was flowing over the weir in 2021, which caused in zero values for flow rates throughout the year.

Parameter decomposition: Other values (net storage)

This parameter decomposition consists of the remaining fluxes for the overall net water storage changes of the water balance, as described in Subsection 3.2.1, such as percolation, infiltration, storage capacity of the sub- and topsoil. These parameters were excluded from the water balances, due to the lack of accurate and reliable estimations and calculations. Various methods were attempted to address this issue, including the calculation of hydraulic conductivity and field capacity, as well as the use of the 'Formule van Hooghoudt' to determine groundwater discharge from drained plots [21]. However, due to the dependence of the depth of phreatic level below ground surface on the field capacity, and the inadequate groundwater measurements in the study area, these approaches were not feasible. It is not possible to determine a constant average value for the entire study area or in fact, for a specific soil type to incorporate into the water balances. The Water Authority Noorderzijlvest currently does not have any measurement tools within in the study area, and the available groundwater data from sources such as 'Grondwatertools' (limited to 2019 and earlier) and DINOloket (covering 1950-1974) is outdated and insufficient [22] [23].
Based on an expert interview with hydrologist Vincent van der Looij and groundwater researcher Moniek Spruit, employees of Noorderzijlvest, it was concluded that the calculations of 'other values' are too complex and cannot be generalized accurately for the whole study area. While various calculations could be done for individual plots, they do not provide meaningful information for the overall water balances of the study area. The differences in soil characteristics are too significant and complex, such as the permeability ranging from 0,0001m/day for heavy clay to 0.5m/day for light sablon, making it impossible to derive consistent outcomes [24]. The more you go towards the dike, the more the soil compositions changes from clay soils towards more sablon soils, with both soil types dominating in the study area, resulting in diverse outcomes. The ability of soils to absorb and flush water varies significantly. In conclusion, the heterogeneity of topsoil and subsoil compositions across the study area, suggest that further research is needed to investigate specific areas or a selected set of plots in greater detail.

Time management & Determining possible solutions as recommendations

- Allow sufficient time to get an understanding of the programs used at Noorderzijlvest, considering the learning curve associated with new systems.

- Allocate time to attend meetings, events, workshops, participate in other teams within Noorderzijlvest, and go on trips to gain insights into the operations and activities of a Water Authority, which is also an opportunity to explore various roles within the organization.
- Not putting too much pressure on the quantification (of the effectiveness analysis) of certain recommendations, because the development of comprehensive qualitative solutions for preventing salinization and reducing flushing requirements is prioritized. Thereby, it is important to integrate the wishes of the stakeholders within the potential solutions, however, considering the limited available time, conducting a comprehensive stakeholder analysis may not be feasible.

Chapter 4

Water Balances of 2021 and 2022 with in-depth Analysis

This chapter is divided into two sections. The first section presents the results of the water balances for the years 2021 and 2022: annual, dry season and monthly. Subsequently, the second section will consists of a comprehensive analysis of the results.

4.1 Results of Water Balances of the Years 2021 and 2022; Annual, Dry Season and Per Month

As explained in Subsection 3.2.1, the bucket model will be used for determining water balances of the study area. This model incorporates various inflow and outflow fluxes, including flow rates from pumping stations, precipitation, evapotranspiration, and flow rates over the weirs. However, fluxes such as, infiltration, percolation, changes in water storage in the soil (whether positive or negative) are excluded from the water balances, due to data insufficiency and the inability to make accurate assumptions. Despite these limitations, a comprehensive analysis could be made to assess the impact of pumping on salt content reduction, utilizing the available data. The section concludes with the visualization of through graphs and tables, providing a summary of the study's findings.

4.1.1 Precipitation and evaporation fluxes

It is essential to initially validate consistency between FEWS WAM with the KNMI data before fully relying on FEWS WAM Portal. Figure 4.1 presents the results of the precipitation data from the Eenrum weather station Eenrum and the reference crop evapotranspiration from the Lauwersoog weather station for each month in 2022. The results indicate a high level of agreement between the two data-sets. The precipitation data match exactly, while there are minor differences in ETc visible, although these differences are considered negligible. Detailed results with corresponding values can be found in the attached Excel file titled 'Waterbalance' on the 'P_ET_KNMI' sheet. To conclude, the meteorological data from FEWS WAM Portal will be utilized for the water balances.

The comprehensive meteorological data analysis for the study area in the years 2021 and 2022 are presented in Table A.1 and Table A.2 respectively of Appendix A.

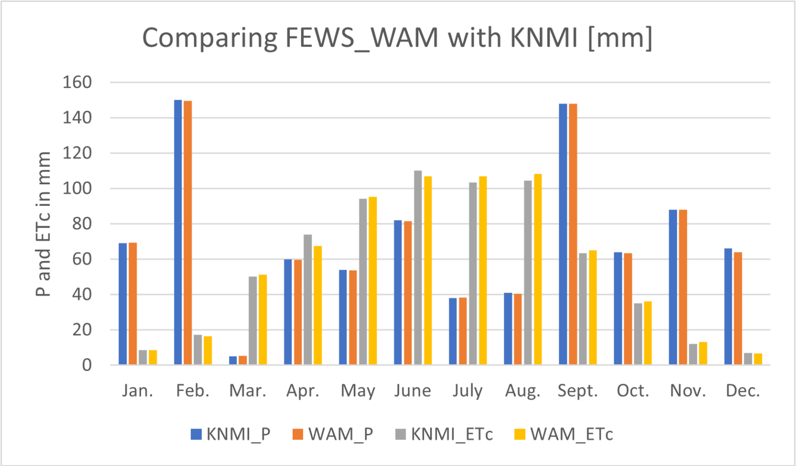


Figure 4.1: Comparison of water balance components in FEWS WAM Portal with KNMI Data in year 2022[mm].

4.1.2 Q_inlet and Q_outlet fluxes

After the field trip with Martin van der Maar, some mistakes in the current ArcGIS maps are discovered. In Figure 4.2, two examples of a fault on the ArcGIS map is visualized. The green lines represent the waterways, where the flow direction is in opposite directions of the water supply season in comparison to the discharge season. The red lines represents that these have the same flow direction, which would mean that the Wierhuizerklief pumping station would pump the freshwater in the bottom waterway. However this is not the actual case, since the pumped fresh water flow from before the dike towards the 'Grote Herculusstuw'. That is why, the red water course marked with the yellow circle should be changed to a green color. The other mistake is that, in reality there exist no pumping station Slikken, namely only a weir called Slikken. The analysis takes into account these discrepancies between the field conditions and the information depicted on the maps.

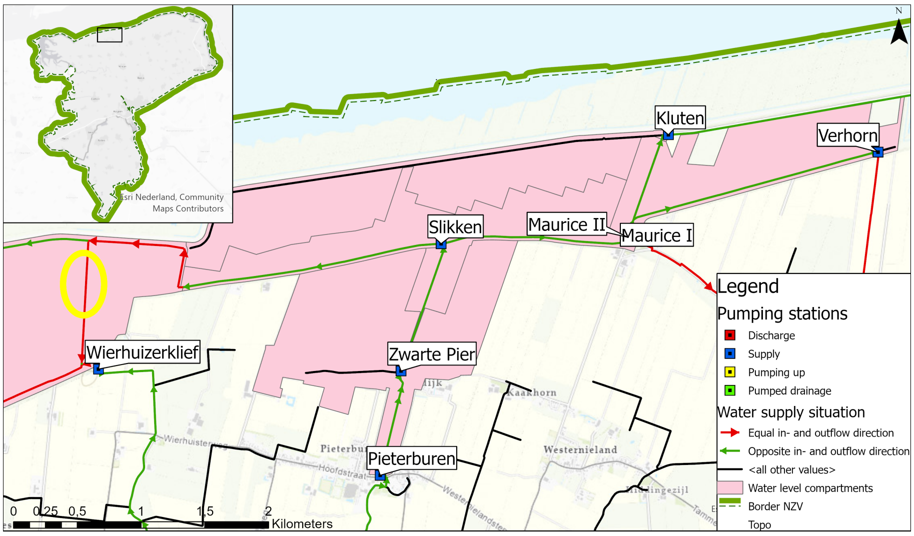


Figure 4.2: Visualized discovered mistakes in the current ArcGIS map at Wierhuizerklief pumping station & Slikken.

In total there are seven inlet pumping station locations, seven outlet weir locations at those pumping stations and five remaining single outlet locations. A comprehensive average flow rate analysis of the years 2021 and 2022 of all these locations are quantified in Appendix A.2 and Appendix A.3 respectively. An example of how these values are obtained is visualized in Figure 4.3 of the Pieterburen pumping station during dry period. Pieterburen (KGM119) consists of two pumps (PMP1/2), and their activation fluctuations are depicted in Figure 4.3. In Figure 4.3, the black line labeled ‘Debiet Pieterburen (KST1)’ represents the discharge of water that will be flowing over the weir out of the water level compartments (system). For this example, the average flow rate of PMP1+2 is 0,082 m^3/sec and of KST1 is 0,001 m^3/sec, in which these numbers are also presented in Table A.8 and Table A.7 respectively. The blue line ’KWK’ represents the total sum discharge of KST1 - (PMP1+2). In Figure 4.3, there is a remarkable gap shown, where both pumps were switched off, corresponding perfectly with the high rainfall in that time-frame. In June 2022, high rainfall was occurring, depicted in Table A.9 in Appendix A.4. The soil was already enough satured by the freshwater from the rainfall, which made it impossible to flush the water ways inside the water level compartments, since first the water had to be discharged to the outlet locations.

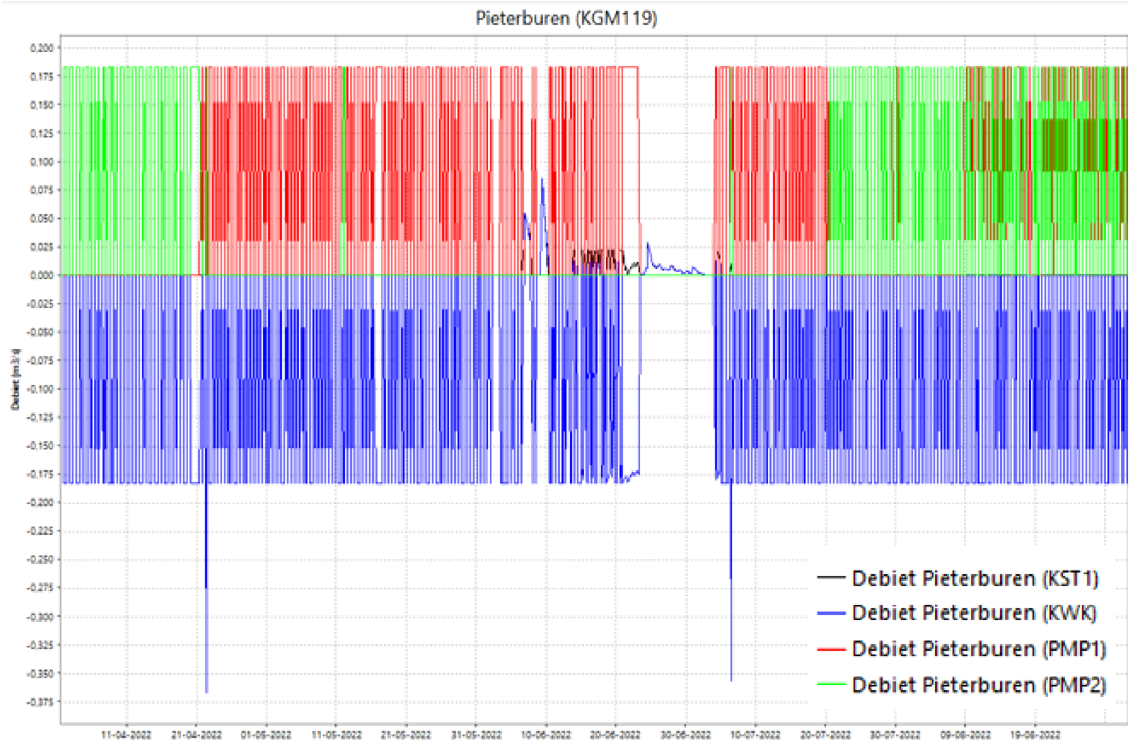


Figure 4.3: Example of measurement station in Pieterburen during the dry period of 2022. The blue line called ‘Debiet Pieterburen (KST1)’ representing the discharge of water that will be flowing over the weir out of the water level compartments (system). PMP1/2 indicates the discharge originating from the pumps and KWK represents the total sum discharge of KST1 - (PMP1+2).

The final results of the water balances are shown in Table 4.1 and Table 4.2 of the years 2021 and 2022: annual, dry season and monthly. The ’Q_inlet’ column represents the cumulative flow rates at all inlet locations of the pumping stations, while the ’Q_outlet’ column represents the cumulative flow rates at all outlet locations. The ’Sum_Influxes’ column is the summation of ’Q_inlet’ + ’P_avg’ and the 'Sum_Outfluxes' column is the summation of 'Q_outlet' + 'ETa'. A more in-depth analysis of the results is performed in the attached Excel file titled 'Waterbalance' under the 'Results' sheet. Furthermore, a more clear and comprehensive study of all in- and outlet location flow rates are performed under the sheets 'In-Outlet_Monthly2021' and 'In-Outlet_Monthly2022'.

These tables provides the importance of understanding variations in precipitation, actual evapotranspiration and other factors that can have a significant impact on the water balances and the amount of water available in the study area. By comparing 2021 and 2022, insights could be obtained regarding how the system responds to certain changes, enabling the identification of potential patterns and trends to make informed decisions about water use and management.

Table 4.1: Final results water balances 2021 $[m^3/sec]$.

2021	**P_avg**	**Q_inlet**	**Sum_Influxes**	**Sum_Outfluxes**	**Q_outlet**	**ETa**
Jan.	1,167	0,012	**1,179**	**0,974**	0,881	0,094
Feb.	0,551	0,008	**0,559**	**0,757**	0,537	0,220
Mar.	0,807	0,168	**0,975**	**0,924**	0,515	0,410
Apr.	0,483	0,361	**0,844**	**1,202**	0,375	0,827
May	1,559	0,187	**1,746**	**1,433**	0,590	0,843
June	0,730	0,578	**1,308**	**1,858**	0,513	1,345
July	1,320	0,343	**1,663**	**1,551**	0,365	1,186
Aug.	1,538	0,031	**1,569**	**1,346**	0,390	0,957
Sept.	0,679	0,004	**0,683**	**0,921**	0,251	0,670
Oct.	1,311	0,001	**1,312**	**0,884**	0,535	0,349
Nov.	0,943	0,002	**0,945**	**0,657**	0,513	0,144
Dec.	0,993	0,006	**0,999**	**0,930**	0,857	0,073
Annual	1,014	0,135	**1,149**	**1,117**	0,522	0,594
Dry_period	1,133	0,280	**1,413**	**1,462**	0,431	1,031

Table 4.2: Final results water balances 2022 $[m^3/sec]$.

2022	**P_avg**	**Q_inlet**	**Sum_Influxes**	**Sum_Outfluxes**	**Q_outlet**	**ETa**
Jan.	0,956	0,007	**0,963**	**0,899**	0,800	0,100
Feb.	2,099	0,009	**2,108**	**1,435**	1,223	0,212
Mar.	0,067	0,197	**0,264**	**1,154**	0,552	0,602
Apr.	0,801	0,315	**1,116**	**1,558**	0,738	0,820
May	0,722	0,517	**1,239**	**1,777**	0,660	1,117
June	1,258	0,351	**1,609**	**1,886**	0,590	1,297
July	0,608	0,455	**1,063**	**1,782**	0,526	1,256
Aug.	0,563	0,446	**1,009**	**1,922**	0,652	1,270
Sept.	1,739	0,109	**1,848**	**1,189**	0,400	0,790
Oct.	0,933	0,006	**0,939**	**0,724**	0,301	0,423
Nov.	1,166	0,007	**1,173**	**0,708**	0,550	0,159
Dec.	0,891	0,007	**0,898**	**0,765**	0,685	0,080
Annual	0,972	0,204	**1,176**	**1,256**	0,576	0,680
Dry_period	0,787	0,408	**1,195**	**1,668**	0,515	1,153

4.2 In-depth Analysis and Discussion of the Water Balances

This section will observations from the water balances conducted in 2021 (Table 4.1) and 2022 (Table 4.2) in bullet-point format. Detailed results with corresponding values of this section can be found in the attached Excel file titled 'Waterbalance' on the 'Results' sheet. It is challenging to substantiate each number and difference with well-founded verified reasons due to the multitude of factors and influences involved. For example, a high Q_inlet could be the cause of the managing of the target water level or the flushing of waterways to reduce the salt content.

