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## **Cost-Benefit Analysis and Environmental Impact of Water Management - A Case study on the West Link Railway project**

Master's Thesis in the Programme for Design and Construction Project Management

ABDULLAHI NUUR  
FARID HADI

Department of Architecture and Civil Engineering  
Division of Water Environment Technology

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CHALMERS UNIVERSITY OF TECHNOLOGY  
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MASTER'S THESIS ACEX30

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ACEX30 Master's Thesis  
Department of Architecture and Civil Engineering  
Chalmers University of Technology, 2024

Department of Architecture and Civil Engineering  
Division of Water Environment Technology  
Chalmers University of Technology  
SE-412 96 Gothenburg, Sweden  
Telephone: + 46 (0)31-772 1000

Department of Architecture and Civil Engineering  
Gothenburg, Sweden, 2024



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ABDULLAHI NUUR  
FARID HADI

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Division of Water Environment Technology  
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## **Abstract**

This report examines the treatment efficiency of excess water and the socio-economic implications of managing this water during the construction of the West Link railway project in Gothenburg, Sweden. Approximately 130,000 cubic meters of excess water require annual treatment at the 'Centralen' site of the West Link project. Data from the Swedish Transportation Administration (STA) collected between 2018 and 2023 on water quality before and after treatment, and the associated costs were analysed. Findings show that the treatment plants achieve an average pollutant removal efficiency of 73%. However, variations in pollutant concentrations in the influent water, and the impact of maintenance practices underscore the importance of continuous monitoring and optimization of the treatment methods. This is essential to ensure high removal efficiency and that the effluent water complies with environmental standards. While the total mass of pollutants released annually, such as suspended solids, oil, arsenic, lead, cadmium, copper, total chromium and chromium VI, nickel, mercury, zinc, and pH give a small contribution to the Göta river compared to background levels, local releases from the construction site could still impact the nearby ecosystem and accumulate in organisms. Thus, stringent environmental protection measures remain necessary. A Cost-Benefit Analysis (CBA) was conducted, revealing that although the STA incurred substantial costs for the water treatment facility, there are significant public health and environmental benefits. In conclusion, the report emphasises the importance of effective water treatment to meet environmental regulations, mitigate ecological and health risks, and promote sustainable construction practices.

**Keywords:** Treatment efficiency, Excess water, West Link Railway Project, Environmental standards, Cost-Benefit Analysis (CBA), Sustainable construction practices.

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## **Acknowledgements**

Firstly, we would like to express our gratitude to our supervisor, Professor Jenny Norrman, who is the Head of the Geology and Geotechnics Unit at Chalmers University of Technology, and our examiner, Professor Ann-Margret Hvitt Strömvall, a full professor in the Division of Water Environment Technology at Chalmers University of Technology, for their valuable guidance and support.

Secondly, we thank our case company for allowing us to visit their workplace and share their valuable data, which has significantly contributed to this thesis. Thank you, Johanna Nilsson, for your help; this study could not have been carried out without it.

Finally, we would like to thank each other for an amazing collaboration despite external challenges, and our opponents and dear friends for their valuable and encouraging feedback.

## List of Acronyms

STA	Swedish Transportation Administration
GRWCA	Göta River Water Conservation Association
GR	Göta River
SHS	Swedish Hydro Solution



# 1. INTRODUCTION

## 1.1 Background

The Swedish Transportation Administration (STA) is constructing the West Link railway, an approximately eight-kilometres-long track designed for commuter and regional trains. Notably, around six kilometres of this railway are within a tunnel beneath central Gothenburg (Sundkvist, 2016). As part of this construction initiative, specific requirements have been established to treat excess water. At the part/area 'Centralen', which is the focus of this thesis, approximately 130,000 cubic meters of excess water are subject to treatment annually. The excess water becomes contaminated to varying degrees through stormwater, e.g., rain falling on the site, groundwater, i.e., leakage in tunnels and excavated areas, or process water generated from activities such as drilling and dust control measures.

In recent years, environmental regulations have become stricter regarding the release of water from construction sites, and it is no longer acceptable for polluted, uncontrolled water to be released into nearby recipients (Nilsson, 2005). The stricter regulations have, in turn, placed higher demands on the STA as the project owner of West Link to identify and implement appropriate treatment methods for excess water (Trafikverket, 2023). This leads to the need to assess and evaluate the current treatment technology used to treat the excess water and its efficiency in line with the target values for the different parameters treated from the excess water.

Cost-benefit analysis (CBA) can be applied to assess the treatment technology's socioeconomic profitability options. CBA is a systematic approach used in many fields to evaluate and compare different alternatives or projects based on whether they are socio-economically profitable, i.e., if the total benefits are higher than the total costs on a societal scale. A cost-benefit analysis aims to achieve, as far as possible, a quantitative comparison between benefits and costs for all affected parties in society, both now and in the future, by measuring them in monetary units (Rosén et al., 2008).

## 1.2 Aim of the Project

The study's overall aim is to investigate the effectiveness of Centralen's water treatment and its societal costs and benefits.

The study analyses data from the STA between (2018 and 2023) related to the West Link subway project, focusing on water quality measurements at Centralen Station. The data analysis evaluates the levels and total amounts of substances released into the Göta river, comparing these with background levels and annual releases. The data is compiled into tables and graphs showing pollutant levels.

A Cost-Benefit Analysis (CBA) was performed, calculating the net present value (NPV) to assess the total cost of treating excess water at Centralen Station. The CBA also compared the costs and benefits of discharging untreated excess water into the Göta river versus treating it before discharge to determine the costs incurred by the STA for water treatment and monitoring.

### 1.3 Research Questions

1. What are the differences in the concentrations of selected pollutants and chemical parameters before and after the treatment of excess water at the 'Centralen' water treatment plant?
2. How efficiently is the water treatment plant treating excess water at 'Centralen'?
3. How much do the discharges from the West Link project contribute to the levels of pollutants in the Göta river?
4. To what extent does a Cost-Benefit Analysis support decision-making regarding implementing advanced water treatment technology for managing excess water from the West Link?

### 1.4 Limitations

The thesis work will not evaluate how the water from the 'Centralen' may affect the Göta river regarding environmental effects. In other words, the environmental consequences that arise if water from the West Link project is discharged directly into the Göta river without treatment will not be evaluated in detail.

Some cost and benefit items in a Cost-Benefit Analysis (CBA) can be challenging to quantify, thereby restricting the possibility to make a fully quantitative analysis. In such cases, qualitative evaluation is used to compensate for the difficulty encountered in quantifying specific items.

## 2. THEORY

The theoretical framework of this report gives a strong foundation for understanding the methodologies and results obtained from this study. The focus of the study is the treatment of excess water from the Central section of the West Link project in Gothenburg. Due to the complexity of water treatment processes, it is essential to consider several factors e.g., the benefits of sustainable practices, relevant regulations and laws, discharge locations of the treated water, involvement of other treatment facilities, and the specific treatment methods employed at 'Centralen', as well as an overview of the project itself. Furthermore, this report covers the basics of Cost-Benefit Analysis (CBA) in sustainable excess water treatment. It explains how CBA helps assess the economic implications of cleanup projects, allowing decision-makers to balance environmental benefits against economic costs effectively.

### 2.1 The Swedish Construction Industry and Sustainability

In Sweden's construction industry, there are four main approaches to environmental sustainability: reactive, proactive, strategic, and passionate (Hagström et al., 2018). These categories demonstrate different levels of commitment to sustainability, ranging from essential compliance with regulations to comprehensive strategies that integrate sustainability into core business practices. Larger companies often have the resources to implement advanced sustainability initiatives, while small and medium-sized enterprises (SMEs), defined as firms with fewer than 250 employees, face more significant challenges. SMEs often struggle with limited financial resources, expertise, and time, making it challenging to prioritise sustainability. As a result, sustainability can be seen as an additional burden rather than a critical part of their business strategy. However, adopting sustainable practices can create goodwill, which enhances a company's reputation and strengthens relationships with stakeholders.

Goodwill is an essential intangible asset related to sustainability. It can be built through improving the company's reputation, strengthening customer relationships, and investing in employee skills (Sjöström & Hamid, 2021). Internally generated goodwill reflects a genuine commitment to responsible practices and can provide companies with a competitive edge in a market that values corporate responsibility. Research by Auvinen and Norrbin (2016) shows that the value attributed to goodwill in acquisitions has increased significantly, highlighting the importance of intangible assets like reputation and sustainability. This underscores how sustainability can be viewed as a vital driver of corporate value, especially when corporate responsibility is becoming increasingly central to business strategies.

Despite the growing significance of goodwill, challenges remain in its valuation and reporting (Auvinen & Norrbin, 2016). Inadequate reporting can lead to the mismanagement of goodwill, which in turn can affect the transparency and reliability of a company's communications. In the construction industry, it is particularly important to understand how companies navigate these challenges. By integrating sustainability into their strategies,

companies can help create a more transparent and responsible industry, where goodwill serves as a force for long-term value creation and trust.

## 2.2 Water Quality Management

Water quality is crucial for environmental sustainability, affecting ecosystems, public health, and the economy. The European Union has set goals to enhance water quality across member states, including Sweden, for water quality management, focusing on the challenges of excess water in construction projects and laws and regulations for treating excess water (European Commission, 2015).

### 2.2.1 Excess Water

The concept of excess water has an unclear definition. However, in this thesis, excess water includes infiltrating groundwater, stormwater or runoff water and water used during the project process, such as flushing water in connection with earthworks i.e., blasting, drilling, excavation, and groundwater lowering (Länsstyrelsen Västra Götaland, 2021). In addition, excess water can also include wastewater from broken sewer pipes which necessitate the need for the excess water to be handled with care, especially in contaminated areas. There can be different degrees of contamination, but it can be assumed that there is always a need to manage the water to meet the set environmental requirements. Regarding excess water from contaminated land, the responsibility lies with the supervisory authority, which must assess how polluted the excess water is. For the supervisory authority to be able to carry out the assessment, companies working at the specified location must provide the necessary information for this assessment to be carried out.

### 2.2.2 Laws and Regulations Regarding the Treatment of Excess Water

According to the Swedish environmental code, the main purpose is to promote sustainable development, and rules and laws have been developed to ensure that companies and individuals work in a way that protects both people and the environment (Regeringskansliet, n.d.). The Environmental Code governs actions that can affect health and the environment. Chapter 9 regulates environmentally hazardous activities, including the emissions of wastewater, solid substances, or gases on land and into surface water or groundwater. Environmentally hazardous activities are defined as:

1. Emissions of wastewater, solid substances, or gases from land, buildings, or facilities into land, water areas, or groundwater.
2. Land, buildings, or facilities are used in a way that can harm human health or the environment through emissions or contamination of land, air, water areas, or groundwater.
3. Use of land, buildings, or facilities in a way that can cause harm through noise, vibrations, light, or radiation.

According to Chapter 9, § 2, wastewater is defined as sewage or other liquid impurities, including water used for cooling or drainage. Construction site water, such as excess water and drainage water from excavation, is classified as sewage. Chapter 9, § 7 requires that all types of wastewater to be managed, treated, or otherwise handled to avoid harm to health or the environment (Regeringskansliet, n.d.).

The Environmental Code also states that those guilty of environmental crimes must be held accountable (Länsstyrelsen Västra Götaland, 2021). Responsibility is simply placed on the practitioner of the activity, and therefore, an obvious requirement is that the companies possess knowledge regarding how emissions affect the recipient and how this can potentially be prevented. This approach aligns with the Polluter Pays Principle (PPP), which is fundamentally rooted in the concept of 'Environmental Justice.' The PPP advocates for equitable access to a clean environment and uniform protection against potential environmental hazards regardless of socioeconomic status (Jephcote et al., 2016).

Suspended solids and pollutants in excess water that require analysis largely depend on the recipient's sensitivity, the compounds expected to be present at the site, as well as on the county where the work is carried out (Hamel, 2018). In smaller watercourses with high conservation value and in protected areas for water intakes, the requirements regarding the emissions of harmful compounds are higher, see Table 1 for more detailed explanation for the different parameters in superscript in various aspects.

Table 1. Guideline values for excess water in different regions of Sweden (Länsstyrelsen Västra Götaland, 2021). Additionally, all values are rounded to two significant digits.

Unit µg/l mg/l *	City of Gothenburg	Municipality of Linköping	Municipality of Sollentuna	Municipality of Jönköping	City of Mölndal	Stockholm Water and Waste
<b>Parameter</b>						
<b>Arsenic</b>	16	15	5.0	15	15	10
<b>Lead</b>	28	3.0	3.0	2.4	14	10
<b>Cadmium</b>	0.90	0.10	0.30	0.20	0.40	0.10
<b>Copper</b>	10	10	9.0	10	10	200
<b>Chromium</b>	7	15	8.0	15	15	10
<b>Mercury</b>	0.070	0.050	0.070	0.070	0.050	0.10
<b>Nickel</b>	68	10	6.0	8.0	40	10
<b>Zinc</b>	30	30	15	10	30	200
<b>pH</b>	6.5 – 9.0	6.0 – 9.0	6.0 – 9.0	6.0 – 9.0	6.0 – 9.0	6.5 - 10
<b>Oil Index *</b>	10/5/1 <sup>1</sup>	1.0	0.50/0.10 <sup>5</sup>	5.0	1.0	50
<b>Suspended solids *</b>	25	25	60	25	25	100
<b>Phosphorus *</b>	0.050	0.050	0.080	0.050	0.050	-
<b>Nitrogen *</b>	1.3	5.0	2.0/1.5 <sup>6</sup>	1.3	1.3	45
<b>PCB</b>	0.014	0.015	-	0.014	0.014	-
<b>TBT</b>	0.0015	0.0015	-	0.0015	0.001	-
<b>Bens(a)pyren</b>	0.27	0.050	0.050	0.00017	0.050	1.0 <sup>8</sup>
<b>MTBE</b>	2600	500	-	-	500	-
<b>Benzene</b>	50	10	-	-	10	-
<b>TOC *</b>	12	12	-	12	-	-
<b>PFAS/PFOS</b>	0.090 <sup>2</sup>	0.050 <sup>3</sup>	-	-	-	< <sup>9</sup>
<b>Trichloroethylene</b>	10	10 <sup>4</sup>	-	-	-	-

<sup>1</sup> The concentrations vary depending on the distance to water protection areas and raw water intake.

<sup>2</sup> Refers to PFAS.

<sup>3</sup> Refers to PFOS.

<sup>4</sup> The total amount includes both trichloroethylene and perchloroethylene.

<sup>5</sup> The concentrations may differ based on where the water is directed.

<sup>6</sup> The guidelines apply to diversion to the treatment plant rather than direct discharge into nature.

<sup>8</sup> Includes the sum of PAH-16.

<sup>9</sup> PFAS are persistent substances that should not be released into the environment, and the permissible level is determined by the treatment plant and must be approved by the responsible authority.

## 2.3 Cost-Benefit Analysis for Excess Water Treatment Plants

Cost-benefit analysis (CBA), which originated in 19th-century France for infrastructure appraisal, is a systematic approach used in many fields to evaluate and compare different alternatives or projects based on their economic benefits to society (Sjöstrand et al., 2019). Pigou's "Economics of Welfare" from 1920 marked a significant turning point in developing the theoretical underpinnings of CBA, which evolved alongside welfare economics during the marginalist revolution (Mishan & Quah, 2020). The goal of a cost-benefit analysis is to compare benefits and costs for all stakeholders in society quantitatively. According to Rosén

et al. (2008), benefits are defined as improvements in human welfare (utility), while costs are defined as decreases in human well-being both now and in the future based on an analysis of the advantages and disadvantages of different courses of action. CBA has historically been applied more frequently in the US than in Europe, especially to encourage the effective use of the limited funds allocated for soil and groundwater decontamination (Rinaudo, 2013). The first step in a CBA involves identifying the project's relevant costs and benefits (Caliman et al., 2011). Sustainability, optimality, and intervention are essential for infrastructure projects like treatment for excess water and tunnel construction. The anticipated costs should account for the costs required to return a site to its pre-contamination state, considering that remediation and mitigation could demand sufficient resources.

CBA weighs a project or policy's economic advantages and disadvantages (Caliman et al., 2011). The remediation level is at its best when the net benefit is maximised. However, as for tunnelling excess water treatment plants, benefits include avoiding environmental damage and other cleanup advantages, while costs account for the financial and environmental expenditures needed for remediation, which must be accounted for simultaneously. Protecting water and marine environments, resources, and ecosystems from pollution, overuse, and structural changes is the focus of efforts to meet the EU's energy and climate targets (Butković et al., 2023).

### 2.3.1 Net Present Value

In a Cost-Benefit Analysis (CBA), the costs and benefits associated with different water treatment alternatives are quantified in monetary terms and compared against a reference alternative. These costs and benefits are adjusted for inflation and discounted over the project's lifetime using a real social discount rate. The social discount rate is crucial in environmental economics as it reflects society's preference for immediate benefits over future ones. This is particularly relevant in projects with long-term environmental impacts (Pearce et al., 2006).

The Net Present Values (NPV) for each alternative are calculated as follows (Norrman et al., 2015).

$$NPV = \sum_{t=0}^T \left( \frac{1}{(1+r_t)} \right) (B_t - C_t) \quad (\text{eq. 1})$$

Where T represents the time horizon, r for the social discount rate, and t signifies the timing of benefits and costs for each item.

The application of NPV in environmental project evaluation is well-documented in the literature. For example, Benedetti et al. (2005) illustrated the use of NPV in assessing different design and upgrade scenarios of urban wastewater systems. Employing numerical models, they quantified ecological consequences, offering a systematic approach that

balances cost efficiency and regulatory compliance risks. This risk-based design methodology is critical in modern water treatment, aiming to achieve compliance with environmental standards at the lowest possible cost.

In addition to direct economic benefits, environmental impacts are increasingly being monetized in CBAs to reflect their actual societal value. For instance, the economic evaluation of the wastewater treatment plant project in Nov Dojran, North Macedonia, included in Cetković et al. (2022), demonstrated that environmental benefits such as reduced nitrogen and phosphorus pollution contribute significantly to the overall project justification. The study further highlighted that the economic internal rate of return (EIRR) exceeded the opportunity cost of capital, with a Benefit-Cost Ratio (BCR) greater than 1, justifying the investment from a financial and environmental perspective. Similarly, Irwin et al. (2017) conducted a benefit transfer analysis for constructed wetlands in Ohio, which are used to improve water quality by removing excessive nutrients. Their study estimated the amenity and recreational benefits of water quality improvements, demonstrating that a 10% reduction in phosphorus loadings generated significant net benefits, with a lifetime cost-benefit ratio 2.92.

## 3. CENTRALEN

One part of the West Link, known as ‘Centralen’. is located beneath central Gothenburg and connects directly to the central station (NCC, 2024). This chapter introduces the case study of ‘Centralen’, with a focus on both technical and environmental aspects of the project. The chapter covers topics such as Gryaab, Ryaverket, the Göta river, the Göta River Water Conservation Association, and the environmental impacts on the river. It also describes the West Link project concerning current water treatment technologies, the discharge points from the treatment plants, and the effluent target values set by the Swedish Transport Administration.

### 3.1 Gryaab

Gryaab is a company owned by several municipalities in the Gothenburg region (Videbris, 2024). Its primary responsibility is to manage wastewater from the region's urban areas and direct it to Ryaverket for treatment. A tunnel system stretching approximately 13 kilometres transports wastewater from all these municipalities to Ryaverket.

#### 3.1.1 Ryaverket

Ryaverket is a sewage treatment plant owned by Gryaab on the Hisingen island in Gothenburg (Videbris, 2024). Here, the wastewater undergoes treatment, removing significant nutrients that otherwise would contribute to marine eutrophication. These nutrients are then returned to the cycle in the form of biogas and treated sludge, and the treated water is discharged to the sea.

### 3.2 The Göta River

The Göta river stretches 93 kilometres from lake Vänern in the north to the sea around Gothenburg in the south, making it Sweden's most water-rich river with an average flow of 565 m<sup>3</sup>/s (Göta älvs vattenvårdsförbund, 2015). This vital natural resource serves multiple purposes, including transportation, energy production, and the provision of drinking water. Approximately 700,000 of the one million people living in its surroundings rely on the Göta river for their water supply. At the same time, numerous industries and neighbouring communities also benefit significantly from its presence. The river's waterways are crucial for industrial processes, highlighting the region's social and economic importance. Additionally, the Göta river supports diverse plant and animal species thriving within its rich ecosystem along its marshes and banks. These areas are essential for outdoor activities and serve as valuable sites for ecological research.



Figure 1. Map over Göta river, originating from lake Vänern in the north and reaching the sea at two points around Gothenburg. The river divides into two parts in Kungälv, known as the Gothenburg branch in the south and Nordre älv in the north (Göta älvs vattenvårdsförbund, 2015).

### 3.2.1 The Göta River Water Conservation Association

In April 1957, the Göta River Water Conservation Association (Göta älvs vattenvårdsförbund) was established in Gothenburg to protect and improve the water quality within the Göta river (Göta älvs vattenvårdsförbund, 2015). A recipient control program is a central part of the Göta River Water Conservation Association's work. This activity is based on the environmental code and decisions made by the government, county administrative boards, municipalities, or other relevant authorities. Recipient control aims to map and highlight the environmental effects of emissions and pollution, to investigate the relationship between the state of the environment and any changes that can be attributed to pollution, and to provide a basis for planning, implementation, and evaluation of environmental protection measures within the area concerned.

### 3.2.2 Environmental Impact of the Göta River

The water quality in the Göta river has significantly improved, reflecting both historical threats and advancements in environmental protection (Göta älvs vattenvårdsförbund, 2015). From being a source of concern in the 1950s to its improved state, the river has developed rapidly due to extensive measures and investments in pollution remediation. Notably, there has been a significant reduction in oxygen-consuming substances, achieved through the establishment of sewage treatment plants and cleanup efforts, which is crucial for restoring ecological balance and ensuring a healthy environment for aquatic life and people reliant on the river. Concentrations of toxic metals like mercury and chromium have also dropped significantly, reducing risks to human health and the environment (Göta älvs

vattenvårdsförbund, 2015). Although mercury is still present, its usage has declined notably since 1995, contributing to overall water quality improvement. However, challenges remain, particularly regarding fecal contamination, which prompts the closure of Gothenburg's raw water intake for about 100 days yearly due to suspected microbiological contamination.

Emerging pollutants also pose a growing concern for the Göta river's ecosystem. Runoff and snowmelt affect water quality in streams near urban areas, which currently presents a significant challenge for maintaining water quality in many locations (Müller et al., 2019). Well known sources of these pollutants include vehicle traffic, atmospheric deposition, and metal coatings on buildings. Climate change and increased precipitation can further exacerbate the impact of these pollution sources. Traffic related activities are the primary source of pollution, with polycyclic aromatic hydrocarbons (PAHs) identified as significant pollutants (Markiewicz et al., 2017). These compounds, formed during the incomplete combustion of organic materials like fossil fuels, are persistent and bioaccumulative, posing serious risks to aquatic ecosystems. When PAHs enter waterways via road runoff from vehicle exhaust, tire wear, and motor oil leakage, they can severely impact aquatic life and diminish the survival rates of sensitive species.

Pollutants from tire wear particles (TWPs) are also significant sources of microplastic pollution in urban waterways. According to Järllskog et al. (2022), these particles majorly contribute to microplastics in the environment, with significant implications for water quality in urban areas. Stormwater systems are a critical transport pathway for TWPs, often leading to high concentrations of microplastics and other pollutants in urban water. Effective management and treatment of stormwater are therefore crucial for reducing pollution in urban waterways. Seasonal variations also affect the concentrations of bitumen wear particles (BiWP). During the winter, BiWP increases, likely due to studded tires (Järllskog et al., 2022). This means pollution levels can vary throughout the year, which should be considered when planning monitoring programs and environmental measures.

Chemicals from industrial and agricultural sources also pose threats to aquatic life and disrupt the ecosystem's balance (Göta älvs vattenvårdsförbund, 2015). Wastewater from industries may contain harmful organic pollutants and microplastics, and agricultural use of fertilisers and pesticides containing nutrients like nitrogen and phosphorus can lead to eutrophication and algae growth. Additionally, introducing invasive species from ships and other waterways threatens the river's biodiversity. It is imperative to reduce these pollutants' emissions and manage them sustainably to protect and improve the Göta river's water quality and environment.

Since the Göta river directly connects from Lake Vänern, its water flows also influences the lake's ecology (Göta älvs vattenvårdsförbund, 2015). Regulation of Lake Vänern's water flow and improvement measures are crucial for sustaining a healthy water environment in the Göta river. The water quality of the Göta river is not just a local concern; it is tied to national legislation and international guidelines like the EU's Water Framework Directive.

Compliance with these standards is vital to achieving good ecological and chemical status and safeguarding the river's value as a crucial resource for people and the environment.

