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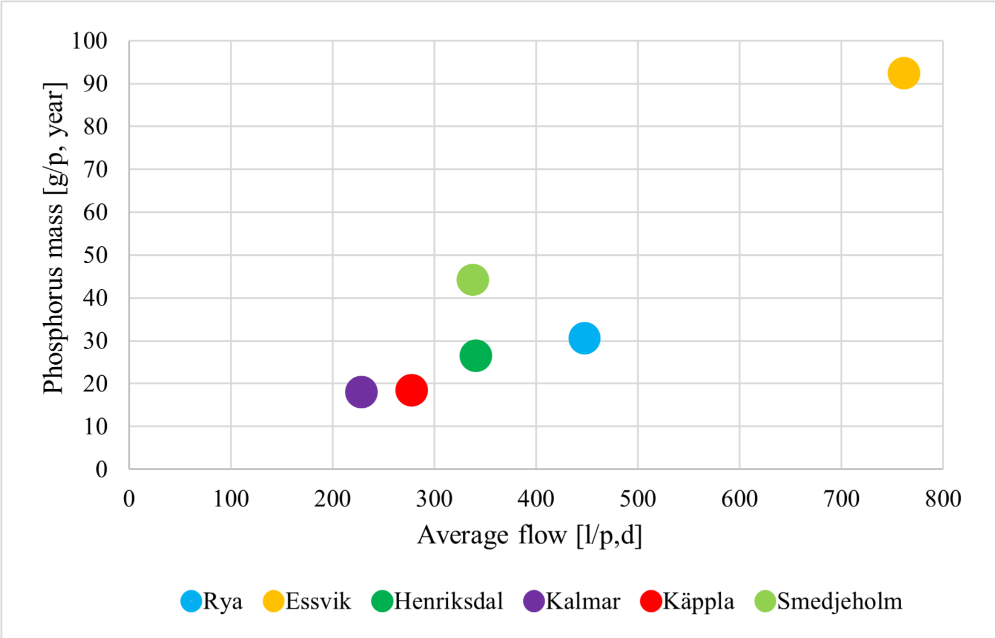

Managing wastewater flows

A case study of six wastewater treatment plants

Master's thesis in the Master's Programme Infrastructure and Environmental Engineering

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MASTER'S THESIS ACEX30

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Cover:
Average phosphorus mass and flow for the six wastewater treatment plants, described in Chapter 5.2.
Department of Architecture and Civil Engineering
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ABSTRACT

Climate change, ageing infrastructure, significant underinvestment and urbanisation are all growing challenges, which makes sustainable infrastructure for wastewater systems increasingly important. These challenges might result in an increase in the level of wastewater entering the wastewater treatment plant (WWTP). This can result in higher pollutant discharges from the WWTP, as the treatment performance decreases during high flows. The aim of the thesis is to support the identification of appropriate measures or strategies to maintain high treatment efficiency despite periods of high flow.

This thesis includes a case study at six WWTPs, which combines model development and scenario analyses with interview studies. It evaluates whether the developed simplified model can be used and how different future scenarios can affect phosphorus mass discharges from the WWTPs through the simplified model. The model estimates effluent phosphorus concentrations based on daily flow data and shows good overall precision, with an average deviation of 7% from actual values. However, the performance varies between WWTPs and years. Scenario analysis reveals that reducing effluent concentrations and decreasing infiltration and inflow (I/I) or sewage water could reduce phosphorus discharges. Further increasing the WWTPs capacity showed limited impact for the studied wastewater treatment plants.

The thesis also collects valuable information considering managing flows and reducing discharges to the recipient from industry professionals from the WWTP and sewer network. The interviews highlight future challenges such as economic conditions, the renewal rate of the sewer network, and increased precipitation and seawater intrusion. The appropriateness of measures to manage flow and decrease discharges are also evaluated, where all suggested measures are considered appropriate. However, measures targeting the sewer network are viewed as even more appropriate than measures targeting the WWTP.

The interviews also conclude that to ensure sustainable wastewater systems, a combination of technical solutions , policy tools, and stakeholder engagement is recommended. Continued investment, regulatory pressure, and increased awareness will be important in improving water quality and efficiently managing future wastewater flows.

Key words: Flow management, high flow, Wastewater Treatment Plant, sewer network , Predictive models, scenario analysis, interview.

Hantering av avloppsvattenflöden
En fallstudieie av sex avloppsreingsverk

Examensarbete inom masterprogrammet infrastruktur och miljöteknik'

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SAMMANFATTNING

Klimatförändringar, åldrande infrastruktur, betydande underinvesteringar och urbanisering är alla växande utmaningar som gör hållbar infrastruktur för avloppssystem allt viktigare. Dessa utmaningar kan leda till att ökade mängder avloppsvatten som når avloppsreningsverken (ARV). Detta kan resultera i högre föroreningsutsläpp, då reningen försämras under höga flöden. Syftet med denna uppsats är att stödja identifieringen av lämpliga åtgärder eller strategier för att upprätthålla en hög reningseffektivitet, även under perioder med höga flöden.

I detta examensarbete ingår en fallstudie på sex avloppsreningsverk som kombinerar utveckling av modell och scenarioanalys med intervjustudier. Examensarbetet utvärderar om en förenklad modell kan användas samt hur olika framtidsscenarier kan påverka utsläppen av fosformassa från avloppsreningsverken, genom modellberäkningar. Modellen, som uppskattar utgående fosforkoncentration baserat på dygnsflöde, visar överlag god noggrannhet med ett genomsnittligt avvikelse på 7% från de faktiska värdena. Avvikelsen varierar dock mellan olika reningsverk och år. Scenarieanalyserna visar att minskade utgående koncentrationer samt minskad volym tillskottsvatten eller spillvatten kan leda till minskade fosforutsläpp. Att öka reningsverkens kapacitet är mindre effektivt för att minska fosforutsläppen.

Examensarbetet samlar även värdefulla insikter kring flödeshantering och hur utsläpp till recipient kan minskas från yrkesverksamma inom reningsverk och ledningsnät. Intervjuerna lyfter framtida utmaningar såsom ekonomiska förutsättningar, förnyelsetakt av ledningsnätet och ökad nederbörd och saltvatteninträngning. Även lämplighet hos åtgärder för att hantera flöden och minska utsläpp graderas, där alla föreslagna åtgärder anses som lämpliga. Däremot bedöms de åtgärder riktade mot ledningsnätet som mer lämpliga än de som riktades mot reningsverken.

Intervjuerna visar också att för att säkerställa hållbara avloppssystem krävs en kombination av tekniska lösningar, styrmedel och engagemang från olika aktörer. Fortsatta investeringar, strängare lagkrav och ökad medvetenhet anses vara viktiga för att förbättra vattenkvaliteten hos recipient och effektivt hantera avloppsvattenflöden.

Nyckelord: Flödeshantering, höga flöden, avloppsreningsverk, ledningsnät, förutsägande model, scenarioanalys och intervjuer

Contents

Preface

This master's thesis was carried out in collaboration with Chalmers University of Technology, Envidan AB, and Kretslopp och Vatten.

I would like to express my sincere gratitude to my supervisor Ann Mattsson and co-supervisor Johan Brunsten and Louise Westin for their valuable guidance, continuous support and constructive feedback throughout the work. I would also like to thank my examiner Oskar Modin for providing helpful input when needed.

A special thanks goes to all the industry professionals who participated in the interviews and generously shared their knowledge and experience. I also want to thank those who provided essential data about the wastewater treatment plants. Their contributions greatly enriched the theis as well as made this thesis possible.

Gothenburg, June 2025
Beatrice Olsson Hansson

1 Introduction

This chapter will explain the background of why wastewater flow management is relevant, as well as explain the aim of the thesis.

1.1 Background

Today's society faces challenges such as how to provide an increasing urban population with sufficient services, as well as climate change, with consequences such as increased precipitation and rising sea levels (Ohlin Saletti, 2021, 2022). Given these challenges, sustainable infrastructure for wastewater systems becomes increasingly important. A difficulty in building water infrastructure is Sweden's large underinvestment debt, where there is a yearly underinvestment of 10 billion SEK according to the investment report released by the professional body Svenskt Vatten (2024b). Moreover, by 2040, 560 billion SEK needs to be invested in Sweden's water and wastewater infrastructure, with the sewer network having the largest investment need. In addition to the ageing sewage system, there is also a problem of inefficient design (Ohlin Saletti, 2021). Wastewater systems receive sanitary sewage but also infiltration and inflow (I/I). This results in additional costs for treatment and pumping, as well as a higher risk of sewer overflows and basement flooding. Another challenge is stricter requirements for wastewater treatment plants (WWTPs). For example, WWTPs, with at least 150 000 connected population equivalents (pe), must implement advanced micropollutant treatment before 2039 (Svenskt Vatten, 2014). In general, there are many challenges, such as urban population growth, climate change, increased precipitation, rising chemical costs, ageing systems, significant underinvestment, and stricter regulations, which will likely make the need for sustainable wastewater infrastructure even more critical.

Gryaab predicts future flows based on population growth, water consumption, external load, and the rate of measures for the sewer network using a simulation tool (I'Ons et al., 2021; Tanskanen et al., 2024). However, forecasting the total inflow to WWTPs is challenging, and the greatest uncertainty is assumed to be the population forecast and the amount of infiltration and inflow. The latest study concludes that both the total yearly amount of incoming water and the water consumption per person per day are expected to decrease (I'Ons et al., 2021). It also states that the design peak flows are likely to remain as high as, or even increase beyond current levels, due to higher rainfall intensity caused by climate change.

Studies show that an increased volume of wastewater leads to a decreased treatment performance (Giokas et al., 2002; Plósz et al., 2009). The master thesis 'Impact of high flow on the performance of phosphorus treatment' also concludes that high flows decrease the removal of phosphorus, after evaluating data for three years from five Swedish WWTPs (Shareef Mohammed, 2024). This master's thesis will continue to investigate how a simple model can be developed that predicts effluent phosphorus concentration based on flow, evaluate scenarios using the model, and explore how industry professionals view various aspects related to wastewater flow management and reducing pollutants discharge.

1.2 Aim and objectives

The aim is to support the identification of appropriate measures or strategies to maintain high treatment efficiency despite periods of high flow. To achieve this aim, the following specific objectives are defined.

• Develop a simplified model that predicts the effluent concentration and evaluate the performance of the model.

• Use the simplified model to perform scenario analyses and assess the effects of various scenarios on pollutant discharge.

• Gather important information from industry professionals on the management of wastewater flow and pollutant discharges to recipients.

1.3 Limitations

The model developed in this thesis focuses solely on phosphorus and uses data from six Swedish wastewater treatment plants. In the model, the concentration is only based on flow and the WWTPs capacity, without accounting for how treatment efficiency varies across different stages of the treatment process. The thesis considers the bypass of different treatment steps in the WWTP but does not consider sewer overflow from the sewer network. The scenario analysis examines the effects of the measures rather than the measures themselves. The thesis focuses solely on pollutants within the water and wastewater sector.

1.4 Specification of issue being investigated

The following research questions are answered in this thesis:

• Does the simplified model represent reality well and how does its results vary with different time resolutions of the flow data?

• How do different scenarios affect the phosphorus load in the effluent from the wastewater treatment plant, and what potential exists for reducing phosphorus discharges through improvements both at the treatment plants and within the sewer network?

• How do stakeholders evaluate potential measures, and how do they perceive future opportunities, challenges, and necessary tools for managing flow and reducing pollutant discharges?

2 Theory

This chapter provides the theoretical foundation for the thesis and explains the necessary key concepts. It describes how high-flow conditions affect treatment performance and various measures and strategies to manage infiltration and inflow and reduce pollutant discharges. Finally, it presents the relevant regulatory and economic context, including legal requirements, sampling obligations, and the financing of water and wastewater services in Sweden.

2.1 Wastewater treatment

This chapter will focus on the technical aspects of wastewater treatment, providing a comprehensive overview of the wastewater system. It will cover different types of wastewater, phosphorus removal methods, and various approaches to estimate the pollutant load per person.

2.1.1 Wastewater system

To treat wastewater from urban areas in Sweden, wastewater treatment plants, sewer networks, and pumping stations have been constructed (Naturvårdsverket, 2022b). The sewage system can be combined, where the stormwater and wastewater share the same pipeline, or separated, where the stormwater and wastewater are separated into two different pipelines. Naturvårdsverket(2022b) continues to explain that in a combined system, both stormwater and wastewater are transported to the WWTP and treated, resulting in a larger amount of water compared to a separate system.

The wastewater treatment plants usually combine mechanical, chemical, and biological treatment (Metcalf & Eddy, AECOM,2014). These processes aim to remove organic matter and nutrients such as nitrogen and phosphorus. In addition to traditional treatment, there are advanced treatment technologies for the removal of pharmaceuticals and microplastics. This advanced treatment is increasingly being implemented (Naturvårdsverket, 2022b).

2.1.2 Types of wastewater

Common types of wastewater are usually domestic wastewater (sewage water), industrial wastewater, infiltration and inflow (I/I), and stormwater. Infiltration and inflow is additional water that enters the collection system (Metcalf & Eddy, AECOM., 2014). Infiltration refers to the water that enters the collection system through leaking joints, cracks, and breaks, while inflow refers to the stormwater that flows into the collection system through roof leaders, foundation and basement drains, manholes or storm drain connections. Inflow can also be divided into steady inflow, direct inflow, and delayed inflow. Steady inflow is a continuous entry of water into the collection system, for example direct connections to springs. Direct inflows lead to an almost immediate increase in wastewater, while delayed inflow enters the collection system gradually over time. This is, for example, delayed entry of water through manholes in ponded areas.

2.1.3 Phosphorus at wastewater treatment plant

Phosphorus is an essential nutrient for the growth of agricultural crops, algae, and other biological organisms (Metcalf & Eddy, AECOM., 2014). Excess phosphorus emissions contribute to eutrophication, which stimulates the rapid growth of algae and can cause harmful algae blooms. To treat phosphorus in wastewater, biological phosphorus removal, chemical phosphorus removal, or a combination of both can be used (Metcalf & Eddy, AECOM., 2014). Chemical phosphorus removal involves the addition of chemicals such as calcium, aluminium, and iron salts. These chemicals are used to precipitate the phosphorus, which can later be separated by sedimentation or filtration. Biological phosphorus removal is a process in which specialized bacteria called polyphosphate-accumulating organisms (PAO) store phosphorus within their cells. PAOs release phosphorus under anaerobic conditions and then take up excess phosphorus during aerobic conditions. Later, PAOs and absorbed phosphorus together with the activated sludge are sedimented and removed.

The advantage of biological removal of phosphorus is the lower chemical cost, reduced sludge volume, and higher nutrient content in the sludge (Borglund, 2004). However, the process is more sensitive to operational conditions and disturbances and requires a skilled operator. Biological phosphorus removal also has a longer startup time compared to chemical phosphorus removal and can experience issues with phosphorus release during the subsequent digestion of bio sludge. Since Sweden has very strict phosphorus discharge requirements, almost all wastewater treatment plants use advanced chemical precipitation (la Cour Jansen et al., 2009). Implementing biological phosphorus removal is challenging under these conditions and biological treatment alone is rarely sufficient. Therefore, WWTPs with biological phosphorus removal usually also employ chemical phosphorus removal.

2.1.4 Population equivalents and pollution load

To simplify the comparison between WWTPs of different sizes, the actual number of connected individuals or population equivalents (pe) can be used. One pe corresponds to the amount of biodegradable organic material with a biochemical oxygen demand of 70 g of dissolved oxygen per day for seven days (Naturvårdsverket, 2022b). pe is a fixed value that accounts for the total pollution load produced by individuals and industries.

For other pollutants, such as nitrogen, phosphorus, and COD, there is no general fixed value, but there are approximations of the average mass to which one individual corresponds. There is a study that analyses influent data from five major Swedish wastewater treatment plants (1992–2012) to track trends in nitrogen, phosphorus, and organic material (Tumlin & Mattsson, 2013). The average value for 2012 is shown in 2.1. Tumlin & Mattsson also shows a decrease in phosphorus and BOD_7 loads per connected person, while nitrogen loads in influent wastewater increased.

In addition, Gryaab has analysed the amount of pollutants discharged by an individual by sampling water from residential areas. Their investigation was carried out to obtain a current picture of the composition of household wastewater and four sampling rounds were conducted in two residential areas during 2017 and 2018 (Press et al., 2020). Sampling was also carried out in the same reference areas in 1988 and 2006/2007. In the 2017/2018 study, 351 parameters were analysed, including BOD_7, COD, nitrogen, and phosphorus. Compared to previous years, the results showed an increase in nitrogen, while BOD_7 and COD increased from 1988 to 2006/2007 but then decreased slightly in 2017 and 2018. Meanwhile, phosphorus levels decreased, likely due to gradual reduction in phosphorus in detergents, which was implemented step by step over the period. The mean value for 2012 (Tumlin & Mattsson, 2013), the average Gryaab values for 2017/2018 (Press et al., 2020), and typical Swedish values (Metcalf & Eddy, AECOM, 2014) are shown in Table 2.1.

Table 2.1: Comparison of typical load values[g/p,d]

Source	**BOD_7** [g/p,])	**COD** [g/p,d]	**P-tot** [g/p,d]	**N-tot** [g/p,d]
Rya household sampling	64	130	1.1	11
Study mean value 2012	61.5		1.59	13.3
Typical Swedish values	68–82		0.8–1.2	11–16

2.2 Treatment performance and high flow

This subsection will summarise the literature on the relationship between treatment performance and high flows. It will also explain various measures to reduce pollutant emissions and manage infiltration and inflow. In addition, the chapter will describe strategies to investigate and understand the situation considering infiltration and inflow.

2.2.1 Treatment performance during high flows

The master's thesis *Impact of High Flow on Phosphorus Treatment Performance* concluded that high flows decrease phosphorus removal, and when the WWTP capacity is exceeded and a bypass scenario occurs, this results in a significant increase in phosphorus in effluent (Shareef Mohammed, 2024). The effectiveness of WWTP in the removal of phosphorus is also closely related to its treatment capacity and the flow received. This highlights the importance of keeping the flow within the designed capacity of the WWTP or increasing the capacity of the WWTP to maintain efficient phosphorus removal. This analysis is performed using statistical analysis and linear regression models with three years of data on weekly flow and phosphorus concentration in the effluent for five Swedish WWTPs. To facilitate easier comparisons between WWTPs of varying sizes, the number of people connected to each plant is used to standardize the flows to litres per person per day.

There is also another master's thesis that analyses and compares the effect that total flow has on performance for seven Swedish WWTPs (Molander, 2015). This is done by evaluating the key performance indicators: flow per capita, extent of dilution, surface loading, and volumetric loading. Rya WWTP had the highest values for key performance indicators and also has the highest percentage of bypassed incoming water. Molander states that these difficulties are due to the high amount of infiltration and inflow that reaches Rya WWTP.

In addition, other papers show how treatment performance decreases during high flow. There is also a paper examining the impact of climate change on an activated sludge plant in the Oslo area during winter, which finds that the frequent occurrence of sudden increases in flow rate and lower wastewater temperatures negatively affect the biological nitrogen removal and secondary clarification processes (Plósz et al., 2009). They further explain that during temporary melting periods, the sewage water is diluted with increased surface run-off, and the total nitrogen concentration decreases. However, this high flow reduces retention time and the reduced sewage concentration decreases nitrogen removal efficiency, resulting in a higher total nitrogen concentration in the effluent. Plósz et al.(2009) highlight that in order to handle these climate-related challenges, it will be important to model and optimize systems for real-time automation and control. Currently, models are unable to predict the impact of these shock-loading events.

There is also a study conducted at an activated sludge plant in Greece, which investigates how performance was affected by flow variations caused by infiltration and inflow (Giokas et al., 2002). The high flow reduced retention time, leading to poor performance and poorer effluent quality. Giokas et al. also discuss performance during dry conditions when water evaporation decreases performance. This is due to reduced dilution and increased feed concentration. They tried to adjust the return sludge flow to mitigate the problems, but it was not enough. The findings emphasize the need for improved design guidelines for both the sewage system and the treatment plant. They also believe that knowledge of the system could be a useful tool for improving process adjustments.

In addition to this, an American article uses data from 24 WWTP in Georgia to determine the relationship between, for example, rainfall and flow, as well as flow and influent BOD and total suspended solids (TSS) concentrations (Mines et al., 2007). A positive correlation for rainfall and flow is observed, which supports the conclusion that rainfall causes infiltration and inflow into the sewer network. Their results show a negative correlation between flow and influent BOD concentration for approx 70 % of the WWTPs. which indicates that increased flows dilute the influent BOD concentration. For TSS a similar trend is observed but for approximately only 60% of the WWTPs. Mines et al also found that the average intensity of rain was negatively correlated with the concentration of BOD in the influent wastewater and the concentration of TSS in approximately 70% of WWTP. When testing the mass loading influent versus the mass loading effluent for both BOD and TSS, a positive correlation is observed in 15 out of 24 cases and 12 out of 23 cases, respectively.

2.2.2 Measures

This section will present measures to manage infiltration and inflow or decrease pollutant discharge. There are many measures to manage wastewater flows or to decrease pollutant discharge. Regarding measures for managing infiltration and inflow von Scherling et al (2023) have compiled and categorized various measures mentioned in a report. The measure categories are the following:

- Prevent inappropriate connections
- Reduce runoff formation
- Remove faulty connections
- Seal
- Protect vulnerable points
- Management of excess flow within the system
- System reconfiguration
- Expansion of the capacity

The first category aims to prevent inappropriate connections by influencing behaviour through public awareness campaigns, policies, stormwater management strategies, water and wastewater tariffs, and more (von Scherling et al., 2023). Next, there are some measures categories to decrease the amount of infiltration and inflow reaching the pipeline system, such as remove faulty connections and reduce runoff formation. Remove faulty connections can be done by inspecting down spouts, backflow preventers, and correcting any ditches connected to the sewer network while runoff reduction can be done with local stormwater retention, diversion ditches, and leak detection.

Then there are some measure categories that are implemented in the sewer network, such as sealing, protecting vulnerable points, managing excess flow within the system, or a system reconfiguration (von Scherling et al., 2023). Sealing can be done by pipe relining, re-laying, or point repairs while vulnerable points can be protected by installing backflow preventers at low-lying connections to prevent flooding and contamination. Another category of measures conducted within the sewer network is the management of excess flow within the system, which can be done by providing hydraulic buffering, controlling combined sewer overflows, and effectively treating overflow discharges. Another measure is system reconfiguration, such as converting combined sewer systems to separate ones.

The last category of measures is the expansion of the capacity, which involves increasing the capacity of the sewer network and the treatment plants. To increase capacity, both normal WWTP expansion and high-flow treatment can be performed. VA-cluster Mälardalen has initiated a project called Minimizing the Discharge of Pollutants from Overflows with Intermittent High-Flow Treatment to study processes for treating overflow water (Levin, 2020). They have investigated different types of high-flow treatment processes and identified the following selection criteria for choosing a treatment method: it should be reliable after long periods of inactivity, able to handle large variations in flow and pollutant load, have a fast start-up time, provide effective removal of suspended solids, minimize the use of chemicals, require little space, not cause disturbances to the surroundings, and have low maintenance costs. However, the process does not need to achieve the same high levels of treatment as the main wastewater treatment process. An example of high-flow treatment is the Actiflo process, used in Käppala (Haarbo & Cederborg, 2009). When the incoming flow exceeds the normal capacity of the treatment plant, excess water is diverted between the screens and the grit chamber to a separate treatment line. After treatment, the water is discharged into the receiving water body. The Actiflo process combines chemical precipitation with lamella separation and uses microsand to enhance flocculation. It is particularly effective for phosphorus removal.

There are also measures to reduce pollutant discharge by treating wastewater. This can be done in WWTP by introducing better treatment, such as quaternary treatment for pharmaceutical residues or membrane bioreactors (MBBRs) to reduce phosphorus and nitrogen. For example, there are MBBR plants for the removal of phosphorus that achieve very low effluent concentrations of nitrogen and phosphorus (0.03–0.3 mg Tot-P/l and 2–7 mg Tot-N/l) even at low or relatively low water temperatures (Andersson. Sofia Lovisa et al., 2023). Reducing pollutant discharges can also be reduced outside the WWTP through sustainable stormwater management. Examples of stormwater solutions include stormwater ponds, wetlands, various technical installations such as filtration systems, advanced facilities with chemical precipitation, and different sedimentation solutions (Naturvårdsverket, 2019).

