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Technical Possibilites of Wastewater Reclamation for Potable Use in Hurva, Scania

Regarding the Waterbalance and From a Process Technical Point of View

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Referat

Tekniska möjligheter för användning av avloppsvatten som råvattenkälla i dricksvattenproduktionen i Hurva

Esmeralda Frihammar

Under de senaste åren har både Sverige och övriga Europa upplevt perioder av torka till följd av varma somrar med lite nederbörd. För byar som förses av dricksvatten från vattenverk med grundvatten som råvattenkälla kan torka leda till stora problem om grundvattenreservoaren blir påverkad.

En by som förses med dricksvatten från ett grundvattenverk och som stött på problem gällande dricksvattenproduktionen under de senaste åren är Hurva, som är beläget utanför Eslöv i Skåne och har en befolkning på strax under 400 personer. Problemen har bestått i att det inte alltid funnits tillräckligt mycket vatten i grundvattenmagasinet. Vid dessa tillfällen har lösningen varit att fylla på drickvattenreservoaren med dricksvatten transporterat i lastbilar från ett annat vattenverk. Detta anses inte som en hållbar lösning och ett förslag har lagts fram om att koppla på Hurva till det regionala dricksvattennätet med hjälp av en överföringsledning.

Detta projekt har utförts i samarbete med VA SYD, som är VA-huvudman i Hurva. Projektets syfte var att undersöka möjligheterna till att implementera ett cirkulärt dricksvattsystem med avloppsvatten som primär råvattenkälla i Hurva utifrån två huvudaspekter. Den första delen av projektet handlade om att beräkna vattenbalansen i systemet för att underöka om det finns tillräckligt med vatten. I den andra delen undersöktes möjligheterna till att implementera ett cirkulärt vattenverk i Hurva utifrån processtekniska aspekter samt hälso- och säkerhetsaspekter.

Enligt beräkningar av vattenbalans har det funnits tillräckligt mycket vatten i systemet för alla månader mellan januari 2018 och december 2019 med undantag för juni 2018, vilket var ett extremt torrt år i Sverige. Utifrån resultaten kan slutsatsen dras att under normala år har det funnits tillräckligt mycket vatten för att kunna implementera ett cirkulärt dricksvattensystem men att det föreligger en viss risk för vattenbrist i torra perioder.

Två möjliga vattenverk, i rapporen kallade *treatment chain 1* och *treatment chain 2*, togs fram. Båda verken designades för att uppfylla kravet om att ha kapacitet att rena avloppsvattnet från Huvas reningsverk till dricksvattenkvalitet. Treatment chain 1 bestod av följande 5 behandlingssteg: ulftrafiltrering, omvänd osmos, granulärt aktivt kol, hårdhet+pH justering och UV disinfektion. För treatment chain 2 valdes följande 4 behandlingssteg: ulftrafiltrering, ozonering, granulärt aktivt kol och UV disinfektion.

Nyckelord: Återanvändning, avloppsvatten, cirkulära vattensystem, dricksvattenverk, reningsverk, VA SYD

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Abstract

Technical Possibilities of Wastewater Reclamation for Potable Use in Hurva

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During recent years both Sweden and the rest of Europe have experienced periods of drought as a consequence of hot summers with low levels of precipitation. For villages provided with drinking water from water plants with groundwater as raw water source droughts can lead to considerable problems if the groundwater reservoir would be affected.

One Swedish village which is provided with drinking water from a groundwater drinking plant and which has faced problems regarding their drinking water production is Hurva, located outside of Eslöv in Scania and with a population of almost 400 people. The problem has been periods of water shortage in the drinking water system. The solution to this problem has consisted in filling up the water reservoir in the drinking water system with drinking water delivered in trucks. This is not considered a sustainable solution to the problem and a transmission pipe connecting Hurva to the regional drinking water system has been suggested.

This project is written in collaboration with VA SYD, the joint municipal authority in Hurva, and consisted of two main objectives. The first objective was to examine the possibilities of implementation of a circular wastewater system in Hurva from a process technical and health and safety point of view. The second objective was to estimate the waterbalance in the system to make sure that there was enough water for a circular water system.

According to the calculations regarding the waterbalance estimation there has been enough water in the system every month of the period January 2018-December 2019 with exception for June 2018 which was a month with extreme droughts in Sweden. The results indicates that there is a risk for water shortage in the system although this is probably not the case for months with normal conditions.

Two possible treatment chains was designed, based on the requirement that they should have the capacity to treat the wastewater from Hurva WWTP into drinking water quality. The first chain, *treatment chain 1* consisted of ultrafiltration, reversed osmosis, granular activated carbon, pH/hardness adjustment and UV treatment. The second chain, *treatment chain 2*, consisted of ultrafiltration, ozonation, granular activated carbon and UV treatment.

Keywords: Potable Wastewater Reclamation, Re-use, VA SYD, WWTP, DWTP

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Preface

This master thesis corresponds to 30 credits and is the final part of the Master's Program in Environmental and Water Engineering at Uppsala University. The report has been written in collaboration with VA SYD. Josefin Barup, development engineer at VA SYD, has been supervisor and Stephan Köhler, Professor at the department of water and environment at Sveriges Lantbruksuniversitet, has been subject reader.

I would like to thank Josefin Barup for supporting me through the project and always taking the time to guide me and answer my questions. I would also like to thank Stephan Köhler for reading my report and providing valuable input throughout the project.

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Populärvetenskaplig sammanfattning

I Sverige har tillgång till obegränsat med dricksvatten av hög kvalitet länge setts som en självklarhet och är ingenting som de flesta funderar på. Under de senaste åren har torra somrar med extrem torka på många håll i landet utmanat bilden av dricksvatten som oändlig resurs. Ett exempel på en by som har upplevt problem gällande tillgången på dricksvatten under de senaste åren är Hurva, belägen i Eslöv utanför Skåne. Vattnet som används i Hurvas dricksvattenproduktion kommer från en grundvattenkälla och vid tillfällen har det inte funnits nog med vatten för att förse byn. VA SYD, som är ansvariga för dricksvattenproduktionen i Hurva, har tidigare löst detta problem med att fylla på vattenreservoaren med dricksvatten transporterat till Hurva i lastbilar.

I områden där låg tillgång på dricksvatten varit ett utbrett problem under längre tid har en lösning varit att införa ett cirkulärt vattensystem där avloppsvatten renas till dricksvattenkvalitet.

Trots att den nödvändiga tekniken för att behandla avloppsvatten till dricksvatten finns tillgänglig och trots att det finns många lyckade exempel på liknande vattenverk världen över finns det ett visst motstånd i frågan. Det finns många anledningar till att cirkulära vattenlösningar inte tagit fart i Sverige. En anledning som nämns ofta är att människor känner en viss osäkerhet i och med att avloppsvatten instinktivt uppfattas som äckligt. I verkligheten är dock avloppsvattenkvaliten inget som förhindrar en tillräcklig rening och det finns dricksvattenverk som använder vatten av sämre kvalitet än avloppsvatten. Dessutom genomgår avloppsvatten redan idag en viss rening som i vissa fall kan resultera i en relativt hög vattenkvalitet.

I framtiden väntas striktare restriktioner gällande vilka ämnen får släppas ut från reningsverken, vilket skulle resultera i högre kvalitet på utgående avloppsvatten. Genom att införa ett cirkulärt vattensystem där det renade avloppsvattnet tas till vara istället för att släppas ut i naturen utnyttjar vi möjligheten att rena miljöfarliga ämnen innan de nått naturen. Dessutom kan vi samtidigt ta tillvara på den resurs som renat avloppsvattnet faktiskt kan vara, särskilt under torra perioder.

I detta projekt undersöks möjligheter att införa ett cirkulärt vattensystem i Hurva i två delar. I den första delen undersökts tillgången på vatten i systemet för att säkerställa att det är tillräckligt för att införa ett cirkulärt vattensystem. Resultatet från den första delen tyder på att det föreligger en viss risk för vattenbrist i systemet under de torraste månaderna. I den andra delen av projektet undersöktes möjligheten utifrån ett process tekniskt perspektiv. Två dricksvattenverk designades för att kunna behandla avloppsvattnet i Hurva till dricksvatten. Båda två av de designade vattenverken ansågs uppfylla kraven om reningskapacitet samtidigt som de var kopplade till vissa utmaningar.

Wordlist

Livsmedelsverket - The National Food Agency in Sweden
VA SYD - The joint municipal authority in Hurva

Treatment Plants
WWTP - Waste water treatment plant
DWTP - Drinking water treatment plant

Water Classifications
Raw Water - The water that is treated to drinking water
Wastewater - The water entering the waste water treatment plant
Drinking Water - The treated water that is delivered to consumers
Additional Water - Inflow and infiltration to pipes

Advanced Treatment Methods
GAC - Granular Activated Carbon
PAC - Powdered Activated Carbon
MF - Microfiltration, membrane treatment step
UF - Ultrafiltration, membrane treatment step
NF - Nanofiltration, membrane treatment step
RO - Reversed Osmosis, membrane treatment step
UV light - Light with a wavelength of 10-340 nm

Water Quality Parameters
NOM - Natural Organic Matter
COD - Chemical Oxygen Demand
BOD - Biologial Oxygen Demand
tot-P - Total phosphorus
tot-N- Total nitrogen
SS - Suspended Solids

Common Water Treatment Methods and Terms
Flocculation - Aggregation of small particles to aggregates
Softening Filter - Treatment method for hardness reduction
Precipitation - Addition of a solution to treated water making substances solid
Nominal Poresize - Corresponds to the size of solid particles for which the majority are removed in a filter

Common WWTP Treatment Methods
CAS - Conventional Active Sludgeproces, biological treatment step in WWTPs
MBR - Membrane bioreactor, CAS with addition of physical separation by membrane process
SBR - Sequencing Batch Reactor, CAS operated in batches

Contents

1 Introduction

During the last 70 years Earth's temperature has increased (IPCC 2013). Generally the effect of climate changes in Sweden is connected to increased precipitation but in the middle and south of Sweden it can also lead to more periods of droughts (Svenskt Vatten 2007). At least 11% of Europe's population has experienced groundwater shortage (European Comission 2019) and in the summer of 2018 (SMHI 2019) and 2019 (MSB 2019) several regions of Sweden were affected.

As water scarcity grows into a bigger issue, more effective managing of water systems is demanded. One approach to handle the problem is by implementing circular water systems, where wastewater can be treated for industrial, agricultural or potable use or for groundwater recharge. In Europe, wastewater is already reused for groundwater recharge, irrigation and industrial use (European Comission 2019) and outside of Europe, there are multiple examples of wastewater reclamation for potable use in areas where water resources have been scarce (PUB n.d.; Wingoc n.d.; World Health Organization 2017). In Sweden there are several ongoing projects regarding treatment of waste water for potable use, (Mörbylånga Kommun 2019; IVL 2018) although there is still no full-scale treatment of municipal wastewater into drinking water quality.

One village that has faced problems in their drinking water production due to water scarcity is Hurva, located outside of Eslöv in Scania and with a population of almost 400 people. In the current drinking water production groundwater is used as raw water source. In the last years there has not always been enough groundwater to provide the village with drinking water. So far, the solution to this problem has been to fill up the water reservoir in the drinking water system with drinking water delivered in trucks. This situation is not considered to be sustainable and a transmission pipe connecting Hurva to the regional drinking water system has been suggested. An alternative solution could be to reuse the wastewater for potable use in a circular water system.

In Hurva, the most obvious incitement for a circular wastewater system is the alleviation of pressure put on the groundwater resource and a more reliable drinking water production. Implementation of a circular waste water system is connected to several positive effects from an environmental point of view, whereof some are connected to the 6 main goals put up by VA SYD, the joint municipal authority that supplies Hurva and other cities and villages in the region with drinking water. The goals are listed below with an explanation of how they can be affected by implementation of circular wastewater systems.

1. **To be climate-neutral and energy-positive by 2030** - Negative/positive effect depending on treatment method.
2. **To productify and to have utilized residual products by 2025** - Positive effect.
3. **To be one of Europe's 10 most efficient water, sanitation and waste organizations by 2025** - Negative/positive effect depending on efficiency of chosen treatment methods.
4. **Lead the development process to achieve high quality water for drinking and recreation by 2025** - Positive.
5. **To eliminate unplanned operational disruption for customers by 2030** - Positive, a more reliable water source would make it easier to reach this goal.

6. **To inspire and have activated all customers to ensure a better environment by 2025** - Opportunity to contribute positively to this goal.

Reuse of wastewater is a complex issue involving numerous components. Figure 1 shows a mind map intended to illustrate the complexity of the subject as well as to give an overview of the most important aspects of waste water reclamation. Water quality risks is considered to be the most fundamental part of the issue and is therefore marked in red. Other colors are chosen randomly. In this project, focus has been limited to water quality risks and technical aspects.

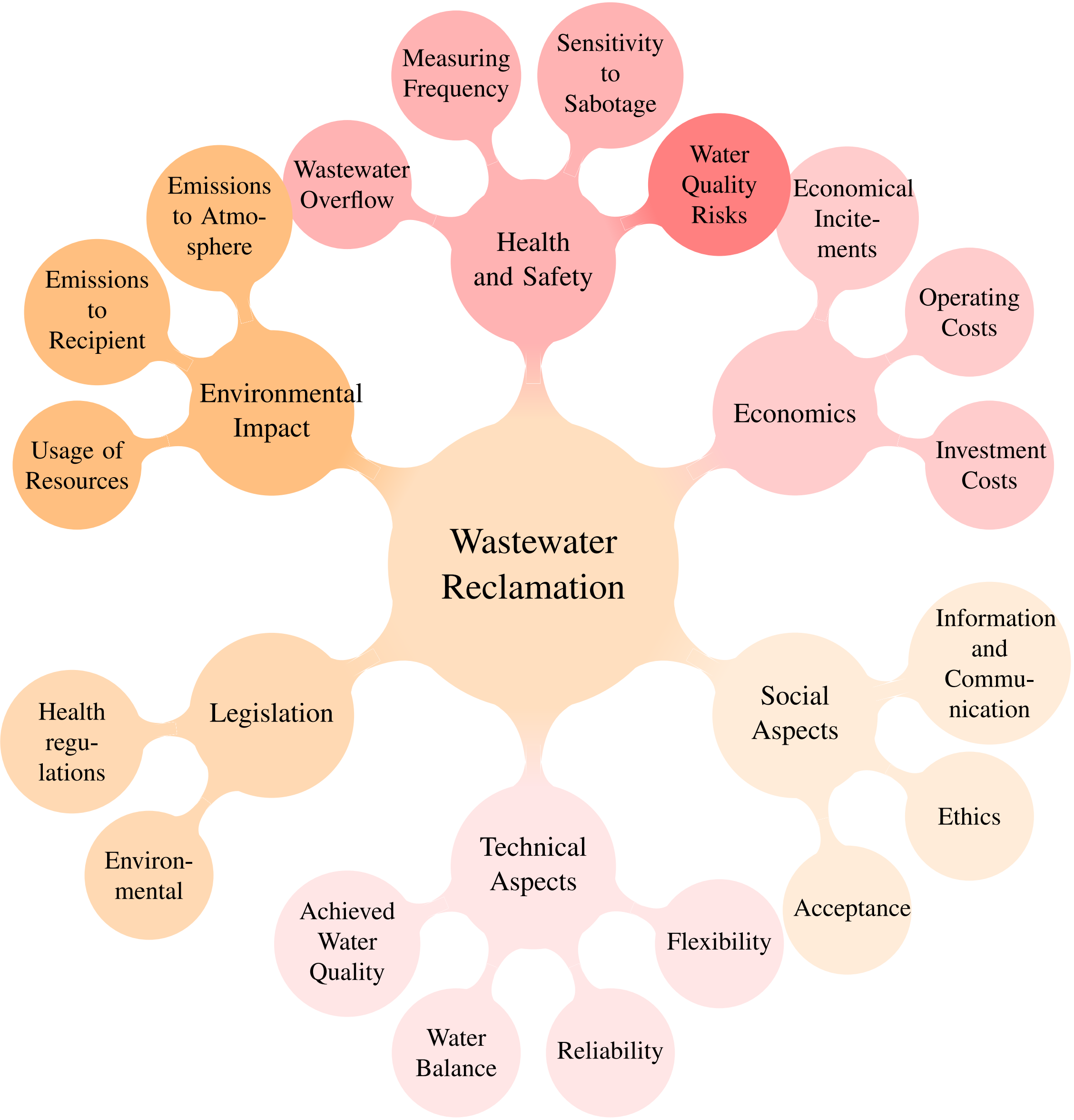

Figure 1: *Mind map made by author intended to illustrate the most important components to consider regarding wastewater reclamation*

1.1 Aim

This project is written in collaboration with VA SYD. The study had two main objectives. The first objective was to estimate the **waterbalance** in the system to make sure that there is enough water. The second objective was to examine the possibility of implementation of a circular waste water system in Hurva from a **process technical** point of view. The approaches for how to achieve the objectives are listed below.