### 3.3 The West Link Project

The West Link Project is a railway project in Gothenburg that started in 2018 and is planned to be completed by 2026 (Kjellberg, 2019). The main goal is to build an 8-kilometre double-track railway, of which 6.6 km will be in tunnels, to improve traffic in the city. The STA is in charge of this project. The project aims to ease congestion and meet the current traffic demands of Gothenburg city, which is experiencing capacity challenges from north, east, and southbound rail traffic. This project combines different construction methods, including drilling, blasting, and open excavation (Stephan et al., 2022). These methods are challenging because the ground in the area is soft. The project strongly emphasises meeting strict environmental standards, especially concerning blasting in Gothenburg. Ultimately, the West Link Project is expected to increase the railway network's capacity, ease traffic congestion, and support sustainable growth in the region. Construction of the west link project is planned for three underground stations: Centralen, Haga, and Korsvägen (Stephan et al., 2022). The tunnels are being constructed using two methods, depending on whether they pass through soil, clay, or rock. In soil or clay areas, the tunnel will be created by excavating the soil and constructing it with concrete, while in rock areas, it will be built by drilling and blasting.



Figure 2, Map over “Västlänken” and its different stages (Trafikverket, 2020). The light blue line in this figure demonstrates the Centralen. The solid black line represents a tunnel in rock, the solid lighter line represents a tunnel in soil/clay, and the dashed black and white line represents a railway above ground. Besides Centralen, there are also the other parts in this project, such as Haga in red, Korsvägen in yellow, Kvarnberget in dark blue, and Olskroken in green.

As illustrated in Figure 2, ‘Centralen’ stretches from Kanaltorget to Nordstan, continues towards Skansen Lejonet, and concludes with a bridge over the E6 highway. The area is approximately two kilometres long and a hundred meters wide. The central segment has been assigned to NCC by the STA. This segment includes an underground train station, approximately 2 km of connecting subway tunnels, and a bridge over E6 to the east (NCC, 2024).

### 3.3.1 Current Treatment Technology

NCC Infrastructure AB (NCC) has awarded Swedish Hydro Solutions AB (SHSAB) a contract to treat excess tunnelling water for the ‘Västlänken E02 Centralen’ project in Gothenburg (Lindqvist, 2018). SHSAB's advanced treatment technology, which utilises particle flocculation and sedimentation, has been further refined to enhance reliability, simplify operation, and reduce costs. This technology is precisely engineered to manage the substantial water flows characteristic of large-scale infrastructure and construction projects.

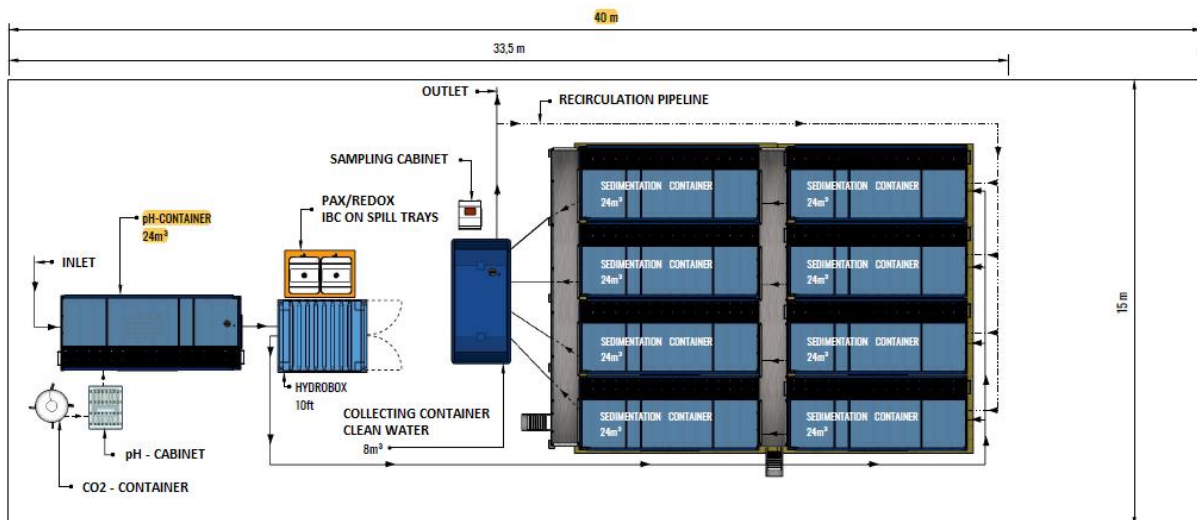


Figure 3. Detailed plan of complete water treatment system (Nilsson, 2024).

To separate particles, a process called flocculation is utilised where chitosan extracted from crab shells and fully biodegradable, serves as a flocculant in the excess water treatment system (Lindqvist, 2018).



*Figure 4. Chitosan from crab shells (Photo by A. Nuur).*

The chitosan is incorporated into a specially designed porous textile material, as shown in Figure 4. The water flow removes the chitosan gel formed on its surface through friction. The dosage adjusts passively, increasing with the flow, providing flexibility without the need for active control or regulation (Lindqvist, 2018).



*Figure 5. Chitosan is added to incoming excess water in a dosing tank with containers. It is dosed passively as water flows over the containers, washing away the chitosan gel (Photo by A. Nuur).*

The dosing equipment is housed within mobile trailers, where untreated water is pumped in (Lindqvist, 2018). Inside these trailers, a dedicated tank holds the chitosan, and incoming water is treated with a dose of chitosan upon arrival, as illustrated in Figure 5.



*Figure 6. Chitosan flocculation with excess water from building sites. The beaker has been dosed with chitosan to start the flocculation process (Photo by A. Nuur).*

After the water is dosed with chitosan, it flows into sedimentation tanks where particles clump together, as illustrated in Figure 6 (Lindqvist, 2018). In the sedimentation tanks, which can be seen in Figure 7, the water moves slowly, which makes it possible for gravity to separate the water from the particles that settle to the bottom before it ends up in a container seen in Figure 7, which is also connected to a sampler that takes samples for analyses to make sure the water quality of the effluent from the tank is good.



*Figure 7. Illustration of the treatment system for the excess tunnelling water on site (Photo by F. Hadi).*

However, if the need arises, dissolved contaminants such as toxic metals and various organic pollutants, including chlorinated and oil-based substances, can be removed in sorption filters (Lindqvist, 2018). This is accomplished with a specialised filtration technique known as BioMedia, which uses activated carbon derived from wood chips, a byproduct from the forest industry.



*Figure 8. Sorption of pollutants using bio-media filters (Photo by F. Hadi).*

The treatment equipment utilised is also equipped with an automated control system, as shown in Figure 9. This enables remote monitoring of parameters such as pH, flow rate, conductivity, and turbidity through digital devices (Lindqvist, 2018). Maintaining the pH level of the water is crucial. Hence, the treatment system also features a pH adjuster that introduces carbon dioxide (CO<sub>2</sub>) before adding chitosan.



Figure 9. Measuring board for automated assessment of turbidity, conductivity, pH, and flow rate (Photo by F. Hadi).

The excess water treatment system also includes an automatic water sampler (Lindqvist, 2018), see Figure 10. It is regulated by flow rate and can also be adjusted based on changes in parameters such as pH, conductivity, or turbidity, as well as predetermined time intervals.



Figure 10. Automatic ISCO sampler (Photo by F. Hadi).

### 3.3.2 Treatment Plants and Discharge Points

At the Centralen stage, several portable water treatment plants have been in operation, with three of them, namely RV-2700N, RV-MT3, and RV-GB, running for most of the project's duration (Nilsson, 2024). The excess water from the site is pumped to these treatment plants where it undergoes the same treatment as all other water before being pumped out to the Göta river through the discharge points as shown in Figure 11.



Figure 11. Map over treatment plants and discharge points in the stage Centralen (Nilsson, 2024).

### 3.3.3 Target Values Established by the Swedish Transport Administration

The STA has established target values for various parameters, as illustrated in Table 2. According to the STA, these target values are derived from the court's decision in case M 638-16, which regulates the discharge levels of excess water into the Göta river (Vänersborgs Tingsrätt, 2018). As displayed in Table 2, the Centralen stage, which has the Göta River as the recipient, has less strict requirements than the guidelines set by the city of Gothenburg due to differing water bodies. According to Trafikverket (2023), there is no specified target value for nitrogen, as high natural levels in the soil make it challenging to control. Furthermore, during tunnel construction, nitrogen levels in discharge water increase significantly due to the use of explosives. To manage this, nitrogen-rich water is directed to the Ryaverket treatment plant for biological treatment, as on-site treatment is difficult. This process ensures that nitrogen levels are effectively managed before the water is released.

Table 2. Target values specified as monthly average values for various chemical parameters according to the STA (Trafikverket, 2023).

<b>Parameter</b>	<b>Unit µg/l mg/l *</b>	<b>Target value, for discharges into other recipients then Göta river</b>	<b>Target value, for discharges into the Göta river</b>
<b>Suspended solids *</b>		25	75
<b>Oil index *</b>		1	3
<b>Nitrogen *</b>		-	-
<b>Arsenic</b>		15	45
<b>Lead</b>		14	42
<b>Cadmium</b>		0.4	1.2
<b>Copper</b>		10	30
<b>Chromium</b>		15	45
<b>Chromium VI</b>		15	15
<b>Mercury</b>		0.05	0.15
<b>Nickel</b>		40	120
<b>Zinc</b>		30	90
<b>pH</b>		6 - 9	9.5

The target values for Göta river, which are higher than those for other recipients, are regulated according to court ruling M 638-16 (Trafikverket, 2023). This adjustment is based on the river's larger water volume and higher flow rate, which allow for more effective dilution of pollutants. Even though the concentration of contaminants may be higher, the overall impact on the environmental status of the waterway is assessed to be less significant than in smaller recipients where discharges have a more noticeable effect.

## 4. METHODOLOGY

This chapter presents the methodology employed for data collection and analysis, focusing on investigating the excess water treatment process before its discharge into the Göta river and conducting an associated cost-benefit analysis. A clear description of the research methods is essential for readers to assess the validity and reliability of the results. By clarifying the methods, the aim is to enhance understanding and facilitate assessment of the study's findings.

### 4.1 Research Approach

An inductive approach was used to address our research questions and fulfil the purpose of our study (Bryman, 2018). Furthermore, a combination of quantitative and qualitative methods was utilised. According to Shorten & Smith (2017), this methodological approach offers advantages, such as enabling a deeper understanding and a more comprehensive research paper analysis.

The quantitative method was employed to analyse data from Excel files obtained from the STA. Various water quality parameters related to the excess water treatment are quantified and analysed, including the amount of treated water and the efficiency of the water treatment process, as well as CBA related to water treatment plants.

The qualitative method included a literature review and interviews. The literature review facilitated the understanding of the theoretical background. It provided information that made it easier for authors and readers to grasp the entire project, as Bryman described (2018). The interview study provided more profound insights and understanding into practical aspects of water treatment, such as challenges, strategies, and success factors according to those working in the field. Additionally, it contributed to a broader understanding of areas that were unclear to us as authors through inspiration and new perspectives, particularly concerning the cost-benefit analysis.

### 4.2 Research Process

To carry out this research, a significant amount of work was required, primarily involving multiple Excel files from the STA, which was also the initial focus at the beginning of the project. Concurrently, a literature review was conducted to support and provide background to our findings, including laws and regulations regarding excess water treatment.

Furthermore, several interviews were conducted to gather more information about our findings and to gain fresh perspectives on how to approach the work.

#### 4.2.1 Evaluation of Water Quality Parameters

The study was initiated by obtaining Excel files from the STA. These files contained water quality analyses from the central section between 2018 and 2023. Due to the relocation of the

water treatment plants during this time, emphasis was placed solely on operational plants for most of the time of the West Link project in the central section. This approach was adopted to ensure data accuracy, as files from intermittently operational plants often lacked essential data. A consolidated Excel file was utilised to merge all data, facilitating the extraction of relevant substances.

Two scenarios were devised to address data points falling below detection limits. In the first scenario, these values were assigned zero; in the second, they were set equal to the detection limit. This methodology enabled the exploration of significant differences between scenarios and their adherence to treatment objectives while also evaluating potential uncertainties. Following data compilation, collaboration with the STA supervisor was initiated to determine quality parameters to focus on. Utilising the consolidated Excel file, the pollutants emissions were computed in kg/year based on volume data.

#### 4.2.1.1 Recipients

To assess the Excel data concerning water quality discharged into the Göta river, comparisons were conducted with two sites near the 'Centralen' stage. Specifically, our results were contrasted with data obtained from 'Stenpiren', situated downstream from our discharge point, and 'Alelyckan', positioned upstream. The Göta River Water Conservation Association obtained these datasets as Excel files.

#### 4.2.2 Analysis of Data from Excel

All the data was consolidated into a single Excel file using the Excel files provided by STA. The data was sorted by the treatment plant, parameter, date, inlet concentration, outlet concentration, average volumes, and units in two different calculation sheets. One sheet included all values and values with concentrations below the detection limit set to 0. In contrast, the other sheet included all values and values with concentrations below the detection limit set to the detection limit itself. This was done to assess the potential impact of this assumption on the results. The Excel files from the Göta River Water Conservation Association (GRWCA), which contained data on the recipients, were also consolidated into Excel to facilitate easier filtering and comparison with the data from the STA.

##### 4.2.2.1 Before and After Excess Water Treatment

To address the first research question in this report, the new consolidated Excel file created using data from STA was filtered. The focus was solely on the treatment plants considered significant by STA, which were the ones that had been active for most of the project's duration, to obtain a more accurate picture of the water purification process. The outlet concentrations for these treatment plants were compiled for all the operational years. It is important to note that measurements were missing for certain months during the operational years of the treatment plants. These minor errors were not given significant focus because the data showed a clear trend regarding how the target values for different parameters were achieved. Two charts were created for each parameter of importance for STA: one showing

the concentrations before and after treatment to clearly illustrate whether STA achieved its target values for various parameters. Most parameters from the STA were measured in mg/l. To facilitate comparison with the target values, some were converted to µg/l.

#### 4.2.2.2 Water Treatment Efficiency

To address the second research question, the consolidated Excel file was again used to determine the inlet concentrations in the treatment plants and compare these with the outlet concentrations. These values were compiled for all the years the treatment plants were operational, allowing for the calculation of their efficiency. All measurements for a particular substance were summed for a given year to determine the concentrations. The total concentration was then divided by the number of measurements to obtain an average concentration. This process was applied to inflow and outflow water, ensuring an equal number of measurements for both to achieve the most reliable results possible. The average concentrations for inflow and outflow water were calculated for all operational years and then used to determine the efficiency of the treatment plants for each respective year.

The equation used for the calculation of the removal efficiency is shown below.

$$x (\%) = \frac{(\textit{Average inlet concentration} - \textit{Average outlet concentration})}{\textit{Average inlet concentration}} \cdot 100 \quad (\text{eq. 2})$$

#### 4.2.2.3 Contribution from Centralen in Relation to Nearby Recipients

The third research question focused on comparing the total emissions from the central facility with the existing concentrations at Stenpiren and Alelyckan during a similar period. Stenpiren downstream and Alelyckan upstream from the central facility has a flow rate of 565 m<sup>3</sup>/s, the average Göta river flow rate. Measurements from GRWCA were taken once a month. In some cases, measurements were missing. This was resolved by calculating an annual average, adding all measurements over a year, and dividing the sum by the number of measurements to obtain a mean concentration. With this concentration and a given flow rate, the mass of emissions for both Stenpiren and Alelyckan could be calculated.

The quality parameters chosen to compare were toxic trace metals, compared between Stenpiren, Alelyckan, and the central facility, including:

- As = Arsenic
- Pb = Lead
- Cd = Cadmium
- Cu = Copper
- Cr = Chromium
- Hg = Mercury
- Ni = Nickel
- Zn = Zinc

Only these parameters could be compared because the Excel files from Stenpiren and Alelyckan only had these parameters in common with the Excel files from STA.

### Calculation of Mass for Stenpiren and Alelyckan:

1. Convert the volume from cubic meters (m<sup>3</sup>) to liters (l):

$$m^3/s = 1000l/s$$

2. Multiply the concentration by the water flow:

$$\mu g/l \cdot l/s = \mu g/s$$

3. Calculate the mass in  $\mu g$  for a whole year by multiplying the new value by the number of seconds in a year:

$$\mu g/s \cdot 60 \times 60 \times 24 \times 365 = \mu g/y$$

4. Finally, convert from  $\mu g/y$  to  $kg/y$  by dividing the sum by  $1 \times 10^9$

$$\frac{(\mu g/y)}{1 \cdot 10^9} = \frac{kg}{y}$$

For the central facility, a compiled Excel file was used to calculate the mass. Data from STA was used to determine the water volume in the central facility. Volumes varied significantly each month while some months lacked data. For each specific site, such as RVGB, all volumes between 2019 and 2023 were added and divided by the number of measured volumes.

In Centralen, there were five different sites with treatment plants used in this study; these were:

RVGB = Gullberg

RVMT3 = MT3

RVSCHEV = EO2 Schev

RVV = Väst

RV2700N = 2700 Norr

The parameters from the central facility were measured in mg/l, except for mercury, which was measured in  $\mu g/l$ . The other parameters were converted to  $\mu g/l$  for comparison purposes. The concentration before and after purification in the central unit was determined by finding the average concentration. For each parameter, the concentrations entering and exiting each purification plant were summed, and an average concentration was calculated for each year.

Mean values for the volume of water processed by the three different treatment plants at Centralen:

RVGB = 860 m<sup>3</sup>/month.  
RVMT3 = 3839 m<sup>3</sup>/month.  
RVSCHEV = 4306 m<sup>3</sup>/month.

Since data for Stenpiren and Alelyckan was missing for 2023, comparisons for that year were not made. Therefore, the treatment plants called RVV and RV2700N were excluded as they only had data for the year 2023.

With the known water volume for each treatment plant in the central facility, a total annual volume was calculated by adding all volumes for the active treatment plants and multiplying by 12. The total volume for the Central facility was 9005 m<sup>3</sup>/month and 108 060 m<sup>3</sup>/year.

### Calculation of Mass for Centralen:

1. Convert the volume from cubic meters (m<sup>3</sup>) to liters (l):

$$m^3/y = 1000l/y$$

2. Multiply the concentration by the water volume:

$$\mu g/l \cdot l/y = \mu g/y$$

3. Finally, convert this to kg/y by dividing the sum by  $1 \times 10^9$ :

$$\frac{(\mu g/y)}{1 \cdot 10^9} = \frac{kg}{y}$$

### 4.2.3 Literature Study

The literature review played a vital role in this research. The process began with acquiring information about the West Link project, excess water, and water quality requirements in various regions of Sweden. Additionally, details were sought regarding the locations and operations of water treatment plants in the 'Centralen' stage, as well as pertinent information about Gryaab and Ryaverket. Furthermore, fundamental aspects of the Göta river were elucidated, culminating in an explanation of the principles underlying cost-benefit analysis.

### 4.2.4 Interview Study

After completing the initial literature review, the empirical phase of the study involved conducting semi-structured interviews characterised by a predefined set of questions (see Appendix B) that offer flexibility to address emerging issues. This approach has both advantages and disadvantages. It can be time-intensive, involving preparation, participant identification, scheduling, execution, and subsequent analysis. This could lead to limitations in the number of interviews conducted, potentially affecting the generalisability of findings (Sreejesh et al., 2014). However, according to Sreejesh et al. (2014), semi-structured

interviews allow for a nuanced exploration of topics, going beyond mere description to uncover underlying processes ('how' rather than 'what').

The semi-structured interview questions focused on the central theme of cost-benefit analysis, explicitly addressing the costs and benefits associated with treating excess water from the "West Link project" compared to not treating it before discharging it into the Göta river. This approach enabled participants to elaborate on their responses, leading to a deeper understanding of the subject matter. Moreover, it allowed for discovery, enabling the exploration of relevant avenues as discussions unfolded.

#### 4.2.4.1 Interviewees

Four interviews were carried out. The interviewees represent various organisations, including NCC, the contractor, and Swedish Hydro Solutions AB, the subcontractor, two companies directly involved in the treatment of excess water from the construction of West link in general and 'Centralen' in particular. The interview also included Gryaab AB and the Göta river Water Conservation Association. Furthermore, for this report, it was decided to make the interviewees anonymous and not publish the interviewees names to maintain privacy.

*Table 4. Compilation of the interviewees.*

<b>Referred as</b>	<b>Role</b>	<b>Company</b>	<b>Description</b>
Representative G	Quality and environmental manager	Gryaab AB	A company that works for a cleaner ocean and a more sustainable future.
Representative V	Secretary	Göta älvs vattenvårdsförbund	An organisation solely founded to protect and improve the water quality within the Göta river.
Representative N	Group leader, (Västlänken E02 Centralen)	NCC	General contractor for the West Link project.
Representative S	Co-founder, Co-owner & CTO	Swedish Hydro Solutions AB	Subcontractor for treatment of excess water from the West Link project.

#### 4.2.4.2 How the Interviews Were Conducted

The participants were interviewed to gain valuable insights into the costs and benefits of operating the excess water treatment facility in the West Link project.

Using a semi-structured approach, open-ended questions were sent to the participants a few days before the interview, fostering a natural flow of conversation, and enabling in-depth discussion. This method allowed interviewees to express their opinions freely while follow-up questions delved deeper into their perspectives.

Each interview, spanning 30 to 45 minutes, was meticulously recorded to ensure precise transcription of the respondents' viewpoints. Prior consent was obtained from the participants regarding the recording. Analysing these insightful interviews involves converting audio recordings into text and rigorously examining the transcripts to uncover crucial insights and trends. The interview findings, research questions, and existing literature are thoroughly scrutinised to guarantee a thorough and credible analysis.

#### 4.2.4.3 Analysis of the Interviews

The qualitative analysis of the interview data followed a structured approach to extract meaningful insights and identify key themes. First, the interviews were accurately transcribed to capture all crucial information. The transcriptions were reviewed to understand the context and main points discussed. An initial coding round labelled significant statements and ideas with descriptive codes, which were then grouped to form broader themes based on recurring concepts. Next, patterns within and across themes were identified, highlighting connections and contrasts. The data were then interpreted to understand underlying meanings and insights, considering the interview context and perspectives.

### 4.3 Critical Reflection

For the first research question, the number of measurements varied occasionally, resulting in data being available for effluent water from the treatment plant but not for influent water. To ensure credible results, only measurements where data for both influent and effluent water were available were included. This ensured that an equal number of measurements was used when calculating concentrations for both influent and effluent water. Furthermore, data where the concentration of influent water was zero and the concentration of effluent water was more significant than zero were excluded, as this was deemed unrealistic in a water treatment process.

Similar issues arose in the second research question, where measurement discrepancies could be attributed to several factors, including the fact that measurements for influent and effluent water only sometimes represented the same water volume due to long retention times. This could lead to situations where the concentration of effluent water sometimes appeared higher than that of influent water. It is also essential to consider that the sampling frequency varied over time, contributing to uncertainties in the results. To mitigate this, averages were calculated, increasing the results' credibility. It should also be noted that RVV and RV2700N were only operational during 2023, resulting in limited data, and therefore, these sites were excluded from the third research question.

For the third research question, data from March 18, 2019, to September 25, 2023, were considered. This aligns with the measurement period for GRWCA up to December 14, 2022, which allows for comparison with data from STA during the same period.

## 4.4 Cost-Benefit Analysis (CBA)

In academic research, case studies are favoured when addressing "how" or "why" questions, especially in situations where the researcher lacks control over events and seeks to understand contemporary phenomena within real-life contexts (Yin, 2009). For the practical component of this thesis, a case study was conducted within a construction project organisation operating as clients in the Swedish infrastructural sector. Specifically, the study focused on the West Link Project in Gothenburg, particularly the Central underground station. The aim was to conduct an economic assessment using a cost-benefit analysis (CBA) for the excess water treatment technology used before discharging into the Göta river.

The CBA followed a methodology that consisted of five steps (Volchko et al., 2017).

1. Identification of excess water treatment plant alternatives and reference alternatives.
2. Identification of costs and benefits.
3. Quantification and monetisation of costs and benefits.
4. Calculating the NPV and associated uncertainties of each alternative by using Monte-Carlo simulations and discounting the cost and benefit items using a social discount rate and a relevant time horizon.
5. Drawing conclusions regarding social profitability to provide decision-support recommendations.

As outlined in Chapter 3.3.1, the excess water treatment technology is already in place. Thus, in this case, when dealing with the treatment of excess water from the construction of the West Link, CBA was used as a starting point to map and compare the potential benefits and costs of releasing the excess water directly into the Göta river without treatment (Reference Alternative, A0) or implementing excess water treatment before the discharge (Remediation Alternative, A1). All assessments of costs and benefits (or negative and positive effects) in a CBA are made about A0 (the Reference Alternative) for the project owner (the Swedish Transport Administration). This means that it is compared to how much more benefit A1 provides compared to A0 and how much greater costs A1 entails compared to A0 for the STA. Table 3 provides a list of categories of benefit and cost items with brief explanations.

Table 5. Benefit (B) and cost (C) items due to the excess water treatment plant (Söderqvist et al, 2015).