Another type of measure is upstream work, which aims to prevent hazardous substances from reaching wastewater treatment plants by addressing problems at the source (Svenskt Vatten, n.d.-b). Because WWTPs are not designed to handle persistent chemicals, costly and energy-intensive technologies would be required, leading to increased carbon dioxide emissions. The treatment of hazardous substances at WWTP can be seen as end-of-pipe solutions, which do not solve the actual problem, and risk to relocate the pollution rather than eliminating it. Through preventive measures, the aquatic environment and the nutrient cycles are protected, and society saves money in the long term.

2.2.3 Strategies for infiltration and inflow

In addition to physical measures, there is a strong focus on collecting information and working strategically to ensure that the actions taken are as effective as possible. This section will briefly describe tools and strategies that provide a comprehensive framework for understanding, evaluating, and reducing infiltration and inflow (I/I) in wastewater systems. By improving data accuracy, offering structured workflows, and enabling customized analysis, they strengthen municipalities' capacity to manage I/I in a sustainable, efficient, and evidence-based way.

There is a report from Svenskt Vatten, in which a stepwise decision support system for managing I/I is presented. It consists of three tools: a water balance tool, a current state analysis tool, and a measure evaluation tool (von Scherling et al., 2023). Managing I/I is complex and requires knowledge of volumes, sources, and distribution, understanding current problems and whether actions are needed (current state analysis) and evaluating which actions are most suitable (measure evaluation). The water balance tool provides an overview of I/I volumes by dividing them into flow types and spatial areas, serving as a simple first step before more advanced investigations (von Scherling et al., 2023). The measure evaluation tools use a multi-criteria analysis where users define scoring systems and evaluate options based on environmental, social, and technical aspects. The tools do not provide definitive answers, but support a structured decision-making process.

There are also some challenges in measuring I/I, as it is highly dependent on weather. A report from Svenskt Vatten proposes a structured workflow that uses new key performance indicators that remain consistent regardless of annual rainfall variations (Clementson et al., 2020). Instead of using the commonly applied share of I/I water, the authors suggest calculating "contributing areas" for fast and slow I/I, providing a more reliable basis for analysis and follow-up. The report divides I/I into three components: rapid rainfall response (SRP), slow rainfall response (TRP), and groundwater infiltration (GVP). These components are related to factors such as service area, sewer length, and population equivalent. The advantage of this method is that it is largely unaffected by the variation in rainfall from year to year, allowing a faster and more consistent evaluation of the effects of the intervention.

There is another report by Svenskt Vatten that focuses on identifying and evaluating different methods to locate extraneous water sources in wastewater systems (Lundblad & Backö, 2013). It also suggests an investigation strategy, which involves dividing the wastewater system into sub-areas to prioritize actions and better understand sources of I/I. Each area is assessed based on three key flow components: wastewater, base flow (from leakage and drainage), and stormwater inflow. Flow and rainfall data are collected using a combination of permanent meters and temporary campaign measurements to calculate reliable performance indicators. This data-driven approach enables targeted investigations, supports capacity planning, and helps reduce flooding and overflow risks in a cost-effective manner.

2.3 Regulations and economy

The chapter will briefly outline the legal requirements in Sweden, sampling obligations, the financing of the Swedish water and wastewater system, and the current investment situation.

2.3.1 Regulatory framework

At the EU level, the treatment of urban wastewater is regulated by the EU directive Council Directive 91/271/EEC, which concerns the collection, treatment, and discharge of urban wastewater, as well as the treatment and discharge of wastewater from certain industrial sectors (European Union, 1991). It further explains that urban areas with a population equivalent (pe) above 2000, are required to establish a collection system for wastewater and treat it with secondary treatment before it is discharged. As mentioned above, 1 pe corresponds to the amount of biodegradable organic material with a biochemical oxygen demand of 70 g of dissolved oxygen per day for seven days. Furthermore, articles 12 and 14 state that water and sludge should be reused when deemed appropriate, with the aim of minimizing negative impacts on the environment.

Member states must also ensure that monitoring methods meet specific requirements, such as a minimum number of samples per year depending on the number of pe the WWTP serves (European Union, 1991). Other monitoring requirements include flow-proportional or time-based daily samples, which must be taken at the outlet and, if needed, at the inlet. This monitoring ensures that the WWTP is operating correctly and that the discharge of wastewater is safe and environmentally responsible. There are also other EU directives concerning wastewater in addition to the Urban Wastewater Treatment Directive (91/271/EEC), for example, the Water Framework Directive (2000/60/EC) and the Marine Strategy Framework Directive (2008/56/EC).

The revised wastewater directive came into effect on January 1, 2025, and must be incorporated into Swedish law by July 31, 2027 (Svenskt Vatten, n.d.-a). The directive lowers the threshold for pe with treatment requirements, introduces new requirements for phosphorus and nitrogen removal, advanced treatment of micro-pollutants, and energy neutrality. The requirements for tertiary treatment specify that by 2045, all WWTPs with a load greater than 150,000 PE must implement tertiary treatment to remove organic, non-biodegradable and hazardous substances, such as pharmaceuticals and cosmetics. Regarding energy neutrality, it mandates that WWTPs with a load greater than 10,000 pe must be energy neutral by 2045. There are also requirements for the existence of wastewater plans n particular in municipalities were a significant proportion of untreated wastewater is overflowed to receiving waters.

In Sweden, many of the EU's environmental acts are implemented at a general level in the Environmental Code, which is the Swedish framework legislation in the field of environmental protection (Swedish Environmental Protection Agency, 2020). The Environmental Code and, along with its ordinances and regulations, is also where the Directive on urban wastewater treatment is incorporated. The legislation, Swedish EPA regulations (NFS 2016: 6) contains more practical applicable requirements for wastewater treatment.

2.3.2 Sampling requirements

There are different types of sampling, such as daily samples, weekend samples, or weekly samples (Naturvårdsverket, 2016). A daily sample consists of water collected over one day, whereas a weekend sample consists of water collected over a weekend, usually from Friday to Monday. A weekly sample consists of either seven daily samples or a combination of four daily samples and one weekend sample over a week. The samples are mixed in proportion to the volume of wastewater discharged during each respective daily or weekend sampling period.

To ensure that the collected samples are representative of the wastewater that is monitored, both sampling and flow measurement must be performed (Naturvårdsverket, 2016). For WWTPs with a capacity of 10,000 pe or more, both treated effluent and any bypassed water at treatment stages within or near the WWTP must be continuously measured and recorded for flow, and flow-proportional sampling must be implemented. For facilities with more than 10,000 pe, the following sampling requirements apply to influent water:

• Two daily samples per month for COD
• One daily sample per week for BOD_7, total phosphorus (P-tot), total nitrogen (N-tot), and ammonium nitrogen (NH_4-N)
• One weekly sample per month to test for various metals (Naturvårdsverket, 2022a)

On 1 January 2023, the sampling requirement for COD was changed from weekly to daily. However, until 31 December 2023, daily COD sampling could be replaced by weekly sampling (Naturvårdsverket, 2022a). When conducting COD tests, mercury is used, which is very toxic and the use of mercury is generally banned in Sweden (Kemikalieinspektionen, 2022). Currently, there are no fully functioning alternatives to COD analysis without the use of mercury and therefore there is an exception allowing mercury compounds to be used for COD analysis and in ampoules for COD analysis until 31 December 2025.

2.3.3 Financing of water and wastewater services

In Sweden, municipal water and wastewater services are financed through fees collected through the water and wastewater tariff (VA taxa) (Svenskt Vatten, 2014). Municipalities are responsible for setting the tariff. However, the Public Water Services Act states that the revenue from the operation must not exceed the necessary costs. The water and wastewater tariff generally covers the operational costs, although some smaller municipalities do not achieve full cost coverage and instead supplement the funding with a small portion from municipal taxes. There are also certain grants available for application. The water and wastewater tariff in Sweden's municipalities increased on average by 14% in 2024 (Svenskt Vatten, 2024). This is almost twice as much as the increase in 8% in 2023. The differences between municipalities have also grown significantly; in 2024, the gap between the highest and lowest fees was 531%, compared to approximately 400% in 2020. Despite the increase, Svenskt Vatten mentions that water and wastewater services are still a relatively affordable service, even in municipalities with high tariffs (2024).

Major investments in the expansion of municipal WWTPs were made in the 1970s. At that time, the government invested approximately 1.5 billion SEK, which is equivalent to approximately 7 to 8 billion SEK in the 2018 value (Naturvårdsverket, 2022b)). During the same period, some industries also received government grants for environmental protection measures, where a large amount of the grants were used to improve wastewater treatment.

Today, Sweden's water and wastewater infrastructure has significant investment needs and the system must be renewed (Svenskt Vatten, 2023). For example, Sweden invests 10 billion SEK less each year than is required. Svenskt Vatten continues to explain that due to new EU directives requiring improvements in water production, treatment, and distribution, even more investment is needed. To meet these investment needs, VA organizations must strengthen their capacity by increasing competence, planning ability, and personnel resources. Another example is that renewing the municipal sewer network would take 200 years at the current pace.

Svenskt Vatten (2023) also outlines how investment needs are expected to be distributed, with two-thirds allocated to existing infrastructure and one-third to new construction. Furthermore, approximately 16 % are expected to go to water treatment plants, 29% to WWTPs, and the remaining portion to the sewer network. The sewer network therefore has a very large investment need. The same article from Svenskt Vatten(2023) also mentions how changing interest rates and inflation have increased uncertainty regarding investments in water and wastewater infrastructure, which affects the financial requirements. Since this infrastructure is largely loan-financed, water and wastewater authorities will need to consider higher capital costs and adjusted financing in their future investment plans.

3 The wastewater treatment plants in the case study

This chapter will provide general information about the wastewater treatment plants (WWTPs), including their discharge limits for phosphorus, the companies responsible for the operation of the WWTPs, and those in charge of the sewer networks. It will also cover the capacities of the WWTPs, treatment during high flows and any planned or ongoing reconstruction projects.

3.1 General info about the WWTPs

The six WWTP included in this case study are Rya, Essvik, Henriksdal, Kalmar, Käppala and Smedjeholm. The locations of these WWTPs are shown in 3.1.

Figure 3.1: Map where the location of the WWTPs is marked with a blue circle (Lantmäteriet, n.d.)

The number of individuals connected ranges from 884 000 at Henriksdal WWTP to 11 200 at Essvik WWTP. A summary of the key characteristics of each WWTP is presented in 3.1, such as location, individuals connected and population equivalents (pe) (Videbris, 2024; M.Tuvesson, personal communication, 6 February, 2025; Eriksson, 2024; Kalmar Vatten, 2024; Käppalaförbundet, 2024; M.Björksund- Tuominen , personal communication, 12 March, 2025). Individuals connected are not included industries. To exemplify the number of pe for Henriksdal WWTP 528 tons/year, which is approximately 10 times higher than the pe at Kalmar WWTP and 100 times higher than the pe at Essvik WWTP. An overview of the treatment processes used at each WWTP is also provided in Appendix A.

Table 3.1: Information about the WWTPs

WWTP	Rya	Essvik	Henriksdal	Kalmar	Käppala	Smedjeholm
Location	Göteborg	Sundsvall	Stockholm	Kalmar	Lidingö	Falkenberg
Individuals connected	824 000	11 200	884 000	66 950	577 000	41 900
Population equivalents	865 000	6 300	799 000	77 300	508 000	72 800

Currently, the discharge limit for all WWTPs is a yearly average of 0.3 mg / L, except Essvik and Smedjeholm WWTP, as shown in 3.2 (Videbris, 2024; M.Tuvesson, personal communication, 6 February, 2025; Eriksson,2024; Kalmar Vatten, 2024; Käppala förbundet, 2024; M.Björksund- Tuominen , personal communication, 12 March, 2025). Smedjeholm has a yearly discharge limit of 0.5 mg/L while Essvik has a discharge limit of 0.5 mg/L for quarterly average. In addition, Rya has an additional discharge limit for the months of May to August, which is also 0.3 mg/L, the same as the yearly discharge limit of Rya. Some WWTPs also have yearly and quantitative discharge limits, as shown in 3.3 (Videbris, 2024; M.Tuvesson, personal communication, 6 February, 2025; Eriksson,2024)

Table 3.2: Discharge limits for P-tot

WWTP	*unit*	Type of limit	Discharge limit
Rya	*mg/l*	Yearly	0.3
Rya	*mg/l*	May–August	0.3
Essvik	*mg/l*	Quarterly	0.5
Henriksdal	*mg/l*	Yearly	0.3
Kalmar	*mg/l*	Yearly	0.3
Käppala	*mg/l*	Yearly	0.3
Smedjeholm	*mg/l*	Yearly	0.5

Table 3.3: Yearly discharge limits for P-tot. Where * refers to a rolling average of three years and ** refers to a rolling average of two years.

WWTP	Unit	Discharge limit
Rya	tons/year	40*
Essvik	tons/year	1.5
Henriksdal	tons/year	35**

In the future, the discharge limits will become even more stringent. The WWTPs often need to be updated to meet these more stringent environmental permits. Table 3.4 shows when the different guidelines are expected to change, along with the environmental permits. To illustrate, for most WWTPs with a discharge limit of 0.3 mg/l, the discharge limit will decrease to 0.20 mg/l or 0.2 mg/l. Additionally, Käppala, which currently does not have quantity requirement of tons/year, will receive such a requirement after the reconstruction (C.Vendel, personal communication, 19 March, 2025). For Kalmar, the new conditions will apply from January 1 of the year following a full calendar year after the commissioning of the new water treatment section (Q.Zhao, Personal Communication, 21 March, 2025). The current environmental permit for Rya WWTP is valid until 31 of December 2036 (Gryaab, n.d.). In 2024, Gryaab applied for a new environmental permit. At present, they are applying to maintain the current load requirement for phosphorus of 40 tons/year, while reducing the effluent concentration to 0.2 mg/l. However, the final requirements remain to be determined.

Table 3.4: New requirements and their changing year.

WWTP	Changing year	New discharge limits mg/l	New quantitive discharge limit ton/year
Rya	2037	Not decided	Not decided
Essvik	2038	Not decided	Not decided
Henriksdal	2029	0.20	27
Kalmar	-	0.2	-
Käppla	2028	0.20	13
Smedjeholm	-	-	-

3.1.1 Rya WWTP

Rya WWTP is located in Gothenburg; however, it treats wastewater from the Göteborg municipality and six neighbouring municipalities: Ale, Härryda, Kungälv, Lerum, Mölndal and Partille. There is also another owner municipality, Bollebygd, but it is not connected via wastewater pipelines. Gryaab, the municipal company responsible for the Rya WWTP, also manages its own tunnel system, which directs wastewater from the urban population to the Rya WWTP (Videbris, 2025). The seven municipalities are responsible for the sewage network and pumping stations located in their municipality. Their current permit is valid until 31 December 2036 and for an average of 1 300 000 pe (Länsstyrelsen Västra Götalands län, n.d.). Gryaab is currently working on a new environmental permit, and in 2024 an application was sent in (Gryaab, n.d.). Rya WWTP is located in a limited space, but has received permission to expand the facility to a nearby area. This expansion is expected to be built before 2036.

Capacity 1, 8.5 m^3/s, in Rya WWTP comes from the limitation of the secondary settling (V.Tanskanen & K.Sundström, personal communication, 24 February, 2025). However, this flow assumes that the recirculation flow from the nitrifying trickling filter is redirected and not directed to the activated sludge tank. When capacity 1 is exceeded, the high flow treatment is used. This involves adding precipitation chemicals to six of the twelve blocks of the pre-sedimentation basins. This excess wastewater flow then bypasses the remaining treatment steps and is directly released to the recipient Göta Älv. The capacity of the biological and chemical treatment is 11.5 m^3/s, while the the total capcity of is 16 m^3/s.

3.1.2 Essvik WWTP

MittSverige Vatten och Avfall is responsible for Essvik and other WWTP in the municipalities of Sundvall, Timrå and Nordanstig (M. Tuvesson, personal communication, March 17, 2025). The same company is also responsible for the sewer network. Essvik WWTP is located in Sundsvall and was commissioned in 1971. A large part of the collection network in the catchment area was built during the 1970s, when the transfer pipelines were also constructed (Sundsvalls kommun, 2019).

In Essvik WWTP the phosphorus is treated using chemical phosphorus removal. The precipitation chemical is added between the drum filter and flocculation basin and later sediments in the pre-sedimentation (Shareef Mohammed, 2024). The total capacity, 860 m^3/h, at Essvik WWTP is determined by the maximum flow for pre-sedimentation and biological treatment (M. Tuvesson, personal communication, 17 March, 2025). When the flow exceeds the total capacity, the water bypasses all treatment steps except a drum filter. Therefore, Essvik WWTP only has total capacity and not capacity 1.

3.1.3 Henriksdal WWTP

Henriksdal WWTP is located in Stockholm Municipality and SVOA (Stockholm Vatten och Avfall) is responsible for the WWTP (Eriksson, 2024). SVOA is responsible for treating wastewater from the municipalities of Stockholm, Huddinge, Haninge, Nacka, Tyresö, Järfälla, Sundbyberg and Ekerö. In addition to Henriksdal, SVOA also operates WWTPs Bromma, where approximately 382 400 persons connected. Part of the wastewater is also sent to Himmerfjärdsverket, which is operated by SYVAB. In 2013, it was decided that Bromma would be decommissioned and instead the water would be redirected to Henriksdal through a tunnel (Stockholm Vatten och Avfall, 2023). Henriksdal WWTP is currently undergoing reconstruction, where membrane technology will replace the secondary sedimentation process to achieve more efficient treatment. Stricter limits will also apply from 2029 for Henriksdal WWTP (Stockholm Vatten AB, 2023). Henriksdal WWTP is divided into two parts, Sickla and Henriksdal. The future plan is to also use Sickla for pre-sedimentation and the water then goes directly to the biological treatment step, compared to today where the water goes to the pre-sedimation. Important that both Henriksdal and Sickla will have pre-sedimation.

The total capacity of Henriksdal is 10 m^3/s, but the treatment becomes less efficient at 6 m^3/s (D. Fujii, personal communication, 10 March, 2025). However, this efficiency is affected by the duration of the high-flow period and the risk of sludge washout. Furthermore, when the inflow exceeds 3.5 m^3/s, increased precipitation is typically applied in the pre-sedimentation basins. Dosing occurs in a shared channel after the sand trap, from which the flow is intended to be distributed across all 12 pre-sedimentation basins. However, in practice, this is not the case, as the flow from Sickla is directly connected to the pre-sedimentation basin.

3.1.4 Kalmar WWTP

Kalmar Vatten is responsible for Kalmar WWTP and the corresponding sewer network. The WWTP was built in 1963 and has been expanded in stages (Kalmar Vatten, n.d.). To better meet future requirements and accommodate increasing capacity, a new treatment plant, Kalmarsundsverket, is planned and expected to be operational by 2027. The new plant will have a strong focus on recycling, such as using self-produced biogas for electricity and heating production, producing certified fertilizer, and utilizing reclaimed water for irrigation of green areas, agriculture, forestry, and industrial purposes. Regarding Kalmars population equivalents, approximately 25 % of the pe comes from the process water from Arla's dairy factory (Kalmar Vatten, 2022).

The maximum flow capacity of the wastewater treatment plant is unclear (Q. Zhao, personal communication, 17 March, 2025). On one occasion, Kalmar experienced exceptionally high inflow, to the extent that all inflow flow meters maxed out, and the flow summary indicated 51 100 m^3/day although the actual flow was significantly higher. This high flow led to flooding in the secondary settling tanks. Despite the fact that the real flow was much higher, this value (51 100 m^3/day) will be used as the total capacity. Kalmar WWTP has no possibility to by-pass treatments steps in the WWTP and potential overflows instead occur before the WWTP (Q. Zhao, personal communication, 17 March, 2025). They have, however, for several years been working with overflow water optimization, where the overflow points are classified according to varying degrees of suitability based on equalization volume, dilution effect in the receiving water, health risks, and the feasibility of clean-up after an overflow event (A. Händevik, personal communication, 2025). For the other WWTP overflows before the WWTP will not be considered, however, for Kalmar exception will also be made for Kalmar in future scenarios where overflow before the WWTP included.

3.1.5 Käppala WWTP

Käppala WWTP is located in Lidingö and treats wastewater from eleven municipalities (Käppalaförbundet, 2025). Käppalaförbundet is responsible for the WWTP and tunnel system, while the municipalities are responsible for their sewer network. Käppala WWTPs is currently under rebuilding (Käppalaförbundet, n.d.). It has been decided that two of the eleven lines will implement MBBR instead of activated sludge, (J.Grundestam, personal communication, June 5, 2025). Further reconstruction is planned, but will be decided in a later stage.

Käppala WWTP has a high-flow treatment step (Käppalaförbundet, 2024). The WWTP therefore has one capacity for normal treatment, 5 m^3/h, and one capacity where bypassed flow treatment is also included, 8 m^3/h. When the flow exceeds 5 m^3/h, all water is coarse-screened and then divided into separate treatment lines. The majority is treated in the regular process, while portions of the water are directed to the high-flow treatment. This process is much faster compared the the normal treatment(Käppalaförbundet, 2024). The process uses chemical precipitation and lamella separation, combined with a technique in which flocculation occurs with microsand. The high-flow treatment significantly reduces organic material, and phosphorus in the wastewater.

They explain that Käppala WWTP has historically been very successful in avoiding bypasses, as it is a large WWTP with multiple treatment lines and a large wastewater tunnel where water can be stored, thus smoothing out flow peaks (Käppalaförbundet, 2024). To illustrate this, between 2013 and 2022, only 13 bypasses occurred. However, in 2023, the bypassing of the water occurred five times. The bypassed water was treated in the high-flow facility. One reason for the increased frequency of bypassing could be the decreased capacity, due to ongoing reconstruction at the plant and temporary shut-down of treatment lines.

3.1.6 Smedjeholm WWTP

Vatten & Miljö i Väst AB (Vivab) are responsible for Smedjeholm WWTP and 22 other WWTP in Falkenberg and Varberg (Vivab, n.d.). They are also responsible for the sewer network. Smedjeholm WWTP is located in Falkenberg and treats domestic and industrial wastewater (M.Björksund-Tuominen , personal communication, 12 March, 2025). Domestic and industrial water has different intakes, the influent water is analysed separately and also partly received different treatment processes. To exemplify in 2024 the average concentration for BOD_7, total nitrogen and total phosphorus for the domestic water were 221, 38 and 4,7 mg / L respectively, while industrial water concentrations were 425, 42 and 11,6 mg/L, respectively. The industrial water is approximately 15% of the total inflow (M.Björksund-Tuominen , personal communication, 12 March, 2025). The domestic water goes through bar screen, grit chamber, primary settling, activated sludge basin, middle-settling and chemical treatment. The industrial water goes through a Sequencing Batch Reactor, SBR, before joining the domestic wastewater for the chemical treatment step. The most significant industrial activities include the manufacture of malt and soft drinks, production of dairy products, slaughter of poultry, marination of chicken parts, production of ice cream, preparation and smoking of fish, and production of salads.

At flows between 1000-1600 m^3/h, domestic water bypasses the biological treatment step directly to the chemical treatment steps (M.Björksund-Tuominen , personal communication, 12 March, 2025). Therefore, capacity 1 is 1000 m^3/s. The next capacity is reached when 1600 m^3/h is exceeded, at which point the domestic and industrial water is bypassed after the pre-sedimentation and goes directly to the recipient. At flows over 2100 m^3/h the pre-sedimentation is also bypassed. However, since both industrial and domestic water are used in the model capacity 1 was increased by 15 % to account for the fact that industrial flow does not pass through the mechanical and biological treatment stages.

4 Methods

This chapter presents the methodology used to address the thesis's objectives and research questions. The study is divided into three main parts: model improvement, scenario analysis, and interview study. Each part employs different methodological approaches. The first part of model improvement focuses on how the model is developed and improved. This includes determining the calculated population based on average pollution load per person and separating sewage from infiltration and inflow. The methodology for the second part scenario analysis is also explained. The third part interview study will explain how the methodology of the interviews, participant selection, and ethical considerations.