- The total water demand in the dry period of 2021 is calculated as $0,280 \times 153 \times 24 \times 3600 = 3,70$ million m^3, while in 2022 it is $0,408 \times 153 \times 24 \times 3600 = 5,39$ million m^3, resulting in a 46% increase. On the other hand, the total water outflow that is leaving the study area (Q_outlet) during the dry period of 2021 is calculated as $0,431 \times 153 \times 24 \times 3600 = 5,70$ million m^3 and in 2022 it is $0,515 \times 153 \times 24 \times 3600 = 6,80$ million m^3, indicating a 19% increase. The first thing to emphasize is that there was much more water needed from the IJsselmeer in 2022. It is notable, that the increased water demand is not directly correlated with the total water outflow. The reasons for this discrepancy are difficult to explain, as it could be attributed to the need of flushing waterways to prevent salinization or to manage the target water levels. However, the difference between Q_inlet - Q_outlet remains relatively consistent in the dry period of 2021 and 2022, as also depicted in Figure 4.4. In 2022, although the Q_inlet is higher, P_avg is lower, and ETa is higher compared to 2021, the Q_outlet does not decrease in the same amount as expected with the reduced precipitation and increased evaporation. Therefore, you could suggests that significant portion of the pumped freshwater is used for flushing purposes. During the summer, the ETa tends to be overestimated, as elaborated in Section 7.2, because less water is evaporated and transpired, primarily due to soil drying. Consequently, this leads to increased salt seepage, as the groundwater level is lower due to desiccation, which contributes to higher water demand for flushing requirement to reduce EC levels. Furthermore, water level manager Martin van der Maar was convinced with his estimation that a small part of the pumped freshwater into the study area is used for irrigation, open surface evaporation etcetera, implying that most of Q_inlet is also part of Q_outlet. The values obtained from the water balances satisfies with this expectation, because the total Q_inlet increased from 0,280 m^3/sec (2021) to 0,408 m^3/sec (2022), and the total Q_outlet increased from 0,431 m^3/sec (2021) to 0,515 m^3/sec (2022). These value differences are approximately of the same magnitude, as shown in Figure 4.4. If the results did not align with this expectation, significant lower values for the total Q_outlet in 2022 would have been expected, considering the lower registered outflow, due to the increased water loss through irrigation or evaporation.

- The Netherlands experienced a national precipitation deficit of 223mm in 2022 and 70mm in 2021, measured across thirteen weather station[25]. The average precipitation deficit in the country is 83mm [25]. The dry period in 2022 had a 31% reduction in rainfall compared to 2021, resulting in a more severe precipitation deficit. It is expected that in 2022, the Sum_Influxes would be lower than the Sum_Outfluxes, due to the precipitation deficit. This expectation is confirmed by the values observed, with 1,176 m^3/sec being less than 1,256 m^3/sec, in which these values can be found in Table 4.2.

- In 2021, there was higher average precipitation and lower ETa compared to 2022. The increased precipitation in 2021 provided more water available for soil infiltration. It is worth to note that the average precipitation from 1991 to 2020 in the study area was 863mm, which is closer to the precipitation levels observed in 2022 (858mm) compared to 2021 (895mm).
- The annual values for Sum_Influxes & Sum_Outfluxes in 2021 were almost similar, meaning almost no change in the 'net storage' of the soil, as explained in Subsection 3.2.1. During summer months, it is expected that Sum_Influxes < Sum_Outfluxes, as the soil dries out, while during winter months, on average Sum_Influxes > Sum_Outfluxes, as the ground absorbs water. This pattern was in general observed in both years, with variations heavily depending on precipitation and actual evapotranspiration. During periods of precipitation deficit, the ETa tends to be overestimated, lagging behind ETp as discussed in Section 7.2. Consequently, this effect contradicts the expected seasonal pattern, because ETa should be slightly lower in summer and higher in winter. This discrepancy leads to lower groundwater levels in summer and increase in salinization in summer. Accounting for this factor in the water balances would bring the Sum_Influxes and Sum_Outfluxes closer together, making the final results more plausible, since major differences are reduced that can be attributed to 'other values'.
- The soil dried out more in 2022 compared to 2021, with six consecutive months having the Sum_Influxes < Sum_Outfluxes; Mar. (almost no rainfall), Apr., May, June, July, Aug. in 2022, while in 2021, this occurred in Feb., Apr., June and Sept. These months experienced more water leaving the area than entering it, indicating soil drying, supported by relative higher ET values. Overall, more water was available for soil infiltration in 2021, potentially because of a need for irrigation or additional freshwater input in 2022.
- During the dry period, significantly more rainfall occurred in 2021 compared to 2022, since 1,133 $m^3/sec \gg$ 0,787 m^3/sec, indicating a larger freshwater deficit in summer in 2022, which is visualized in Figure 4.5 with the more negative bars during the summer months and dry period. Therefore, more freshwater was pumped into the study area in 2022, with Q_inlet of 0,408 $m^3/sec \gg$ Q_inlet of 0,280 m^3/sec in 2021.
- The difference between Q_inlet - Q_outlet is typically negative, visualized in Figure 4.4, which is logical since Q_outlet is the sum of water originating from the pumping stations and precipitations. Only June 2021 has a positive difference, due to high actual evapotranspiration (1,345 m^3/sec) and low precipitation (0,730 m^3/sec), resulting in the utilization of freshwater from pumping stations for irrigation, soil storage, and evaporation.
- The percolation/groundwater recharge rate (Sum_Influxes − Sum_Outfluxes) is generally decreased in 2022 compared to 2021, indicating less water percolation into the groundwater system. This could have implications for groundwater recharge and availability in the future. Furthermore, it is more prominent during the dry period, with values of -0,47 m^3/sec for 2022 and -0,05 m^3/sec, for 2021 , as shown in Figure 4.5, where the gray bars (2022) are mostly more negative than the green bars (2021). Annually, the value is negative for 2022 at -0.08 m^3/sec and positive for 2021 at 0.03 m^3/sec. Based solely on these values, the expectation is that more water will be leaving the system than entering it in 2022, implying a change in storage of -0,08 m^3/sec and the soil drying out that year. However, as explained in Subsection 3.2.1, over longer time frames, the significance of water storage diminishes as it tends to

balance out over time. This expectation is verified by the water balances, since both values being close to zero, supporting a fairly accurate determination of the water balance.

- Finally, in September 2022, high rainfall was recorded, while there was still a significant amount of freshwater being pumped into the study area in September (Q_inlet = 0,109 m^3/sec). July and Augustus 2022 were both drier months compared to 2021, indicating the soil drying out and a higher need for water infiltration into the soil. That is why, a large positive difference between Sum_Influxes - Sum_Outfluxes was observed, as illustrated in Figure 4.5.

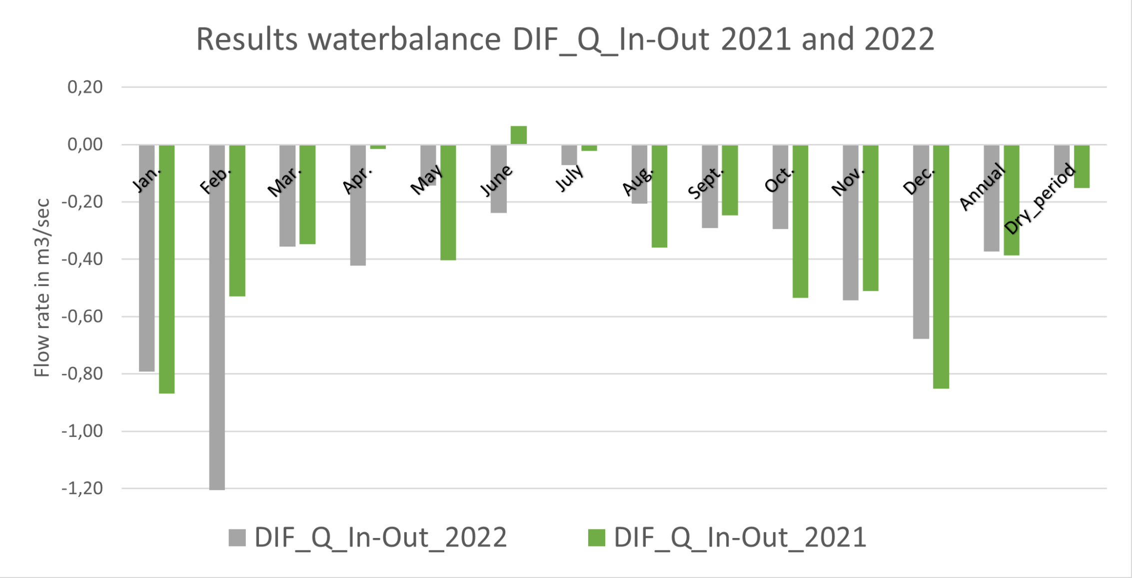


Figure 4.4: Results waterbalance DIF Q In-Out 2021 and 2022.

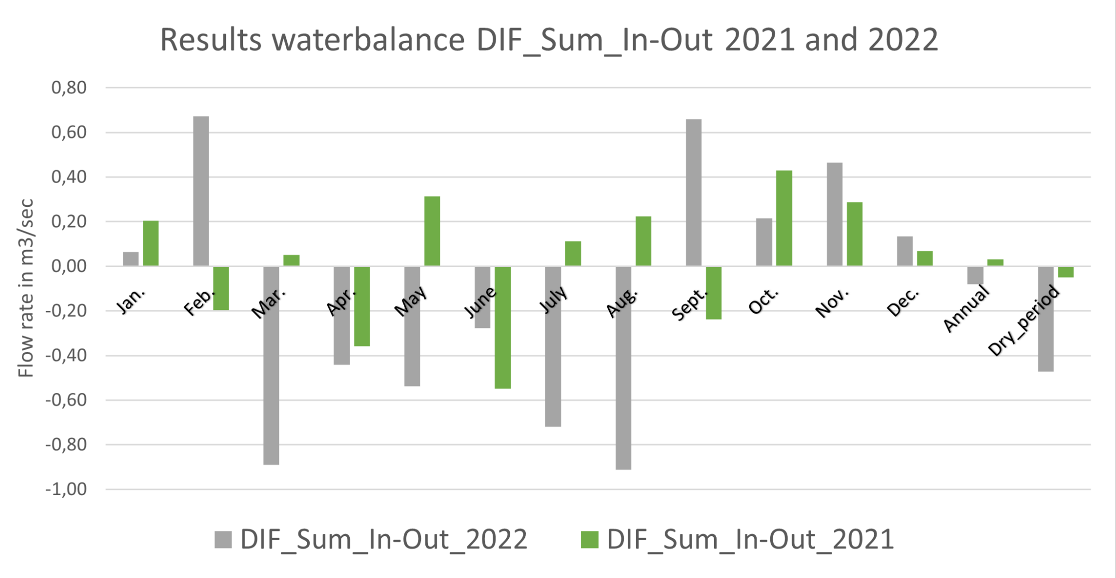


Figure 4.5: Results waterbalance DIF Sum In-Out 2021 and 2022.

As explained in Subsection 3.4, there is insufficient groundwater measurement data available for the study area. Otherwise, it would have been interesting to compare the groundwater levels throughout 2021 and 2022 with the results of the water balances. For this comparison, the water balance unit needs to be converted from m^3/sec to mm/corresponding time unit by multiplying it by 1000 and the number of seconds within the respective month, dry period or year, and dividing it by the total area of 36753845 m^3. The results of these calculations are visualized in Figure 4.6 and detailed calculations with the all numerical values can be found in the attached Excel file titled 'Waterbalance' on the 'Results' sheet. In Figure 4.6, the dry period of 2022 and 2021 is not considered, as their values of -170mm and -18mm, respectively, would have resulted in a large bar on the graph, obscuring the visibility of other bars. It is evident from Figure 4.6 that the soil is significant drying out during the summer months of 2022, whereas the effect was much less pronounced in 2021. The exceptionally dry month of March 2022, with almost no rain, the impact on the groundwater level is huge, with a difference of -65mm between the Sum_Influxes and Sum_Outfluxes. This suggests that according to these results, the groundwater level would have decreased by 65mm, what would have been taken into account as the change in storage. The impact of the dry months on the overall year 2022 is also clearly outlined, with a reduction of almost -70mm / -0.08 m^3/sec. This difference of unit arises, because a year contains approximately twice as much seconds than a single month. That is why, even a small in- or decrease in the unit of m^3/sec (Figure 4.5) translates into a substantial impact when depicted in mm (Figure 4.6).

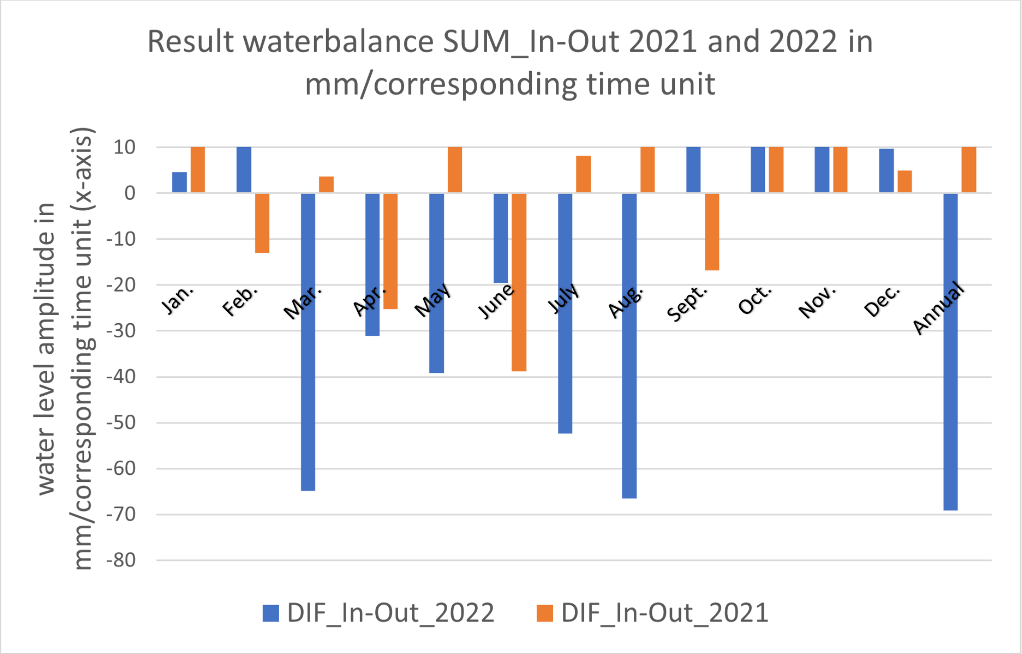


Figure 4.6: Results water balances SUM In-Out 2021 and 2022 in mm/corresponding time unit.

Chapter 5

Mapping of EC Measurements Averages and Insights

In this section, the results of the average EC value measurements will be presented, and subsequently together with the water balance, these results will be analyzed.

5.1 Results of the EC Averages across All Years and of the Dry- and Wet Periods of 2022

In this section, the results of the calculated average EC values will be presented. The attached Excel file titled 'EC-values_measurements' contains clear tables displaying these results for further exploration. The first two Excel sheets, ArcGIS_Table_SB' and 'ArcGIS_Table_RC', were implemented in ArcGIS to map the EC measurement locations and to determine which waterways carry a high salt load.

The EC network of the rat catchers, along with the corresponding x/y-coordinates of each measurement location, is presented in the 'EC_network_RC' Excel sheet and also in Table B.1 of Appendix B.1. The rat catchers' EC network is divided into four groups: 'Pieterburen' (3 locations), 'Linthorst Homanpolder' (18 locations), 'Negenboerenpolder' (15 points), 'Westpolder + Other' (12 locations) with the results of the average EC values stated in the corresponding Excel sheets.