Benefit (B)	Cost (C)
<p><b>B1: Direct benefits</b></p> <p>Direct benefits associated with the STA that come with the treatment of excess water from West link i.e., increased goodwill for its environmental efforts.</p>	<p><b>C1: Cost for water excess water treatment plant.</b></p> <p>The cost of excess water treatment for the STA as the project owner.</p>
<p><b>B2: Improved health.</b></p> <p>Improved health resulting from excess water treatment, for instance, a reduced number of illnesses for workers or other individuals using the Göta river in any capacity.</p>	<p><b>C2: Impaired health due to remedial action.</b></p> <p>C2 refers to health effects affecting the public or workers, rather than the project owner directly.</p>
<p><b>B3: Increased provision of ecosystem services.</b></p> <p>Improved environment resulting from the Remediation Alternative, which does not directly impact the project's finances but rather burdens the public through, for example, area restrictions.</p>	<p><b>C3: Decreased provision of ecosystem services due to remedial action.</b></p> <p>Deteriorated environment resulting from the Remediation Alternative, which does not directly impact the project's finances but rather burdens the public.</p>
<p><b>B4: Other positive externalities than B2 and B3.</b></p> <p>B4 represents other positive effects that may not necessarily pertain to health or the environment. It can include improvements in land values for surrounding properties.</p>	<p><b>C4: Other negative externalities than C2 and C3.</b></p> <p>C4 may include declines in land values for surrounding properties or increased costs of the excess water treatment for other stakeholders.</p>

Cost and benefit items were identified, followed by a qualitative assessment of their importance. These were then adjusted for inflation and discounted over a 14-year horizon, i.e., the construction lifetime from 2018 to 2032. The social discount rate chosen was 3.5%, which aligns with recommended practices for CBAs in Sweden (STA, 2023). Quantifying and monetising costs and benefits is demanding due to excess data requirements. Qualitative evaluation is used to guide prioritisation in identifying costs and benefits. If quantification is not feasible for some aspects, qualitative valuation from step 2 is retained.

The NPV calculation was performed using Equation 1 in Chapter 2.3.1, with economic data collected from NCC and STA, which was used to establish and operate the excess water treatment plan. The discounting of costs and benefits was conducted using the social discount rate and time horizon specified earlier. The most economically beneficial alternative for society is regarded as the one with the highest positive NPV.

## 5. RESULTS & DISCUSSION

In this chapter, the results and findings from the study are presented, including a detailed comparison of various parameters selected by the STA, both before and after the treatment of excess water. This comparison shows the differences in levels and assess whether the target values have been met. Additionally, the efficiencies of the treatment plants in managing excess water are reported on, including the yearly kilogram equivalents of each parameter relative to baseline levels in the Göta river, measured at two points i.e., upstream at Alelyckan and downstream at Stenpiren. Alongside this, the findings from the cost-benefit analysis are discussed. To further explain these results, interviews are incorporated to clarify the findings and highlight key aspects for understanding the connection between the results and our insights. The strengths and weaknesses of our findings are also identified by comparing them with similar studies to provide a comprehensive evaluation.

### 5.1 Parameters Before and After Excess Water Treatment

In the results for section 5.1, the three excess water treatment plants that have been operational for most of the project's duration are depicted in a graph from the beginning of 2019 to the end of 2023. Since RV2700N and RVV were only operational during 2023, they were merged with RVSCHEV, as the Swedish Transport Administration proposed. In the following figures, coloured lines represent different locations where treatment plants have been operating. The red line indicates a target value established by the Swedish Transport Administration, and the goal of the water treatment is for the measured parameters to fall below the red line.

RVGB = Gullberg = Orange line  
RVMT3 = MT3 = Blue line  
RVSCHEV = EO2 Schev = Black line  
RVV = Väst = Black line  
RV2700N = 2700 Norr = Black line  
Target value after purification = Red line

The results indicate that target values for all parameters are mainly achieved after treatment. In a few isolated cases, some parameters exhibit very high concentrations, causing spikes in the graph. However, a clear trend is evident, which can be seen in the figures in this chapter called “OUT,” demonstrating the effectiveness of treating excess water. A logarithmic scale was applied to the y-axis to visualise and interpret the data better. This approach is particularly useful for handling data with a wide range of values, as it compresses large numbers and expands small ones, making trends and differences more discernible. This method helps present variations that extreme values might otherwise obscure.

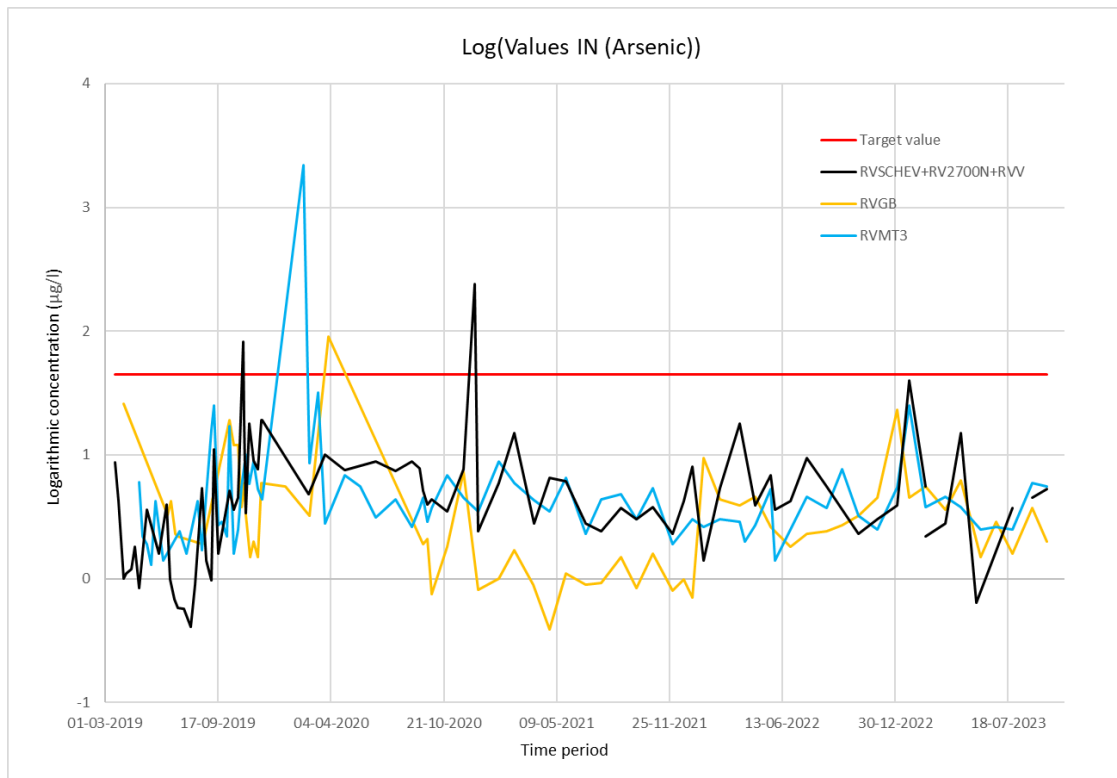


Figure 12. Concentrations of arsenic in influents before treatment.

Figure 12 shows the concentration of arsenic in the water before treatment. When compared with Figure 22, which displays the water's pH levels over the same period, it is possible to interpret that high arsenic levels are also associated with higher pH values. According to Fatslund (2018), the solubility of arsenic is influenced by pH and redox potential, and these factors are crucial in determining the behaviour of arsenic compounds such as arsenite (As(III)) and arsenate (As(V)) in various environments.

Arsenite and arsenate are oxyanions. They carry a negative charge, which affects how they bind to soil and mineral surfaces (Fatslund, 2018). Higher pH values reduce the adsorption of arsenate, increasing its mobility in the environment, while arsenite tends to adsorb better under similar pH conditions. This means arsenic can become more mobile, bioavailable, and toxic in high-pH environments.

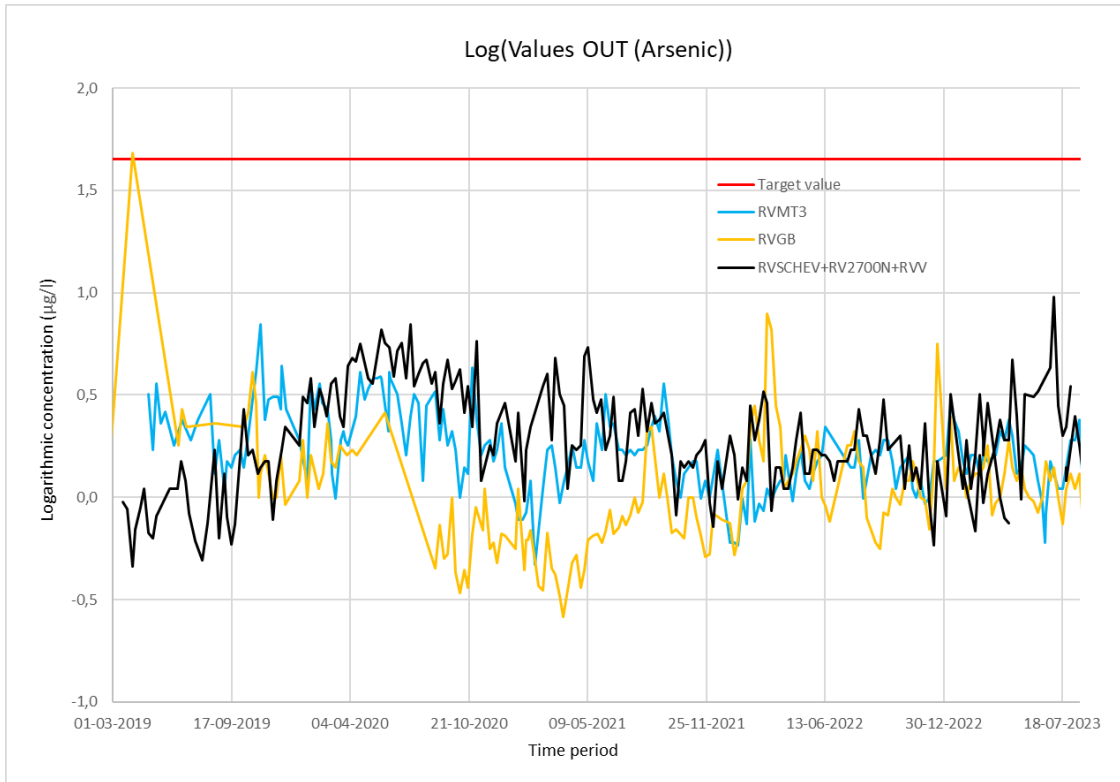


Figure 13. Concentrations of arsenic in effluents after treatment.

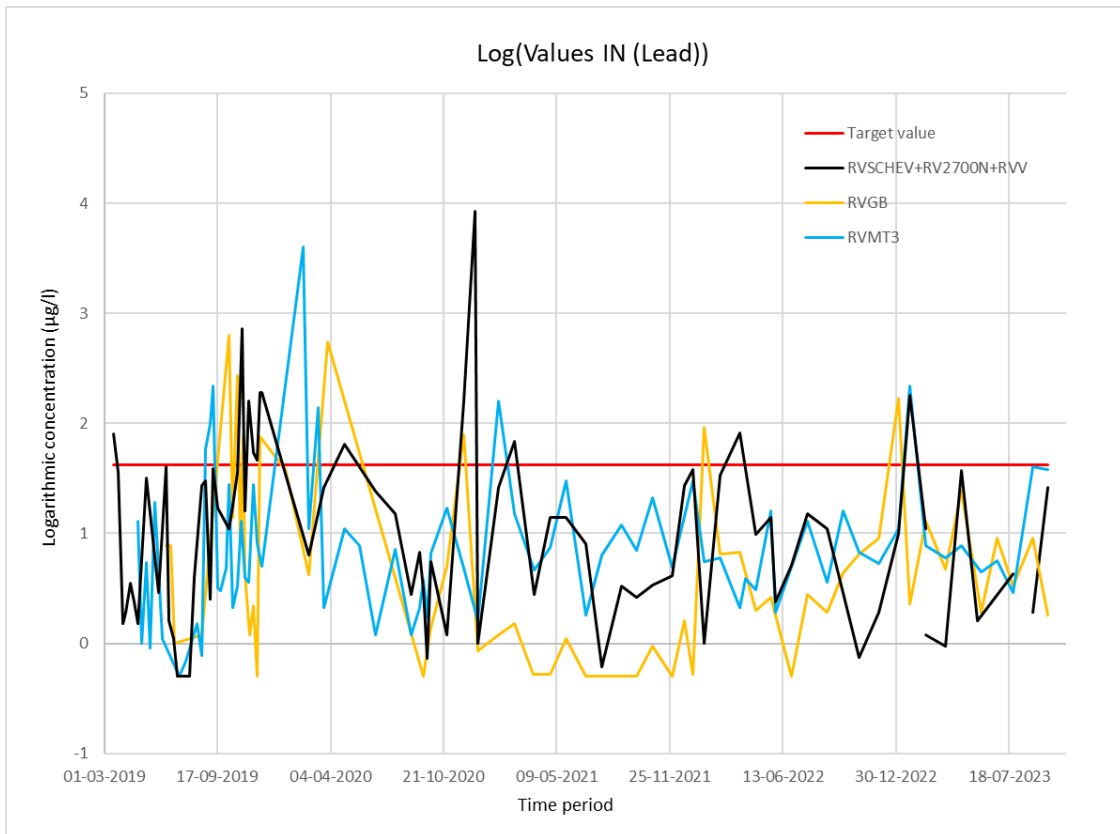


Figure 14. Concentrations of lead in influents before treatment.

In Figure 14, lead concentrations increase with higher pH values, which contrasts with Åbrink (2018), who states that lead solubility rises at low pH. Lead, a toxic metal that is

typically immobile, usually results in low concentrations in groundwater. While lead solubility is expected to increase at low pH, the results presented here contradict this expectation. Additionally, elevated lead levels may be attributed to sources such as industrial activities and old paint, indicating that the high lead concentrations observed at higher pH levels could stem from factors other than pH.

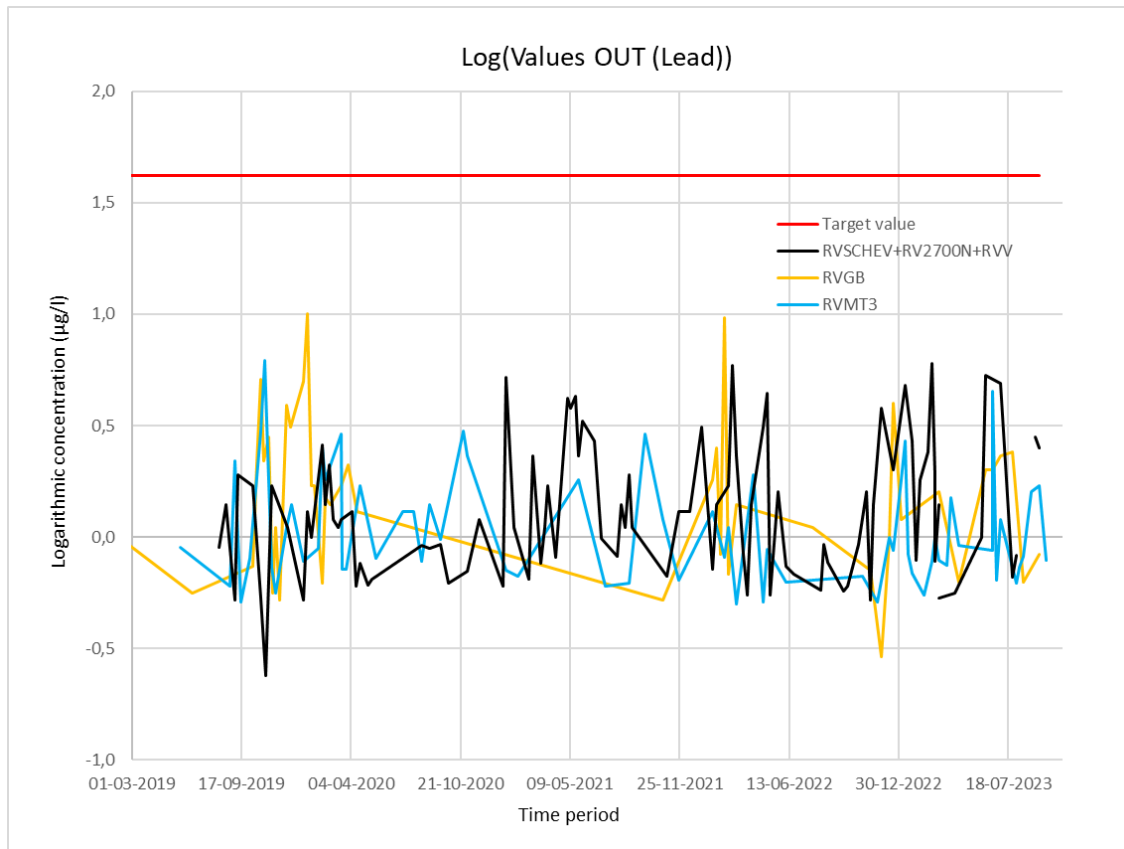


Figure 15. Concentrations of lead in effluents after treatment.

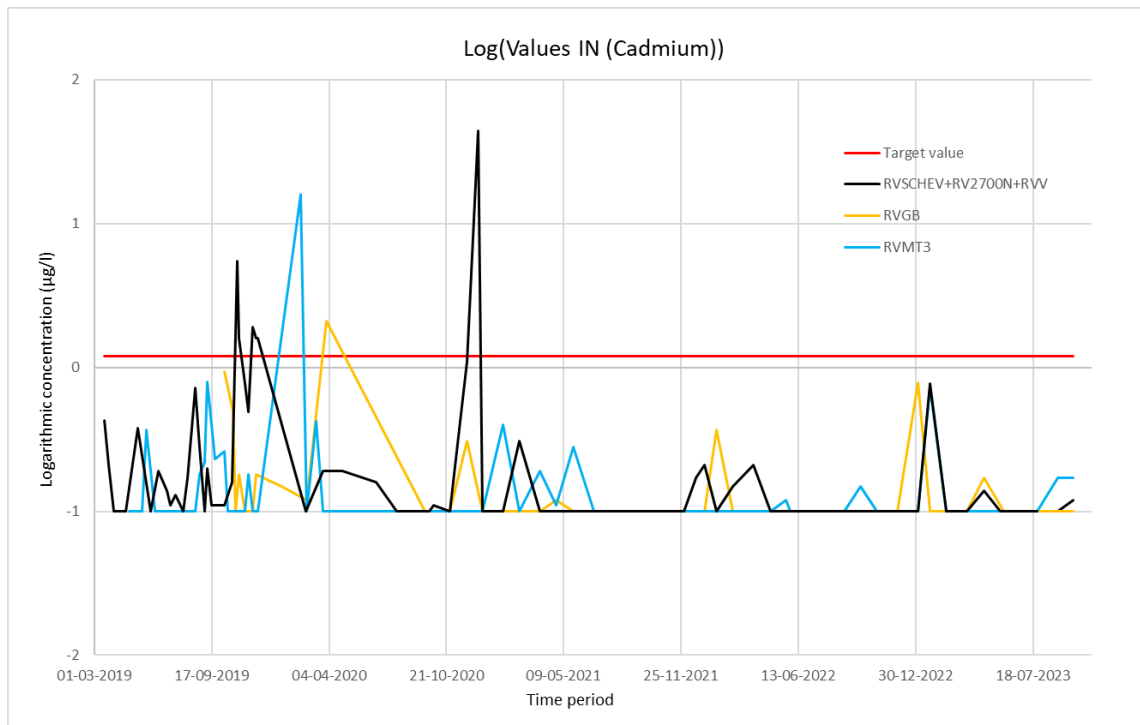


Figure 16. Concentrations of cadmium in influents before treatment.

In Figure 16, cadmium concentrations are notably high before treatment, occurring concurrently with the other metals. Åbrink (2018) indicates that cadmium should show reduced solubility at higher pH values, suggesting that other factors likely contribute to the elevated concentrations. Potential sources of high cadmium levels include fertilizers, vehicle emissions, waste incineration, industrial activities, and construction materials.

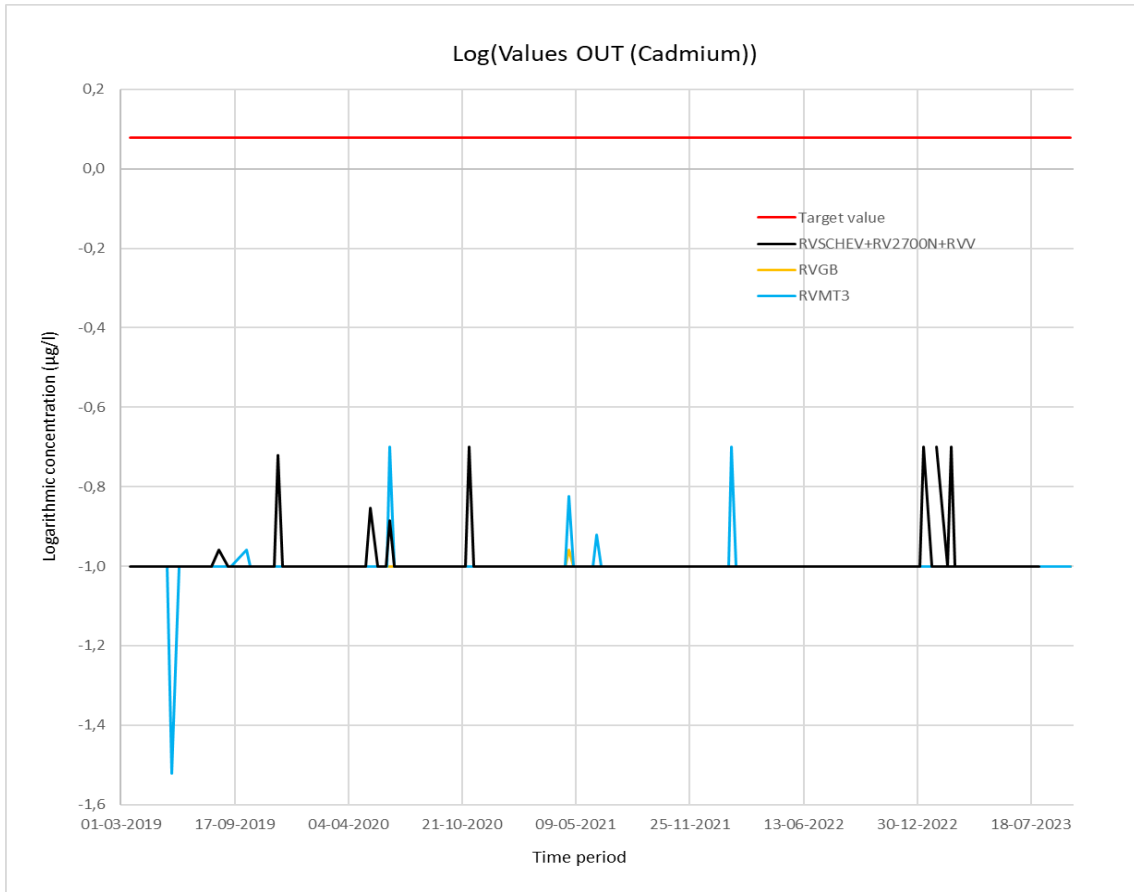


Figure 17. Concentrations of cadmium in effluents after treatment.

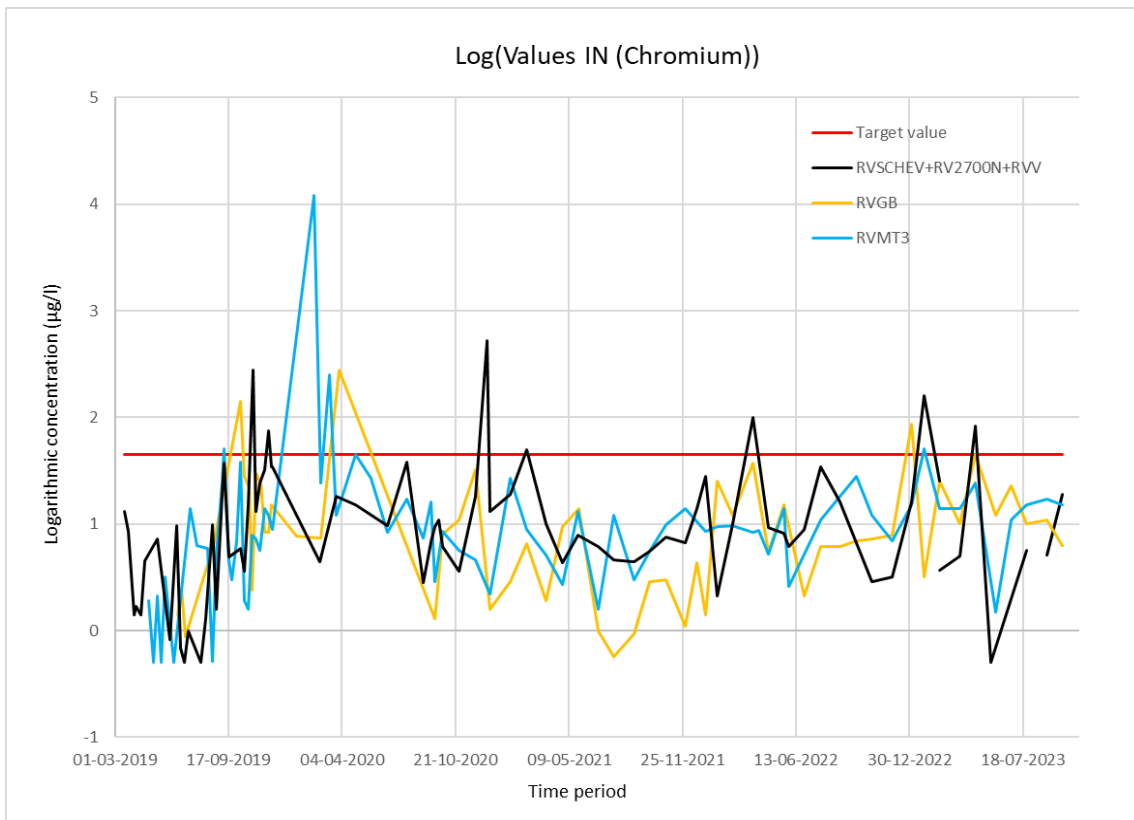


Figure 18. Concentrations of chromium influents before treatment.