4.1 Model development

This section will explain how the model was developed and the steps that were taken to improve the model. This includes, for example, calculating population equivalents, separating sewage water and infiltration and inflow, and the final model. The result of the model will be compared with the actual mass of phosphorus. It compares the result when the daily flow is used with the hourly and weekly flow.

4.1.1 Determining the calculated population

This section explains the different steps for determining the calculated population, which used to easier compare the WWTP by standardisation of the wastewater flow and phosphorus discharge to l/p,d and g/p, year, respectively.

4.1.1.1 Calculating average pollution load per person

The yearly pollutant mass was calculated with the volume of wastewater together with the influent concentration for total phosphorus, total nitrogen, BOD_7 and COD. When the yearly pollutant mass was calculated, the next step was to calculate the daily pollution load per person. This was calculated with the annual mass of the four parameters and the number of individuals connected to the WWTPs. Then the daily pollution load per person for each year and WWTP was used to calculate the average pollution load, sample standard deviation, and coefficient of variation (CVe), for all WWTPs over the four years. See equations 4.1 and 4.2 for sample standard deviation and CV. . For the equation for sample standard variation n is the number of values in the sample and $\bar{x}$ is the average value of the samples. The parameter or parameters with the lowest CV for daily pollution load was used as basis for calculating the new population equivalent.

$$\text{Sample standard deviation} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{4.1}$$

$$\text{Coefficient of Variation (CV)} = \frac{\text{Standard Deviation}}{\text{Average Value}} \times 100 \tag{4.2}$$

4.1.1.2 Calculated population

When calculating the calculated population, two methods and verification step were used. The first method will be referred to as calculation method 1. For calculation method 1 the total mass for all six WWTPs was divided with the total number of individuals connected, to get the much pollutant 1 new "population equivalent" represented. To calculate the calculated population for each WWTP, the average pollution load for each year and WWTP is divided with the pollutant mass 1 "population equivalent" represented, see 4.3. If more than one parameter is chosen, the calculated population is based on the different pollutants will be calculated separately and then the average number of calculated population will be used.

$$\text{Number of "pe"} = \frac{\text{The yearly pollutant mass for each WWTP}}{\text{Average pollutant mass per person}} \tag{4.3}$$

The second method will be referred to as calculation method 2. The new "population equivalent" will be calculated by dividing the average pollution load for each year and WWTP by the average pollution for the six WWTP. In this method, all WWTP are weighted as equal for calculating the "population equivalent". If more than one parameter is chosen, the calculated population is based on the different pollutants and will be calculated separately, and then the average calculated population will be used.

In addition, a verification step was performed, in which the average ratios between BOD_7/P, BOD_7/N, N/P, COD/BOD_7 were calculated to see if any proportions of pollutants for WWTP were unusual. The ratios were compared with each other. An average ratio, sample standard deviation, and cv were calculated on the basis of the ratio for all WWTPs during the four years.

4.1.1.3 Data used for calculating population equivalents

This section will explain which data have been used to calculate the population equivalents. The data is from the years 2021-2024 and from six WWTP located in Sweden. For the volume of wastewater, daily flows were used most often, except for Kalmar 2021-2023, where weekly flows were used. For influent concentration, both weekly and daily samples were used, depending on the data available. If both samples were available, the weekly sample was chosen since this is representative for the whole week. If daily sample was used, it was assumed to be representative for the whole week. The daily flow was then multiplied by the pollutant concentration for its corresponding week, to get daily mass of total phosphorus, total nitrogen, BOD_7 and COD. Then, all daily pollution masses during a year were added together to get the yearly pollution mass. The data used for the calculations can be seen in 4.1.

Table 4.1: Data for calculting flow and pollutant concentration at different WWTPs

WWTP	Flow	Pollutant concentration
Rya	• Daily	• Weekly
Essvik	• Daily	• P-tot and COD weekly • BOD_7 and N-tot daily
Henriksdal	• Daily	• N-tot weekly • BOD_7 and P-tot daily
Kalmar	• Weekly 2021–2023 • Daily 2024	• 2021–2022 N-tot daily, P-tot, COD and BOD_7 weekly • 2023 N-tot and COD daily, BOD_7 and P-tot weekly • 2024 all daily • COD calculated based on TOC
Käppala	• Daily	• P-tot, N-tot and COD weekly • BOD_7 daily
Smedjeholm	• Daily	• P-tot, N-tot and BOD_7 daily • COD calculated based on TOC

4.1.1.4 Managing missing and incomplete data

There were a couple of days that lacked data for the wastewater volume, and then the yearly average value was used instead. When pollutant concentration was lacking a nearby value was assumed instead. For Henriksdal the time period between 2022-05-25 and 2022-07-15 lacks data for influent concentration, due to problems with sampler (D.Fujii,personal communication, 30 April, 2025). For this long period the average concentration for 2022 was used instead. For Smedjeholm WWTP and Kalmar WWTP, the COD is not analysed but calculated from total organic carbon (TOC), while Henriksdal WWTP has neither calculated nor analysed COD. Also, the number of individuals connected during 2023 was used for some of the WWTPs, since this data for 2024 was not available yet.

4.1.2 The model for calculating effluent phosphorus based on flow

This section will explain how the simplified model has been developed. The model will predict the effluent phosphorus concentration on the basis of the daily flow. Data such as effluent concentration, daily flow and capacity were used. The model will use three different flows and their corresponding capacities, as shown in Figure 2. The different flows are based on the capacities of the WWTPs. Two types of capacity levels were defined. Capacity 1 refers to the flow level up to which optimal treatment is applied. When this capacity is exceeded, it occurs some kind of treatment adaption to the high flow. In this case treatment adaption to the high flow refers to bypassing treatments steps, precipitation in the primary sedimentation or advanced high-flow treatment. Capacity 2 represents the combined capacity of both optimal and high-flow treatment. When this capacity is exceeded, the water bypasses all treatment except mechanical treatment. An overview of the methodology for calculating the concentration for each flow can be seen in Figure 4.1.

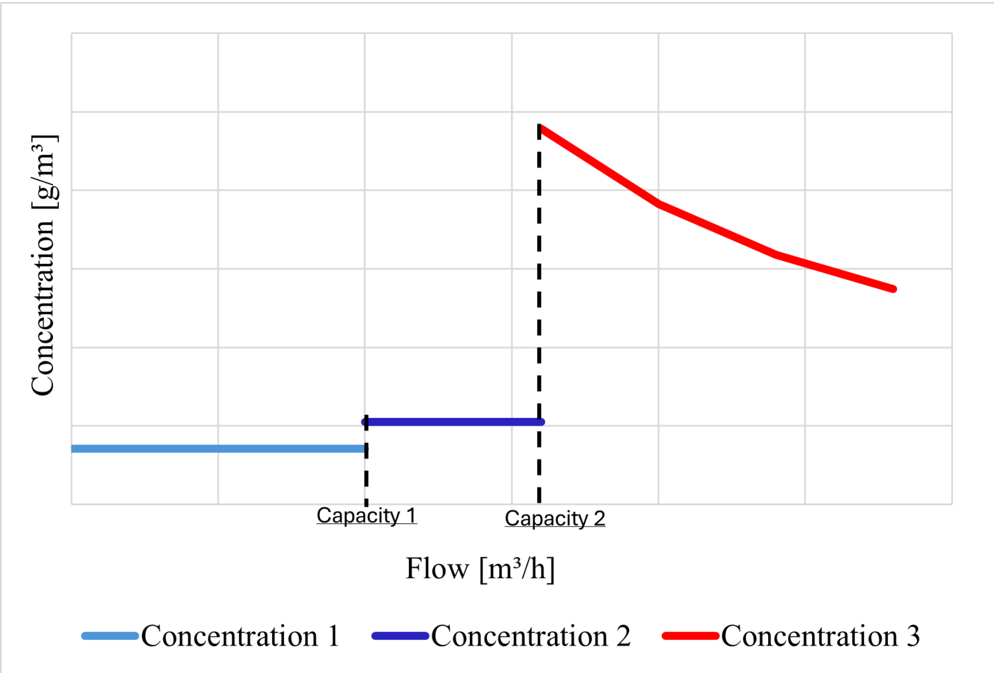


Figure 4.1: Illustration of how the model works

4.1.2.1 Calculating the different concentrations

First all the daily flows and their corresponding phosphorus concentration for weekly sampling for each WWTP between 2021-2024 were arranged in ascending order based on daily flow. Then concentration 1 was estimated based on the average value. This is the concentration for flow 1, which is used from 0 up to capacity 1. Concentration 1 is calculated as the average concentration for flow values falling between the 0th and 80th percentiles within capacity 1. For some WWTPs which had very high concentrations during low flows, the lowest percentile was also excluded. The highest flows were excluded to ensure that high flow treatment is not used during the day and has an impact on effluent concentration. It is important to note that this project uses daily flow data rather than hourly flow data, which may give a misleading impression that high-flow treatment was not used on a particular day, although capacity 1 may have been exceeded during peak hourly flows. The problem is illustrated by figure 4.2 and figure 4.3 , where weekly, daily and hourly flow for Rya WWTP 2024 is compared.

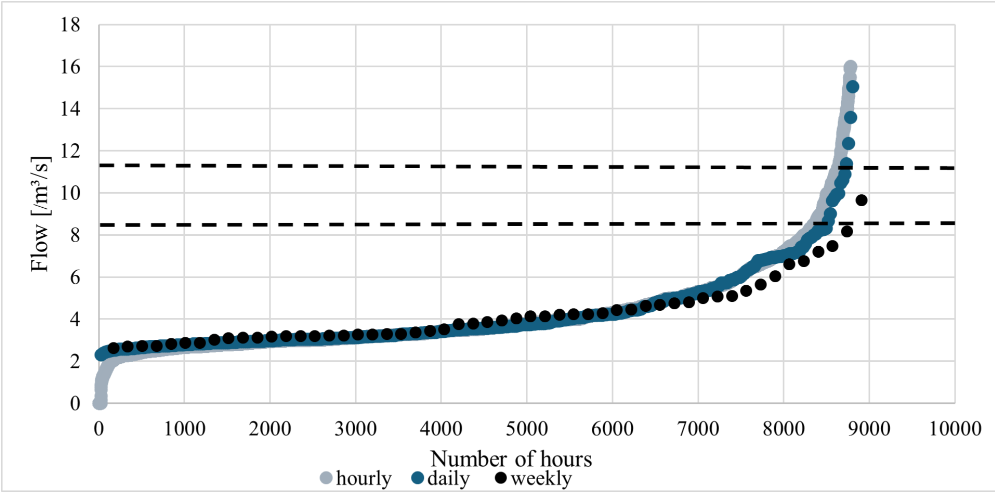


Figure 4.2: Comparison between hourly, daily and weekly flow during 2024 for Rya WWTP in assending order

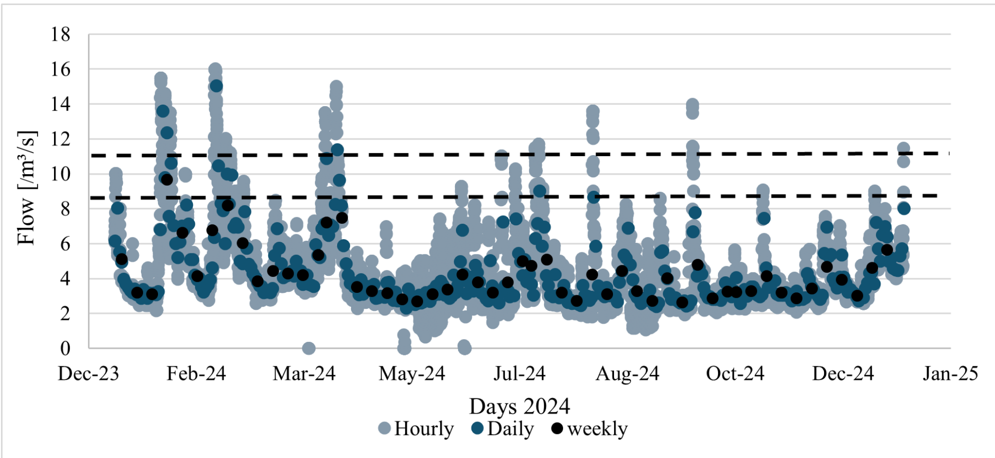


Figure 4.3: Comparison between hourly, daily and weekly flow during 2024 for Rya WWTP in chronlogical order

Concentration 2 is generally not measured, but is calculated backwards using flow 1, flow 2, concentration 1 and the final concentration of the total flow 1 and flow 2 ,see equations 4.4 and 4.5. First the average concentration between 0-80 percentile between capacity 1 and 2 was calculated, referred to as C_{tot}. Concentration 2 is calculated by multiplying the flow up to capacity 1 with concentration 1 and adding the exceeding flow multiplied with C_{tot} and then dividing this with flow 2. This is calculated for the flows for each WWTP. In the first part of the interval, when Q_2 is small the concentration 2 becomes very high. These values are therefore not considered when calculating the average value for concentration 2.

$$Q_{\text{tot}} \cdot C_{\text{tot}} = Q_1 \cdot C_1 + Q_2 \cdot C_2 \tag{4.4}$$

$$C_2 = \frac{Q_{\text{tot}} \cdot C_{\text{tot}} - Q_1 \cdot C_1}{Q_2} \tag{4.5}$$

Lastly, concentration 3 was calculated; this is used when the flow exceed the total capacity. The exceeding flow is assumed to have the same concentration as the influent. Concentration 3 calculated by dividing the average phosphorus mass in the influent by the total flow. The average phosphorus mass is based on multiplying the population equivalents by the average phosphorus concentration per person. Concentration 3 therefore varies with flow and partly accounts for dilution.

Then these concentrations were used in an Excel model. The model in Excel also had the capacity and daily flow for each WWTP and year. The three flows and the corresponding concentrations were multiplied and then summed to calculate the daily mass, see 4.6. To obtain the total annual phosphorus mass in the effluent, all days were added together. Then to better compare the different WWTP the yearly mass can later be normalised to mass/person and day.

$$m_{\text{daily phosphorus}} = Q_1C_1 + Q_2C_2 + Q_3C_3 \tag{4.6}$$

4.1.2.2 Separating sewage water and infiltration and inflow

The total wastewater flow was divided into sewage water and infiltration and inflow. The volume of sewage water was assumed to be constant, while infiltration and inflow varies. To calculate the amount of sewage water, the average calculated population was multiplied by the volume of sewage water per person, which was assumed to be 180 l/p,d. On certain days, the volume of wastewater was lower than 180 l/p,d, and in which case the actual wastewater volume was used. However, for the remaining days, the volume of sewage water was kept constant. To calculate the volume of infiltration and inflow, the volume of sewage water was subtracted from the total volume of wastewater.

4.1.3 Comparing result from model with real values

To evaluate how well the model worked, the result was compared to the real values. These were found in environmental reports or through personal communication, and the exact reference is shown in table 4.2. The difference between the model value and the real value was calculated with equation 4.7

WWTP	Reference
Rya	(Videbris, 2022), (Videbris, 2023), (Videbris, 2024), (Videbris, 2025)
Essvik	(M. Tuvesson, personal communication, 2025)
Henriksdal	(Eriksson, 2022), (Eriksson, 2023), (Eriksson, 2024), (D. Fujii, personal communication, 2025)
Kalmar	(Kalmar Vatten, 2022), (Kalmar Vatten, 2023),(Kalmar Vatten, 2024) , (Kalmar Vatten, 2025)
Käppala	(Käppalaförbundet, 2022), (J. Grundestam, personal communication, 2025)
Smedjeholm	(M. Björksund-Tuominen, personal communication, 2025)

Table 4.2: References used for real phosphorus mass (ton/year)

$$\text{RE} = \frac{\sqrt{(x_{\text{real}} - x_{\text{model}})^2}}{x_{\text{real}}} \tag{4.7}$$

4.2 Scenario analysis

To see how different scenarios affected the mass of the phosphorus in the effluent for the WWTP the baseline scenario was calculated. The baseline scenario was compared with the different scenarios. To develop the baseline scenario, the daily flow data from 2021 to 2024 were used in the model and then divided by four to obtain the annual phosphorus load. Various parameters were then adjusted to test how the phosphorus load was affected. The following parameters were changed:

• Change effluent phosphorus concentration to, 0.35 (typical for sedimentation), 0.2 (typical for filter) and 0.15 (typical for membrane).

• Change the infiltration and inflow by +50%, +20%, +10%, -10%, -20% and -50%.

• Change the sewage water from 180 l/p,d to 270 200, 160, 140 and 90 l/p,d.

• Change capacity with -50%, -25%, +25% and +50%.

4.3 Interview study

The interview study has collected information about flow management and pollutant discharge to the recipient from representatives from the wastewater treatment plant and the sewer network department. This section will explain the methodology of the interview study, interview participants, participant selection and ethical considerations.

4.3.1 Methodology of the interview study

The methodology of the interview study was the following, first the interview participants were chosen, which is explained further down. Then a interview protocol and multiply choice form were developed. A test interview called interview 2b was held and the interview protocol was further developed afterward. The final interview protocol is included in Appendix B. Both the interview protocol and the multiply choice form were written in Swedish, and the interviews were also conducted in Swedish. The same interview protocol was used for all interviews and contains questions about challenges, opportunities, collaboration with the wastewater treatment plant and the sewer network, changes in flows and measures. The multiple choice form contains questions about acceptance in 2050, challenges, and the suitability of different measures considering ecological, social, and economic aspects.

The interview study was conducted in Mars and April 2025. The interview protocol was sent out in advance. The interviews were transcribed. In addition, the results of the interview study were sent to the interview participants to ensure the accuracy of the information, for example, nothing was lacking or that some information was incorrect.

4.3.2 Interview participants and participant selection

Two interviews were conducted for each WWTP area: one with a representative or representatives of the WWTP and one with a representative or representatives of the sewer network department. Both industry professionals involved in current operations work and development work were interviewed, and they were often development engineers, process engineers, and water and wastewater strategists. In 4.3 information about the different interviews is seen such as participating in WWTP, whether the person works with the WWTP or the sewer network and work title. Participating in the WWTP does not mean that the interviewees work at the WWTP. For example, interviewees from Kretslopp och Vatten manage Gothenburg's sewer network, with water treated at Rya WWTP. Similarly, MSVA is responsible for Essvik and around 30 other WWTPs in Sundsvall, Timrå, and Nordanstig, so the interview participants work with larger areas beyond Essvik. Figure 4.4 shows some information about those who filled out the multiple choice form, for example, most of the interview participants had many years of experience in water and wastewater.

Table 4.3: Interviews conducted with staff from various WWTPs. The following abbreviations is used: SN=sewer network and W&WW= water and wastewater

Participating WWTP	Interview	WWTP/SN	Job title
	Interview 1	WWTP	Development Engineer
		WWTP	Development Engineer
Rya		WWTP	Process Engineer
	Interview 2a	SN	W&WW-Strategist
	Interview 2b	SN	W&WW-Specialist
	Interview 3	WWTP	Development Manager
Essvik	Interview 4	SN	Development Manager
	Interview 5	WWTP	Program Manager, W&WW
Henriksdal			Development
	Interview 6	SN	Investigation Engineer
		SN	Investigation Engineer
	Interview 7	WWTP	Development/Process Engineer
Kalmar		Mixed	Environmental Engineer
	Interview 8	SN	W&WW-Strategist
	Interview 9	WWTP	W&WW-Strategist
Käppla		WWTP	Process and Development Manager
	Interview 10	SN	Investigation Engineer
	Interview 11	WWTP	Process engineer
Smedjeholm	Interview 12	SN	Operations Manager for Network Systems
		SN	Production Technician for Network Systems

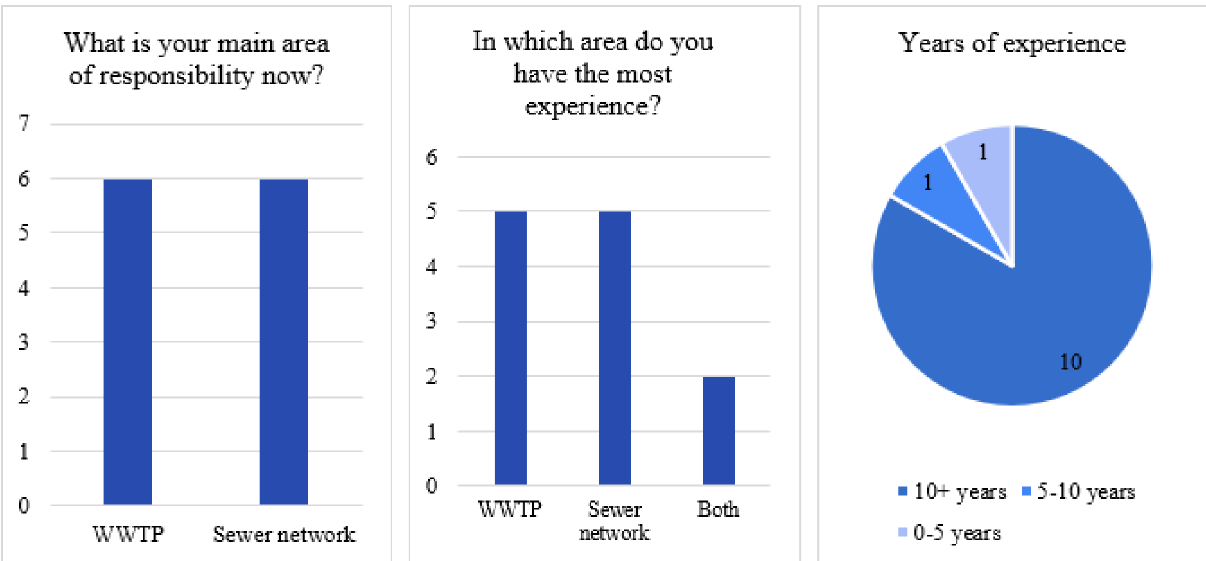


Figure 4.4: Background information about the respondents of the Google Form, such as main area of responsibilities, experience and years of experience within Water and wastewater.

Many of the interview participants working at the WWTP were identified because they contributed data to both this thesis and a thesis from 2024 by Aboobacker Siddique Mohammed Shareef. After identifying the initial participants, they were asked to recommend individuals with expertise in the sewer network. The suggested individuals were then contacted for interviews. To gain broader insight, sometimes multiple individuals were interviewed. Since this is not an in-depth research study to map the whole industry's opinions, it seemed appropriate to select interviewees who are well versed in the subject. The purpose is to collect information from representatives of the wastewater treatment plant and the sewer network department.

4.3.3 Ethical considerations

To conduct the interviews ethically, the following was done, interview participants were informed about the purpose of the interview study and how the information would be used. The questions concerned the interviewees' work and their thoughts on managing flows and reducing pollution to the recipient, rather than questions about their private lives. The interview participants were informed that the interviews were transcribed. To ensure accurate results and that nothing important was overlooked, the results of the interview study were sent to the interview participants for review.

5 Results and discussion

This chapter will present the result from the model development, scenario analysis and interviews. It also discusses potential sources of errors and parameters that might have impacted the results.

5.1 Model development

This chapter presents results from the model development. It will explain how the model was developed and improved, such as the calculated population and setting the prerequisites of the model. It will also assess how well the model performs compared to the data from the wastewater treatment plants (WWTPs) and how the result of the model changes when using hourly and weekly flow instead of daily flow.

5.1.1 Determining the calculated population

This section presents the results for determining the calculated population based on the influent pollution load.

5.1.1.1 Average pollution load

Figure 5.1 shows the average pollutant mass per connected individual for each WWTP divided by the average value for the six WWTPs and shows how much the specific load in a WWTP deviates from the overall average. Overall, Rya, Henriksdal, Kalmar, and Käppala WWTP are quite similar, and their average value is quite close to the average value for all six WWTPs, since their values are approximately around 1. The total average yearly pollutant masses for the WWTPs can be found in Appendix C. Figure 5.1 also shows that Essvik WWTP is noticeably lower for all four parameters. The opposite occurs for Smedjeholm WWTP where all four parameters are significantly higher than the average, with particularly high BOD_7 levels. Smedjeholm WWTP‘s increased pollution load might be explained by the impact of industries. The reason why Essvik WWTP values are low is unclear. For example, although Essvik WWTP also has connected industries, the number may be lower compared to other WWTPs. The area may have a higher proportion of households, and due to the smaller size of Essvik WWTP, uncertainties in the number of connected individuals could have a greater impact. Another possible explanation is that larger cities have more daily commuters, which could affect the per capita load. However, this is also seen by looking at the the number of pe based on BOD_7, where Smedjeholm WWTP has higher calculated population compared to individuals connected, while Essvik has lower calculated population compared to individuals connected. A major uncertainty in calculating influent loads is that, in some cases, only daily samples were available and were consequently assumed to represent the entire week, which may be incorrect.