For the analysis of the determination of the impact of pumping on salt content reduction, the average EC values during the years 2021 and 2022, are of particular interest. These values are calculated and presented in the respective four Excel sheets. Appendix B.2 provides an example of the structure of the four Excel sheets for better understanding. In this Appendix B.2, Table B.2 displays the average EC values of the three measurements coordinates in Pieterburen. Note that only the monthly averages of 2021 and 2022 are shown in this table to avoid unnecessary information. However, the values for the other months in other years can be found in the attached Excel file. Thereby, Table B.3 presents the calculated average EC values during the dry- and wet period of 2021 and 2022 in Pieterburen, which is important information for the analysis. Finally, Table B.4 shows the total number of measurements taken during each time period, determining the accuracy of the calculated average EC value of the three measurements coordinates in Pieterburen. The remaining three Excel sheets of 'Linthorst Homanpolder', 'Negenboerenpolder' and 'Westpolder + Other' follows a similar structure.

To conclude, Table B.5 in Appendix B.1 provides the average EC values of all years, as well as the wet- and dry periods of 2021 and 2022, obtained from all measurements conducted by the rat catchers within 100m of the study area. This Table is also available in the 'EC_Results_RC' Excel sheet of the 'EC-values_measurements' file. Finally, values with an orange background in Table B.5 indicate that they are based on less than five measurements, implying lower reliability. However, the measurement dates and the accuracy of the EC measurement device are clearly provided. Thereby, this values are taken into account when mapping the averages, but it is advisable to exercise caution.

The final remaining Excel sheet titled 'MEAS_SB', contains the calculated average EC values and the corresponding number of EC measurements taken by Martin van der Maar. These measurements primarily cover locations in storage basins and near hydraulic structures, such as weirs and pumping stations. Table B.6 in Appendix B.4 displays the final results, with no values highlighted in orange background, implying good reliability of the data due to a large number of measurements.

5.2 Spatial Distribution EC Averages: All Years and 2022

In this section, maps are presented showing the average EC values for all years, as well as the wet and dry period of **year 2022**, obtained from all measurements conducted by Martin van der Maar and the rat catchers within 100m of the study area. The spatial distribution of the average EC value for the wet and dry period of **year 2021** can be found in Appendix B.5, including Figure B.1 conducted by the rat catchers, and Figure B.2 conducted by Martin van der Maar.

5.2.1 Mapping of the average EC Values conducted by the rat catchers

Figure 5.1, illustrates the spatial distribution of average EC value obtained from the 42 measurement locations labeled by their FID. Their corresponding name and EC values can be found in Table B.6 in Appendix B.3. Additionally, Figure 5.1 depicts the direction of water-flow during the water supply season, with green color indicating opposite in- and outflow directions. Meaning that when water is pumped inside the study area, it flows in opposite direction compared to the discharged water from heavy rainfall, where water flows over the weir away from the study area. The 42 measurement points are mainly located in ditches rather than the storage basin. In Section 5.3, the effect of the pumping on the EC reduction in the ditches will be researched by using the water balances.

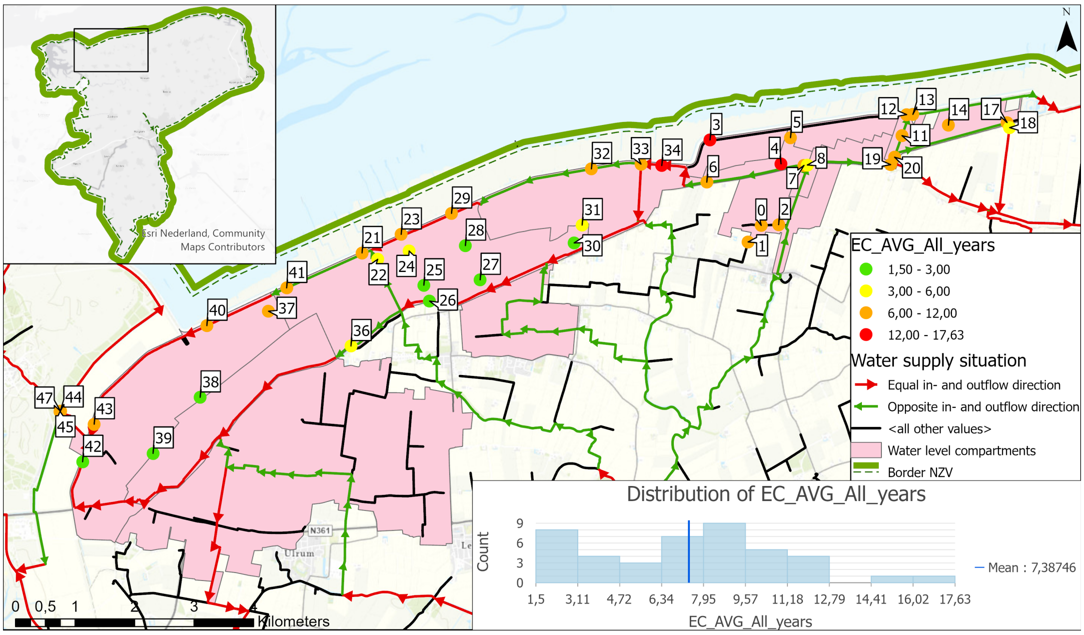
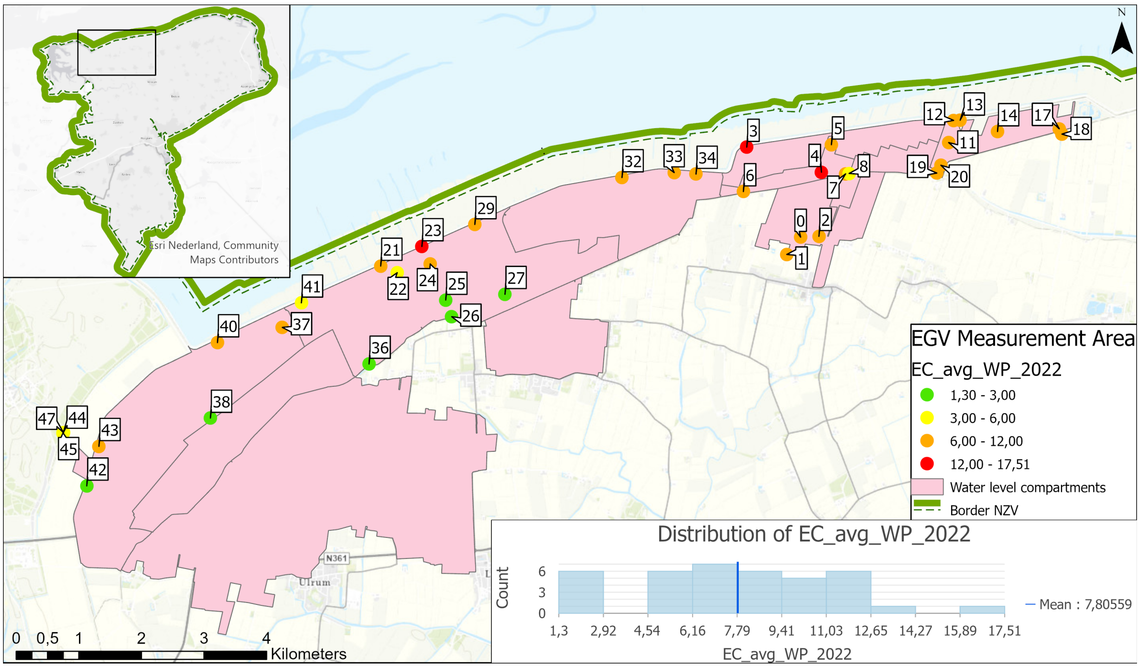
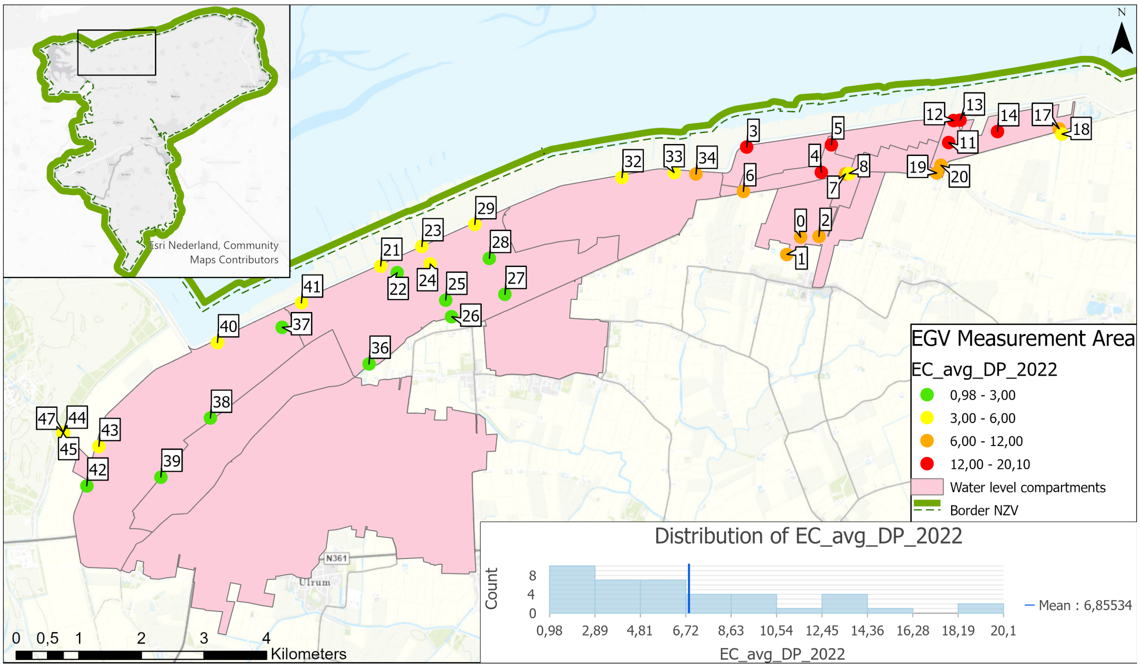


Figure 5.1: Map of the average EC Values of all Years measured, including the storage basin waterways and flow direction during water supply season(RC).

Figure 5.2, illustrates the spatial distribution of the average EC value during the wet period in Figure 5.2a and during the dry period in Figure 5.2b of **year 2022** conducted by the rat catchers.The difference of salt content across the locations and period could be investigated by observing the color variations, with green being the striving color.



(a) Map of the average EC values of the Wet Period in 2022(RC).



(b) Map of the average EC values of the Dry Period in 2022(RC).

Figure 5.2: Map of the average EC values in year 2022 conducted by the rat catchers(RC).

5.2.2 Mapping of the EC averages in the storage basin

Figure 5.3, illustrates the spatial distribution of average EC value obtained from the 21 measurement locations labeled by their MPNIDENT. Their average numerical EC values can be found in Table B.6 in Appendix B.4. Additionally, Figure 5.3 clearly show that the locations of the measurements are in the storage basin water ways. In Section 5.3, the impact of the pumping on the salt reduction in the storage basin could be investigated.

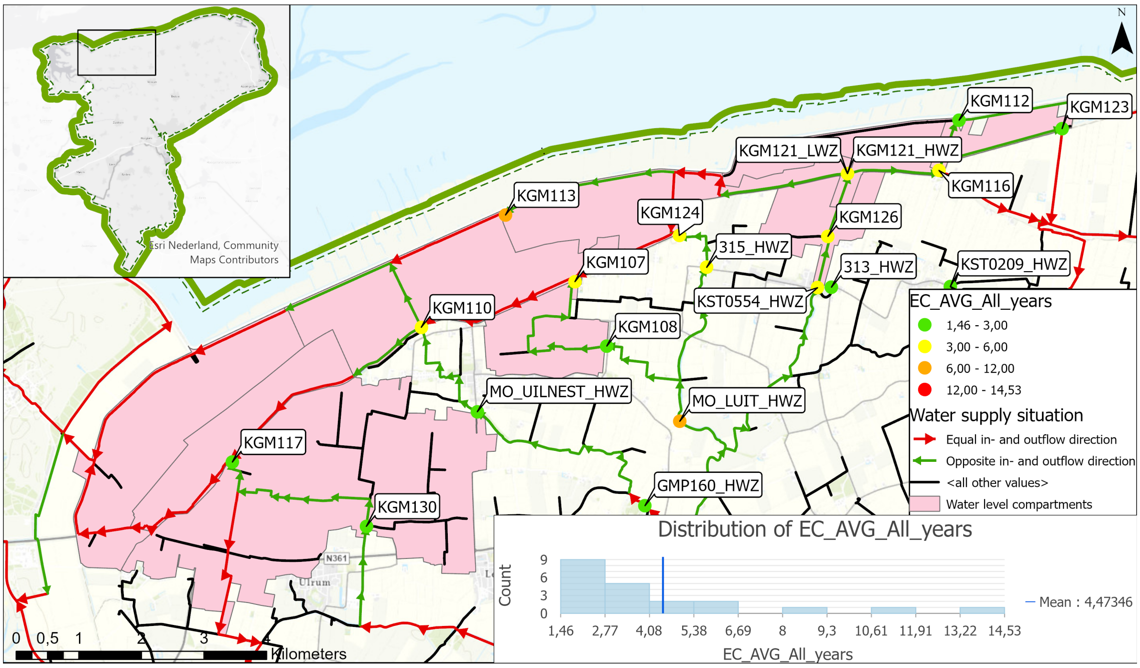
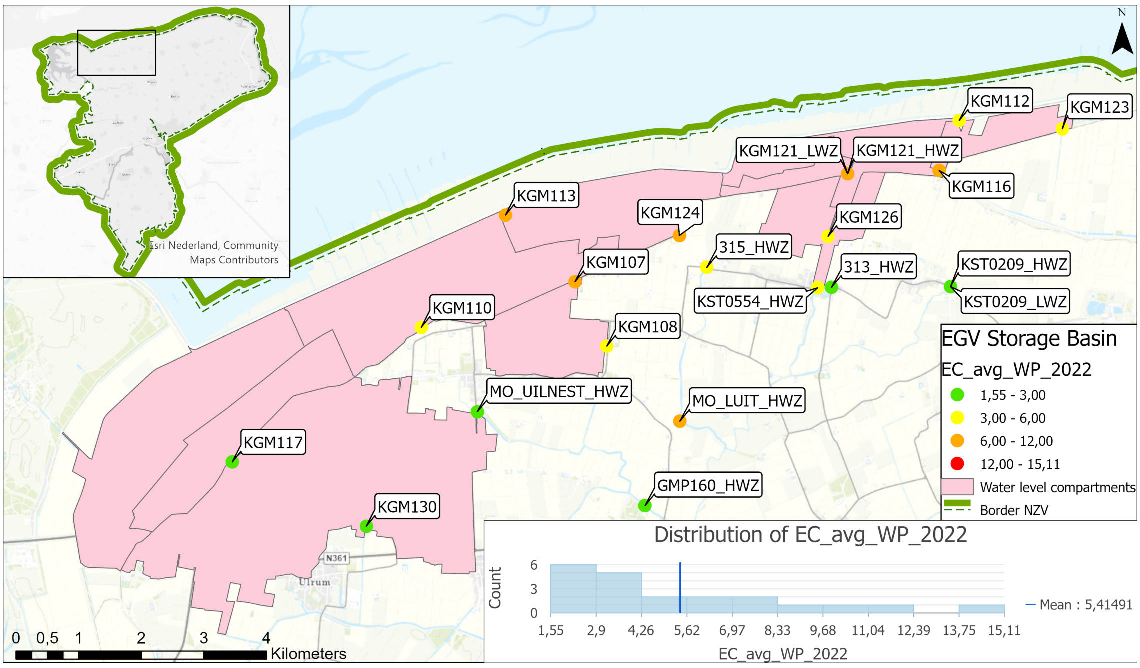
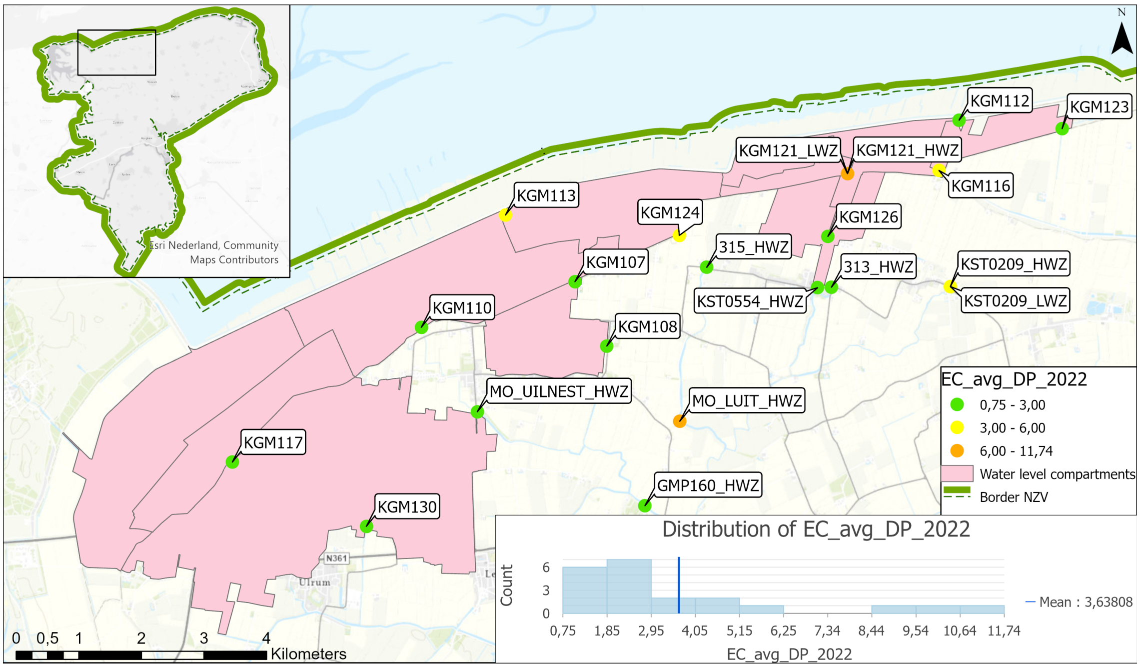


Figure 5.3: Map of the average EC Values of all Years measured, including the storage basin waterways and flow direction during water supply season(SB).