1. **Waterbalance:** By calculations
2. **Process Technical Aspects:** Design of treatment chains that can treat the wastewater from Hurva wastewater treatment plant (WWTP) into drinking water quality

1.2 Limitations

In this project, there has been no attempt to investigate every aspect of implementing a circular waste water system in Hurva. As mentioned in section 1.1, the project has been limited to examine the issue from process technical point of view and the waterbalance. Other aspects, such as economical, social and environmental have not been considered in the project. Additional technical limitations are listed below.

1. Case studies were limited to projects and treatment plants within Sweden. This limitation was used to make sure that all of the cases studied were comparable to Hurva regarding both legal, and site related conditions.

2. Monthly values were used for flow in waterbalance calculations. The reason for this limitation was that there were no other data available for the drinking water treatment plant (DWTP).

3. The examined technical solutions were limited to treatment steps that are described in at least one of the reports listed below. However, it should be noted that none of the two reports is focusing on wastewater reclamation for *potable use*.

    - *Tekniska lösningar för avancerad avloppsrening* by Baresel, Magnér, et al. (2017)
    - "*Återvunnet avloppsvatten för industriell användning och bevattning*" by Hoyer (2019)

    The reason for this limitation was that it was not considered realistic within the frames of his project to perform a more thorough review over relevant treatment steps for wastewater reclamation than what has already been done by Hoyer 2019 and Baresel, Magnér, et al. 2017. The two reports were considered to be representative for technical solutions since they both summarize available techniques for wastewater reclamation, are written for Swedish conditions and are published within the last 5 years.

4. The examined technical solutions were limited to treatment steps that have been implemented in wastewater treatment processes.

5. Only reclamation for direct potable use was examined in the project since the geological conditions were not considered suitable for groundwater recharge.

6. No measurements were performed during the project, meaning that all data and information known by VA SYD about flows, concentrations etc. were assumed to be accurate. For water quality parameters that were not measured, concentrations were assumed based on data from other water plants.

1.3 Premises for the Project

Some premises for the project were given by VA SYD, these are listed below.

- All of the drinking water is supposed to be delivered by VA SYD and there will be no extra water from private wells
- The main raw water source should be municipal wastewater

1.4 System Boundaries

Throughout this project, the complete circular wastewater plant has been viewed as two separate systems according to Figure 2. The part of the treatment plant examined in this project is defined as the DWTP. The DWTP is placed after the WWTP and consist of the more advanced methods in the treatment plant.

In the WWTP, wastewater is treated with a certain wastewater treatment method, for example a conventional active sludgeprocess (CAS) or a membrane bioreactor (MBR). In this project the WWTP was seen as a pretreatment plant with the aim that the effluent would be of high enough quality to enter the DWTP. The design of the WWTP was not considered and the effluent quality was assumed to be of high enough quality in the design of the DWTPs.

In the DWTP the effluent from the WWTP is treated into drinking water quality. In this project suggested DWTPs were designed by combining treatment methods described in Section 2.2. When treatment chains are mentioned in this report, it refers to the designed DWTPs.

When the already existing treatment plants are mentioned, these are referred to as the current WWTP/DWTP.

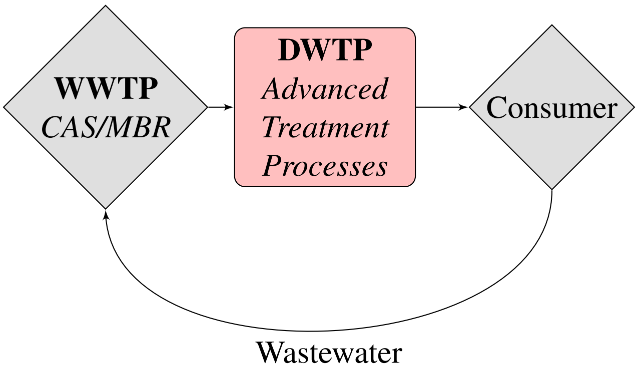

Figure 2: *System Boundaries in the Project.*

1.5 Challenges and Opportunities

It is important to be aware of both opportunities and challenges connected to the issue of reclamation of waste water, some of these are presented in Figure 3. Before initiating the project it was noted that the challenges are not primarily technical but rather social, economical and legal. One challenge is the lack of guidance and regulations from authorities such as the European Union or the Swedish national food agency regarding waste water reclamation for potable use.

However, there are a lot of opportunities connected to wastewater reclamation motivating the implementation of a circular system, or at least a thorough investigation of the subject. One opportunity is the possibility to remove pollutants before they reach recipient. Furthermore, there is a need for more exhaustive wastewater treatments in Sweden, especially regarding pharmaceuticals (Naturvårdsverket 2017). This could be a motivation for implementation of wastewater reclamation since it would consist of one combined advanced treatment plant instead of one plant for wastewater treatment and one for drinking water preparation. Furthermore, treatment of pharmaceuticals demand treatment that result in high quality effluents which should be seen as a resource rather than a waste product.

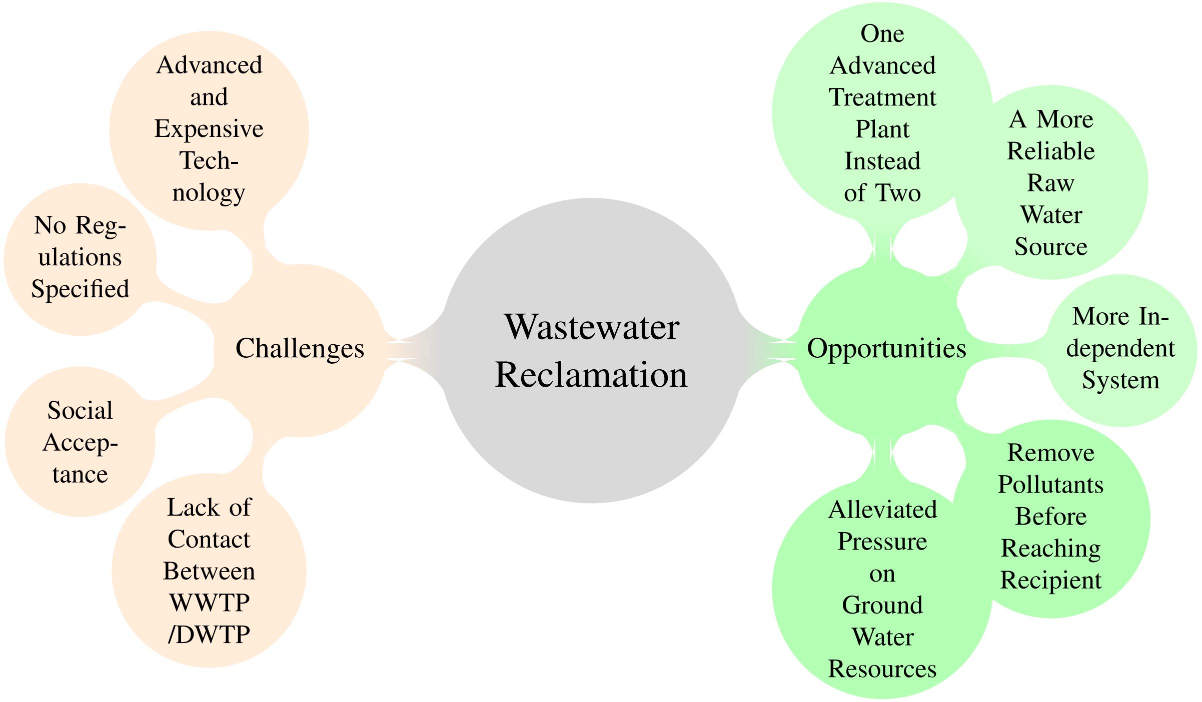

Figure 3: *Mind map made by author to illustrate opportunities and challenges connected to wastewater reclamation*

2 Theory and Background

To understand the challenges connected to reclamation of wastewater it is important to have information about the quality of the treated water and to identify problematic compounds and pollutants. Therefore, this chapter contains a short summary of the most important parameters regarding treated municipal wastewater.

Furthermore, it is important to understand the technical processes used for further treatment of wastewater. Background information about the treatment methods considered in this project is presented in this chapter and can be used as an encyclopedia when reading about the design of treatment chains in Chapter 3.

To put the project into perspective two case studies of plants for reclamation of industrial or municipal wastewater for direct potable use were performed. The information for the case studies were mostly collected through interviews with the project managers for each plant.

After the case studies follows a description regarding conditions for the current WWTP and DWTP in Hurva.

Finally, the health and safety aspects connected to the issue of wastewater reclamation for direct potable use are recognized. The health and safety aspects are presented in this chapter from a legal perspective as regulations for drinking water production given by the Swedish national food agency (Livsmedelsverket).

2.1 Treated Municipal Wastewater

The WWTPs main purpose is to reduce the spread of potentially health threatening microorganisms and decrease overfertilization (Naturvårdsverket 2008). Most WWTPs consist of mechanical treatment for reduction of large particles, chemical treatment for precipitation of phosphorus and biological treatment for reduction of primarily nitrogen and organic matter. The most common biological treatment is the activated sludge process. (Hörsing et al. 2014) However, the treatment plants will not only contribute to reduction of targeted compounds. This means that contaminants entering the plants does not necessarily occur in the outgoing water even though the process is not designed to treat the specific compound. When reading this section, it is important to have in mind that the current WWTP in Hurva does not include any biological treatment step (Section 2.5) and therefore it is likely that the concentration of parameters described in this section is higher than for a WWTP with biological treatment.

In this section, a short summary of commonly occurring compounds in treated municipal wastewater is presented. It should be noted that the summary only include a small fraction of all possible substances and pollutants to occur in wastewater. Since there is no considerable impact on the wastewater in Hurva other than household use, pollutants connected to industrial wastewater will not be included.

The water quality parameters are divided into four main groups, being inorganic compounds, organic compounds, microorganisms and micro plastics. By looking at pollutants with different properties, the aim is to get a broad picture of what kind of treatment is needed for the water although most pollutants are not measured.

2.1.1 Microbiological Parameters

Microorganisms are present in wastewater mainly from feces and can cause severe health problems for humans. Microorganisms that cause health problems in humans are called pathogens and are often divided into viruses, bacteria and protozoa. Most pathogens causes acute diseases such as gastrointestinal related illness, although there are chronic risks connected to the exposure of some pathogens. (USEPA 2017)

2.1.2 Micro Plastics

In households, micro plastics can be found both in textiles and in a number of beauty products (Naturskyddsföreningen 2013). Tests of wastewater from Swedish and Finnish WWTPs have shown a reduction level of around 99% for plastics $>300\mu$m and around 70-90% for plastics $>20\mu$m (K. Norén et al. 2016,Magnusson, Jörundsdóttir, & F. Norén 2016).

2.1.3 Inorganic Compounds

Nutrients - Even though municipal wastewater plants are designed to reduce phosphorus and nitrogen, it is not completely reduced in the process. The level of total phosphorus (Tot-P) and total nitrogen (Tot-N) are measured for the effluent from Hurva WWTP and can be found in Table 2.

Heavy Metals - The most considerable contribution of heavy metals to wastewater is during heavy precipitation through runoff. The reason for this is metals in sediments from the distribution pipes and in particles on hard surfaces are suspended by the runoff to WWTPs. The majority of heavy metals are particle bound and are therefore reduced in separation processes. (Baresel, Ek, Ejhed, et al. 2017)

2.1.4 Organic Compounds

Measures of Organic Matter - There are different measures for the organic content in wastewater. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are the two organic measurements analyzed for the effluent of Hurva WWTP and these can be found in Table 2. COD is a measurement of the needed amount of oxygen to oxidize all organic material (Walker et al. 2019). BOD is a measurement of the demanded oxygen to biochemically oxidize organic material in the water (Hocking 2005). If the chemical and biochemical oxygen demands are about the same size, the water is easily biodegradable. If COD is much bigger than BOD it is not and in this case it could be toxic to microorganisms (Scholz 2006). Another measurement for organic material is the total organic carbon (TOC) which is an indirect measurement of the amount organic material (Balmér 2015). The dissolved organic compounds (DOC) is the measurement of the amount organic carbon in a filtered sample that is oxidized in the presence of a catalyst (Dahlberg, Knutsson, & Heinicke 2009).

Pharmaceutical Residues - Pharmaceutical residues include all of the active substances in medicine as well as byproducts that might be formed in or after leaving the human body. There are many types of pharmaceuticals with different properties.

In tests using wastewater from two major WWTPs in Stockholm the big majority of pharmaceutical residues were found as non particle bound (Wahlberg, Björlenius, & Paxéus 2010) and therefore no significant reduction of pharmaceuticals should be expected in a precipitation step. Although the reduction of pharmaceuticals during the chemical treatment is small, the process still contributes to the pharmaceutical reduction as a pretreatment step that enhances the efficiency of the biological treatment (Cimbritz et al. 2016).

Reduction of pharmaceuticals can be expected in the biological treatment step, but the reduction level varies for different types of pharmaceuticals, where some are almost completely reduced while some are not reduced at all (Hörsing et al. 2014).

Phenols - Phenols are used in paints and baby products such as bottles and food jars (Baresel, Ek, Ejhed, et al. 2017). In analysis of wastewater from two WWTPs in Stockholm the reduction level of phenols varied from 70% to 93% (Wahlberg 2016).

Phtalates and Other Plasticizers - Phtalates and other plasticizers are used in polymer materials. Due to carcinogenic properties of phtalates they are not as widely used today as they have been. Instead of phtalates other plasticizers are used, for example diisononylcyklohexandikarboxylat. (Baresel, Ek, Ejhed, et al. 2017)

Per - and Polyfluoroalkyl Substances (PFAS) - The contribution of PFAS to municipal wastewater originates from usage of products such as floor and window polish, cosmetic products and products for car cleaning (Hansson et al. 2016). Another source for PFAS can be leakage from clothing containing PFAS during laundry. There are over 3000 types of PFOS (Kemikalieinspektionen 2015) and only a few of these can be measured (Hansson et al. 2016).

Biocides - Biocides are mainly used in pesticides within the agriculture but it can also be used for other purposes. Generally there are low levels of biocides in Swedish wastewater, but it is worth to mention due to it's toxicity to humans. (Baresel, Ek, Ejhed, et al. 2017)

2.1.5 Whole Effluent Approach

In reality, the number of parameters analyzed is limited due to both economy, time constrains and knowledge. No matter how exhaustive an analysis of a raw water is it will never be able to give information about the whole water matrix. One approach to reduce the risks followed by the limited information is called the whole effluent approach. The idea of this approach is to examine the actual toxicity of the water rather than to measure levels of specific pollutants. With whole effluent approach the toxicity of the wastewater is tested on organisms of different trophic levels (Naturvårdsverket 2011). An advantage with this approach is that toxicity connected to the cocktail effect is examined. However, it should be noted the tests are only performed on specific organisms and the results does not necessarily correspond to the toxicity for the whole ecosystem or for humans. Therefore, this kind of tests only give an estimation of the toxicity, and in reality the water can be more toxic than what is indicated

2.2 Techniques for Further Treatment of Wastewater

In this project a total of 10 treatment methods were considered for the design of possible treatment chains. The treatment steps include both separating, oxidizing and inactivating processes.

The efficiency of the treatment methods is dependent on both the quality of the treated water and operating conditions, meaning that there is no general answer to how a method will work. The following information should be viewed as guidelines for how the treatment can be expected to perform rather than a definite answer.

2.2.1 Membrane Separation

Membrane processes are used in plants for advanced water treatment and result in high water quality. The method can be used for reduction of microorganisms, micro plastics as well as organic and inorganic substances.

The principle for membrane treatment is to remove contaminants through separation (Peters 2010). The membranes act as selective barriers which allow dissolved substances and particulate matter to pass through depending either on physical or chemical properties (Shirazi, Lin, & Chen 2010).

There are two main methods for how the flow is transported through the membranes, called crossflow and dead end (Figure 4). In dead end filtration the total flow passes through the membrane and the rejected material accumulates on the filter surface. As rejected materials accumulate on the filter, the treatment efficiency decreases and therefore a step for removal of rejected materials from the membrane needs to be added. In cross-flow the flow is parallel to the membrane, usually going through a pipe with the membrane material on the walls. While the flow passes through the pipe, water is pressed through the membrane according to Figure 4, making the flow through the pipes more concentrated. The treated flow that has passed through the membrane is called permeate and the rejected concentrated flow is called retentate. In contrast to dead end filtration, there is no accumulation of rejected substances on the membrane. (Calabrò & Basile 2011)

When using cross flow, the retentate need to be taken care of. Generally, the percentage of the feed that turns into retentate increases with decreasing pore size. If the water composition of the retentate allow, it might be possible to recirculate the flow into the WWTP. However, if the retentate contains compounds that are not treated in the WWTP, additional treatment of the retentate might be necessary. To know how the retentate should be treated, the retentate quality need to be analyzed. If the retentate cannot be recirculated into the system the water will be lost from the system.

