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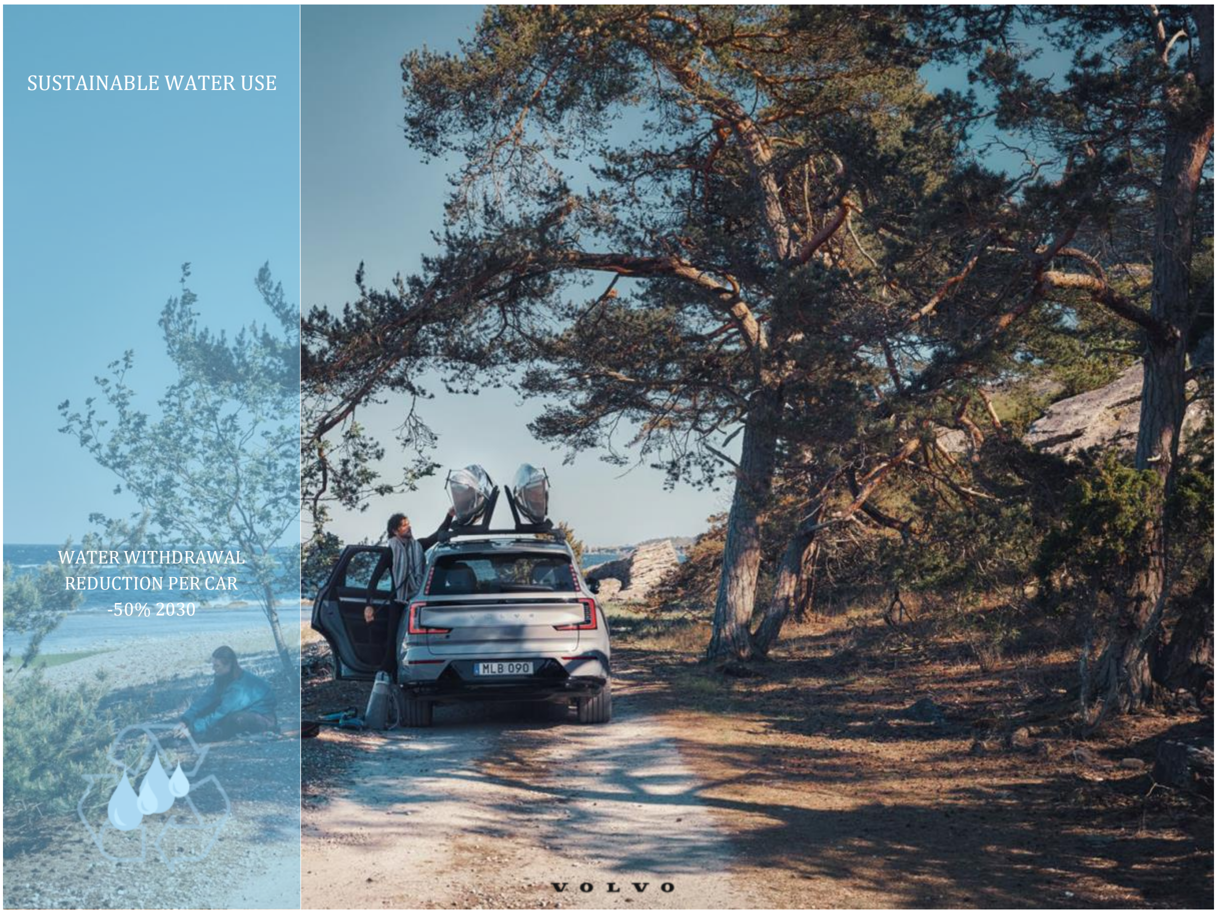

Sustainable Water Use at Volvo Cars Torslanda

An Assessment of Water Use and Potential Reduction Strategies at Volvo Cars Operations in Gothenburg

Master’s thesis in Industrial Ecology

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Cover image: A Volvo Car during an outdoor recreation highlighting Volvo Cars sustainability ambition for water use [1].

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Abstract

This thesis investigates water use and potential reduction strategies at Volvo Cars' manufacturing site in Torslanda (VCT), Gothenburg. With increasing global water scarcity and rising costs for municipal water, the automotive industry must identify opportunities for more sustainable water management. In 2024, the total water withdrawal at VCT was 357 700 m^3, with the paint shop accounting for approximately 79 % of this volume. Current water use amounts to 1.32 m^3/car for manufacturing operations and 2.81 m^3/car when non-manufacturing operations are included.

The aim of this study was to analyze existing water flows, characterize water quality and evaluate strategies for water reuse and recycling. Laboratory work and process mapping were combined with feasibility analysis using a Sustainability Benefit-Cost (SBC) model. Four main actions were evaluated: (1) recycling effluent water to the demineralization process, (2) recycling effluent water to surface treatment processes, (3) reusing wastewater collected from condensate tanks to the demineralization process, and (4) reusing wastewater for processes in TB4.

Results indicate that recycling 71 000 m^3 of effluent water to the demineralization process could reduce water withdrawal by 20 %, with a short payback time (<1 year) and a high water benefit score (7.5). Reusing wastewater from a collection tank could save an additional 9 300 m^3, further reducing water use and organic wastewater volume sent to the municipal treatment plant, Gryaab. If all actions are implemented, total water use could decrease by 22 %, reaching 1.03 m^3/car for manufacturing and 2.51 m^3/car including all operations.
The findings highlight that both economic and environmental benefits can be achieved through strategic water management and investment in water recycling and reuse. However, the long-term success depends on ensuring water quality, addressing membrane degradation, and validating cost assumptions.

Keywords: Automotive industry, Sustainability, Water use, Water reduction strategies, Wastewater treatment, Water reuse, Water recycling, Volvo Cars.

List of clarifications and abbreviations

DI-water – Deionized water

EC – Electrocoagulation

ED – Electrodialysis

Effluent – Effluent is the treated form of wastewater. It is a liquid discharged from an industrial process or a wastewater treatment plant.

HW – Hot water

IWA – International Water Association

MBR – Membrane bioreactors

PAX – Polyaluminum chloride

RO – Reverse osmosis

RWHSS – Rainwater Harvesting and Storage System

SBC – Sustainability Benefit-Cost

TOC – Total organic carbon

TW – Tap water

VCT – Volvo Cars Torslanda

Water discharge – Effluents and other water leaving the system and released to surface water, groundwater or third parties over the course of the reporting period

Water recycling – Water put into use again after more than simple treatment processes

Water reuse – Water put into use again after no treatment or rough filtering

Water use & Water withdrawal – The sum of all water drawn into a system of the undertaking from all sources for any use over the course of the reporting period

Wastewater – Water that has been contaminated by human activities or natural occurring processes, typically originating from industrial or domestic sources.

WWTP – Wastewater treatment plant

Acknowledgements

This master thesis would not have been possible without the invaluable support and collaboration of Chalmers University of Technology and Volvo Cars. We are sincerely grateful to everyone who contributed to the success of this project.

We would like to show our gratitude towards our supervisor at Chalmers, Jesper Knutsson and our supervisors at Volvo Cars, Martin Dejerot, Anna Wilhelmsson and Christer Egerlind for their continuous guidance and expertise throughout the course of this project. We would also like to extend our special thanks to Amanda Hellgren and Lars Löfgren for their valuable and much appreciated insights and input, and to Amir Saeid Mohammadi for his kind assistance during our laboratory work.

Patricia Gavrilov and Isac Lanqvist, Gothenburg, June 2025

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1. Introduction

With a growing global water crisis, businesses and industries worldwide are intensifying their engagement to reach sustainability goals and responsible resource management. Water is one of the fundamental resources for humanity and society is inherently dependent on a reliable and sustainable supply of water. Both public and private sector organizations are looking to improve their water management practices and contribute to responsible water stewardship [1]. Although some areas do not currently face water shortages, the increasing population and expanding industries will challenge the capacity of the infrastructure and distribution system.

At Volvo Cars operations in Gothenburg, water is essential for several processes, including car body manufacturing, painting and surface treatment and assembly. The water used in these processes is sourced from the municipal water treatment plant at Alelyckan. Wastewater from the processes is treated at an on-site wastewater treatment plant (WWTP) using physical-chemical precipitation (flocculation and sedimentation). The effluent water is either discharged to the recipient (Göta älv estuary) or sent to Gryaab, the municipal WWTP. Currently, water from rinsing processes is partially reused, but there is significant potential for increased water reuse and recycling, presenting opportunities for enhanced sustainability and resource efficiency [Personal communication Hellgren A, January 29th, 2025].

Volvo Cars is committed to an environmental strategy aiming for efficient resource utilization. As part of this strategy, Volvo Cars aims to significantly reduce water withdrawal within their operations in Gothenburg, contributing to both cost reduction and minimized environmental impact. These Gothenburg operations play a key role in Volvo Cars' production of premium vehicles and are equipped with state-of-the-art technology and sustainable practices to maintain high standards of quality and environmental responsibility. This project is aligned with Volvo Cars' ambition to reduce their per-car withdrawal of water within their own operations by 50 % between 2018 and 2030, supporting global efforts to conserve water resources and mitigate environmental impact [1]. At present, the water use in manufacturing operations at VCT is 1.32 m^3/car. When including non-manufacturing operations at VCT, the total water use is 2.81 m^3/car. It is important to note that these figures exclusively represent water usage within the operations at VCT and do not include the water use in upstream or downstream value chain.

1.1 Aim and specific objectives

The aim of this master thesis project is to develop a comprehensive strategy for sustainable water use at Volvo Cars Torslanda (VCT) facilities. This will be achieved by conducting a thorough assessment of current water use and consumption, identifying opportunities for reduction and recycling and formulating actionable implementation pathways that align with Volvo's operational framework and sustainability goals.

Specific objectives are to:

- Analyze current water use and consumption levels at VCT facilities and identify water-intensive operations by developing a water flow analysis.
- Investigate potential reuse of wastewater in processes to evaluate reduction strategies for water use.
- Evaluate the recycling of effluent water as replacement of municipal water and water management strategies that could be implied to reduce water withdrawal per car.
- Assess the feasibility of potential solutions for water reduction strategies using a Sustainability-Benefit Cost model.

1.2 Limitations

The limitations of this study include the following:

- The treated wastewater from the organic line will not be considered for recirculation due to the absence of biological treatment and high cost of implementing such equipment at present. However, this will be addressed as a future opportunity to explore potential investments and treatment solutions to enable reuse and recycling of this water.
- The water withdrawal per car and the potential reduction strategies only addresses the in-house operations and do not encompass the upstream or downstream value chain.
- The scope of the investigation is limited to facilities located in the western part of VCT.

2. Theory

This chapter provides the theoretical background necessary to understand the context, challenges and technical aspects discussed in the report. It begins with a general overview of water scarcity and water stress in Gothenburg, followed by a section on water use in the car manufacturing industry, including strategies for recycling and reuse. A detailed description of water usage at VCT is then presented, with a particular focus on the paint shop process. This includes the demineralization of municipal water, surface treatment and painting, wastewater characteristics, and the on-site WWTP. Finally, the chapter outlines relevant water treatment technologies, such as reverse osmosis (RO) and ion exchangers, which are key components in achieving high water quality for reuse and recycling within industrial processes.

2.1 Water scarcity and water stress in Gothenburg

Water stress is defined as a condition where the water demand exceeds the available amount of water for a specific period [2]. Water scarcity, on the other hand, occurs either when the demand surpasses the supply or when the water supply is affected by decreasing quantity or quality [3]. Globally, four billion people experience water scarcity at least one month each year and over two billion people live in countries where water supply is insufficient [4]. Figure 1 below illustrates the water stress levels in southern Sweden, highlighting that Gothenburg experiences low water stress. This indicates that the city's water demand does not exceed its available supply.

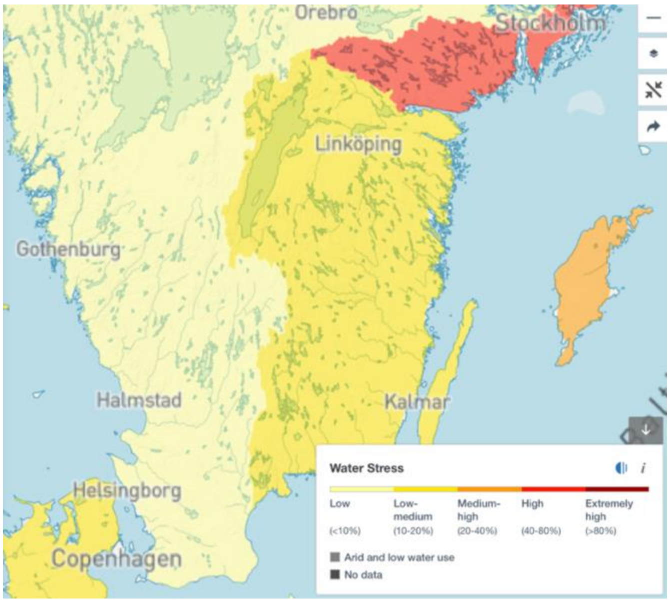

Figure 1: Water stress level in southern Sweden [5].

Although Gothenburg currently has sufficient water supply to meet its demands, the increasing water use driven by a growing population and expanding industries could place more pressure on the city's infrastructure and distribution systems. This increasing demand will necessitate investments to enhance the capacity and efficiency of water infrastructure. Therefore, solutions to minimize water demand in industrial processes could be necessary to mitigate the need for extensive infrastructure and distribution capacity upgrades [6, 7].

2.2 Water use in the car manufacturing industry

The car manufacturing sector uses significant amount of freshwater, characterized by water-intensive processes. These encompass for instance surface treatment and coating, paint spray booth operations, washing and rinsing, cooling systems, assembly lines, and car body fabrication. Notably, the paint shop, encompassing both surface treatment and painting stages, represents the most substantial water consumer within the facility. This domain is further compounded by utilization of chemicals and the necessity for regular equipment maintenance, including cleaning with water. Consequently, the industry generates substantial volumes of wastewater, varying in composition and pollution load, necessitating the implementation of wastewater treatment methodologies [8].

Based on data from The European Automobile Manufactures' Association (ACEA), the total water used in car production in the EU has been reduced by approximately 57 % since 2005. In 2023 the average water use per car was 2.84 m^3/car, and the total water use was 26.12 million m^3/year. These figures only include the in-house operations at various car manufactures and do not account for the upstream or downstream levels of water use. One of the reasons for the water reduction includes strategies for water reuse and recycling using technologies for recirculation of wastewater [9].

2.2.1 Water recycling and reuse in the car manufacturing industry

Treatment methods are typically used to handle the wastewater generated from the various processes within the industry. The primary and secondary treatment methods are typically physical-chemical processes such as coagulation, neutralization, flocculation, sedimentation and filtration which are used to treat the wastewater for it to be further discharged to the recipient [10]. Besides physical-chemical treatment, biological treatment could be a necessary step if the wastewater contains organic substances. With a global concern for water scarcity, it is important for car manufactures to look at potential for reuse of water to minimize the need for new municipal water [11]. To recycle the wastewater, it must be further treated using additional secondary steps and more advanced tertiary treatment steps. These secondary and tertiary steps typically include more advanced treatment methods such as ion exchange, biological processes, membrane separation processes and absorption [10].

First, the wastewater must be characterized and classified to determine its specific content. Based on the substances present in the wastewater, appropriate secondary and tertiary treatment steps need to be selected. Second, the treatment train must be decided based on the quality requirements for the recycled water. This concept is typically called fit-for-purpose wastewater treatment and aims to optimize the treatment processes, ensuring economic feasibility and environmental sustainability by avoiding both excessive and insufficient treatment of wastewater [12].

Figure 2 below presents an example of a typical process scheme for water flows in a WWTP utilized in the automotive industry. The scheme highlights the potential recycling of water through additional treatment stages, including membrane bioreactor (MBR), nanofiltration (NF) and desalination, aimed at reducing the overall water use.

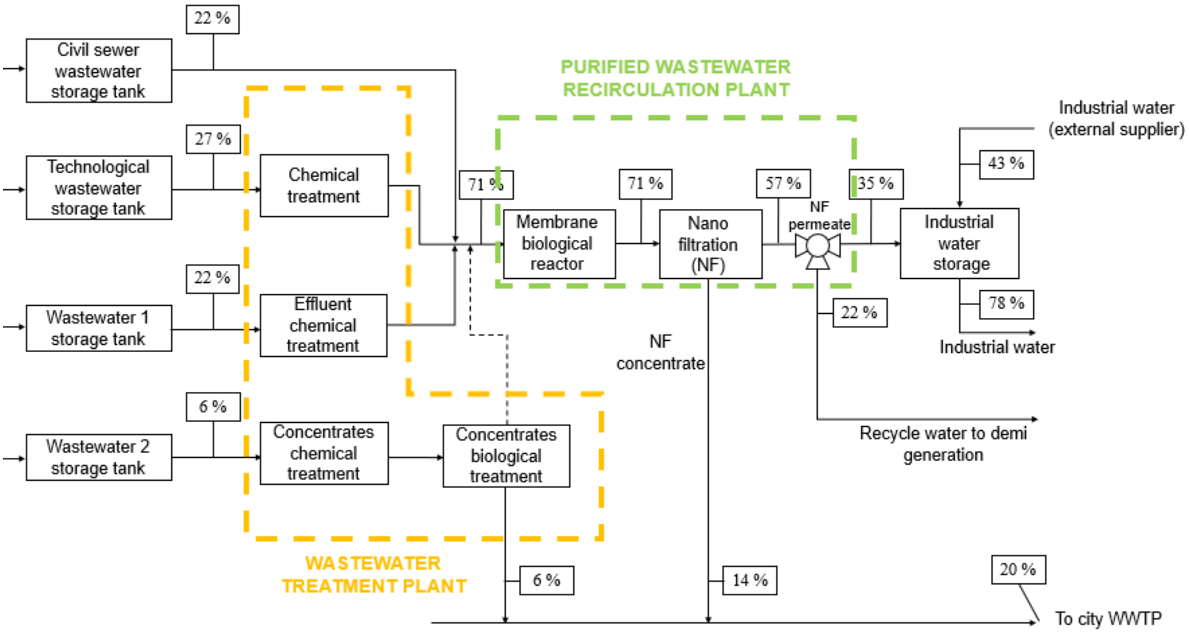

Figure 2: Process scheme of a WWTP with a purified wastewater recirculation plant [11].

Depending on the intended application for water recycling and the characteristics of the wastewater, the treatment process involves either two steps (MBR and NF) or three steps (MBR, NF and desalination) [11]. In this process, 77 % of the wastewater can be collected, while 23 % is directly consumed during the process. Of the collected wastewater, 71 % can be further treated in the purified wastewater recirculation plant. The treated water is then either recycled directly in processes or sent to the demineralized water production plant.

2.2.2 Water treatment method – Reverse Osmosis

To effectively treat wastewater and effluents from various processes, it is essential to evaluate water treatment methods that efficiently remove unwanted particles and solids. This ensures that the treated water can be safely disposed of or recycled.

RO is one of the most widely used and well-established methods for seawater desalination and is also utilized in the automotive industry for paint manufacturing [13]. In this process, a pump forces water molecules through a semi-permeable membrane with pores as small as 0.1 nm, functioning like a highly efficient water filter. While the membrane allows only the solvent to pass through, dissolved particles, such as metals, chloride and fluoride ions are retained and stick on the other side of the membrane. Since the solvent moves from a region of high concentration to one of lower concentration, it goes against its natural concentration gradient. This makes RO an energy-intensive process, requiring the application of high pressure to drive the separation [14].