Figure 5.4, illustrates the spatial distribution of the average EC value during the wet period in Figure 5.4a and during the dry period in Figure 5.4b of **year 2022** conducted by Martin van der Maar.



(a) Map of the average EC values of the Wet Period in Year 2022(SB).



(b) Map of the average EC values of the Dry Period in Year 2022(SB).

Figure 5.4: Map of the average EC values in Year 2022 conducted by Martin van der Maar in the storage basin(SB).

5.3 Analysis and discussion of the Mapped EC Averages with the Water Balances of the Years 2021 and 2022

This section is dedicated to comprehensively analyze the potential relationship between pumping and the reduction of water salt content of the water. However, providing a one-to-one relationship is challenging, due to the complexity of the problem, as was explained in Subsection 3.2.3. The distribution of freshwater during flushing with their impact on the reduction in salt content is not uniform across the study area, as it depends on water flow rates and salt seepage, which vary spatially. Nonetheless, mapping the average electrical conductivity (EC) enables for investigation into areas with high salt fluxes and which areas contains significant salinization issues. Several factors align with our expectations, such as a decrease in salt content during intense rainfall. As an example, in May 2021, when there was high rainfall of 1,559 m^3/sec (see Table 4.1), the monthly average EC values at the measurement locations decreased, even with minimal pumping, as Q_inlet was 0,187 m^3/sec. In the Westpolder, the EC values decreased by an average of 50%, implying a significant reduction. These specific numerical average EC values conducted by the rat catchers and Martin van der Maar, can be found in the attached Excelfile titles 'ÉC-Values_Measurements'. During the summer months, characterized by high actual evapotranspiration and limited rainfall, the EC values noticeable increased when the pumps were operational. Therefore, the necessity of flushing the waterways is clearly highlighted. The following bullet-points present all insights from the salt mapping combined with the water balances, allowing for an analysis for the effect pumping to answer both the second and third sub-question of Research Question Two.

- The Figures of the mapped EC averages, indicate that the 'problem area' is located on the east side of the study area, around water level compartment Pieterburen, Zwarte-Pier, Slikken, Magazijn and Maurice. In fact, during dry period these waterways exhibit higher EC values compared to the wet period, as is shown by the transformation of orange/yellow points to more red/orange points on the maps. Pumping station Pieterburen is the sole station capable of introducing freshwater into the Linthorst Homanpolder. Additionally, rainfall-induced freshwater is quickly discharged from the study area, unlike for example the Negenboerenpolder, where freshwater flows inside and through the study area, resulting in dilution and counter pressure to salt seepage, thereby reducing EC content. The flow rate of the pumps at Pieterburen is often smaller than that of Wierhuizerklief/ Hornhuizerklief, despite the larger area to be flushed and the freshwater to be pumped step by step through different compartments, such as Zwarte-Pier, leading to a slower reduction in EC content. Furthermore, the pumps at Pieterburen cannot operate at maximum capacity due to the limitations of the waterways. If the pumps are operating at full capacity, the attracted freshwater would quickly flow back over the Pieterburen weir.

- The Westpolder and Negenboerenpolder have significantly lower EC values during the dry period compared to the winter period, as indicated by the transformation from red/orange points to more yellow/green points on the maps. However, the measurements in the Westpolder and around the Herculusstuw are not highly reliable, with an average of only one measurement per month. Nevertheless, during the dry period of 2022, seven measurements were conducted at each location, providing a more accurate reflection of the reality and demonstrating the positive effect of flushing. Particularly in 2022, most points in the Westpolder and Negenboerenpolder changed to green, indicating a positive outcome. These maps also reveal the difficulties in lowering the EC values in the waterways near the dike, which is as expected, due to higher salt seepage pressure in that area. As distance from the dike increases, the salt seepage pressure originating from the sea and subsoil layers decreases, which leads to relatively fresher soils [20]. Furthermore, the freshwater flowing towards the dike becomes mixed with saltier water within the study area, leading to higher EC values as the 'fresh water' reaches the dike compared to the salt content at the inlet pumps themselves.

- In general, the effect of pumping is much faster visible in locations that cover the storage basin and near hydraulic structures. In fact, the measurement locations of the rat catchers in canals, ditches, and water bodies are sometimes not or almost not even influenced by the pumping, as example FID 4 and 5 (MO_LHP2 and MO_LHP3) in Linthorst Homanpolder. This means that the freshwater that is flowing from the pumps does not reach those ditches, in which you can also look for the distribution of freshwater throughout the ditches. This expectation is also in line in the different result outcomes of Martin van der Maar in comparison with the rat catchers, because the mean EC value during dry period is more than 30% lower compared to the mean EC value during winter period for the maps with EC measurements in the storage basin, while the mean EC value decrease with only at least 12% for the maps with EC measurements conducted by the rat catchers. This is also visible in that relatively more points transformed to a more green / yellow color in the dry period for the locations of Martin van der Maar compared with the rat catchers.

- The combination of water balances with the average EC values reveals that during periods of high rainfall, the salt content in the waterways decreases. However, this depends on various factors, such as the timing and time-frame, since after long duration of tillage activities (spreading manure and fertilizer over the parcels) that can contribute to leaching causing an increase of the EC values, as was explained in Subsection 3.2.2. In general, intense rainfall leads to a decrease in EC values due to flushing of the waterways and increased water levels exerting greater pressure against salt seepage from the soil. For instance, in February 2022, with an average precipitation of 2,099 m^3/sec , most locations experienced a significant reduction in EC values. For example, FID 3 (MO_LHP1) decreased from an average of 32,03 EC in January to 6,09 EC in February or FID 23 (MO_NBP03) decreased from an average of 16,70 EC in January to 4,55 EC in February. Similarly, in June 2022, with a high precipitation of 1,258 m^3/sec, resulting in a significant decrease in EC values, despite lower total pumping flow rates, as Q_inlet in June 2022 was 0,351 m^3/sec, which is much lower than 0,517 m^3/sec in May 2022. This reduction sometimes ranged from 12 EC (May) to 6 EC (June) at FID 17 (kgm123_LWZ) and from 16 EC (May) to 9 EC (June) at FID 5 (MO_LHP3).

- When the pumps in Pieterburen are activated in March 2022, the chloride values decrease. However, they are still remain high, causing a red or orange color in the spatial distribution maps of Section 5.2, probably because of significant salt seepage in that area. The presence of a higher salt bubble/lens around Pieterburen is evident from the relatively higher salinity of the pumped water compared with the water quality near other pumping stations like Hornhuizen. In May 2022, despite the freshwater being pumped into the area, the EC values increasing significantly, possibly due to relatively low rainfall and high actual evapotranspiration. This outcome emphasizes the necessity of pumping, as much higher EC values would likely have been recorded in the absence of pumping.

- As discussed in Section 4.2, the water demand in 2022 was considerably higher than in 2021, logically implying an increased flushing requirement, which is calculated as the sum of Q_inlet + Precipitation - Q_outlet - ETa - other values (e.g. open surface evaporation, irrigation and change in net storage). The ETa was lower and P_avg higher during the dry period of 2021 compared to 2022, resulting in a dual effect of higher freshwater demand from the IJsselmeer. However, it cannot be guaranteed that the higher water demand is the reason of the increased need for flushing or water level management within the study area. Nevertheless, the average EC value calculations clearly indicate that during during the dry period of 2022, more locations exhibited lower EC values on the maps, visualized by more green and yellow points, compared to 2021. Regardless of less precipitation, the higher water demand in 2022 tends to suggest that more freshwater was used for the flushing requirement, resulting in a positive effect on lowering EC values in the waterways. This is further supported by the fact that Q_outlet during the dry period was higher in 2022 (0,515 m^3/sec) than in 2021 (0,431 m^3/sec), despite less rainfall, implying increased water flow from the pumping stations for flushing the waterways.
- The activation of the Wierhuizerklief pumping station has a significant effect on reducing the average EC values in the measurement locations of the Negenboerenpolder. The pumping stations introduces a substantial amount of freshwater into the area in 2022, resulting in often halved EC average values from May compared to April 2022 in the impacted measurement locations (e.g. FID 21, 22, 32, 33 - MO_NBP01, MO_NBP02, MO_NBP012 en MO_NBP013). For instance, FID 24 (MO_NBP04), where EC values sometimes exceeds 20 EC during winter months, decreases to below 2 EC in May 2021 and 2022, indicating a very positive outcome. This analysis highlights the positive and crucial impact of the Wierhuizerklief pumping station, suggesting that its activation is necessary to prevent salinization issues.
- The Hornhuizerklief pumping station has a remarkable high average flow rate of 0,165 m^3/sec in August 2022, resulting to a significant decrease in the average EC values of the connected measurement locations. For instance, FID 36 (KDU013093) reduces from 7,3 EC in July to 3,55 EC in August, and FID 42 (KDU005375) reduces from 3,95 EC in July to 1,15 EC in August. In September 2022, with an average flow rate of 0,031 m^3/sec through the pumps of the Hornhuizerklief pumping station, it is observed that all EC averages increases again, with some locations in the Westpolder doubling their values.
- The Herculusstuw is by far the largest drainage outlet in the study area, with over 60% of the discharged water flowing over it annually. The average EC values of the measurement locations around the Herculusstuw (FID 44, 45 and 47 - KST0285_LWZ, KST0169_HWZ and INL226_LWZ) decrease by more than half during the summer months compared to the winter months, with an average reduction in EC values recorded in 2022 compared with 2021. In July and August, there was twice as much precipitation in 2021 than 2022, and the Q_inlet (sum of flow rates at the pumps) was very low in August 2021 (0,031 m^3/sec) compared to August 2022 (0,446 m^3/sec). Despite the primary function of managing the water levels in August 2022, the average EC values were halved from 6,8 EC in July to 3,4 EC in August 2022, in contrast to 2021, where average EC values doubled from 4,6 EC in July to 10 EC in August.

- During the wet period of 2022, FID 37 (KDU031136) had an average EC value of 11,4 EC. However, the reliability of this outcome is questionable, since only one measurement was conducted on September 16. If the measurement had been performed in for example late February 2022, when there was substantial rainfall (2,099 m^3/sec), a much lower EC value would have been recorded due to the flushing of waterways. Furthermore, in 2020 and 2021, all measurements conducted in each month had EC values lower than 2,6 EC.

- Finally, the measurement locations in the 'Westpolder + Other' group, remarkable high average EC values were recorded in March compared to January, with e.g. FID 43 (KDU005386) being an outlier, increasing from 1,65 EC in January to 13,96 EC in March 2021. The remaining measurement locations in the groups 'Pieterburen', 'Linthorst Homanpolder', and 'Negenboerenpolder' either maintained similar or even lower EC values in March compared to January in 2021 and 2022. Unfortunately, no EC measurements were conducted in the 'Westpolder + Other' group from January to May 2022, making it impossible to compare with 2022.

Chapter 6

Recommendations for Potential Solution Directions

In this section, recommendations focus on providing potential solution directions based on research findings in Section 6.1 and based on more general solutions where further research will be required in Section 6.2. The freshwater construction circuit, which originated in the 1990s is in high need of new changes and innovations. As the freshwater demand rises, while the water supply from the IJsselmeer decreases, efficient utilization of freshwater is of high importance. Together with the increasing salinization, it is crucial to come up with solutions to manage this problem and ensure good water quality, particularly for irrigation purposes. The identified problems, their underlying causes, and potential solutions presented in this study are derived from expert consultations, including presentations, webinars, meetings, interviews, day trips, and discussions with colleagues unless different sources are added or specified. These sources of expert information are extensively described in Section 3.3.

6.1 Potential Solutions based on Research Findings

These qualitative proposed solutions are based on a literature review, expert consultations with various employees at Noorderzijlvest, and results & analysis from this report. The findings of this report were presented and discussed during weekly meetings as a source for identifying potential solutions unless there is an additional source added. These meetings serve as a platform for engaging with colleagues and seeking input based on the report's outcomes, as described in Section 3.3. Three potential solutions can be thought about after the performed analysis of the report and expert meetings & interviews:

1. Based on the analysis in Section 5.3, it is evident that the waterways near Pieterburen and the eastern side of the study area exhibit high EC values. Limited waterway capacity restricts the pumps in Pieterburen from operating at maximum capacity. For instance, during June 2021, the Pieterburen pumping station had an average flow rate of 0.171 m^3/sec, and the Pieterburen weir had an average flow rate of 0.067 m^3/sec, while the total average precipitation over the entire study area was only 0.73 m^3/sec. This indicates that a portion of the pumped freshwater from the pumping station directly returns over the weir due to the waterway limitations. in both May and July 2021, the total average precipitation over the entire study area exceeded 1.3 m^3/sec, while the weir in Pieterburen had an average flow rate of less than 0.01 m^3/sec and the pumps had a flow rate of less than 0.05 m^3/sec.
   Lowering water levels to increase pumping efficiency and create a less steep water surface flow gradient is not feasible due to significant salt seepage, resulting in elevated EC levels and making irrigation impossible. Additionally, sometimes the region has to deal with prolonged droughts, implying that taking too much risk is not affordable in reducing water levels, as Noorderzijlvest heavily relies on the limited supply from the IJsselmeer. Moreover, irrigation

is never actually prohibited, indicating the need for an adequate supply of low EC freshwater. A potential first solution could be to keep a close eye on minimizing the silt layer (through dredging) and ensuring minimal vegetation along the storage basin waterways originating from Pieterburen. The depth and width of the watercourse, along with the presence of sediment and vegetation, significantly impact water flow and quality, as all three suggestions are described by the Royal Dutch water network [26]. Minimizing vegetation along the banks increases the width of the waterways while reducing the silt layer enhances their depth, which has a relatively big impact on intermediate ditches between plots [26]. At the end of the dry season, the locks may become completely obstructed by vegetation, hindering water flow, emphasizing the importance of proper and well-timed maintenance of the ditches.

The responsibility for maintaining the storage basin waterways (in Dutch: 'Boezem watergangen') lies with the Water Authority Noorderzijlvest. Effective maintenance practices would facilitate faster and easier flushing of the waterways, reducing limitations and enhancing pumping station capacity, implying lower EC values. During the irrigation, water shortage, and sprinkling season, it is also recommended to clearly discuss this problem with the farmers. With good communication and close collaboration, the importance of well-maintained intermediate ditches (the responsibility of the farmers) can be emphasized, ensuring sufficient water supply, well-managed water levels, and improved water quality [27].