In Figure 18, chromium concentration is presented, with the most common and stable form being Cr(III), also known as trivalent chromium (Pettersen, 2008). Water often forms poorly soluble hydroxide compounds such as  $\text{Cr}(\text{OH})_3$ , particularly at neutral pH. Under acidic conditions, Cr(III) is more soluble, whereas, in basic conditions, it can form  $\text{Cr}(\text{OH})_4^-$ . Due to its low solubility, Cr(III) typically remains in the soil, bound to particles, and disperses minimally. Additionally, the toxic Cr(VI) is often converted to the less toxic form Cr(III) in the presence of organic materials or reducing agents like Fe(II). Cr(III) is not soluble at high pH values, which is evident when comparing Figure 18 with Figure 22.

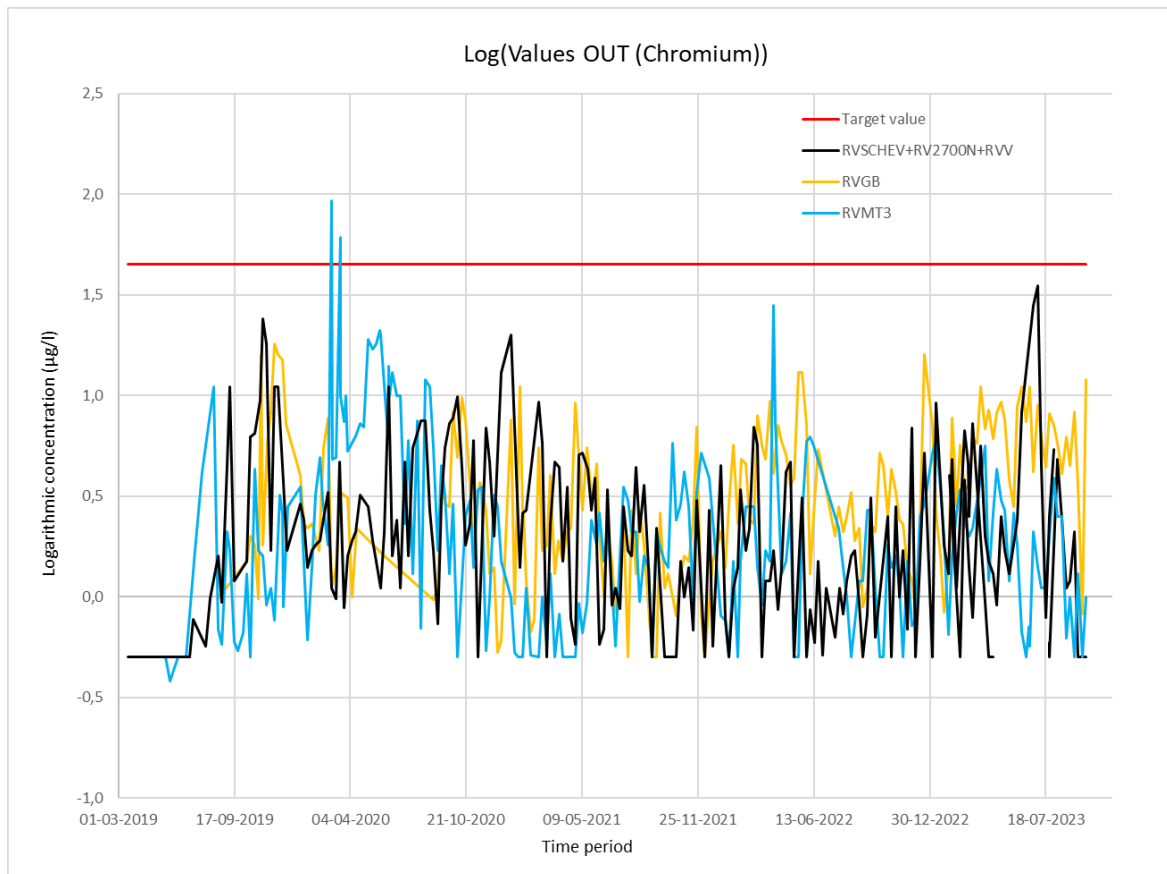


Figure 19. Concentrations of chromium in effluents after treatment.

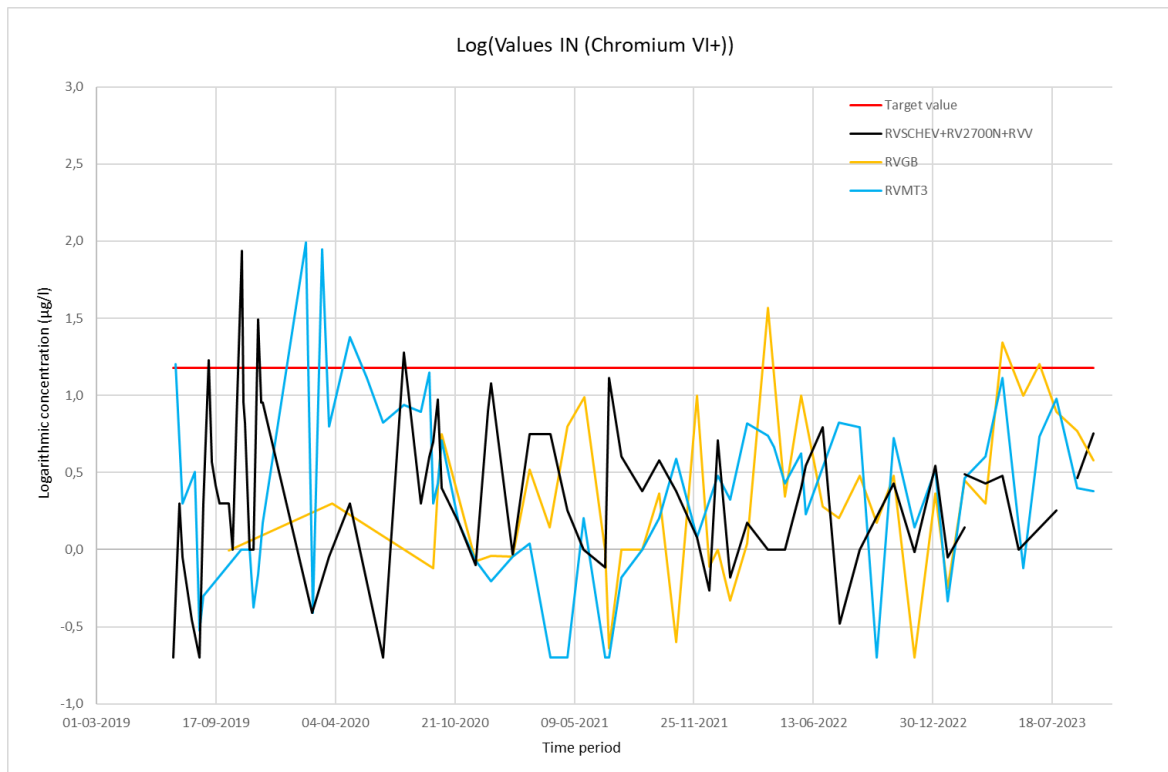


Figure 20. Concentrations of chromium VI+ in influents before treatment.

Cr(VI) or hexavalent chromium, is significantly more soluble and toxic than Cr(III). In aqueous solutions, Cr(VI) exists as chromate ions ( $\text{CrO}_4^{2-}$ ) at higher pH and as dichromate ions ( $\text{Cr}_2\text{O}_7^{2-}$ ) in acidic environments. These forms are easily soluble and can spread readily in both acidic and alkaline conditions when the pH is above 7, which increases the risk of environmental damage because Cr(VI) can be transported over long distances and is more toxic. Reducing Cr(VI) to Cr(III) is an important process for mitigating its environmental risks.

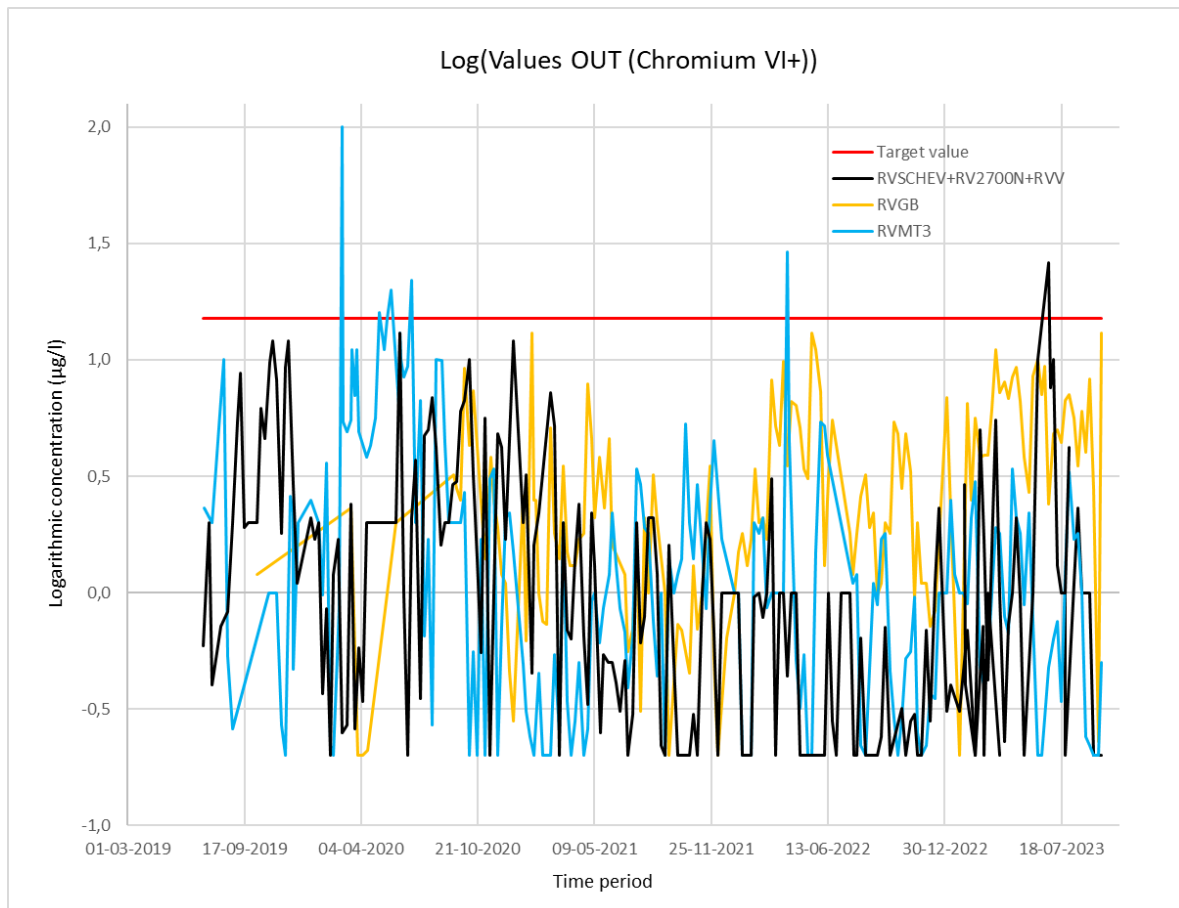


Figure 21. Concentrations of chromium VI in effluents after treatment.

After treatment, Figure 21 shows that the concentrations of Cr(VI) in the effluents exceed the target limit at certain times. Cr(VI) is more harmful than Cr(III) (Pettersson, 2008), and exposure to high levels of Cr(VI) can irritate the respiratory system and increase the risk of lung cancer with prolonged contact. At extremely high doses, it can also cause severe kidney and liver damage and be life-threatening. Cr(III) is generally less irritating but can cause throat issues at high intakes and may sometimes trigger allergies.

Plants use chromium as hexavalent chromium in the environment, while animals bind metals to proteins for storage (Pettersson, 2008). Cr(VI) can pass through cell membranes and be converted to Cr(III) within cells. In aquatic environments, chromium's toxicity varies depending on the species, size, and water quality. Fish tend to be more resistant to chromium, accumulating it primarily in the liver, with concentrations influenced by pH and body length.

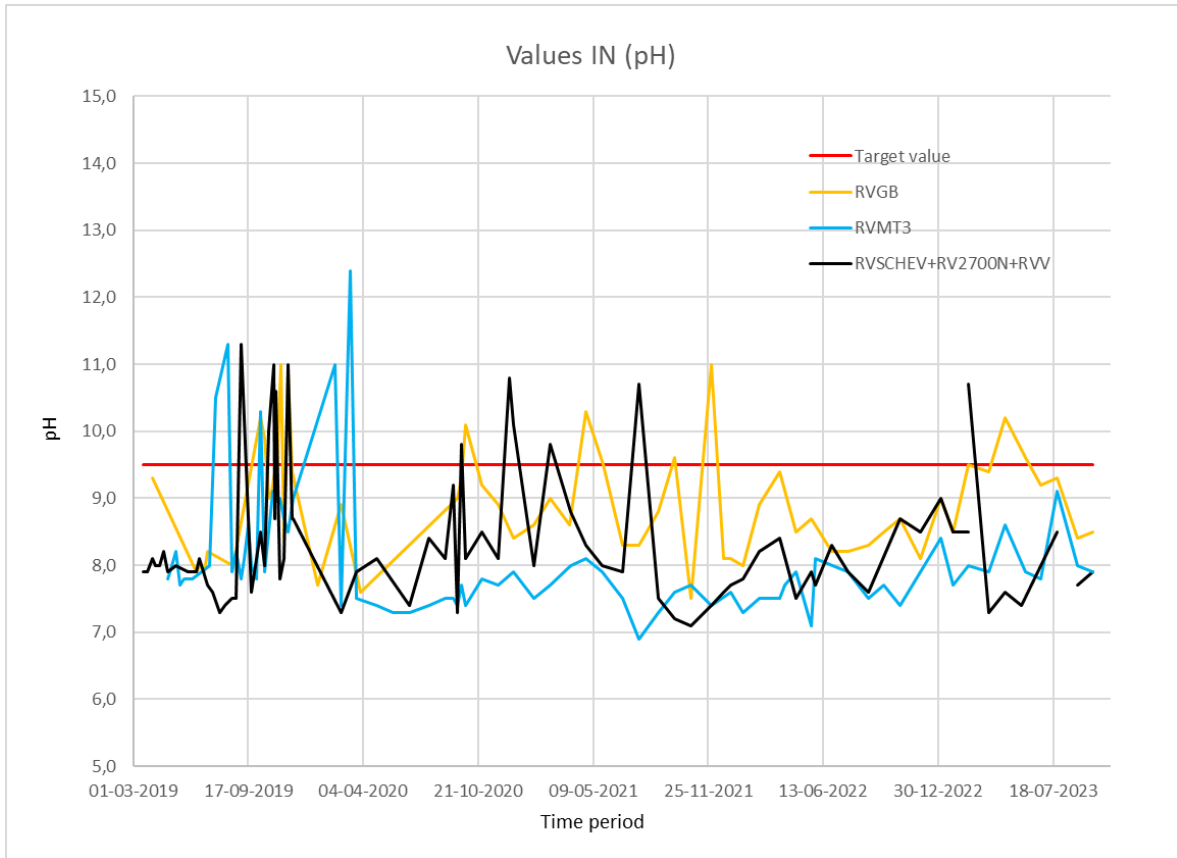


Figure 22. Values of pH in influents before treatment.

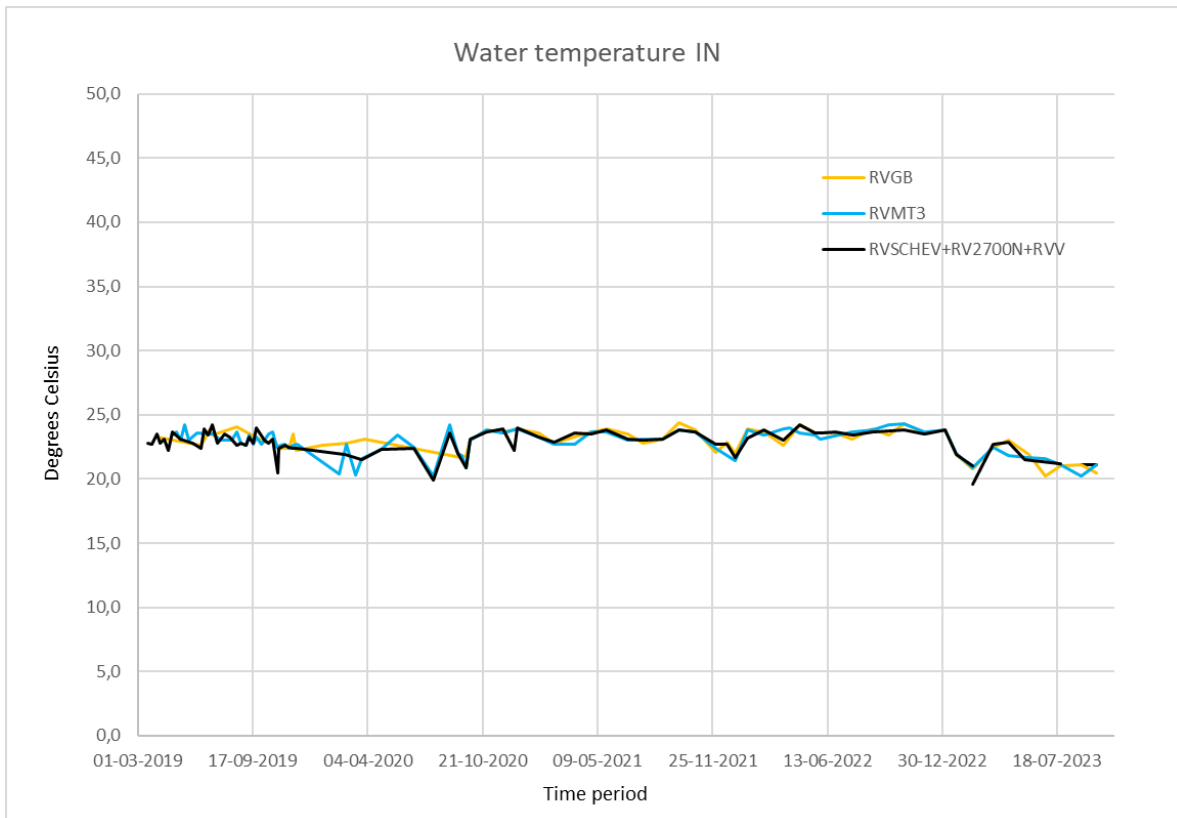


Figure 23. Temperature for influent water before treatment.

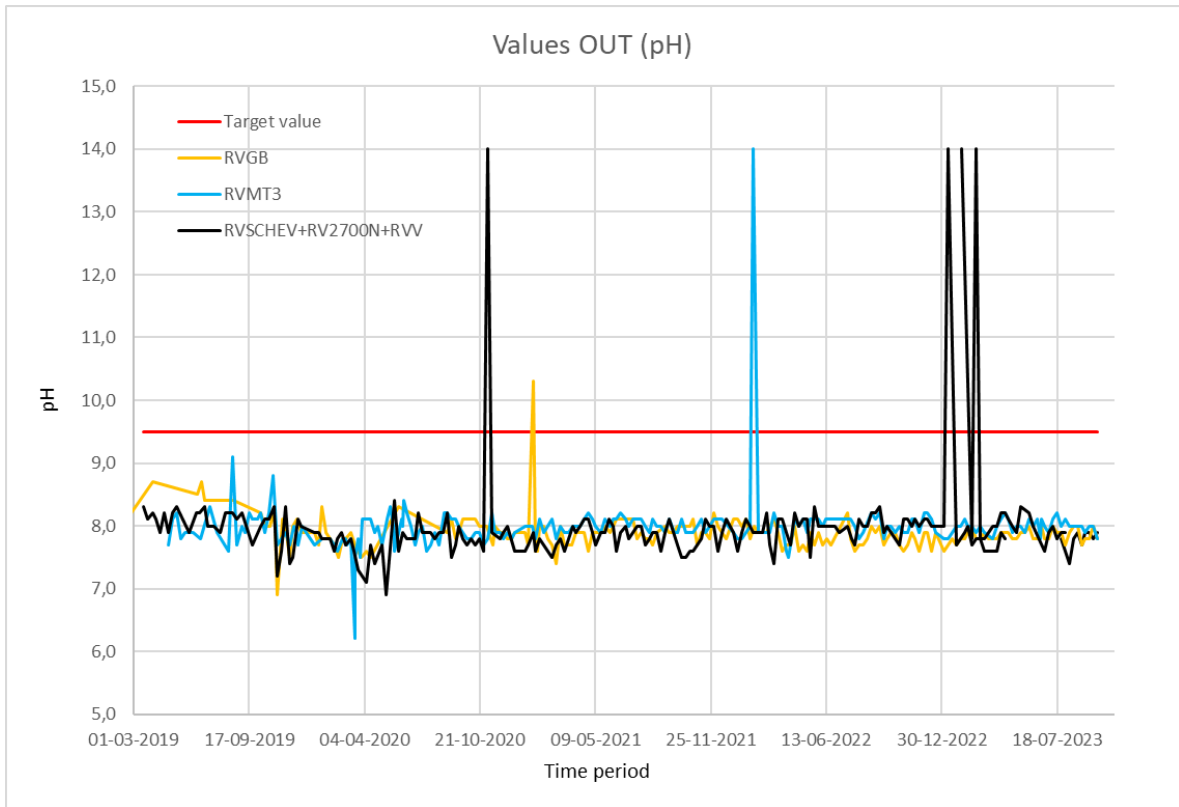


Figure 24. Values of pH in effluents after treatment.

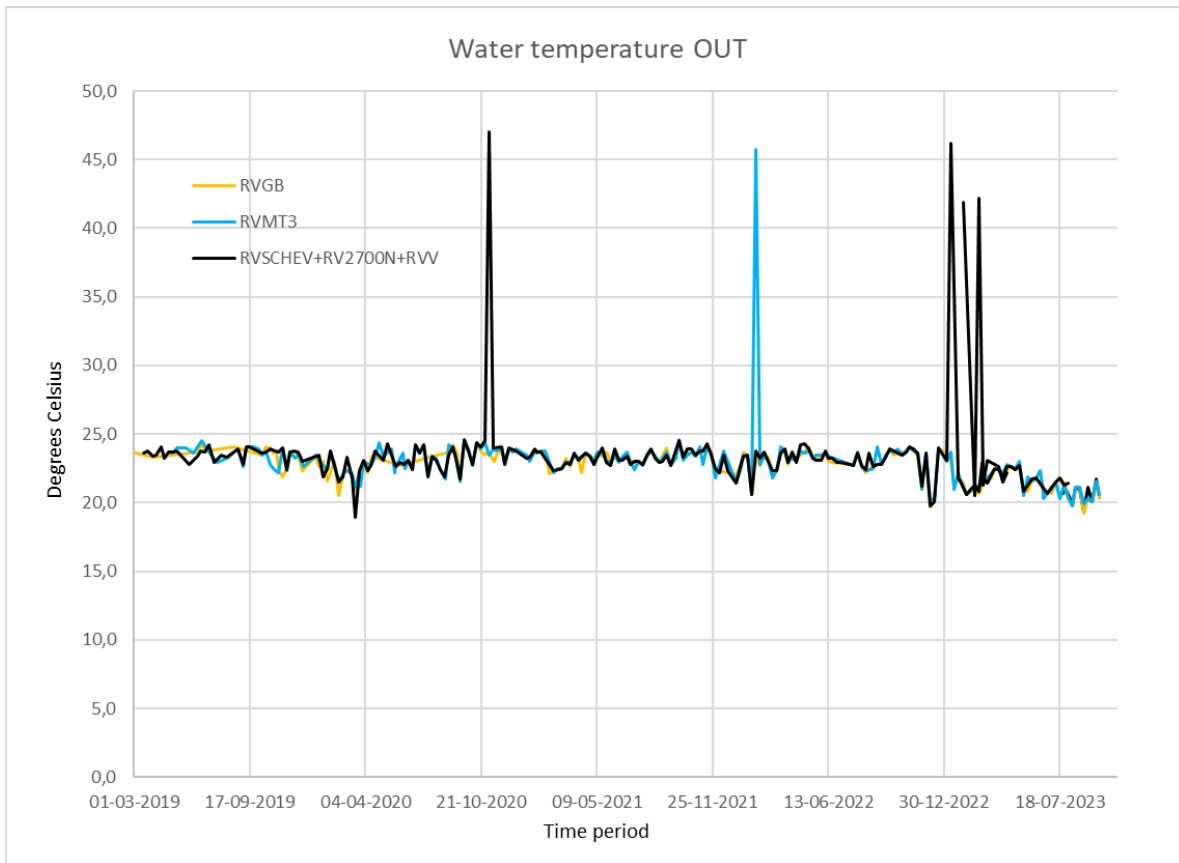


Figure 25. Temperature for water in effluent after treatment.