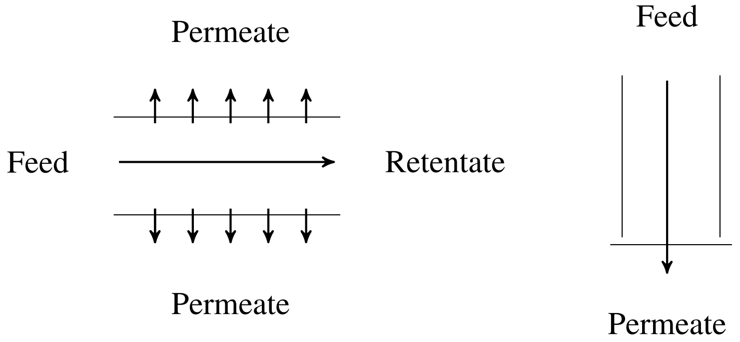

__Figure 4:__ Schematic sketch of crossflow (left) and dead end filtration (right). Figure made by author.

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With membrane processes a high quality effluent can often be achieved without being very affected by changes in the feed water quality (Peters 2010). Nevertheless it is important that some quality requirements are fulfilled for the feed water in order for the process to work properly. If the feed water is of poor quality the risk for fouling, i.e. clogging of the membrane increases.

Membrane fouling causes a higher energy need to maintain the same flow through the membrane (Voutchkov 2017) and is probably the biggest challenge connected to membrane treatment. Fouling can either be reversible or irreversible. Reversible fouling is the less damaging type and can be treated physically with backwash. Irreversible fouling can be caused by blocked pores or gel/biofilm layer formation and need to be treated with chemicals which decreases the life length of the membrane (Huyskens et al. 2008). Examples of types of fouling are biological fouling (Flemming et al. 1997) and inorganic fouling (Shirazi, Lin, & Chen 2010). One of the most important foulants for MF and UF is natural organic matter (NOM) (Howe et al. 2006). Especially the biopolymer fraction of the NOM has shown to cause irreversible fouling for UF and MF (Kimura & Oki 2017). Fouling is a complex process and different types of fouling can occur simultaneously and interact (Voutchkov 2017). The complexity makes it hard to foresee how the membranes will work for a specific wastewater, and it is important to test the membranes before implementation.

Perhaps the most crucial method for counteracting fouling is sufficient treatment of the feed water. Demanded quality of the feed water into the membranes are presented in page 11-13. Another essential method for limiting the fouling is backwash of the membranes (ibid.). The membranes are usually backwashed regularly based on a timer and common backwashing intervals are around 30-60 seconds every 20-120 minute (ibid.). Depending on the contaminants clogging the membrane, the backwash flow can either be recirculated to the start of the treatment plant, treated in an additional treatment step or disposed at another site.

A phenomenon that can cause operational problems for cross flow filtration is scaling. Scaling occurs when salts precipitates on the membrane surface as the retentate becomes more concentrated. To avoid this problem antiscaling chemicals can be used. (M Persson, Berghult, & Elfström-Broo 2003).

There are four main types of membrane filtration techniques being microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reversed osmosis (RO). The membrane types are primarily separated by pore size, which vary from around 0.1-0.0001μm (Baresel, Magnér, et al. 2017; CORPUD 2014). Membranes of smaller poresize results in higher water quality at the cost of a more expensive and energy demanding process and higher requirements for the feed water quality. A comparison for the four main membrane processes is presented in Table 1.

Table 1: *Comparison of the membrane processes.*

Membrane Processes	Pore Size [μm]	Pressure [bar]	Treated Parameters	Filtration Type
Microfiltration	0.04-0.1[1]	<5[8]	Turbidity[7], Some Bacteria[7], Large Macromolecules[7]	Dead end or Crossflow[7]
Ultrafiltration	0.01-0.1[2]	1-5[4]	Turbidity[6], Microorganisms[5] , Microplastics[3]	Dead end or Crossflow[7]
Nanofiltration	0.001-0.01[3]	2-50[3]	Same as UF + Multivalent Ions[7] Small Organics[7]	Crossflow[7]
Reversed Osmosis	0.0001-0.001[3]	5-70[3]	Same as NF+ Monovalent Ions[7]	Crossflow[7]

[2]*Hoyer 2019;* [2]*Heinicke et al. 2011;* [3]*Baresel, Magnér, et al. 2017;*
[4]*Calabrò & Basile 2011;* [5]*Svenskt Vatten 2015;* [6]*Edefell, Ullman, & Bengtsson 2019;*
[7]*Van der Bruggen 2018;* [8]*Tarleton & Wakeman 2007*

Micro Filtration

Purpose of Treatment - The pore size for MF is 0.04-0.1μm (Hoyer 2019). The method can be used for reduction of suspended solids and turbidity is removed in the process. Large macromolecules, large bacteria, Cryptosporidium and Giardia can be reduced by MF treatment. (Van der Bruggen 2018) In contrast to UF, viruses are able to pass through the MF membrane (Baresel, Magnér, et al. 2017).

Treatment Principle - The principle of MF is physical separation based on filtration.

Operational Aspects - Both dead end and crossflow can be applied in MF processes, although dead end is the most common method (Van der Bruggen 2018).

Quality Requirements for Feed Water - A disinfection step to prevent biological fouling of the membrane. (USEPA 2017)

Placement in Treatment Chain - The method is often used as a pretreatment step for RO or NF (Van der Bruggen 2018). Since there is no exhaustive pretreatment needed for the feed water to MF, it can be placed early in the treatment chain, although the demand for pretreatment due to risks connected to fouling should be examined before implementation.

Ultra Filtration (UF)

Purpose of Treatment - The poresize of UF is 10-100 nm (Heinicke et al. 2011) and only particulate compounds can be treated (Baresel, Ek, Ejhed, et al. 2017). UF can be used for reduction of parasites, bacteria and viruses and in Sweden the method is considered a microbiological barrier (Svenskt Vatten 2015). The turbidity is effectively removed and UF can be used for color reduction (Van der Bruggen 2018). Treatment with UF can also cause removal of tot-P, DOC and TOC (Edefell, Ullman, & Bengtsson 2019). Another effect of treatment with UF is efficient reduction of micro plastics (Baresel, Magnér, et al. 2017).

Treatment Principle - The principle of UF is physical separation through filtration.

Operational Aspects - UF can be operated with both crossflow and dead end flow, although the most common method is crossflow (Van der Bruggen 2018). The needed pressure difference for UF is 1-5 bar (Calabrò & Basile 2011).

Quality Requirements for Feed Water - Since there are many types of fouling that can occur, it is important to analyze the feed water and run the filter in pilot scale before implementation. Treatment of natural organic matter (NOM) might be needed before the UF step (Howe et al. 2006).

Placement in Treatment Chain - One application for UF is as a protective step before RO or NF. UF can also be implemented as a last step in a treatment chain as a microbiological barrier (Lidén 2020). As for all membrane processes, the demand for pretreatment due to risks connected to fouling should be examined before implementation.

Membrane Bio-Reactor (MBR) - One method for UF treatment is to use it in a membrane bioreactor, where an activated sludge process is combined with UF as a separating step instead of the conventional sedimentation step. (Baresel, Ek, Ejhed, et al. 2017)

Nano Filtration

Purpose of Treatment - The nominal poresize of nanofilters is 0.01-0.001μm (Baresel, Magnér, et al. 2017). Treatment with nanofiltration causes rejection of multivalent ions of more than 99% and for monovalent ions around 70% and for organic compounds with a molecule weight greater than the one for the membrane the reduction rate is around 90% (Nagy 2019). There are many types of nanofilters that target different groups of pollutants which can make them a more cost efficient alternative to RO, in the case where a less exhaustive reduction is needed than what is achieved with RO treatment (Roth, Poh, & Vuong 2014). Disadvantage of NF compared to RO is the poor rejection of nitrate and total dissolved solids (CORPUD 2014).

Principle of Treatment - In contrast to MF and UF, the treatment principle for NF is not solely filtration but it also has an osmotic effect meaning that pollutants are not only removed based on size (Roth, Poh, & Vuong 2014).

Operational Aspects - NF can only be operated with crossflow (Van der Bruggen 2018). A pressure difference of 2-50 bar is needed to operate the filter, due to the small nominal pore size (Baresel, Magnér, et al. 2017).

Quality Requirements for Feed Water - The feed water can be treated with UF or MF before entering the NF.

Placement in Treatment Chain - Due to the low rejection rate of nitrate the method might need to be combined with an effective method for nitrogen removal (CORPUD 2014). In the case of other membrane processes in the same train NF should be placed after MF/UF and before RO.

Reversed osmosis

Purpose of Treatment - The nominal poresize for RO is 0.0001-0.001 μm (Baresel, Magnér, et al. 2017) which means that generally all particles smaller than this is reduced. RO is the membrane that reduces most substances and is used for desalination of saltwater in drinking water production (Van der Bruggen 2018). The method has also been used in preparation of water to industries due to the high quality of the treated water (Saleh & Gupta 2016). Since the poresize of RO is smaller than for NF, basically it rejects the same compounds as NF with an addition of monovalent ions (Van der Bruggen 2018). Although RO treatment results in a high quality water, it should be noted that there are still some substances that might pass through the membrane (Baresel, Magnér, et al. 2017).

Treatment Principle - The principle for treatment with RO is osmosis where the flow is driven by an applied transmembrane pressure that is higher than the osmotic pressure.

Operational Aspects - RO can only be operated with cross flow (Van der Bruggen 2018) and as much as about one fourth of the treated water can be turned into retentate (M Persson, Berghult, & Elfström-Broo 2003). How much water is turned into retentate depend of the quality of feed water where higher quality of the feed water results in less rejection water. A pressure difference of 5-70 bar is needed to run the process (Baresel, Magnér, et al. 2017). The lifetime of an RO membrane is around 2-5 years and is increased with proper pretreatment (Saleh & Gupta 2016).

Quality Requirements for Feed Water - For the RO to work properly, it is important that the incoming water is of high quality, therefore UF and MF are good pretreatment methods (Bartels 2006). To reduce the risk of biofouling a disinfection step can be added before going into the membrane (Hoyer 2019). High levels of ions in the treated water can be problematic since it can cause scaling of the membrane, to prevent this to happen, anti scaling chemicals can be used (Bartels 2006). Calcium phosphate can be especially problematic in treatment of wastewater due to it's low solubility and that the concentration in wastewater can fluctuate (ibid.).

Placement in Treatment Chain - Due to the high quality demands for RO feed water, the method should be placed as one of the last steps in a treatment chain. The process should be followed by pH and hardness adjustment due to the ion reduction.

2.2.2 Advanced Oxidation Processes

In oxidation processes radicals are formed and react with microorganisms. The reactions cause both an increase of the decomposition rate for the water and degradation of contaminants to other compounds.

Ozonation

Purpose of Treatment - Ozonation is an effective treatment method both for reduction of many pharmaceuticals as well as for disinfection and color reduction by oxidation of humus molecules (Huber et al. 2003,Wahlberg, Björlenius, & Paxéus 2010 Svenskt Vatten 2015). Most organic compounds can be oxidized through ozonation given the right circumstances, although high doses might be needed to get the desired result with a temperature around 10-20 ^oC and a natural pH value (Wahlberg, Björlenius, & Paxéus 2010).

Treatment Principle - For all applications of the method the principle is oxidation of the treated substance by ozone and hydroxyl radicals. The hydroxyl radicals are formed through spontaneous break down of ozone and causes a more effective and less selective oxidation than the ozone molecules (Hoyer 2019). For example, sufficient reduction of Ibuprofen cannot be achieved even with a high O_3 concentration (Baresel, Ek, Ejhed, et al. 2017).

Operational Aspects - The effect of the ozonation depends on the ozon dosage where a lower dosage (around 0.5-1.0 mg O_3l^{-1}) is needed for disinfection than color reduction (around 5 mg O_3l^{-1}) (Svenskt Vatten 2015). For reduction of pharmaceuticals the required dosage can be 0.3-1.2mgO_3/mg DOC (Baresel, Ek, Ejhed, et al. 2017) There are no given dosages for different levels of reduction, mainly due to the varying chemical and microbial composition of the water over time (Baresel, Ek, Harding, & Bergström 2014). Consequently it is hard to regulate the process since contaminants would not be reduced at the desired extent in the case of under dosage at the same time as over dosage would lead to an unnecessary increase of byproducts. Furthermore, it is stated in Livsmedelsverket's (2017) drinking water regulations that the use of chemicals should not exceed the necessary amount which might be hard to ensure due to the difficulties regarding dosage regulation. One important aspect of ozonation, especially in the case of drinking water production, is the formation of unwanted byproducts including the carcinogen bromate and N-nitrosedimethylamine (Urs. von Gunten & Hoigne 1994, Baresel, Magnér, et al. 2017, Hübner, Urs von Gunten, & Jekel 2015, Richardson et al. 2007). Another aspect to consider regarding ozonation is that ozon is a non stable gas and therefore need to be produced directly at the treatment plant (Hoyer 2019).

Quality Requirements for Treated Water - The reduction rate is negatively affected by high levels of suspended material and studies have shown ozon concentrations of 0.3-1.2mg O_3/mg DOC (Baresel, Ek, Ejhed, et al. 2017). If the water has a high nitrite content, ozone concentrations of 1.1 mg/mg N_2 might be needed to compensate for the ozon that is used for oxidation of nitrite (Wert, Rosario-Ortiz, & Snyder 2009).

Placement in Treatment Chain - The placement of ozonation in the treatment chain depends on the purpose of the treatment. The most common placement of the ozonation treatment is in the end of the treatment chain. When the purpose of the ozonation is reduction of pharmaceuticals or other micropollutants, it is common to implement the treatment step between two biological steps or to recirculate the ozone in the active sludge process. (Baresel, Magnér, et al. 2017) It is generally positive for the treatment if the treated water has gone through a thorough biological treatment, for example an MBR-process, before the ozonation (Baresel, Ek, Harding, & Bergström 2014). Ozonation can be used before a membrane process to inhibit fouling (Zhang et al. 2013). Due to risks connected to formation of toxic byproducts a complementing treatment step after ozonation might be needed.

Ozonation / Hydrogen Peroxide

An alternative ozonation method is to combine ozone and hydrogen peroxide. With this method the oxidation of contaminants susceptible to reactions with hydroxyl radicals is effective and usually stands for a big part of the degradation of contaminants (Ikehata & Li 2018).

Ultraviolet Light / Hydrogen Peroxide

Another oxidation method is combination of hydrogen peroxide and exposing the water with ultraviolet light. The principle for the method is that hydroxide peroxide is radiated with ultraviolet light which causes hydroxyl radicals to form. Since the hydroxyl groups are strong oxidants this is an effective method for oxidation of contaminants. (Mierzwa, Rodrigues, & Teixeira 2018)

2.2.3 Ultraviolet Light (UV) Treatment

Purpose of Treatment UV treatment is an effective disinfection method against bacteria, parasites and some viruses. It is a highly effective method to treat both Giardia and Cryptosporidum as well as for E-coli. Generally the treatment is less efficient for reduction of spore forming bacteria and it is especially ineffective against Adenovirus. The disinfection has no effect in the distribution network. (Svenskt Vatten 2009)

Treatment Principle - The principle of the method is to expose the water to UV light. The main principle for inactivation using UV light is that the light reaches the cell of microorganisms which damages the DNA and inhibits reproduction. Another effect is that the light might react with enzymes or other proteins in the cell which inactivates the microorganisms due to disruption of their metabolism. (ibid.)

Operational Aspects - The efficiency depends on the UV dosage, i.e. the amount of light a specific point is exposed to after passing through a UV aggregate. The dosage of UV light is expressed as energy per area and in Europe the most common unit is Jm^{-2}. The most common dosage in large parts of Europe is $400\mathrm{Jm}^{-2}$ and therefore this is the most convenient choice. In general this dosage will result in a greater reduction than 4-log for most microorganisms. However, if the UV treatment is meant to be a complementing step in a plant with a high microbial safety level a lower dosage might be relevant. Overall, UV treatment is a compact method with a low demand for maintenance. The method is sensitive to small dips in the energy distribution. (ibid.)

Quality Requirements for Treated Water - For UV treatment to perform efficiently the treated water need to have a low transmissivity/high absorbance for UV light (UV_{abs}). For this to be true the concentration of organic substances, especially humus particles must be low. Optimally there are measurements of UV_{abs} that can be used for the dimensioning water quality but if this is not possible measurements of TOC, COD or color can be used since these often follow the same patterns as the UV_{abs}. Other parameters that can have a negative affect for the UV treatment are high concentrations of ozon, iron, permanganate and thiosulfate. (ibid.)

Placement in Treatment Chain - Regarding the placement of UV treatment in the treatment chain it should be one of the last steps in the treatment chain, and the most common placement is right before the low reservoir. If the treatment is placed after the reservoir there is a risk for the UV aggregate to be damaged due to pressure strokes which could lead to glass or mercury in the distribution pipes, in contrast to the case of placement before the reservoir where it would sink to the bottom of the reservoir. UV aggregates should be placed before pH-adjustment and other disinfection steps if there are any. There should always be a possibility for measurements between the UV aggregate and other disinfection steps. (ibid.)