The resolution of the waterway limitations leads to faster flushing of the waterways between Pieterburen and the Zwarte Pier pumping station. The pumped water from Zwarte Pier will flow towards Slikken or Maurice water level compartments (dependent on the height of the Slikkenweir) through larger waterways, promoting more adequate flow. Finally, raising the weir at the Pieterburen could prevent water from flowing back over the weir during pumping, but further extensive research is needed to assess potential issues on other compartments, drainage systems, and the risk of flooding during heavy rainfall.

2. The analysis in Section 5.3 indicates that the waterways in the storage basin exhibit favorable EC values during the dry period compared to the winter period. This is in contrast with the intermediate ditches, implying that it is more challenging to efficiently flush those smaller intermediate ditches between plots. Therefore, an alternative solution to reduce water demand from the IJsselmeer and prevent salinization is to selectively flush waterways. The aim is to separate freshwater and saltwater to extend the residence time of the inflow of freshwater inside the system and reduce the time to mix it with salter water. This involves constructing new manual weirs in the intermediate ditches, strategically placed in areas where freshwater delivery is difficult.

   During summer, raising the manual weirs prevents water from flowing through the ditches into the main storage basin waterway system. This reduces the need for flushing as the salty water will stay behind the weirs in the intermediate ditches, resulting in higher EC values in those ditches but faster flushing in the main waterways, leading to lower EC values. This approach ensures that specific locations maintain higher EC levels, while less affecting the other areas [28]. Farmers will probably need longer irrigation pipes, as they can no longer extract water from each ditch and will need to access water from the main waterways.

   By using these manual weirs, less freshwater is required for flushing, maintaining good water quality, and reducing salt content. During periods of high rainfall, the heavier saltwater (higher density) is mostly retained behind the weirs, allowing fresher water to flow over the

weirs inside the storage basin waterways [29]. Although this temporarily increases EC values in the storage basin waterways, it is not a problem, since the need for irrigation significantly decreases after intense rainfall. When irrigation demand increases again, the waterways are likely flushed, ensuring good EC levels. In winter, the manual weirs can be lowered to promote the flushing of the intermediate waterways. Collaborating with farmers to discuss the advantages of these weirs, which are easy, accessible, and cost-effective to implement, is recommended. However, it is important to investigate the long-term impact of closing certain waterways on the water system, as it may have negative effects on ecological and hydrological processes within the intermediate ditches. Moreover, to determine the effectiveness of this potential solution, investigation into the spatial arrangement and dynamics of the freshwater system will be needed.
To conclude, minor interventions, such as these manual weirs or potentially also the construction of small culverts in other locations can alter the existing flushing pattern, to optimize freshwater utilization and improve water allocation and management.

3. As a third proposed solution based on the research findings, an effective approach would be pumping the relatively salt water from the waterways directly into the Wadden Sea over the dike. For instance, a pumping station could be implemented in the waterway before the dike between Magazijn and Wierhuizerklief, where high EC values have been observed according to the salt mapping charts. By pumping the salt water over the dike and occasionally clearing the waterway fairly empty to facilitate flushing, significant improvements could be achieved in reducing the salt content in the Negenboerenpolder and Westpolder. However, it is important to note that the dikes are well protected and there may be concerns raised by civil engineers and ecologists regarding this approach. Therefore, it is recommended to conduct a pilot study to test this potential solution for one year, focusing on pumping the salt water on both the west and east sides of the Magazijn water level compartment over the dike. The pilot study aims to assess the reduction in EC values and identify opportunities to optimize freshwater utilization by minimizing the need for flushing.

6.2 Potential Solutions without Evidence-based Support from the Report Findings

It is valuable to propose other 'general' solutions that require further research, which can contribute to the benefit of continuing the study. For these other solutions, research findings from Section 5.1 to 5.3 do not provide specific insights into effects or feasibility, as data was lacking for concluding. Therefore, to qualitatively address Research Question Three, suggestions for specific adapted or additional analyses based on literature review and expert consultations will encompass the following four potential solution directions:

1. Raising water levels inside the water level compartments (in Dutch: 'Opzetten van peil') could provide counter pressure against the salt seepage, which is a potentially effective solution, but difficult to quantify. However, if specific areas with high salt concentrations are identified, raising water levels in those ditches could be considered. This solution may reduce saltwater influx but could negatively impact agricultural productivity if drainage becomes flooded. Furthermore, when the water levels are already high in the ditches, it becomes more difficult to

flush the waterways with freshwater due to reduced pump capacity. For instance, in the early months of 2023, high water levels in the study area exerted significant counter pressure on pumping station pumps, resulting in a large reduction in the maximum capacity of the pumps. Consequently, it took nearly five weeks to achieve the desired EC level in the waterways, which was significantly longer than in previous years.

To assess the impact of raising water levels on EC reduction, a closer examination of specific water level compartments would be interesting. However, there is insufficient data on salt seepage at various locations. Conducting measurements in the silt at all waterways to identify areas of the highest salt seepage could solve this knowledge gap. With that knowledge, the relationship between salt seepage and different waterways could be quantified, and the potential effect of raising water levels estimated.

2. Adjusting the amount and height of drainage can be a straightforward measure to reduce saltwater intrusion. Deeper drainage systems or avoiding excessive drainage (or over-extraction of groundwater) can lower the water table and increase the freshwater lens. This creates a barrier against saltwater intrusion caused by the upward movement of saline groundwater due to a shallow water table. Figure 6.1, presents several factors affecting the freshwater lens of a parcel, such as a drainage distance, soil permeability, degree of seepage, and layering of the soil [30]. In Figure 6.1, the consequences of excessive drainage and the impact of altering drainage distance and height are visualized.

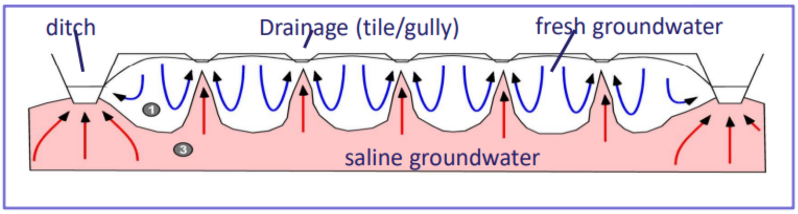
   

   Figure 6.1: Visualized impact of the drainage to the freshwater lens.

   The effectiveness of this solution depends on specific conditions, such as the geology, hydrology, willingness of farmers, and soil properties. It may impact hydrology, soil quality, and crop growth, so an assessment of the study area is necessary to determine appropriate drainage heights and amounts.

3. Considering the types of crops grown in the area, planting crops that are more tolerant to salinity near watercourses with high electrical conductivity (EC) values or difficult-to-flush areas, and sensitive crops near storage basin waterways with low EC values, could be a potential solution. Some plants adjust more efficiently, or are more efficient at excluding salt, giving them greater tolerance to salinity [31]. In the report of van Dam [2007], much info is given about the tolerance of each crop grown on salinization [32]. Due to a lack of time, this was not possible to investigate within the research, but by using the salt mapping charts and identification of crop types & amounts of crops grown, advice on suitable crop distribution could be provided to the farmers.

4. Finally, a potential solution entails optimizing irrigation practices through measures such as implementing drip irrigation, utilizing desalinated, recycled, rain-harvested water, adding

organic matter and manure to keep moisture, and preventing over-irrigation. However, the effectiveness and feasibility of these measures depend on the local conditions, knowledge, and resources of the stakeholders.

As discussed in Subsection 3.4, the absence of groundwater measurement data and the spatial variability of topsoil and subsoil compositions in the study area hindered the quantification of these potential solutions. However, if future data on groundwater levels becomes available and specific assessments of these potential solutions are conducted on a specific set of plots or water level compartments, it would be possible to determine their effectiveness through quantification. Furthermore, conducting comprehensive salt measurements in all intermediate ditches in the future would be highly beneficial in gaining an in-depth understanding of the spatial distribution of the salt seepage within the area, as well as determining the impact of pumping on salt content reduction in the waterways.

To summarize, it is important to take an integrated and adaptive approach to come up with potential solutions to effectively manage the salinization problem and to efficiently utilize the freshwater coming from the IJsselmeer.

Chapter 7

Discussion

The first section of this chapter is dedicated to the description of the both practical and theoretical significance of the research study, where the importance and relevance of the results are explained and evaluated [33]. The second section will discuss the limitations and implications of the study, where recommendations to do it differently next time will be given.

7.1 Importance of Results for Water Authority

The research objective was to analyze the effect of pumping on the salt content in the water to enable potential solution directions to decrease the flushing requirement and enhance the efficiency of the freshwater system.

This was done by developing as precise as possible water balances for the study area, focusing on defined time intervals: Years 2021 and 2022, annual, dry season, and per month. These water balances provided insights into the quantification of the key inlet and outlet fluxes, presented in clear Excel files with their corresponding calculations. This enables Noorderzijlvest to gain insight into, for instance, the water demand from different pumps, which was previously not quantified. With this information, accurate estimations can be made regarding the required volume of freshwater from the IJsselmeer.

Before this research, EC measurements were not systematically considered in projects or discussions with stakeholders, relying mainly on employees' measurements and experiences. By mapping all measurements, the waterways that carry a high salt load were determined, facilitating communication with stakeholders, such as clients and farmers. Although this study presents only a few spatial distributions to analyze the effect of pumping on EC reduction, such charts can now be easily generated for specific months or periods, which is crucial for the Water Authority Noorderzijlvest. The analysis of pumping effects is important, as it defines and quantifies 'problem areas', providing substantiation and validation for water level managers' experiences. The research findings suggested three possible solutions directions in Chapter 6 and four recommendations that require further investigation were offered. Data analysis, literature research, and interviews were conducted to gain a comprehensive understanding of the research outcomes and the impact of these recommendations.

Despite several limitations being identified, raising awareness among the Noorderzijlvest team about the critical evaluation of data from the FEWS WAM Portal and the importance of detecting possible inaccuracies is useful. Within the team Water Systems and Water Safety, this research made us more vigilant and cautious in handling data with precision, instead of blindly accepting it. Mistakes encountered in this research have been documented, and necessary modifications and improvements, such as rectifying flow directions in ArcGIS layer files, will be made by Noorderzijlvest. The next Section 7.2, describes the limitations and implications, which are challenging to quantify in terms of error margins, but provide valuable qualitative insights that warrant further investigation and highlight the importance of addressing specific anomalies during similar studies.

Finally, this research solely focused on the west side of the freshwater management plan of

Noorderzijlvest, covering eleven water level compartments. The relevance of this study is also that the research methodology and spatial distribution charts for EC measurements can be applied to other study areas or water level compartments, thereby simplifying potential future studies on 'salinization'.

7.2 Limitations and Implications

The broad scope of the study was a potential limitation in achieving a fully closed water balance, resulting in a more analytical rather than quantitative report. Although the study area was completely defined with all possible inlet and outlet locations, accurately quantifying 'other values' such as net storage, percolation, infiltration, and actual evapotranspiration was not ideal. Due to the broad scope, these 'other values' were not taken into account, implying a less accurate water balance, as explained in Subsection 3.4. A narrower scope, focusing on specific plots or a single water level compartment, would reduce the heterogeneity of soil compositions and drainage characteristics, making it easier and more accurate to determine these 'other value' parameters for the water balance.

Some major assumptions or choices for data sources influenced results, and are discussed point-wise:

- The assumptions made for the Elensterstuw and Egelneststuw do not have a big impact on the water balances, as their flow rates are only a small part (approximately 3%) of the total outflow. Therefore, using, for example, 25% or 30% of the relative drainage/discharge area of the pumping station and weir Klei does not significantly affect the results.
- The flow rate data in the FEWS WAM Portal of the pumping stations are calculated and not directly measured which introduces some uncertainty and may not fully align with the actual flow rates. The Q_inlet would be slightly lower in reality, since the pumps do not always operate at maximum capacity, resulting in a lower flow rate. The FEWS WAM Portal does not account for this variability as it calculated the flow rate based on the activation of the pumps, multiplying the pumping hours by the maximum capacity of each pump. Various units can be selected for the pumping stations, including activation hours [h], flow rate [m^3/sec], or volume [m^3]. These units are interconnected through intern calculations, rather than relying on separate direct measurements.
- The closest weather stations used for data collection are not located within the study area. Although the precipitation and reference crop evapotranspiration data from these stations have been validated the variations in rainfall amounts may exist due to their spatial mismatch. Similarly, the reference crop evaporation (ETc) data from Lauwersoog may differ slightly from what would have been measured in the east/south of the study area.
- The calculation of actual evaporation calculation (ETa) is associated with a large margin of error. The conversion from ETc to ETa has an error margin of approximately ± 11% [17], as described in Subsection 3.2.1. This error margin is bigger during specific periods, as ETa tends to be underestimated during wet periods and overestimated during dry periods. In the relatively wet year of 2021, the calculated ETa values are underestimated and would probably be a bit higher in reality. The underestimation during wet periods is due to increased soil moisture and vegetative activity, as the vegetation is relatively evergreen. In contrast, the

overestimation during dry periods is caused by soil drying out and reduced water availability for evaporation from the soil surface and transpiration from plants.

Additionally, the research did not consider the amount of irrigation, which is an important factor influencing ETa. If 100% irrigation is implemented, the potential evapotranspiration (ETp) is approximated ETa, since the water supply through irrigation ensures the maximum availability of water for evaporation of the plants and soil, allowing ETa to reach the maximum value of ETp. However, the study did not focus on irrigation and its impact on ETa, as irrigation will be more important if you want to thoroughly investigate a smaller study area, such as a water level compartment or a selection of plots. Martin van der Maar (water level manager) estimates that approximately 10% of the water demand from the pumps will be used for irrigation annually.

Furthermore, evaporation from open water surfaces was not considered in the water balance calculations, reducing the accuracy of the estimates.

In conclusion, the under- and overestimation of ETa are associated with significant uncertainty, making it challenging to quantify a specific error margin, but this discussion indicates a high margin of error qualitatively. To obtain more accurate values of ETa, it is advisable to consider various other factors such as solar radiation, air temperature, wind speed, humidity, vegetation characteristics, and water availability, and incorporate them into the ETa calculation. However, for the purposes of this research, a rough estimation of ETa was sufficient to address the research questions and analyze the effect of pumping on EC reduction.

- The assessment of the accuracy of past EC measurements involves considering multiple factors that cannot be quantified. Uncertainties and the risk of incorrect measurements are qualitatively analyzed to evaluate accuracy. This discussion addresses the fourth sub-question of Research Question Two.

  It is assumed that the EC measurements are taken at the surface layer of the water, which may introduce potential errors in average EC calculations. To improve accuracy, knowledge of water depth and measurement depth is essential. For instance, extensive measurements were conducted in the IJsselmeer to get insight into the variations of EC values at different depths in the water. The depth at which the EC levels are measured significantly influences the results, as evidenced by higher EC values (30EC) at a depth of 9m compared to the surface (3EC), implying high variations[20].

  Therefore, if the intermediate ditches were nearly empty while EC measurements were still conducted, significantly higher EC values will be recorded compared to measurements in ditches with higher water levels, resulting in an inaccurate comparison. Water depths of the waterways were not recorded during EC measurements, indicating probably errors when comparing EC values in the ditches. The primary objective of improving water quality in the waterways by reducing EC levels remains the same regardless of measurement depth. However, EC values would be significantly higher if measured in the silt layer or at the bottom of the water channels. Consequently, may perceive the waterway to be of good quality, while in reality, it is saltier than expected and measured. The flow speed inside the waterways plays also a crucial role. In storage basin waterways, the variation in EC levels with depth is significantly less compared to more stagnant water in intermediate ditches. The flow speed varies also vertically within the waterway, whereby it is anticipated that with an increase in water levels or flow speed, relatively bigger differences in EC measurements will be observed between the upper and lower sections of the waterway. Therefore, for further investigation into the quantification of the salt flux accurately in the waterway, it is crucial to determine what is representative of the flowing water.