Figures 23 and 25 illustrate that the water temperatures remain relatively stable between the treatment plant's inlet and outlet, with occasional deviations at specific sampling points. Notably, when pH values fluctuate, as shown in Figure 24, there are corresponding increases in water temperature in Figure 25, indicating a direct relationship between pH and water temperature. This suggests that temperature may significantly influence pH levels. Additionally, changes in water temperature can alter the chemical composition of the water (Bergström, 2016), as increased temperatures enhance chemical reactivity, often resulting in higher electrical conductivity.

Understanding why the temperature of the treated water from the water treatment plant increases significantly at certain times (see Figure 25) is complex and may require speculation. Potential errors in the measuring instruments can affect the results, complicating the assessment. It is also important to note the elevated pH levels observed in conjunction with the temperature increases (see Figure 24), which suggests that biological processes may play a crucial role. An increased amount of organic material may have led to more intense degradation, which in turn could explain both the higher temperature and the elevated pH (Alisawi, 2020).

### 5.1.1 Target Values and Their Significance for Various Parameters

By carefully examining the tables in chapter 4.1 of the report, one can see that almost all the contaminated or, in other words, the untreated water contains very high concentrations of the parameters measured before it passes through the treatment plants. These results highlight the importance of the treatment plants, especially for the West link project. The construction of the West link is conducted in the city center, i.e., where old railway tracks have left significant amounts of oil and tar since the turn of the century. To achieve the target values for water quality, thorough treatment of the excess water is required, as indicated in the results.

Generally, the treatment process worked well, but there are occasions when the concentrations in the influent parameters that enter the treatment plants are higher than the concentrations that are released via the effluent from the treatment plants. A representative from SHS explains that this is because contaminated water is formed when rainwater or groundwater interact with contaminated clay in the excavations and is then pumped into the pipeline system. When measuring IN and OUT parameters simultaneously, one must consider the delay in the treatment system, meaning that the water pumped in takes several hours to pass through the treatment plant before it comes out clean on the other side.

Another significant point to consider is that the excess water comes from different parts of the construction project with varying levels of contamination, as explained by the representative from SHS. This means the excess water from one excavation can be much cleaner than from another with a more contaminated site. Thus, lack of maintenance, such as not refilling treatment chemicals or replacing pH adjustment agents, leads to some of the

parameters exceeding the target values, which has negatively impacted the efficiency of the treatment technology.

Handling values below the detection limit was a significant challenge for this study. Values where concentrations are below the detection limit have been set to the detection limit to create a margin in the analysis of discharged concentrations, treatment plant efficiency, and the amount released into the Göta river. Treating values below the detection limit as equal to the limit can be practical to avoid undue focus on minor differences. This approach makes us safer, even though it means overestimating the effect.

Regarding environmental consequences, this work provides an overview of the emissions on the Göta river rather than a detailed analysis, as the latter would be too demanding. As for example nitrogen, was not included in the results because the naturally high levels in the soil already represent a significant burden. According to the interview with Representative S, excess water with a high nitrogen level due to explosives often requires biological treatment. Since this is difficult to carry on-site, the water is directed to Gryaab, whereas excess water with less nitrogen is directly treated within the treatment plants in ‘Centralen’.

## 5.2 Removal Efficiency of the Water Treatment Plant

This chapter presents the efficiency assessment of the five treatment plants. It is noteworthy that RVV and RV2700N were operational solely in 2023. The results indicate that the treatment plants maintain a relatively high-efficiency level. However, the findings also reveal notably low efficiency and, in some cases, even negative efficiency.

The Tables 6 – 10, show the average concentrations for each parameter from 2019 to 2023, covering both the inflow and outflow water at the treatment plant. Using these values, the efficiency of the treatment process has been calculated. The results indicate that the efficiency varies significantly, ranging from negative to high values. This variation is explained in more detail in the chapter that follows.

*Table 6. The average concentrations for RVGB, both inflow and outflow are rounded to three significant digits. Additionally, the treatment plants' efficiency for each parameter has been calculated. Missing values are denoted by the sign (-).*

		<b>RVGB</b>				
<b>Parameters</b>		<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>	<b>2023</b>
<b>Suspended solids (mg/l)</b>	Inflow mean	104	1650	64.2	201	716
	Outflow mean	12.3	15.3	7.97	12.0	8.70
	<b>Efficiency (%)</b>	<b>88.2 %</b>	<b>99.1 %</b>	<b>87.6 %</b>	<b>94 %</b>	<b>98.8 %</b>
<b>Oil index (mg/l)</b>	Inflow mean	0.150	0.490	0.360	0.250	0.580

	Outflow mean	0.110	0.130	0.110	0.100	0.120
	<b>Efficiency (%)</b>	<b>26.7 %</b>	<b>73.5 %</b>	<b>69.4 %</b>	<b>60 %</b>	<b>79.3 %</b>
<b>Arsenic (µg/l)</b>	Inflow mean	6.68	12.6	1.05	3.54	5.46
	Outflow mean	4.75	1.07	0.580	1.18	1.13
	<b>Efficiency (%)</b>	<b>28.9 %</b>	<b>91.5 %</b>	<b>44.8 %</b>	<b>66.8 %</b>	<b>79.3 %</b>
<b>Lead (µg/l)</b>	Inflow mean	78.6	75.4	0.820	11.3	23.9
	Outflow mean	1.12	1.83	0.460	0.610	0.760
	<b>Efficiency (%)</b>	<b>98.6 %</b>	<b>97.6 %</b>	<b>43.9 %</b>	<b>94.6 %</b>	<b>96.8 %</b>
<b>Cadmium (µg/l)</b>	Inflow mean	0.270	0.350	0.100	0.120	0.180
	Outflow mean	0.050	0.100	0.090	0.090	0.100
	<b>Efficiency (%)</b>	<b>81.5 %</b>	<b>71.4 %</b>	<b>10 %</b>	<b>25 %</b>	<b>44.4 %</b>
<b>Copper (µg/l)</b>	Inflow mean	34.0	58.8	9.42	18.8	33.0
	Outflow mean	6.93	5.13	4.27	4.32	5.97
	<b>Efficiency (%)</b>	<b>79.6 %</b>	<b>91.3 %</b>	<b>54.7 %</b>	<b>77 %</b>	<b>81.9 %</b>
<b>Chromium (µg/l)</b>	Inflow mean	21.7	39.1	4.04	11.0	23.2
	Outflow mean	5.23	3.78	2.41	4.19	7.04
	<b>Efficiency (%)</b>	<b>75.9 %</b>	<b>90.3 %</b>	<b>40.3 %</b>	<b>61.9 %</b>	<b>69.6 %</b>
<b>Chromium VI (µg/l)</b>	Inflow mean	0.990	2.10	2.93	5.25	7.32
	Outflow mean	1.20	2.81	1.87	3.45	6.67
	<b>Efficiency (%)</b>	<b>- 21.2 %</b>	<b>- 33.8 %</b>	<b>36.2 %</b>	<b>34.3 %</b>	<b>8.9 %</b>
<b>Mercury (µg/l)</b>	Inflow mean	-	$3.40 \cdot 10^{-2}$	$5.00 \cdot 10^{-3}$	$8.30 \cdot 10^{-3}$	$1.70 \cdot 10^{-2}$
	Outflow mean	-	$5.00 \cdot 10^{-3}$	$4.60 \cdot 10^{-3}$	$4.60 \cdot 10^{-3}$	$6.60 \cdot 10^{-3}$
	<b>Efficiency (%)</b>	-	<b>85.3 %</b>	<b>8 %</b>	<b>44.6 %</b>	<b>61.2 %</b>
<b>Nickel (µg/l)</b>	Inflow mean	11.8	32.3	6.55	7.61	13.6
	Outflow mean	5.46	4.44	3.81	3.26	2.50
	<b>Efficiency (%)</b>	<b>53.7 %</b>	<b>86.3 %</b>	<b>41.8 %</b>	<b>57.2 %</b>	<b>81.7 %</b>
<b>Zinc (µg/l)</b>	Inflow mean	81.9	237	10.4	43.6	145
	Outflow mean	13.13	14.5	10.6	11.8	20.1
	<b>Efficiency (%)</b>	<b>84 %</b>	<b>93.9 %</b>	<b>- 1.2 %</b>	<b>73 %</b>	<b>86.1 %</b>

Table 7. The average concentrations for RVMT3, both inflow and outflow are rounded to three significant digits. Additionally, the efficiency of the treatment plants for each parameter has been calculated.

<b>RVMT3</b>						
<b>Parameters</b>		<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>	<b>2023</b>
<b>Suspended solids (mg/l)</b>	Inflow mean	227	995	175	94.2	272
	Outflow mean	9.96	14.4	6.69	5.32	6.75
	<b>Efficiency (%)</b>	<b>95.6 %</b>	<b>94.5 %</b>	<b>96.2 %</b>	<b>94.3 %</b>	<b>97.5 %</b>
<b>Oil index (mg/l)</b>	Inflow mean	0.160	0.300	0.430	0.190	0.930
	Outflow mean	0.110	0.100	0.100	0.100	0.100
	<b>Efficiency (%)</b>	<b>31.2 %</b>	<b>66.7 %</b>	<b>76.7 %</b>	<b>47.4 %</b>	<b>89.2 %</b>
<b>Arsenic (µg/l)</b>	Inflow mean	5.66	143	4.63	3.42	6.18
	Outflow mean	2.25	2.31	1.51	1.29	1.49
	<b>Efficiency (%)</b>	<b>60.2 %</b>	<b>98.4 %</b>	<b>67.4 %</b>	<b>62.3 %</b>	<b>75.9 %</b>
<b>Lead (µg/l)</b>	Inflow mean	21.1	264	24.6	8.70	34.4
	Outflow mean	0.950	0.700	0.680	0.730	0.830
	<b>Efficiency (%)</b>	<b>95.5 %</b>	<b>99.7 %</b>	<b>97.2 %</b>	<b>91.6 %</b>	<b>97.6 %</b>
<b>Cadmium (µg/l)</b>	Inflow mean	0.170	1.18	0.150	0.110	0.180
	Outflow mean	0.090	0.090	0.110	0.100	0.100
	<b>Efficiency (%)</b>	<b>47.1 %</b>	<b>92.4 %</b>	<b>26.7 %</b>	<b>9.1 %</b>	<b>44.4 %</b>
<b>Copper (µg/l)</b>	Inflow mean	26.2	2810	27.1	21.9	37.7
	Outflow mean	6.28	6.21	4.66	5.14	5.80
	<b>Efficiency (%)</b>	<b>76.1 %</b>	<b>99.8 %</b>	<b>82.8 %</b>	<b>76.5 %</b>	<b>84.6 %</b>
<b>Chromium (µg/l)</b>	Inflow mean	9.07	777	9.33	11.0	17.8
	Outflow mean	1.68	4.76	1.80	2.35	2.67
	<b>Efficiency (%)</b>	<b>81.5 %</b>	<b>99.4 %</b>	<b>80.7 %</b>	<b>78.6 %</b>	<b>85 %</b>
<b>Chromium VI+ (µg/l)</b>	Inflow mean	2.51	17.5	1.06	3.86	4.42
	Outflow mean	1.92	3.82	1.15	1.49	1.35
	<b>Efficiency (%)</b>	<b>23.5 %</b>	<b>78.2 %</b>	<b>- 8.5 %</b>	<b>61.4 %</b>	<b>69.5 %</b>
<b>Mercury (µg/l)</b>	Inflow mean	$8.20 \cdot 10^{-5}$	$7.30 \cdot 10^{-3}$	$4.80 \cdot 10^{-2}$	$1.00 \cdot 10^{-2}$	$1.40 \cdot 10^{-1}$
	Outflow mean	$3.80 \cdot 10^{-5}$	$4.50 \cdot 10^{-3}$	$4.60 \cdot 10^{-3}$	$5.00 \cdot 10^{-3}$	$5.00 \cdot 10^{-3}$
	<b>Efficiency (%)</b>	<b>53.7 %</b>	<b>38.4 %</b>	<b>90.4 %</b>	<b>50 %</b>	<b>96.4 %</b>

<b>Nickel</b> (µg/l)	Inflow mean	18.0	307	18.4	8.23	11.0
	Outflow mean	8.93	5.58	7.92	4.09	2.43
	<b>Efficiency (%)</b>	<b>50.3 %</b>	<b>98.2 %</b>	<b>56.9 %</b>	<b>50.3 %</b>	<b>77.8 %</b>
<b>Zinc</b> (µg/l)	Inflow mean	64.1	3540	73.2	73.8	186
	Outflow mean	13.3	16.3	16.0	15.2	32.6
	<b>Efficiency (%)</b>	<b>79.3 %</b>	<b>99.5 %</b>	<b>78.1 %</b>	<b>79.4 %</b>	<b>82.5 %</b>

Table 8. The average concentrations for RVS CHEV, both inflow and outflow are rounded to three significant digits. Additionally, the efficiency of the treatment plants for each parameter has been calculated. Missing values are denoted by the sign (-).

<b>RVS CHEV</b>						
<b>Parameters</b>		<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>	<b>2023</b>
<b>Suspended solids</b> (mg/l)	Inflow mean	1590	4830	277	308	1910
	Outflow mean	5.49	10.9	14.7	23.9	27.2
	<b>Efficiency (%)</b>	<b>99.8 %</b>	<b>99.8 %</b>	<b>94.7 %</b>	<b>92.2 %</b>	<b>98.6 %</b>
<b>Oil index</b> (mg/l)	Inflow mean	0.200	1.17	0.360	0.300	0.600
	Outflow mean	0.100	0.100	0.100	0.130	0.130
	<b>Efficiency (%)</b>	<b>50 %</b>	<b>91.4 %</b>	<b>0.7 %</b>	<b>56.7 %</b>	<b>78.3 %</b>
<b>Arsenic</b> (µg/l)	Inflow mean	7.59	23.0	4.88	5.98	16.5
	Outflow mean	1.02	2.88	1.98	1.70	1.34
	<b>Efficiency (%)</b>	<b>86.6 %</b>	<b>87.5 %</b>	<b>59.4 %</b>	<b>71.6 %</b>	<b>91.9 %</b>
<b>Lead</b> (µg/l)	Inflow mean	63.1	630	14.6	17.9	67.0
	Outflow mean	0.570	0.680	0.860	1.42	1.87
	<b>Efficiency (%)</b>	<b>99.1 %</b>	<b>99.9 %</b>	<b>94.1 %</b>	<b>92.1 %</b>	<b>97.2 %</b>
<b>Cadmium</b> (µg/l)	Inflow mean	0.610	3.33	0.120	0.120	0.320
	Outflow mean	0.090	0.090	0.100	0.100	0.100
	<b>Efficiency (%)</b>	<b>85.2 %</b>	<b>97.3 %</b>	<b>16.7 %</b>	<b>16.7 %</b>	<b>68.7 %</b>
<b>Copper</b> (µg/l)	Inflow mean	57.8	271	22.5	24.9	63.0
	Outflow mean	2.40	4.61	6.22	5.50	4.23
	<b>Efficiency (%)</b>	<b>95.8 %</b>	<b>98.3 %</b>	<b>72.4 %</b>	<b>77.9 %</b>	<b>93.3 %</b>
<b>Chromium</b> (µg/l)	Inflow mean	22.5	48.3	11.7	19.1	67.0

	Outflow mean	3.87	4.32	2.27	2.23	1.57
	<b>Efficiency (%)</b>	<b>82.9 %</b>	<b>91 %</b>	<b>80.5 %</b>	<b>88.3 %</b>	<b>97.7 %</b>
<b>Chromium VI+</b> (µg/l)	Inflow mean	9.26	4.83	3.31	2.21	1.93
	Outflow mean	4.31	3.22	1.09	0.420	0.270
	<b>Efficiency (%)</b>	<b>53.5 %</b>	<b>33.3 %</b>	<b>66.7 %</b>	<b>81 %</b>	<b>86 %</b>
<b>Mercury</b> (µg/l)	Inflow mean	$4.00 \cdot 10^{-4}$	$2.50 \cdot 10^{-1}$	$3.30 \cdot 10^{-2}$	$5.10 \cdot 10^{-2}$	$4.10 \cdot 10^{-1}$
	Outflow mean	$4.00 \cdot 10^{-5}$	$4.00 \cdot 10^{-3}$	$5.00 \cdot 10^{-3}$	$5.30 \cdot 10^{-3}$	$1.40 \cdot 10^{-2}$
	<b>Efficiency (%)</b>	<b>90 %</b>	<b>98.4 %</b>	<b>84.8 %</b>	<b>89.6 %</b>	<b>96.6 %</b>
<b>Nickel</b> (µg/l)	Inflow mean	16.5	44.4	11.7	15.4	48.9
	Outflow mean	1.99	5.67	6.33	4.58	3.30
	<b>Efficiency (%)</b>	<b>87.9 %</b>	<b>87.2 %</b>	<b>46 %</b>	<b>70.3 %</b>	<b>93.3 %</b>
<b>Zinc</b> (µg/l)	Inflow mean	226	612	84.3	97.4	330
	Outflow mean	16.7	13.9	20.8	16.1	29.0
	<b>Efficiency (%)</b>	<b>92.6 %</b>	<b>97.7 %</b>	<b>75.3 %</b>	<b>83.5 %</b>	<b>91.2 %</b>

Table 9. The average concentrations for RVV, both inflow and outflow are rounded to three significant digits. Additionally, the efficiency of the treatment plants for each parameter has been calculated. Missing values are denoted by the sign (-).

		<b>RVV</b>				
<b>Parameters</b>		<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>	<b>2023</b>
<b>Suspended solids</b> (mg/l)	Inflow mean	-	-	-	-	204
	Outflow mean	-	-	-	-	9.10
	<b>Efficiency (%)</b>	-	-	-	-	<b>95.5 %</b>
<b>Oil index</b> (mg/l)	Inflow mean	-	-	-	-	0.160
	Outflow mean	-	-	-	-	0.09
	<b>Efficiency (%)</b>	-	-	-	-	<b>43.8 %</b>
<b>Arsenic</b> (µg/l)	Inflow mean	-	-	-	-	4.87
	Outflow mean	-	-	-	-	1.88
	<b>Efficiency (%)</b>	-	-	-	-	<b>61.4 %</b>
<b>Lead</b> (µg/l)	Inflow mean	-	-	-	-	9.01
	Outflow mean	-	-	-	-	0.430

	<b>Efficiency (%)</b>	-	-	-	-	<b>95.2 %</b>
<b>Cadmium</b> (µg/l)	Inflow mean	-	-	-	-	0.110
	Outflow mean	-	-	-	-	0.080
	<b>Efficiency (%)</b>	-	-	-	-	<b>27.3 %</b>
<b>Copper</b> (µg/l)	Inflow mean	-	-	-	-	28.1
	Outflow mean	-	-	-	-	3.70
	<b>Efficiency (%)</b>	-	-	-	-	<b>86.9 %</b>
<b>Chromium</b> (µg/l)	Inflow mean	-	-	-	-	19.6
	Outflow mean	-	-	-	-	1.90
	<b>Efficiency (%)</b>	-	-	-	-	<b>90.3 %</b>
<b>Chromium VI</b> (µg/l)	Inflow mean	-	-	-	-	2.32
	Outflow mean	-	-	-	-	1.54
	<b>Efficiency (%)</b>	-	-	-	-	<b>33.6 %</b>
<b>Mercury</b> (µg/l)	Inflow mean	-	-	-	-	5.00 •10 <sup>-6</sup>
	Outflow mean	-	-	-	-	0
	<b>Efficiency (%)</b>	-	-	-	-	<b>100 %</b>
<b>Nickel</b> (µg/l)	Inflow mean	-	-	-	-	12.7
	Outflow mean	-	-	-	-	4.50
	<b>Efficiency (%)</b>	-	-	-	-	<b>64.5 %</b>
<b>Zinc</b> (µg/l)	Inflow mean	-	-	-	-	76.0
	Outflow mean	-	-	-	-	14.9
	<b>Efficiency (%)</b>	-	-	-	-	<b>92.6 %</b>

Table 10. The average concentrations for RV2700N, both inflow and outflow are rounded to three significant digits. Additionally, the efficiency of the treatment plants for each parameter has been calculated. Missing values are denoted by the sign (-).

		<b>RV2700N</b>				
<b>Parameters</b>		<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>	<b>2023</b>
<b>Suspended solids</b> (mg/l)	Inflow mean	-	-	-	-	230
	Outflow mean	-	-	-	-	2.70
	<b>Efficiency (%)</b>	-	-	-	-	<b>98.8 %</b>

<b>Oil index (mg/l)</b>	Inflow mean	-	-	-	-	0.190
	Outflow mean	-	-	-	-	0.100
	<b>Efficiency (%)</b>	-	-	-	-	<b>47.4 %</b>
<b>Arsenic (µg/l)</b>	Inflow mean	-	-	-	-	4.90
	Outflow mean	-	-	-	-	0.860
	<b>Efficiency (%)</b>	-	-	-	-	<b>82.4 %</b>
<b>Lead (µg/l)</b>	Inflow mean	-	-	-	-	14.0
	Outflow mean	-	-	-	-	0.500
	<b>Efficiency (%)</b>	-	-	-	-	<b>96.4 %</b>
<b>Cadmium (µg/l)</b>	Inflow mean	-	-	-	-	0.110
	Outflow mean	-	-	-	-	0.100
	<b>Efficiency (%)</b>	-	-	-	-	<b>9.1 %</b>
<b>Copper (µg/l)</b>	Inflow mean	-	-	-	-	30.5
	Outflow mean	-	-	-	-	3.85
	<b>Efficiency (%)</b>	-	-	-	-	<b>87.4 %</b>
<b>Chromium (µg/l)</b>	Inflow mean	-	-	-	-	12.1
	Outflow mean	-	-	-	-	0.850
	<b>Efficiency (%)</b>	-	-	-	-	<b>92.9 %</b>
<b>Chromium VI (µg/l)</b>	Inflow mean	-	-	-	-	4.30
	Outflow mean	-	-	-	-	0.60
	<b>Efficiency (%)</b>	-	-	-	-	<b>86 %</b>
<b>Mercury (µg/l)</b>	Inflow mean	-	-	-	-	$3.00 \cdot 10^{-5}$
	Outflow mean	-	-	-	-	0
	<b>Efficiency (%)</b>	-	-	-	-	<b>100 %</b>
<b>Nickel (µg/l)</b>	Inflow mean	-	-	-	-	16.0
	Outflow mean	-	-	-	-	4.55
	<b>Efficiency (%)</b>	-	-	-	-	<b>71.6 %</b>
<b>Zinc (µg/l)</b>	Inflow mean	-	-	-	-	102
	Outflow mean	-	-	-	-	12.5
	<b>Efficiency (%)</b>	-	-	-	-	<b>87.7 %</b>

### 5.2.1 Importance of the Efficiency of the Treatment Plants

The treatment plants that have been operational for most of the project's duration have demonstrated high removal efficiencies, which is crucial given the stringent environmental regulations imposed on companies engaged in hazardous activities, as noted by the NCC representative. By calculating the average of all percentage values generated for the pollutants discussed in section 5.2, it is determined that the removal efficiency for the treatment of the tunnelling water is 72.5%.

However, it is important to note that among these percentage values (see Tables 6–10), several low and even negative values are present. As previously explained, when measuring the IN and OUT parameters, one must consider the delay inherent in the treatment system. This delay means that the water pumped takes several hours to pass through the treatment plant before being released into the effluent, as highlighted by the SHS representatives. Continuous sampling leads to a discrepancy between the effluents and the influents, resulting in errors since the concentrations for the water do not align accurately. Consequently, treated water may have a higher concentration of a particular substance than the contaminated water entering the system. Therefore, it becomes essential to focus on average values over time rather than relying solely on individual measurements.

In addition to this, Tables 6–10 reveal a trend concerning substances such as Cr(VI), oil, and cadmium, which pose particular challenges due to their lower purification efficiency. The difficulty in separating oil from water during treatment can be attributed to several factors, one of which is the formation of emulsions (Bhushan, 2019). Emulsions are mixtures of two liquids that normally do not blend well, and over time, these two phases become increasingly difficult to separate. Although chemicals are available to facilitate the separation of oil and water, their use is generally not recommended due to their toxicity and poor biodegradability.