2.2.4 Treatment with Activated Carbon

Processes with activated carbon are used in drinking water production for removal of organic micropollutants and dissolved organic carbon (DOC). Some reduction of inorganic ions can occur. (Worch 2012)

The principle for the treatment is adsorption of contaminants to the surface area of the activated carbon. Small pores are desired to achieve a large surface area at the same time as large pores are needed to enable faster contaminant transportation to adsorption sites, therefore the pore size distribution is of importance. Generally it can be said that the adsorption increases with decreasing temperature, increasing internal surface for the activated carbon and increasing molecule size of the compound. (Worch 2012)

There are two different methods for treatment with activated carbon namely Granular Activated Carbon (GAC) and Powdered Activated Carbon (PAC). In GAC processes granular activated carbon is placed in filter beds. In treatment with PAC, powdered activated carbon is added in a reactor. (ibid.)

Granular Activated Carbon

Purpose of Treatment - According to Baresel, Magnér, et al. (2017) GAC might be the most effective treatment for reduction of pharmaceuticals. The reduction varies for different types of pharmaceuticals, for example tests using a full-scale GAC treatment plant resulted in a reduction rate from 17% for propranonol up to >98% for indomethacine. (Grover et al. 2011) Furthermore, GAC treatment has a significant reduction of microorganism. (Baresel, Magnér, et al. 2017). Reduction of Nitrate has been observed and is most likely a result of spontaneous nitrification due to the anoxic environment as a consequence of bacterial growth. Reduction has been observed of COD as well as for some metals (Zn, Cu, Hg, Ni, Co, Mn) although the effect on the metals decreases after some time of operation with exception to Cu and Hg. (Ek et al. 2013) In tests where wastewater from an MBR process was treated with GAC, triklosan and oktylphenol were efficiently reduced while no considerable reduction of Bisphenol A or nonylphenol could be observed (Baresel, Ek, Harding, & Bergström 2014).

Treatment Principle - In addition to adsorption GAC also has a filtering property and therefore can operate without any additional separation step (Worch 2012). The filter effect can be compared to a microfilter with a poresize of around 10μm (Baresel, Ek, Ejhed, et al. 2017).

Operational Aspects - The filters can be designed with circular or rectangular cross section and can either be closed pressure or gravity filters. A common method is to place a layer of sand between the activated carbon and the bottom of the filter to separate carbon from the next treatment step. In the case of an added sand layer the filter need to be backwashed regularly to maintain the desired pressure. (Worch 2012) After a while of operating most of the pores is filled and the process will be less efficient. When the material in the GAC filters is saturated it can be reactivated. Usually the reactivation is done by the manufacturer rather than at the treatment plant (Hoyer 2019). The reactivation can be done either chemically where dehydration chemicals are added to extract liquid or thermally where the material is heated by a being exposed to gas of 800^oC-1000^oC. The thermal method is the most common reactivation method. Typically the filter has an empty bed contact time (EBCT) is 5-30 min. (Worch 2012)

Quality Requirements for Treated Water - The absorption is competitive and therefore it is beneficial to treat the water from pollutants that are not targeted in the process. When the targeted pollution is pharmaceutical or other micro pollutants, NOM particles are competing for absorption spots and should therefore be reduced before going into the treatment step.

Placement in Treatment Chain - It is usually beneficial to implement the GAC as a complementing last step in the treatment process since the pollutants the filter is meant to reduce will be better targeted if the treated water is more clean. (Baresel, Magnér, et al. 2017).

Biologically Active Filter (BAF)
If there are degradable compounds in the wastewater treated in a GAC filter, a biofilm can be formed, making it a biologically active filter (BAF). The biofilm enhances the reduction of pharmaceuticals since they can be degraded by microorganisms in the biofilm (Baresel, Ek, Harding, Magnér, et al. 2017). Although BAC has been investigated in multiple projects, the knowledge of the phenomenon is still limited and further research is needed. Nevertheless, the potential of biofilm formation should be taken into account in the consideration of implementation of GAC filters.

Powdered Activated Carbon
Purpose of Treatment - See GAC.

Treatment Principle - In contrast to GAC filter treatment there is no biological function or physical barrier when using PAC. (Baresel, Magnér, et al. 2017)

Operational Aspects - PAC has a grain size of <40μm which leads a faster adsorption process than for the GAC filters and consequently, the needed EBCT is shorter (Worch 2012). In PAC treatment a powder of activated carbon is mixed with the water which means that the technical equipment and materials used must be resistant to corrosion (Baresel, Magnér, et al. 2017). PAC can be operated both at a constant flow rate or added in batches. The most common method is to add PAC in a constant flow. (Worch 2012) A negative effect of treatment with PAC is losses of PAC to the sludge which ca be a problem for implementation in Swedish treatment plants due to the usage of sludge. (Baresel, Magnér, et al. 2017)

Quality Requirements for Treated Water - See GAC.

Placement in Treatment Chain - One method for treatment with PAC is to implement it in an activated sludge process which enhances the removal of organic material both by providing an area for microorganisms to adsorb to and by adsorption of non biodegradable substances and substances that prevent biological processes. Another method for PAC treatment is to combine the process with nano- or ultrafiltration. (Worch 2012)

2.3 Case studies

2.3.1 PU:REST beer, Stockholm, Sweden

In the spring of 2018 IVL (Swedish environmental institute) launched a beer made with treated wastewater. The raw water was municipal wastewater treated in a research plant connected to Hammarby Sjöstadsverk in Stockholm municipality. One objective with the project was to demonstrate that there are technical solutions available to treat waste water into drinking water quality. (IVL 2018) In the process 200 liters per hour was produced in batches.

In this project a fast production of drinking water was prioritized. Therefore, it should be noted that the operation in this process is not optimized and cannot be compared with a DWTP providing households with drinking water continuously.

The first step in the treatment process was MBR using an UF with a poresize of 0.04μm. The hydraulic retention time in the MBR was 13 hours. The purpose of this step was to improve the quality of the incoming water to the RO step in order to protect the RO membrane. In the RO step almost all compounds with exception to some molecules were removed. The recovery rate for the RO was 20%. The purpose of the GAC filter was to remove molecules that have passed through the RO membrane and the empty bed contact time was around 15 minutes. As a last complementing step UV was used for disinfection.

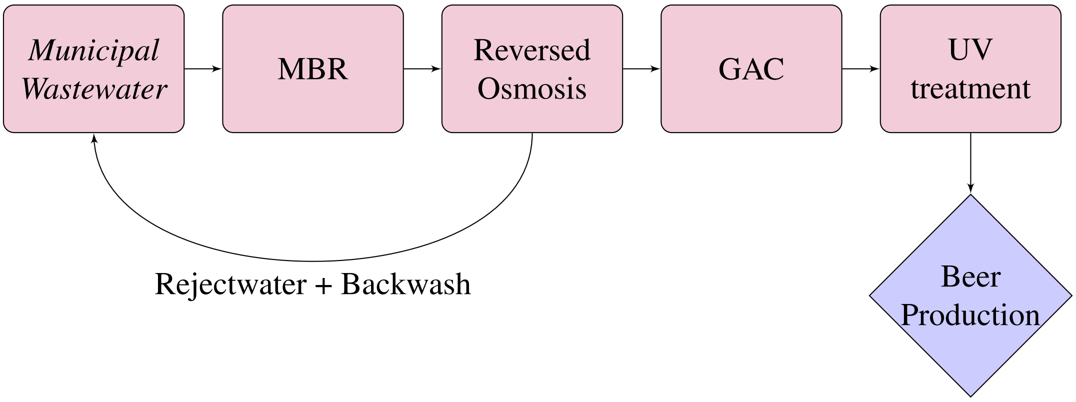


Figure 5: *Flowchart made by author over the DWTP for the raw water used in the production of PU:REST beer*

The project has been successful in terms of quality where the quality was even higher than for regular tap water for chemical parameters with exception for color, iron, COD and ammonium. The quality was fulfilled regarding microbiological parameters, as well as for Nonyl and octyphenols, phthalates, PAHs, PCBs, PFASs and the only micro plastics measured came from sample contamination and no pharmaceutical residues were found in the drinking water.

2.3.2 Mörbylånga, Sweden

Mörbylånga municipality, located on the Swedish island Öland, has faced problems with water scarcity in recent years. To solve this problem a new WWTP has been built with the raw water being a mixture of brackish water from wells and industrial wastewater from a chicken factory. The plant was opened for treatment of the brackish water in the summer of 2019. (Mörbylånga Kommun 2019)

The DWTP (Figure 6) has the capacity to produce 4000m^3 drinking water every day. For this, 5800m^3 raw water is needed, whereof 1350m^3 can consist of recovered industrial wastewater.

Before reaching the DWTP the brackish water is treated with oxidation and the industrial wastewater is treated in an advanced WWTP and in an industrial WWTP (IWWTP). Before going into the IWWTP, the industrial wastewater goes through treatment at the chicken industry consisting of filtration and flotation. In the IWWTP the water is treated in sequential batch reactors (SBR), followed by sand filtration.

The first step in the DWTP consist of UF with a nominal poresize of 20nm. The purpose of the UF treatment is both to remove microorganisms and particles that may harm the following RO membrane. The next step in the DWTP is RO treatment with a recovery rate of 75%, after this step, there should be no unwanted substances in the water. After the RO the water goes through remineralization in limestone contractors to adjust the hardness. The last step in the treatment process is disinfection through UV treatment with an intensity of 400Jm^{-2}. If needed, additional disinfection through chlorination is possible as a last treatment step before the water reaches the distribution network. (Asteberg & Rogers 2019)

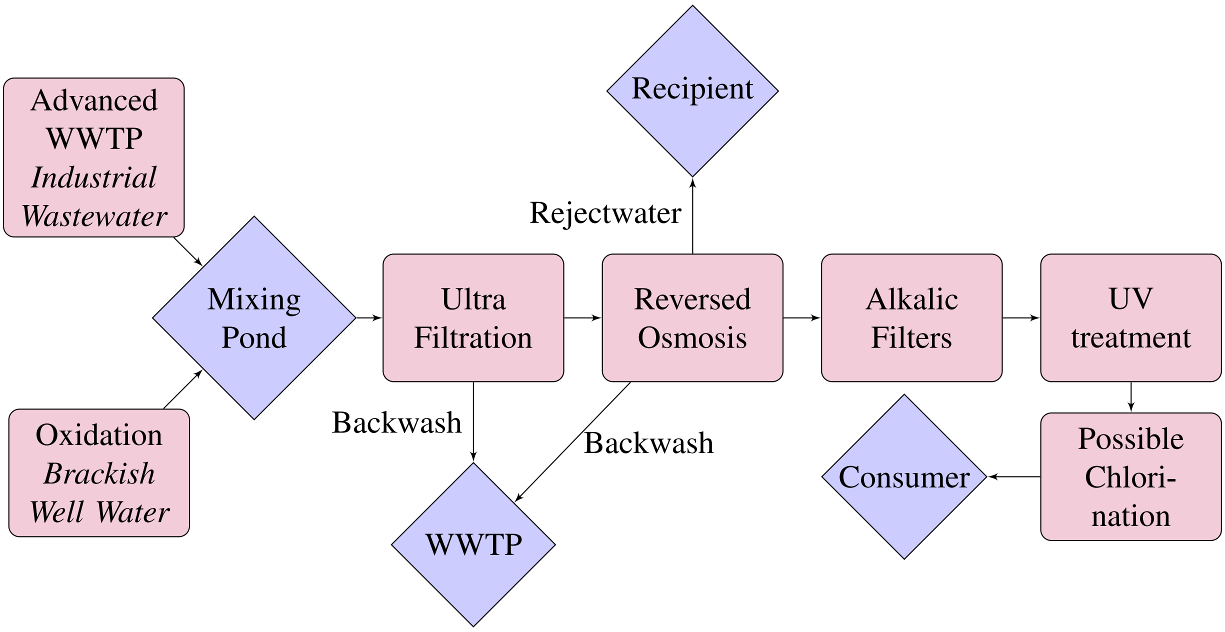


Figure 6: *Flowchart made by author over the complete drinking water treatment process at Mörbylånga DWTP*

The main purpose of the advanced WWTP is to significantly reduce the content of microorganisms and the process is contains three treatment methods (Figure 8). The first step in the advanced WWTP for the industrial wastewater is flocculation with ferric chloride, using 5 mg $FECl_3$ for each liter treated water, for removal of suspended solids in the water phase as a pretreatment step for the following UF. The UF has a nominal poresize of 20nm and the purpose of the treatment is to remove microorganisms from the water phase. The industrial wastewater treatment process is still being tested and has not yet been put in use. As a last step UV treatment with an intensity of 400Jm^{-2} is used for disinfection.

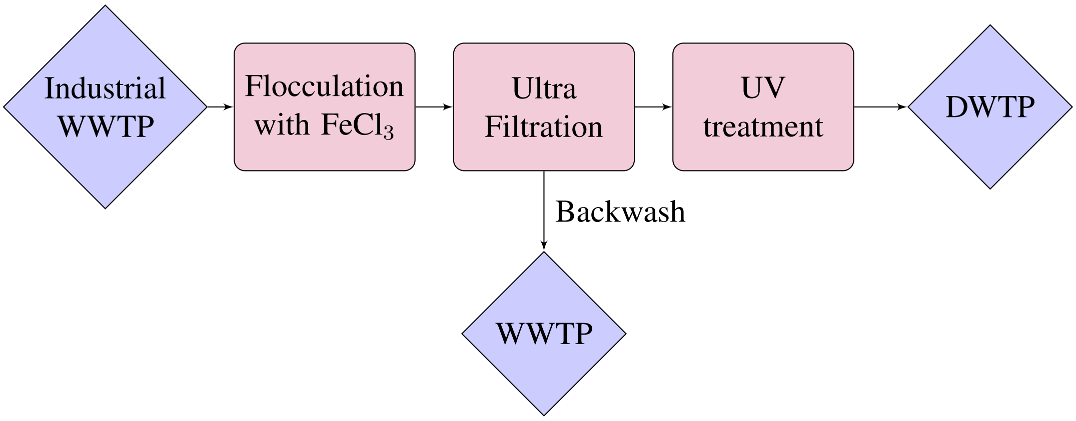


Figure 7: *Flowchart made by author over the advanced WWTP that treat the industrial wastewater from the chicken factory*

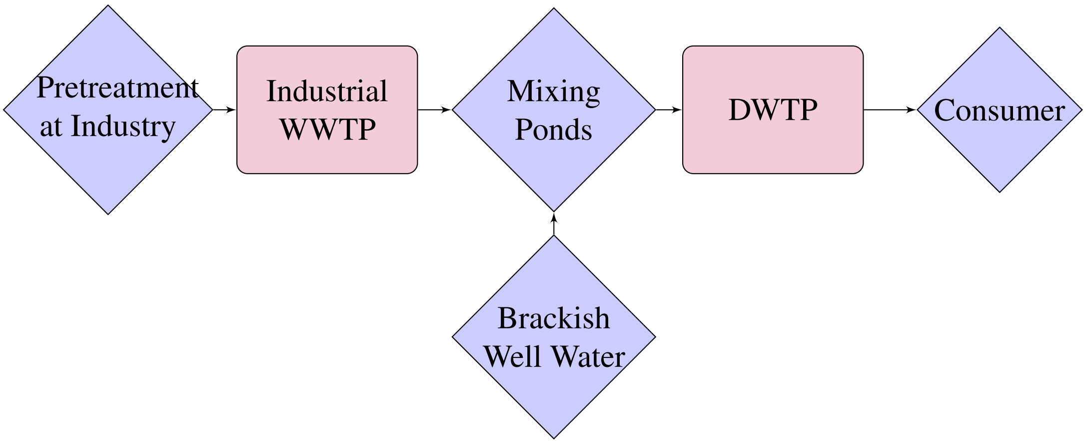


Figure 8: *Flowchart made by author over the advanced WWTP that treat the industrial wastewater from the chicken factory*

2.4 Current Drinking Water Treatment Plant in Hurva

The raw water used in Hurva's drinking water production is groundwater from a drilled well that is pumped from the well to Hurva DWTP. All information about the DWTP in Hurva is gathered by visiting the plant and talking to operating technician at site. The DWTP provides all of Hurva's population with drinking water. The treatment plant is rather simple and does not include any treatment steps demanding high levels of maintenance, energy consumption or a large area (Figure 9). For data of flows into and out from Hurva DWTP, see Table 8 in Appendix.

The first step in the treatment process is a bagfilter with a poresize of 100μm which is changed once in 14 days. After the bagfilter the water is transported to a softening filter (BWT Rondomat HVD 300-1200) which is regenerated with salt pellets 2 times in 7 days. The salt dosage corresponds to around 20 kg/day. After passing the softening filter the water is treated with UV radiation. The calculated UV dosage in the end of the filters lifetime is 400Jm^{-2} and the transmission is 90%. After the UV treatment the water is transported to a reservoir of 100m^{2} were it is stored before going to the consumers via another UV filter with the same intensity as the former UV-treatment.