RO is the most efficient method for removing chloride ions from wastewater, capable of eliminating up to 99 % of all chlorides, depending on the composition of the water and the operating parameters [15, 16]. RO is also highly effective in removing other compounds, such as sulfates, with a removal rate up to 98 % [17]. It is also used for reduction of certain metals ions, for instance nickel, chromium and aluminum ions as well as being highly efficient in removing total organic carbon (TOC), when operating under specific conditions [18, 19, 20]. Even less abundant compounds, such as phosphorus, can be reduced using RO. In combination with other membrane filtrations such as NF, the amount of tot-P removed can reach a level of 95 % [21]. To enhance the removal of all these contaminants, RO is often combined with additional treatment methods, including precipitation, UV-oxidation and activated carbon filtration.

RO is the most commonly used method for removing fluoride ions from wastewater, with a potential reduction up to 99 %, depending on the operating parameters [22]. To achieve this level of removal, RO is often used in combination with UF, crystallization or precipitation, which can lower the final fluoride concentration below 1 mg/L. However, when using RO alone, a more realistic reduction rate is between 85 % and 95 %, typically resulting in a final fluoride concentration of around 1 mg/L [23].

One drawback to consider when using RO membranes is the risk of fouling, which occurs when suspended solids accumulate on the membrane surface, and scaling, which happens when dissolved salts and minerals precipitate and clog the membrane pores [24]. Additionally, RO membranes can be damaged by certain chemical compounds, such as chlorine, which degrades the membrane material and contributes to scaling [25]. The RO membranes used at VCT are no exception; to maintain their performance, they must not be exposed to chlorine concentrations exceeding 0.2 mg/L [Personal communication Hellgren A, March 3rd, 2025].

2.3 Water use at Volvo Cars Torslanda

Water is a crucial resource at VCT, utilized in various processes throughout the car manufacturing operations. Figure 3 illustrates the VCT site and the distribution of water flows among the different facilities. The water, sourced from the Alelyckan, the water treatment plant in Gothenburg, is used in these processes and treated as wastewater upon exiting the various operations. As the water leaves the different processes, it is either treated and discharged as effluent water to the recipient (Göta älv estuary) or directed as wastewater to Gryaab, the regional WWTP, for further treatment. The effluent water and wastewater discharged from the site originates from the on-site WWTP located within the paint shop facility [Personal communication Hellgren A, January 29th, 2025].

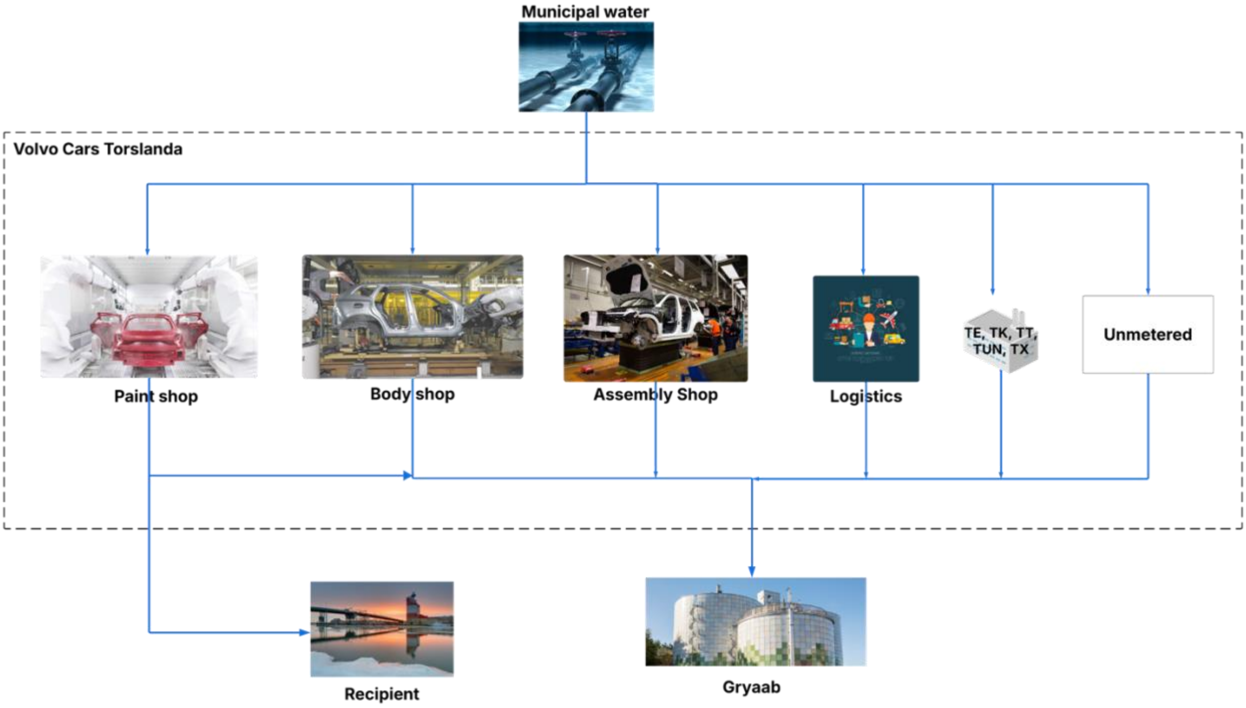

Figure 3: Basic outline of water flows at Volvo Cars Torslanda.

2.4 The Paint shop process

This section describes the various processes within the paint shop, including the production of deionized water through the demineralization process, the surface treatment and painting of car bodies as well as the WWTP at VCT. These processes are essential for ensuring high-quality coating application, corrosion resistance and sustainable water management within the facility.

Figure 4 illustrates the various processes within the paint shop, with different colored arrows indicating the characteristics of the water flowing between the systems and processes. The municipal tap water flows directly to TB3 (training center), TB1 (offices, cleaning water), TB4 (the painting process) and TB2 (surface treatment, WWTP and demineralization process). A portion of the incoming water is further treated in the demineralization process to produce deionized water (DI-water) for use in processes requiring very pure water. Some of the outgoing wastewater is first treated in the WWTP before exiting the system to recipient or Gryaab, while some flows directly to Gryaab without further treatment.

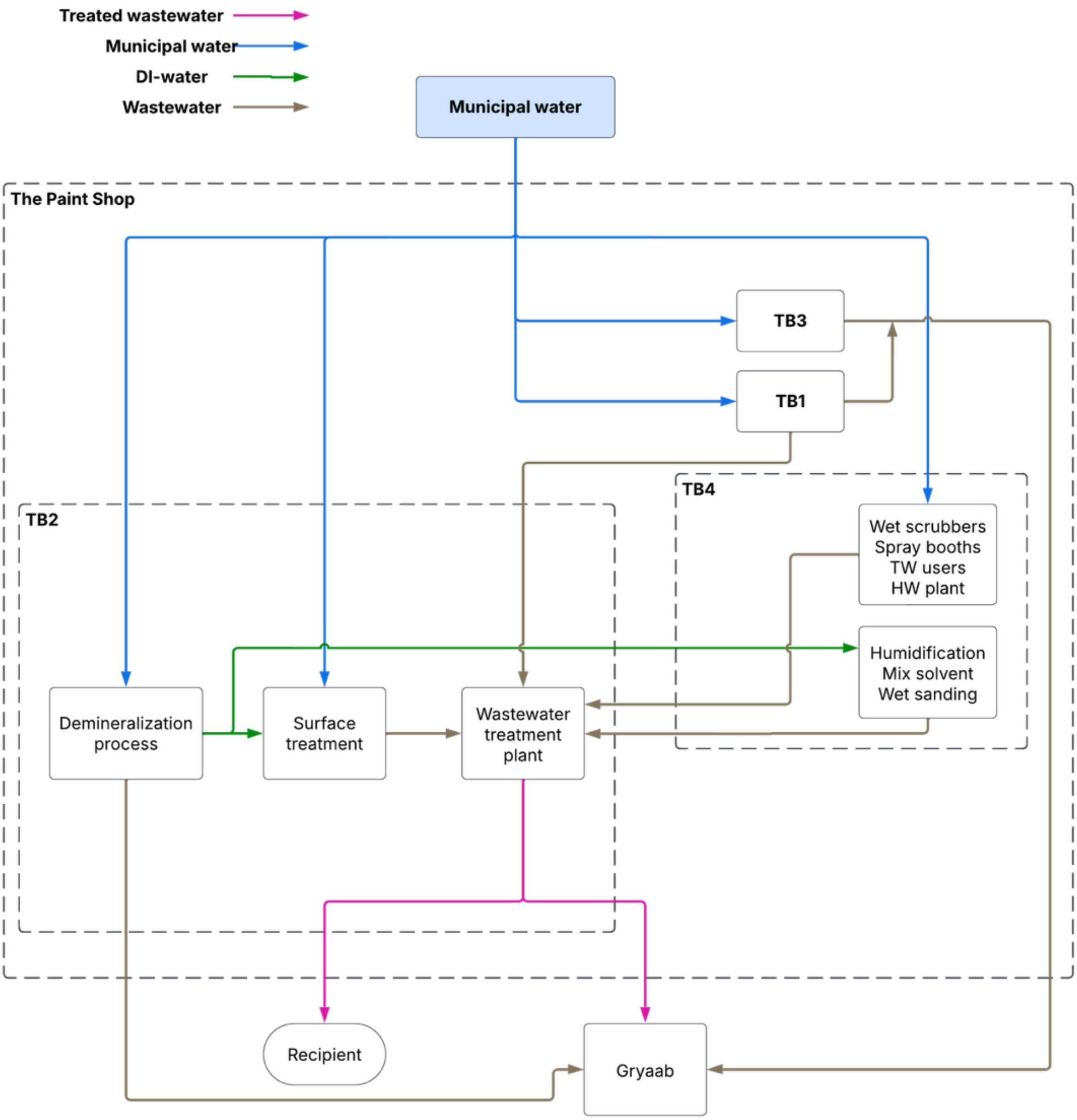

Figure 4: Process scheme of the paint shop.

2.4.1 Demineralization process of Municipal tap water

Figure 5 illustrates the demineralization process of municipal tap water sourced from Alelyckan, the water treatment plant. The initial stages of the demineralization process involve multilayer filtration and RO. The multilayer filters function similarly to a gravel filter, removing suspended solids from the water. Additionally, the filters can serve as a water softening unit, operating in a similar manner to an ion exchanger. The filtered water then undergoes RO, where it is deionized and transferred to the DI-water tank for storage prior to further processing. Before the DI-water can be utilized in the process, it must undergo disinfection through UV-sterilization to kill microorganisms and pass through a final particle filter to remove residual particles [26].

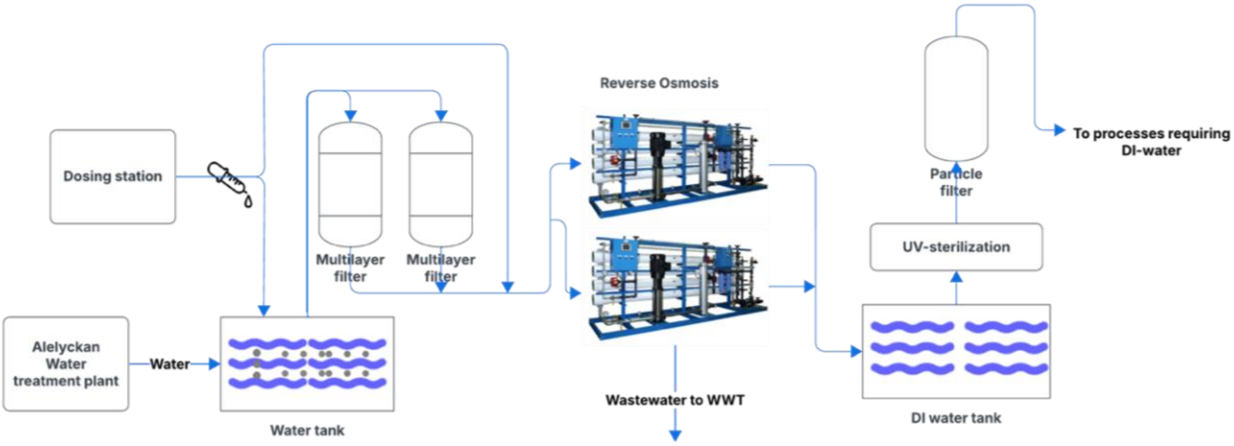

Figure 5: Process scheme of the demineralization process.

2.4.2 Surface treatment and painting of the car body

Figure 6 describes the surface treatment process which is divided into two steps: pretreatment and electrocoating. In the pretreatment step, municipal tap water is used for the degreasing/cleaning process whereas DI-water is used for activating, phosphating, passivating and rinsing. DI-water is also used for the electrocoating process where a coating created by an electrodialysis is added.

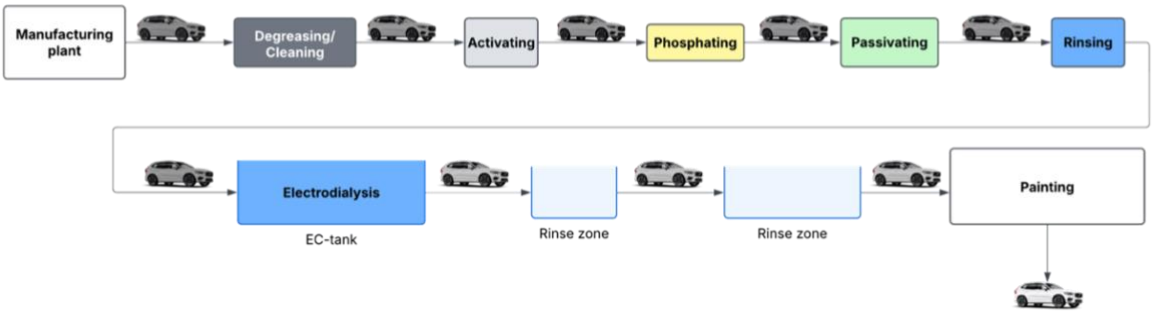

Figure 6: Process scheme of pretreatment and electrocoating process.

After the surface treatment, the car body is sent to the painting process where three coat layers are added [27]. The wastewater produced in the process is sent to the WWTP where it is further treated. The characteristic of the wastewater is described in Section 2.4.3 and the WWTP on-site is described in Section 2.4.4.

2.4.3 Characteristics of wastewater from processes

The wastewater generated during the surface treatment and painting processes is categorized into organic and inorganic wastewater. Specifically, wastewater from the degreasing process and electrodialysis is classified as organic, while wastewater from the phosphating and passivating steps is classified as inorganic. The treatment procedures for these two types of wastewaters differ due to the particles, pollutants and contaminants that must be removed during the treatment stages. This differentiation is further elaborated in Section 2.4.4, which presents detailed process schemes for both the organic and inorganic lines within the on-site wastewater treatment plant.

2.4.4 Wastewater treatment plant of process water

Figures 7 and 8 illustrate the WWTP and the various treatment steps for both the inorganic and organic line. The outgoing inorganic wastewater from the surface treatment processes is collected in two buffer tanks, as highlighted in Figure 7. The wastewater is then neutralized in two steps by adding chemicals to adjust the pH. The flocculation step includes adding a flocculant to promote flocculation and bind contaminants. Heavier particles are then separated through pre-sedimentation, followed by further treatment in a lamella separator. The resulting sludge is transported to a sludge consolidator and then transferred to a filter press to remove some of the remaining wastewater. The sludge is pumped to a sludge container before being sent to Stena Recycling for final disposal. The pretreated wastewater undergoes post-neutralization and is pumped through two gravel filters to retain solid particles. After passing through the gravel filters, the wastewater is purified from metal ions via two ion exchangers. Before being discharged to the recipient, the wastewater goes through a final neutralization step and a final inspection where the wastewater is sampled for quality control [28].

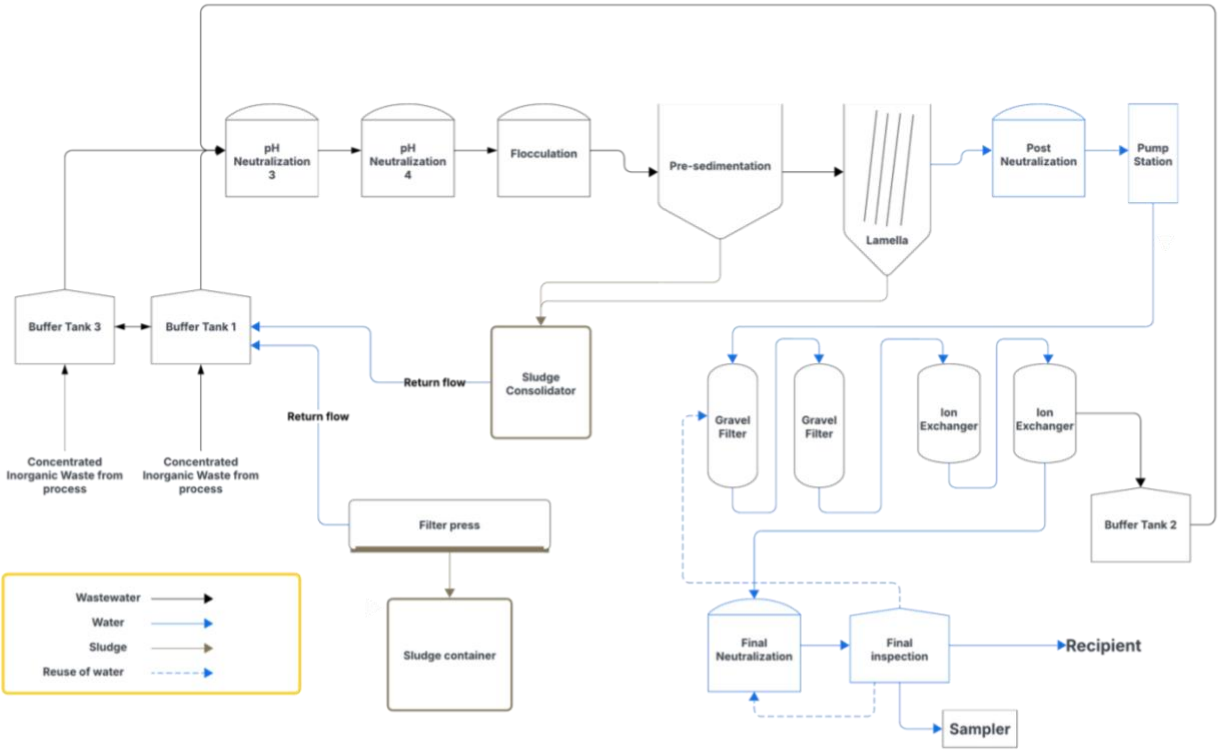

Figure 7: Process scheme of the inorganic line in the treatment plant.

In the organic line (Figure 8), the wastewater treatment steps are similar to those in the inorganic line. However, the main differences are the presence of two pre-sedimentation tanks, the absence of ion exchangers and the fact that the wastewater is directed to the public sewage channel leading to Gryaab. At Gryaab the wastewater is then processed and treated to remove all organic matter that has been formed along the way, e.g. paint residues. The reason for this is because VCT does not have proper treatment equipment for handling organic waste and wastewater. Thus, the wastewater needs to be sent to the municipal WWTP before being sent to the recipient.