Another significant challenge arises with hexavalent chromium Cr(VI), which forms when trivalent chromium Cr(III) is oxidised under certain natural conditions, thereby posing a substantial environmental risk. According to Apte, Tare, and Bose (2005), this transformation occurs particularly in the presence of oxygen and manganese oxides, influenced by factors such as pH levels and the concentration of dissolved Cr(III). Cr(VI) is a highly toxic compound associated with cancer risks and high mobility in aquatic environments, making its management particularly challenging (Liu & Yu, 2021). Additionally, the high solubility of Cr(VI) in water complicates its removal through conventional methods like precipitation, adsorption, and flocculation, as these techniques often prove ineffective due to Cr(VI)'s inability to form solid particles that can easily precipitate or aggregate. As a result, more advanced techniques are required to reduce its toxicity and solubility. In contrast, cadmium, a heavy metal highly toxic to humans, necessitates effective removal methods (Pyrzynska, 2019). The low efficiency in removing cadmium in water treatment plants can partly be attributed to its already low concentration before entering the treatment process.

To better understand these challenges, Figure 3 illustrates a detailed plan of the entire treatment system, highlighting a feature known as the recirculation pipeline. According to the SHS representative, this pipeline is designed to pump back treated water that fails to meet quality requirements. If, during any sampling occasion, the concentration of a substance is found to be exceptionally high, it is likely that this water had to pass through the recirculation pipeline for additional treatment, an aspect that may not have been captured in the Excel file. Consequently, the efficiency of the treatment plants may not significantly impact whether the treatment goals are achieved.

Analysing the diagrams from section 5.1 reveals a clear trend, indicating that the concentrations of the various parameters consistently remain below the target value. While there may be occasional deviations in specific values, this does not necessarily imply that these values are discharged into the Göta river. Rather, it suggests the possibility that they are diverted into the recirculation pipeline for further treatment.

### 5.3 Amounts of Metals Emitted to the Göta River

The mass of metals discharged from the central unit is very small compared to mass load of the metals in the Göta river water at the treated water effluent points at Stenpiren and Alelyckan. Additionally, only the metals described below could be compared, not all of them, because these were the only values available for comparison from the Excel files downloaded from GRWCA and those received from STA. It is also important to note that there was no data available for the effluent at Stenpiren between 2019 and 2020, and some data is missing from January to June in 2021.

#### 5.3.1 Centralen

At 'Centralen', results consistently indicate a clear reduction in the concentration of all parameters after treatment. This reduction applies across all years from 2019 to 2022, showing that lower amounts of substances such as arsenic, lead, cadmium, copper, chromium, mercury, nickel, and zinc are discharged into the Göta River compared to untreated water. This outcome aligns with the expected effects of the treatment process.

Table 11. Average concentrations for all parameters between 2019 and 2022 in Centralen, along with the average flow from the three water treatment plants active, enabling the calculation of the corresponding mass in kg/year. Additionally, all values are rounded to three significant digits.

<b>Centralen before treatment</b>					
<b>Parameters</b>		<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>
<b>Arsenic</b> (µg/l)	Concentration (µg/l)	6.73	70.0	3.49	4.29
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>0.727</b>	<b>7.56</b>	<b>0.377</b>	<b>0.463</b>
<b>Lead</b> (µg/l)	Concentration (µg/l)	51.2	350.0	13.0	12.5
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>5.53</b>	<b>37.8</b>	<b>1.40</b>	<b>1.35</b>
<b>Cadmium</b> (µg/l)	Concentration (µg/l)	0.404	1.80	0.125	0.116
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>4.37 • 10<sup>-2</sup></b>	<b>0.195</b>	<b>1.35 • 10<sup>-2</sup></b>	<b>1.25 • 10<sup>-2</sup></b>
<b>Copper</b> (µg/l)	Concentration (µg/l)	42.0	1260	19.4	21.8
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>4.54</b>	<b>136.0</b>	<b>2.10</b>	<b>2.36</b>
<b>Chromium</b> (µg/l)	Concentration (µg/l)	17.5	345.0	8.32	13.6
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>1.89</b>	<b>37.3</b>	<b>0.900</b>	<b>1.47</b>
<b>Mercury</b> (µg/l)	Concentration (µg/l)	2.41 • 10 <sup>-4</sup>	0.103	2.81 • 10 <sup>-2</sup>	2.26 • 10 <sup>-2</sup>
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>2.60 • 10<sup>-5</sup></b>	<b>1.11 • 10<sup>-2</sup></b>	<b>3.03 • 10<sup>-3</sup></b>	<b>2.44 • 10<sup>-3</sup></b>
<b>Nickel</b> (µg/l)	Concentration (µg/l)	16.0	149.0	12.0	10.4
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>1.73</b>	<b>16.1</b>	<b>1.30</b>	<b>1.12</b>
<b>Zinc</b> (µg/l)	Concentration (µg/l)	140.0	1730	55.5	71.7
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>15.1</b>	<b>187.0</b>	<b>6.00</b>	<b>7.75</b>

Table 12. Average concentrations for all parameters between 2019 and 2022 in Centralen, along with the average flow from the three water treatment plants active, enabling the calculation of the corresponding mass in kg/year. Additionally, all values are rounded to three significant digits.

<b>Centralen after treatment</b>					
<b>Parameters</b>		<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>
<b>Arsenic</b> (µg/l)	Concentration (µg/l)	2.34	2.23	1.35	1.39
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>0.253</b>	<b>0.241</b>	<b>0.146</b>	<b>0.150</b>
<b>Lead</b> (µg/l)	Concentration (µg/l)	0.820	0.954	0.668	0.917
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>8.86 • 10<sup>-2</sup></b>	<b>0.103</b>	<b>7.21 • 10<sup>-2</sup></b>	<b>9.91 • 10<sup>-2</sup></b>
<b>Cadmium</b> (µg/l)	Concentration (µg/l)	0.082	0.090	0.099	0.098
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>8.86 • 10<sup>-3</sup></b>	<b>9.72 • 10<sup>-3</sup></b>	<b>1.07 • 10<sup>-2</sup></b>	<b>1.06 • 10<sup>-2</sup></b>
<b>Copper</b> (µg/l)	Concentration (µg/l)	4.70	5.39	5.06	4.99
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>0.508</b>	<b>0.582</b>	<b>0.547</b>	<b>0.539</b>
<b>Chromium</b> (µg/l)	Concentration (µg/l)	3.35	4.38	2.17	2.91
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>0.362</b>	<b>0.473</b>	<b>0.234</b>	<b>0.314</b>
<b>Mercury</b> (µg/l)	Concentration (µg/l)	3.30 • 10 <sup>-5</sup>	3.94 • 10 <sup>-3</sup>	4.97 • 10 <sup>-3</sup>	4.95 • 10 <sup>-3</sup>
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>3.57 • 10<sup>-6</sup></b>	<b>4.26 • 10<sup>-4</sup></b>	<b>5.37 • 10<sup>-4</sup></b>	<b>5.35 • 10<sup>-4</sup></b>
<b>Nickel</b> (µg/l)	Concentration (µg/l)	5.13	5.35	5.97	3.98
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>0.554</b>	<b>0.578</b>	<b>0.645</b>	<b>0.430</b>
<b>Zinc</b> (µg/l)	Concentration (µg/l)	14.8	15.0	15.8	14.4
	Water flow (m <sup>3</sup> /s)	108 000	108 000	108 000	108 000
	<b>Mass</b> (kg/y)	<b>1.60</b>	<b>1.62</b>	<b>1.71</b>	<b>1.56</b>

### 5.3.2 Recipients in the Göta River

When comparing the recipients, the differences are not particularly large, except that specific parameters in some years exhibit significantly larger masses. However, the comparison can only be made for 2021 and 2022 as Stenpiren lacks data for 2019 and 2020. The difference in the mass of various parameters can range from a few percent to as much as three times higher. For example, the estimated mass of copper at Alelyckan in 2021 was around 928 tons, while at Stenpiren in the same year, it was estimated to be about 519 tons. In 2022, the difference was even more significant, with the estimated copper mass at Alelyckan being 904 tons compared to Stenpiren, where it was estimated at around 249 tons. The largest mass recorded was for nickel in 2022 near Stenpiren, where it was estimated to be around 1025 tons, while the most negligible estimated mass was for mercury, estimated at about 0.26 tons, also at Stenpiren. The differences in masses can be attributed to several factors. Generally, the estimated mass is often more significant at Stenpiren, which is reasonable considering the significantly higher boat traffic in that area compared to Alelyckan. However, the results also show that specific parameters, such as copper, are more significant at Alelyckan, as previously discussed.

Table 13. Average concentrations for all parameters between 2019 and 2022 in Alelyckan, along with the average flow in Göta river, enabling the calculation of the corresponding mass in kg/year. Additionally, all values are rounded to three significant digits.

<b>Alelyckan</b>					
<b>Parameters</b>		<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>
<b>Arsenic</b> (µg/l)	Concentration (µg/l)	22.9	18.4	23.0	19.2
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	<b>408 000</b>	<b>328 000</b>	<b>410 000</b>	<b>342 000</b>
<b>Lead</b> (µg/l)	Concentration (µg/l)	19.3	15.5	21.3	21.3
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	<b>344 000</b>	<b>276 000</b>	<b>380 000</b>	<b>380 000</b>
<b>Cadmium</b> (µg/l)	Concentration (µg/l)	6.09	6.25	5.83	5.17
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	<b>109 000</b>	<b>111 000</b>	<b>104 000</b>	<b>92 100</b>
<b>Copper</b> (µg/l)	Concentration (µg/l)	53.8	30.2	52.1	50.8
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	<b>959 000</b>	<b>538 000</b>	<b>928 000</b>	<b>904 000</b>
<b>Chromium</b> (µg/l)	Concentration (µg/l)	29.5	27.3	24.8	25.6
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	<b>525 000</b>	<b>486 000</b>	<b>441 000</b>	<b>458 000</b>
<b>Mercury</b> (µg/l)	Concentration (µg/l)	2.70 · 10 <sup>-2</sup>	5.10 · 10 <sup>-2</sup>	4.80 · 10 <sup>-2</sup>	2.80 · 10 <sup>-2</sup>
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	<b>476</b>	<b>903</b>	<b>858</b>	<b>493</b>
<b>Nickel</b> (µg/l)	Concentration (µg/l)	38.6	44.1	41.4	43.3
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	<b>688 000</b>	<b>785 000</b>	<b>738 000</b>	<b>771 000</b>
<b>Zinc</b> (µg/l)	Concentration (µg/l)	16.82	20.83	18.17	18.08
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	<b>300 000</b>	<b>371 000</b>	<b>324 000</b>	<b>322 000</b>

Table 14. Average concentrations for all parameters between 2019 and 2022 in Stenpiren, along with the average flow in Göta river, enabling the calculation of the corresponding mass in kg/year. Additionally, all values are rounded to three significant digits. Missing values are denoted by the sign (-).

		<b>Stenpiren</b>			
<b>Parameters</b>		<b>2019</b>	<b>2020</b>	<b>2021</b>	<b>2022</b>
<b>Arsenic</b> (µg/l)	Concentration (µg/l)	-	-	31.0	36.0
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	-	-	<b>552 000</b>	<b>641 000</b>
<b>Lead</b> (µg/l)	Concentration (µg/l)	-	-	22.0	34.8
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	-	-	<b>392 000</b>	<b>621 000</b>
<b>Cadmium</b> (µg/l)	Concentration (µg/l)	-	-	7.83	9.83
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	-	-	<b>140 000</b>	<b>175 000</b>
<b>Copper</b> (µg/l)	Concentration (µg/l)	-	-	29.2	14.0
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	-	-	<b>520 000</b>	<b>249 000</b>
<b>Chromium</b> (µg/l)	Concentration (µg/l)	-	-	33.5	35.1
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	-	-	<b>597 000</b>	<b>625 000</b>
<b>Mercury</b> (µg/l)	Concentration (µg/l)	-	-	$1.50 \cdot 10^{-2}$	$2.30 \cdot 10^{-2}$
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	-	-	<b>264</b>	<b>413</b>
<b>Nickel</b> (µg/l)	Concentration (µg/l)	-	-	45.0	57.5
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	-	-	<b>802 000</b>	<b>1 020 000</b>
<b>Zinc</b> (µg/l)	Concentration (µg/l)	-	-	39.2	41.3
	Water flow (m <sup>3</sup> /s)	565	565	565	565
	<b>Mass</b> (kg/y)	-	-	<b>698 000</b>	<b>735 000</b>

### 5.3.3 Impact of Centralen's Emissions on Göta River Water Quality

Significant differences can be observed when comparing the emissions in kg/year from the treatment plants with the two recipients, Stenpiren downstream and Alelyckan upstream. The Göta river has an average flow of 565 m<sup>3</sup>/s, which is considerable in terms of the volume of water focused on from the treatment plants. To demonstrate how small the contribution is comparing emissions from the central facility with what is already measured at Stenpiren and Alelyckan. The average for the years 2021 and 2022 is shown in Table 15, as data for both recipients and the central facility during that period was available.

*Table 15. The average value in kilograms for the recipients, Alelyckan and Stenpiren, and the discharge point Centralen. The average value is based on the years 2021 and 2022. Additionally, all values are rounded to three significant digits.*

<b>Parameter</b>	<b>Centralen before treatment (kg/y)</b>	<b>Centralen after treatment (kg/y)</b>	<b>Alelyckan background (kg/y)</b>	<b>Stenpiren background (kg/y)</b>
<b>Arsenic</b>	0.420	0.148	377 000	597 000
<b>Lead</b>	1.38	$8.56 \cdot 10^2$	380 000	506 000
<b>Cadmium</b>	$1.30 \cdot 10^2$	$1.07 \cdot 10^3$	98 000	157 000
<b>Copper</b>	2.23	0.543	916 000	385 000
<b>Chromium</b>	1.19	0.274	449 000	611 000
<b>Mercury</b>	$2.74 \cdot 10^{-3}$	$5.37 \cdot 10^{-4}$	676	339
<b>Nickel</b>	1.21	0.538	754 000	913 000
<b>Zinc</b>	6.86	1.64	323 000	716 000

By placing the quantities side by side, it is evident that emissions from the central facility represent a small proportion compared to the existing contaminant loads in the Göta river water at Alelyckan and Stenpiren. For instance, the central facility's emissions of arsenic account for 0.00039 ‰ of Alelyckan's and 0.00025 ‰ of Stenpiren's estimated annual amounts. Similar results can be anticipated for other metals, as demonstrated by calculating the ratios for nickel, where the central facility's emissions correspond to 0.00071 ‰ of Alelyckan's and 0.00059 ‰ of Stenpiren's. Additionally, when comparing the central facility's emissions before and after treatment, it is observed that all values are lower after treatment than before, indicating a reduction in the concentration of all substances following treatment. These concentrations remain very low and comply with the target values set by the STA.

As discussed during the interviews, the pollutants discharged from the treatment plants do not significantly impact the Göta river, which is relatively small in comparison, as indicated by all representatives. According to the Gryaab representative, the impact of the Västlänken project cannot be directly measured in the river's water flow. However, if no treatment occurred, all emissions would be measurable.

Regarding environmental and ecological impact on the Göta river, the representative from NCC suggests that organisms near the discharge are at risk of accumulating high levels of

pollutants, which accumulate up the food chain as other animals consume them. This pollution primarily affects aquatic life. Additionally, waterworks like Gryaab benefit from cleaner water at the source, reducing the need to handle pollutants later. It is emphasised that limiting pollution at the source is crucial for reducing the need for later treatment.

In addition to environmental damage, emissions also pose health risks. According to the Gryaab representative, these risks do not arise from drinking the water but rather from activities such as swimming in the river or consuming fish with elevated levels of toxic metals. Furthermore, there are swimming bans due to heavy vehicles moving in the river (Jusufi, 2021). However, there are saltwater basins at Lindholmen today that pump water from the bottom of the river, providing uncontaminated saltwater. Therefore, the saltwater in the basin is clean and does not pose health effects in that manner. Jusufi (2021) suggests that swimming in the Göta river can be feasible from a health standpoint, particularly during warmer summers, with up to 75% of the time deemed suitable for swimming. However, during colder periods, the viability decreases.

Apart from environmental and health damages, the SHS representative argues that pollution emissions harm society economically. Just as determining the exact environmental effects of these emissions is difficult, quantifying whether the economic damage is negligible or significant would require considerable time. However, since taxpayer money is used to finance water treatment plant, it entails a cost for society. Everyone who pays taxes contributes to treatment, protecting our biological systems and recipients, leading to a healthy environment and improved public health. Reduced emissions reduce the risk of diseases, decreasing healthcare costs.

Regarding properties along the Göta river, the SHS representative suggests that a single project likely does not affect property values due to the ample water flows in the river. However, deteriorated water or mud emissions that discolor the water can negatively impact property values. If many projects release pollutants over time, it can lead to poor ecological status and negatively affect property values. The NCC representative agrees and suggests that a pleasant and favourable environment along the river is attractive for property values, and cleaner water can increase property value. Cleaner water also reduces unpleasant smells and increases attractiveness for swimming and fishing. Treating water at the source reduces the need for later treatment and filtration, leading to more efficient water management and a cleaner environment.

## 5.4 Results from the Interviewees

In this chapter, the results from four interviews conducted solely for the purpose of Cost-benefit analysis (CBA) regarding the socioeconomic effects of treating excess water during the construction of West link in particular the ‘Centralen’ are presented.

#### 5.4.1 Representative from Gryaab

Representative G from Gryaab mentioned that the STA has obtained environmental permits specifying permissible levels of substances to be discharged into the Göta river, which needs to be fulfilled. This means the STA must adhere to these standards and implement the best available excess water treatment technology. However, Gryaab's assessment, similar to that of West Link (Västlänken), indicates that their activities, including blasting through mountain areas, would not impact water quality according to environmental standards.

Representative G stressed that for Gryaab, treating excess water entails additional costs and work without clear, direct benefit. He assumes this perspective to be valid for Trafikverket despite potential benefits such as avoiding legal conflicts and projecting an environmentally conscious image through the excess water treatment. He added, looking from a holistic picture, if companies conducting environmentally hazardous activities similar to the STA are allowed to discharge untreated excess water into the Göta river, then the levels in the recipient would increase significantly. Thus, it is crucial for the recipient that everyone treats excess water in advance. Otherwise, the environmental quality would deteriorate, making it more challenging to meet ecological standards.

Regarding potential health impacts on the public, Representative G suggested that while the West Link (Västlänken) 's effects on the Göta river might not be directly measurable due to its relatively low flow compared to the river's volume, the absence of water treatment could affect public health, particularly if recreational activities like swimming become more prevalent. He also highlighted the risks of consuming fish from the river due to potential contamination.

In the interview, Representative G also mentioned politicians' plans to establish public swimming areas inside Gothenburg. If swimming were permitted, people in the area would be exposed to the water's quality, further underscoring the importance of water treatment to ensure a healthy and safe environment for residents.

Lastly, representative G from Gryaab suggested that property values along the Göta river might not be affected by the lack of water treatment during the West Link's construction. "I do not believe it would have a significant impact. It is hard to imagine it would affect property prices, partly because it is a short period, i.e., 15 - year and partly because the impact is minor, mainly involving disturbances like noise affecting those living near the construction site in the short term," said the representative.

#### 5.4.2 Representative from the Göta River Water Conservation Association

The interview with representative V from the Göta River Water Conservation Association highlights essential aspects of treating the excess water before it is released into the Göta river.

Representative V emphasises that excess water treatment benefits the STA by removing harmful substances and protects against potential sanctions if permitted levels are exceeded. “It is also clear that there will be consequences if they do not follow the requirements. If they clean the water, the cost is for treatment, but if they do not, the costs would probably be fines for not fulfilling the regulatory standards,” said Representative V.

Regarding public health impacts, Representative V points out that direct health effects on people are unlikely, as drinking water is typically taken upstream. According to representative V, only a few people use the river, although there is some form of swimming in it, even though there is a swimming ban for safety reasons due to marine traffic. However, there is concern for the ecosystem and its inhabitants, especially fish and other aquatic animals that may be affected by the pollutants.

The discussion on environmental impact emphasises that the immediate vicinity around the discharge point may be most vulnerable. Despite the Göta river's large flow, high concentrations can still affect local organisms. The accumulation of toxic substances in the food chain primarily affects animals.

Lastly, Representative V pointed out that property values along the river may not be significantly affected, especially if the emissions are not noticeable or visible. Since most properties are commercial or multi-family buildings, it is mainly property owners who may be affected economically rather than individuals.

#### 5.4.3 Representative From NCC

Representative N from NCC emphasises the importance of treating excess water right from the source. According to representative N, the approach brings immediate benefits like ensuring a consistent supply of clean water for secondary purposes such as irrigation or project reuse, thus reducing the need to constantly seek drinking water for specific needs. However, there are direct costs involved. The STA must shell out between 150,000 to 300,000 Swedish kronor monthly for leasing and maintaining treatment equipment and additional expenses for cleaning the excess water treatment infrastructure, ranging from 100,000 to 200,000 kronor per month. So, the excess water treatment technology sets them back by 250,000 to 500,000 kronor each month.

Representative N insists that attention needs to be paid to public health in general and, more specifically, to the well-being of workers in the area. The representative also pointed out the potential harm caused by untreated water with elevated pH levels, especially for those who interact with the Göta river. Even though swimming in the river is banned, people still come into contact with the water, highlighting the importance of cleaner water for a healthier environment, especially for those nearby.

According to the interviewee, environmental impacts are also significant. Untreated municipal water contains high levels of sediment, metals from old industrial processes, and

oil pollutants, which harm aquatic life and the ecosystem. Treated water, however, creates better conditions for plant and animal life in and around the river.

Representative N notes that properties near treated water sources tend to increase in value because cleaner surroundings are more attractive to residents and workers. Treatment processes also help reduce the unpleasant smells of polluted water, making the area more inviting. Equally, dirty, and contaminated water can decrease property values and diminish the area's appeal.

Representative N sees investing in water treatment upfront as a cost-effective measure in the long run. It helps avoid the need for extensive and expensive treatment efforts later on. Additionally, cleaner water encourages tourism and recreational activities, which bring economic benefits. Neglecting the excess water treatment efforts could result in environmental damage, such as depleted fish populations and decreased tourism due to contaminated beaches.

Lastly, representative N stressed the importance of consistent adherence to treatment standards across all activities to achieve optimal results. Without this uniformity, ensuring enhanced water quality in the river becomes a challenge. As the interviewee puts it, one must keep in mind that different projects have different prerequisites, and almost always, an EIA (Environmental Impact Assessment) is conducted where the natural values present are reviewed and how these should be managed. In nearly all projects, the guidelines for water set by the City of Gothenburg are followed, and this has also been applied to the West Link project and the Environmental Permit we have.

It is essential to consider the recipient; it is paradoxical to impose strict treatment requirements on some while others engaging in environmentally harmful activities are not held to the same standards. To be more precise, not all projects have been conducted as clearly an EIA as the West Link project, which, in practice, can look very different for different projects even though, in theory, they all have similar requirements.

#### 5.4.4 Representative from Swedish Hydro Solutions AB

According to representative S from SHS, water treatment in the West Link project is governed by an environmental ruling based on the EU Water Framework Directive, which prohibits the deterioration of water bodies in Europe. The environmental ruling sets the requirements for the project and ensures that water quality parameters are met. "Each project is assessed based on the sensitivity of the recipient. For example, Göta river and Mölndalsån have different requirements depending on how sensitive they are to pollution," says representative S.

West Link has two permits for discharging water. One permit allows water to be discharged directly to the recipient, meaning the nearest water body. This could be a street drain leading to the excess water network and often directly to Göta river or discharging to a sewer system

like Gryaab, especially during tunnel construction when the water has a high nitrogen content due to explosives. In such cases, biological treatment is needed, which is challenging to carry out on-site.

Representative S notes that the requirements for West Link are generally milder than Gothenburg's municipal requirement standards. For instance, Gothenburg's limit requirement for suspended solids is 25 mg/l, while West Link is allowed 75 mg/l at 'Centralen'. On the other hand, Gryaab has stricter requirements for metal content than required by Gothenburg's municipality, meaning that water with high nitrogen content also needs to meet Gryaab's requirement.

According to Representative S, the STA benefits from the excess water treatment through goodwill for its environmental efforts, compliance with legislation to avoid fines, and the ability to legally carry out the project. Similarly, having treatment facilities is also a cost for the STA, and the economic benefit to them is very minimal if there is any. The STA has contracted NCC and other contractors to construct and treat the excess water. NCC needs financial compensation for its costs, including excess water treatment.

"Having the excess water treatment facilities on the construction site also negatively impacts the construction process, requiring time and resources beyond their primary goal of building a tunnel," said Representative S.

Representative S discussed that even if one could debate the benefits of not treating the excess water by arguing that the effect might be minimal for smaller projects, the problem is the cumulative effect. If one project is not demanded to treat its excess water before discharge, all other projects will do the same, and no one can stop them. Thus, the cumulative discharge over time will significantly damage the recipient. With this in mind, there are no benefits for the Göta river for not treating the excess water before discharge; the same goes for our ecosystems and human health.

According to representative S, contaminated water can cause cancer or other health problems. As explained by representative S, the most significant cost to society and the population is that biological damage to the recipient will occur if the water is not treated. This biological damage includes everything from suspended solids to metals and other harmful substances that end up in the environment and destroy ecosystems, which has an economic value linked to fishing and the health of our fish, which affects the fishing industry.

If contaminated water is discharged, it leads to increased harm to human health. Discharges of heavy metals or chlorinated solvents can cause cancer or other damage, which in turn incurs healthcare costs and reduces economic productivity. Thus, protecting our biological ecosystems significantly benefits swimming, fishing, and human health.