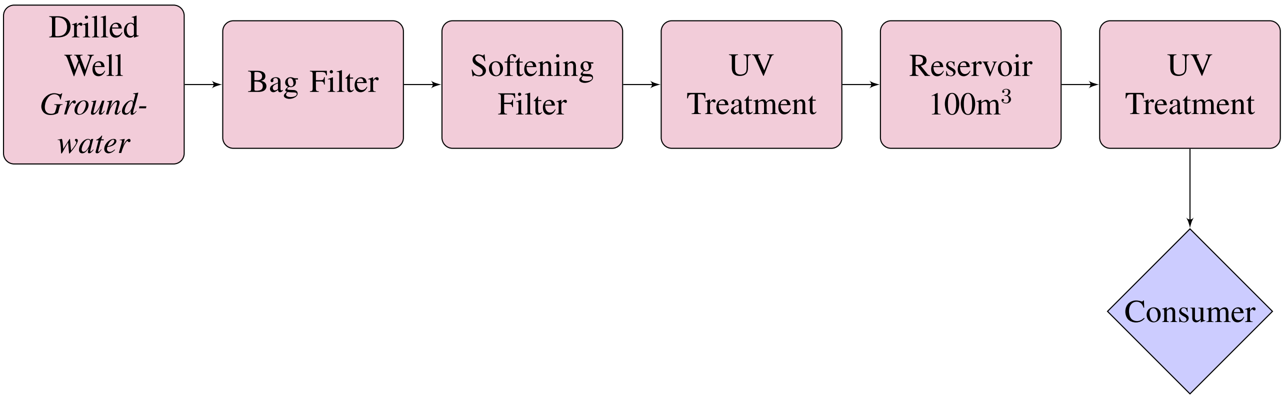


Figure 9: *Flowchart made by author over the present DWTP in Hurva*

2.5 Current Wastewater Treatment Plant in Hurva

The water is treated mechanically and chemically according to Figure 10. The chemical treatment consist of phosphorus precipitation by addition of an iron based precipitation chemical (PIX 118). The dosage of PIX 118 varies over the year where the yearly mean dosage is 280 mg for each liter treated water. Addition of the flocculation chemical PAX is possible and is mostly used during summers when there is a high content of algae. The dosage of PAX depends on the algea content where more algea requires higher dosages. VA SYD does not have any measurements of the PAX dosage. Since there is no biological treatment step, the nitrogen reduction is low. In case of high flows the water can be bypassed directly from the balancing pond to the Polishing pond, skipping the chemical treatment. Chemical sludge is extracted and transported to Ellinge WWTP. (VA SYD 2018a)

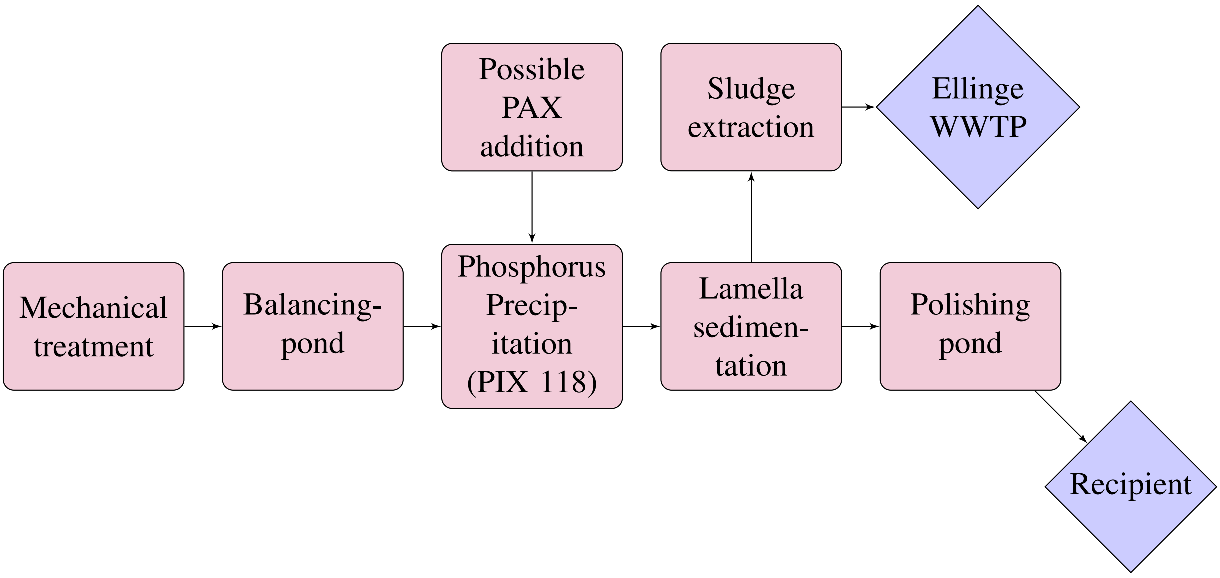


Figure 10: *Flowchart made by author over the present WWTP in Hurva based on information given in the year report 2018 (VA SYD 2018)*

Hurva WWTP is dimensioned for 500 pe and treats water from both Hurva and the nearby village Östra Strö, with the larger fraction coming from Hurva. In total 421 persons were connected to the plant in February 2019.

In 2018 the amount of additional water was 62% of the total inflow to the WWTP and 2017 and 2016 the fraction was 72% and 76% respectively (VA SYD 2016, VA SYD 2017, VA SYD 2018a). The wastewater flow from Hurva is driven by gravitational pressure while the wastewater from Östra Strö is pumped through the pipes.

The energy consumption consist of giving power for the treatment and to heat facilities. The energy consumption both 2018 and 2017 was around $0.75\mathrm{kWhm}^{-3}$. The WWTP and the distribution pipes were put into use in 1960. (ibid.)

Quality restrictions for the plant were stated by the Swedish board for environmental and health safety in 1996 and includes a limiting value for the residue level of tot-P and BOD_7 of 0.5 and $15\mathrm{mgl}^{-1}$ respectively. The quality restrictions also include a lowest value for the oxygen saturation of 60%. (ibid.) It should be noted that the restrictions are not very restrictive and does not include requirements for nitrogen reduction.

Measurements are made on the in- and outgoing water to and from the WWTP of tot-P, tot-N, BOD_7, SS and COD_{cr}. Mean values of measurements from March 2017 to February 2020 are shown in Table 2. The quality of the treated wastewater is not high enough to be treated in the advanced processes described in section 2.2. Before a more advanced treatment plant can be considered relevant, nitrogen removal need to be implemented in Hurva WWTP. For data of the outflow from Hurva WWTP, see Table 9 in Appendix.

	SS [$\mathrm{mgl^{-1}}$]	BOD_7 [$\mathrm{mgl^{-1}}$]	COD_{cr} [$\mathrm{mgl^{-1}}$]	P-tot [$\mathrm{mgl^{-1}}$]	N-tot [$\mathrm{mgl^{-1}}$]
January	6	3	30	0.10	14
February	8	4	30	0.15	15
March	10	4	31	0.16	13
April	13	6	38	0.17	14
May	9	4	34	0.11	16
June	5	4	34	0.09	20
July	3	4	38	0.15	17
August	3	4	31	0.08	17
September	2	3	32	0.12	13
October	4	3	33	0.06	21
November	5	4	30	0.07	20
December	4	3	30	0.08	16

Table 2: *Mean values for quality parameters in the effluent from Hurva WWTP between March 2017 and February 2020*

2.6 National Food Agency's (NFA) Regulations for Drinking Water Quality

In Sweden the regulations for acquired drinking water quality are given by Livsmedelsverket, the Swedish national food agency. The guidelines apply to several parts of the drinking water production in addition to the quality of the final product (Livsmedelsverket 2017). In Figure 11 some of the different compartments restricted by Livsmedelsverket are shown, with the parts considered to be most relevant for implementation of a circular waste water system marked with red color. The parts viewed as more important for waste water recycling in this project are the ones considered to differ most from a conventional waste water system. In this section the parts considered most important are described further.

Sampling and analysis frequency is marked with red in the figure since a circular system should have extensive sampling and analysis, but is not discussed further in this project.

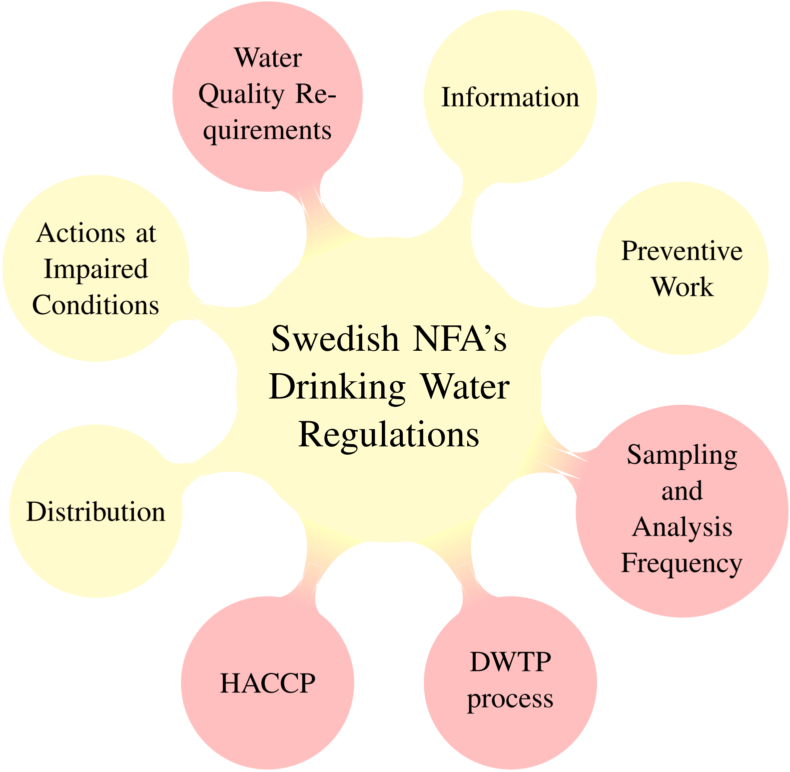


Figure 11: *Compartments of Swedish NFA's guidelines with the parts considered most relevant marked in red. Figure made by author.*

2.6.1 Water Quality Requirements

The regulations for the quality of drinking water consist of concentration limits and are divided into chemical and biological parameters of which the chemical part also include radioactive parameters. The guidelines include highest recommended concentrations both for outgoing water from the treatment plant and for the water that is delivered to consumers. (Livsmedelsverket 2019b)

Chemical Parameters

Some of the chemical contaminants included in Livsmedelsverkets guidelines are typically occurring in high concentrations for sewerage water including nitrite, nitrate and ammonium.

Microbiological parameters

Microbiological contaminants in a DWTP is often as a consequence of fecal contamination which indicates that there is waste water in the system. There are 8 microbiological parameters regulated by Livsmedelsverket and 5 of the parameters indicate contamination of sewerage water (Livsmedelsverket 2019a). It should be noted that the microbiological parameters measured are not necessarily toxic but rather an indication that there is a risk for waterborne diseases. (ibid.)

2.6.2 DWTP process

A treatment plant should be designed and constructed to meet all of the quality demands for drinking water. Substances that are added for the treatment process should be used in such a concentration so that the treatment is as effective as possible without resulting in higher concentrations of the substances in the drinking water than necessary (Livsmedelsverket 2017).

Microbiological Barriers

A microbiological barrier is a treatment step that reduces bacteria, viruses and protozoa. There should always be microbiological barriers in a DWTP, where the number of barriers needed depends on the raw water quality (Livsmedelsverket 2019a). In Sweden, following five treatment steps can be defined as microbiological barriers: Infiltration with a residence time under 14 days, chemical precipitation followed by filtration, slow sand filter, primal disinfection and membranes. (Svenskt Vatten 2015) For more information about the microbiological barriers considered in this project, see section 2.2.

To calculate the microbiological safety level in a certain DWTP, Microbiological Barrier Analysis (MBA), a tool developed by Norskt Vann and Svenskt Vatten, can be used. The calculations in the MBA tool is based on the DWTP's size, type and quality of the raw water, precautionary actions in the raw water source and the operational conditions. The MBA contains specified regulations for different types of surface water and groundwater but there are no recommendations specified for waste water reclamation. If the raw water is exposed to a risk for contamination of wastewater it is automatically considered to need the highest microbial safety level. The analysis is divided into the 5 main steps listed below.

1. Decision of microbiological safety level needed based on the water quality and the size of the treatment plant
2. Examination of whether actions or monitoring of the water source should be seen as contributing to the reduction of microorganisms
3. Identification of the log removal provided by *Separating Barriers*
4. Identification of the log removal provided by *Inactivating Barriers*
5. Results

The microbiological safety level is based on the microbiological quality of the treated water and the size of the treatment plant. The quality parameters included in the analysis are Clostridium Perfringens, parasites and E.coli and the different safety levels are defined as the needed Log-reduction of the three microbiological parameters. The regulations based on plant size is divided into three categories: < 1000 pe, 1000 pe < 10 000 pe and >10 000 pe. (ibid.)

The second step examines whether monitoring of the water source or other precautionary actions should be seen as an addition to reduction of the microbiological parameters. (Svenskt Vatten 2015)

In the third step the separating barriers' contribution to the microorganism reduction is studied. The MBA tool contains standard values for the reduction of the three categories of microorganisms for a number of treatment steps. For the standard values to be accurate the monitoring of both power supply and certain water quality parameters need to be working satisfactorily. The quality parameters considered in this step are those that affect the efficiency of the treatment. (ibid.)

The fourth step in the MBA focuses on inactivating barriers. The disinfection steps are coupled into pre disinfection, primary disinfection and secondary disinfection. Pre disinfection refers to a treatment step which results in reduction of microorganisms even though it is not the purpose of the specific treatment step. In primary disinfection the aim with the treatment step is to reduce microorganisms in the water and in secondary disinfection a disinfection chemical is added as a last polishing step and the reduction occurs in the distribution lines. There are a number of reactions happening during a disinfection process and there is no possibility to have full control over all reactions. When calculating the contributed reduction level from a treatment step, simplifications are made. The calculations are based on a number of parameters including pH, temperature, contact time and concentration. Optimally the values used in the calculations come from measurements on the treated water. However, if there are no measured values available theoretical models can be used to calculate the expected reduction. (ibid.)

In the last step the results from the 4 first steps are combined. For the microbiological treatment of the water to be adequate Equation 1 must be fulfilled. In the equation r represents the Log reduction needed, b, v and p represent bacteria, viruses and parasites and $s1 - s4$ represents step 1-4 in the MBA. (ibid.)

$$(rb + rv + rp)_{s1} \leq (rb + rv + rp)_{s2} + (rb + rv + rp)_{s3} + (rb + rv + rp)_{s4} \tag{1}$$

Another tool for microbiological barrier, which has not been considered in this project, is analysis is Quantitative Microbiological Risk Assessment (QMRA). QMRA is a modeling tool for calculating the microbiological risks for a DWTP (Livsmedelsverket 2019a). The tool is more exhaustive and allows adjustments in inputs for microbiological quality of the raw water, effectiveness and treatment steps and size of the DWTP. The model also allows simulation of disruptions in the process. (Pettersson et al. 2017)

2.6.3 HACCP

To ensure a safe drinking water the Hazard Analysis and Critical Control Points (HACCP) tool is used. The HACCP tool is designed by Livsmedelsverket and applies to all food and drinks that are produced in Sweden. Producers and providers of drinking water are responsible to identify and reduce or eliminate possible hazards according to the HACCP principle. Suppliers of drinking water are responsible to follow the list below. (Svenst Vatten 2014)

- Identify potential hazards and, if needed reduce, eliminate or prevent these.
- Identify critical control points in the processes where control is necessary to prevent, eliminate or reduce a hazard.
- Determine threshold values by critical control points for what is acceptable.
- To maintain and implement procedures to monitor the critical control points.
- Determine actions that should be taken when a critical control point is not under control.
- Determine procedures to be done regularly to make sure that the former points are fulfilled.
- To document that the former points are fulfilled according to journals customized for the size of the DWTP.

3 Methods and Materials

As mentioned in Section 1.1, the two objectives of this study were to examine the process technical aspects of the possibilities to implement a circular waste water system in Hurva and to estimate the waterbalance in the system. Therefore, this chapter is divided into two parts where the first part describes the waterbalance estimate methodology and the second part the design process for the treatment chains.

The waterbalance estimation was based on mass balance equations where the input to the system was assumed to equal the outputs. The calculations were done using monthly data of the inflow to the WWTP and DWTP, since this was the data available.

The design process was divided into the five parts listed below. To better understand the design process it might be helpful to return to Section 2.2 for information about the treatment methods.