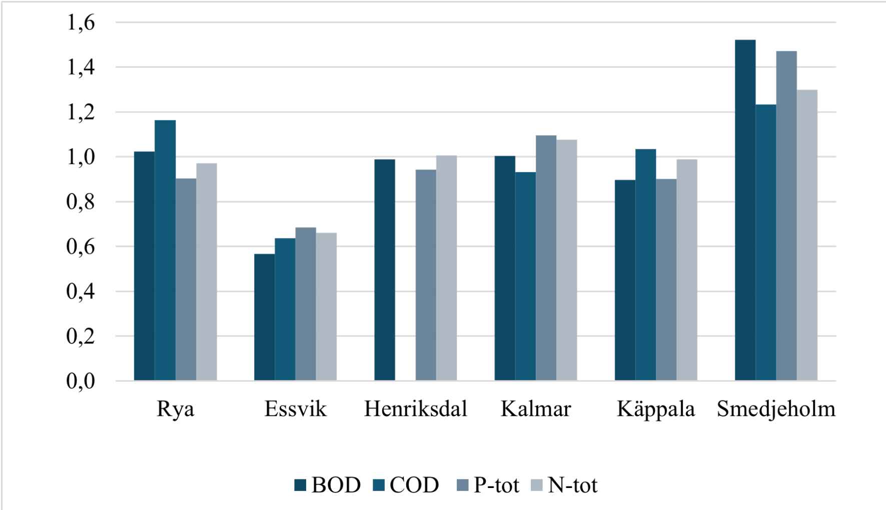


Figure 5.1: The ratio between specific pollution load at every WWTP and the average pollution load for all six WWTPs.

Figure 5.2 shows the box diagrams for the specific mass of BOD_7, COD, total phosphorus and total nitrogen in the influent water per person and day for the WWTPs. Note the different scales. The BOD_7, COD, total phosphorus and total nitrogen range between 39-119 g/p, d, 94-286 g/p, d, 1,04-2.64 g/p, d and 8.6-17.5 g/p, d respectively. For all parameters, Essvik has the lowest specific mass, while Smedjeholm has the highest specific mass.

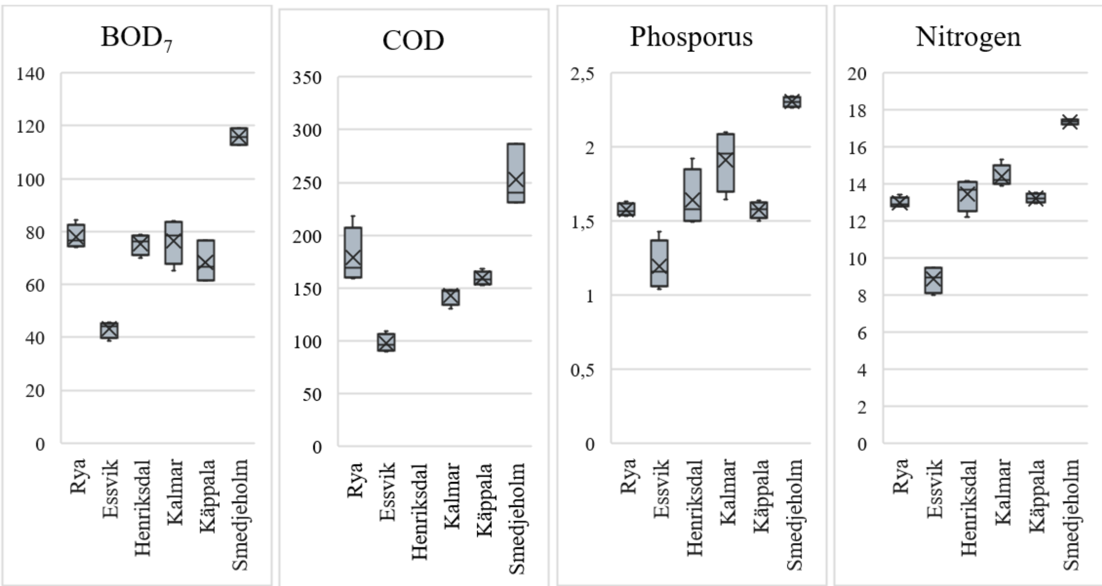


Figure 5.2: Specific mass[g/p,d] of BOD_7, COD, total phosphorus and total nitrogen in the influent water for WWTPs. The average value is marked with a cross, the mean is marked with a line in the box and the box shows the spread of the middle 50% of the data.

The average value, standard deviation, and coefficient of variation for the four parameters are shown in Table 5.1. This is based on the annual average for 2021-2024 for all six WWTPs. The coefficient of variation also shows that the variation of total phosphorus and total nitrogen is slightly less compared to BOD_7 and COD.

Table 5.1: Average value [g/p,d], standard deviation and coefficient of variation for BOD_7, COD, P-tot and N-tot

	BOD_7	**COD**	**P-tot**	**N-tot**
Average value	76	154	1.7	13
Standard deviation	26	49	0.4	2
CV	0.34	0.32	0.25	0.19

When comparing these values with typical values in Table 5.2 they seemed reasonable, but P-tot and BOD_7 might be slightly higher than most values (Press et al., 2012, Tumlin & Mattson,2013, Metcalf & Eddy, AECOM, 2014). When comparing the values with the results of the sampling of domestic water done by Gryaab, the domestic water is slightly lower than these. This is probably due to the calculated numbers that are also impacted by industries while the sampling was conducted in residential areas.

Table 5.2: Comparison of typical load values [g/p,d] for different sources

Source	**BOD_7**	**COD**	**P-tot**	**N-tot**
Rya sampling	64	130	1.1	11
Study mean value 2012	61.5		1.59	13.3
Typical Swedish values	68–82		0.8–1.2	11–16

5.1.1.2 Ratios between the pollutants

The pollution ratios are a verification step and to see how they correlate to each other. The average value of the ratio, standard deviation, and coefficient of variation for the four ratios are shown in Table 3. The coefficient of variation, CV shows that the ratio between N/P and COD/BOD_7 was more consistent compared to BOD_7/P and BOD_7/N. N/P had the lowest variation, this motivates choosing these parameters to calculate the new population equivalent. The ratios for each WWTP can be found in Appendix C. An explanation why the variation of BOD_7 and COD is higher is that these parameters are partially broken down within the sewer network. This is affected by the size of the sewer network.

Table 5.3: Average value, standard deviation, and coefficient of variation (CV) for the ratios BOD_7/P, BOD_7/N, N/P, and COD/BOD_7

	BOD_7/P	**BOD_7/N**	**N/P**	**COD/BOD_7**
Average value	43.3	5.6	7.8	2.1
Standard deviation	9.9	1.3	0.7	0.2
CV	0.23	0.23	0.09	0.12

5.1.1.3 Calculated population based on phosphorus and nitrogen

Since the CV for the total phosphorus, the total nitrogen as well as the ratio N/P were the lowest, these parameters were chosen to calculate a new population equivalent for the WWTPs. The new population equivalents based on the two calculation methods as well as and the number of individuals connected for each WWTP are shown in Table 4. The specific nitrogen load did not differ between the two calculation methods, and the specific phosphorus load was 1.6 and 1.7 g per person per day for Method 1 and Method 2, respectively.

The results of the two methods did not differ significantly. Essvik and Smedjeholm WWTPs were adjusted the most compared by the number of connected individuals. A difference with the two calculation methods is that in calculation method 1 the number of individuals connected stays roughly the same, while in calculation method 2 the total individuals connected for the six WWTPs decreases from 2 387 000 to 2 331 000 individuals. This is a decrease of approximately 55 000 individuals each year. Another comment on the two calculation methods is that the smaller WWTPs have a larger impact in calculation model 2 compared to calculation method 1.

Table 5.4: Average number of individuals connected (2021–2024), population equivalents calculated with two methods, and their percentual differences

WWTP	Individuals connected	Calculated population Method 1	Calculated population Method 2	Percentage difference Method 1	Percentage difference Method 2
Rya	816 000	794 000	776 000	-2.6	-4.8
Essvik	11 200	7 850	7 660	-29.9	-31.6
Henriksdal	880 000	891 000	871 000	1.3	-1.1
Kalmar	66 400	75 100	73 300	13.2	10.4
Käppala	571 000	561 000	548 000	-1.7	-4.0
Smedjeholm	42 600	61 600	60 000	44.6	40.9
All WWTPs	2 387 000	2 391 000	2 334 000	0.2	-2.3

In this thesis a calculated population was used. The calculated population accounts for incoming loads , rather than the number of connected individuals, can provide a more accurate representation of how WWTPs are affected, considering factors such as industries and commuters. The use of the calculated population also simplifies the comparison between different WWTPs. An aspect that could be changed in the model is using the actual number of connected individuals instead of the calculated population. However, this is only an improvement if the actual number of individuals connected is known and comparable between the wastewater treatment plants. For example, it is difficult to compare WWTPs with different levels of industrial load. Using the number of individuals connected will slightly affect concentration 3 but will mostly affect normalization to g/p,year and l/p,d. This will have the greatest impact on Smedjeholm and Essvik WWTP.

5.1.2 Setting the prerequisites of the model

This section will explain the model's prerequisites such a capacities and concentrations. Table 5.5 shows the assumed capacities that were used to develop the model. Total capacity refers to the capacity before untreated wastewater is discharged. The WWTPs that have some kind of treatment adaption to high flow also have a capacity 1. This is the capacity for the normal treatment steps at WWTP before treatment adaption to high flow, which could be by-pass of treatment steps, increased precipitation in the pre-sedimentation basin, and a separate high-flow treatment facility. For example, Kalmar and Essvik WWTP cannot bypass certain treatment steps, they will be referred to as WWTPs without treatment adaptation to high flow, while the rest will be referred to as WWTPs with treatment adaptation to high flow.

Table 5.5: Capacity 1 and total capacity for the WWTP

WWTP	Rya	Essvik	Henriksdal	Kalmar	Käppala	Varberg
Capacity 1 [m^3/h]	30 600	–	21 600	–	18 000	1 150
Total capacity [m^3/h]	41 400	860	36 000	2 100	28 800	1 750

Figure 5.3 shows the average value of total phosphorus effluent concentration during different percentiles, where the daily flow has been arranged from the highest to the lowest flow. It is observed that the WWTPs behave differently, but generally a slightly larger increase is shown for the interval with the highest flow. Also, for Essvik and Rya WWTP an increase is shown during the first percentile. The black line showing the average concentration for each percentile for the different WWTPs is showing this. However, individual trends are shown as well, for example, at Henriksdal WWTP where the concentration is quite constant at 0.2 mg/litre and then increases from 0.2 to 0.4 between percentile 60 and 100. At Käppala WWTP lowest concentration is observed at the interval with the highest flow, this might be due to dilution and that the water from the high-flow treatment is not included in the sampling.

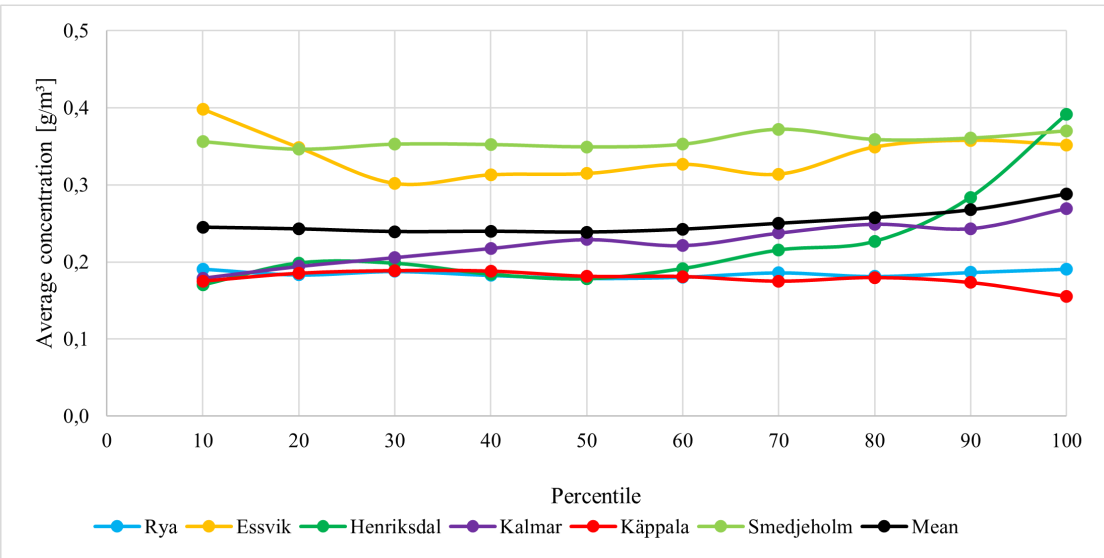


Figure 5.3: Average value of effluent phosphorus concentration [mg/litre] during different percentiles.

Because of the different trends, the interval on which the concentration was based was chosen differently. Generally, the 0-80 percentile was used, to not include values that could be impacted by flows exceeding the capacity. However, when calculating concentration 1 for Rya WWTP lowest 20 percentiles was also excluded, since the highest value was found in the 10 percentiles. The same interval for calculating the concentration was tested for Essvik WWTP, however, this gave less accurate result and 0-80 percentile was used for Essvik WWTP as well. Currently unweighted averages of concentration samples are used, where each measurement contributes equally regardless of the flow volume at the time of sampling. This method gives too much weight to the samples taken when flow is low, but concentration is high. As a result, the average concentration is higher than it would be if each sample had been weighted by its flow. An alternative way to determine the concentration would have been to base it on a flow-weighted average. In this way, high concentrations during low-flow periods would have less influence on the average concentration. Appendix D shows the different intervals that each concentration is based on.

To calculate the concentration 2 for the WWTPs with treatment adaptation to high flow, mass balance based on concentration 1 and total concentration when Q is between capacity 1 and capacity 2 was used. The mass balance calculation of concentration 2 for Rya WWTP was quite near an advanced approximation made by Gryaab and therefore deemed as appropriate. For Käppala WWTP the concentration 2, concentration from high-flow treatment, is 0,15 mg/litre (J. Grundestam, personal communication, March 25, 2025). Since the water passing the high-flow treatment is not included in the normal sample, mass balance to calculate concentration 2 was not done for Käppala WWTP. Table 5.6 shows the different capacities and their corresponding concentration. The capacity is shown in both m^3/h and l/p,d. For Kalmar WWTP and Essvik WWTP , concentration 2 is valid for from zero to capacity 2 is exceeded. This is because they do not have treatment adaptation due to high flow which result in a different concentration.

Table 5.6: Capacities and concentrations for each WWTP

Parameter	Rya	Essvik	Henriksdal	Kalmar	Käppala	Smedjeholm
Capacity 1 [m^3/h]	30 600	–	21 600	–	18 000	1 150
Capacity 1 [l/p,d]	930	–	600	–	790	450
Concentration 1 [g/m^3]	0.183	–	0.198	–	0.182	0.355
Total capacity [m^3/h]	41 400	860	36 000	2 100	28 800	1 750
Total capacity [l/p,d]	1 300	2 320	1 000	620	1 300	680
Concentration 2 [g/m^3]	0.202	0.332	1.720	0.217	0.150	0.524

Concentration 3 occurs when total capacity is exceeded and by-pass of all treatment steps except mechanical treatment. It is assumed to have the same concentration of the influent water, where the daily phosphorus load is constant but the volume, and therefore also the concentration, changes. This means that the same curve is used for all WWTPs. An example of how effluent concentration varies depending on flow in Smedjeholm WWTP is seen in Figure 5.4. Later, the flow was normalized to l/p,d to better compare WWTP, as shown in Figure 5.5. The black line shows concentration 3, which all WWTPs follow but depends on the flow. The concentration 1 for Rya WWTP is partly behind Käppala WWTP and is therefore difficult to see.

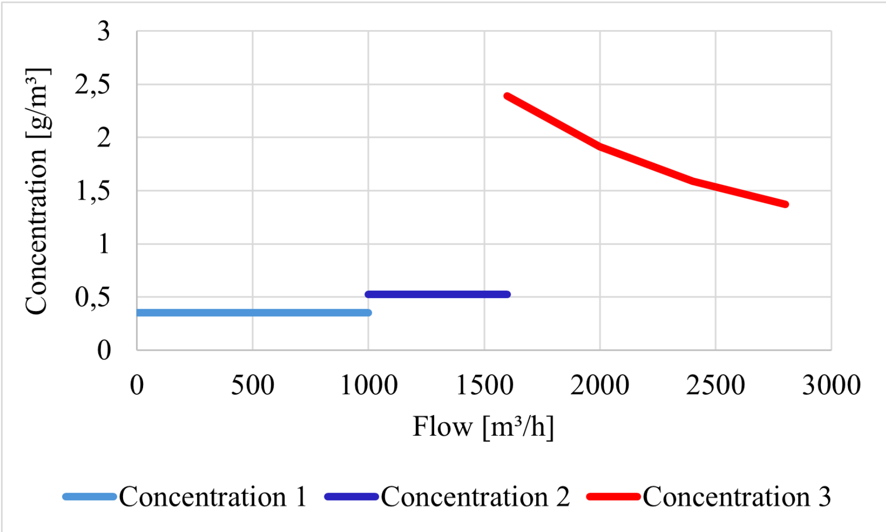


Figure 5.4: Effluent concentration depending on flow at Smedjeholm

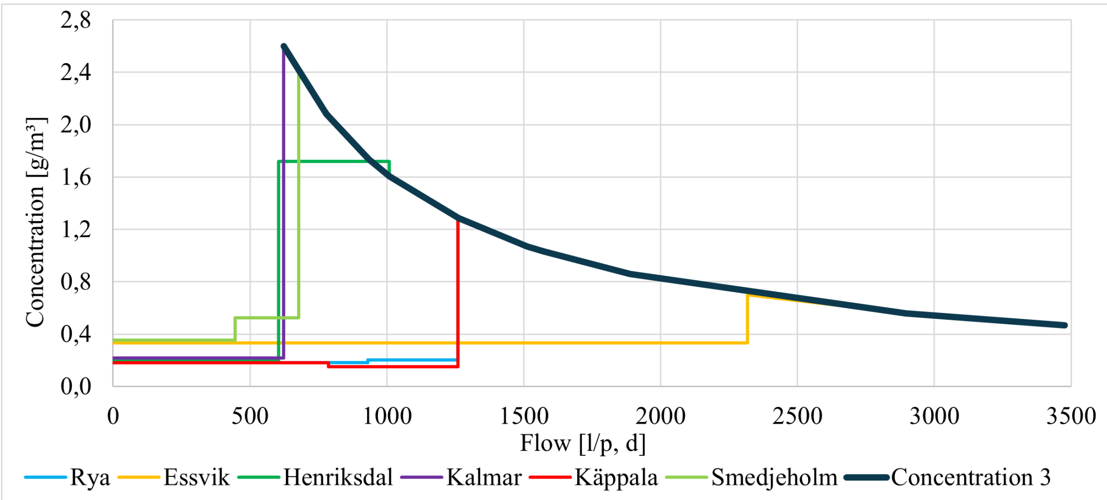


Figure 5.5: The effluent concentration during different flows for the different WWTPs

A comment in Figure 5.5 is that for Henriksdals WWTP concentration 2 is higher than concentration 3, which it should not be since concentration 3 is influent concentration. It is not supposed to be this way, but what has gone wrong remains unclear. Possibly concentration 2 is too high or that the general way to calculate concentration 3 is not representative for Henriksdals WWTP.

5.1.3 Comparison between the model and the real values

The degree to which the results correspond to the real value could be seen in figure 5.6. If the circle is on the gray line, the model value and the real value are the same, if the circle is above the line, the model overestimates the real value, and if it is below the line, the model underestimates the real value. On average, the absolute difference between the model and the real value is 7 %. In general, the model value is lower than the real value. The real values without standardisation can be found in Appendix E. One possible reason why the model underestimates the actual values is that the top 20th percentile of the capacities was excluded when calculating the capacities. This may have resulted in concentrations that were too low, which in turn led the model to underestimate the values. Another possible reason is that the model is based on the assumption that the facility is operating optimally and does not take into account operational failures or renovations.

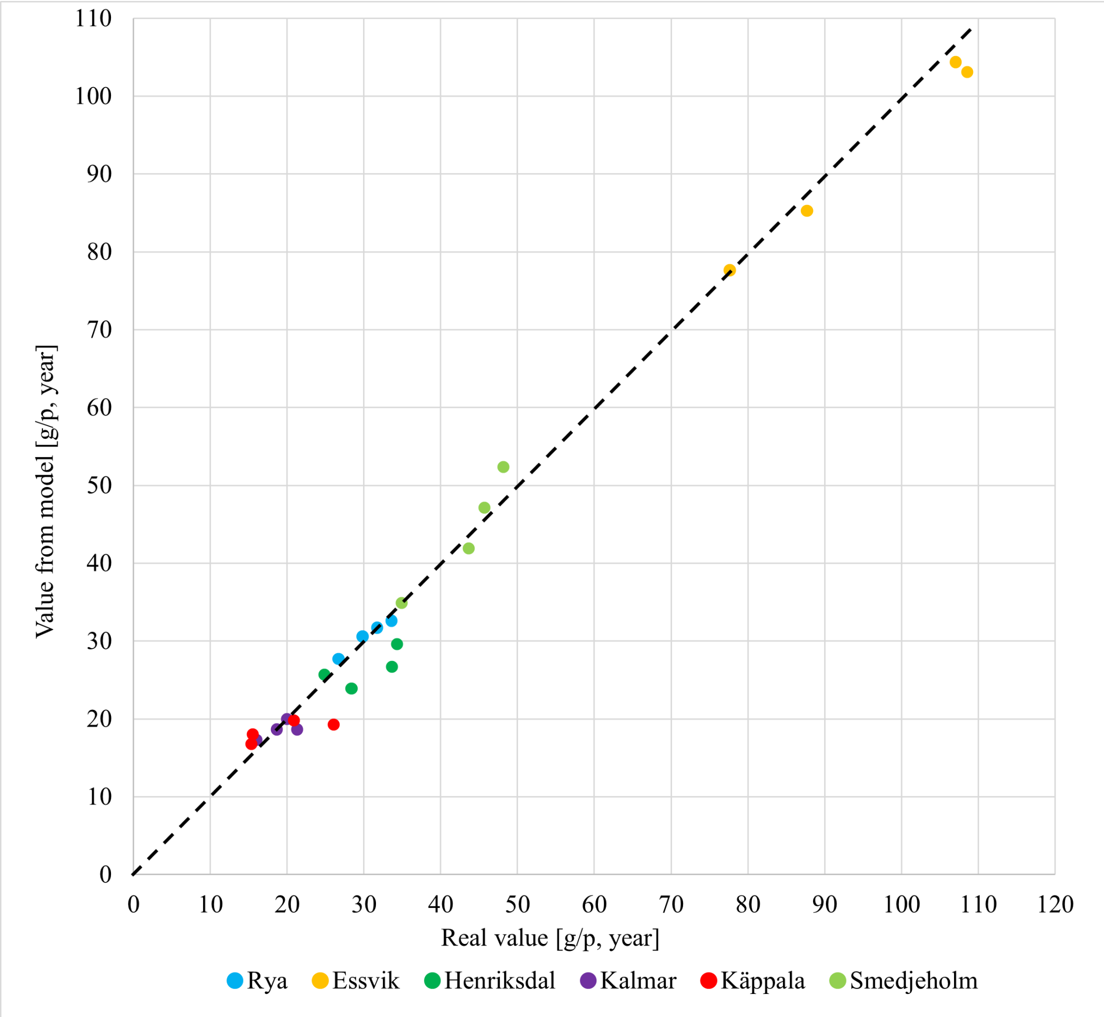


Figure 5.6: Comparison between value from model and real value

Table 5.7 shows that the model is very accurate for Rya and Essvik WWTP, slightly less accurate for Kalmar and Smedjeholm WWTP. For Henriksdal and Käppala WWTP the model works less well, and the average difference is around 13 % and 14 %, respectively. Table 5.8 shows how the model works for different years. It was seen to be more accurate for 2021-2022 and worked less well for 2023-2024.