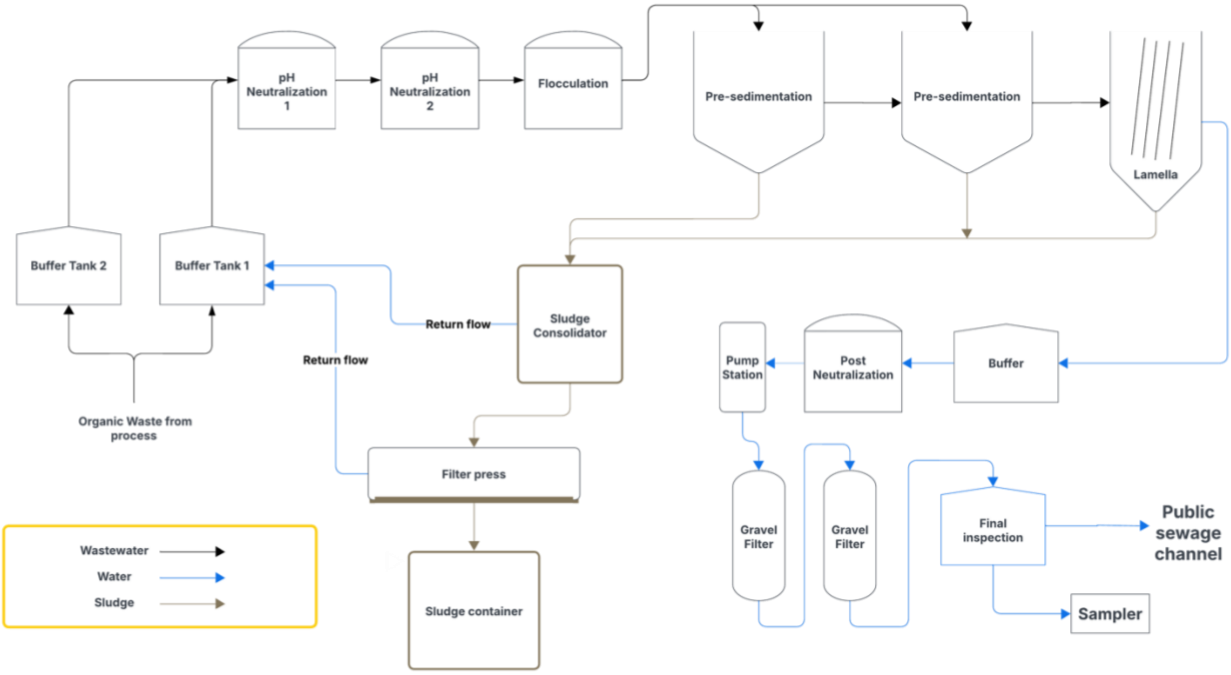

Figure 8: Process scheme of the organic line in the treatment plant.

3. Methodology

This chapter presents the methodology used to address the specific objectives of the study. The method includes several steps, structured to ensure clarity and understanding of how the study was performed. Figure 9 aids in comprehending the work process by visualizing the step-by-step progression of the methodology. Each step will be described in greater detail throughout this chapter.

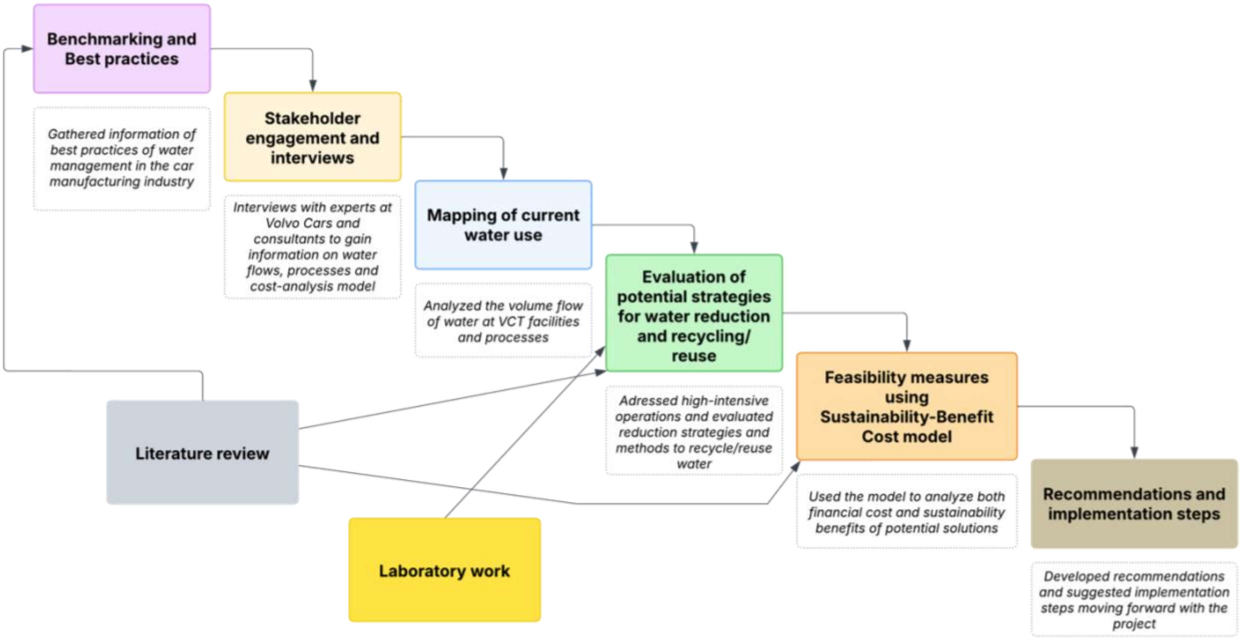

Figure 9: Visualization of the methodological process.

3.1 Benchmarking and Best practices

To gain insights into best practices in water management within the car manufacturing industry and to benchmark these against Volvo Cars' water management strategies, information was collected from a variety of sources. This included scientific articles, industry documents and papers from other car manufacturers. The gathered information was synthesized through a comprehensive literature review, which is presented below.

3.1.1 Literature review

A literature review was conducted to gather relevant information on the water use and consumption in car manufacturing industries and best practices of water management, reuse and recycling. The primary sources for conducting the literature review were Google Scholar, Science Direct, International Water Association (IWA), webpages and research papers from other car manufacturing companies. The review involved searching for research papers, articles and journals using the following keywords: *water use, car manufacturing industries, industrial wastewater treatment*, *water reuse/recycling.*

3.2 Mapping of current water use, consumption and potential reduction strategies

To conduct the water flow analysis and map the current water use and consumption at Volvo Cars, information was gathered through interviews and meetings with employees. Once the data was collected, a detailed analysis of water flows was performed and illustrated using a Sankey diagram.

Additionally, several steps were undertaken to develop potential reduction strategies. First, a literature review was conducted to gather information on methods for reusing and recycling wastewater and effluent water. Second, interviews and meetings were held with employees at both VCT and Volvo Cars Gent (VCG) to obtain relevant information regarding water quality and purity requirements for reuse or recycling. Third, the insights gained about water quality and purity requirements necessitated laboratory work to determine the concentration levels of key parameters. The laboratory work was conducted according to Section 3.3.

3.2.1 Personal communication, meetings and interviews with employees at VCT

To gain a comprehensive understanding of water use and consumption at the site, various meetings and interviews were conducted with key employees. One of these meetings included a guided tour of the process, accompanied by personal communication with a process engineer and a maintenance engineer specialized in the paint shop operations. Following this, technical descriptions of the different process steps were collected, and flowcharts were provided to facilitate the understanding of water flows at VCT and to obtain specific water flow data. Additionally, the two engineers shared insights on potential water reuse and recycling strategies and ideas were exchanged on how to further evaluate these potential reduction strategies as the thesis project progressed.

Furthermore, an online meeting was held with an energy engineer to further examine the distribution of water across different processes. Another online meeting was conducted with a technical expert in Gent specializing in pretreatment and WWT, who provided insights into best practices and alternative solutions implemented at other facilities, as well as ongoing projects for more sustainable water management in water-stressed areas. All meetings and interviews are summarized in Table 1, which also highlights the topic of each meeting.

Table 1: Summary of meetings and interviews with employees at Volvo Cars.

Volvo Cars region	Role at Volvo Cars	Topic of meeting
Torslanda	Process Engineer	Processes at VCT paint shop. Water use, treatment and reduction strategies in the paint shop. Water purity requirements.
Torslanda	Energy Engineer	Water flows at VCT and specific processes. Wastewater quality and composition.
Torslanda	Maintenance Engineer	Processes at VCT paint shop, specifically the painting process. Water recirculation and potential reuse of wastewater within the paint shop.
Torslanda	Senior Environmental Specialist Water Emissions	Information regarding water reduction projects at Volvo Cars. Treatment of wastewater and potential reuse/recycling strategies.
Gent	Technical expert – Pretreatment and WWT	Current ongoing water management projects within Volvo Cars. Potential strategies for reduction of water Potential reuse of wastewater.

3.2.2 Literature study of strategies for water reduction, reuse and recycling

To gain a greater understanding of strategies for water reuse, recycling and reduction, information regarding water treatment methods and water management was gathered. The study was conducted by searching for research papers, scientific articles and journals using primary sources such as Science Direct, IWA and ResearchGate. At first, the following keywords were used: *wastewater treatment, water treatment methods, recycling of industrial wastewater, water management strategies, reusing wastewater, water reduction.*

As the study progressed, a deeper knowledge of Volvo Cars' processes was gained which allowed for more refined searches. The following keywords were then used: *reverse osmosis, membrane separation, electrodialysis, ion exchangers, membrane bioreactors, fluoride removal, phosphorus removal, chloride/chlorine removal, flocculation, wet scrubber, humidification.*

3.3 Laboratory work – Water quality analysis

Laboratory work was conducted to analyze the composition of outgoing water (DI-water) from the demineralization plant and the effluent water from the WWTP. The DI-water was analyzed for the compounds marked with an (X) in Table 2 to determine the extent to which these compounds were retained during the demineralization plant process. The effluent water was analyzed to assess the concentration levels of the compounds marked with an (X), as shown in Table 2, to further investigate the recycling and reuse potential of this water. To ensure a reliable analysis, five different water samples of DI-water and four samples of effluent water were collected at various times over a two-week period.

Effluent water data was derived from two sources: laboratory analyses conducted at Chalmers during the spring of 2025 and results from a commercial laboratory contracted by VCT, covering sampling weeks 2 through 9 of 2025. Notably, the metal concentration levels in the effluent water were based on data from weeks 8 to 9, following process adjustments in the facility [Personal communication Hellgren A, March 10th, 2025].

Table 2: Parameters analyzed during laboratory work.

Parameters	**Effluent water VCT** (2025)	**DI-water VCT** (2025)
Nickel (Ni)		X
Aluminum (Al)	X	X
Total phosphorus (tot-P)		X
TOC	X	X
Calcium (Ca)	X	
Magnesium (Mg)	X	
Total chlorine (Cl_2)	X	
Chloride (Cl^-)	X	
Sulfate (SO_4)	X	
Sodium (Na)		X
Cadmium (Cd)		X
Lead (Pb)		X

The following sections describe the laboratory procedures of the various analysis methods used to evaluate different parameters.

3.3.1 Analysis of various compounds using Inductively Coupled Plasma - Mass Spectrometry (ICP-MS)

ICP-MS (see Figure 10) was used to perform the analysis of Cd, Cr, Pb, Ni, Al, Ca, Na, Mg, SO_4. It works by ionizing the water sample using argon plasma, which atomizes the sample and creates ions. These ions are then analyzed by a mass spectrometer to determine the element composition and concentration [29].

Figure 10: ICP-MS instrument at Chalmers lab.

3.3.2 Analysis of total phosphorus using PhosVer® 3 Method

The tot-P concentration was analyzed using the PhosVer® 3 Acid Hydrolysis Method, which is capable of detecting phosphorus levels ranging from 0.02 to 1.1 mg/L [30]. The procedure involved adding 5 mL of the water sample to a vial, which was then placed in the DRB200 reactor for 30 minutes. After the reaction period, the vial was retrieved and 2 mL of 1.54 N sodium hydroxide solution was added along with the contents of one PhosVer® 3 Powder Pillow. The vial was shaken thoroughly to ensure proper mixing before the phosphorus concentration was measured. Finally, the vial was placed in a colorimeter for 2 minutes, as can be seen in Figure 11 and the phosphorus concentration in mg/L was recorded.

Figure 11: HACH DR/890 colorimeter.

3.3.3 Analysis of chlorine using USEPA DPD Method

The chlorine content of the water samples was analyzed using the USEPA DPD Method which can analyze concentration levels of 0.02 to 2 mg/L Cl_2 [31]. The analysis was performed by adding 10 mL of the water sample and the content of one DPD Free Chlorine Reagent Powder Pillow to the vial. The vial was swirled for the content to be properly mixed and then directly put in the colorimeter (see Figure 11) for analysis of Chlorine content (mg/L Cl_2).

3.3.4 Analysis of chloride using ion chromatography

The amount of chloride ions in the effluent water was analyzed through ion chromatography (IC) to determine its concentration. The samples were measured for conductivity and then diluted to the correct volume. Figure 12 illustrates the IC-equipment used at Chalmers lab.

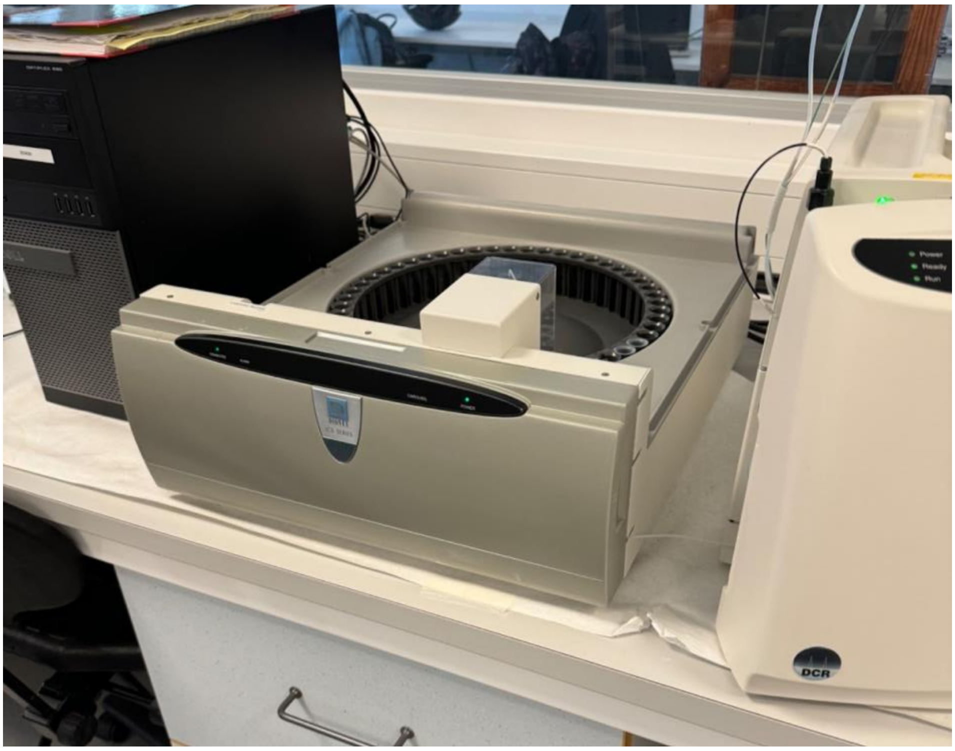

Figure 12: Ion Chromatography instrument at Chalmers lab.

3.4 Feasibility measures using a Sustainability Benefit-Cost model

To assess the financial and sustainability aspects of the proposed solutions, an analysis was conducted using a proprietary Sustainability Benefit-Cost model (SBC-model). This analysis was based on information gathered through a meeting with a consultant specialized at the model, as well as a literature review of costs associated with various equipment and installations. During the meeting the consultant provided a detailed explanation of the SBC-model, including how to apply the model and interpret the results to ensure an accurate and comprehensive analysis.

The SBC-model served as a supporting tool for comparing different alternative solutions from both cost and sustainability perspectives. It was used to evaluate proposed investments, prioritize them, and identify the best solution to address the problem [Personal communication Moritz M, February 6th, 2025].

The financial impact assessed the business case of an action in terms of payback time, considering capital expenditures (CapEx), operational expenditures (OpEx) and revenues over its lifetime. The financial impact was evaluated in terms of payback time, within a range of 0 and 10 years, based on CapEx, OpEx as well as revenues generated from water savings. The sustainability benefit score was based on four key dimensions: climate, energy, water and waste, and an overall score between 0 and 10 was assigned. For this evaluation, only the water benefit score was considered, which included parameters such as the volume of water saved, local water stress level, and whether the investment aligned with VCT's water ambitions.

3.4.1 Literature review of cost analysis

To understand the financial impacts of the potential solutions, information regarding costs of investment, both Capital Expenditures (CapEx) and Operational Expenditures (OpEx) were gathered. The information was collected by both connecting with suppliers of water treatment equipment and searching for research papers, scientific articles and journals using primary sources such as Science Direct and IWA.

4. Results and discussion

This section presents and discusses the findings of the study. It begins with a comprehensive analysis of water flows across the entire site, followed by a detailed examination of water flows within the paint shop process. The quality of municipal tap water, effluent water, and DI-water is then evaluated and presented. The potential for reuse and recycling of both effluent water and wastewater is explored, considering the intended applications and water purity requirements. Finally, the SBC-model is employed to assess the financial costs and sustainability scores of the proposed solutions.

4.1 Analysis of water flows at Volvo Cars Torslanda Facilities

The distribution of water at VCT is illustrated in a Sankey diagram in Figure 13. The total municipal tap water usage amounts to 357 700 m^3, which is distributed across six divisions [Personal communication Löfgren L, February 19th, 2025].

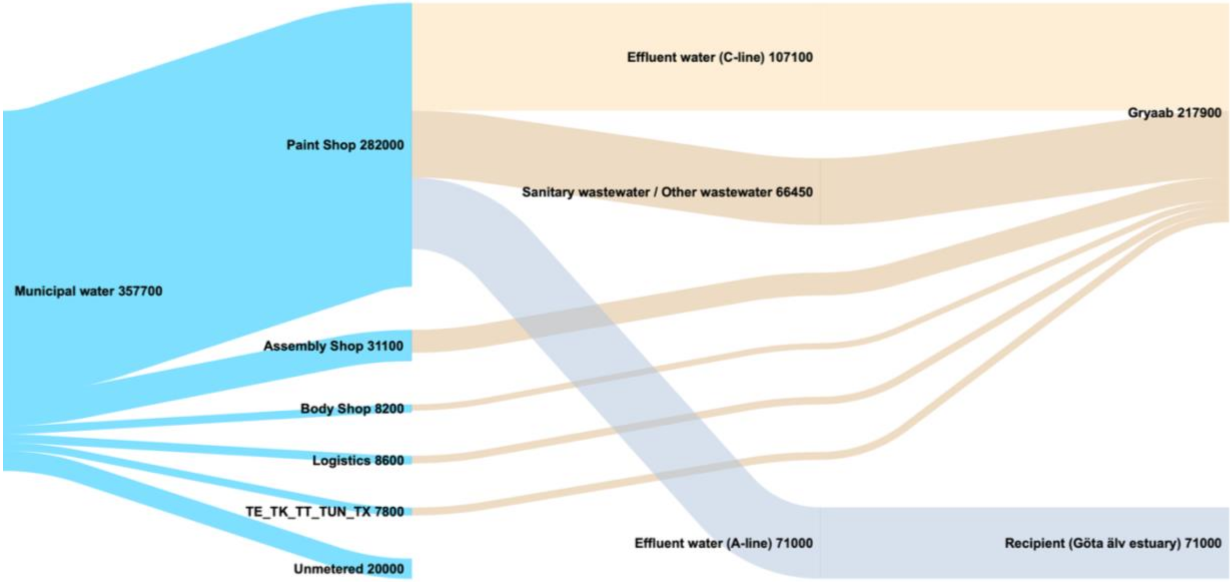

Figure 13: Water distribution at VCT in 2024 measured in m^3.