1. Treatment efficiency demands were determined. (Table 3)
2. The methods were evaluated separately and five of these were considered not to be relevant in the treatment chains. (Table 4)
3. Information about treatment performance and feed water quality for the remaining treatment methods was summarized. (Table 5, 6 and 7).
4. Designing the treatment chains based on information found in the three former steps, the list of guidelines, assumptions and simplifications given on page 32 and by following the flowchart shown in Figure 14.
5. A simplified MBA was performed for the generated treatment chains.

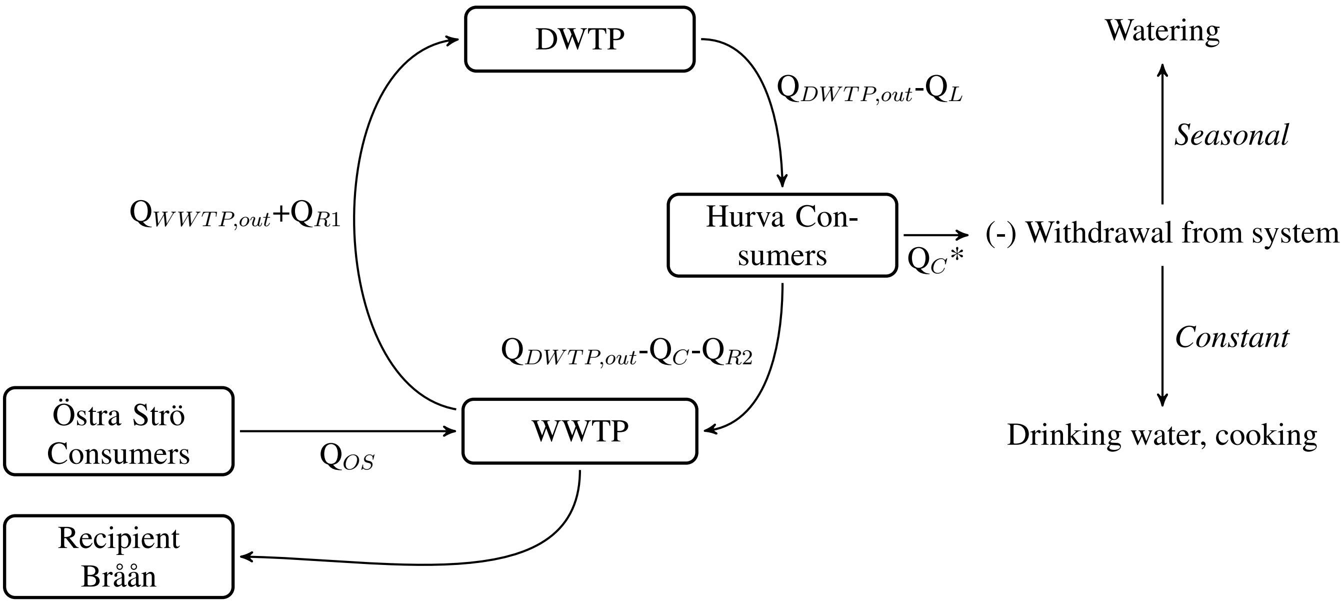
The methodology has been formed based on information in Section 2 which has been gathered in literature studies. Additional to this, operational engineers and other persons working within the field have been consulted regarding the methodology for the design of treatment chains.

3.1 Waterbalance Estimate Methodology

Since there are both losses and additions of water to the water system during the process, a water balance was calculated to make sure that there is enough water in the system. When DWTP and WWTP is used in this section, it refers to the wastewater/drinking water part of the planned circular treatment plant if nothing else is given.

In Figure 12 the water cycle as it has been viewed in the calculations is presented. In the figure Q_{R1} (m^3s^{-1}) represents infiltration and inflow through the pipes between the WWTP and the DWTP, Q_{OS} (m^3s^{-1}) the inflow to the WWTP from consumers in Östra Strö, Q_{R2} (m^3s^{-1}) represents the infiltration and inflow in the pipes between the consumers in Hurva and the WWTP, $Q_L(m^3s^{-1})$ represents the leakage of water through the pipes between the DWTP and the consumers, $Q_C(m^3s^{-1})$ the losses of water through consumption in Hurva and $\mathrm{Q}_{DWTP,out}(m^3s^{-1})$ the outflow from the DWTP and $\mathrm{Q}_{WWTP,out}(m^3s^{-1})$ the outflow from the WWTP.

Since the pipes between the WWTP and DWTP will be located closely and that the pipes will be new, the flow of additional water between the plants is assumed to be negligible in the calculations.



*=Might be related to both addition and withdrawal to the system.

Figure 12: *Flowchart illustrating the water cycle considered in calculations of water balance, (-)/(+) means that there is an output/input from/to the system*

In the calculations it was assumed that there would be no storage in either of the treatment plants, i.e. inflow equals outflow. In reality there will be a reservoir in the system, but in the worst case scenario the reservoir is empty and therefore it was not taken into account in the calculations. This means that for the system to contain enough water at all times the inputs to the system cannot be smaller than the outputs. If the outputs are greater than the inputs there are not enough water and if the inputs are greater than the outputs water is being stored somewhere in the system. In this case, there is a possibility to take out excess water out of the system by discharging it to the recipient Bråån. However, according to the terms of this project, there is no possibility to add water to the system in the case of a shortage, therefore it is important to make sure that Equation 2 is always true.

$$\sum_{Inputs} \geq \sum_{Outputs} \iff Q_{OS} + Q_{R1} + Q_{R2} \geq Q_C + Q_L \tag{2}$$

The losses and additions of water due to leakage can be seen as percentage of the flow going through the relevant pipe. This is expressed in Equation 3-5 where P_{R1}, P_L and P_{R2} represent the percentage of leakage of the flow from the WWTP to the DWTP, the DWTP to consumers in Hurva and between the consumers in Hurva to the WWTP respectively.

$$Q_{R1} = Q_{WWTP_out} * p_{R1} \tag{3}$$

$$Q_{R2} = Q_H * p_{R2} \tag{4}$$

$$Q_L = Q_{DWTP,out} * p_l \tag{5}$$

By rearranging and combining Equation 2 with Equation 3-5 Equation 6 was given. When the equation is fulfilled there is enough water in the system.

$$\frac{Q_{OS} + Q_{WWTO,out} * p_{R1} + Q_H * p_{R2} + Q_{R3}}{Q_c + Q_{DWTP,out} * P_l} \geq 1 \tag{6}$$

In practice, Equation 6 needed to be adjusted to the data available in this project. Therefore the data used in the calculations was inflow to both the current WWTP and DWTP. Measurements of the inflow to the current WWTP was assumed to be equal to the outflow since the measurements of the outflow were not considered to be reliable. By assuming that the implementation of the new water treatment plant will not affect the demanded inflow to the DWTP and that there are no losses or additions of water between the WWTP and the DWTP, Equation 7 was given. This equation is a simplification which can only give a rough estimation of the real situation.

$$\frac{Q_{WWTP,out}}{Q_{DWTP,in}} \geq 1 \tag{7}$$

To the current WWTP there was data both for the total inflow and the flow from Östra Strö was given as average hourly flows from January 2017 to March 2020. The data from the current DWTP was given as total monthly flows from January 2013 to March 2020. To enable comparison the data from the current WWTP was converted to total monthly flows.

Equation 7 was calculated and plotted for each of the months of which data was available from both plants resulting in a plot with 28 specific months on the X-axis and the corresponding results from the equation on the Y-axis. The lines X=1 and X=1.3 was plotted with the data for comparison. If the fraction would be <1, there is a shortage of water in the system. The line X=1.3 represents the points of water shortage in the case of an overestimation of the amount water in the system by 30%. Equations were calculated in MatLab, see Appendix, Section 7.3 for script.

3.2 Design of Treatment Chains

Below follows a short description of how the treatment chains were designed and evaluated, for details see Section 3.2.1-3.2.5. In Figure 13 the complete evaluation process is illustrated starting with the definition of reduction requirements and ending with the creation of treatment chains.

The first step in the process was to define demands regarding treatment efficiency for some parameters (Table 2).

From the start all of the treatment steps described in section 2.2 were considered. Before the design of treatment chains the considered treatment steps were evaluated separately and some were sorted out. For the remaining treatment steps, information about reduction capacity and requirements for the incoming water were summarized in Table 5, 6 and 7.

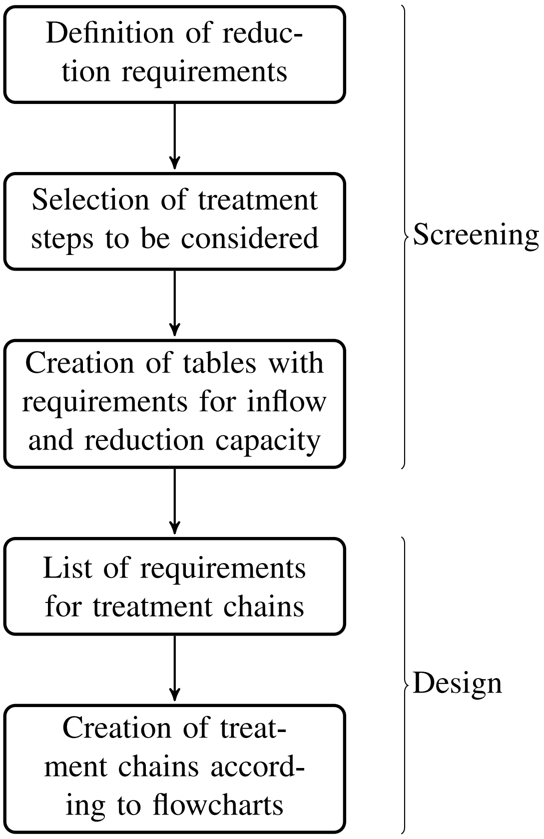


Figure 13: *Method for design and evaluation of treatment chains*

The next step was to design the treatment chains. Focus in the design was to generate treatment chains with the capacity to treat the wastewater from Hurva WWTP into drinking water quality and no other parameters were taken into account in this step. The treatment chains were generated by following the guidelines, assumptions and simplifications given on page 34 and the flowchart in Figure 14.

3.2.1 Treatment Requirements

The most essential qualification for the treatment chains was to be able to treat wastewater from Hurva WWTP into drinking water quality, therefore the wastewater quality needed to be known. Due to the lack of information about the treated wastewater in Hurva, the quality was assumed regarding most parameters.

For the parameters with unknown concentrations, concentrations were assumed to be the same as measured in the effluent from Sjölunda WWTP, a plant located in Malmö which is run by VA SYD.The data used from Sjölunda WWTP was based on measurements from December 2018 to November 2019,The reason that this plant was chosen for reference is that it is run by VA SYD and therefore data were available for the project. It should be noted that the incoming water to Sjölunda consist of both household and industrial water while there is no industrial wastewater treated in Hurva WWTP (see Section 2.5) and that Sjölunda WWTP has a more advanced treatment process than Hurva WWTP (Höglind et al. n.d.).

The known parameters from Hurva effluent were tot-P, tot-N, BOD_7, COD_{cr} and suspended solids. In Table 2 these parameters are presented as the highest and lowest maximum monthly values measured in the effluent from Hurva WWTP 2014-2020.

Table 3: *Some compounds and particles that are assumed to occur in the treated wastewater from Hurva WWTP, n.d=no data*

Pollutant	Approximate Concentration [mgl^{-1}]	Reference Values [ngl^{-1}]
tot-P	0.06-0.17[1]	0.37[2]
tot-N	13-21[1]	14[2]
BOD_7	3-6[1]	10[2]
COD_{cr}	30-38[1]	52[2]
Suspended Solids	2-13[1]	n.d
Pharmaceuticals	n.d	0.2-1377.5[3]
Micro Plastics	n.d	n.d
Phenols	n.d	78.1[3]
PFAS	n.d	7.5-10.6[3]
Plasticizers	n.d	n.d
Insecticides	n.d	0.1-18.7[3]
Estrone	n.d	9.3[3]
Heavy Metals	n.d	n.d
Viruses	n.d	n.d
Bacteria	n.d	n.d
Pathogens	n.d	n.d

[1] *Based on lowest and highest monthly maximum concentration measured in the effluent from Hurva WWTP*
[3] *Höglind et al. n.d.*
[3] VA SYD 2018b

3.2.2 Screening of Treatment Steps to be Considered

The steps considered from start is presented in Table 4, where they are organized based on treatment principle. Of the treatment steps five were not considered in the design process. These five methods were *NF, MF, PAC, ozonation + hydrogen peroxide and UV + hydrogen peroxide*, marked with gray text in the table.

Of the membrane filtration methods NF and MF were excluded since these were seen as inferior to RO and UF regarding their specific purposes. The purpose for MF/UF in the treatment chains would be pretreatment before another method and for this UF was considered superior based on effluent quality. NF/RO would be placed as one of the last steps in a treatment chain to generate a high quality water, for this purpose RO was considered inferior to NF due to the higher quality of the generated permeate.

The exclusion of PAC was based on a comparison with GAC filter, since these were considered to serve the same purpose in a treatment chain. GAC filter was considered the preferable method of the pair due to the filtering and biological treatment quality which are missing in PAC. Another aspect where the GAC filters were considered superior to PAC was regarding waste products, since PAC cannot be regenerated.

The methods using hydrogen peroxide were not included in the design process from the beginning since it is preferable to use as few chemicals and as low concentration of chemicals as possible. These methods were seen as complements for when UV treatment or ozonation is not enough and therefore these would only be considered if the desired water quality would not be achieved with UV treatment and/or ozonation alone.

Table 4: *Treatment steps considered in the analysis sorted by treatment principle, the steps marked with gray are not considered in the design process for the treatment chains.*

Separating Processes		Inactivating Processes	
Membranes	Activated Carbon	Oxidants	Other
UF	GAC Filter	O_3	UV
RO	*PAC*	$O_3 + H_2O_2$	$UV + H_2O_2$
MF			
NF			

3.2.3 Synthesis of Performance and Operational Aspects for Treatment Steps

Since the treatment chains were generated to treat the wastewater in Hurva into drinking water quality the steps were chosen based on their ability to reduce unwanted compounds. In order to evaluate the the treatment steps they were organized according to Table 6 and 5. The information in the tables is taken from section 2.2 if nothing else is given.

In the tables a treatment method is marked as reducing of a pollutant, only if it is considered efficient to reduce the specific pollutant with the method. The criteria for a efficient reduction was that the method is known to be used for the purpose. For example, it would be possible to reduce turbidity with membranes, but this would be economically inefficient and also cause a high risk for fouling and therefore it is not used for the purpose. It should be noted that the information in Table 6 is accurate only when the processes are working properly. To be sure that the desired processes and reactions are occurring monitoring and maintenance should be done regularly.

Table 5: *Maximum Log-reduction achieved for microbiological parameters with the considered treatment steps. Red=low reduction, yellow=medium high reduction, light green=high reduction, dark green=very high reduction.*

	Viruses	Bacteria	Parasites
GAC filter	-	Coliform	-
Ultrafiltration[1]	2	2.5	2.5
Ultrafiltration + precipitation[1]	3	3	3
Reversed Osmosis[2]	3	3	3
Ozonation 4^{o}C, ct=1.5[3]	3*	3*	2**
Ozonation 0.5^{o}C, ct=2[3]	3*	3*	2
UV treatment 400(Jm^{-2})[4]	3.5/1.25***	4	4

[1] *From table 3.1 in "Introduktion till mikrobiologisk barriäranalys, MBA"*
[2] *Assumed to have at least same log-removal as NF according to table 3.1 in "in Introduktion till mikrobiologisk barriäranalys, MBA" by Svenskt Vatten (2015)*
[3] *From table 4.6 in "Introduktion till mikrobiologisk barriäranalys, MBA" by Svenskt Vatten (2015)*
[4] *From table 4.9 in "Introduktion till mikrobiologisk barriäranalys, MBA" by Svenskt Vatten (2015)*
**Same reduction level can be achieved with lower contact time*
***Effective against Giardia and ineffective against Cryptosporidium*
****With/without adenovirus*

Table 6: *Reduction efficiency for non microbiological parameters. Green=The method is used for reduction of the pollutant, Yellow=Reduction of pollutant has been observed, red=low or no reduction has been observed, crossed line=economically inefficient.*

	Pharma-ceuticals	Micro plastics	TOC	Turbidity	Nutrients	Suspended materials	Other
GAC filter	🟩	🟥	🟩	🟥	🟩	🟥	Hg, Cu, Phenol compounds,
Ultrafiltration	🟥	🟩	🟨	🟩	🟨	🟩	Heavy metals
Reversed Osmosis	🟩	🟩	🟩 ╲	🟩 ╲	🟩	🟩 ╲	Heavy metals
Ozonation	🟩	🟥	🟥	🟥	🟨	🟥	
UV treatment	🟥	🟥	🟥	🟥	🟥	🟥	

The decision of placement of a method in the treatment chain was taken with consideration to the quality of the incoming water. A summary of quality requirements regarding the incoming water to the treatment steps is presented in Table 7.