- The period of dredging is also important to know. For instance, Noordpolderkanaal was dredged at the beginning of the water supply season when the pumps are activated, causing issues with salt leaching from the silt. The high salt content in the soil resulted in much crop damage for the farmers, leading to high compensation paid by Noorderzijlvest. Therefore, it is preferable to dredge waterways with relatively high salt loads towards the end of the dry period or freshwater supply season to prevent salt leaching into fertile soil and the main freshwater system, which makes it more challenging to flush the waterways and maintain good water quality. In winter, rainfall has the potential to leach a significant portion of salt from the fertile soil of farmland, thereby restoring its workability for the following season. Additionally, conducting dredging activities prior to the dry period is often quite complicated and not possible, because flora and fauna (plants and animals) cannot be adversely affected (no damage) by the dredging work [34]. These dredging periods were not considered in this research, due to the lack of data and research simplification. In reality, sporadic instances of high reported EC values in the waterways could be attributed to dredging activities.

- Finally, all units in this research were presented in m^3/sec, but a more conventional unit would have been cubic meters [m^3]. During the final presentation about the research at the Water Authority Noorderzijlvest, a colleague explained how to convert the unit from m^3/sec to m^3 in FEWS WAM Portal, requiring a few more steps. Using m^3, data near a pumping station would display information about positive volume (flow rate from all the pumps), negative volume (flow rate at the weir), and net volume (sum of positive and negative volume). In this research, the precipitation and evaporation unit of [mm] was converted to [m^3/sec] using Equation 3.2. While the choice of the unit does not fundamentally impact the findings, expressing values in volumes makes it easier for the client to understand and compare values. Therefore, in hindsight, using the conventional unit of cubic meters would have been preferable. Moreover, the water demand from IJsselmeer becomes directly transparent, making the need for manual calculations unnecessary, as was done for the dry period analysis in Section 4.2. For further research, calculating a flushing requirement would be more straightforward as well.

Chapter 8

Conclusions

The research titled 'Enhancing Efficiency in Noorderzijlvest's Freshwater System: Analyzing Freshwater Utilization' aligns precisely with the essence of the research objective. The Water Authority Noorderzijlvest initiated this study to address their unresolved queries, resulting in three research questions and associated sub-questions. Throughout this report, these research questions have been composed and answered. In this chapter, the key findings and advancements made in this study are highlighted.

The management area of Noorderzijlvest is facing increasing salinization in its freshwater system which is accompanied by a rising freshwater demand, while the supply from the IJsselmeer cannot be guaranteed. Therefore, the goal of this research was to identify potential solutions to reduce flushing requirements, enhance freshwater system efficiency, and ensure sustainable utilization of freshwater resources while addressing salinization challenges.

1- What is the water balance for the group water level compartments located on the western side of Noordpolder, and what level of precision is achieved in the estimation?

A quantitative investigation was conducted to determine the water balances for the years 2021 and 2022, including annual, per-month, and dry periods. The focus was on quantifying the flow rates of weirs and pumping stations at the border of the study area to assess the water demand per pumping station and identify relative differences in flow rates.

The results revealed a significant increase of 46% in water demand during the dry period in 2022 compared to 2021, accompanied by a 31% decrease in precipitation. Based on the water balance analysis, it was concluded that the pumping stations exhibited sustained high flow rates at the end of the dry period in 2022 compared to 2021. Over longer time frames, the influence of water storage diminishes as it tends to balance out over time, evident by the close-to-zero values of Sum_Influxes – Sum_Outfluxes in both 2021 and 2022, indicating a relatively accurate estimation of the water balance. Despite higher actual evapotranspiration and lower precipitation in 2021 compared to 2022, the flushing requirement remained significantly higher in 2021 due to increased water inflow and outflow from the study area. Finally, the Herculusstuw is by far the largest drainage outlet in the study area, with over 60% of the discharged water flowing over it annually.

While the level of precision is difficult to quantify, it is important to acknowledge the high associated error margins and limitations when conducting further in-depth studies in specific time-frames or water level compartments, such as the under- and overestimation of ETa.

2- Is it feasible to map the waterways and sources that carry a high salt load and can the water demand be determined for the western side of the freshwater system to maintain a good water quality for preventing salinization?

The average electrical conductivity (EC) values were calculated in the same time periods as the water balances of all measurements conducted in and around the study area, which were used to create spatial distribution maps indicating the variability in EC levels. Ten maps of the spatial distribution of the variability in average EC values of all years, wet periods, and dry periods in the

years 2021 and 2022 are created.
Qualitative analysis revealed elevated EC levels in the waterways around and in the northern region of Pieterburen, because of higher salt seepage, increased difficulty in flushing the waterways, and higher EC levels in the incoming freshwater at the Pieterburen pumping station compared to pumping stations located further west side in the study area. It was observed that the Westpolder and Negenboerenpolder have significantly lower EC values during the dry period compared to the winter period. Additionally, it was observed that an increase in precipitation or water level, depending on the time frame, resulted in significant reductions in EC levels.
Determining the precisely needed flushing requirement or water demand to maintain good water quality and prevent salinization is challenging due to factors such as non-uniform water flow and difficulties in the complexities associated with quantifying salt seepage.

3- What are the potential solutions in reducing the freshwater requirement in the study area between Lauwersoog and Noordpolderzijl to effectively manage the increasing salinization?
Based on the research findings, three recommendations for potential solution directions have been formulated and explained in the following three paragraphs. Furthermore, general solutions without a research-based approach and areas requiring further research are outlined. The identified problems, their underlying causes, and potential solutions presented in this research are primarily derived from expert consultations.

To solve the problem of the limited waterway capacity near Pieterburen, it is crucial to ensure well-dredged ditches with minimal vegetation along the waterways, in which the timing of dredging is important to facilitate salt leaching from the silt.
Another potential cost-effective and quickly implementable solution would be to selectively flush waterways through the construction of manual weirs, strategically placed in areas where freshwater delivery is difficult. The aim is to separate freshwater and saltwater to extend the residence time of the inflow of freshwater inside the system. These manual weirs reduce the need for extensive flushing, maintaining good water quality for irrigation.
Pumping saltwater from the waterways directly into the Wadden Sea over the dike to prevent the inflow of highly saline water into the freshwater management system is another viable and efficient solution. It is suggested to first conduct a pilot study to assess the effectiveness of these solutions and gain support from stakeholders.

To conclude, this research contributes to enhancing efficiency in Noorderzijlvest's freshwater management system by providing new insights into freshwater utilization, salinization challenges, and potential solution directions.

Chapter 9

Suggestions for Further Research

This chapter presents suggestions for further research aimed at highlighting areas that require additional investigation to enhance knowledge and understanding, which contextualized the conclusions described in Chapter 8. This chapter tends to be more informal, subjective, and open-ended.

The salinization problem is projected to increase in the future due to climate change (higher sea levels and meteorological fluctuations) and subsidence of land [3]. Especially, areas affected by gas extraction will increase the necessity for improvements in the freshwater management plan. To address this, a recommendation for further research is to utilize water system models. For instance, D-HYDRO Suite 2D3D or SOBEK are integrated modeling suites for integral water solutions made by Deltares (technical institute in the Netherlands) [35] [36]. Employing these kinds of programs can enhance understanding and transparency regarding the salinization problem, including various limitations as discussed in Section 7.2. This powerful modeling suite could be utilized for predicting floods, optimizing drainage systems, controlling irrigation systems, studying river morphology, analyzing salt intrusion, and evaluating surface water quality [35].

To gain a comprehensive understanding of the salt loads in waterways, additional EC measurements should be conducted in the management area. It would be beneficial to measure also EC in the silt layer to assess the extent of salt seepage, or to measure EC at different depths to investigate the variations in EC content of the cross-section of a waterway. These measurements should be at least performed before the dry season, and for example, during the middle of the dry season, and shortly after dredging. By analyzing the temporal EC variations and comparing the EC levels, insights can be gained into the impact of dredging on EC levels over time and the amount of salt seepage within the silt layer.

For instance, studying the salinity progression from Pieterburen towards the dike and mapping the waterway profile can provide insights into the increasing salt seepage and the format of the salt bubble/lens. In such a smaller study area, the heterogeneity of topsoil and subsoil compositions is reduced, implying ’other values’ of water balances, such as percolation, net storage, and infiltration, can be investigated more accurately. Furthermore, calculating open surface evaporation and estimating the total freshwater required for irrigation is interesting for determining their respective contributions to the overall water balances.

Another crucial suggestion for future research is the understanding of salt tolerance of different crops and nature target types, as it determines whether and when increasing salinization becomes a significant problem [3]. In the future, the possibility of (genetically modifying) certain types of potatoes to grow in salinized soil could be explored. This direction of looking at the salt tolerance of crops is necessary as it is not feasible to constantly prevent salinization; instead, we must find and explore ways to coexist with it.

Chapter 6 provided various suggestions for further research, focusing on potential solutions for improving the freshwater management system. It is important to evaluate the effectiveness of each proposed potential solution and estimate the potential impact of their implementation, where also the utilization of D_HYDRO or SOBEK will be recommended. Further research could also narrow down the investigation to specific 'problem areas', such as around Pieterburen.

By addressing these research gaps, future studies can contribute to a better understanding of how to live with the increasing salinization problem and make efficient use of the freshwater.

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Appendix A

Water balance results

A.1 The meteorological data analysis

The meteorological data analysis for the study area in the years 2021 and 2022 are presented in Table A.1 and Table A.2 respectively. The ”P_avg’ rows indicate the average precipitation measured at the three weather stations of Zoutkamp, Eenrum and Warffum, while the ETc values are recorded in the Lauwersoog weather station. The actual evapotranspiration (ETa) is calculated by multiplying the ETc values by 0.88 as explained in paragraph 3.2.1. All recorded precipitation and evapotranspiration data, along with their corresponding monthly average calculations, are documented in the attached Excel file titled ’Waterbalance’ on the ’P_ET_WAM’ sheet.

Table A.1: Comprehensive analysis of meteorological data for the study area in 2021.

2021	**P_avg [mm]**	**ETc [mm]**	**# Days**	**P_avg [m3/sec]**	**ETc [m3/sec]**	**Eta [m3/sec]**
Jan.	87,5	8,0	31	1,201	0,110	0,097
Feb.	37,3	16,9	28	0,567	0,257	0,226
Mar.	60,5	34,9	31	0,830	0,479	0,421
Apr.	35,1	68,2	30	0,497	0,967	0,851
May	116,9	71,8	31	1,604	0,985	0,867
June	53,0	110,9	30	0,751	1,572	1,384
July	98,9	101,0	31	1,358	1,386	1,220
Aug.	115,3	81,5	31	1,583	1,118	0,984
Sept.	49,2	55,2	30	0,698	0,783	0,689
Oct.	98,3	29,7	31	1,349	0,407	0,359
Nov.	68,4	11,9	30	0,970	0,169	0,149
Dec.	74,4	6,2	31	1,021	0,085	0,075
Annual	894,9	596,2	365	1,043	0,695	0,611
Dry_period	419,2	433,4	153	1,166	1,205	1,060

Table A.2: Comprehensive analysis of meteorological data for the study area in 2022.

2022	P_avg [mm]	ETc [mm]	# Days	P_avg [m3/sec]	ETc [m3/sec]	Eta [m3/sec]
Jan.	71,6	8,5	31	0,983	0,117	0,103
Feb.	142,1	16,3	28	2,159	0,248	0,218
Mar.	5,0	51,3	31	0,069	0,704	0,619
Apr.	58,1	67,6	30	0,824	0,958	0,843
May	54,1	95,2	31	0,743	1,306	1,150
June	91,3	106,9	30	1,294	1,516	1,334
July	45,6	107,0	31	0,625	1,468	1,292
Aug.	42,2	108,2	31	0,579	1,485	1,306
Sept.	126,2	65,1	30	1,789	0,923	0,812
Oct.	70,0	36,0	31	0,960	0,494	0,435
Nov.	84,6	13,1	30	1,200	0,186	0,163
Dec.	66,8	6,8	31	0,917	0,093	0,082
Annual	857,6	682,0	365	1,000	0,795	0,699
Dry_period	291,3	484,9	153	0,810	1,348	1,186

A.2 The Q_inlet and Q_outlet data analysis of 2021

Table A.3: Comprehensive average flow rate analysis of the fixed single discharged outlet locations of the study area in 2021 $[m^3/sec]$.

Location	Maurice-I	Maurice-II	Kleine Herculesstuw 2	Grote herculesstuw	Elensterstuw
Identity	**KGM115**	**KGM116**	**KST0285**	**KST0169**	**KST0244**
Jan.	0,154	-0,062	0	0,462	0,018
Feb.	0,066	-0,058	0	0,307	0,008
Mar.	0,165	-0,037	0	0,28	0,005
Apr.	0,167	-0,022	0	0,222	0,000
May	0,083	-0,007	0	0,314	0,035
June	0,082	-0,004	0	0,335	0,006
July	0,096	-0,001	0	0,209	0,000
Aug.	0,039	-0,002	0	0,181	0,021
Sept.	0,005	-0,003	0	0,051	0,027
Oct.	0,041	-0,008	0	0,338	0,008
Nov.	0,039	-0,006	0	0,397	0,003
Dec.	0,082	-0,02	0	0,601	0,006
Annual	0,084	-0,019	0	0,309	0,011
Dry_period	0,091	-0,007	0	0,252	0,013

Table A.4: Comprehensive average flow rate analysis of the weirs at the pumping stations outlet locations of the study area in 2021 $[m^3/sec]$.

Location	Klei	Pieterburen	Kluten	Wierhuizerklief	Egelnest	Bokumerklief	Hornhuizerklief
Identity	**KGM130**	**KGM119**	**KGM112**	**KGM124**	**KGM107**	**KGM108**	**KGM110**
Jan.	0,071	0,115	0	0,096	0,018	0,001	0,008
Feb.	0,03	0,106	0	0,065	0,008	0,004	0,002
Mar.	0,018	0,037	0,006	0,032	0,003	0,005	0,001
Apr.	0,001	0	0,007	0	0	0	0
May	0,139	0,009	0,015	0	0	0	0,002
June	0,022	0,067	0,005	0	0	0	0
July	0	0,002	0,003	0	0	0	0,056
Aug.	0,085	0,022	0,002	0,03	0,011	0	0,001
Sept.	0,108	0,035	0	0,001	0,027	0	0
Oct.	0,032	0,067	0	0,014	0,008	0,021	0,014
Nov.	0,011	0,03	0	0,021	0,003	0,003	0,012
Dec.	0,024	0,085	0	0,048	0,006	0,001	0,024
Annual	0,045	0,048	0,003	0,026	0,007	0,003	0,005
Dry_period	0,05	0,02	0,006	0,006	0,001	0	0

Table A.5: Comprehensive average flow rate analysis of the pumping stations inlet locations of the study area in 2021 $[m^3/sec]$.

Location	Klei	Pieterburen	Kluten	Wierhuizerklief	Egelnest	Bokumerklief	Hornhuizerklief
Identity	**KGM130**	**KGM119**	**KGM112**	**KGM124**	**KGM107**	**KGM108**	**KGM110**
Jan.	0	0	0,012	0	0	0	0
Feb.	0	0	0,008	0	0	0	0
Mar.	0	0,061	0,003	0,03	0	0,003	0,071
Apr.	0,034	0,121	0	0,087	0,005	0,014	0,1
May	0,001	0,05	0	0,079	0,001	0,014	0,042
June	0,062	0,171	0	0,149	0,024	0,015	0,157
July	0,09	0,037	0	0,059	0,038	0,009	0,11
Aug.	0	0	0,004	0,023	0	0	0,004
Sept.	0	0	0,004	0	0	0	0
Oct.	0	0	0,001	0	0	0	0
Nov.	0	0	0,002	0	0	0	0
Dec.	0	0	0,006	0	0	0	0
Annual	0,009	0,036	0,003	0,036	0,006	0,005	0,04
Dry_period	0,02	0,075	0,001	0,079	0,013	0,01	0,082

A.3 The Q_inlet and Q_outlet data analysis of 2022

Table A.6: Comprehensive average flow rate analysis of the fixed single discharged outlet locations of the study area in 2022 [m^3/sec].