Approximately 7 800 m^3 is used in office buildings that are not involved in car production. The body shop, where car bodies are manufactured as the first step in the car manufacturing process, utilizes 8 200 m^3. Logistics operations consume another 8 600 m^3, while 31 100 m^3 is used in the assembly shop, which is where the cars are assembled before being sent to customers. Additionally, 20 000 m^3 of water is unmetered. The paint shop, however, consumes 282 000 m^3, representing approximately 79 % of the total municipal water intake.

This highlights the paint shop as the most water-intensive part of the car manufacturing process, thereby offering the greatest potential for water reduction.

A total of 288 900 m^3 leaves the facilities, resulting in a remaining water stock of 68 800 m^3. This residual volume primarily results from leakages, which are categorized as Unmetered in Figure 13, as well as evaporation losses occurring within various industrial processes. The paint shop generates approximately 244 550 m^3 of wastewater annually. Of this volume, 110 800 m^3 is sent directly to Gryaab without treatment, 107 100 m^3 is treated but is then sent to Gryaab for further organic treatment and 71 000 m^3 is treated on-site before being discharged as effluent water to the recipient.

4.1.1 Analysis of water flows at the Paint shop

Figure 14 illustrates the distribution of water flows within the paint shop for the year 2024, see Appendix A1 for a more detailed process scheme. A total of 282 000 m^3 of municipal tap water enters the system and is allocated to various operations within the paint shop. According to the figure, most of the municipal water is directed to TB2, which is the surface treatment and demineralization process. Approximately 45 % of all water entering the paint shop is used in the demineralization process to produce DI-water, which is essential for both the surface treatment and the painting process (TB4). Important to note, however, that not all water flows are balanced. This discrepancy arises because some values are based on actual measurements from flow meters within the process, while others are derived from estimations. As a result, the total inflows and outflows may not match completely. Additionally, certain process steps involve inherent water losses–such as evaporation or water retained on the car body as it exits a stage, for example during the surface treatment step [Personal communication Löfgren L, February 19th, 2025].

The brown arrows in the figure represent the wastewater from various processes, which either flows directly to Gryaab (38 %) or enters the WWTP (62 %) for further treatment before leaving the system. The pink arrows indicate the effluent water, with 71 000 m^3 being inorganic and 107 100 m^3 being organic. The organic effluent water is sent to Gryaab for additional treatment before it can be discharged, whereas the inorganic effluent water flows directly to the recipient, as it meets the required purity limits.

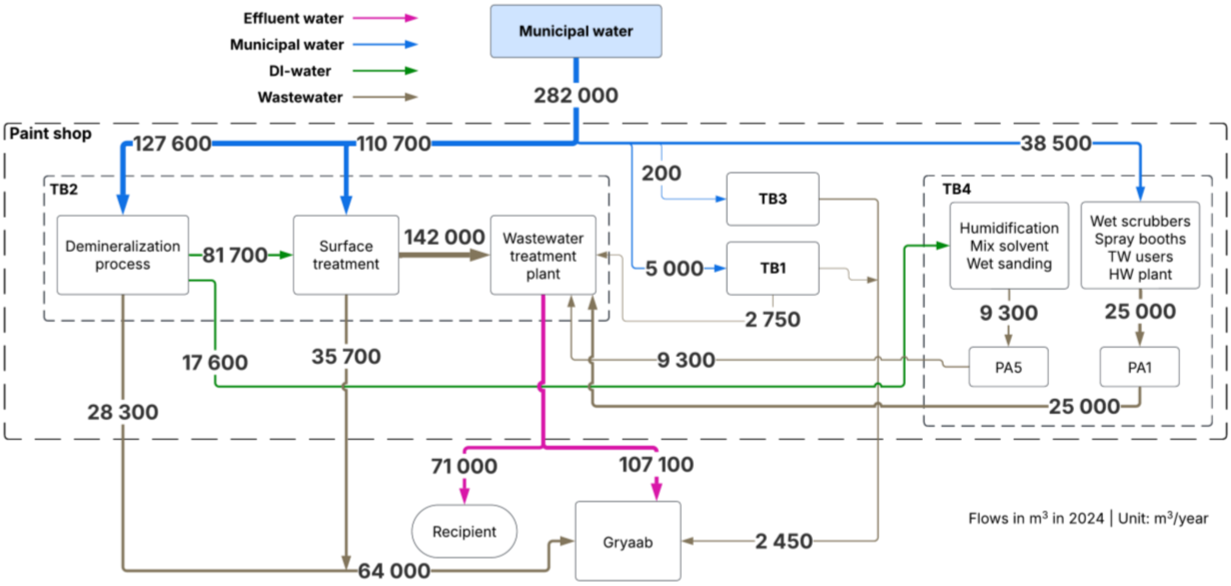

Figure 14: Flowchart illustrating water flows in the paint shop at VCT.

Given that the effluent water of 71 000 m^3 contains only small amounts of inorganic pollutants, there is potential for recycling and reusing this water to reduce the demand for municipal tap water. Depending on whether the water is to be used directly as a replacement of municipal tap water in various processes or for producing DI-water, different levels of advanced water treatment methods may be required. This is further discussed in Section 4.3, whereas the characteristics and composition of the inorganic effluent water is further described in Section 4.2.1.

4.2 Characterization of water quality

This section provides information on the quality and characterization of three water types: the municipal tap water, effluent water and the DI-water. The assessment includes comparisons between discharged effluent water and municipal tap water, as well as between DI-water and municipal tap water. These comparisons aim to provide insights into what compounds present and their concentrations, emphasizing the differences in water quality and treatment efficiency.

4.2.1 Comparison of discharged effluent water and municipal tap water

Table 3 presents the median concentration values of selected parameters in both tap water and effluent water. Tap water values were obtained from measurements conducted at Alelyckan in 2024 [32, 33]. In contrast, the values for the effluent water were obtained as described in Section 3.3 (laboratory analyses conducted at Chalmers are indicated with an *). All data from the analyses performed at Chalmers can be seen in Appendix A2. To ensure consistency and enable meaningful comparisons, all values are reported as medians, in line with the data format provided by Alelyckan for tap water.

When assessing water quality and composition, several parameters must be considered, such as number of contaminants and pH levels. Since VCT purchases municipal tap water for their processes it is crucial to compare the concentration levels of substances in the purchased water with those of effluent water sent to the recipient from the WWTP. This comparison is essential when evaluating potential solutions for reusing the discharged effluent water.

Table 3: Median concentration values for specific parameters in tap water and discharged effluent water.

Parameters except for pH	**Median concentration value, effluent water** (VCT January–March 2025)	**Median concentration value, tap water** (Alelyckan 2024)
Pb [µg/L]	0.03	0.08
Cr [µg/L]	0.60	< 0.10
Ni [µg/L]	7.70	0.30
Zn [µg/L]	2.00	3.00
Al [mg/L]	0.43	0.019
F^- [mg/L]	5.8	< 0.10
Tot–P [mg/L]	0.06	< 0.005
TOC [mg/L]	1.81*	2.20
Ca [mg/L]	641.6*	19.00
Mg [mg/L]	1.60*	1.40
Cl_2 [mg/L]	0.00*	0.05
Cl^- [mg/L]	1319.82*	9.00
SO_4 [mg/L]	59.56*	23.00
pH	7.90	8.00

** Concentration value analyzed and measured at Chalmers lab.*

When comparing the numbers, the discharged effluent water contains higher concentration levels of all compounds, except Zn, TOC and Cl_2, that were tested at Chalmers lab which could potentially affect the product quality (i.e. the car body) in a negative way. These values may need to be further reduced to enable reuse or recycling to other processes. However, it is important to note that the median values are based on only four samples, two of which were taken on a day when the conductivity appeared to be deviant, which can be seen in Appendix A2, resulting in unusually high concentrations. Therefore, the median values may not accurately reflect the typical conditions.

4.2.2 Comparison of demineralized water and municipal water

Table 4 presents the median concentration levels for specific parameters in both DI-water and municipal tap water (the complete data of the DI-water can be seen in Appendix A3). When comparing the numbers, the concentration levels in the DI-water are lower than those in the municipal tap water for all compounds except tot-P. These lower values are expected, as the DI-water is produced through the demineralization process, which includes treatment methods that reduce pollutants and deionize the water. This comparison is essential as it provides information on the efficiency of the demineralization process, which is crucial when evaluating the potential solution of recycling the effluent water into the demineralization process. Additionally, it is important for determining the potential increase in membrane degradation due to higher concentration levels in the effluent water compared to the municipal tap water.

Table 4: Median concentration values for specific parameters in tap water and DI-water.

Parameters	**Median concentration value, DI-water** (March 2025, measured at Chalmers lab)	**Median concentration value, tap water** (Alelyckan, 2024)
Al [mg/L]	0.0590	0.019
Cr [µg/L]	0.02	< 0.1
Ni [µg/L]	0.15	0.3
Na [mg/L]	0.74	18
Pb [µg/L]	0.01	0.08
Cd [µg/L]	0	<0.01
Tot–P [mg/L]	0.035	< 0.005
TOC [mg/L]	0.11	2.20

4.3 Potential for Recycling of Effluent Water in processes at VCT

This section discusses the potential for recycling the effluent water that is currently being sent to the recipient. If all the 71 000 m^3 of effluent water were to be recycled, it would decrease the total water withdrawal for manufacturing operations by 20 %, resulting in a 25 % reduction in water use specifically in the paint shop. The two potential solutions for recycling effluent water are as follows:

- Recycling of effluent water to the demineralization process (Action 1).
- Recycling of effluent water to surface treatment processes (Action 2).

To recycle the effluent water in processes requiring DI-water, it must first be directed through the demineralization process. This step is necessary to reduce the level of contaminants present in the water to meet the standards for DI-water currently used in the processes. Alternatively, the effluent water can be recycled directly to processes that require tap water (see Section 4.1.1). Depending on the specific requirements for the water used and the water purity requirements, this solution most likely involves further treatment methods to purify the water before use, as further discussed in Section 4.3.2.

4.3.1 Recycling of effluent water to the demineralization process

Instead of being discharged to recipient, the effluent water could be recycled to the demineralization process, as illustrated with a pink dotted arrow in Figure 15 (See Appendix A4 for more detailed process schemes). The flow to this process is 127 600 m^3, with 56 600 m^3 would have to be sourced as municipal tap water and 71 000 m^3 could be sourced from recycling (indicated by the pink dotted line). This approach would result in a 20 % reduction in total water use for manufacturing operations.

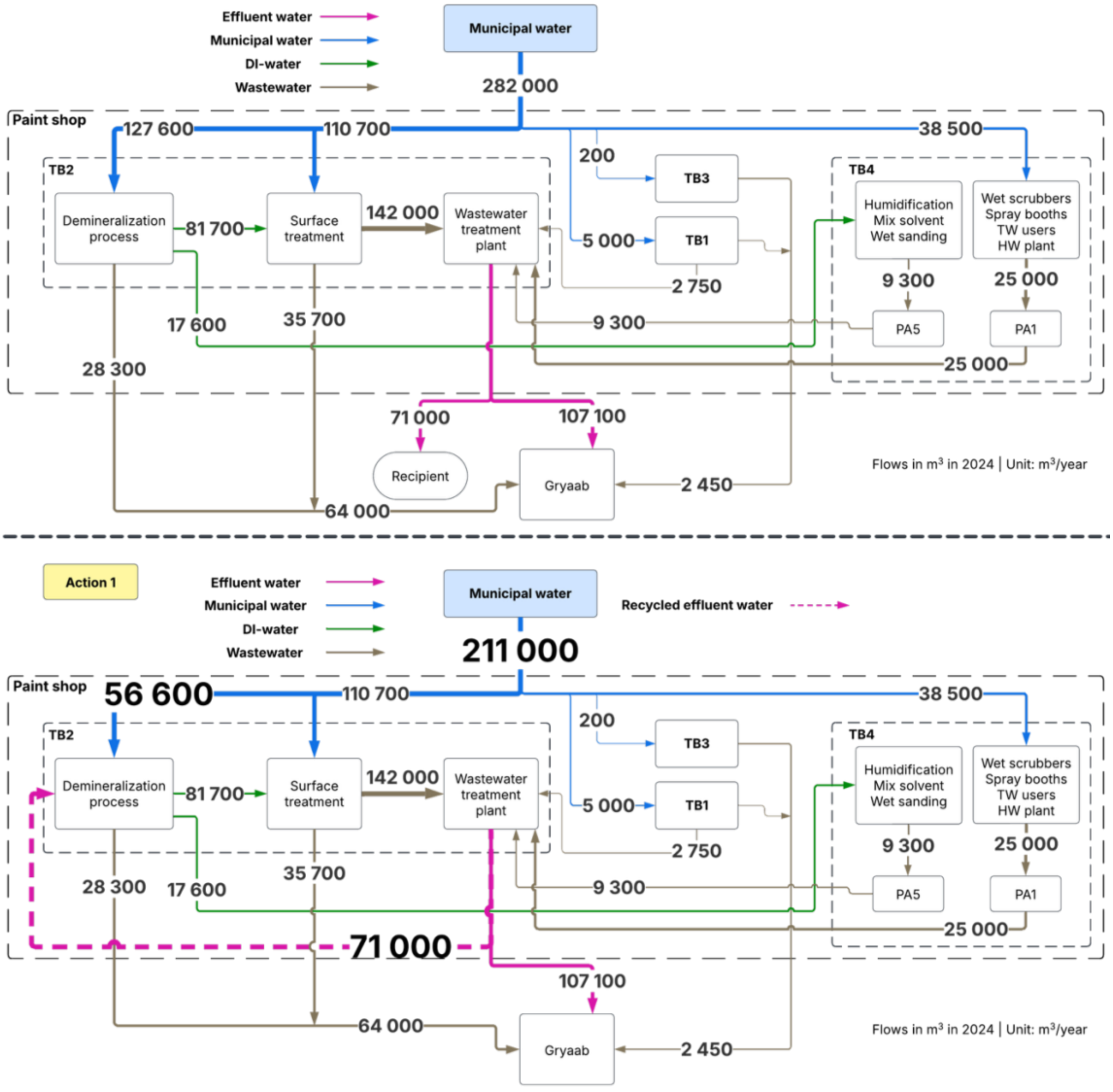

Figure 15: Water flows with recycling of effluent water to the demineralization process (Action 1), in comparison to the current situation.

According to the numbers presented above, this will generate a mix of 44 % tap water and 56 % effluent water supplied to the demineralization process. The composition of this mix is given in Table 5 below. The data for effluent water parameters was obtained either from laboratory analyses conducted during the spring of 2025 at Chalmers (marked with *) or from data gathered from a commercial laboratory working with VCT during weeks 2 to 9 of 2025.

Table 5: Median concentration values for tap water, effluent water and mixture.

Parameters	**Median concentration value, effluent water** (January–March 2025)	**Median concentration value, tap water** (Alelyckan 2024)	**Mix** Tap water / Effluent water**
Pb [µg/L]	0.03	0.08	0.05
Cr [µg/L]	0.60	< 0.10	0.38
Ni [µg/L]	7.70	0.30	4.40
Zn [µg/L]	2.00	3.00	2.40
Cd [µg/L]	0.005	< 0.01	0.007
Cu [µg/L]	0.24	20.00	8.90
Al [mg/L]	0.43*	0.019	0.25
F^- [mg/L]	5.80	< 0.10	3.29
Tot–P [mg/L]	0.06	< 0.005	0.036
TOC [mg/L]	1.81*	2.20	2.00
Ca [mg/L]	641.60*	19.00	367.70
Mg [mg/L]	1.60*	1.40	1.51
Cl_2 [mg/L]	0.00*	0.05	0.02
Cl^- [mg/L]	1319.82*	9.00	743.00
SO_4 [mg/L]	59.56*	23	43.47
Fe [mg/L]	0.01	0.01	0.01
Mn [mg/L]	0.15	0.002	0.09
pH	7.90	8.00	8.00

** Concentration value analyzed and measured at Chalmers lab.*
*** 44 % Tap water / 56 % Effluent water.*

Water quality and requirements of water purity for use in processes

The DI-water produced from the demineralization process is used in several steps within the paint shop, including phosphating and passivating, the EC-line, humidification, mix solvent and wet sanding. The requirements of the DI-water can be seen in Table 4 in Section 4.2.2.

The mix of 44 % tap water and 56 % effluent water (see Table 5) will result in higher levels of F^-, tot-P, Cl^-, SO_4, Ca, Cr, Ni and Al compared to the municipal tap water. The concentration levels of Cr and Ni are only slightly higher than for the municipal tap water and will most likely not impact the material quality of the car body [Personal communication Ryding P-O, March 21st, 2025]. The higher concentration levels of Ca could potentially impact the material quality negatively. However, the demineralization process includes (as previously mentioned in Section 2.4.1) a multilayer filtration which can be adapted to act like an ion exchanger by using a resin and regenerating the resin using sodium chloride [26]. This would reduce the concentration levels of calcium ions, effectively softening the water.

Furthermore, the demineralization process is equipped with an RO which can retain F^-, Cl^-, Al, SO_4 and tot-P, to a certain extent, reducing the concentration levels of these parameters. Consequently, recycling the effluent water to produce DI-water is a potential solution that would result in a 20 % reduction of water use for manufacturing operations. However, as the recycled effluent water contains higher concentration levels of several compounds compared to the municipal water going to the demineralization plant, this increased concentration is expected to accelerate membrane degradation [34].

Membrane degradation and potential pretreatment steps

As mentioned in Section 2.2.2, fouling and scaling are two potential drawbacks of using RO membranes. Since RO is designed to reduce salt concentrations in water, chlorides do not typically contribute to either fouling or scaling. However, a high membrane recovery rate increases the risk of surface precipitation, which can reduce the efficiency of the RO process [34].

One risk with elevated levels of certain compounds is biofouling, which occurs when organic materials serve as a nutrient source for bacteria, fungi and algae that adhere to the membrane surface, forming a biofilm. As the biofilm grows, it reduces membrane flux and permeability, increasing the need for higher operational pressure. In combination with calcium, phosphorus–primarily in the form of phosphates–is likely to contribute to biofilm formation, leading to both biofouling and scaling due to the accumulation of mineral deposits [34, 35]. A common method for cleaning biofilms from membranes is disinfection with chlorine. However, residual chlorine can cause oxidation and membrane degradation, which may compromise system performance over time [34, 36].