Table 7: *Some quality requirements regarding the incoming water to the treatment steps for them to work properly*

	Microbial	Chemical	Organic Material	Physical
GAC			Low org.mat	
O_3	After biostep	Low nitrogen	Low org.mat	Low SS
UV	None	Low O_3, Fe ($KMnO_4$, $S_2O_3^{2-}$)	Low humus TOC + COD	FNU<0.1 low color
UF	Benefitial after biostep			No Large Particles
RO	UF for pretreatment			

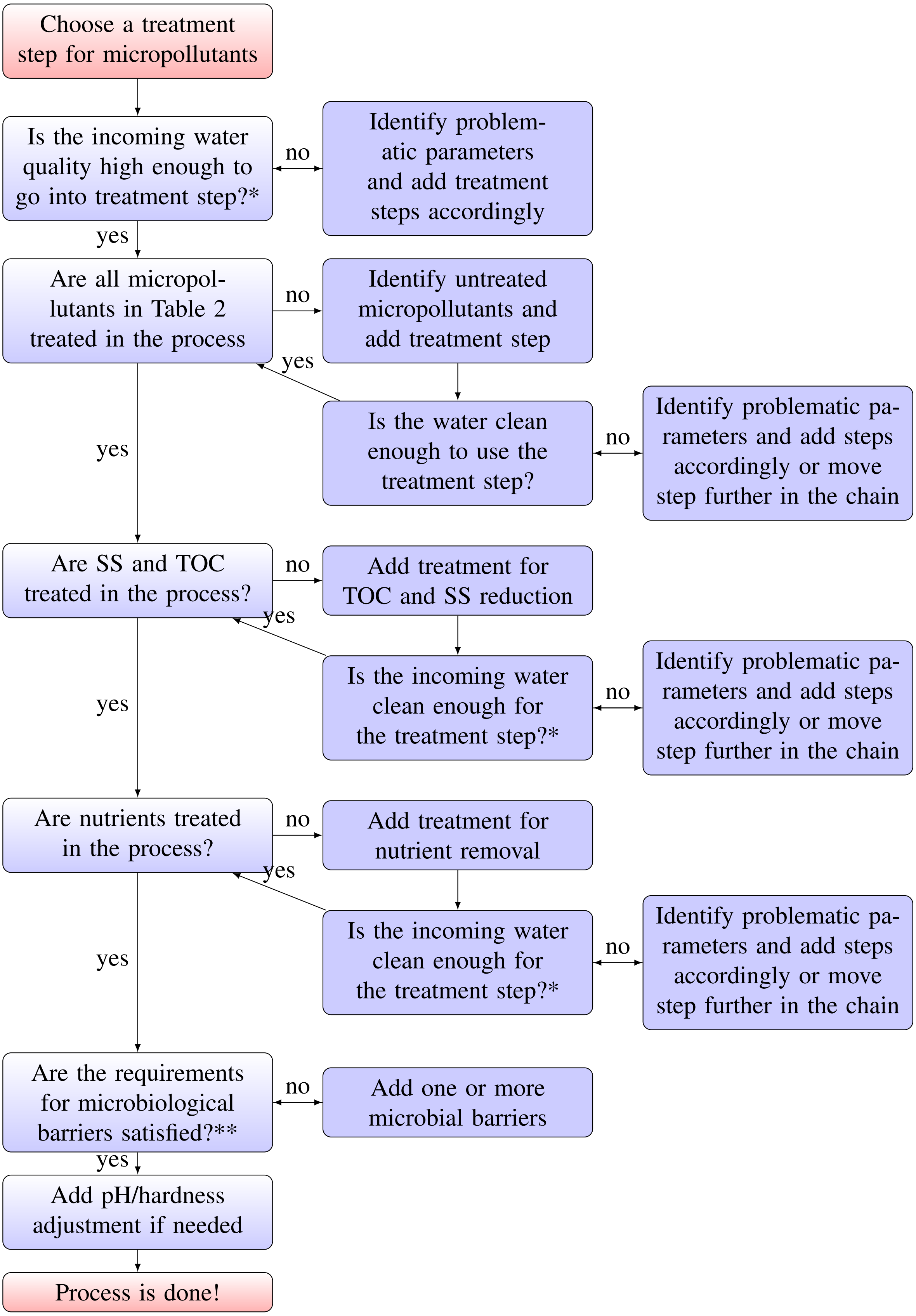
3.2.4 Design of Treament Chains

The design process was done by following the flowchart in Figure 14 and the guidelines, assumptions and simplifications listed below.

List of Guidelines, Assumptions and Simplifications Used in the Design Process

- At least one disinfection step and one separating step in the process.
- O_3 needs to be followed by GAC as a separating post treatment to ensure that no byproducts reaches the distribution network. Technically, the post treatment step could be RO but O_3 treatment would be considered excessive if RO is used.
- When GAC/O_3 is used for treatment of micropollutants these are combined. The reason for this is that they are not considered to give a sufficient reduction of micropollutants on their own. GAC filters are placed after the ozonation for reduction of byproducts. According to Baresel, Magnér, et al. (2017) the combination of GAC and ozonation can reduce most known compounds efficiently with exception to micro plastics and microorganisms.
- A treatment chain cannot contain both RO and O_3+GAC.The reason is that the methods were considered excessive in presence of each other.
- Since O_3 need to be followed by a post treatment step, UV is preferred to O_3 as inactivating microbiological barrier.
- In the case of RO, the water should be treated with UF before entering the membrane.

The flowchart was made to generate treatment chains that can treat the assumed quality of the treated wastewater, given in Table 3, into drinking water quality. It was known that at least one treatment step for treatment of micropollutants would be needed. Therefore, the starting point was to choose one of these treatment steps for the treatment chain. All choices taken in the design process were based on information given in Table 6 and 5. For the whole process and design of each treatment chain, see Figure18 and 19 in Appendix.



**According to Table 7*

***According to the simplified MBA described in Section 3.2.5. Place the microbial barrier in such a way that the quality of the incoming water to the barrier is high enough.*

Figure 14: *Flowchart used for the design of treatment chains*

3.2.5 Simplified Microbiological Risk Analysis

A simplified MBA was performed on the generated treatment chains. The method was a simplified version of the MBA described by Svenskt Vatten (2015) in the report *"Introduktion till mikrobiologisk barriäranalys, MBA"*, by author translated to *"Introduction to Microbial Risk Analysis"*.

Step 1

In the first step of the MBA the desired reduction level for microorganisms was decided based on the raw water quality of the treated wastewater in Hurva. If the raw water is exposed to a risk for contamination of wastewater it is automatically classified as the category in need of most microbiological barriers. There are no guidelines for the removal level in the case of treated wastewater as raw water. The highest reduction level was chosen with the addition of a 1 Log reduction for all three parameters. This is safety level Dc in the MBA tool which corresponds to a 99.9999% (Log 6.0) reduction of bacteria and viruses and a 99.999% (log 5.0) reduction of parasites. The desired reduction level is shown in Equation 8. Additional to achieving the desired Log reduction there should also be at least 1 separating barrier and at least one inactivating barrier. In the equation r stands for reduction level, b, v and p stands for bacteria, viruses and parasites and $s1$ stands for step 1.

$$(rb + rv + rp)_{s1} = (6 + 1)b + (6 + 1)v + (5 + 1)p = 7b + 7v + 6p \tag{8}$$

Step 2

In the second step the scenario without any precautionary actions or monitoring of the water source was chosen. The reason for this was that the raw water source was considered to differ to much from the raw water sources included in the MBA analysis to use the MBA value system regarding this aspect. Equation 9 describes the chosen reduction values in step 2. In the equation $s2$ stands for step 2.

$$(rb + rv + rp)_{s2} = 0b + 0v + 0p \tag{9}$$

Step 3 and 4

In the third and forth step the log reduction added by separating and inactivating barriers respectively was added to Equation 10. In the equation s3 and s4 represents step 3 and 4.

$$0 \geq (7b + 7v + 6p) - (rb + rv + rp)_{s3} - (rb + rv + rp)_{s4} \tag{10}$$

4 Results

In the first part of this section results from the waterbalance estimation are presented. From the calculations it was shown that there was enough water in the system every month for which data was available, except for one.

In the second part of this section the results from the design process are presented. Two treatment chains were generated in the design process. For the first treatment chain RO was chosen for treatment of micropollutants and for the second chain the combination of ozonation and GAC filter was chosen for the same purpose.

4.1 Waterbalance Estimation

From calculations using Equation 7, it was shown that the assumed outflow from the WWTP ($Q_{WWTP,out}$) divided by inflow to the DWTP ($Q_{DWTP,in}$) was >1 for every month except for June 2018 (Figure 15). It can also be noted that the difference between the flows was greater during the winter months for both years. For July-October 2018 the fraction was <1 for the case of a 30% overastimation of the amount water in the system.

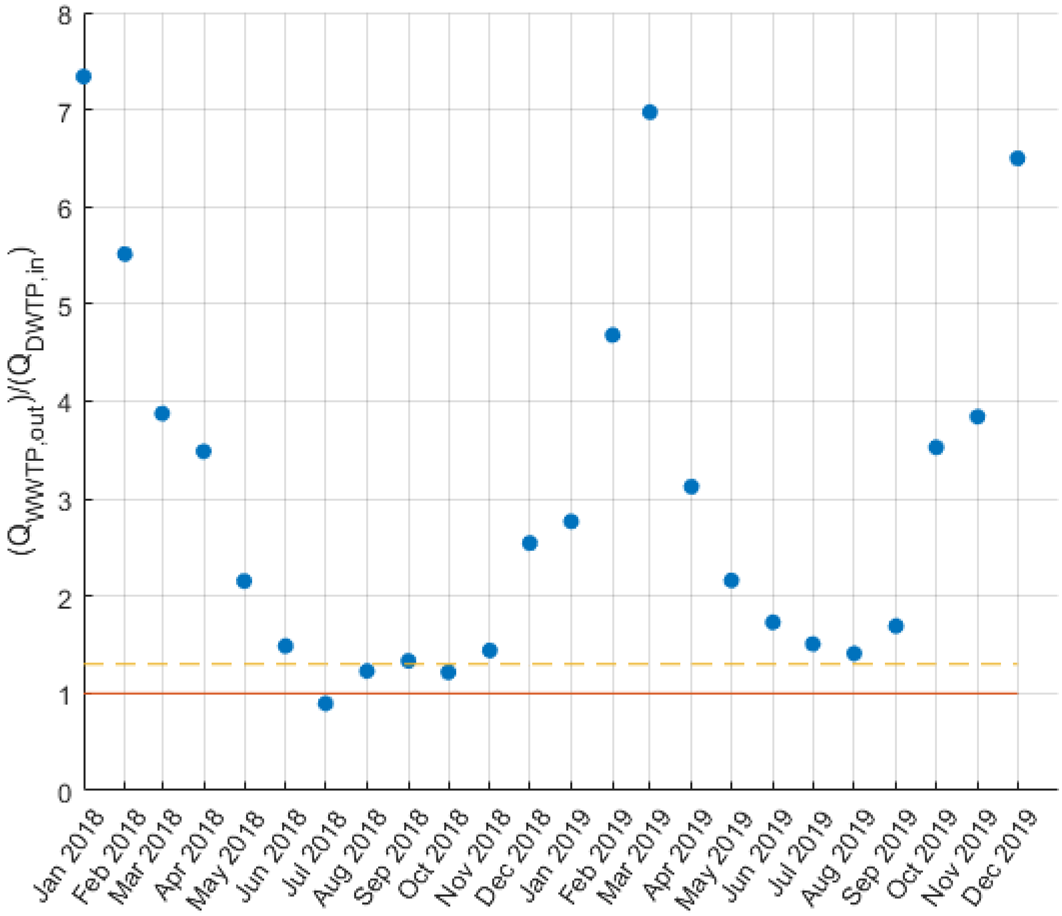


Figure 15: *Monthly assumed outflow from the WWTP divided by monthly inflow to the DWTP compared to a constant line x=1 (red) and x=1.3 (yellow).*

4.2 Treatment Chains

In the design process two treatment chains were generated, for the whole process see Appendix, Section 7.4. In the first treatment chain RO was chosen for treatment of micropollutants and for the second treatment chain the combination of ozonation and GAC was chosen for the same purpose.

The first step in both treatment chains is the WWTP, in agreement with the system boundaries for this project presented in Section 1.4. If the WWTP would consist of a MBR process, the UF steps would be excessive and can be removed from the treatment chains.

The two generated treatment chains fulfill the requirements regarding treatment capacity according to the flowchart in Figure 14. However, it should be noted that this is not enough for the chains to be considered suitable to implement for drinking water preparation in Hurva, for further discussions regarding this, see Section 5.2

4.2.1 Treatment Chain 1

The treatment chain with RO for removal of micropollutants is called Treatment Chain 1 and is presented in Figure 16. UF was chosen as pretreatment step before the RO membrane. If possible, the retentate from the RO membrane is recirculated in the system. After the RO membrane, the pH and hardness have to be adjusted. As a last disinfection step UV treatment was chosen to fulfill the requirement that there always has to be at least one treatment step for disinfection.

The microbiological safety level for the DWTP was calculated to be 8.5v+10.5b+9.5p. This is 1.5v+3.5b+3.5p more than what was demanded according to the MBA in section 3.2.5

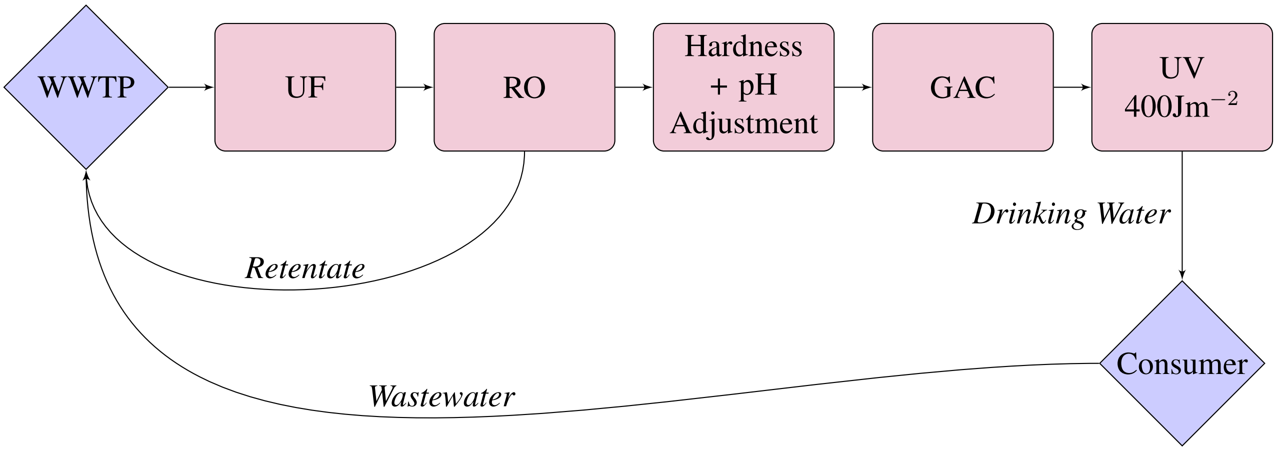


Figure 16: *Treatment Chain 1*

4.2.2 Treatment Chain 2

In treatment chain 2 a combination of ozonation and GAC filter was chosen for reduction of micropollutants. The treatment chain is presented in Figure 17. The first step after the WWTP was chosen to be UF for reduction of mainly turbidity before the ozonation step. After the GAC filter a complementing UV step was added to fulfill the requirement that there should be at least one treatment step for disinfection.

The total microbiological safety level for the treatment chain was calculated to 8.5v + 10.5b + 8.5p, which is 1.5v+3.5b+2.5p more than what would be needed according to the MBA in Section 3.2.5.

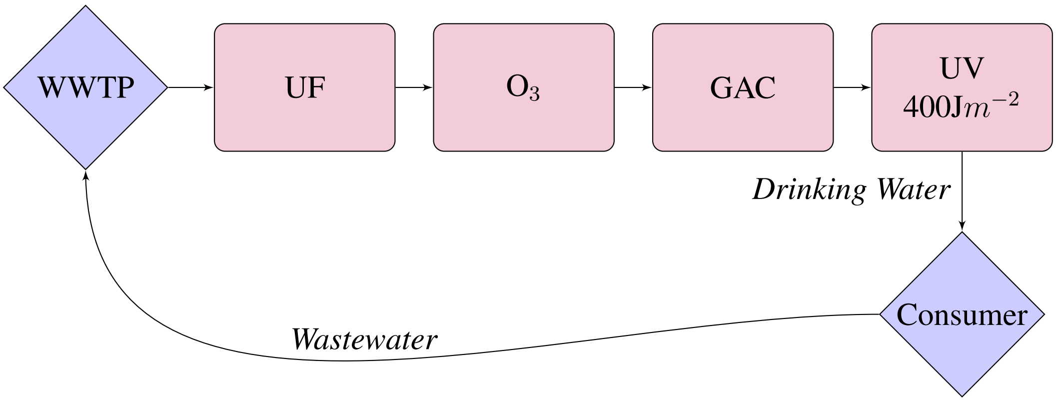


Figure 17: *Treatment Chain 2*

5 Discussion

According to the calculations of the waterbalance in the system, there is enough water in the system for all months during normal conditions. In the design process, two treatment chains were generated based on the qualification for the chains to have the capacity to treat wastewater into drinking water quality. The results from both the water balance estimation and the design of treatment chains indicates that there are possibilities for implementation of a circular wastewater system in Hurva, although it entails some challenges.