Location	**Maurice-I**	**Maurice-II**	**Kleine Herculesstuw 2**	**Grote herculesstuw**	**Elensterstuw**
Identity	**KGM115**	**KGM116**	**KST0285**	**KST0169**	**KST0244**
Jan.	0,1	-0,028	0	0,516	0,006
Feb.	0,188	-0,039	0	0,626	0,014
Mar.	0,202	-0,002	0	0,292	0,000
Apr.	0,214	0	0	0,44	0,001
May	0,109	0	0,034	0,371	0,007
June	0,053	0,001	0,049	0,34	0,017
July	0,064	0	0,052	0,207	0,028
Aug.	0,021	0,001	0,052	0,283	0,021
Sept.	0,024	-0,014	0,049	0,173	0,021
Oct.	0,045	-0,055	0,058	0,15	0,009
Nov.	0,092	-0,053	0,014	0,384	0,005
Dec.	0,11	-0,056	0	0,445	0,008
Annual	0,088	-0,02	0,026	0,353	0,011
Dry_period	0,09	0,001	0,039	0,302	0,015

Table A.7: Comprehensive average flow rate analysis of the weirs at the pumping stations outlet locations of the study area in 2022 [m^3/sec].

Location	**Klei**	**Pieterburen**	**Kluten**	**Wierhuizerklief**	**Egelnest**	**Bokumerklief**	**Hornhuizerklief**
Identity	**KGM130**	**KGM119**	**KGM112**	**KGM124**	**KGM107**	**KGM108**	**KGM110**
Jan.	0,023	0,083	0	0,072	0,006	0,002	0,02
Feb.	0,054	0,185	0	0,1	0,014	0,009	0,073
Mar.	0,001	0,012	0	0,003	0	0	0,044
Apr.	0,003	0	0,001	0,001	0	0	0,078
May	0,026	0	0,002	0,002	0	0	0,109
June	0,067	0,007	0,001	0,008	0	0	0,047
July	0,111	0	0,001	0,007	0	0	0,056
Aug.	0,085	0	0	0,013	0,011	0	0,165
Sept.	0,083	0,011	0	0,001	0,021	0	0,031
Oct.	0,034	0,026	0	0,006	0,009	0	0,02
Nov.	0,021	0,056	0	0,007	0,005	0,01	0,008
Dec.	0,03	0,06	0	0,009	0,008	0,012	0,06
Annual	0,045	0,036	0	0,019	0,006	0,003	0,009
Dry_period	0,059	0,001	0,001	0,006	0,001	0	0

Table A.8: Comprehensive average flow rate analysis of the pumping stations inlet locations of the study area in 2022 $[m^3/sec]$.

Location	Klei	Pieterburen	Kluten	Wierhuizerklief	Egelnest	Bokumerklief	Hornhuizerklief
Identity	**KGM130**	**KGM119**	**KGM112**	**KGM124**	**KGM107**	**KGM108**	**KGM110**
Jan.	0	0	0,007	0	0	0	0
Feb.	0	0	0,009	0	0	0	0
Mar.	0	0,102	0,002	0,042	0	0,007	0,044
Apr.	0	0,121	0,001	0,065	0,035	0,015	0,078
May	0,001	0,127	0	0,177	0,093	0,01	0,109
June	0,001	0,043	0,001	0,178	0,075	0,006	0,047
July	0,13	0,087	0	0,117	0,059	0,006	0,056
Aug.	0,068	0,034	0	0,141	0,028	0,01	0,165
Sept.	0,012	0,018	0	0,046	0	0,002	0,031
Oct.	0	0	0,006	0	0	0	0
Nov.	0	0	0,007	0	0	0	0
Dec.	0	0	0,007	0	0	0	0
Annual	0,018	0,045	0,003	0,064	0,024	0,005	0,045
Dry_period	0,041	0,082	0,001	0,136	0,058	0,009	0,081

A.4 Example of Pieterburen meteorological data of June 2022

Table A.9: Meteorological data for Pieterburen of the month June 2022 [mm].

Date	ET	P_Zoutkamp	P_Eenrum	P_Warffum
6-6-2022 01:00	2,5	13	15	20,8
7-6-2022 01:00	1	14	12	16,6
8-6-2022 01:00	1,4	0	0	0
9-6-2022 01:00	1,8	23,8	14,9	11
10-6-2022 01:00	4,4	0	0	0
11-6-2022 01:00	2,1	0	0,1	0,4
12-6-2022 01:00	5	0	0	0
13-6-2022 01:00	4,7	4,3	2,6	4,6
14-6-2022 01:00	4,4	0	0	0
15-6-2022 01:00	2,8	0	0	0
16-6-2022 01:00	5	0	0	0
17-6-2022 01:00	5	0	0	0
18-6-2022 01:00	3,1	0	0	0
19-6-2022 01:00	4,1	5,9	4,5	4,9
20-6-2022 01:00	2,4	0	0	0
21-6-2022 01:00	4,4	0	0	0
22-6-2022 01:00	4,6	0	0	0
23-6-2022 01:00	5,1	0	0	0
24-6-2022 01:00	5,5	2,4	3,1	7,4
25-6-2022 01:00	1,9	13,4	16,5	16,4
26-6-2022 01:00	3,1	1,5	6,2	2,4
27-6-2022 01:00	2,5	0,5	0,4	0,7
28-6-2022 01:00	1,3	2,7	1,9	12,5

Appendix B

Average EC Values Network Results

In this Appendix, the calculation of the average EC values from the EC-measurement network conducted by the rat catchers and Martin van der Maar will be displayed along with an example of the three measurement locations in Pieterburen.

B.1 EC-measurement network conducted by the rat catchers

In Table B.1, all 49 measurement locations for the average EC-values determination are shown conducted by the rat catchers, with its corresponding FID, name, x/y coordinates and unique code. Important to note is, that the rows with FID 9, 10, 15, 16, 35, 48 are colored with an orange background, since for these locations there are no average EC-values calculated, because of insufficient and a lack of adequate data.

Table B.1: EC-measurement network conducted by the rat catchers, with orange background indicating unavailable EC-values due to insufficient and a lack of adequate data.

FID	MPNIDENT/CODE	MPNOMSCH	POINT_X	POINT_Y
0	**MO_PTBRN04**	EGV Pieterbuurstermaar Pieterburen 04	225877,02	602838,56
1	**MO_PTBRN05**	EGV Broekstermaar Pieterburen 05	225654,77	602561,93
2	**MO_PTBRN07**	EGV Pieterbuurstermaar Pieterburen 07	226168,9	602852,72
3	**MO_LHP1**	Zout 01 Linthorst Homanpolder	225015,912	604274,328
4	**MO_LHP2**	Zout 02 Linthorst Homanpolder	226209,714	603874,277
5	**MO_LHP3**	Zout 03 Linthorst Homanpolder	226368,465	604312,428
6	**MO_LHP4**	Zout 04 Linthorst Homanpolder	224961,937	603565,508
7	**KGM121_HWZ**	Zout 05 Linthorst Homanpolder	226596,536	603849,142
8	**KGM121_LWZ**	Zout 06 Linthorst Homanpolder	226650,511	603854,433
9	**MO_LHP7**	Zout 07 Linthorst Homanpolder	227347,954	604451,758
10	**MO_LHP8**	Zout 08 Linthorst Homanpolder	228010,472	604623,208
11	**MO_LHP9**	Zout 09 Linthorst Homanpolder	228241,189	604348,041
12	**KGM112_LWZ**	Zout 10 Linthorst Homanpolder	228321,623	604701,525
13	**KGM112_HWZ**	Zout 11 Linthorst Homanpolder	228425,34	604703,642
14	**MO_LHP12**	Zout 12 Linthorst Homanpolder	229022,241	604523,725
15	**MO_LHP13**	Zout 13 Linthorst Homanpolder	228999,804	604176,591
16	**MO_LHP14**	Zout 14 Linthorst Homanpolder	230220,326	604812,993
17	**KGM123_LWZ**	Zout 15 Linthorst Homanpolder	230009,245	604566,733
18	**KGM123_HWZ**	Zout 14 Linthorst Homanpolder	230051,461	604482,3
19	**KGM116_LWZ**	Zout 23 Linthorst Homanpolder	228052,527	603860,785
20	**MO_LHP24**	Zout 24 Linthorst Homanpolder	228116,484	603985,668
21	**MO_NBP01**	Negenboerenpolder 01	219167,2	602376,9
22	**MO_NBP02**	Negenboerenpolder 02	219431,78	602271,06
23	**MO_NBP03**	Negenboerenpolder 03	219825,37	602688,57
24	**MO_NBP04**	Negenboerenpolder 04	219958,31	602410,76
25	**MO_NBP05**	Negenboerenpolder 05	220205,96	601833,97
26	**MO_NBP06**	Negenboerenpolder 06	220301,21	601569,39
27	**MO_NBP07**	Negenboerenpolder 07	221153,17	601926,57
28	**MO_NBP08**	Negenboerenpolder 08	220904,46	602500,72
29	**MO_NBP09**	Negenboerenpolder 09	220671,62	603040,47
30	**MO_NBP010**	Negenboerenpolder 10	222731,67	602545,7
31	**MO_NBP011**	Negenboerenpolder 11	222866,61	602845,03
32	**MO_NBP012**	Negenboerenpolder 12	223022,72	603789,24
33	**MO_NBP013**	Negenboerenpolder 13	223856,15	603868,62
34	**MO_NBP014**	Negenboerenpolder 14	224205,41	603844,81
35	**MO_NBP015**	Negenboerenpolder 15	224009,61	603122,49
36	**KDU013093**	MO_WESTPOLDER_01	218980,86	600813,82
37	**KDU031136**	MO_WESTPOLDER 02	217595,2224	601398,7194
38	**KDU031171**	MO_WESTPOLDER_03	216446,72	599951,22
39	**KST009149**	MO_WESTPOLDER_04	215654,88	599009,47
40	**KDU031091**	MO_WESTPOLDER_05	216559,19	601155,67
41	**KDU000409**	MO_WESTPOLDER_06	217900,19	601789,59
42	**KDU005375**	MO_WESTPOLDER_07	214471,12	598869,2
43	**KDU005386**	MO_WESTPOLDER_08	214665,58	599500,58
44	**KST0285_LWZ**	Kleine Herculesstuw 2	214091,95	599707,47
45	**KST0169_HWZ**	Grote Herculesstuw	214092,74	599716,26
46	**KST0073 (weir claassens)**	Westerhalmerstuw	215158,47	598201,98
47	**INL226_LWZ**	Herculesinlaat	214100,83	599717,92
48	**KDU000199**	Duiker Uilenestermaar julianatocht	220711,4686	600050,5228

B.2 Pieterburen Example

In this section, the methodology for obtaining and structuring the results of average EC values is presented, along with an example of the three coordinates in Pieterburen. The attached Excel file, titled 'EC-Values Measurements', contains the following tables in the 'Pieterburen' sheet: Tables B.2, B.3 and B.4.

Table B.2: Average EC-values of the three measurements coordinates in Pieterburen for salt content.

Row labels	**AVG_MO_PTBRN04**	**AVG_MO_PTBRN05**	**AVG_MO_PTBRN07**
2019	**13,90**	**12,52**	**9,19**
2020	**9,88**	**10,37**	**10,43**
2021	**10,15**	**7,12**	**8,02**
Jan.	2,01	5,48	2,69
Feb.	1,41	3,89	3,17
Mar.	4,01	4,44	2,92
Apr.	9,81	7,65	7,41
May	12,38	6,59	8,61
June	14,91	7,41	6,08
July	21,93	11,64	8,72
Aug.	6,22	5,69	8,30
Sept.	23,30	15,45	23,77
Oct.	10,45	7,16	13,54
Nov.	4,39	4,18	5,41
2022	**8,51**	**7,50**	**7,76**
Jan.	3,37	4,52	4,55
Feb.	3,59	5,04	4,37
Mar.	16,17	10,77	8,75
Apr.	9,59	5,94	5,67
May	13,18	12,47	12,59
June	5,01	5,31	6,78
July	8,64	-	12,33
Aug.	13,71	-	7,51
Sept.	9,07	-	9,97
Oct.	4,90	-	6,13
Nov.	2,81	-	3,69
2023	**2,67**	**4,89**	**3,68**
Total_AVG	**9,50**	**8,65**	**8,33**

Table B.3: Average EC-values in the dry and wet period of 2021 and 2022 of the three measurement coordinates in Pieterburen.

	AVG_MO_PTBRN04	AVG_MO_PTBRN05	AVG_MO_PTBRN07
WP_2021	7,59	6,76	8,58
DP_2021	13,05	7,79	7,82
WP_2022	6,65	6,78	6,24
DP_2022	10,03	7,90	8,97

Table B.4: Total number of measurements taken of the measurements coordinates in Pieterburen.

	AVG_MO_PTBRN04	AVG_MO_PTBRN05	AVG_MO_PTBRN07
All Years	88	70	88
WP_2021	12	12	12
DP_2021	10	10	10
WP_2022	15	6	15
DP_2022	17	9	17

B.3 Average EC results conducted by the rat catchers

Table B.5: Average EC-values of all years, as well as the wet- and dry periods, obtained from all measurements coordinates conducted by the rat catchers within 100m of the study area.

FID	MPNIDENT	EC_AVG_All_years	EC_AVG_WP_2021	EC_AVG_DP_2021	EC_AVG_WP_2022	EC_AVG_DP_2022
0	**MO_PTBRN04**	9,50	7,59	13,05	6,65	10,03
1	**MO_PTBRN05**	8,65	6,76	7,79	6,78	7,90
2	**MO_PTBRN07**	8,33	8,58	7,82	6,24	8,97
3	**MO_LHP1**	17,63	17,95	18,08	17,51	19,71
4	**MO_LHP2**	15,40	21,42	17,28	13,49	20,10
5	**MO_LHP3**	9,61	7,08	13,77	8,92	12,65
6	**MO_LHP4**	8,24	8,05	7,88	7,85	8,38
7	**KGM121_HWZ**	7,39	5,81	7,14	7,74	10,50
8	**KGM121_LWZ**	4,41	5,66	3,11	5,71	3,60
11	**MO_LHP9**	11,33	10,89	12,04	10,51	12,91
12	**KGM112_LWZ**	11,50	10,46	12,17	11,32	13,08
13	**KGM112_HWZ**	10,83	9,92	12,19	10,21	12,80
14	**MO_LHP12**	11,52	7,37	11,06	10,59	15,76
17	**KGM123_LWZ**	10,92	11,61	10,23	10,26	8,58
18	**KGM123_HWZ**	5,29	6,94	2,82	6,90	3,88
19	**KGM116_LWZ**	8,89	10,69	11,11	7,86	8,39
20	**MO_LHP24**	9,62	10,55	10,15	9,34	8,97
21	**MO_NBP01**	8,50	11,79	6,86	10,53	4,61
22	**MO_NBP02**	3,96	7,25	2,91	4,72	2,62
23	**MO_NBP03**	10,14	14,93	8,08	12,57	5,30
24	**MO_NBP04**	4,06	8,96	2,85	11,38	5,80
25	**MO_NBP05**	1,53	2,03	1,07	2,09	1,30
26	**MO_NBP06**	2,70	3,73	7,14	2,58	1,82
27	**MO_NBP07**	1,71	0,86	1,69	2,28	1,72
28	**MO_NBP08**	1,50	0,90	0,76	n.a.	1,13
29	**MO_NBP09**	9,28	13,63	7,64	11,77	4,75
30	**MO_NBP010**	2,30	2,66	1,83	n.a.	n.a.
31	**MO_NBP011**	5,58	7,88	5,12	n.a.	n.a.
32	**MO_NBP012**	8,75	13,23	5,28	8,05	3,54
33	**MO_NBP013**	7,51	11,12	4,72	9,19	3,01
34	**MO_NBP014**	12,36	12,30	13,56	11,77	11,21
36	**KDU013093**	3,95	2,15	2,85	1,40	1,66
37	**KDU031136**	9,41	1,60	2,05	11,40	1,35
38	**KDU031171**	2,44	3,74	5,34	2,30	2,33
39	**KST009149**	2,84	1,33	1,77	n.a.	0,98
40	**KDU031091**	7,64	14,25	8,09	7,00	5,97
41	**KDU000409**	6,84	13,96	7,29	5,40	4,72
42	**KDU005375**	2,68	4,67	2,70	1,30	2,20
43	**KDU005386**	7,29	13,78	7,89	6,50	5,77
44	**KST0285_LWZ**	4,88	4,04	4,05	5,30	5,36
45	**KST0169_HWZ**	6,56	12,99	6,74	5,60	5,50
46	**KST0073**	1,74	2,57	2,51	1,40	0,89
47	**INL226_LWZ**	6,81	12,91	6,78	5,60	5,34