To reduce the risk of membrane degradation, pretreatment steps could be implemented, thereby decreasing the maintenance requirements for the RO membranes. However, this solution is not considered reasonable in this case due to the high investment cost required for such pretreatment steps compared to the projected increase in costs for purchasing new membranes at shorter intervals due to the increased degradation rate.

4.3.2 Recycling of effluent water to surface treatment processes

A total of 192 400 m^3 of water is used in the surface treatment processes, whereas 81 700 m^3 of them are DI-water and 110 700 m^3 is municipal tap water. Of these 110 700 m^3 of tap water, 6 500 m^3 water is used for the skid cleaning step and 68 500 m^3 of water is being used in the degreasing process, resulting in a total water use for these two processes of 75 000 m^3. At the same time 71 000 m^3 of effluent water is being sent to the recipient. If the effluent water were to be recycled back to the skid cleaning and degreasing step instead of being discharged it would result in a water use reduction for these processes of 95 % and a total reduction of water use for manufacturing operations at VCT of 20 %. In Figure 16, both current scenario at VCT as well as Action 2, where the effluent water is recycled to the surface treatment processes, is illustrated showing that all 71 000 m^3 of effluent water will be recycled (pink dotted arrow), while the inorganic effluent water will continue to be sent to Gryaab for further treatment. For a more detailed process scheme, see appendix A5.

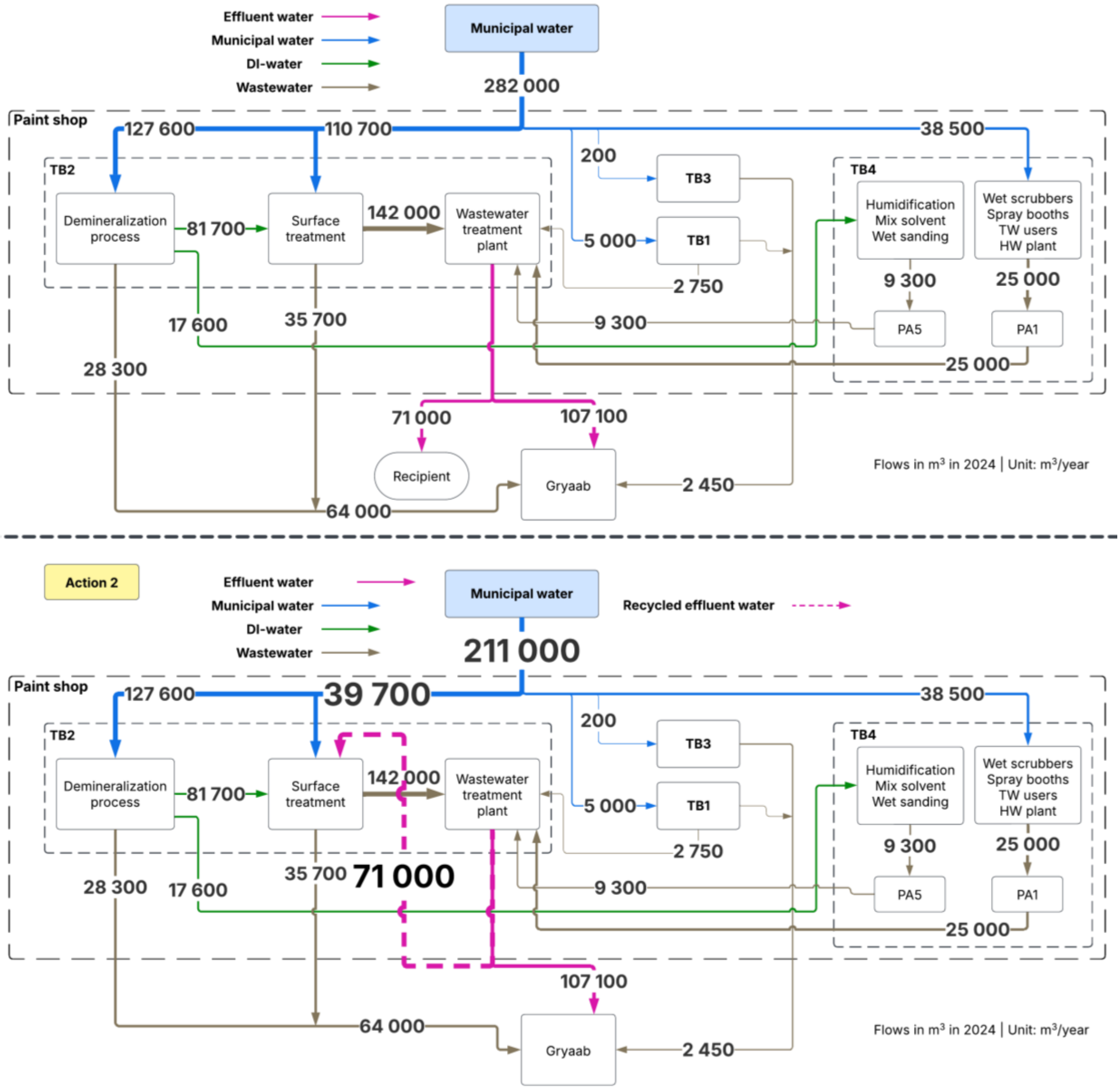

Figure 16: Water flows with recycling to surface treatment processes (Action 2), in comparison to the current scenario.

Water quality and requirements of water purity for use in processes

The concentration levels of various compounds in the effluent water highlighted in Table 5 determines its suitability for recycling in different processes. Some processes have lower water purity requirements while others depend on stricter water quality control to ensure the product integrity and process efficiency, for instance the processes following the demineralization process, discussed in Section 4.3.1.

When comparing the concentration of the municipal water and the effluent water, the effluent could be recycled back to the skid cleaning and degreasing processes, however pretreatment steps are required. The higher concentration levels of fluoride in the effluent compared to the municipal water is one parameter that could potentially have a negative impact on the product quality, since the effluent water contains a fluoride concentration that is 58 times higher than the municipal water, reinforcing the need for additional treatment if the water is to be recycled to ensure the product quality. Additionally, the sulfate concentration is slightly higher, and the chloride levels are considerably elevated, which might lead to corrosion on the finished product. To avoid any eventual corrosion issues a pretreatment step to reduce these parameters will be necessary [37]. Another parameter that could affect the product quality is the hardness of the water, including the concentration levels of Ca and Mg. This means that the water would need to be softened before entering the degreasing and skid cleaning processes [38]. This could be done by using the same principle where a resin is used, as previously mentioned in Section 4.3.1.

Other contaminants such as tot-P, Cr and Ni are also higher in the effluent water but are not expected to impact the product quality negatively and therefore does not need to be reduced. However, theoretically recycling of the effluent in the degreasing process could mean that there will be more ions that could react with other compounds in the degreasing medium that could lead to a reduced effect. [Personal communication Ryding P-O, March 21st, 2025]. Moreover, if the effluent water is recycled, the wastewater discharged to Gryaab will contain a higher concentration of contaminants, though still within acceptable limits.

Potential solutions for fluoride, chloride and sulfate removal

It is possible to remove chloride, fluoride and sulfate using RO, as explained in Section 2.2.2. There is also a possibility to reduce the fluoride concentrations by lowering the pH which could make the polyaluminum chloride (PAX) more efficient in precipitating fluoride. At present, the pH is maintained between 9 and 10 to optimize metal removal. Although lower pH may reduce metal removal efficiency, the low metal levels in the effluent and the ion exchangers will ensure remaining metal ions are eliminated in the ion exchange step [Personal communication Hellgren A, March 24th, 2025]. This approach would allow for improved fluoride removal without requiring new instruments, as the necessary infrastructure is already at place at VCT. However, a potential drawback is that the fluoride levels may not be reduced to the same extent as those found the municipal tap water does, meaning that the treated water may still contain residual fluoride that could affect the final product.

4.4 Reuse of wastewater from collections tank in the painting process

In the painting process at TB4 there are two collection tanks–PA1 and PA5. The water in PA1 originates from the tap water (TW) users and hot water (HW) plant as well as the wet scrubber spray booths and contains organic waste. In contrast, the water in PA5 mainly collects condensate from the humidification process, along with smaller volumes from the mix solvent and wet sanding processes. Since the water in PA5 is largely composed of condensate, it is of higher quality than the water in PA1.

Currently, the water used in the spray booths is already being reused, which reduces the need for municipal water by approximately 13 500 m^3 annually. However, no water reuse is taking place for the TW users, and HW plant, resulting in a water demand of 18 000 m^3. Likewise, no reuse is currently implemented for the water collected in PA5, despite its relatively high quality due to its condensate origin. To reduce VCT's dependency on municipal water, the contents of collection tank PA5 could potentially be reused in the demineralization process (Action 3). This would save around 9 300 m^3 of water, representing 3.3 % of the paint shop's water use and a 2.6 % reduction in total water use for manufacturing operations at VCT, as illustrated with in Figure 17 (red dotted arrow), a more detailed process scheme can be seen in Appendix A6.

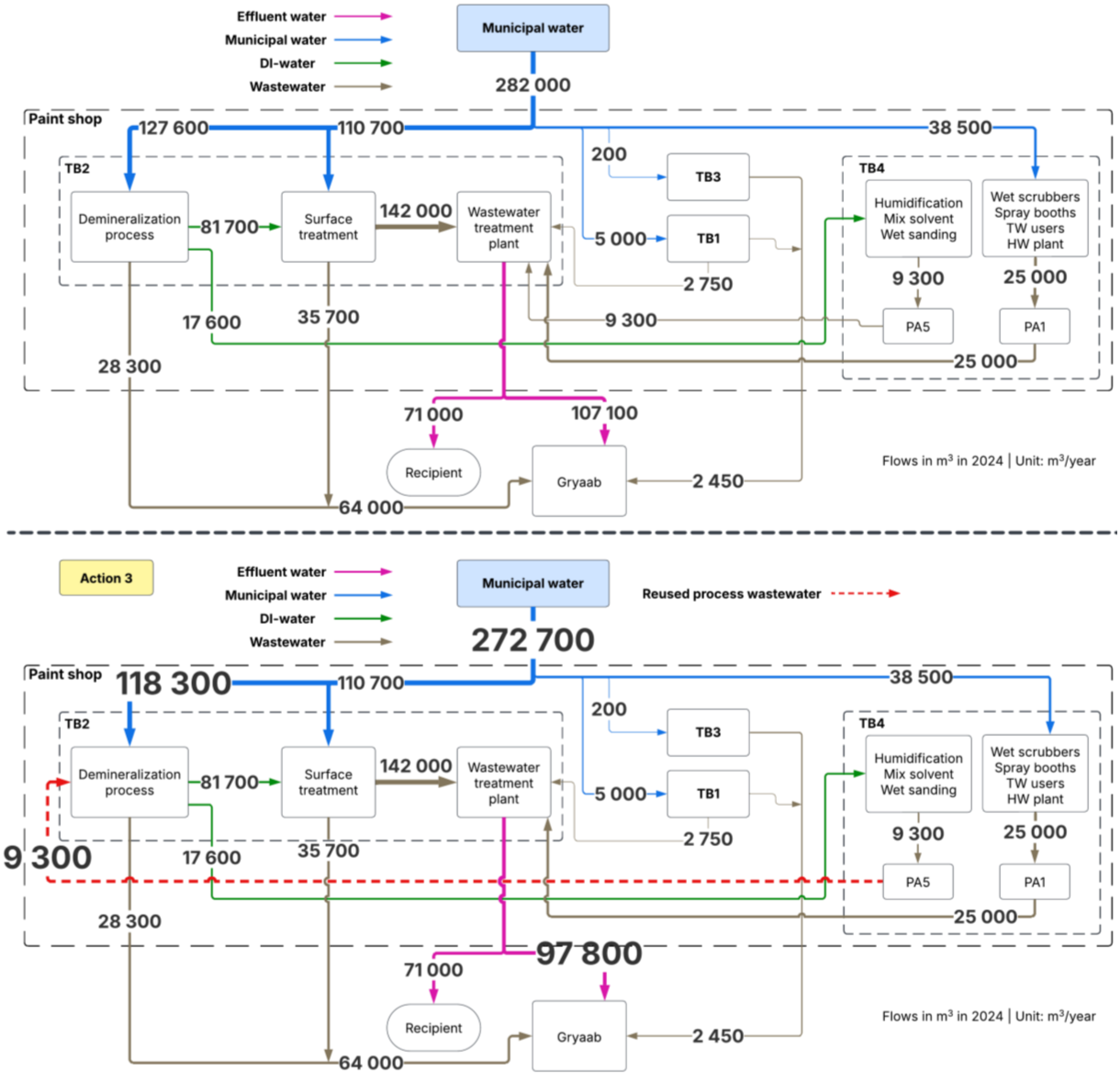

Figure 17: Water flows with reuse to the demineralization process (Action 3), in comparison to the current scenario.

Given the higher quality of water in PA5, additional recycling options may be feasible. This water can potentially be reused within TB4, supplying the spray booths, TW uses, and the HW plant (Action 4), thereby reducing the freshwater demand for these processes by up to 24 %, which can be seen in Figure 18 (red dotted arrow), see Appendix A7 for a detailed process scheme. Another potential use is for general cleaning purposes, replacing the need for municipal water.

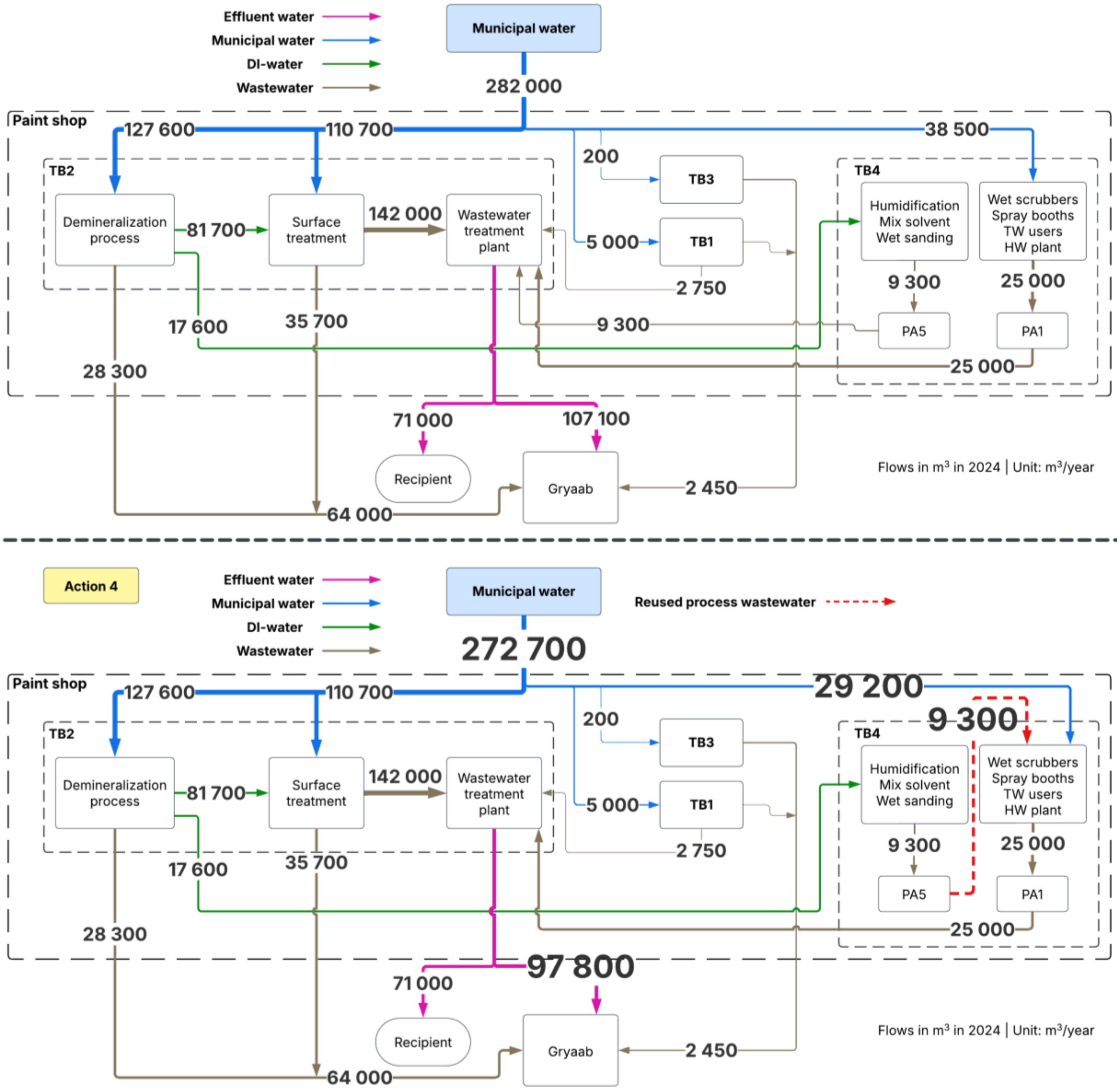

Figure 18: Water flows with reuse to TB4 processes (Action 4), in comparison to the current scenario.

Importantly, both alternatives (Action 3 & 4) would not only reduce the intake of municipal water but also lower the volume of effluent water sent to Gryaab (the pink arrows in Figure 18). With full implementation, the current discharge of 107 100 m^3, could be reduced to approximately 97 800 m^3 annually, representing an 8.7 % decrease in treated organic wastewater volume from the paint shop operations and a 4.3 % reduction of organic wastewater in total at VCT.

However, the feasibility of these solutions depends on the quality of the collected water. Currently, no data is available regarding the water quality in PA5, nor on the volumes of water used for cleaning. Therefore, further analysis is required to determine the suitability of this water for reuse and quantify the possible savings.

Table 6 summarizes the numbers for reductions of municipal water, organic wastewater and water use per car for Actions 1–4 described above. The figures for water use (manufacturing operations only) refer specifically to water use per car during manufacturing. In contrast, the total water use figures represent the water use at the whole site, including both manufacturing and non-manufacturing operations. It is important to note that these figures exclusively represent water usage within the operations at VCT and do not account for the water use in the upstream or downstream value chain.

Table 6: Summary of reductions in municipal water, organic wastewater and water use for Actions 1–4.

	Unit	**Action 1*, 2****	**Action 3***, 4******
Total municipal water reduction	%	20	2.60
Total municipal water reduction	m^3	71 000	9 300
Total treated organic wastewater reduction	%	-	8.70
Total treated organic wastewater reduction	m^3	-	9 300
Water use (manufacturing operations only)	m^3/car	1.06	1.29
Total water use	m^3/car	2.54	2.77

** Recycling of effluent water to the demineralization process.*
*** Recycling of effluent water to surface treatment processes.*
**** Reuse of wastewater from PA5 to the demineralization process.*
***** Reuse of wastewater from PA5 to processes in TB4.*

4.5 Sustainability Benefit–Cost Model to evaluate potential solutions

The SBC-model is used to analyze both the financial impacts and sustainable benefits of potential water-saving solutions. In this section, the evaluated alternatives include recycling of effluent water to the demineralization process (Action 1) and reuse of wastewater either in the demineralization process (Action 3) or in selected processes in TB4 (Action 4).