Lastly, representative S stresses that the impact of not treating excess water on property values near Göta river is difficult to quantify for individual projects. Still, cumulative effects

from multiple projects can lead to ecological damage and negatively impact property values, especially in smaller recipients like Mölndalsån.

## 5.5 Cost-Benefit Analysis for Excess Water Treatment Plants

A cost-benefit analysis for excess water treatment plants involves evaluating both the financial and economic costs and the potential benefits they bring to the company and society.

### 5.5.1 Identification and Qualitative Assessment of Benefits and Costs

Identifying benefits and costs and qualitatively assessing them are necessary CBA steps, specifically in economic analysis. This assessment was conducted through semi-structured interviews with open-ended questions sent to the participants a few days before the interview. The results are presented in Table 4.5.1.1 (benefits) and Table 4.5.1.2 (costs), where the scope of each benefit and cost item is described qualitatively in words. The items have also been assessed using the following codes:

- X: The benefit/cost is considered to be of great importance
- (X): The benefit/cost is considered to be of minor importance.
- NR: The benefit/cost is considered to be of no importance or not relevant.

#### 5.5.1.1 Benefits: Qualitative assessment

Table 16: Qualitative assessment of benefits (X indicates significant importance, (X) for minor importance, and NR for not relevant). Sig = Significance, AA = Affected Actors.

<b>Benefit (B)</b>			
	<b>Sig</b>	<b>(Excess water treatment alternative, A1)</b>	<b>AA</b>
<b>B1: Direct</b> benefits	X	<b>Goodwill:</b> Positive for the STA's environmental work.	STA
Direct benefits associated with the STA that come with the treatment of excess water from West Link i.e., increased goodwill for its environmental efforts.		<b>Legislation:</b> Follows environmental laws and avoids fines or environmental violations for the STA.  <b>Feasibility of the project:</b> Excess water treatment is necessary for the project to be carried out legally.	
<b>B2: Improved</b> health.	X	Treating the contaminated excess water before discharge would reduce the risk of cancer and other health problems by removing harmful substances, such as suspended solids and metals, from the water. Even though the impact of the West Link on the Göta River is not directly measurable due to its relatively low flow compared to the river's volume. On the other hand, the complete absence of water treatment from	The public
Improved health resulting from excess water treatment, for instance, a reduced			

number of illnesses for workers or other individuals using the Göta river in any capacity.		similar projects such as West Link and the cumulative effects from different projects could affect public health, particularly if recreational activities like swimming become more prevalent, resulting in potential harm caused by the untreated water with elevated pH levels, especially for those who interact with the Göta river.	
<b>B3:</b> Increased provision of ecosystem services.  Improved environment resulting from the Remediation Alternative, which does not directly impact the project's finances but rather burdens the general public through, for example, area restrictions.	(X)	Treating the excess water would protect ecosystems and fish stocks in the Göta river by preventing the biological damage caused by untreated excess water. This includes protecting aquatic life from harmful substances, ensuring healthier fish populations, and supporting the fishing industry. The economic value linked to fishing and the health of fish would be preserved, benefiting both the environment and the local economy.	The public
<b>B4:</b> Other positive externalities than <b>B2</b> and <b>B3</b> .  B4 represents other positive effects that may not necessarily pertain to health or the environment. It can include improvements in land values for surrounding properties.	NR	This post is measured as unimportant or irrelevant since property values along the Göta river are not significantly affected or improved by treating the excess water before discharging it Göta river.	The public

As illustrated in Table 16, excess water treatment in the West Link is strictly regulated by an environmental court ruling that sets specific requirements for the project and the water quality parameters that must be met. This ruling is based on the EU Water Framework Directive, environmental legislation to prevent the deterioration of European water bodies (Hucham & Pollard, 1998).

It is of utmost importance for the STA to comply with this environmental legislation. Failure to do so would risk environmental crimes and potential sanctions such as fines. Thus, a significant benefit of STA adhering to environmental legislation is that the project can only proceed if the requirements are met, which, in this case, means that the water must be treated according to the court's ruling. Complying with environmental legislation also contributes to STA's goodwill and enhances its reputation regarding sustainability and environmental profile.

### 5.5.1.2 Costs: Qualitative assessment

Table 17: Qualitative assessment of cost (X indicates significant importance, (X) minor importance, and NR for not relevant). Sig = Significance, AA = Affected Actors.

Cost ©			
	Sig	(Excess water treatment alternative, A1)	AA
<p><b>C1:</b> Remediation costs.</p> <p>The cost of excess water treatment for the STA as the project owner.</p>	X	From 2018 to 2024, the STA spent 21 million SEK on treating excess water. This expense is projected to increase to 37.9 million SEK by the end of 2032.	STA
<p><b>C2:</b> Impaired health due to remedial action.</p> <p>C2 refers to health effects affecting the general public or workers, rather than the project owner directly.</p>	X	As explained in chapter 3.3.1, the Sweden Hydro Solution uses Chitosan for their excess water treatment plant to remove contaminants, including heavy metals. Chitosan, while widely used in water treatment due to its biodegradability and non-toxic properties, it also presents certain health risks, particularly for workers handling the material for the water treatment plant. Some individuals may experience allergic reactions, especially those sensitive to shellfish, since chitosan is derived from shellfish exoskeletons (Waibel et al., 2011). Since this is more of a concern for water treatment plant employees, appropriate handling and dose control will be required in order to reduce these risks in the water treatment plant.	The public
<p><b>C3:</b> Decreased provision of ecosystem services due to remedial action.</p> <p>Deteriorated environment resulting from the Remediation Alternative, which does not directly impact the project's finances but rather burdens the general public.</p>	(X)	The use of chitosan in tunnelling excess water treatment can reduce certain ecosystem services, such as natural water filtration and nutrient cycling, potentially disrupting aquatic ecosystems (Collin et al., 2024). Additionally, the extraction of chitosan from marine sources could be detrimental to environments which means if not managed properly, it can add to existing problems like overfishing and pollution (Vieira et al., 2023).	The public

<b>C4: Other negative externalities than C2 and C3.</b>	NR	This post is measured as unimportant or irrelevant since property values along the Göta river are not significantly affected or improved by treating the excess water before discharging it Göta river.	The public
C4 may include declines in land values for surrounding properties or increased costs of the excess water treatment for other stakeholders.			

The installation and running of the excess water treatment plants on the construction site represents extra cost for STA beyond its primary goal of building the tunnel. As indicated in Table 16, the lack of treatment for excess water can lead to significant public health costs and environmental damage. While the potential biological impacts on the recipient ecosystems are substantial, attributing these effects to a single source, such as the West Link project, is challenging due to multiple contributing factors. The overall water quality degradation, including suspended solids, metals, and other harmful substances, has economic implications, particularly for industries like fishing. However, it is essential to note that, unlike the clear point source pollution observed in the case of Persöfjärden in Boden, fish exhibited high levels of metals such as cadmium in their liver (Byrsten & Sandberg, 2005). Thus, pollution in areas affected by projects like West Link likely stems from various sources, therefore this complexity makes it difficult to directly link the environmental and economic impacts solely to the untreated excess water from the West Link project.

Beyond the challenge of attributing environmental impacts to a single source, there is an additional difficulty in assessing the economic value of both environmental and social consequences related to pollution and improvements. For example, having cleaner water can enhance recreational opportunities such as swimming and fishing, while also creating better spawning grounds for fish. This not only benefits biodiversity but also supports the local economy. However, determining an economic value for these intangible benefits is quite complex. Although they do not have a direct market price, these advantages can be highly significant for local communities and industries like fishing and tourism.

Overall, there are two main challenges that needs to be considered. First, it is essential to figure out how much of the negative effects that can directly be attributed to the West Link project. Second, one must consider how to assign an economic value to those effects, especially regarding intangible benefits such as recreation and environmental quality. These assessments require careful analysis, and a degree of uncertainty will always remain which makes difficult to fully quantify the economic outcomes of both the negative and positive environmental impacts.

## 5.5.2 Net Present Value

The focus of this chapter is solely on cost item C1. Despite the effort to gather relevant information and data, the remaining costs have proven to be too complex to quantify any of the other cost items in this analysis.

In Table 17, the total cost is reported for each action cost item, first the cost excluding VAT, and then the present value based on the cost excluding VAT. The NPV method is used to calculate the total cost of the water treatment project, emphasising the significance of discounting in financial planning. The table demonstrates that with a consistent annual operation and maintenance cost of 3,000,000 kr, when these costs are discounted at a rate of 3.5%, their present value decreases over time. This shows that while the nominal costs remain constant, their financial impact on the project decreases in present value terms as time goes on.

Table 18: Net Present Value

Net Present Value				
Year	Initial investment for the water treatment (kr)			PV (kr)
2018	- 5 234 303			-5 234 303
Year	Time (r)	Discount Rate	Cost (kr) for water treatment, operation, and maintenance/year.	PV (kr)
2019	1	3.5 %	-3 000 000	-2 910 000
2020	2	3.5 %	-3 000 000	-2 790 000
2021	3	3.5 %	-3 000 000	-2 700 000
2022	4	3.5 %	-3 000 000	-2 610 000
2023	5	3.5 %	-3 000 000	-2 520 000
2024	6	3.5 %	-3 000 000	-2 430 000
2025	7	3.5 %	-3 000 000	-2 370 000
2026	8	3.5 %	-3 000 000	-2 280 000
2027	9	3.5 %	-3 000 000	-2 190 000
2028	10	3.5 %	-3 000 000	-2 130 000
2029	11	3.5 %	-3 000 000	-2 040 000
2030	12	3.5 %	-3 000 000	-1 980 000
2031	13	3.5 %	-3 000 000	-1 920 000
2032	14	3.5 %	-3 000 000	-1 860 000
<b>NPV</b>				<b>-37 964 303</b>

STA, which is primarily state funded, has contracted NCC and other contractors to construct the tunnel and treat excess water from the construction. NCC, in return, requires financial compensation for its costs, including water treatment costs. From 2018 to 2023, excess water treatment from 'Centralen' cost STA around 21 million SEK, as illustrated in Table 17. This shows that maintaining excess water treatment plants is an expense for STA with minimal

direct economic benefit. However, it's important to ensure that all factors affecting the final economic value are represented. A reasonable starting point could be to investigate the willingness to pay among the residents of Gothenburg which according to Burn & Jönsson (2017) more than half a million residents in Gothenburg who are supplied with surface water from the Göta river had an average willingness to pay 50 SEK per month to ensure clean water from the Göta river. This amounts to 25 million SEK annually, which over 14 years sums up to 350 million SEK. This figure is 10 times the total cost of the excess water treatment over the same period, which is 38 million SEK. This clearly indicates that the water treatment measures could be seen as a benefit in the long term. In addition to Gothenburg's residents, other groups along the Göta river should also be considered. Including all residents along the Göta river significantly increases the potential willingness to pay, providing a stronger case for the long-term benefits of the treatment measures.

## 6. CONCLUSION

The aim of the study was to assess the effectiveness of the water treatment for tunnelling excess water at 'Centralen' station by analysing data from 2018-2023 on pollutant concentrations and conducting a Cost-Benefit Analysis to compare the costs of treating excess water compared to discharging the untreated excess water into the Göta river.

### **Analysis of water treatment and its contribution to Göta River**

- Overall, the water treatment process generally meets regulatory requirements. However, certain parameter concentrations sometimes exceed acceptable thresholds, indicating room for improvement.
- The efficiency of the treatment plants varies significantly, with an average performance of approximately 72.5%. Pollutants such as Cr(VI), Cd, and Oil, are particularly challenging to remove, highlighting the need for enhanced treatment methods.
- Emissions from the central facility are very low compared to the pollution levels at Alelyckan and Stenpiren. For instance, after treatment, the facility releases 0.039% of the arsenic in Alelyckan and 0.025% in Stenpiren, as well as 0.071% and 0.059% of nickel.
- The central facility's emissions show a significant reduction after treatment. For the average emissions in 2021 and 2022, arsenic decreased from 0.420 kg to 0.148 kg, and nickel dropped from 1.21 kg to 0.538 kg. This indicates a clear trend of improving water quality, with all post-treatment values lower than before and compliant with STA target values, highlighting the effectiveness of the treatment process.

### **Cost-Benefit Analysis**

- The STA is legally required to conduct the excess water treatment in order to comply with stringent laws and regulations designed to protect public health and the environment. A key piece of legislation governing water quality across Europe is the EU Water Framework Directive (WFD), which applies to the Göta river.
- The cost of the excess water treatment, although significant, helps the STA avoid fines, legal battles, and potential project delays. Complying with these strict environmental regulations not only protects the environment but also upholds the STA's reputation as a responsible public entity.
- The ongoing plan by Gothenburg municipality to introduce public swimming areas along the Göta river adds a significant layer of importance to these efforts. The investment in water treatment not only preserves public health and the environment but also ensures that the Göta river becomes a safe and appealing destination for recreational activities like swimming.
- While the immediate costs of the excess water treatment, totaling approximately 38 million SEK over 14 years, present a significant expense, the broader economic value

of these measures outweighs the costs. The willingness-to-pay study conducted by Burn & Jönsson (2017) shows that Gothenburg residents alone would be willing to contribute 350 million SEK over the same period to ensure clean water from the Göta river, indicating strong public support for environmental protection.

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# APPENDICES

## Appendix A: Logarithmic In/Out Values from the Treatment Plant

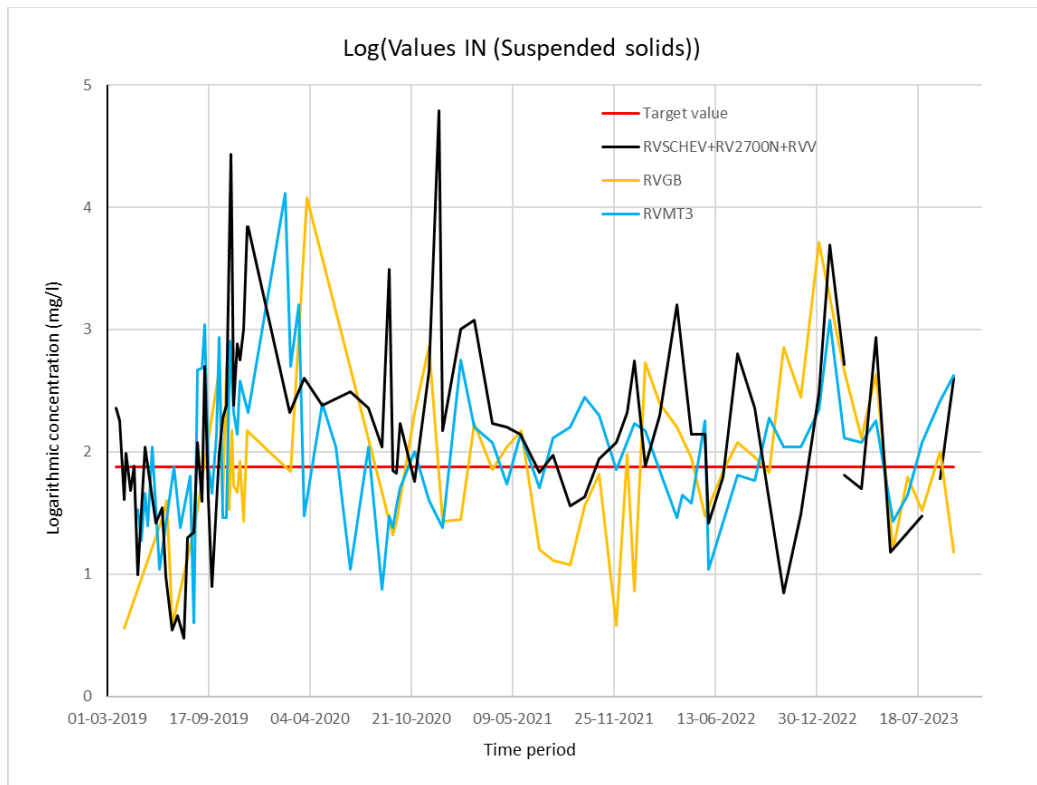


Figure 26. Concentrations of suspended solids influents before treatment.

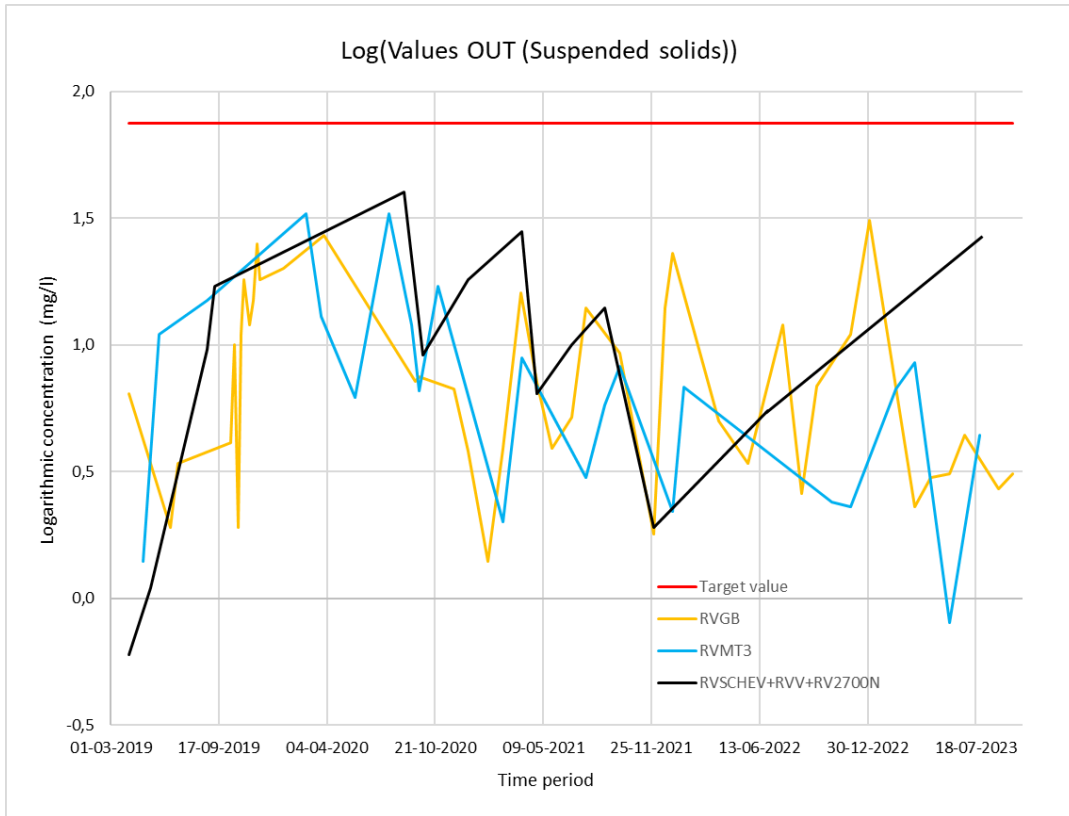


Figure 27. Concentrations of suspended solids in effluents after treatment.

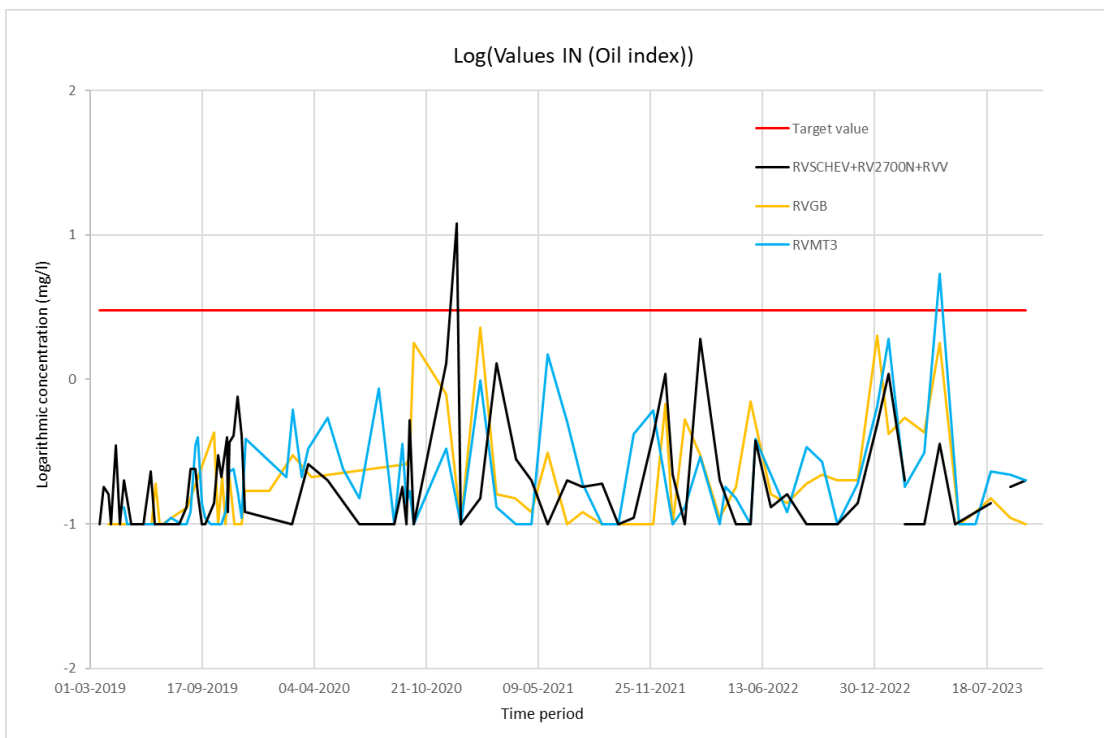


Figure 28. Concentrations of oil index influents before treatment.

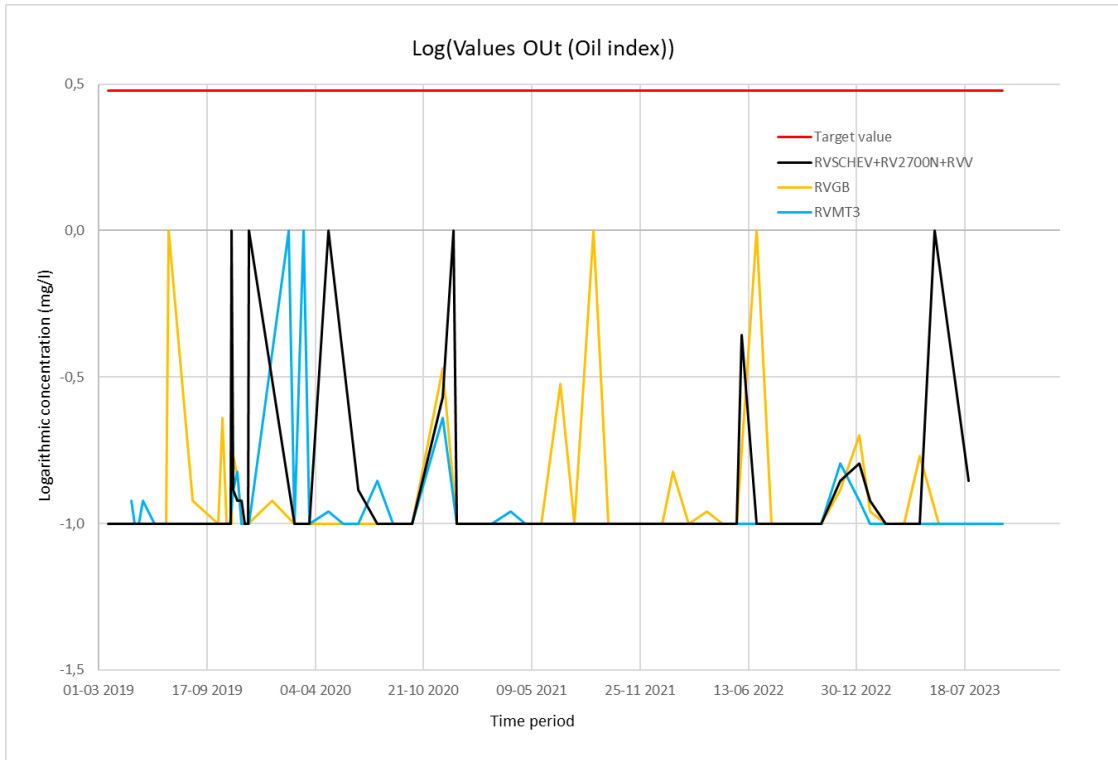


Figure 29. Concentrations of oil index in effluents after treatment.