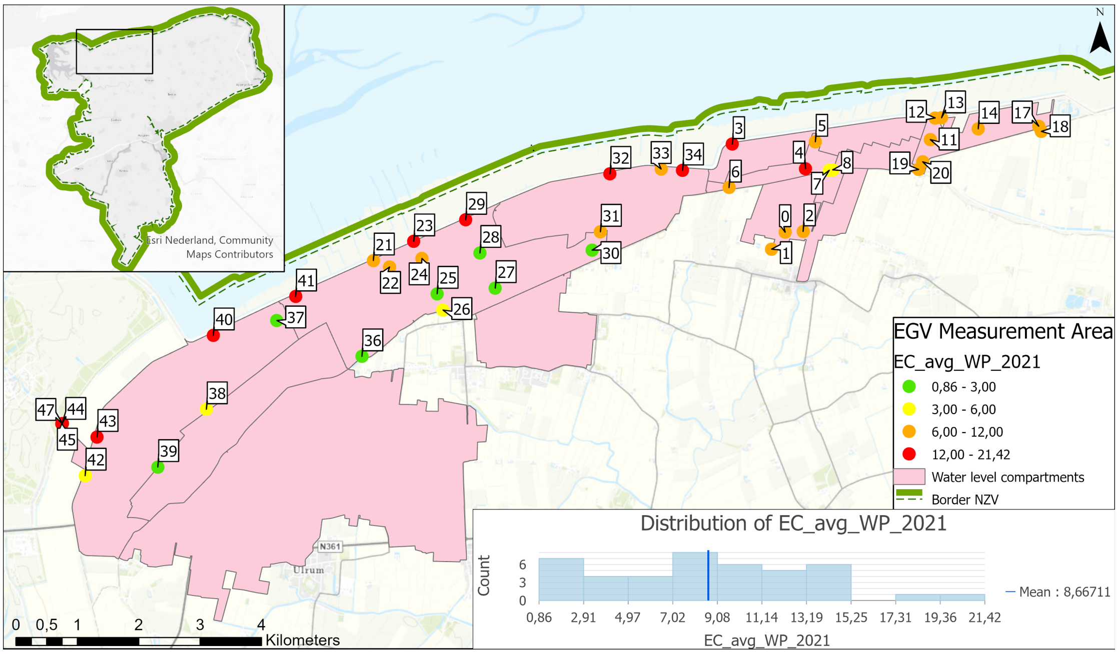
B.4 Average EC results conducted by Martin van der Maar in the storage basin

Table B.6: Average EC-values of all years, as well as the wet- and dry periods, obtained from all measurements coordinates conducted by Martin van der Maar in the storage basin in and near the study area.

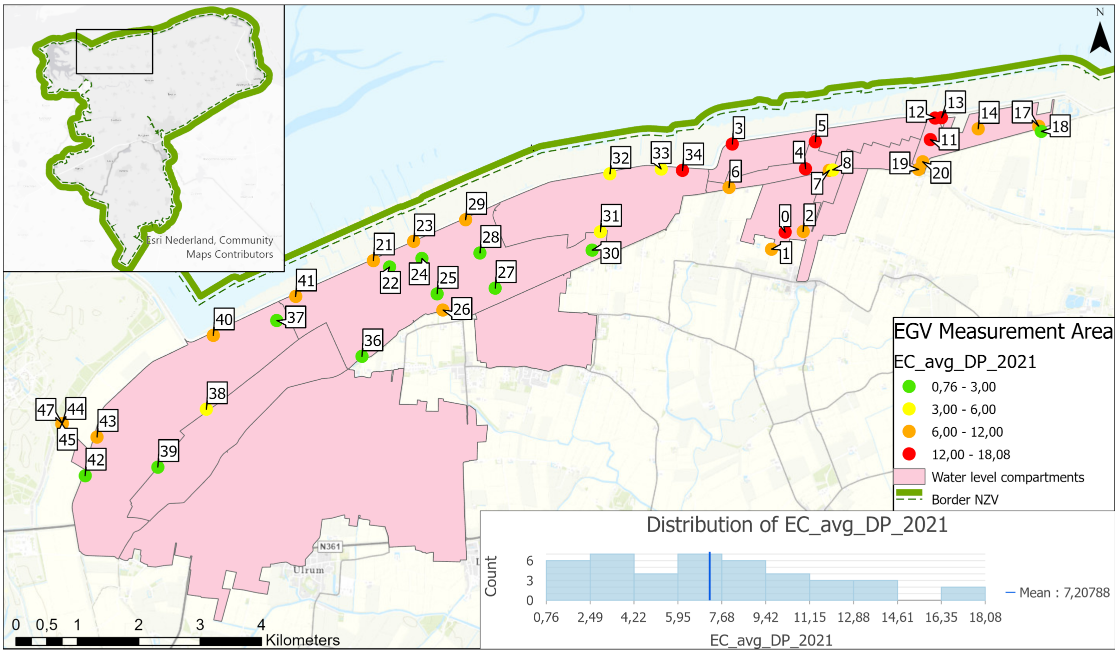
MPNIDENT	EC_AVG_All_years	EC_AVG_WP_2021	EC_AVG_DP_2021	EC_AVG_WP_2022	EC_AVG_DP_2022
315_HWZ	3,79	4,82	4,57	4,18	2,46
GMP160_HWZ	1,46	1,94	1,07	1,90	0,75
MO_UILNEST_HWZ	2,32	1,62	2,09	1,55	2,49
KGM112	2,42	3,55	1,95	3,55	1,66
MO_LUIT_HWZ	11,73	9,62	15,20	10,28	11,74
KGM123	2,28	3,28	1,87	3,31	1,17
KST0209_HWZ	14,53	13,93	13,24	15,11	9,31
KST0209_LWZ	2,59	1,73	2,36	1,68	3,16
KGM121_HWZ	6,60	6,44	6,93	7,05	9,84
KGM121_LWZ	4,70	5,02	4,17	6,53	6,21
KGM116	4,75	7,21	3,33	7,29	4,05
313_HWZ	2,47	2,85	1,68	2,70	2,01
KGM126	3,79	6,19	2,29	5,49	2,83
KST0554_HWZ	3,21	5,47	2,03	4,66	2,16
KGM124	5,92	12,02	4,87	9,52	3,15
KGM113	8,34	13,13	7,26	11,40	4,49
KGM108	2,32	3,15	2,34	3,33	1,56
KGM107	3,87	7,25	3,51	6,63	1,88
KGM110	3,49	5,29	3,27	3,29	2,87
KGM117	1,66	2,19	2,29	1,82	1,38
KGM130	1,71	2,38	1,88	2,46	1,21

B.5 Spatial Distribution EC Averages across 2021

Figure B.1, illustrates the spatial distribution of the average EC value for the wet period in Figure B.1a and for the dry period in Figure B.1b of **year 2021**. The difference of salt content across the locations and period could be investigated by observing the color variations, with green being the striving color.



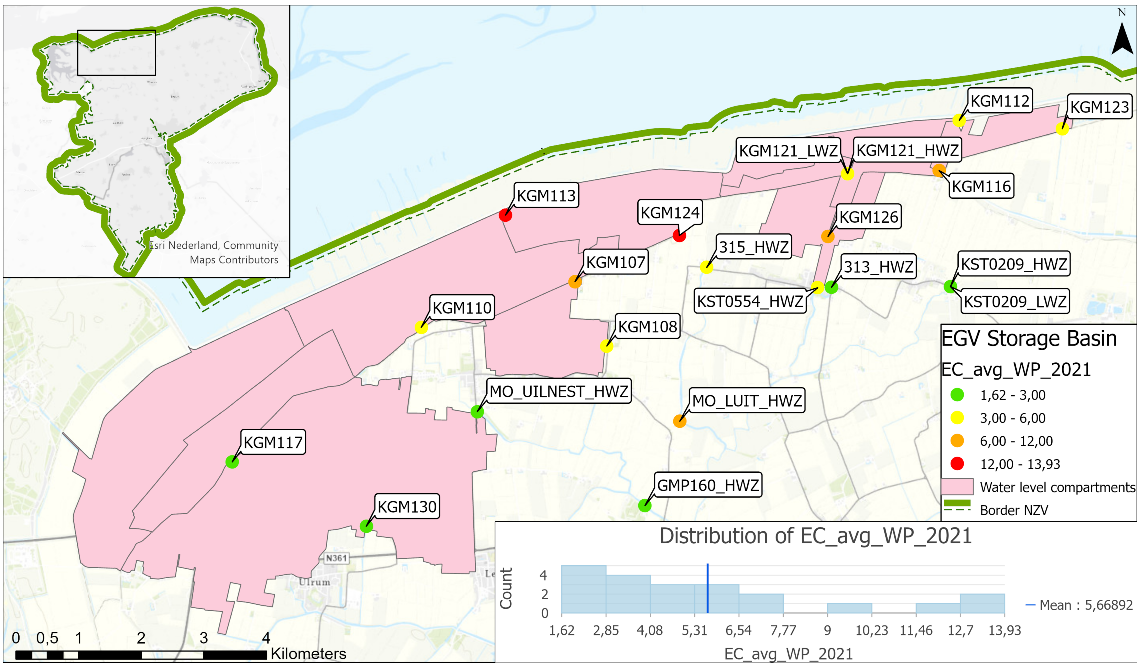
(a) Map of the average EC values of the Wet Period in 2021(RC).



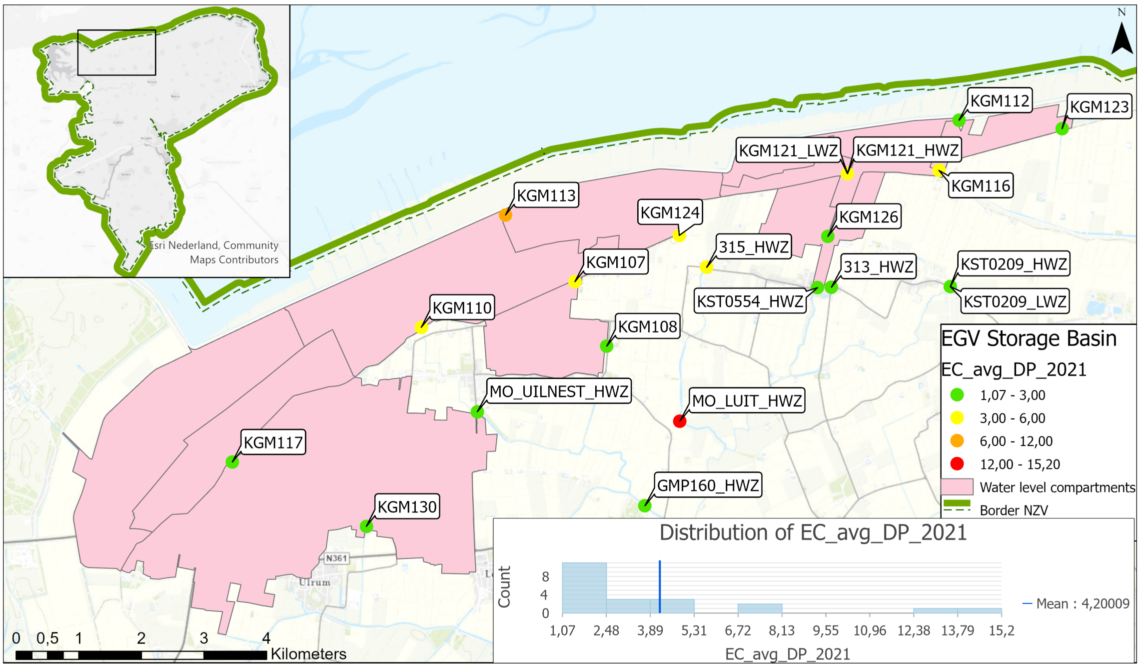
(b) Map of the average EC values of the Dry Period in 2021(RC).

Figure B.1: Map of the average EC values in year 2021 conducted by the rat catchers(RC).

Figure B.2, illustrates the spatial distribution of the average EC value during the wet period in Figure B.2a and during the dry period in Figure B.2b of **year 2021** conducted by Martin van der Maar.



(a) Map of the average EC values of the Wet Period in Year 2021(SB).



(b) Map of the average EC values of the Dry Period in Year 2021(SB).

Figure B.2: Map of the average EC values in Year 2021 conducted by Martin van der Maar in the storage basin(SB).

Appendix C

Glossary

This chapter is used to declare the meanings of Dutch jargon and other potentially unfamiliar terms to the reader. The definitions are derived from the hydrological glossary developed by the Dutch Hydrological Association [37]. Since all activities within the Water Authority Noorderzijlvest region are conducted in Dutch, it could be challenging to accurately translate certain words, meanings, or concepts into English. Therefore, this is section is dedicated to simplify some meanings, getting a better understanding of the jargon and conserving space within the report itself.

Discharge = in Dutch ’*Afvoer*’, referring to the flow rate of water to another location.

Hydraulic structures = in Dutch ’*water kunstwerken*’, such as weirs and pumping stations.

Field capacity = in Dutch ’*Veld capaciteit*’, representing to the water content in the top layer of the soil after a period of rainfall followed by a period of settling that typically lasts for several days.

Flow rate = in Dutch ’*Debiet*’, which is the volume of fluid passing through a cross-section per unit of time, typically measured in cubic meters per second (m^3/sec).

In- and outflow direction = in Dutch ’*Aan- en afvoerrichting*’, refers to the direction of water movement into and out of a system.

Plot = in Dutch ’*Perceel*’, which is a delimited area of land owned by e.g. a farmer, with boundaries determined by the Kadaster.

Polder = in Dutch ’*Boezem*’ and ’*Polder*’. Polders are areas that are situated lower than the surrounding water or land. The surrounding watercourses are called ’*boezemwater*’ (reservoir or polder water), ’*boezemkanaal*’, or ’*ringvaart*’ in Dutch water management terminology.

Pumped Drainage = in Dutch ’*Onderbemalen*’, which is the removal of excess water by means of a pumping station.

Pumping station = in Dutch ’*Gemaal*’, which is a facility used to pump water for flushing the waterways or maintaining the target water level.

(Un)Registered weir = in Dutch ’*Stuw (niet) op de legger*’, representing a structure used to control water flow, sometimes not officially recorded (unregistered weir).

Salinity & Salinization = The salt content of the soil is called the salinity. The term ’*salinization*’ refers to the increase of the salt content in the soil.

Silt = in Dutch ’*Slib*’, which is a layer of silt on the solid bed of a waterway, typically formed through natural deposition.

Spillway = in Dutch ’*Spuisluis*’, sometimes in English called a discharge sluice, which is a sluice (water management system) that is used to release excess water or regulate the water level in a river or canal. So, it is a sluice to discharge inland water and to restrain outside water (e.g. Waddensea).

Storage basin = in Dutch ’*Boezem*’, the system of interconnected watercourses and lakes that are in open communication with each other, used for discharging water from lower-lying polders and potentially providing temporary storage and discharge into the external water bodies.

Target water level = in Dutch ’*Streefpeil*’, refers to the desired / targeted water level in rivers, streams and ditches. Mostly, a higher water level is aimed for in the summer than in winter, because the water demand is higher.

Water level compartments = in Dutch '*Peilvakken*', representing specific sections of a water body or network that are monitored and managed by water level managers (in Dutch '*Peilbeheerders*') to ensure that water levels remain within desired parameters.
Watershed & River basin = Both are areas of land that drain to a particular water body, e.g. river, estuary or lake. A watershed is a 'small version' of a river basin, which is a smaller area of land that drains to a smaller stream, lake or wetland. Every stream and tributary has its own watershed, which drains to a larger stream or wetland. The term 'river (drainage) basin', refers to the entire area that is drained by a river and all of its tributaries.
Water supply = in Dutch '*Wateraanvoer*', refers to the provision of water.
Weir = in Dutch '*Stuw*', referring to a water management structure designed to influence the water level in a stream, ditch, or river. Weirs can be fixed or adjustable.