The model supports prioritization of solutions, enabling the identification of the most effective options in terms of both economic viability and sustainability. In the graphical representation, the water benefit score is shown on the y-axis value and payback time on the x-axis. Solutions that exhibit a short payback time combined with a high sustainability score are positioned in the green area, indicating their favorable status. Conversely, solutions with a long payback time and low benefit are placed in the red zone, highlighting their less desirable status. All investments were assumed to have a technical lifetime of 10 years, with the local water stress considered low. Furthermore, all solutions are aligned VCT's water-related sustainability ambitions.

Water revenues and projected water price increase

The revenues were calculated based on the volume of water saved and the assumption that water prices will continue to rise. In 2024, the water price was 19.25 SEK/m^3, increasing to 22.7 SEK/m^3 in 2025. Given this trend, it is assumed that the water price will continue to rise during the payback period of the investments. Over the next ten years, it is projected to increase by 15 % annually for the first four years, followed by a 5 % annual increase for the remaining six years [39, 40]. As shown in Table 7, this results in a water price of 34.52 SEK/m^3 by 2028 and 46.27 SEK/m^3 by the end of the 10-year period.

Table 7: Projected water prices (2025–2034) in SEK/m^3.

Year	**Projected water price [SEK/m^3]**
2025	22.70
2026	26.11
2027	30.02
2028	34.52
2029	36.25
2030	38.06
2031	39.97
2032	41.96
2033	44.06
2034	46.27

The total water cost savings were calculated using the following formula:

$$\text{Water cost savings} = \text{Water saved } [\text{m}^3] \cdot 22.7 \cdot \frac{1.15^4-1}{1.15-1} + \text{Water saved } [\text{m}^3] \cdot\ 34.52 \cdot \frac{1.05^6-1}{1.05-1} \qquad (1)$$

This provides a more realistic estimation of the financial benefit over the lifetime of the investment, considering the expected development of water prices. To calculate the annual water cost savings, Equation (1) is divided by 10, since all action are based on a 10-year time horizon.

Pipe laying cost and additional uncertain expenditures

When conducting the SBC analysis, various uncertain and additional expenditures are assumed to have a significant impact on the total costs and are based on estimations made by a consultancy firm in Belgium. All figures are rough estimations due to several influencing factors. These include pump costs, uncertainties regarding the number of pumps required and their associated operational expenses. The cost of the buffer tank is also included and may vary depending on factors such as tank size, material and design specifications. Additional expenditures such as consultancy services, R&D activities, laboratory testing and similar related services are also considered. Furthermore, the cost estimation includes expenses related to material transportation, complex piping configurations (e.g. corner or bent pipes), as well as components such as steering and flow meters [41]. The pipe laying costs are not assumed to have as large of an impact as the uncertain and additional expenditures, however the figures for this are based on actual data provided by VCT [Personal communication Svensson R, May 9th, 2025]

The total costs for pipe laying can be calculated through Equation (2), where the contractor fees are an additional 10 % of the total cost and the skylift cost is 800 SEK/day. The rest of the parameters vary depending on the action.

$$\text{Pipe laying costs} = \text{Contractor fees} \cdot (\text{Pipe length [m]} \cdot \left(\text{Pipe cost}\left[\frac{\text{SEK}}{\text{m}}\right] + \text{Manhour cost}\left[\frac{\text{SEK}}{\text{m}}\right]\right) + \text{Skylift cost}\left[\frac{\text{SEK}}{\text{workday}}\right] \cdot \text{Workdays}) \quad (2)$$

The CapEx pipe laying costs for Actions 1, 3 and 4 that are to be discussed further in coming paragraphs and is summarized in Table 8.

Table 8: Pipe laying costs.

	Unit	Action 1*	Action 3***	Action 4****
Pipe length	m	30	230	120
Pipe cost	SEK/m	2318	1445	1445
Man-hour cost	SEK/m	543	448	448
Skylift	SEK/day	800	800	800
Workdays	Days	4	22	12
Contractor fees	%	10	10	10
Total pipe laying cost	kSEK	98	498	269

* *Recycling of effluent water to the demineralization process.*
*** *Reuse of wastewater from PA5 to the demineralization process.*
**** *Reuse of wastewater from PA5 to processes in TB4.*

4.5.1 SBC analysis of recycled effluent water to the demineralization process

Figure 19 illustrates the SBC graph for the solution of recycling effluent water to the demineralization process. The orange dot indicates that the solution is positioned in the green area, indicating a favorable status with a low payback time of less than one year and a high water benefit score of 7.5. The numbers for both CapEx and OpEx are based on the equipment requirements, primarily focusing on the cost of piping, investment in new membranes for the RO-process and resin cost for the multilayer filtration. The potential water savings is based on annual savings of 71 000 m^3 of water, resulting in approximately 2.47 million SEK/year. The water savings figures are also estimations based on the projected increase in water cost as explained in Section 4.5.

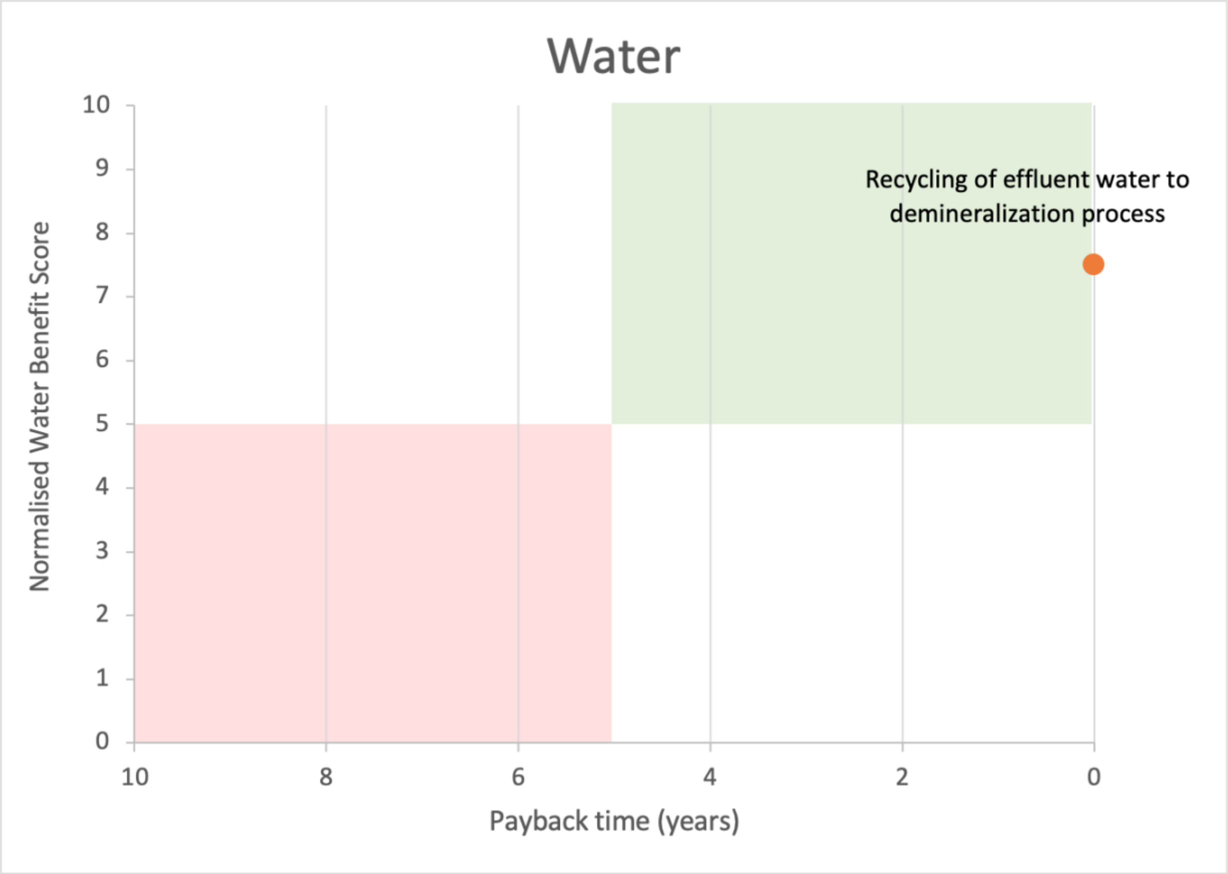

Figure 19: Sustainability Benefit-Cost result graph for the solution of recycling effluent water.

Both CapEx and OpEx are presented in Table 9. The pipe laying costs are derived from Equation (2) and are considered reasonably accurate, based on supplier data and personal communication [Personal communication Svensson R, May 9th, 2025]. Equipment costs and unforeseen expenditures have been estimated using supplier insights from comparable past projects. These costs are both substantial and highly uncertain, primarily due to the unpredictable nature of potential additional expenses. Nevertheless, their inclusion is essential to avoid underrepresenting the true cost of the proposed solutions.

The cost of RO membranes is categorized under OpEx, as it includes more frequent membrane replacements—every two years instead of four—due to elevated impurity concentrations in the effluent water. The detailed calculation supporting this assumption is provided in Appendix A8. CapEx and OpEx costs associated with the resin used in multilayer filtration are based on supplier information and personal communication [Personal communication Hellgren A, April 7th, 2025].

Table 9: CapEx and OpEx expenditures for Action 1

Action 1*	**Capital Expenditures [million SEK]**	**Operational Expenditures [million SEK/year]**
Pipe laying costs	0.098	-
Equipment / Uncertain and additional expenditures	1	0.05–0.1
RO membrane	-	0.047
Resin for multilayer filtration	0.25	0.015
Sum of costs	1.35	0.14

** Recycling of effluent water to the demineralization process.*

In total, the CapEx cost is approximately 1.35 million SEK and the OpEx cost 0.137 million SEK/year. It is important to note that the financial parameters of both CapEx and OpEx are rough estimations and require further investigation to provide more precise financial costs.

4.5.2 SBC analysis of reused wastewater to the demineralization process or TB4 processes

Figure 20 illustrates the SBC graph for the solutions of reusing wastewater to the demineralization process (blue dot) or TB4 processes (yellow dot). Both dots are positioned in the green area, indicating a high sustainability score and a low payback time. The solution of reusing wastewater to the demineralization process has a payback time of 1.4 years and a water benefit score of 7.5. The solution of reusing wastewater to TB4 processes has a payback time of 0.7 years and a sustainability score of 7.5.

The potential water savings is based on annual savings of 9 300 m^3 of water, resulting in approximately 0.32 million SEK/year. The water savings figures are estimations based on the projected increase in water cost as explained in Section 4.5. Additionally, there are savings associated with not having to treat these 9 300 m^3 of wastewater in the WWTP. Since this wastewater is to be reused and not sent to the on-site WWTP, the cost savings of this amounts to approximately 0.99 million SEK.

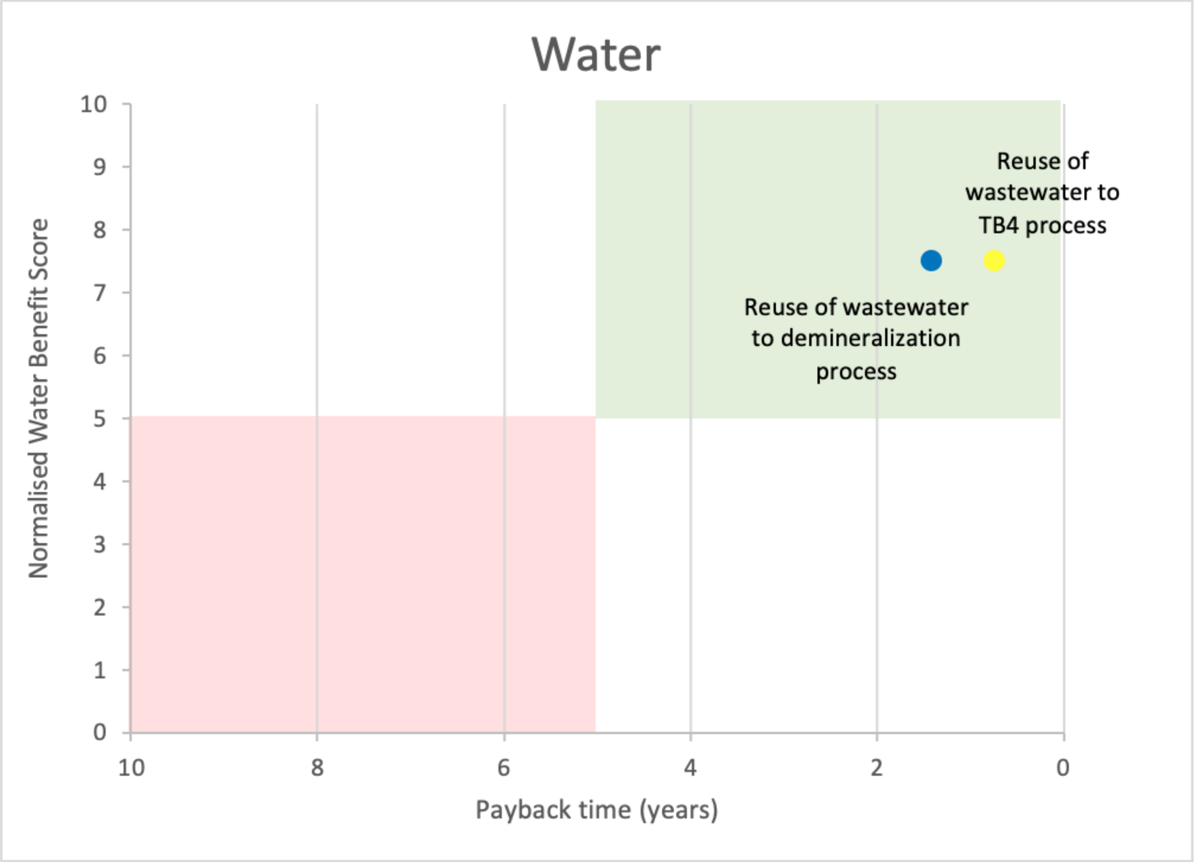

Figure 20: Sustainability Benefit-Cost result graph for the solutions of reusing wastewater to demineralization process or TB4 processes.

The CapEx and OpEx cost estimates are based on the required equipment, with a primary focus on the costs associated with piping, pumps, the intake at PA5 and the supply to either the demineralization process or the TB4 processes, see Table 10. Pipe laying costs are calculated using Equation (2) and are considered reasonably accurate, based on supplier data and personal communication [Personal communication Svensson R, May 9th, 2025]. The primary cost difference between the two alternatives lies in the length of the required piping and the associated uncertainties regarding additional expenditures. Specifically, the distance between the PA5 tank and the demineralization process is greater than the distance to the TB4 processes. This results in higher pipe laying costs and potentially greater additional expenses, such as the need for more pumps and related infrastructure.

Table 10: CapEx and OpEx expenditures for Action 3 and 4.

	Capital Expenditures [million SEK]		**Operational Expenditures [million SEK/year]**	
	Action 3***	**Action 4******	**Action 3*****	**Action 4******
Pipe laying costs	0.498	0.269	-	-
Equipment / Uncertain and additional expenditures	2	1.5	0.05–0.1	0.05–0.1
Sum of costs	2.5	1.77	0.075	0.075

*** *Reuse of wastewater from PA5 to the demineralization process.*
**** *Reuse of wastewater from PA5 to processes in TB4.*

Consequently, the CapEx cost is approximately 2.50 million SEK for reusing the wastewater to the demineralization process and approximately 1.77 million SEK for reusing the wastewater to TB4 processes. The OpEx is the same for both solutions, at approximately 0.075 million SEK/year. It is important to note that the financial parameters of both CapEx and OpEx are rough estimations and require further investigation to provide more precise financial costs.

5. Conclusions

This thesis aimed to address the ambition of reducing water use in operations at Volvo Cars Torslanda, specifically by identifying water-intensive operations and developing strategies for water reduction, reuse and recycling. In 2024, the water use was 1.32 m^3/car for manufacturing operations and 2.81 m^3/car when including non-manufacturing operations. The result of this thesis shows that water use per car can be reduced by between 2 % and 22 % using strategies for both recycling of effluent water and reuse of wastewater.

The possibility of recycling effluent water to the demineralization process at VCT can significantly reduce the use of municipal tap water. By substituting municipal water with effluent water, the water use can be reduced to 1.06 m^3/car for manufacturing operations and 2.54 m^3/car when including non-manufacturing operations. Although the recycled water does contain higher concentrations of several compounds, existing treatment steps can effectively retain most of these, mitigating their potential impacts. However, the elevated impurity levels are expected to accelerate membrane degradation, shortening membrane lifespan and increasing operational costs over time. Despite these drawbacks, the SBC analysis indicates that the solution yields a water benefit score of 7.5 and a payback time of less than one year.

Furthermore, there is potential to recycle effluent water for use in surface treatment processes, specifically the degreasing and skid cleaning processes. Elevated levels of tot-P are not expected to negatively impact these applications. However, increased concentrations of chlorides, fluorides and other compounds do require treatment to avoid material degradation or process interference. While fluoride levels can be reduced–e.g. through increased PAX levels–the treatment is likely insufficient and not economically justifiable for this specific use. Further investigations into material compatibility and additional R&D are recommended to assess feasibility, as can be read about in Section 6.

Another conclusion from the study is that wastewater from the collection tank (PA5) can be reused to the demineralization process or painting processes in TB4. This would result in a reduction in water use to 1.29 m^3/car in the manufacturing operations and 2.77 m^3/car when including non-manufacturing operations. In total, the reuse of PA5 water would also reduce organic wastewater discharged to Gryaab by 8.7 %. Economically, both reuse solutions show a favorable return of investments where the reuse to the demineralization process has a payback time of 1.4 years, while reuse to TB4 has an even shorter payback time of 0.7 years; both alternatives have a water benefit score of 7.5. These estimates are based on preliminary calculations and subject to further refinement, but the assessment indicates that water reuse from PA5 is both environmentally and economically viable. However, the actual implementation of these reuse alternatives depends on confirming the water quality in PA5 and assessing potential impacts on equipment and processes

By combining recycling and reuse solutions it can be concluded that the water use in manufacturing operations will be reduced to 1.03 m^3/car and 2.51 m^3/car when also including non-manufacturing operations. This integrated approach achieves a water benefit score of 7.5 and a payback time of 0.3 years, offering a sustainable and cost-effective strategy for minimizing the need for municipal tap water and reducing the wastewater sent to Gryaab for treatment. Further investigations into water quality to ensure material compatibility and financial aspects are necessary to ensure implementation.

6. Recommendations for future actions

This section presents recommendations for the three proposed solutions identified in Section 5. Each solution will be evaluated regarding technical feasibility and necessary actions to support decision-making and future planning.

Recycling of effluent water to the demineralization process:

- Conduct further investigation into the quality of deionized (DI) water, considering the mix of effluent and tap water (TW).
- Assess the impact on material quality (specifically the car body) due to slightly higher concentration levels of certain compounds, depending on the efficiency of the demineralization process in retaining these compounds.
- Evaluate the potential degradation of membranes due to higher levels of impurities in the effluent water.
- Investigate the use of resin in multilayer filtration systems.
- Assess the costs associated with equipment, including pipes and other necessary components.

Recycling of effluent water to surface treatment processes:

- Investigate cost for equipment and methods to reduce chloride concentrations.
- Evaluate options for fluoride, chloride and sulfate removal.
- Investigate material compatibility due to increased concentration levels of certain compounds.
- Assess the costs associated with equipment, including pipes and other necessary components.

Reuse of wastewater to demineralization process:

- Conduct further investigation into water quality of condensate water (wastewater in PA5).
- More extensive assessment of the cost associated with equipment, including pipes and other necessary components.