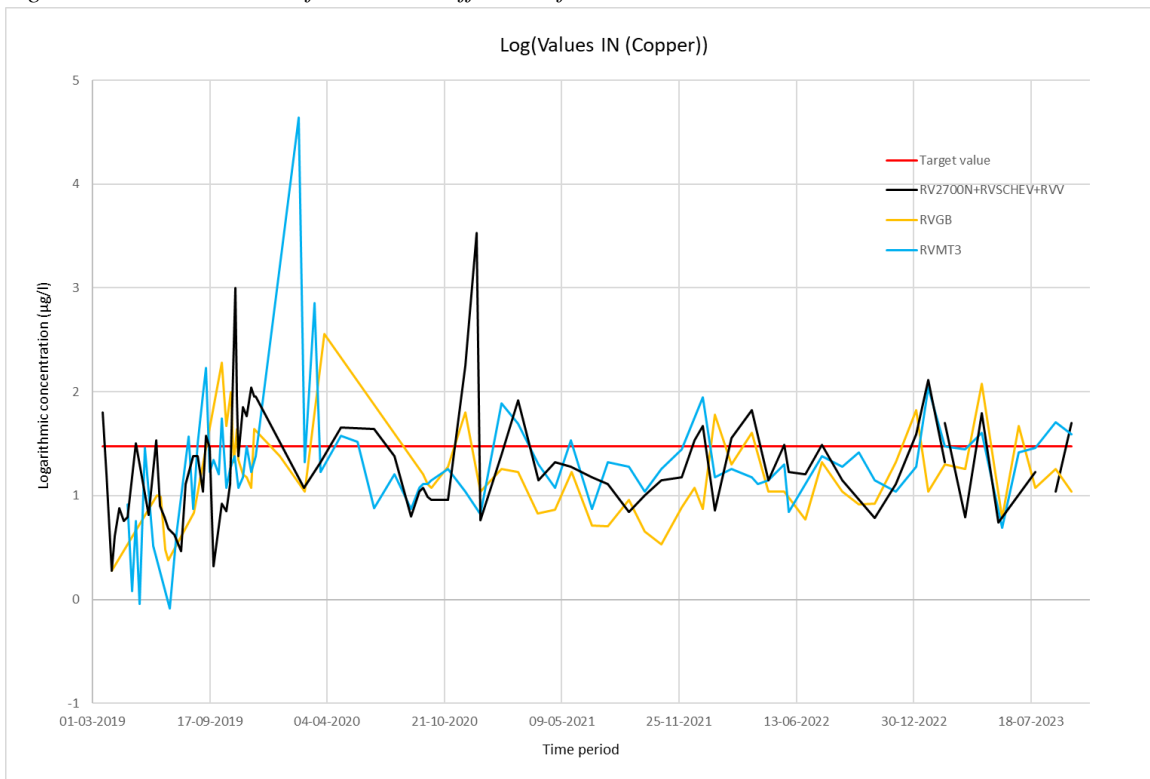


Figure 30. Concentrations of copper influents before treatment.

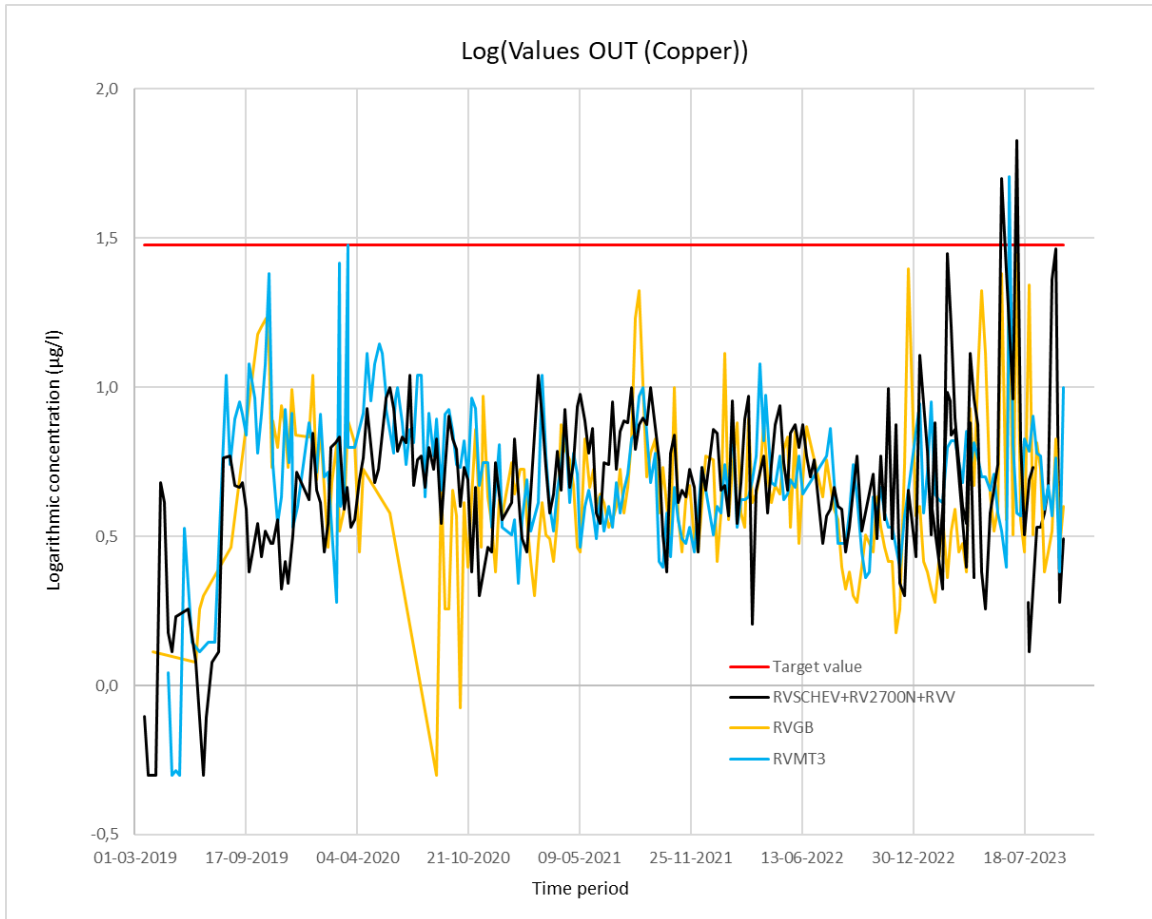


Figure 31. Concentrations of copper in effluents after treatment.

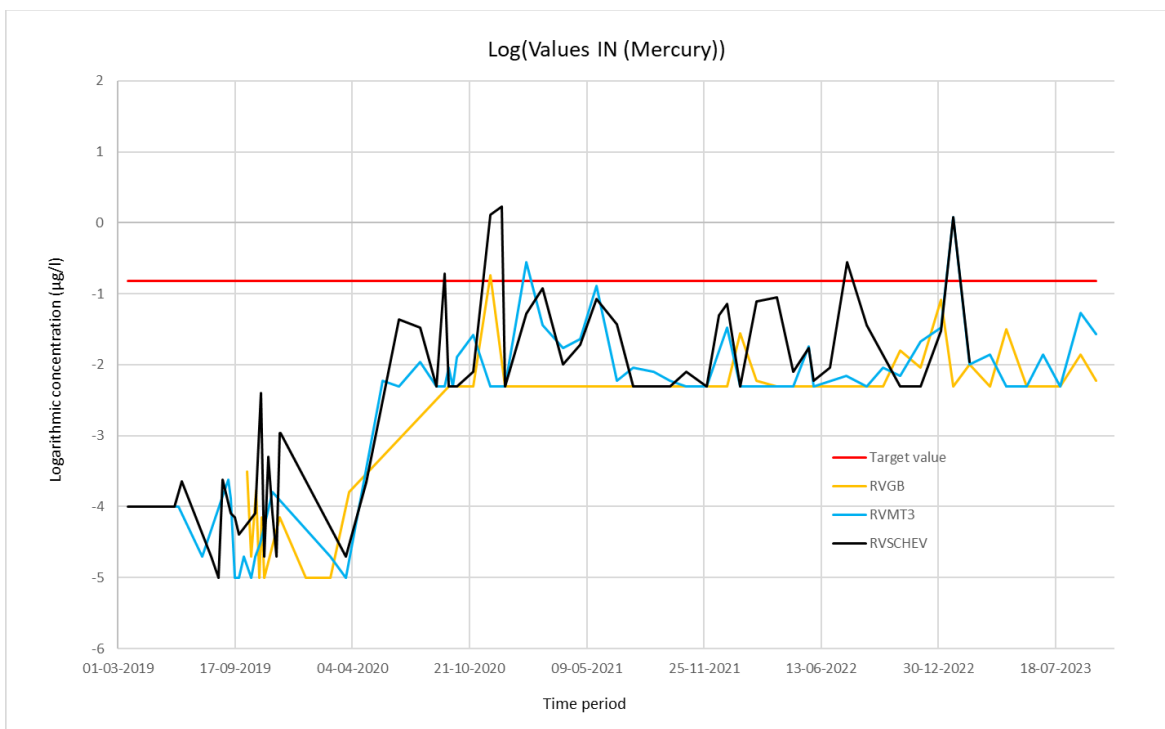


Figure 32. Concentrations of mercury influents before treatment.

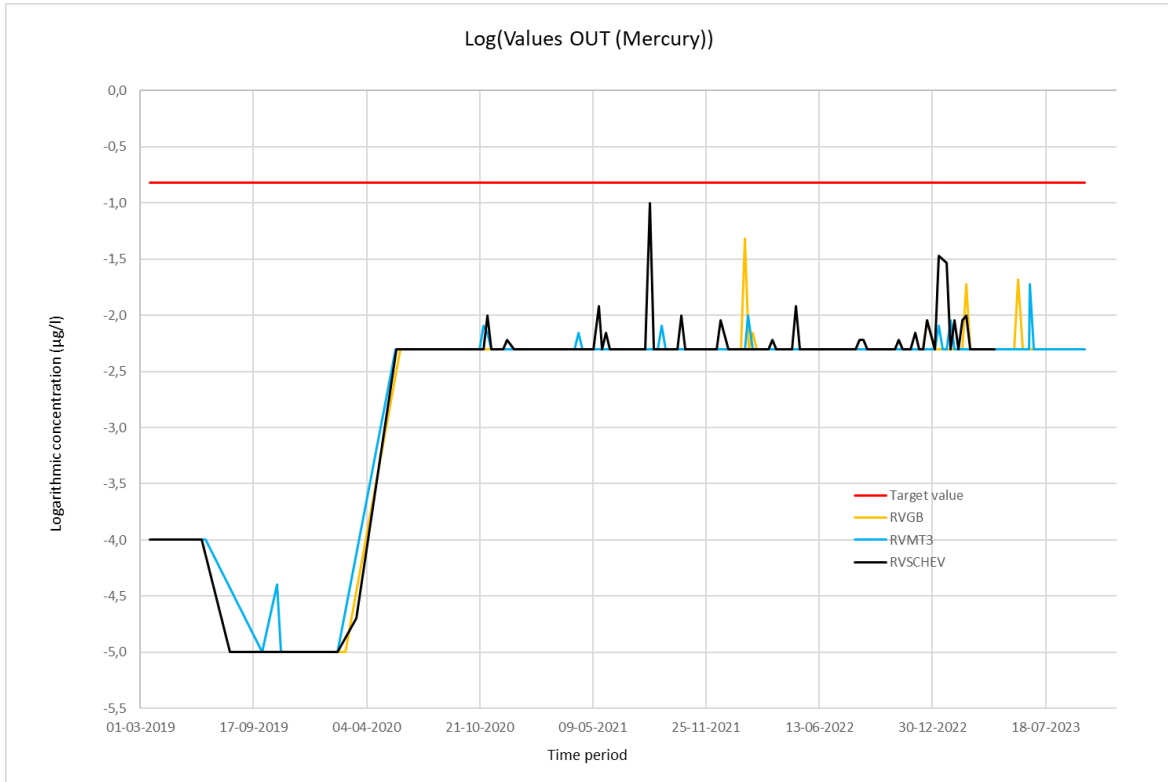


Figure 33. Concentrations of mercury after in effluents treatment.

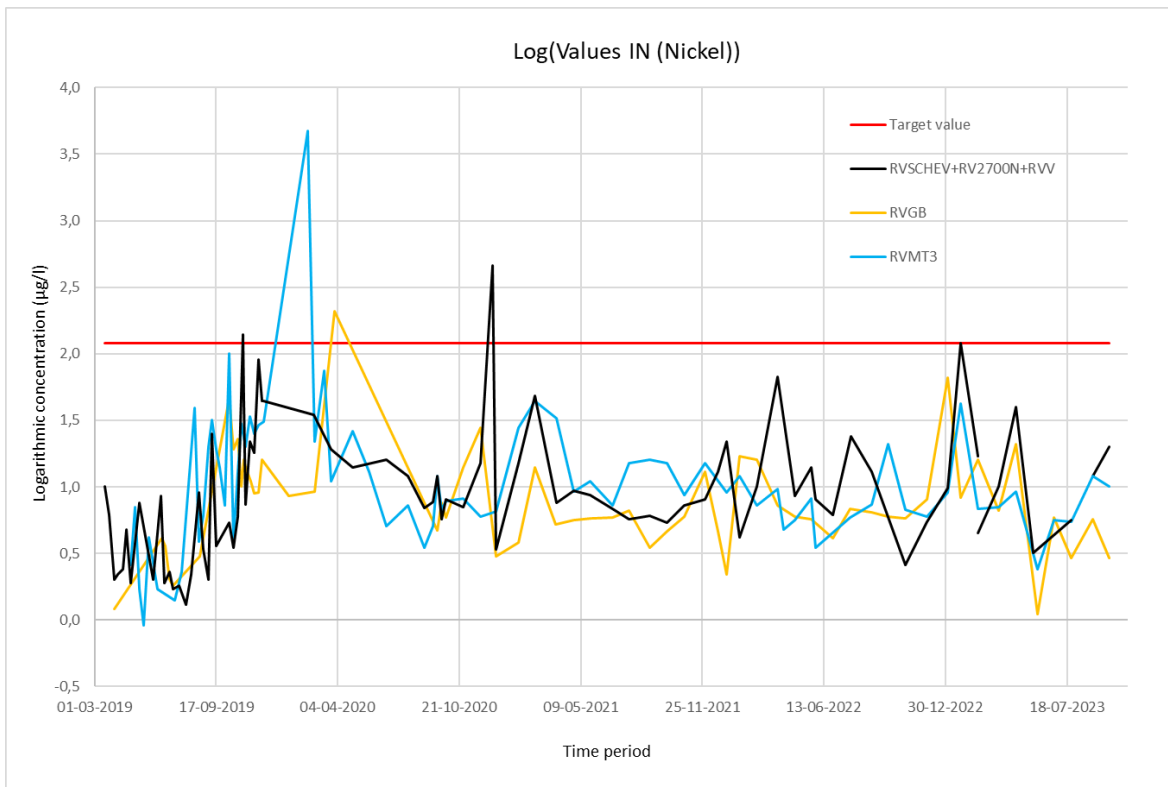


Figure 34. Concentrations of nickel influents before treatment.

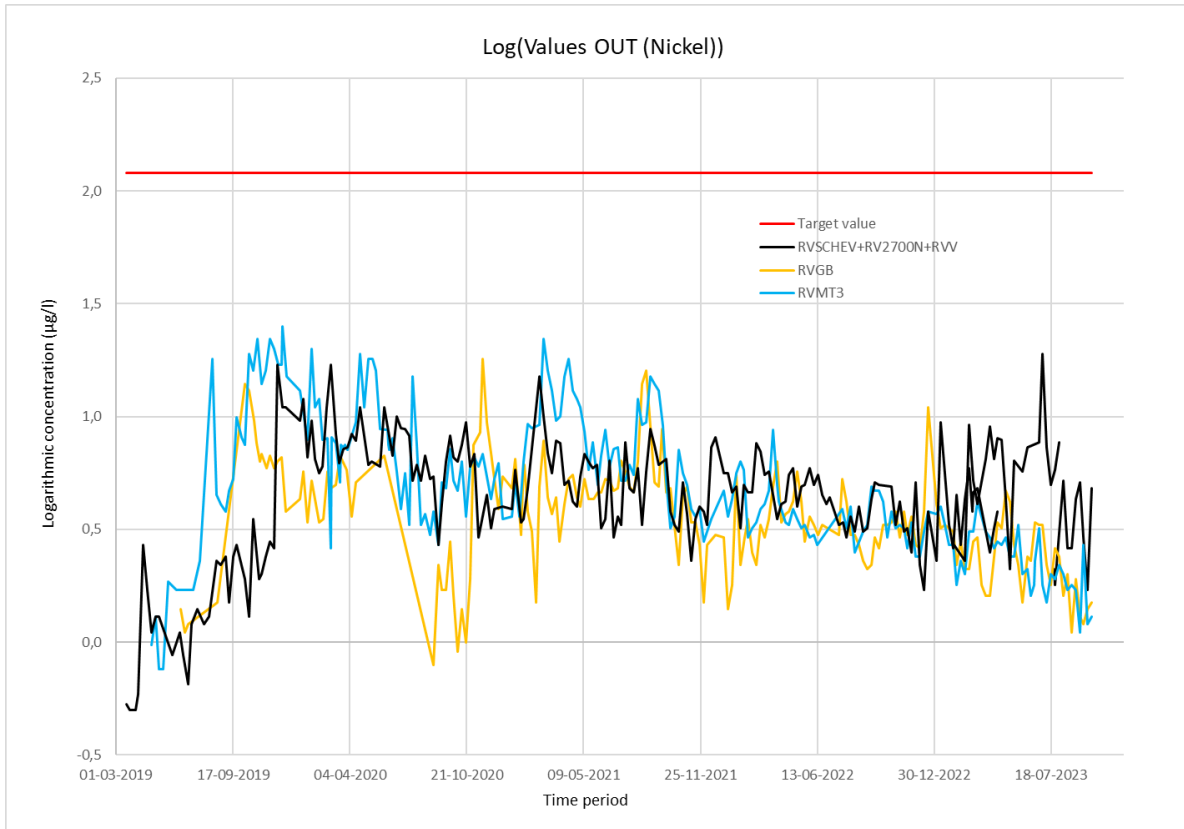


Figure 35. Concentrations of nickel after in effluents treatment.

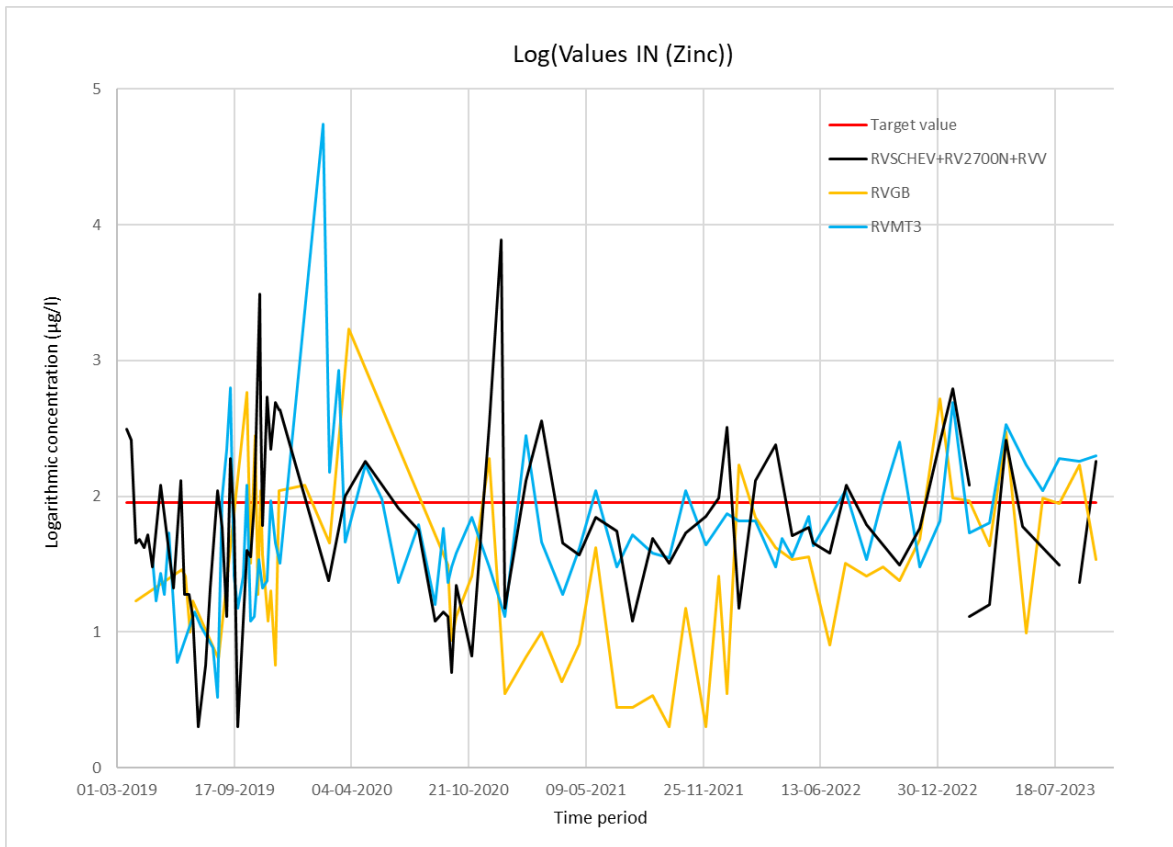


Figure 36. Concentrations of zinc influents before treatment.

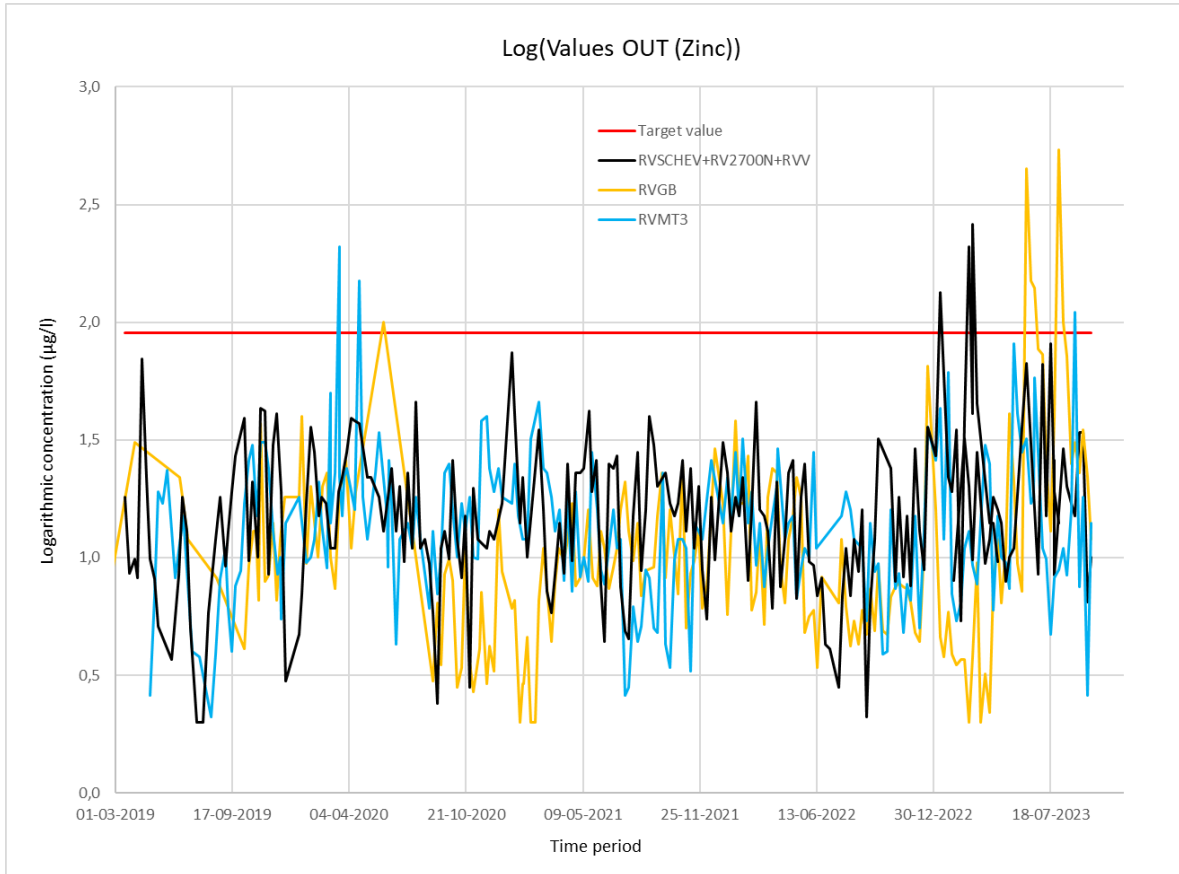


Figure 37. Concentrations of zinc in effluents after treatment.

## Appendix B: Interview Questions

- 1) Are there any direct benefits and costs for the Swedish Transportation Administration in carrying out the treatment of excess water before discharge compared to releasing the water untreated into the Göta river?
- 2) What potential health effects do you expect for the general public or workers specifically in the area where the construction of “Västlänken” is carried out, as well as areas along the river upstream and downstream from the discharge point if excess water is treated compared to untreated excess water?
- 3) Do you think there are any environmental impacts for the area around the Göta river and its surroundings if excess water is released untreated? And how would these change if the water is treated before discharge?
- 4) As a follow-up question, which groups in society would be affected or benefited by these effects?
- 5) Regarding property values, how do you think nearby areas, i.e., areas along the river upstream and downstream from the discharge point, would be affected if excess water from “Västlänken” is not cleaned before being pumped into the Göta river?
- 6) Are there any other potential costs or benefits besides health and the environment that should be considered or that you believe may be important to include in this comparison, specifically from the project owner's perspective?