Table 5.7: Percentual difference between model and actual value for each WWTP

WWTP	Rya	Essvik	Henriksdal	Kalmar	Käppala	Smedjeholm
	2,3	2,6	13,4	5,2	14,1	4,1

Table 5.8: Percentage difference between model and actual value for each year

2021	2022	2023	2024
4,9	6,2	8,2	8,5

5.1.3.1 Explaining variations in model performance

This section will discuss possible explainations why the model perform differently for the WWTPs and between years. One possible explanation is that the model works less well in the rainy years. The fact that 2023 was the year with high flow was often mentioned during the interviews and is also shown in Figure 5.7. For 2024 the model works quite well for all WWTP except Henriksdal and Käppala where the difference for both 26 %. If the average difference for 2024 is calculated on the remaining four WWTPs it approximately 2 %. In other words, the very large errors for Henriksdal and Käppala WWTP inflate the total error for 2024. In Figure 5.8, the average flow for each year and treatment plant is shown, and it can be seen that the values for 2024 and 2023 are quite high for Henriksdal and Käppala. Also when reading their environmental reports for 2024 Käppalaförbundet reports disturbances and slightly higher effluent concentrations than previous years (Käppalaförbundet, 2025). Henriksdal WWTP also had disturbances during 2024 (Eriksson, 2025).

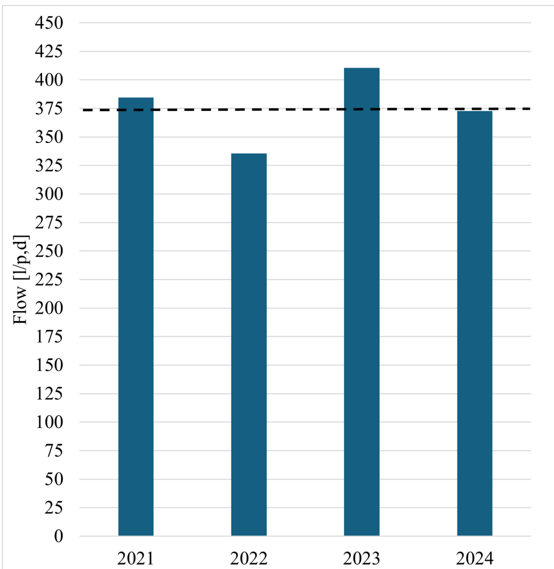


Figure 5.7: Average flow [l/p,d] for the six WWTP between 2021-2024, the black line shows the average flow for all four years

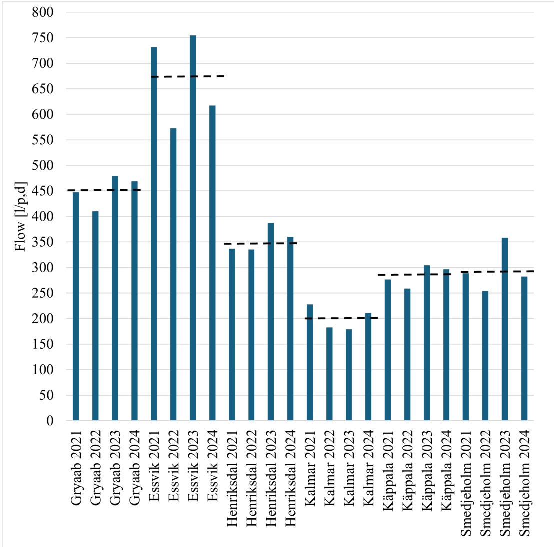


Figure 5.8: Average flow [l/p,d] for the six WWTP separately between 2021-2024, the black line shows the average flow for all four years for each WWTP

5.1.3.2 Comparison between different types of data

The difference between the model and the actual value depends on which WWTP is shown in Table 5.9. Most often, the daily data work best or about the same as the weekly data, except for Smedjeholm WWTP. This might be due to Smedjeholm WWTP having two values that are too high according to the model based on daily data. For Essvik, Kalmar and Käppala WWTP there was almost no difference. For Essvik, Kalmar and Käppala WWTP the capacity was either never exceeded or rarely exceeded. For Rya and Henriksdal WWTP, capacity 1 is exceeded more frequently and therefore it has a larger impact compared to the other WWTP. As a result, for it is preferable to use daily flow in the model for these two WWTPs.

Table 5.9: Percentual difference between model and actual value for each WWTP

WWTP	Rya	Essvik	Henriksdal	Kalmar	Käppala	Smedjeholm
Daily	2,3	2,6	13,4	5,2	14,1	4,1
Weekly	4,3	2,9	16,5	5,2	13,9	3,4

The percentage difference between the model and the actual value for each year is shown in Table 5.10. It can be seen that the model worked better in 2021 and 2022 than in 2023 and 2024. The reason is unclear, but it may be due to the higher rainfall in 2023 and 2024. In 2024, both Henriksdal and Käppala WWTP show approximately a 20% difference, which significantly impacts the results, while the average for the other four plants is around 2%. In addition, the difference between the daily and weekly data also increases during these years.

Table 5.10: Percentage difference between model and actual value for each year

	2021	**2022**	**2023**	**2024**
Daily	4,9	6,2	8,2	8,5
Weekly	5,0	6,8	9,3	9,7

It was also tested to base the model on the hourly flow for 2024. Table 5.11 shows the difference between the model and the actual value. For 2024 it is seen that hourly and daily is almost the same, while the weekly is a little bit higher. The results based on the weekly data were unexpectedly positive. It was initially assumed that using weekly data would significantly underestimate peak flows and, consequently, result in a lower calculated phosphorus load. An explanation for this is that the water exceeding capacities is a relatively low percentage. For example, at Rya WWTP in 2023, the total phosphorus of bypassed water accounted for 2.3% of the total phosphorus emissions, although the volume of this water was only 0.4% of the total water volume. Despite the small volume, it had a greater impact on phosphorus emissions. This is probably why the use of weekly or daily data is not playing such an important role. However, using weekly data has a greater impact for WWTPs where the capacity is exceeded more frequently, which can lead to less accurate results.

Table 5.11: Differences depending on data resolution (hourly, daily or weekly)

Flow data used	**Percentual difference 2021–2024**	**Percentual difference 2024**
Hourly	–	9,1
Daily	6,9	8,8
Weekly	7,9	10,4

5.2 Scenario analysis

Figure 5.9 shows the average yearly phosphorus mass [gram/person, year] from the model and average flow [liter/person, day]. These are the baseline scenarios. It can be seen that Kalmar and Käppala WWTP have the lowest phosphorus mass. Henriksdal and Smedjeholm WWTP then have approximately the same amount of water, but Henriksdal WWTP's more advanced treatment results in a lower phosphorus effluent concentration. Essvik WWTP is much higher than the rest, which might be due to the higher effluent concentration and the large problems with infiltration and inflow. Also, for Essvik WWTP, the calculated population was approximately 30 % less compared to the numbers of individuals connected, which could also have an impact. The real value of all scenarios in the scenario analysis in tons/year and m^3/h can be found in Appendix F.

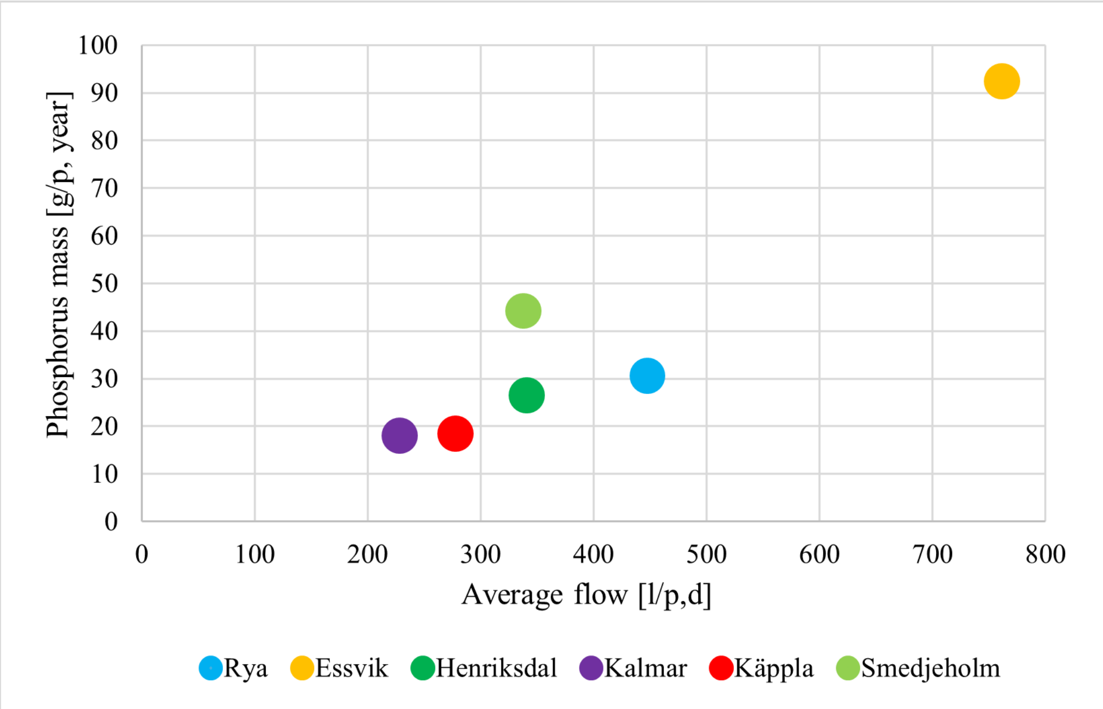


Figure 5.9: Phosphorus mass and average flow for the baseline scenarios

5.2.1 Changing the effluent concentration and capacity

During the scenario analysis the phosphorus effluent concentration for the normal treatment was changed in order to show how different treatment technology at the WWTP would influence effluent mass flows of phosphorus. Concentration 2, which occurs during treatment adaptation to high flow, remains the same. Figure 5.10 shows the difference between the phosphorus mass from the baseline and the different scenarios. For example, changing the effluent concentration of Rya WWTP to 0.35 mg/l, caused an increase of almost 30 g/p,d. It is seen that Essvik and Smedjeholm WWTP have a higher decrease in phosphors than the rest. This is reasonable since the other four WWTPs have an average effluent concentration of around 0.2 mg/L. It should also be noted that the new environmental permits for these four WWTPs require effluent concentrations to be below 0.20 mg/L, which is the scenario for the light purple circle. It is therefore highly likely that the performance will have to improve to meet the new limit. Another note is that changing the effluent concentration does not change the flow.

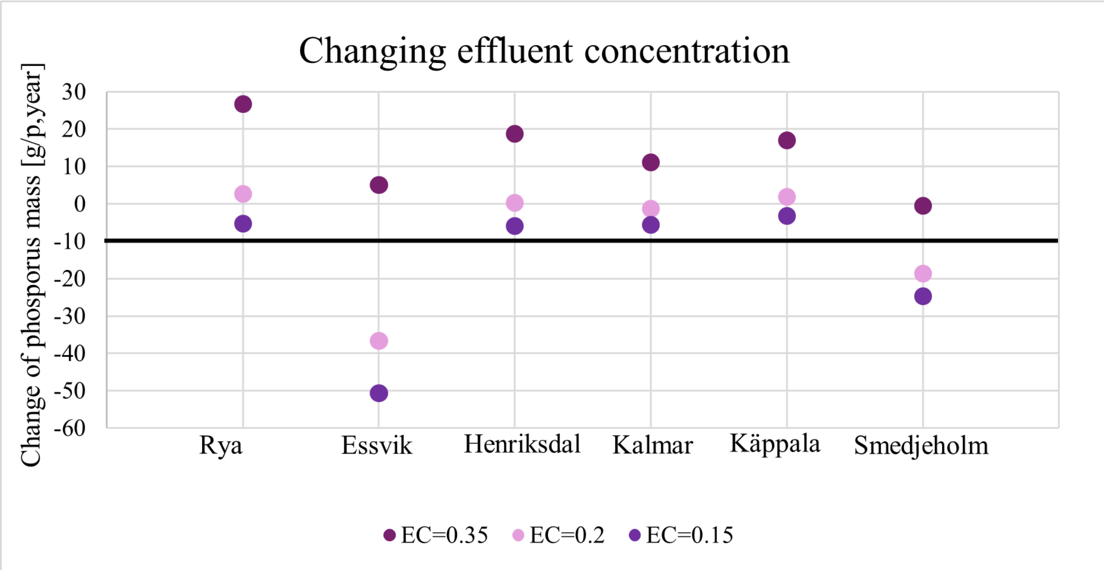


Figure 5.10: Effect of changes in effluent concentration on annual phosphorus mass

Figure 5.11 shows how the change in capacity changes the mass of phosphorus. Changing the capacity does not change the total flow. Even if there was a large increase in capacity, it did not affect the result much, probably because total capacity is rarely exceeded. At Rya and Henriksdal WWTP a small improvement was seen. Decreasing the capacity with 50% resulted in a very high increase in phosphorus mass for Rya, Henriksdal, and Smedjeholm. Essvik WWTP. Kalmar, and Käppala WWTP were less affected by the capacity decrease. An explanation for this is that both had quite low effluent concentrations and quite high capacity compared to their received flow.

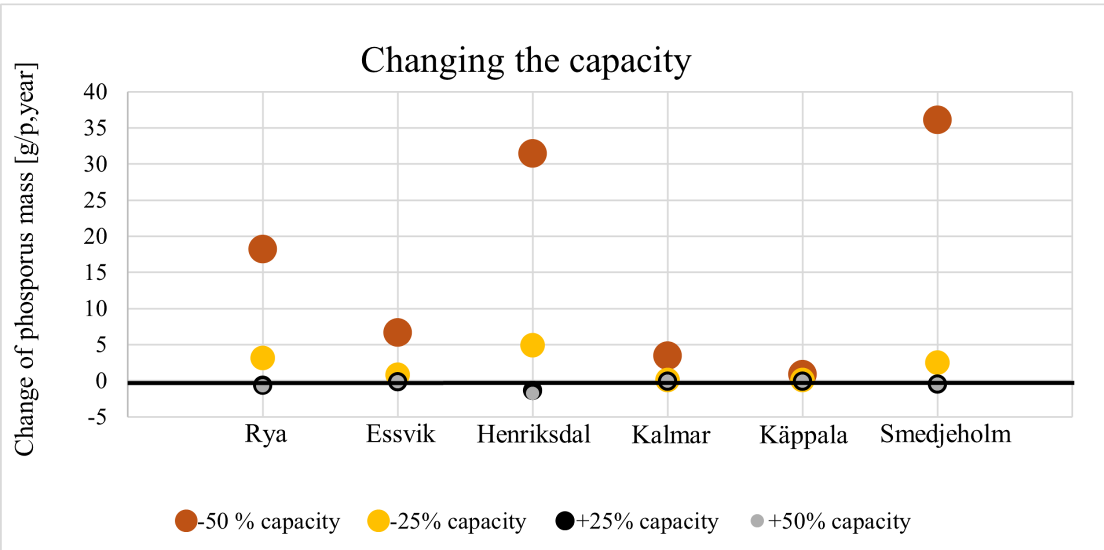


Figure 5.11: Effect of changes in capacity on annual phosphorus mass

5.2.2 Changing the wastewater flow

Figure 5.12 shows how the changed volume of infiltration and inflow affects the mass of phosphorus and the volume of wastewater. A close-up view is presented in the figure 5.13. The following scenarios were tested: decrease of 50%, 20%, 10% and increase of 10%, 20%, 50%. Generally, all WWTPs follow the same trend. Since Essvik experiences a large amount of infiltration and inflow, a percentage change corresponds to a greater volume measured in l/p,d. For Käppala and Kalmar WWTP the opposite occurs. They also show the least steep trend, suggesting that they are less affected by variations in infiltration and inflow.

For a reduction in infiltration and inflow (I/I), the curve is steepest for Smedjeholm and Essvik WWTP. For increases, the curve is steepest for Smedjeholm and Henriksdal WWTP. Therefore these plants most affected by decreases or increases in I/I. The reason why Smedjeholm and Essvik WWTP are most affected by a reduction is that their effluent concentrations are higher, resulting in a steeper curve. That Smedjeholm WWTP and Henriksdal WWTP are most affected by an increase may be explained by the fact that their "concentration 2" differs from "concentration 1", and as flows exceed a certain capacity, an increasing share of the effluent has a higher concentration. It can also be observed that the curves become steeper around +30 l/p,d.

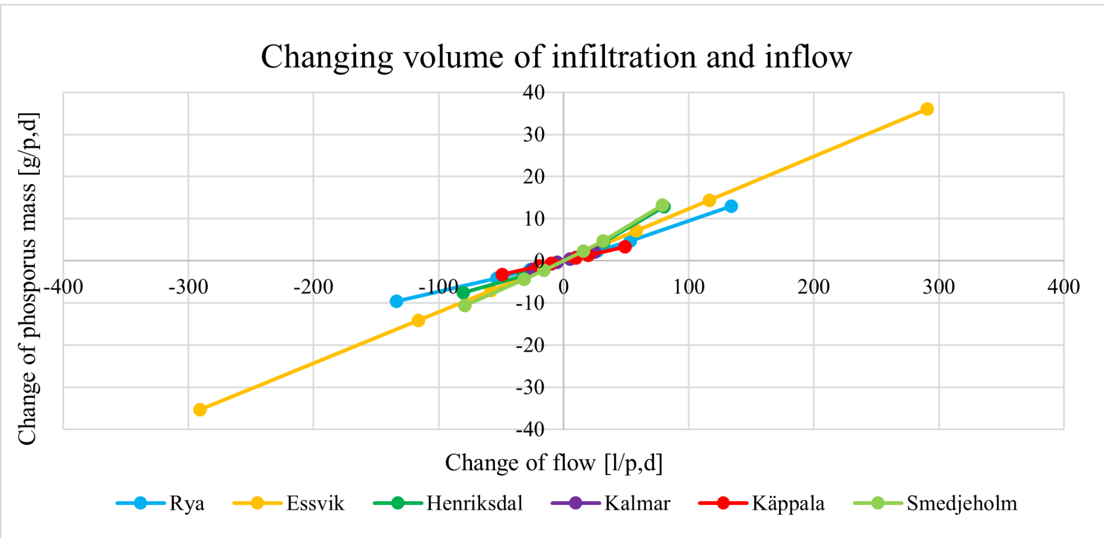


Figure 5.12: Effect of changes in I/I on annual phosphorus mass and total wastewater volume

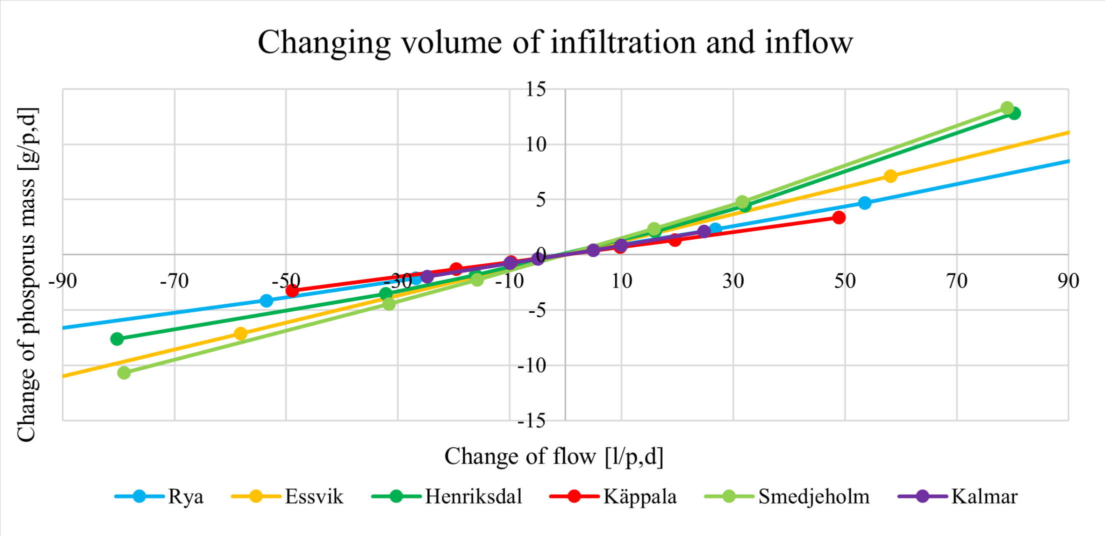


Figure 5.13: Close-up view of the effect of changes in I/I on annual phosphorus mass and total wastewater volume

Figure 5.14 shows how the change in the volume of sewage water [l / p, d] affects the mass of phosphorus. 180 l/p,d was used for the base-line and the following volumes were tested 90, 140,160, 200 and 270 l/p. Essvik and Smedjeholm WWTP have the steepest slopes. However, all other treatment plants, with the exception of Essvik and Smedjeholm WWTP, follow a similar trend. Probably due to the different effluent concentrations of WWTPs, where Essvik and Smedjeholm are around 0,3 mg / l and the rest are around 0,2 mg / l.

A general comment is that the same volume of sewage water was assumed for all WWTPs, which might not be the case. It would be better to base the volume on the volume of drinking water that is produced.

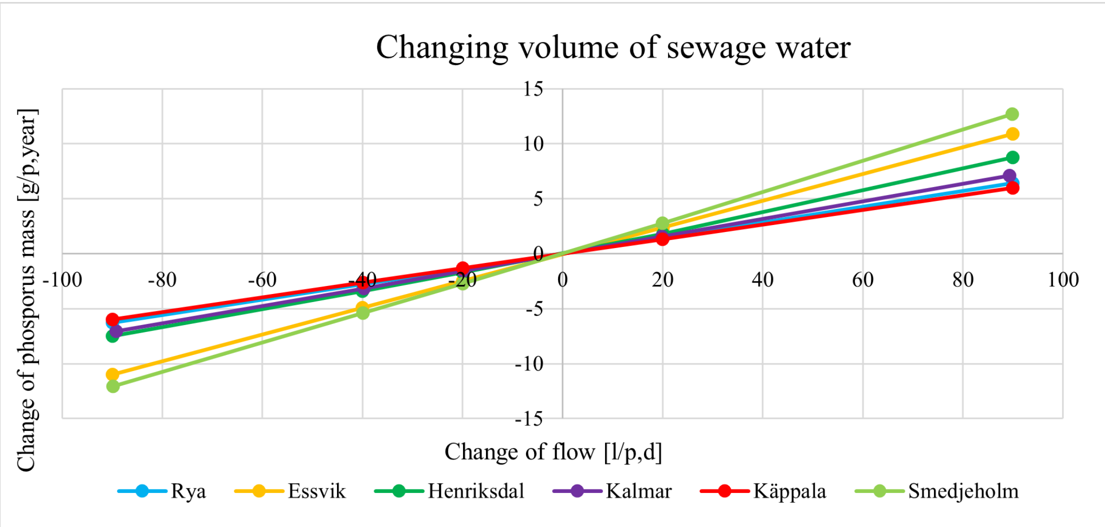


Figure 5.14: Effect of changes in sewage flow on annual phosphorus mass and total wastewater volume

A comparison between sewage water and infiltration and inflow shows that municipal flow remains constant, where infiltration and inflow shows variability. Consequently, capacity exceedances and treatment performance declines are driven to a greater extent by infiltration and inflow. It can also be observed that the slope of the municipal flow curve is constant, while the slope varies for most treatment plants in response to changes in infiltration and inflow. Figures 5.15, 5.16 and 5.17 show both infiltration and inflow and sewage water on the same graph, demonstrating that they either follow the same curve or that infiltration/inflow has a steeper curve. This steeper curve indicates that reducing infiltration and inflow is more effective than reducing sewage water.

Figure 5.15 shows the result for Kalmar and Käppala WWTP, where infiltration and inflow and sewage water follow the same curve. When increasing flow, a change of infiltration and inflow is that the curve has a marginally steeper slope. The similarity of the curves is likely due to the capacity that is rarely exceeded and the low proportion of infiltration and inflow in these WWTPs.