Reuse of wastewater to TB4 processes:

- Conduct further investigation into water quality of condensate water (wastewater in PA5).
- R&D work regarding the impact on material quality if the concentration levels are slightly higher for certain compounds.
- More extensive assessment of the cost associated with equipment, including pipes and other necessary components.
- Evaluate potential use of wastewater for cleaning activities

7. Future opportunities and investigations

This section identifies several potential future investigations and outlooks for strategies to reduce water withdrawal and the demand for municipal tap water at VCT. It explores possible future solutions, including advancements in rainwater harvesting and storage system (RWHSS), inorganic WWT and water reuse within the manufacturing process. By integrating these solutions, VCT has the potential to significantly reduce its water withdrawal while maintaining high operational standards.

7.1 Rainwater harvesting and storage system

Rainwater harvesting technology can be used to collect rainwater and utilize this alternative water source for various applications, promoting water resource sustainability and reducing the demand for municipal tap water [42].

Components of a rainwater harvesting and storage system

A rainwater harvesting and storage system (RWHSS) should consist of catchment areas, which can be either land -or roof-based, transport systems (pumps and pipes) that allows for the water to be transported to a treatment and filtration systems to purify the water to meet the quality standards of water required for industrial use [11]. In more detail, the main primary components of a RWHSS are described in Table 11 and the secondary components in Table 12 [43].

Table 11: Primary components of a RWHSS

Primary component	Material	Description / Explanation
Catchment area	Roofs (often in concrete)	To capture the water
Gutter system	Gutters (plastic or metal)	Collect the rainwater and transfer it to the pipes
Piping system	Pipes	Transporting the water to the storage tank
Storage system	Tanks (polypropylene or concrete)	To store the collected water before use in processes etc.

Table 12: Secondary components of a RWHSS

Secondary component	Material	Description / Explanation
First flush system	Polyvinylchloride (PVC) tubes	To get rid of the initial run-off water that is typically more contaminated.
Filters	Metallic or Nylon mesh filters	Filters to retain impurities and sediment.
Overflow pipe	Pipes	To prevent overflow by discharging water from the tank.
Pumping system	Pump and pipes	Pumps to discharge the water from the tank to be used in processes etc.

Planning and Design Considerations

When planning and designing a rainwater harvesting and storage system, several factors should be taken into consideration [42]:

- **Size of catchment area**: Determines the amount of rainwater that can be captured.
- **Rainwater storage capacity and rainfall intensity:** Storage capacity should match the rainfall intensity and water demand.
- **The end use and required treatment equipment:** Treatment equipment depends on the rainwater quality and intended use.

Rainwater Quality and Treatment methods

Rainwater quality is influenced by the location, surface material and contaminants present on the catchment area. Contaminants can include nutrients, microorganisms, dissolved minerals and heavy metals. Treatment methods such as screening, sedimentation, filtration and disinfection are necessary to ensure the water meets quality standards. These methods can be costly, so a thorough assessment of the required water quality is essential [44].

Catchment area and rainwater intensity

A large catchment area is crucial for an effective RWHSS. The total roof area at VCT is approximately 442 000 m², which indicates a significant potential for rainwater capture.

However, considering the costs associated with pumping water and installation of pipes, it may be more efficient to implement the RWHSS near water-intensive processes. Thus, facilities close to the paint shop, see Figure 21 (i.e. TB2, TB3, TB4 and TB5) could be ideal. The roof area of these facilities is approximately 60 000 m^2 [Personal communication Gustavsson E, March 25th, 2025].

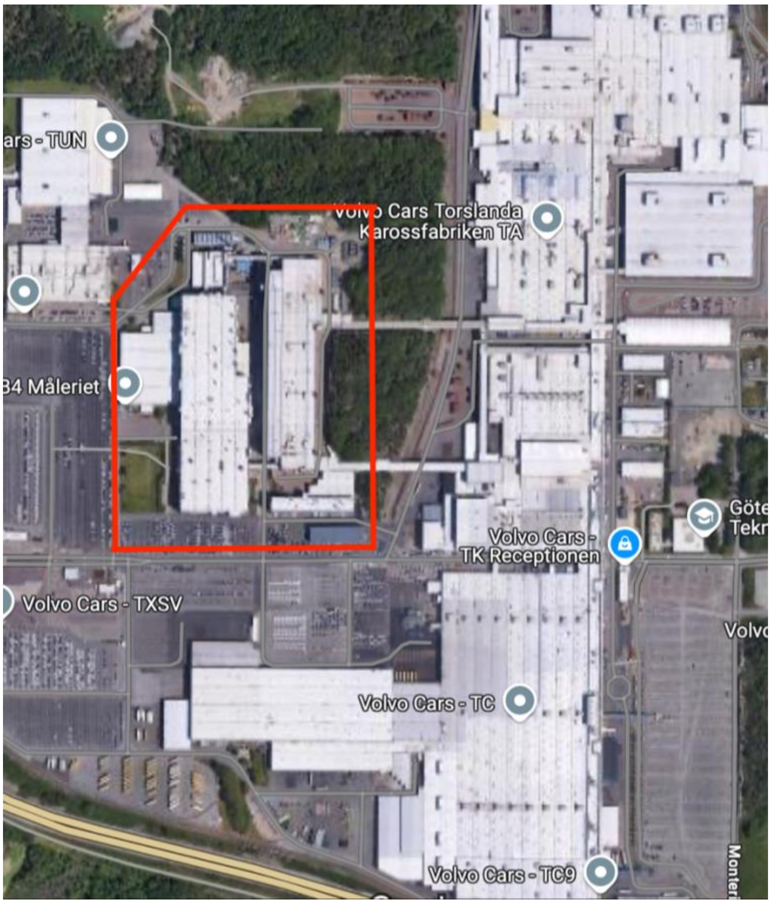

Figure 21: A map highlighting the paint shop facilities at VCT [45].

With an average annual rainfall of 1 054 mm, the potential rainwater capture is 1 054 L/m^2 per year [46]. Assuming a run-off coefficient of 65%, this results in an annual total rainwater collection of 41 106 m^3 (see Appendix A9 for the detailed calculation) [44]. This rainwater could be used to supply a demineralization plant and produce DI-water. The required equipment includes drainpipes, a pump station, buffer tank, flowmeter, micro/ultra filtration, and piping to the demineralization process.

Benefits and costs

Implementing a RWHSS can reduce municipal tap water demand by approximately 12 %, resulting in annual water cost savings of around 1.4 million SEK (see Appendix A9 for the detailed calculation). However, the financial costs remain uncertain and need to be examined to accurately evaluate the payback time and feasibility of the solution.

7.2 Organic wastewater treatment plant at Volvo Cars Torslanda

When looking at a sustainable water management strategy, a potential investment in an organic WWTP at VCT presents an opportunity to enhance the resource efficiency and reduce the environmental impact. Currently, discharged organic wastewater is sent to Gryaab for treatment, but by implementing an on-site WWTP system it could potentially enable water recycling within the facility, with the potential to recycle all of the organic wastewater of 173 550 m^3, resulting in a water use reduction of 49 % at VCT and thereby a reduction in municipal water costs. This combined with the recycling of the inorganic effluent would result in a total reduction of 68 % at VCT. This approach would not only decrease the water use but also alleviate pressure on municipal water treatment infrastructure.

Looking ahead. Integrating such a system aligns with long-term sustainability goals, ensuring compliance with stricter environmental regulations while enabling circular water usage. Further studies on cost-effectiveness, feasibility, as well as potential treatment technologies will be essential to determine the viability of this investment.

7.3 Using technical water from Novo

The battery manufacturer NOVO Energy is a part of Volvo Cars, and a new battery plant is currently under construction at VCT to reach the company's goal of becoming a fully electrified car manufacturer by 2030. Like Volvo, NOVO Energy utilizes water in its processes, and an existing infrastructure of pipelines will be used for water transportation to and from the plant. The process involves Gryaab as a supplier of treated wastewater, known as technical water, through these pipelines, see Figure 22 below that illustrates the water flows throughout the system. Additionally, the pipelines are integrated into Göteborg Energi's energy system, allowing the heat from the water to be recovered and utilized within the district heating system, which provides heating for buildings. The now-cooled water is then transported to the battery plant, where it is used for cooling in the manufacturing process. As the water absorbs heat during production, it is subsequently redirected back to Göteborg Energi for further use in district heating. Once the water has been cooled again, it can be sent to the recipient [47].

In the future, a potential solution for reducing water use at VCT could be to reuse the cooled water in the car manufacturing process–such as in the paint shop, rather than discharging it to Gryaab and then recipient. In Figure 22, this is highlighted as step number six, which means that the water could flow back to VCT to be used in several processes before being discharged as effluent water. This would allow Volvo Cars to lower its overall water withdrawal while also providing financial benefits by reducing the need to purchase water from Gryaab and avoiding the construction of new pipelines.

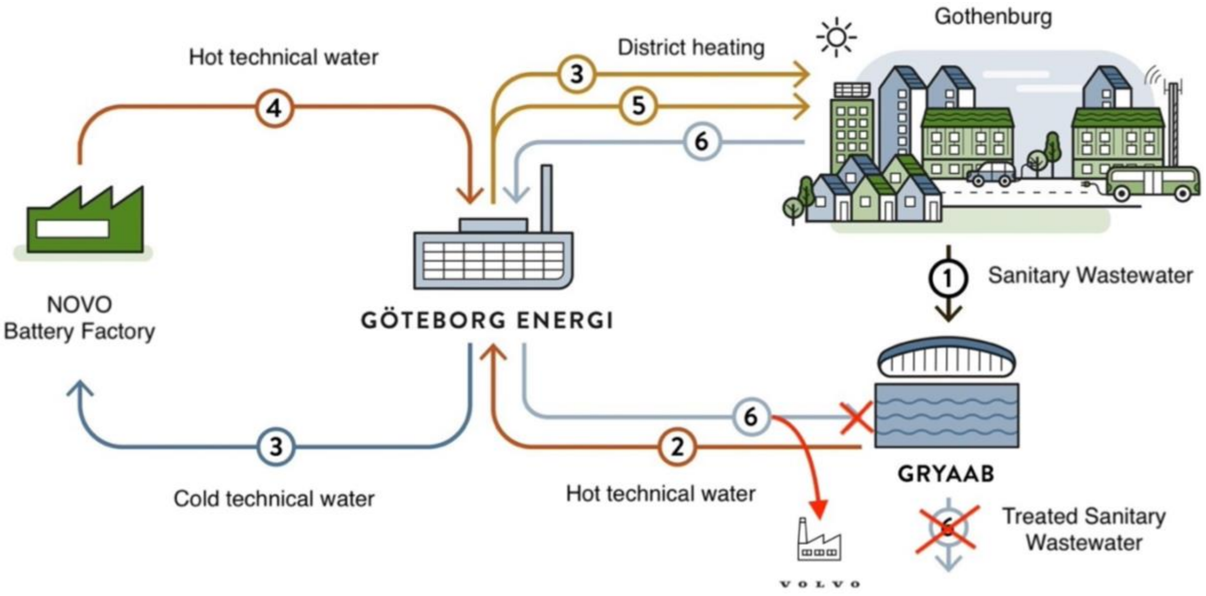

Figure 22: Technical water route–from Gryaab to VCT [47].

However, while the practical implementation of water reuse presents few technical challenges, the main obstacle is legal and regulatory. Approval from authorities is required before the water can be reused, a process that could take considerable time due to the need for thorough analyses of water quality, costs, climate impact and other relevant factors.

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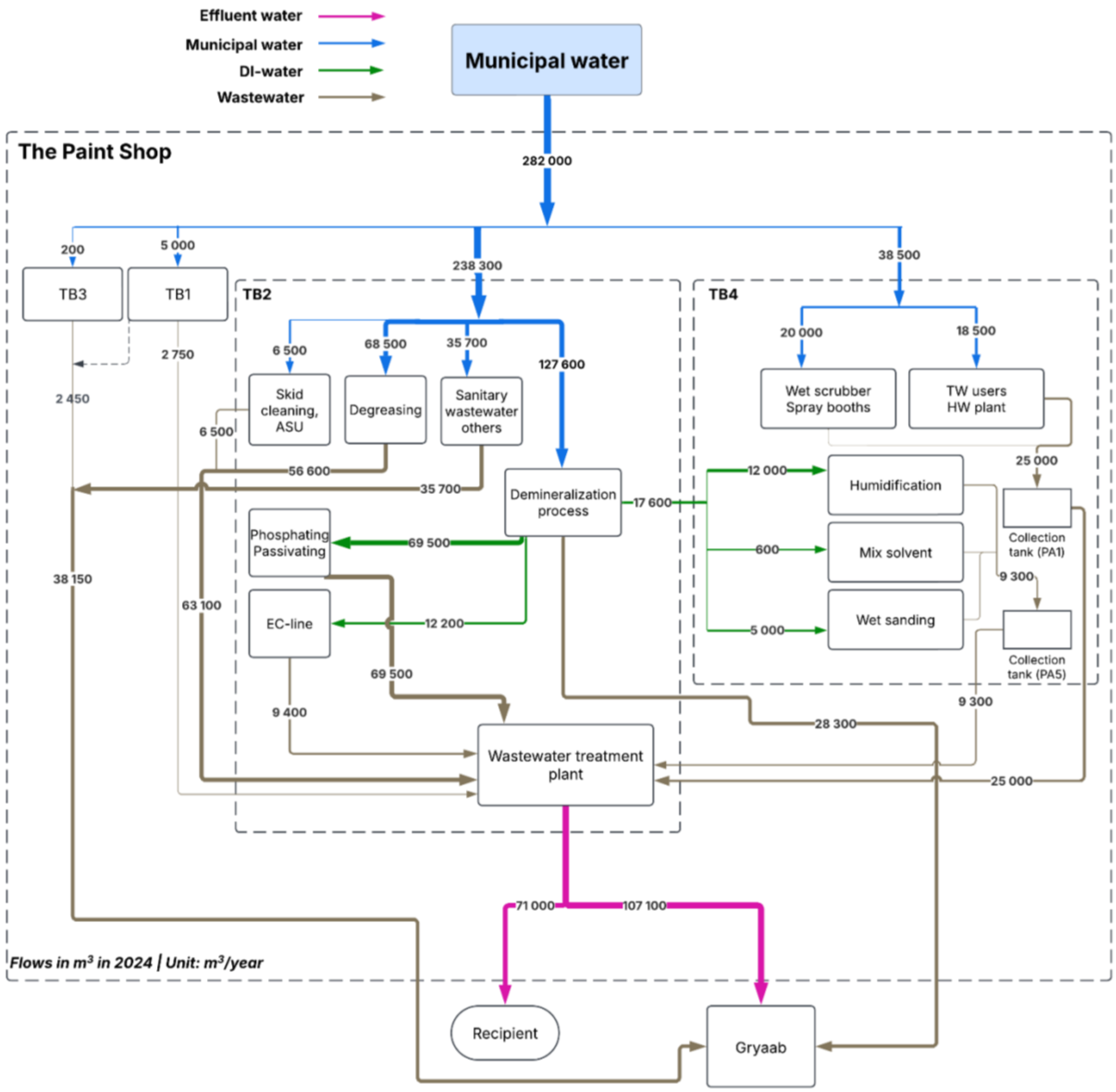
Appendices

A1 – Detailed process scheme of water flows at the paint shop at VCT



A2 – Measured concentrations, effluent water (Chalmers lab March 2025)

Ion Chromatography

Samples Parameters [mg/L]	Sample 1 (12/3)	Sample 2 (14/3)	Sample 3 (20/3)	Sample 4 (20/3)
TOC	2.17	1.28	1.45	2.26
Ca	311.90	223.10	613.44	669.72
Mg	1.02	0.58	2.67	2.19
Cl_2	0.00	0.01	0.00	0.00
Cl^-	824.64	574.40	1815	2057.62
SO_4	48.03	37.58	80.11	71.08
Conductivity [mS/m]	244	204	465	435

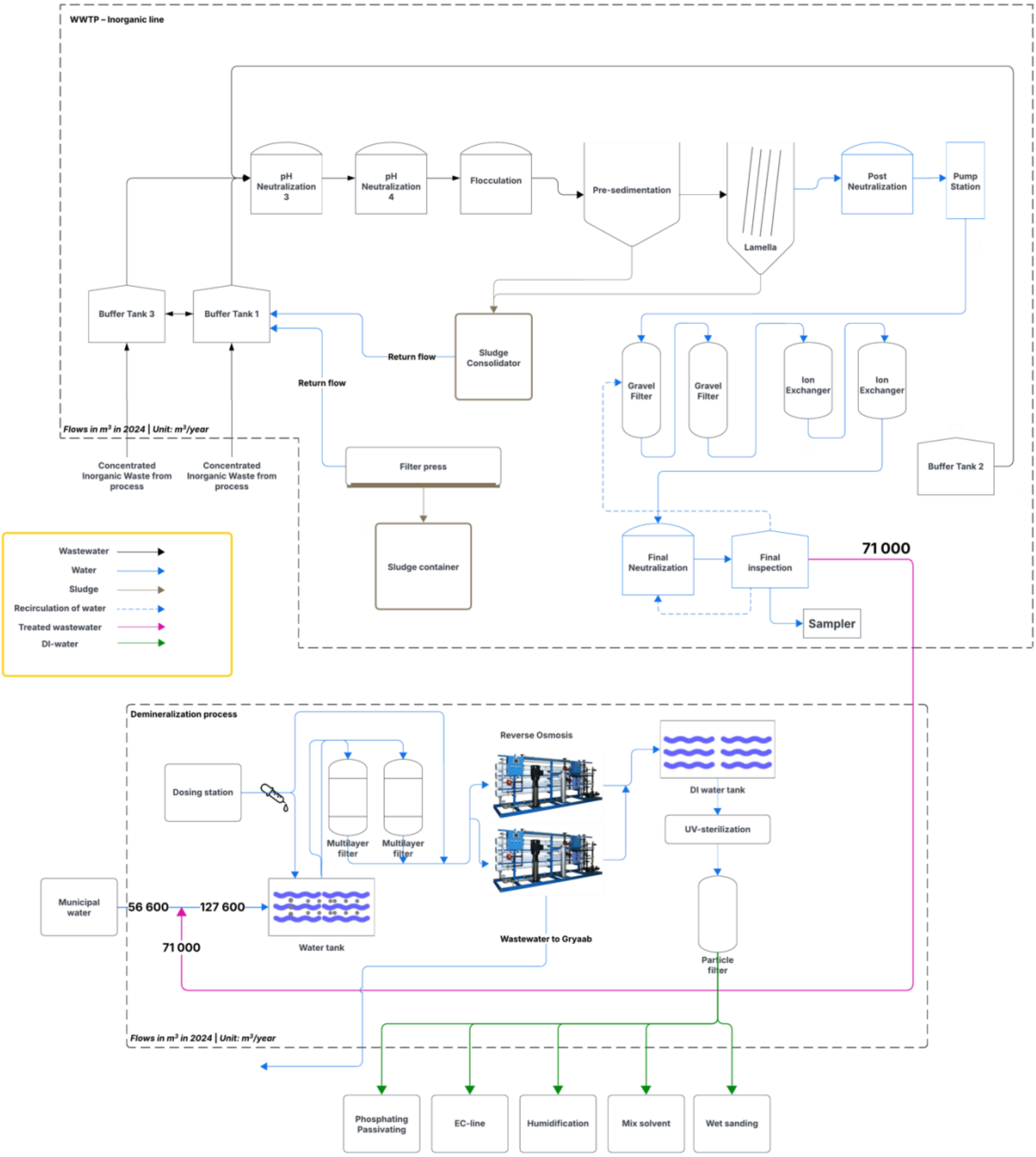
ICP-MS

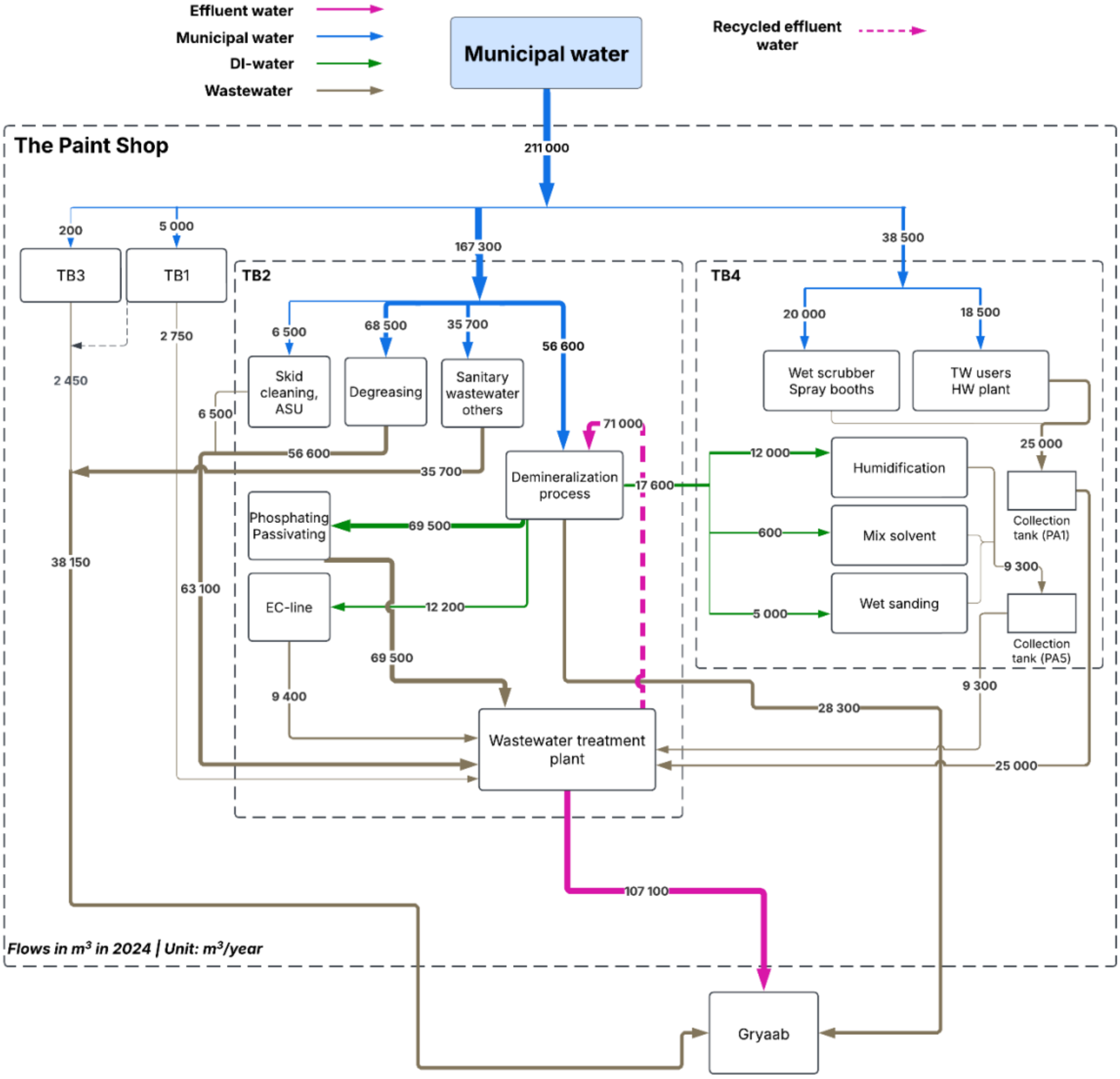
Samples Parameters [mg/L]	Sample 1 (12/3)	Sample 2 (14/3)	Sample 3 (20/3)	Sample 4 (20/3)
Al	0.64	2.29	0.19	0.22
Ca	960.96	589.34	1419.47	2444.37
Mg	0.89	0.50	3.40	5.75

A3 – Measured concentrations, DI-water (Chalmers lab March 2025)

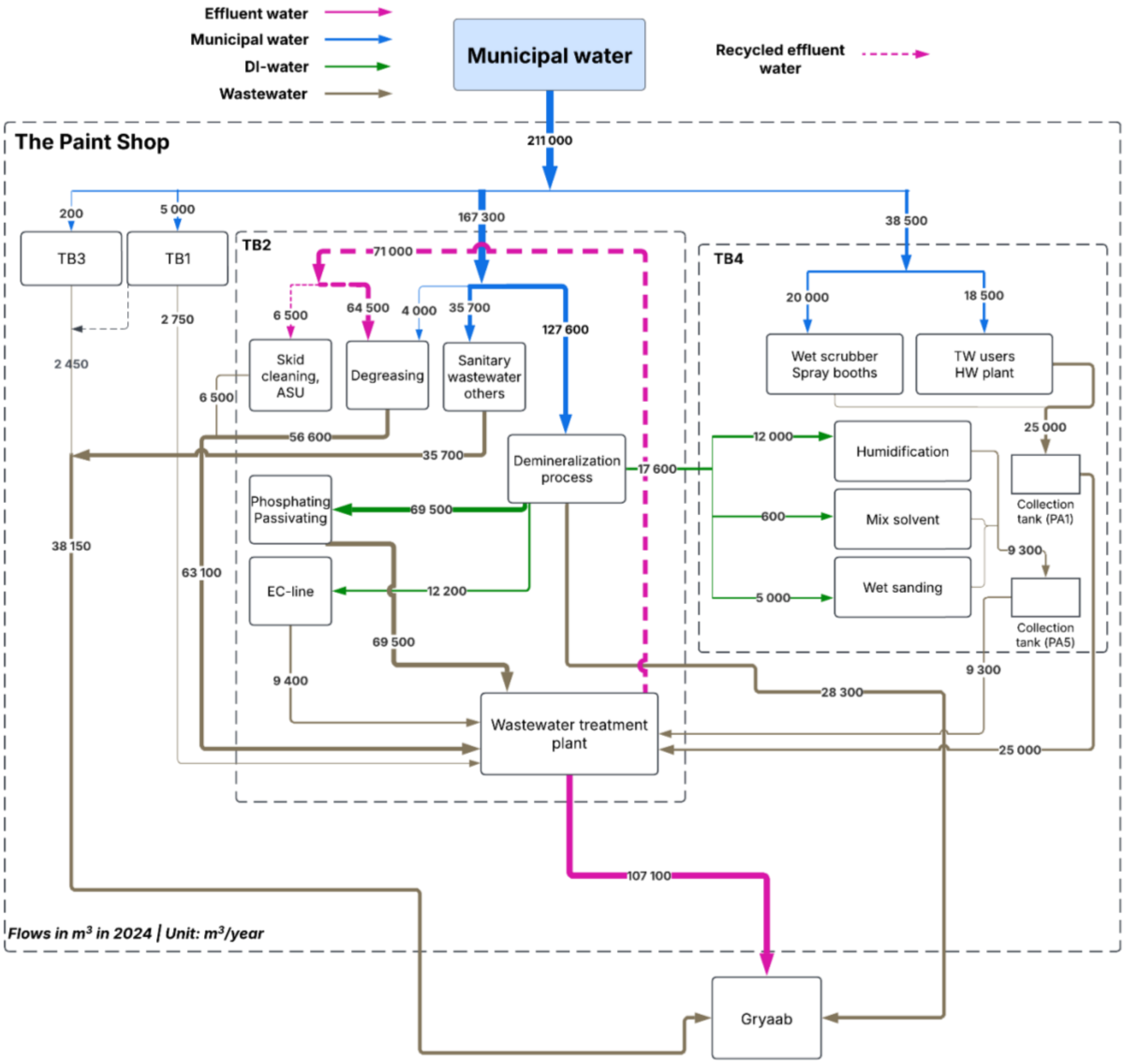
Samples / **Parameters [µg/L]**	**Sample 1 (12/3)**	**Sample 2 (14/3)**	**Sample 3 (17/3)**	**Sample 4 (20/3)**	**Sample 5 (20/3)**
Al	5.90	17.41	8.50	5.14	4.49
Cr	0.05	0.02	0.02	0.02	0.02
Ni	0.15	0.15	0.12	0.11	0.16
Tot-P	20.00	30.00	0	40.00	50.00
TOC	258.50	119.90	-	20.57	94.97
Na	867.22	735.86	820.43	616.62	719.91
Pb	0.02	0.01	0.01	0.02	0.01
Cd	0.00	0.00	0.00	0.00	0.00

A4 – Detailed process schemes for recycling effluent water to demineralization process

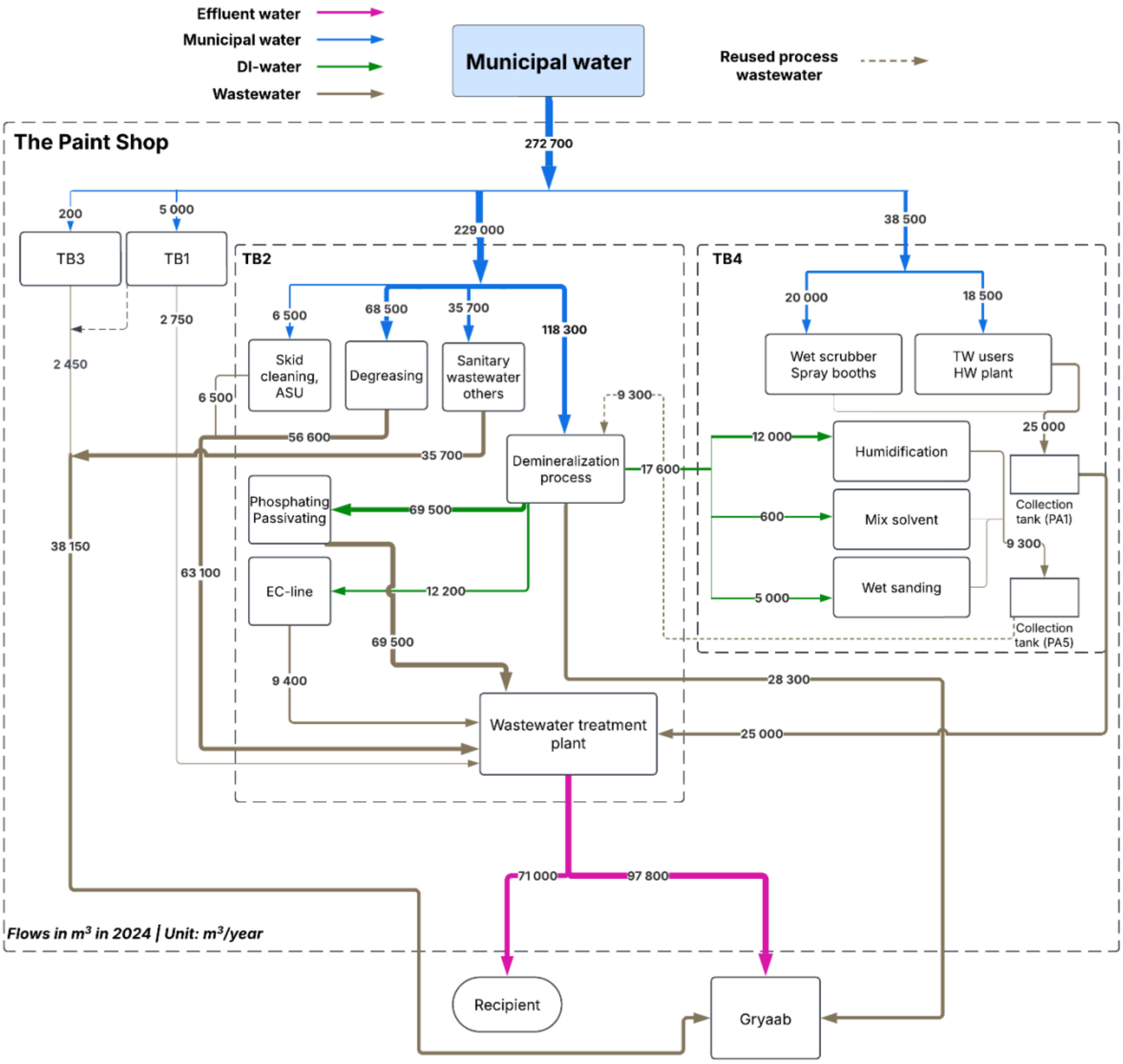



Effluent water
Municipal water
DI-water
Wastewater
Municipal water
Recycled effluent water
The Paint Shop
211 000
200
5 000
167 300
38 500
TB3
TB1
TB2
TB4
2 750
2 450
6 500
68 500
35 700
56 600
20 000
18 500
Skid cleaning, ASU
Degreasing
Sanitary wastewater others
Wet scrubber Spray booths
TW users HW plant
6 500
71 000
25 000
56 600
35 700
Demineralization process
17 600
12 000
Humidification
Collection tank (PA1)
Phosphating Passivating
69 500
600
Mix solvent
38 150
9 300
63 100
EC-line
12 200
5 000
Wet sanding
Collection tank (PA5)
69 500
9 300
9 400
28 300
Wastewater treatment plant
25 000
107 100
Flows in m³ in 2024 | Unit: m³/year
Gryaab

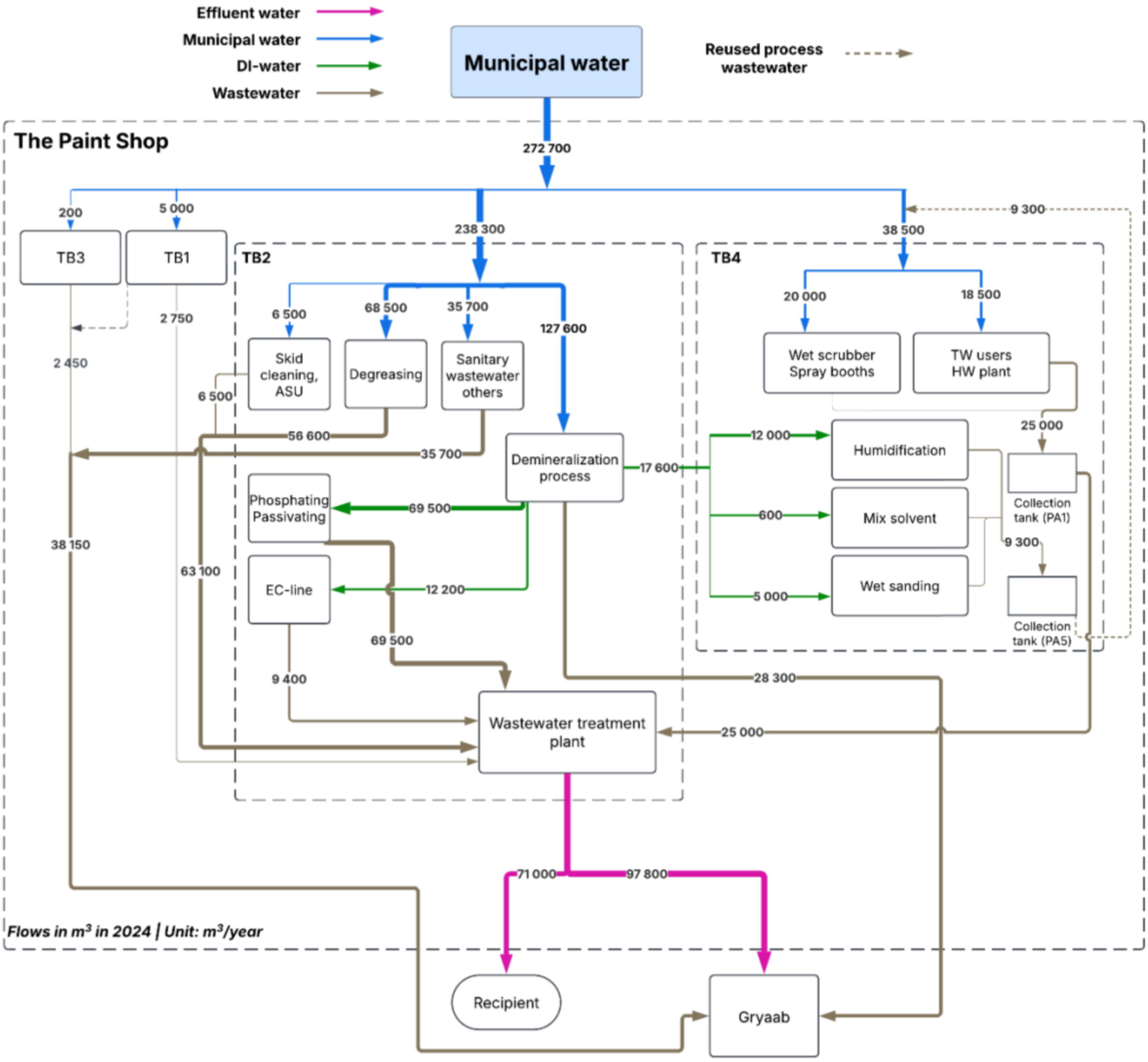
A5 – Detailed process scheme for recycling effluent water to skid cleaning and degreasing process



A6 – Detailed process scheme for reuse of wastewater from PA5 to the demineralization process



A7 – Detailed process scheme for reuse of wastewater from PA5 to selected processes in TB4



A8 – Calculations regarding increased membrane degradation

The RO-system at VCT includes 25 membranes which needs to be replaced approximately every 4 years [48]. In the case of recycling the effluent water, the membrane will degrade at a higher rate, thus needing to be replaced every two years. This increased cost of replacing the membranes more often can be calculated accordingly:

$$Cost\ of\ 25\ new\ membranes = 7500\ SEK * 25 = 187\ 500\ SEK \tag{3}$$

$$Annual\ cost\ of\ replacing\ the\ membranes\ every\ fourth\ year = 46\ 875\ \frac{SEK}{year}$$

$$Annual\ cost\ of\ replacing\ the\ membranes\ every\ second\ year = 93\ 750\ \frac{SEK}{year}$$

Consequently, the increased cost will be 46 875 SEK/year.

A9 – Calculations for a Rainwater Harvesting and Storage system

$$\text{Total annual rainwater collection} = 1054 \frac{\text{L}}{m^2} \cdot 60\ 000\ m^2 \cdot 0.65 = 41\ 106\ 000\ L = 41\ 106\ m^3 \tag{4}$$

$$\text{Water cost savings} = \frac{\left(41\ 106\ \text{m}^3 \cdot 22.7 \cdot \frac{1.15^4 - 1}{1.15 - 1} + 41\ 106\ \text{m}^3 \cdot 34.52 \cdot \frac{1.05^6 - 1}{1.05 - 1}\right)}{10\ years}$$

$$= 1\ 431\ 112\ SEK/year$$

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