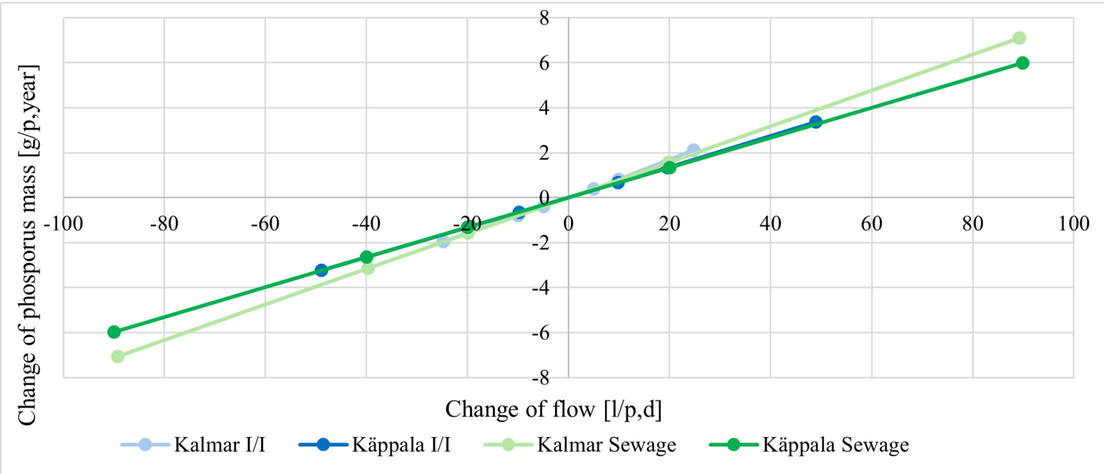


Figure 5.15: Comparison of the effects of changing infiltration/inflow versus sewage flow for the Kalmar and Käppala WWTPs.

Figure 5.16 shows the result for Essvik and Smedjeholm WWTP. For Essvik WWTP the curves for infiltration and inflow and sewage water are quite similar, which might also be because the capacity of Essvik WWTP is rarely exceeded. For Smedjeholm WWTP, the increase in infiltration and inflow has a steeper slope at the end of the curve. This likely indicates that an increase in the average volume of infiltration and inflow leads to capacities being exceeded more frequently than an equivalent increase in the average volume of sewage water.

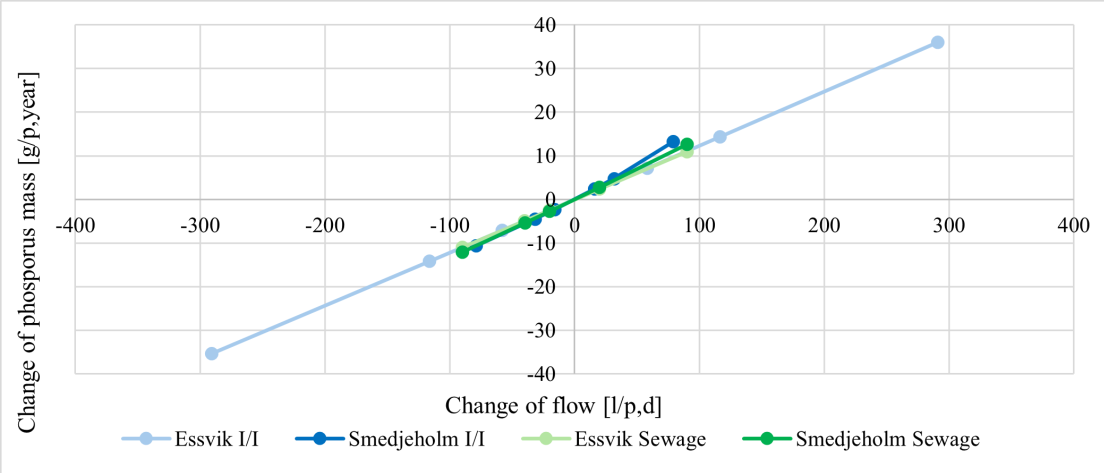


Figure 5.16: Comparison of the effects of changing infiltration/inflow versus sewage flow for the Essvik and Smedjeholm WWTPs.

Figure 5.17 shows the result for Rya and Henriksdal WWTP. Both WWTPs show a steeper curve for infiltration and inflow compared to sewage water. At Henriksdal WWTP, it is also apparent that the infiltration and inflow curve becomes increasingly steep as the magnitude of change grows. The curves indicate that an increase in I/I yields a larger volume exceeding a given capacity and thus higher phosphorus emissions than an equivalent increase in sewage flow.

It should be noted that an increase 50 % in total influent at Henriksdal WWTP represents a possible future scenario, since an upstream treatment plant will be decommissioned and its load redirected to Henriksdal WWTP. This would likely result in an increase 50 % in both infiltration and inflow and sewage flow under the same scenario. The baseline is currently 350 l/p,d, so a 50 % increase corresponds to an additional 175 l/p,d for the present population estimate. Because the population itself is also projected to increase, normalizing to l / p,d becomes somewhat problematic and does not show the increase. However, such population increase would lead to higher phosphorus emission[ton/year] for Henriksdal WWTP in total.

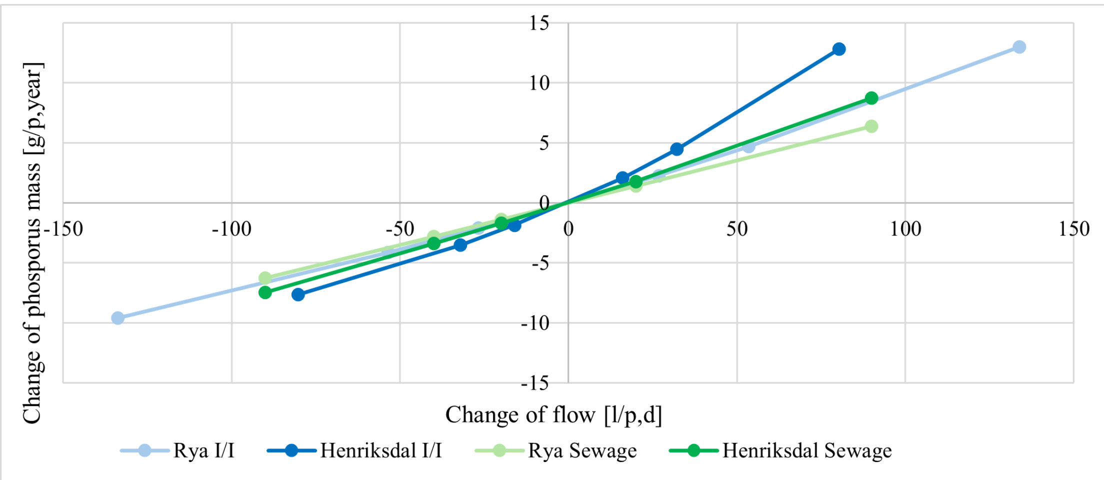


Figure 5.17: Comparison of the effects of changing infiltration/inflow versus sewage flow for the Rya and Henriksdal WWTPs.

5.3 Interview

This chapter presents the findings of the interviews conducted, focusing on the management of wastewater flow and the mitigation of pollutant discharge into receiving waters. Some of the topics in this chapter are the current state, future forecasts, challenges, opportunities, and necessary tools.

5.3.1 Current work and situation

This section describes briefly how municipalities currently manage wastewater flows and the collaboration between WWTP and pipeline personnel. It also covers perceived changes in flow and problems caused by infiltration and inflow (I/I). A longer version about the current work and situation can be found in Appendix G.

5.3.1.1 Collaboration

Preventive collaboration between professionals at the WWTP and the pipline network is generally limited, though joint efforts occur when problems arise or in specific projects, often related to infiltration and inflow. Most interviewees report regular communication and some note improved collaboration over time. For example, Käppalaförbundet plans increased cooperation with its member municipalities due to new operational requirements regarding infiltration and inflow.

Whether WWTPs and sewer networks belong to the same organization varies. In Essvik, Kalmar, Smedjeholm, and Henriksdal they are integrated, while Käppala and Ryaverket only manage the WWTP and tunnel system; their connected municipalities handle their own pipline networks.Municipalities and WWTPs often participate in knowledge-sharing networks. These are often regional. Larger WWTPs such as Ryaverket, Henriksdal, and Käppala are also part of PING, a Nordic process engineering network. Collaboration includes study visits, shared forums, and information networks. Smaller municipalities rely more on external cooperation compared to larger municipalities due to limited internal resources.

5.3.1.2 Changed flows and problems related to high flow

Many industry professionals report increased flow and capacity exceedances. MSVA also reports an increase in melt periods during winter. Whether infiltration and inflow is decreasing varies between the WWTP. Reported problems include overflows, basement flooding, increased energy and chemical use, and reduced treatment performance. Kalmar also has additional challenges such as saltwater intrusion, which disrupts biological processes. Industry professionals at Rya WWTP notes that stormwater from high-trafficked roads adds metals to the sludge, making it more difficult to meet certification standards.Another thing mentioned is that despite infiltration and inflows many downsides, it may reduce gas formation and sediment build-up.

5.3.1.3 Measures

Data collection and mapping are used to identify critical areas. Digital tools like digital twins support system analysis and planning. Overflow optimization strategies, where overflows are redirected within the sewer network based on factors such as dilution and the sensitivity of the receiving water body, aim to prevent overflows at the wastewater treatment plant. This approach helps reduce the total amount of pollutant discharges.

WWTPs implement measures such as high-flow treatment and pharmaceutical removal.They also perform an upstream work by controlling connected industries. Another measure is public outreach campaigns aiming to discourage the use of PFAS-containing products and washing cars on the street. On the pipeline side, measures include stormwater management, prioritization in sensitive areas, pipeline renewal, and conversion from combined to separate systems. Field inspections and inventories help locate leaks and faulty connections.

5.3.2 Future forecasts

This chapter will present the results of interviews concerning future development in Sweden and how acceptance will change in 2050.

5.3.2.1 Future development in Sweden

Most industry professionals believe that there is a risk of increased flows to WWTPs in the future. They further explain that this is most likely due to heavy rainfall, climate change, and increased populations connected to the treatment plants. They are preparing for increased flows by expanding the capacity of treatment plants and implementing measures to reduce flows. For example, MSVA is choosing to increase the capacity of the first treatment stage in their new WWTPs to handle higher flows.

Industry professionals believe that the pace of renewal will increase. This has been a known issue for several years and there is a large maintenance debt. It is a difficult issue that cannot be ignored and action must be taken. An increased renewal pace is expected to result in higher water and wastewater tariffs. Some also believe that property owners are becoming more informed and placing higher demands on water services and water quality. Most industry professionals believe that legal requirements will become stricter, particularly concerning the sewer network. For example, there will likely be stricter regulations around stormwater, inflow water and overflow monitoring in the sewer network. In the near future, stricter legal requirements are also expected, since the new Urban Wastewater Directive will be implemented into Swedish law no later than 2027 (Svenskt Vatten, n.d.-a). .

5.3.2.2 Acceptance in 2050.

In Figure 5.18, it is shown how the interviewees believe the level of social acceptance about the following topics is expected to change by the year 2050 compared to today. A score of 1 indicates significantly lower acceptance than today, 3 indicates the same level of acceptance, and 5 indicates significantly higher acceptance compared to today. Table 5.12 also presents the average value for all responses. In general, the opinion is that reduced acceptance in 2050 compared to today applies to almost all issues. Overflow from the sewer network and pump stations has the lowest average score, 1.6, with half of the respondents believing that there will be much lower acceptance compared to today. The other alternatives mentioned are around 2, indicating lower acceptance compared to today. From this, it can be inferred that most interviewees believe that acceptance will decrease for most parameters, which means that expectations for the water operator are likely to become stricter.

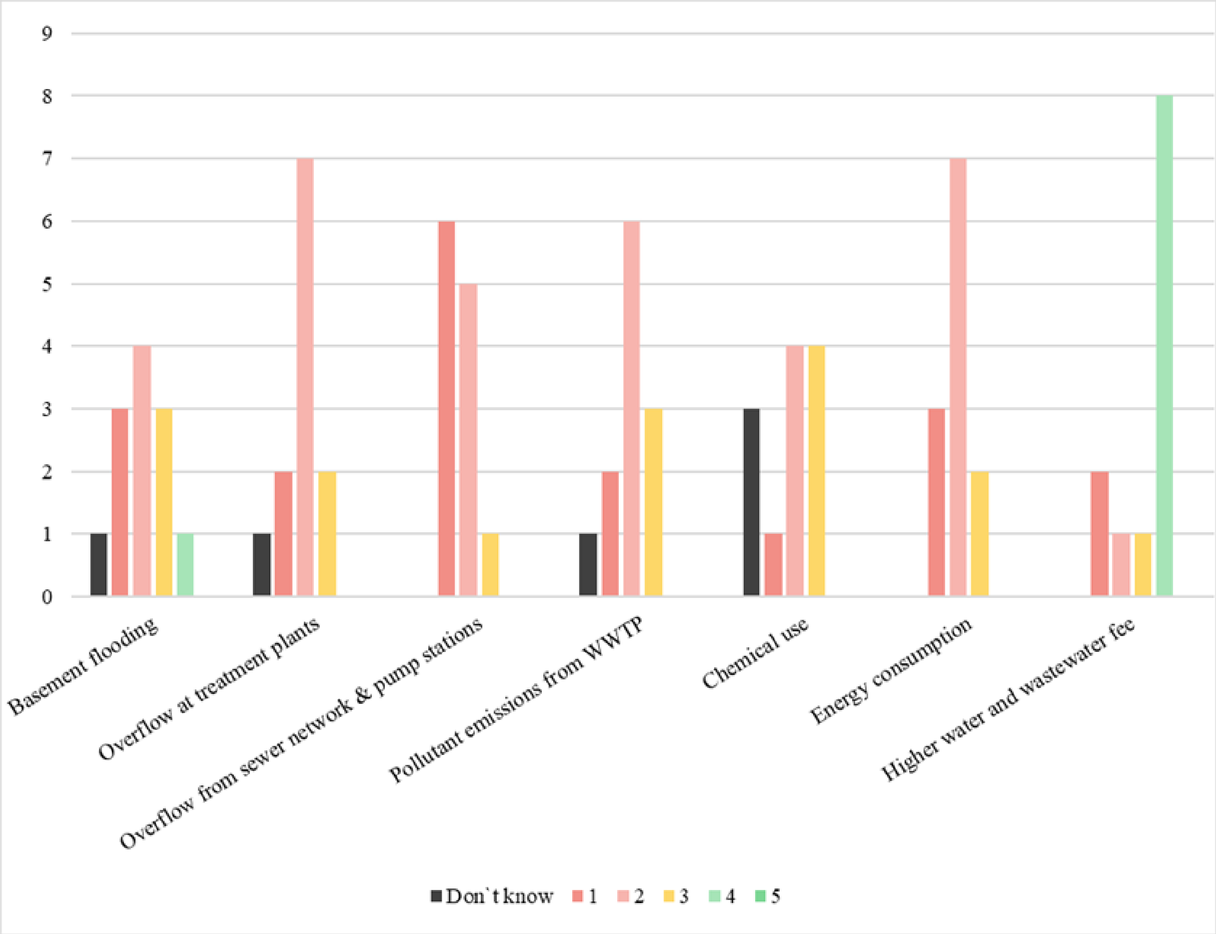


Figure 5.18: The level of social acceptance regarding the following topics is expected to change by the year 2050 compared to today

Table 5.12: Average acceptance value

Issue	Average Ranking
Basement flooding	2.2
Overflow at treatment plants	2.0
Overflow from sewer network & pump stations	1.6
Pollutant emissions from WWTP	1.9
Chemical use	2.3
Energy consumption	1.9
Higher water and wastewater tariff	3.5

For higher water and wastewater tariff, 8 out of 12 respondents answered with higher acceptance in 2050 compared to today, with an average value of 3.5. This indicates a slightly higher acceptance level compared to today in 2050. At the same time, it also emerges from the interviews that everyone believes that the future expansion of the water system will be funded by water and wastewater tariffs, and thus, it will increase. Most are therefore in agreement with the need for increased water tariffs; however, the results are not unanimous regarding how the public will respond to the increased water tariffs.

5.3.3 Assessment of measures

In the survey, different measures were graded according to their suitability from ecological, economic and social perspectives. The measures aim to manage wastewater flows and reduce pollution discharges to the recipient. The grading was done using the responses of yes, no, partially, and don't know. The amount of yes and partially answered are shown in figure 5.19, while a more detailed summary can be found in the Appendix. H. Additionally, the average rating of measures on a scale of 1-5, based on all perspectives, where 1 is a very inappropriate measure and 5 is a very appropriate measure. The different scores are shown in Table 5.13. The measure with the highest score was marked in green, while the measure with the lowest score was marked in red, and the second lowest in light red. Figure 5.20 shows the rating of measures on a scale of 1-5.

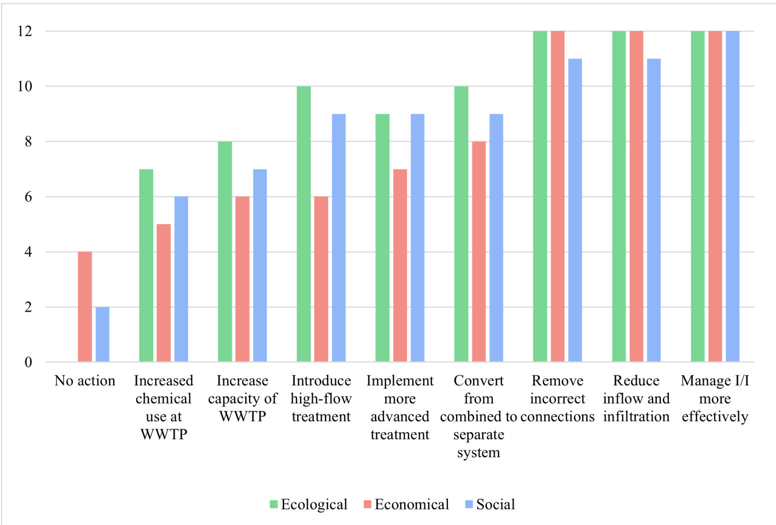


Figure 5.19: The number of "yes" and "partially" responses regarding whether the measures are appropriate from an ecological, economic, and social perspective.

All measures were assessed as neutral or appropriate based on the total score. In general, the measures were considered slightly more suitable from an ecological perspective compared to an economic and social. Both figure 5.13 and table 5.20 shows that the measures “Manage infiltration and inflow more effectively”, “Remove incorrect connections”, and “Reduce infiltration and inflow” all received very high scores. These are all measures related to the pipeline system that aim to reduce or delay inflow water. Overall, “remove incorrect connections” received the highest score, although it scored slightly lower on the social aspects. One possible explanation is that it affects property owners to a greater extent, causing disturbances and excavation work. The pipeline measure “Convert from combined to separate sewer system” received significantly lower scores than the other pipeline measures. Four people also responded that it was an inappropriate measure, which is the measure most interviewees considered to be inappropriate, when excluding “no measures”. This is likely because it is a very resource-intensive measure that can disturb the public during the construction phase, while the benefits are not immediately clear.

Table 5.13: Average rating of different measures to reduce pollution and manage high flows. 1 is a very inappropriate measure and 5 is a very appropriate measure.

Measure	Average Rating
No action	1.6
Increase the amount of chemicals at WWTP	3.0
Increase capacity of WWTP	3.5
Introduce high-flow treatment	4.0
Implement more advanced treatment	3.3
Convert from combined to separate sewer system	3.3
Remove incorrect connections	4.8
Reduce infiltration and inflow	4.2
Manage infiltration and inflow more effectively	4.2

The measures performed by the treatment plant scored between 3-4 points, with "Introduce high-flow treatment receiving the highest score", while "increase the amount of chemicals at WWTP" received the lowest score. The reason for the high score of "Introduce high-flow treatment" is likely because it is considered relatively cost-effective for handling high flows, compared to building additional treatment steps. The low score for "Increase the amount of chemicals at WWTP" is likely due to the increased environmental burden, larger amounts of chemical sludge, rising operational costs, deteriorated working conditions, and reduced resilience due to potential chemical shortages and supply chain disruptions.

"No measure" received the lowest score in all perspectives, and the measure "Increase the amount of chemicals at WWTP" received the second lowest score in the perspectives. It was expected that no measure would receive the lowest score, as the problems are only expected to grow, thus requiring action. There was also no one who considered that "no measure" was an appropriate measure in either ecological, economic or social perspective, but some industry professionals thought it was partially an appropriate measure.

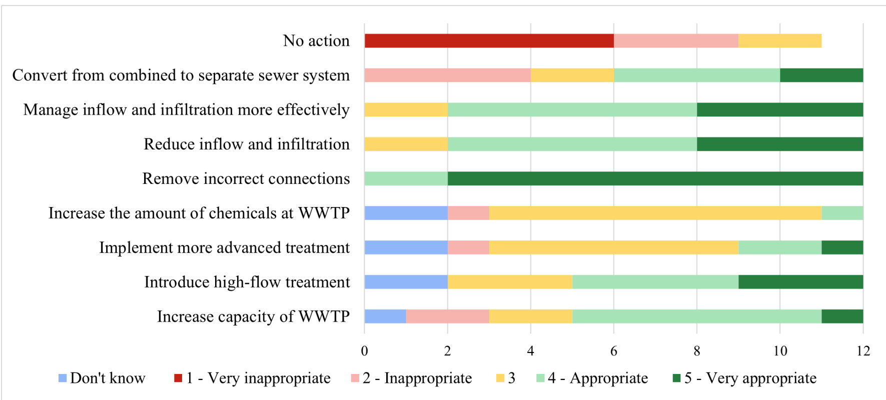


Figure 5.20: Rating of different measures to reduce pollution and manage high flows. 1 is a very inappropriate measure and 5 is a very appropriate measure.

5.3.4 Challenges

Figures 5.21 and 5.22 illustrate the different largest challenges regarding maintaining good water quality in our natural waters and managing or decreasing flows. The main challenges for each issue were similar, but there was a greater variation in responses regarding the problem of reducing pollution discharges to the recipient. For managing or decreasing flows, the responses were more uniform; for example, all respondents identified economic conditions as one of the three greatest challenges. There is also consensus that the renewal rate for the sewer network is a greater challenge than the renewal rate for wastewater treatment plants. This is also consistent with the investment report from Svenskt Vatten, which assesses that the investment needs for the sewer network are higher (2023). It's important to note that participants were only asked to list the three largest challenges for managing flows and reducing pollution to the recipient, not the actual magnitude of how the challenge is perceived. It may also be difficult to rank the challenges, and the fourth largest challenge is not included.

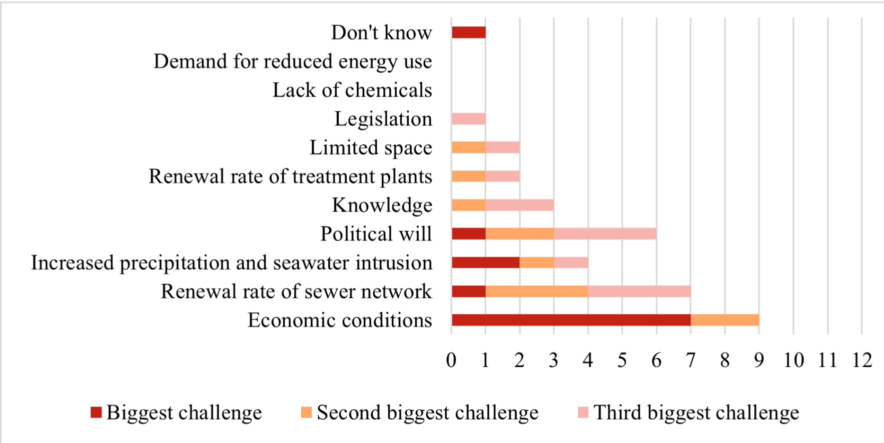


Figure 5.21: The greatest challenges in the water and wastewater sector for maintaining good water quality in our natural water bodies up to the year 2050

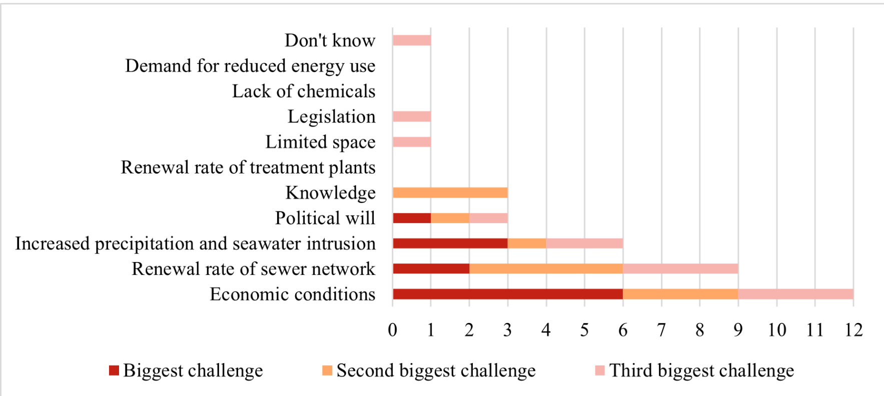


Figure 5.22: The greatest challenges in the water and wastewater sector for managing or reducing the volume of wastewater.

Later, participants were asked to explain their choices. Economic conditions are crucial when it comes to managing flows and maintaining good water quality in our natural water bodies. This is further explained by the fact that water and wastewater projects are extremely expensive and that the need for investments is very high. For example, the new WWTP in Kalmar is the largest investment of the municipality ever. The water and wastewater infrastructure must then last for many years to come.

Economic conditions are closely linked to the challenge of political will, since politicians decide the sector's funding. For the sector to receive adequate resources, politicians must understand the importance of water and wastewater. However, water and wastewater projects are long-term investments, while political terms are short. This makes it harder to prioritize projects that lack immediate visible benefits despite their long-term value. Another challenge mentioned is the difficulty of recruiting enough personnel, which to some extent is also tied to securing sufficient economic resources and gaining owner acceptance that more staff is necessary. The renewal rate of the sewer network is low and to avoid future problems, action must be taken. The renewal rate and economic conditions are also closely linked, as large resources are needed to renew the network.

Increased rainfall and rising sea levels will also lead to more future problems with infiltration and inflow. Another challenge that was mentioned during the interviews was that at the national level, treatment plants above 10,000 PE are expected to be energy-neutral at a national level by 2045, which may also present a significant challenge. Limited space is often explained as a challenge due to the difficulties in expanding WWTPs in central areas, but due to that stormwater treatment requires large areas. Stormwater treatment compete with urban densification, paving, and land sales. However, Kalmar Vatten benefits from the municipality's cloudburst adaptation efforts, working together to promote solutions that manage stormwater and adapt the city to heavy rainfall.

Regarding the challenge of knowledge, it was considered an important challenge for different reasons. Some related to competence are that there is a lack of knowledge needed to maximize the benefits of investments and a greater understanding of how to optimize measures, since financial resources are limited. It would be beneficial to make knowledge about water quality more accessible to all involved stakeholders. Other thought that while there is high competence within the sector, the general public and politicians usually do not have the same level of knowledge when it comes to water and wastewater issues. This lack of understanding can create a challenge when it comes to justifying higher water and wastewater tariffs. A common wish for supervisory authorities is to better understand the complexity of pipeline and WWTP work. Results take time and may not be immediately visible, so greater insight into these long-term processes would be valuable. Another challenge also related to competence is to increase public awareness and address everyday habits that impact the environment. Small individual changes could make a big difference in the network, for example, using a barrel to slow stormwater from downspouts.

5.3.5 Opportunities and tools for efficient water management

This chapter will explain the opportunities for effective water management and the different tools needed to achieve more effective water management. With regard to tools in general, there is a strong emphasis on the importance of economic resources, system analyses/mappings, practical tools, decision support, and methods for assessing environmental impact.

5.3.5.1 Opportunities for efficient water management

Many believe that the issue will be solved through better knowledge, more efficient technology, stricter legal requirements, and greater awareness within the industry and society at large. When it comes to efficient technology, treatment plants are already efficient and new technologies are being implemented in parallel with the introduction of new regulations. Stricter legal requirements are also an important factor. For example, the new Urban Wastewater Treatment Directive will drive sector adaptation with stricter standards. New laws and political decisions are expected to be the main drivers of future development and justifies investment in water management. Although water and wastewater organizations face a heavy workload, issues such as pharmaceutical residue treatment are not prioritized until regulations are in place. Despite known needs, actions often come only after new rules are introduced. There is also a growing discussion about the challenge of infiltration and infiltration. For example, Sweden probably faces the same infiltration and inflow issues as a decade ago, the issue is now being addressed more actively, which is essential for finding solutions.

There is growing awareness in both the industry and society. There is a greater understanding that renewing water and wastewater infrastructure is a time-consuming process and that measures must be taken. Water collection areas are being viewed as assets, with open water surfaces and vegetation acting as carbon sinks in cities. Media coverage and public interest, such as in relation to the Paris Olympics and sewer overflows, have increased. However, some argue that public interest remains low. Increased awareness could lead to upstream improvements such as reduced PFAS pollution, better pharmaceutical handling, and avoiding car washing in the streets.

5.3.5.2 Technical tools for efficient water management

System analyses are often mentioned to improve overall understanding of the system and prevent potential problems. Digital solutions are crucial for managing flows, especially during heavy rainfall. By forecasting and predicting these flows, the system can be prepared, for example, by draining tunnel systems or creating storage capacity to prevent overload. Tools such as Digital Twin models can test different measures, ensuring that investments in the water sector provide the maximum benefit for the cost.

In addition to mapping, effective tools, particularly economic models, are needed to compare the costs and benefits of various measures. For example, deciding whether to invest in expanding treatment plants or repairing the pipeline system requires careful evaluation. Better decision-making tools are needed to identify the most beneficial actions. Some interviewees also mentioned that the right amount of infiltration and inflow is crucial for the water system to function effectively. An infiltration and inflow budget for each community could help balance the right amount without increasing operational or maintenance demand.

There is a discussion on the use of tools such as sensors, warning systems, and health indicators to improve early detection and proactive management. For example, sensors could detect oil in stormwater or prevent overflows caused by technical issues by monitoring pump capacity. Public campaigns are also considered useful for raising awareness and improving water quality, for instance, by encouraging people to avoid certain products.

5.3.5.3 Economical, legal and ecological tools for efficient Water Management

To build and maintain a robust system, it is essential that necessary investments receive adequate support and financial resources. Increased funding could enable a larger workforce, improve system control and oversight, and support overall system improvements. There is also a need for more strategic long-term planning, particularly for investments, infiltration water, renewal, and maintenance. Another important aspect is the use of political tools, which can set requirements for individual properties and improve the management of infiltration and inflow. For example, clearer responsibilities for property owners can help prevent basement flooding and ensure proper management of their own water and sewer systems.

Many interviewees believe that laws are a good tool, as they force the water industry to address important issues and provide financial resources. However, it is essential that the laws are designed appropriately. At times, laws can be seen to be rigid and inflexible. For example, there may be more beneficial alternatives, but the law forces the industry to adhere to specific requirements. EU-level laws may also be less suitable for varying climates, such as dry Greece versus the Nordic countries.

Various tools for analysing environmental impact are also discussed. Multi-criteria analysis, which includes ecological and monetary aspects, and more comprehensive life cycle assessments that consider treatment plants and reduced emissions to recipients, are important. Ecological factors such as nitrogen emissions, energy consumption, chemical usage during operation, and impacts on recipients must be taken into account. Social aspects, such as working conditions, could also be considered. A tool focusing on ecological aspects is a national method for classifying the sensitivity of recipients and how emission requirements should be set to meet environmental quality standards. It is not just about calculating loads in kilograms per year, factors such as water flow and volumes also matter, and more research on the long-term effects of emissions on recipients would be beneficial.

5.3.6 Discussion for the interviews

This section will explain uncertainties, limitations and possible improvements for the interviews. The questions were quite broad and, to clarify them, several examples of possible answers were often provided. The examples may have influenced the interviewees to give more limited responses, although they certainly mentioned things that were not included in the examples. There is also a risk that the information was misinterpreted or wrongly translated, although efforts were made to avoid this by transcribing the interviews and allowing the interviewees to review the text. The questionnaire consisted largely of multiple choice questions or rating scales, which did not capture the nuance that some questions required. For example, it is difficult to determine whether a measure is generally appropriate from an ecological perspective when some factors speak in favour and others against it.

It is also possible to discuss how representative the selected WWTPs are for Sweden and how this may have influenced the results. The WWTPs are located in different parts of Sweden both in the south and in the north, where temperature has a greater impact on treatment processes. Both the west and east coasts are represented. It is possible that some differences could be observed among the WWTP located along the Baltic Sea, given the particularly sensitive nature of this marine environment. However, the six WWTPs are located near the coast and it might have been beneficial to include a WWTP located in central Sweden to explore how they could differ in terms of operational conditions.

The WWTPs vary in size. Three of them, Rya, Henriksdal, and Käppala WWTP, are among the largest plants in Sweden, which may not be fully representative of Sweden. These larger plants are likely to have more personnel and greater capacity to focus on development issues, which can contribute to a broader understanding.

It is also worth discussing why these specific WWTPs chose to participate in the case study and how their level of expertise compared to that of other WWTPs. To clarify, during the interviews it became evident that industry professionals possessed a high level of knowledge on the subject. However, it remains unclear how their knowledge compares with that of WWTP professionals who did not participate in the study. One possibility is that they consider wastewater management to be an important issue and therefore may have greater knowledge in this area. Another possibility is that they are currently facing problems related to high flows and less knowledge compared to other WWTPs but hope that the results of this study will provide useful insights or solutions.

5.4 Insights and limitations of combining interview and model

The model provides quantitative results, while the interviews offer qualitative context. Together, they can give a more complete and broader picture. The model can show more concrete outcomes, whereas interviews provide qualitative data on the why behind those outcomes. Interviews can also offer information on opportunities and limitations that are not captured by the model. More aspects were considered during the interviews, while the model only takes into account reduced phosphorus emissions.

Including economic, social, and other ecological parameters would also have been beneficial.

One disadvantage of combining two methods is that neither method is as in-depth as it could have been on its own. Another weakness of the study, specifically the scenario analysis, is the uncertainty regarding which scenarios are realistically achievable and what would be required to achieve, for example, a certain treatment efficiency or a specific reduction in infiltration and inflow. Being able to better link concrete measures to how they influence scenarios would have made scenario analysis more relevant.

5.4.1 Comparison of the result from model and interviews

This section will discuss whether the results from the scenario analysis and interviews indicate the same conclusions. Measures to address infiltration and inflow received high scores in the interviews, and the model showed that reducing infiltration and inflow also led to a reduction in phosphorus emissions. Thus, both the model and the interview results indicate that actions aimed at managing or reducing infiltration and inflow resulted in positive outcomes. In the interviews, the implementation of more advanced treatment and the increase in chemical doses received scores of 3.3 and 3 respectively, where a score of 3 is considered neutral. However, the model showed that the treatment measures that resulted in lower effluent concentrations were effective in reducing total phosphorus discharge. This may suggest that other aspects, such as economic, social, and ecological factors, lower the overall rating. These measures also do not help decrease the number of overflow events in the sewer network.

Increasing treatment capacity resulted in only minor improvements in the model, while receiving a score of 3.5 in interviews, which is still relatively good. However, a significant number of respondents considered it not an appropriate measure from social, ecological and economic perspectives. For example, 5 out of 12 participants felt that it was not appropriate from an economic point of view. In general, the measures discussed in the interviews were relatively detailed and concrete, while the modeling approach was limited to adjustments of individual parameters. For instance, high-flow treatment was not explicitly tested in the model. However, it might have been possible to simulate such a measure by increasing the treatment capacity for high-flow events and assigning a lower phosphorus removal efficiency to those specific flow.

6 Conclusion

The simplified model represents reality quite well, with an average 7 % difference between the model‘s value and the actual values. However, the accuracy of the model varies between the different WWTPs and the years. The simplified model also most often underestimates the value compared to the actual value. The model gives significantly better accuracy when daily or hourly flows are used than when weekly flows are used. The potential gain in accuracy from using hourly data instead of daily data is limited.

The result of the scenario analysis shows that potential improvements can be made to reduce phosphorus discharges in both the WWTPs and the sewer network. Improvement can be achieved by decreasing the effluent concentration of phosphorus, decreasing sewage water, or decreasing infiltration and inflow. An increase in the WWTP’s capacity resulted in either no improvement or very little improvement.

The result of the interviews indicated that in terms of handling flow and reducing pollutant discharge in the future it is likely to involve higher flows to wastewater treatment plants and stricter legal requirements. Significant future challenges are the economic conditions, the renewal rate of the sewer network and increased precipitation and seawater intrusion. In the measure evaluation, it was seen that all suggested measures were either appropriate or neutral. In general, the measures conducted on the sewer network were considered more appropriate than the measures conducted on the WWTP.

In order to achieve sustainable and efficient water management in the future, a combination of tools is suggested, such as technical tools such as digital modeling and sensors, alongside economic, legal and ecological instruments to guide investment, planning and regulation. Many believe that future progress in wastewater management will be driven by improved knowledge, stricter regulations, technological advancements, and greater awareness. Although challenges like infiltration and inflow still exist, growing attention from both policymakers and the public is supporting action toward sustainable and proactive solutions.

6.1 Suggestion to future research

It would be interesting to also test the model for other pollutants, such as BOD or nitrogen. Because all WWTPs use chemical removal of phosphorus, phosphorus is not particularly affected by biological disturbances, and the concentration remains fairly constant until the WWTP capacity is significantly exceeded. (Nitrogen removal is a slightly more complex process that occurs in two steps, nitrification and denitrification, and is more sensitive to temperature and oxygen availability. Also nitrogen removal is often actively controlled, which will complicate the analysis. For the removal of BOD, both retention time and sludge volume are important). They likely follow the same pattern as phosphorus, with stable concentrations until capacity is exceeded, and then increase, but with greater variation. Another difference with changing the pollutant is that high-flow treatment is much more effective at removing phosphorus than BOD and nitrogen. It would have been very interesting to include the entire wastewater system and incorporate overflows from pumping stations. However, this is significantly more demanding, as it requires much more data and a better understanding of a larger geographical system.

It would also be valuable to connect various measures to how they affect the model, for instance, how much infiltration water is reduced when converting from a combined to a separate sewer system. It would also be interesting to link these measures to economic and ecological consequences, for example how much an action costs versus how much is saved. Similarly, it would be valuable to analyse the ecological benefits and drawbacks of each measure and attempt to monetise these effects.

For future interview studies, it would be interesting to get insights from more people and stakeholders. Most of the industry professionals interviewed mainly focused on technical aspects as well as some economic and ecological perspectives. It would also be interesting to focus more on legal requirements, politics, economics, and ecological perspectives. An additional improvement could involve expanding the number of interviewees, since this thesis included only industry professionals from six wastewater treatment plants and their associated sewer networks.

7 References

Andersson. Sofia Lovisa, Andersson. Sofia, & Baresel, C. (2023). *MBR-tekniken utmaningar och möjligheter för svenska avloppsreningsverk* (tech. rep.). Svenskt Vatten. https://vattenbokhandeln.svensktvatten.se/wp-content/uploads/2023/08/svu-rapport-2023-08.pdf

Borglund, A. M. (2004). *Kombinerad kemisk och biologisk fosforrening på Käppalaverket, Lidingö* (tech. rep.). VA-Forsk. www.svensktvatten.se

Clementson, I., Alenius, E., & Gustafsson, L.-G. (2020). *Tillskottsvatten i avloppssystem-nya tankar om nyckeltal* (tech. rep.). Svenskt Vatten AB. www.svensktvatten.se

Eriksson, M. (2022). *Miljörapport 2021 Avloppsverksamheten Stockholm Vatten och Avfall* (tech. rep.). Avloppsverksamheten Stockholm Vatten och Avfall. www.stockholmvattenochavfall.se.

Eriksson, M. (2023). *Miljörapport 2022 Avloppsverksamheten Stockholm Vatten och Avfall* (tech. rep.). Avloppsverksamheten Stockholm Vatten och Avfall. www.stockholmvattenochavfall.se.

Eriksson, M. (2024). *Miljörapport 2023 Avloppsverksamheten Stockholm Vatten och Avfall* (tech. rep.). Avloppsverksamheten Stockholm Vatten och Avfall. www.stockholmvattenochavfall.se.

Eriksson, M. (2025). Miljörapport 2024 Avloppsverksamheten Stockholm Vatten och Avfall. www.stockholmvattenochavfall.se.

European Union. (1991). Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment. Official Journal of the European Communities. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31991L0271

Giokas, D. L., Vlessidis, A. G., Angelidis, M. O., Tsimarakis, G. J., & Karayannis, M. I. (2002). Systematic analysis of the operational response of activated sludge process to variable wastewater flows. A case study. *Clean Technologies and Environmental Policy 2002 4:3*, *4*(3), 183–190. https://doi.org/10.1007/S10098-002-0145-Z

Gryaab. (n.d.). Gryaabs miljötillstånd - Gryaab. https://www.gryaab.se/om-gryaab/gryaabs-miljotillstand/

Haarbo, A., & Cederborg, R. (2009). *KÄPPALAFÖRBUNDET BRÄDDVATTENBEHANDLING* (tech. rep.). VA-Ingenjörerna. https://www.kappala.se/globalassets/dokument/om-kappalaforbundet/utokad-verksamhet/bilaga-21/braddvattenrening-med-actiflo-pa-kappalaverket.pdf

I'Ons, D., Alenius, E., Mattson, A., & Lorick, D. (2021, November). *Prognoser för flöden och belastning till Ryaverket- Utvecklingen från 2020 till 2070* (tech. rep.). Gryaab.

Kalmar Vatten. (n.d.). Kalmarsundsverket - Kalmar Vatten. https://kalmarvatten.se/om-vatten-och-avlopp/kalmarsundsverket.html

Kalmar Vatten. (2022). *MILJÖRAPPORT 2021 Kalmar avloppsreningsverk* (tech. rep.).

Kalmar Vatten. (2023). *MILJÖRAPPORT 2022 Kalmar avloppsreningsverk* (tech. rep.).

Kalmar Vatten. (2024). *MILJÖRAPPORT 2023 Kalmar avloppsreningsverk* (tech. rep.).
Kalmar Vatten. (2025). *MILJÖRAPPORT 2024 Kalmar avloppsreningsverk* (tech. rep.).
Käppalaförbundet. (n.d.). Käppala 900k - Käppalaförbundet. https://www.kappala.se/projekt-och-utveckling/pagaende-projekt/kappala-900k/
Käppalaförbundet. (2022). *Miljörapport 2021 Käppalaförbundet* (tech. rep.).
Käppalaförbundet. (2024). *Årsredovisning 2023 – Käppalaförbundet* (tech. rep.).
Käppalaförbundet. (2025). *Miljörapport 2024 Käppalaförbundet* (tech. rep.).
Kemikalieinspektionen. (2022, November). Kemikalieinspektionen förlänger undantag från kvicksilverförbud - Kemikalieinspektionen. https://www.kemi.se/arkiv/nyhetsarkiv/nyheter/2022-11-22-kemikalieinspektionen-forlanger-undantag-fran-kvicksilverforbud
la Cour Jansen, J., Särner, E., Tykesson, E., Jönsson, K., & Jönsson, L.-E. (2009). Biologisk fosfor-avskiljning i Sverige-Uppstart och drift. www.svensktvatten.se
Länsstyrelsen Västra Götalands län. (n.d.). Tillstånd till miljöfarlig verksamhet vid Ryaverkets avloppsreningsverk i Göteborgs kommun. https://www.gryaab.se/wp-content/uploads/2020/02/Beslut-om-bifall-med-villkor12212286.pdf
Lantmäteriet. (n.d.). Min Karta. https://minkarta.lantmateriet.se/
Levin, E. (2020). Intermittent högflödesrening för bräddvatten. *Svenskt Vatten Utveckling*.
Lundblad, U., & Backö, J. (2013). *Undersökningsmetoder för att hitta källorna till tillskottsvatten* (tech. rep.). Svenskt Vatten AB. www.svensktvatten.se
Metcalf & Eddy & AECOM. (2014). *Wastewater engineering : treatment and resource recovery* (F. L. Burton, G. Tchobanoglous, R. Tsuchihashi, & H. D. Stensel, Eds.; 5th). McGraw-Hill Education. https://openurl.ebsco.com/contentitem/cat09075a:clpc.oai.edge.chalmers.folio.ebsco.com.fs00001000.07c6f411.25e2.44c2.b968.445a2b070161?sid=ebsco:plink:crawler&id=ebsco:cat09075a:clpc.oai.edge.chalmers.folio.ebsco.com.fs00001000.07c6f411.25e2.44c2.b968.445a2b070161&crl=c
Mines, R. O., Lackey, L. W., & Behrend, G. H. (2007). The impact of rainfall on flows and loadings at Georgia's wastewater treatment plants. *Water, Air, and Soil Pollution*, *179*(1-4), 135–157. https://doi.org/10.1007/S11270-006-9220-0/METRICS
Molander, C. (2015). *Influence of excessive water on wastewater treatment performance* [Doctoral dissertation, Chalmers University of Technology].
Naturvårdsverket. (2016). *NFS 2016:6 Naturvårdsverkets föreskrifter om rening och kontroll av utsläpp av avloppsvatten från tätbebyggelse.* (tech. rep.).
Naturvårdsverket. (2019, March). *Regeringsuppdrag att föreslå etappmål om dagvatten* (tech. rep.).
Naturvårdsverket. (2022a). *NFS 2022:6 Föreskrifter om ändring av Naturvårdsverkets föreskrifter (NFS 2016:6) om rening och kontroll av utsläpp av avloppsvatten från tätbebyggelse* (tech. rep.).
Naturvårdsverket. (2022b). *Rening av avloppsvatten i Sverige 2020* (tech. rep.). www.naturvardsverket.se/publikationer
Ohlin Saletti, A. (2021). Infiltration and inflow to wastewater sewer systems A literature review on risk management and decision support. www.chalmers.se

Ohlin Saletti, A. (2022). *Risk-based management of the cost to society from infiltration and inflow to wastewater systems* [Doctoral dissertation, Chalmers University of Technology]. Chalmers University of Technology. https://research.chalmers.se/en/publication/530358

Plósz, B. G., Liltved, H., & Ratnaweera, H. (2009). Climate change impacts on activated sludge wastewater treatment: a case study from Norway. *Water Science and Technology*, *60*(2), 533–541. https://doi.org/10.2166/WST.2009.386

Press, C., Davidsson, F., LastNameWellsjö, L., Grubbström, E., & Ridelius, A. (2020, March). *Hushållspillvattenundersökning Provtagningar i referensområdet 2017/2018* (tech. rep.). Gryaab.

Shareef Mohammed, A. S. (2024). *Impact of High Flow on Phosphorus Treatment Performance* [Doctoral dissertation, Chalmers University of Technology]. http://hdl.handle.net/20.500.12380/308831

Stockholm Vatten och Avfall. (2023). Stockholms framtida avloppsrening - Reviderat genomförandebeslut. https://meetingspublic.stockholm.se/welcome-sv/namnder-styrelser/stockholm-vatten-ab/mote-2023-12-07/agenda/11stockholms-framtida-avloppsrening-reviderat-genomforandebeslutpdf?downloadMode=open

Sundsvalls kommun. (2019). *VA-översikt* (tech. rep.).

Svenskt Vatten. (n.d.-a). Avloppsdirektivet. https://www.svensktvatten.se/vara-sakomraden/avlopp-och-miljo/avloppsdirektivet/

Svenskt Vatten. (n.d.-b). Uppströmsarbete: stoppa farliga ämnen vid källan | Svenskt Vatten. https://www.svensktvatten.se/vara-sakomraden/avlopp-och-miljo/uppstromsarbete/

Svenskt Vatten. (2014). vatten och avlopp fakta om fakta om. www.svensktvatten.se

Svenskt Vatten. (2023). *Investeringsbehov och framtida kostnader för kommunalt vatten och avlopp* (tech. rep.). https://vattenbokhandeln.svensktvatten.se/wp-content/uploads/2023/05/SvensktVatten-Investeringsrapport_2023.pdf

Svenskt Vatten. (2024). 2024 års taxestatistik. www.svensktvatten.se

Tanskanen, V., Lorick, D., & Tumlin, S. (2024). *Rapport om prognoser för flöden och belastning till Ryaverket* (tech. rep.). Gryaab.

Tumlin, S., & Mattsson, A. (2013). *Influent loads – observed trends at large wastewater treatment plants in Sweden* (tech. rep.).

Videbris, K.-E. (2022). *Miljörapport Gryaab, Ryaverket 2021* (tech. rep.). Gryaab.

Videbris, K.-E. (2023). *Miljörapport Gryaab, Ryaverket 2022* (tech. rep.). Gryaab. https://goteborg.se/wps/PA_Pabolagshandlingar/file?id=45127

Videbris, K.-E. (2024). *Miljörapport Ryaverket 2023* (tech. rep.). Gryaab.

Videbris, K.-E. (2025). *Miljörapport Gryaab, Ryaverket 2024* (tech. rep.). Gryaab. https://www.gryaab.se/om-gryaab/publikationer-och-informationsmaterial/pdf/https%3A%2F%2Fwww.gryaab.se%2Fwp-content%2Fuploads%2F2025%2F04%2FMiljorapport-2024-Ryaverket-inklusive-bilagor.pdf/

Vivab. (n.d.). Avloppsvatten. https://vivab.se/vatten-avlopp/avloppsvatten

von Scherling, M., Ohlin Saletti, A., & Sjöstrand, K. (2023). *Beslutsstöd för tillskottsvatten* (tech. rep.). Svenskt Vatten. https://vattenbokhandeln.svensktvatten.se/wp-content/uploads/2023/08/svu-rapport-2023-06.pdf

Appendix A

Overview of treatment proccess

Overview of treatment processes at selected WWTPs, including treatment during high flow (Shareef Mohammed, 2024;M.Björksund- Tuominen , personal communication, 12 March, 2025)

WWTP	**Preliminary and Primary**	**Secondary**	**Tertiary**	**Treatment during high flow**
Rya	Mechanical treatment (coarse bar screen, sand trap, fine bar screen), pre-sedimentation/primary settlers (direct precipitation)	Activated sludge process with pre-denitrification and chemical treatment, nitrification (trickling filter), post-sedimentation, post-nitrification & post-denitrification (MBBR)	Disc filtering	Precipitation in pre-sedimentation basin
Essvik	Mechanical treatment (drum screens, flocculation basin), pre-sedimentation with chemical treatment	Activated sludge process (BOD-removal), post sedimentation	—	x
Henriksdal	Mechanical treatment (screens, sand), pre-sedimentation with chemical precipitation, traps, pre-aeration	Activated sludge process, post-sedimentation(Currently rebuild to Membrane tanks)	Membrane filtering and sand filtering	Increased precipitation in pre-sedimentation basin
Kalmar	Mechanical treatment (screens, sand trap, grease separator, pre-aeration), pre-sedimentation	Activated sludge process with pre-denitrification, bio sedimentation and post-sedimentation with chemical precipitation	—	x
Käppla	Mechanical treatment (pre-aeration, fine screens, sand traps), pre-sedimentation	Activated sludge process with chemical treatment, post-sedimentation	Sand filtering	Actiflo (chemical treatment with sedimentation)
Smedjeholm	Mechanical treatment and pre-sedimentation	Biological treatment stage with pre-denitrification. Chemical treatment stage, precipitation with aluminum and flotation. Separate SBR stage for industrial flow, which joins domestic water before the chemical treament.	—	By-pass of biological treatment step

Appendix B

Interviews protocol

About the Person(s)

Name:
Municipality/company/wastewater treatment plant:
Wastewater treatment plant or sewer network?
Brief description of your role/work:

Cooperation between WWTP and the Sewer Network

- How close is the cooperation between the WWTP and the sewer network?
  - Is it the same company/department?
  - How often are there regular meetings? (You do not necessarily have to attend.)
- How do you collaborate:
  - To reduce discharges to receiving waters?
  - To manage flows?
- Do you collaborate with others (e.g., other municipalities or organizations):
  - To reduce discharges to receving waters?
  - To manage flows?
  - The cooperation can include both practical aspects and knowledge exchange.

Measures

- Are there any measures or projects you're working on to improve water quality or treatment processes?
  - If so, how? Examples?
  - E.g., new treatment processes, stormwater ponds, overflow control, rain gardens.
- Are there any measures to reduce or manage added/infiltration water?
  - If so, how? Examples?

Changing Flows

- Have you noticed changes in flows to the WWTP or within the sewer network?
  - If yes, how?
  - E.g., volumes, number or intensity of flow peaks.
- Changes in infiltration/inflow flows?
  - If yes, how?

  - E.g., changes in volume or ratio of wastewater vs. I/I water.
- Challenges with I/I water?
  - E.g., overflows, basement flooding, increased chemical usage, poor treatment efficiency.

Future Outlook and Planning

- Do you see a risk for increased flows?
  - If yes, how are you preparing?
  - Long-term action plan?
- How do you see the future development in Sweden?
  - Will legal requirements become stricter?
  - Will the rate of renewal change?

Challenges

- Any additional comments on the challenges in the survey?
  - Other challenges not mentioned?
  - Why are some challenges more important?

Opportunities and Tools

- What opportunities exist to reduce discharges and manage flows?
  - E.g., political focus, media, increased industry knowledge.
  - Are the opportunities different for discharges vs. flow?
- What needs to be done to manage flows and reduce pollutants despite future challenges?
  - What tools are needed?
  - How will upgrades be funded? (Higher fees or government funding?)
  - Are laws an effective tool? Do legal requirements help?

Other

- Any other comments or additions?
  - E.g., anything you want to add to a specific question.

Appendix C

Calculated population

The average yearly flow and average yearly pollution load in influent for BOD_7, COD, total phosphorus and total nitrogen for 2021-2024

WWTP	**Flow**	**Average yearly pollution load (ton/year)**			
	Mm^3/year	BOD_7	COD	P-tot	N-tot
Rya	130	23 200	53 300	470	3 900
Essvik	2	200	400	5	36
Henriksdal	111	24 200	–	530	4 300
Kalmar	6	1 900	3 500	46	350
Käppala	57	14 200	33 500	330	2 800
Smedjeholm	7	1 800	3 900	36	260

Nutrient and organic matter ratios at different WWTPs

WWTP	**BOD/P**	**BOD/N**	**N/P**	**COD/BOD**
Rya	49.4	6.0	8.2	2.3
Essvik	36.1	4.9	7.4	2.3
Henriksdal	45.8	5.6	8.2	–
Kalmar	40.0	5.3	7.5	1.9
Käppala	43.4	5.2	8.4	2.3
Smedjeholm	45.1	6.7	6.8	1.6

Appendix D

Interval ranges

Interval ranges used to calculate different concentrations

WWTP	Concentration 1	Total concentration (between capacity 1 and 2)	Total concentration during normal treatment
Rya	20–80 percentile of capacity 1	0–80 percentile of the values between capacity 1 and 2	
Essvik			20–80 percentile of the total capacity
Henriksdal	0–80 percentile of capacity 1	0–80 percentile of the values between capacity 1 and 2	
Kalmar			0–80 percentile of the total capacity
Käppala	0–80 percentile of capacity 1	From capacity 1 to capacity 2 (very few values)	
Smedjeholm	0–80 percentile of capacity 1	0–80 percentile of the values between capacity 1 and 2	

Appendix E

Modell comparasion

Result from yearly phosphorus load[ton/year] for each WWTP depending on method.
Model from 2024 is result from a model in a previous master thesis last year (Shareef Mohammed, 2024)

Rya: Comparison of values [ton/year] from 2021 to 2024

Year	2021	2022	2023	2024
Actual value	23.7	21.2	26.7	25.2
Model using weekly flow	24.2	22.3	24.7	24.6
Model using daily flow	24.3	22.0	25.9	25.2
Model using hourly flow				25.5
Model from 2024	24.3	24.3	24.3	

Essvik: Comparison of values [ton/year] from 2021 to 2024

Year	2021	2022	2023	2024
Actual value	0.853	0.61	0.841	0.689
Model using weekly flow	0.8	0.61	0.82	0.67
Model using daily flow	0.81	0.61	0.82	0.67
Model using hourly flow				0.67
Model from 2024	0.7	0.7	0.7	

Henriksdal: Comparison of values [ton/year] from 2021 to 2024

Year	2021	2022	2023	2024
Actual value	22,14	25,3	30,6	30
Model using weekly flow	21,4	20,8	24,7	22,3
Model using daily flow	22,9	21,3	26,4	23,8
Model using hourly flow				25,5
Model from 2024	27,9	27,9	27,9	

Kalmar: Comparison of values [ton/year] from 2021 to 2024

Year	2021	2022	2023	2024
Actual value	1,5	1,2	1,6	1,4
Model using weekly flow	1,5	1,3	1,4	1,4
Model using daily flow	1,5	1,3	1,4	1,4
Model using hourly flow				1,4
Model from 2024	1,4	1,4	1,4	

Käppala: Comparison of values [ton/year] from 2021 to 2024

Year	2021	2022	2023	2024
Actual value	8,7	8,6	11,7	14,6
Model using weekly flow	10	9,4	11,1	10,8
Model using daily flow	10,1	9,4	11,1	10,8
Model using hourly flow				10,8
Model from 2024	9,6	9,6	9,6	

Smedjeholm: Comparison of values [ton/year] from 2021 to 2024

Year	2021	2022	2023	2024
Actual value	2,5	2	2,76	2,6
Model using weekly flow	2,42	2	3	2,66
Model using daily flow	2,44	2	3,1	2,66
Model using hourly flow				2,67
Model from 2024				

Appendix F

Scenario analysis

Result after the different measures in total mass [ton/year]

	Rya	Essvik	Henriksdal	Kalmar	Käppala	Smedjeholm
Base-line	24	0.73	24	1.4	10	2.5
Effluent conc =0.35	46	0.77	40	2.2	20	2.5
Effluent conc =0.2	26	0.44	24	1.3	11	1.5
Effluent conc =0.15	20	0.33	18	0.9	9	1.1
Increase I/I 50%	35	1.01	35	1.5	12	3.3
Increase I/I 20%	28	0.84	28	1.4	11	2.8
Increase I/I 10%	26	0.78	25	1.4	11	2.7
Decrease I/I 10%	23	0.67	22	1.3	10	2.4
Decrease I/I 20%	21	0.61	20	1.3	10	2.3
Decrease I/I 50%	17	0.45	17	1.2	9	1.9
Change sewagewater 270 l/p,d	29	0.81	31	1.9	14	3.3
Change sewagewater 200 l/p,d	25	0.74	25	1.5	11	2.7
Change sewagewater 160 l/p,d	23	0.71	22	1.2	10	2.4
Change sewagewater 140 l/p,d	22	0.69	21	1.1	9	2.2
Change sewagewater 90 l/p,d	19	0.64	17	0.8	7	1.8
Decrease capacity with 50%	39	0.78	52	1.6	11	4.6
Decrease capacity with 25%	27	0.73	28	1.4	10	2.7
Increase capacity with 25%	24	0.73	22	1.4	10	2.5
Increase capacity with 50%	24	0.73	22	1.4	10	2.5

Impact of various scenarios on phosphorus mass[ton/year] for different treatment plants

Impact of various scenarios on hourly inflow[m3/h] for different treatment plants

Scenario	**Rya**	**Essvik**	**Henriksdal**	**Kalmar**	**Käppala**	**Smedjeholm**
Base-line	14 818	249	12 652	714	6 488	806
Effluent concentration = 0.35	14 818	249	12 652	714	6 488	806
Effluent concentration = 0.2	14 818	249	12 652	714	6 488	806
Effluent concentration = 0.15	14 818	249	12 652	714	6 488	806
Increase I/I 50%	19 247	344	15 635	791	7 632	995
Increase I/I 20%	16 590	287	13 845	745	6 946	882
Increase I/I 10%	15 704	268	13 248	729	6 717	844
Decrease I/I 10%	13 932	230	12 055	698	6 260	769
Decrease I/I 20%	13 046	211	11 458	683	6 031	731
Decrease I/I 30%	10 388	154	9 669	636	5 345	618
Change sewage water 270 l/p,d	17 797	279	15 994	993	8 589	1 021
Change sewage water 200 l/p,d	15 480	256	13 395	776	6 955	854
Change sewage water 160 l/p,d	14 156	243	11 909	652	6 022	759
Change sewage water 140 l/p,d	13 494	236	11 166	590	5 555	711
Change sewage water 90 l/p,d	11 838	220	9 309	434	4 388	592
Decrease capacity with 50%	14 818	249	12 652	714	6 488	806
Decrease capacity with 25%	14 818	249	12 652	714	6 488	806
Increase capacity with 25%	14 818	249	12 652	714	6 488	806
Increase capacity with 50%	14 818	249	12 652	714	6 488	806

Appendix G

Current work and situation regarding managing wastewater flows and decreasing pollutant discharge

This section will explain how the municipalities are currently working. The chapter will describe how personnel at the treatment plant and within the pipeline network collaborate. Collaboration occurs at various levels, ranging from management and project leaders to operational processes, however this focus mostly on how interviews participants collaborate with other. It will also cover their experience of changed wastewater flow and what problems infiltration and inflow causes in their municipality.

Collaboration between WWTP and the pipeline network

In general, no preventive collaboration is carried out regarding the management of flows and the reduction of discharges to recipients. However, collaboration takes place when problems arise or within certain projects often related to infiltration and inflow. Usually, the WWWTP side and the pipeline networks side have some kind of regular communication. Some mention that they have cooperation at many levels from top management down to operational work. Some believe that communication has improved and that there is more collaboration today compared to the past. For example, Käppalaförbundet plans to increase their collaboration with the member municipalities regarding infiltration and inflow issues, as its new operational requirements calls for actively reducing infiltration and inflow in its member municipalities.

Whether the WWTP and pipeline network belong to the same organsation varies. In Essvik, Kalmar, Smedjeholm, and Henriksdal both the networks and the wastewater treatment plant belong to the same organisation. It is worth mentioning that, except for Kalmar Vatten, these companies operate in multiple municipalities. SVOA works with pipeline networks in Stockholm and Bromma but also receives water from nearby municipalities, where the municipalities are responsible for their own pipeline networks. For example, both Ryaverket and Käppala WWTP are large treatment plants owned by 8 and 11 municipalities, respectively. They are responsible for the treatment plant and the tunnel system, while the individual municipalities are responsible for the pipeline networks.

Collaboration with others

Collaboration with others, such as professional bodies and municipalities, is mostly knowledge-based. They are often participating in various development projects, collaborating with Svenskt Vatten and involved in different cooperation forums where experiences are shared. Many are part of network on infiltration and inflow and overflows, which is led by Anna Ohlin Saletti on behalf of the research clusters VA-teknik Södra, Mälardalsklustret and Dag&Nät. There are also various regional collaborations and networks. The larger treatment plants, Ryaverket Henriksdal WWTP, and Käppala WWTP, are part of PING, a network for process engineers at major wastewater treatment plants in the Nordic region. Some collaboration that is mentioned is sharing experiences, frequent study visits and an email list connects treatment plants in southern Sweden for questions and support. Since this is not a competitive industry, the sector is generally keen on supporting other WWTPs as well.

One interview participant, who has worked in both larger and smaller municipalities, notes that collaboration becomes more vital in smaller municipalities, where individuals often handle issues alone and lack colleagues to consult with. Larger municipalities with substantial workforces can more readily rely on colleagues for valuable support. Even though the systems may differ, there is still much to learn from one another. Some mention that neighbouring WWTPs, and areas differ significantly from their own, therefore, it might be more beneficial to collaborate with plants facing similar challenges.

Changed Flows and problems caused by high flow

Many respondents have noted increased flows to treatment plants in recent years, with more frequent exceedances of WWTP‘s capacity. Some also observed more intense rainfall peaks and longer rainy and dry periods. However, a few didn’t perceive any significant changes in flow. Kalmar wastewater treatment plant experiences relatively lower flows in summer probably due to pipeline system leakage and low inflow and infiltration. For Essvik and Käppala plants, which used to rely on dry winter weather with thawing typically only occurring in March, more thaw periods are now happening during winter. Whether the amount of inflow and infiltration has changed varies between municipalities. Some report a decrease, while others see an increase. However, since inflow and infiltration can vary significantly from year to year, some believe there is a lack of good indicators to measure it. It is important to note that all responses in this section are based on the interviewees’ experiences rather than actual statistics.

In general, most interviewees agree that infiltration and inflow cause problems such as overflows into recipients, basement flooding, surface flooding, increased chemical usage, greater pumping needs, and poorer treatment performance due to diluted wastewater. Kalmar Vatten has rough calculation of the electricity cost caused by infiltration and inflow in the WWTP and the pipeline network to approximately 2 million SEK per year. This is despite Kalmar having a relatively low proportion of infiltration and inflow for a municipality located in a coastal area. . Another consequence of the high proportion of infiltration and inflow is that existing treatment plants are often insufficient, leading to the need for expansions or new facilities. Also high inflow and infiltration increases the risk of overloads and disruptions, for example during snowmelt, some pump stations in Kalmar run constantly but still can’t keep up.

Another issue raised by Ryaverket is that stormwater from heavily trafficked roads contains high levels of metals, which end up in the sludge. This becomes problematic as the sludge is certified and must meet strict requirements. A specific issue in coastal areas like Kalmar is saltwater intrusion, which increases wastewater conductivity. Higher conductivity harms biological treatment processes, as microorganisms are sensitive to salinity changes, weakening the treatment performance. It is also noted by interviewees that inflow and infiltration has many disadvantages, it has some advantages as well, such as prevent gas formation and sediment buildup.

Measures taken by WWTP and the pipeline network

WWTPs often work with upstream measures, including monitoring connected industries, implementing new treatment processes, optimizations, and reconstructions at the treatment facilities. Examples on implemeting treatments processes are high-flow treatment systems and preparation for pharmaceutical removal. Additionally, some WWTP also work with water retention in tunnel systems.

Another type of upstream work involves public outreach such as campaigns in order to make people avoiding products containing PFAS or stop washing the car on the street. Some mention this kind of information campaign, with the possibility of future legislation, such as banning certain car brake pads or requiring prescriptions for products like diclofenac. Some municipalities are also working to view wastewater and infiltration/inflow as a resource. For example, drinking water doesn't necessarily need to be used for irrigation. While it doesn't directly impact flow management or reduce discharges, it promotes viewing wastewater and stormwater as resources and reduces drinking water demand.

Many are working on collecting data about the system and mapping out the overflows. Ensuring accurate measurements from overflow stations or from pump stations is important to better describe the current situation and thereby take appropriate measures where it is needed the most. Some organisations even utilize digital twins to better estimate system performance, test measures, and identify critical areas. In Kalmar and Gothenburg, they are also working on overflow optimization. For example, allowing overflows of relatively diluted wastewater within the pipeline system may enable the treatment plant to receive and treat more water without overflowing, which can result in reduced total discharges to the recipient.

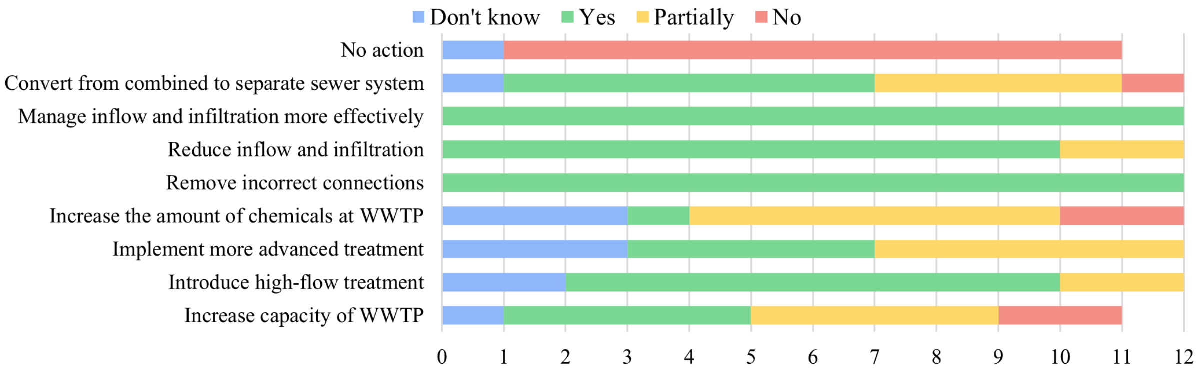
On the pipeline network side, efforts are often focused on various types of stormwater management, such as stormwater ponds, stormwater treatment, screening basins, overflow reservoirs, filters, etc. There is also a focus on prioritizing actions in sensitive areas. SVOA also works on recipient water quality and measures in the recipient. Action plans are often used, for example, renewing pump stations and pipelines or converting combined systems to separate ones. Renewal of pump stations may be necessary due to occupational health and safety issues, reducing overflows, and improving operational reliability. Some use flexible renewal plans to prioritize key areas. Many also address point sources, inspect properties, and conduct inventories of the network to find leaking manholes and stormwater drains in ditches.

MSVA aims to treat or delay wastewater close to the source. They've joined municipal projects and built stormwater treatment plants. To reduce inflow and infiltration, a dedicated team inspects areas to find and fix issues like leaks or damaged pipes. They prioritize areas based on potential flow reduction, currently focusing on one treatment plant's catchment. Many others use similar methods. NSVA notes that new construction in Nacka, with updated systems, may explain a downward trend in inflow and infiltration.

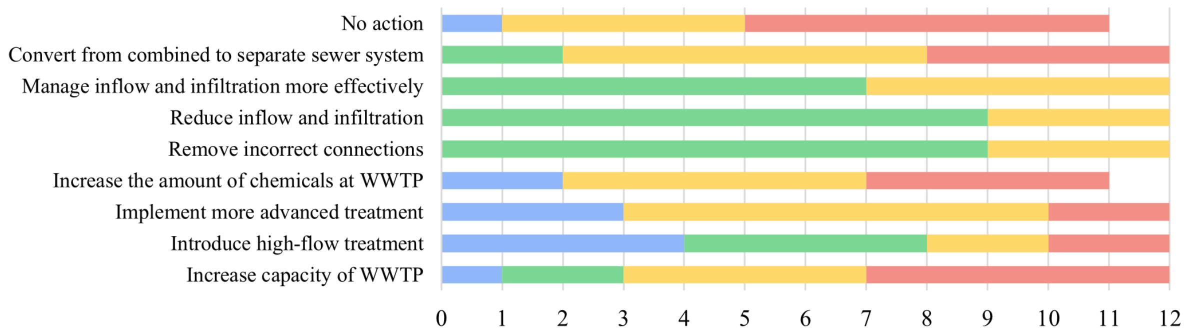
Appendix H

Result from the questionarie

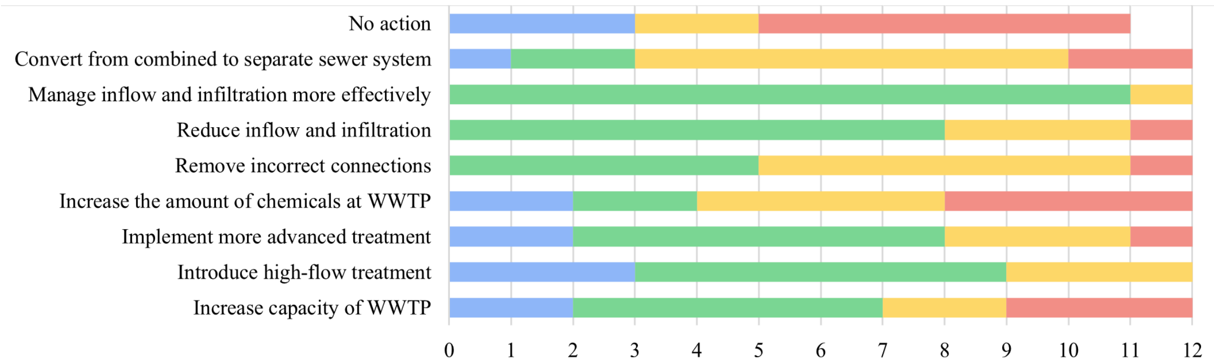
Rating of whether measure is appropriate in ecological aspects. Possible answers are don't know, yes, partially and no.



Rating of whether measure is appropriate in economical aspects. Possible answers are don't know, yes, partially and no.



Rating of whether measure is appropriate in social aspects. Possible answers are don't know, yes, partially and no.



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