Regarding the waterbalance, the most important challenge is to make sure that there is enough water in the system during dry periods that may occur during the summer months. In Section 5.1, some suggestions of measures that can be taken to decrease the risk for water shortage in the system are presented.

The fact that the treatment chains have the capacity to treat wastewater into drinking quality is not enough for the health and safety requirements to be fulfilled. To make sure that the implementation of the designed DWTP would be safe, it is important to consider safety aspects in form of resilience to disturbances and changes in the system. In Section 5.2, health and safety aspects for each of the generated treatment chains are discussed. Additionally, suggested measures to be taken for increasing the resilience to disturbances and changes in the treatment chains are presented.

5.1 Waterbalance Estimation

Results from the Waterbalance calculations showed a distinct surplus of water in the system during the winter months, especially in the beginning of the year (Figure 15). During the summer months, the fraction $Q_{WWTP,out}/Q_{DWTP,in}$ was closer to 1, thereby indicating risk for shortage of water, especially in May, June and July. For the system to always have enough water, $Q_{WWTP,out}/Q_{DWTP,in} \leq 1$. This was true for all months with exception for July 2018. It should be noted that the only month for which a shortage of water would have been experienced according to the calculations was in June 2018, which was a month when Sweden experienced extreme droughts.

Overall, the results from the waterbalance calculations indicates that there is enough water in the system during normal circumstances and that there exists a risk for water shortage in dry periods. However, the results should be seen as a rough estimation of the real situation. Some factors affecting the reliability of the calculations are discussed below.

One aspect to consider regarding the uncertainties in the calculations that data for total monthly inflows to the WWTP and the DWTP was used. For the WWTP it would have been preferable to use measurements of the outflow but since these values was considered unreliable this was not possible. The assumption that the outflow equals the inflow is probably not completely true. In Figure 15, the line representing a 30% overestimation of the available amount water in the system would imply water shortage for August and October 2018 in addition to July the same year.

Another aspect that is important to remember regarding uncertainties in the calculations is that total values for whole months were used. In reality, the interesting data is for the hour and day of maximum water consumption. VA SYD is responsible to provide drinking water to Hurva at all times, therefore it does not matter if there is enough water in the system every month if this is not correct for every moment. Before further research regarding the possibilities of a circular water system in Hurva is performed, a thorough waterbalance estimate should be done to get information about maximum consumption hour and day.

Assuming that the results are valid and that there is an existing risk for water shortage during very dry months, adjustments can be made to compensate for the water shortage. Some suggested adjustments are listed below.

- VA SYD has a responsibility to always deliver drinking water to the citizens of Hurva. However, this does not include water for watering plants. Therefore, one approach to solve the problem in situations of water shortage could be to limit the usage of drinking water, for example by banning outdoor watering of plants or encourage people to use less water.
- Another method for making sure that there is enough water in the system could be to use the water from the existing groundwater source in periods of water shortage. Based on the flow out of the DWTP every month, it should not be a problem with the quantity of water available. Whether or not this would be possible needs to be examined.
- One last approach is to keep transporting drinking water in trucks in the case of shortage. A requirement for this to be possible is that there is a reservoir for water storage in the system. The possibilities for this to work is dependent of how big the water shortage is and for how long periods it lasts.

As mentioned in Section 2.5 there is a significant percentage additional water as infiltration and inflow into the system between the consumers and the WWTP. Usually, additional water to the system is seen as something negative since more water to the system means that more water is treated, making the process more expensive. In a circular wastewater system it is important never to experience too little water in the system. Therefore, it is possible to think that additional water actually might be positive or even necessary. However, even if the additional water is a potentially positive factor, it could be connected to both legal difficulties when defining the raw water source and an unreliable water supply to the system. If the additional water is necessary for the system to have enough water it is important to take into account that this might lead to problems regarding the definition and approval of the raw water source. If the plans of implementing a circular wastewater system in Hurva would proceed, the usage of additional water will have to be examined further.

5.2 Treatment Chains

The treatment chains in this project were designed to have the capacity to treat the wastewater from Hurva WWTP into drinking water quality. Important aspects from a health and safety point of view are both the capacity to treat the wastewater into high enough quality and for the process to be robust and resilient to disturbances in the process and fluctuations in the incoming water quality or flow.

In the first part of this section, aspects that are expected to be of importance for each treatment chain regarding health and safety aspects are considered. However, both treatment chains contain multiple processes which are affected by each other and other parameters such as water quality and flow. Therefore, it is not possible to predict either the achieved quality of the final product or the disturbances that will occur. To achieve the needed information about each treatment chain, pilot tests using treated wastewater from Hurva WWTP need to be performed before implementation.

After the performance regarding health and safety aspects are discussed, some measurements for strengthening the safety of the treatment chains are presented.

Finally, the impact from the two chains on the waterbalance is examined.

5.2.1 Health and Safety Aspects

Regarding health and safety aspects for a DWTP there are two fundamental requirements that need to be fulfilled. These requirements are listed below.

1. The treatment plant must have the capacity to treat the raw water into drinking water quality. The most interesting quality parameters for reclamation of wastewater are micropollutants and microorganisms.
2. The quality of the final product need to be guaranteed not to be affected by fluctuations in the incoming water quality and flow as well as other disturbances that may occur in the process.

For a treatment chain to be considered safe to implement, it cannot lack in performance regarding any of the two main requirements.

Since both treatment chains are designed to have the *capacity* to treat Hurva's wastewater into drinking water quality, the first health and safety requirement can be considered to be fulfilled for both chains given that the processes are optimized.

Regarding the microbiological safety level, treatment chain 1 was calculated to result in a 1 log higher reduction of parasites than treatment chain 2. Although the treatment chain has a higher safety level according to the MBA, in reality, it is not relevant since both plants fulfill the requirements for the chosen microbial safety level with margin. Furthermore, the microbiological safety level was set to have one log reduction more than the maximum required level according to Svenskt Vatten (2015) and therefore both treatment chains can be considered safe from a microbiological perspective.

The fact that both treatment chains fulfill the first requirement regarding treatment capacity for the plant is irrelevant as long as the second requirement cannot be fulfilled. Below follows a failure analysis explaining how the two treatment chains are expected to perform regarding resilience to disturbances in the process and resilience to fluctuations in incoming water quality.

Risk for Failure in Treatment Chain 1

Overall, the most crucial step in treatment chain 1 (Figure 16) can be seen as the reversed osmosis step. If the RO step would fail, this would mean that substances can pass through that cannot be treated in later steps. With the same reasoning, the GAC filter is a crucial step since it is the only step treating some of the micropollutants. However, if the GAC filter is regenerated in time and the treated water is of high enough quality, which it is if the RO step works properly, the targeted substances will be removed. Therefore RO is seen as the most crucial step in the process.

Ultrafiltration Step - Situations with fluctuating effluent quality from the UF is mostly connected to fouling of the membrane due to poor feed water quality. In the case that unwanted products would pass through the UF this would imply a risk for the final water quality due to a increased risk for fouling of the following RO membrane.

Reversed Osmosis Step - As mentioned, the most crucial operational aspect of the first treatment chain is the feed water quality into the RO membrane, due to the risk for fouling and scaling of the membrane. It might seem excessive to have an extensive treatment of the water before going into the RO, since the effluent from the RO is of such a high quality. However, it is of high importance since a high quality of the feed water both prevents fouling and decease the percentage of feed water turning into retentate.

The RO membrane provides a physical barrier which inhibits pollutants to pass through the membrane based on molecule size. If the membrane is intact and not subject to fouling or scaling, the treatment is independent of fluctuations in feed water quality and disturbances earlier in the treatment chain. However, fluctuations in feed water quality and other disturbances might cause fouling or scaling of the RO membrane which can affect the treatment negatively.

In the case of a low feed water quality, there is a risk of fouling which is connected to a more expensive treatment due to higher energy demand (Voutchkov 2017). Furthermore, membrane fouling might compromise the quality of the final product (Singh 2005; Maddah & Chogle 2017). To prevent fouling in the RO, UF provides a safety level in form of a lowest possible feed water quality due to the physical separation principle, given that the UF membrane works satisfactorily.

As the soluble salts in the retentate becomes more concentrated, the risk for scaling increases (Singh 2005). Since a higher recovery rate results in a more concentrated reject flow, there is an opposition in the desired recovery rate considering water losses and formation of scaling.

GAC step - For the GAC filter to reduce the targeted pollutants it is important that the treated water is of a high enough quality. The reason for this is that the adsorption is competitive meaning that only the easiest adsorbed pollutants will be removed. However, as long as the RO step is intact, the feed water should be of a high enough quality for the GAC filter to work as intended. For the GAC filter to work properly it is also important to exchange and regenerate the filter before saturation is reached. Another challenge for treatment with GAC filters is that the effect of the filter can vary for different GAC filters. Therefore, the choice of filter is highly important for the treatment to work properly.

UV step - As for many treatment steps, the efficiency of the UV treatment depends of the incoming water quality. Furthermore, there needs to be a constant energy source to make sure that the radiation is constant and the lamps need to be changed before the intensity is lower than wanted.

Treatment chain 2

The treatment of micropollutants can be considered a critical point for treatment chain 2 (Figure 17). The reason for this is that decreased efficiency in one of the treatment steps for micropollutants cannot be compensated later in the treatment chain. The fact that there are two treatment steps for micropollutants might lead to the conclusion that the system is redundant regarding micropollutants. However, there are some properties of the methods which speaks against this. First of all, the methods does not treat the same types of micropollutants. Secondly, if the ozonation does not work properly, there will be more organic compounds competing for the adsorption spots in the GAC filter which will decrease it's efficiency.

Ultrafiltration Step - As for in treatment chain 1, failure of the UF step is mostly connected to fouling as a consequence of poor feed water quality. UF is the only physical barrier in treatment chain 2. Similar to the RO membrane, the UF contributes with a physical barrier which is independent of the surrounding conditions as long as it is intact. In contrast to RO, the restrictions for the substances passing through the membrane are not strict enough for the barrier to be enough from a safety point of view since pharmaceuticals and other pollutants are not removed in the UF (Table 6).

Ozonation Step - One major challenge connected to using ozonation in the drinking water production is that the required dosage depends on the quality of the treated water. Another aspect which further complicates the control of the ozonation is that both too high and too low levels of O_3 can lead to a toxic effluent and thereby it is not possible to put a safety margin in form of a higher dosage. One risk which is especially important to consider in the case of to high O_3 dosages is the potential formation from bromide to the carcinogenic bromate (Lavonen et al. 2018).

Another weakness in the ozonation step is the sensitivity to operational disturbances. For example, if the ozonation would stop for some reason, the water would still pass through the ozonation step in comparison to membranes where a stop in the process would mean that no water would pass through.

GAC step - Although GAC provides physical separation, it cannot be seen as a physical barrier for micropollutants since the adsorption in the process is competitive and depends on the quality of the treated water. An operational weakness with the treatment step is that the GAC treatment is dependent of the microbial activity in the filter, this means that the desired treatment might not be achieved if the microbiological activity would decrease. As mentioned for treatment chain 1, the choice of GAC filter and the time between reactivation is of high importance.

UV step - As mentioned for treatment chain 1 it is important that to have a constant radiation of UV light and to change the UV lamps when needed.

5.2.2 Measures for Strengthening the Safety of the Treatment Chains

The optimal solution from a health and safety point of view, would be to have more than one treatment step for each parameter including micropollutants. In reality, health and safety is not the only aspect of the problem and the benefits need to be in proportion to the costs. There are many methods for optimizing treatment plants and making them as safe as possible without adding more treatment steps than what is necessary. Some of these methods, that could be used for the two treatment chains are discussed in this section.

One requirement for making the implementation of the DWTP safe, is monitoring of the water quality throughout the whole process. By monitoring the influent and effluent water quality for each step, the aim is to identify and eliminate disturbances before the final product is affected.

For both treatment chains it is important to operate the process in a way that minimizes the risk for fouling of the membranes. UF is the first treatment step after the WWTP. Therefore, any treatment for counteracting fouling of the UF would be placed in the WWTP. Which processes to use in the WWTP is not examined in this project, but it is clear that fouling mechanisms for the UF membrane need to be considered in the design process.

An important concept in wastewater reclamation is redundancy, which is the usage of measures beyond the minimal requirements (World Health Organization 2017). In a redundant system there is a safety margin, making the system resilient to changes and disturbances. For example, the extra log reduction added in the simplified MBA analysis in Section 3.2.5 provides with a level of redundancy for the microbiological safety level. If the treatment efficiency would decrease for one of the microbial barriers, the final product would most likely still achieve the required microbiological quality.

One measure for increasing the redundancy of the DWTP is to divide the process into two or more parallel treatment chains. With this kind of measure, the effect of disturbances in one of treatment chain is reduced. Another positive effect of multiple chains is that the plant can operate even if a treatment step in one of the chains would fail.

Another measure for increasing the redundancy is to have more than one treatment step for each parameter. In the design of the two treatment chains in this project, the aim was for the chains to treat the water into drinking water quality. The qualification was for each of the considered parameters to be treated in the process, without having specified the removal or reduction rate for any of the parameters except for microorganisms. Therefore, the only parameter for which redundancy was considered was the microbiological parameters.

5.2.3 The Treatment Chains Influence on the Waterbalance

For both treatment chains the backwashed water and potential retentate from the UF need to be taken care of. The plan for both flows is to be recirculated into the WWTP. The basis for this assumption is that the substances that accumulates on the UF and in the retentate will be treated in a biological treatment step in the WWTP. The hypothesis is that the substances have been partly degraded the first time they were treated in the WWTP and hopefully, they can be completely degraded after passing the biological treatment a couple of times. However, there is no guarantee that this is going to work. If the backwashed water or the retentate needs to be treated at another site the water would be lost from the system which would affect the waterbalance negatively.

Treatment Chain 1
The most considerable risk for water losses in treatment chains 1 is connected to the reject water from the RO. The reject stream in an RO process can stand for a substantial part of the total flow. For example, in Mörbylånga 25% of the water turns into retentate during the RO treatment.

The retentate from the RO is planned to be recirculated to the system. However, if the retentate contains compounds that cannot be treated in the WWTP, it needs to be transported and disposed at another site or treated in an additional step before entering the WWTP. If this would be the case, the workload, price and environmental impact would increase due to transportation and the production of a concentrated waste flow. Whether the retentate can be recirculated into the WWTP or not, depends on processes earlier in the chain as well as quality of the incoming wastewater to the WWTP. To make sure that the retentate can be recirculated it need to be analyzed.

If the rejected water cannot be recirculated into the WWTP it will be lost from the system. In Figure 15, it is shown that in the case of a 30% overestimation of the amount available water according to the waterbalance estimation would imply water shortage for at least 3 of the months examined. Considering this, it is possible that the formation of reject water might prevent the implementation of the system to be possible regarding the waterbalance.

Treatment chain 2
For treatment chain 2 there would be no large water losses in the system other than in the case of disposal or further treatment of the UF retentate and/or backwashed water.

6 Conclusions

The results from this project indicate that it is possible to implement a circular water system with reclamation of wastewater for potable use in Hurva, although the implementation comes with some challenges.

According to the waterbalance estimation, there is enough water in the system during normal conditions and a risk for water shortage during very dry periods (Figure 15). Regarding the water balance the biggest challenge is to make sure that there is water available in the system at all times. This could be done by any of the measures suggested in Section 5.1. To confirm that there is enough water during the hour of maximum water consumption, more thorough calculations need to be performed. Another aspect which is important to be aware of, is how the treatment chains might impact the waterbalance in the system.

Based on the requirement that the DWTP should have the capacity to treat the wastewater in Hurva into drinking water quality, both of the generated treatment chains are possible for implementation, given that all processes are optimized.

If treatment chain 2 (Figure 16) would be chosen, extensive monitoring of the quality of the water entering the ozonation and GAC as well as control of the O_3 dosage is a demand for safe implementation. It is likely that these demands would entail a too heavy work load to be reasonable for implementation in Hurva.

If treatment chain 1 (Figure 17) is chosen, the feed water quality for the RO membrane is the most important aspect to consider. As long as the RO membrane is intact and not exposed to fouling or scaling, the treatment will be sufficient for drinking water production. However, treatment chain 1 might be connected to water losses if the rejected stream from the RO membrane cannot be recirculated and it is essential that this is examined before implementation.

In this project, the possibilities for implementation of a circular wastewater have been examined from a process technical and health and safety point of view. In the study, other aspects, such as economics and social aspects, have not been considered. Some measures that need to be taken before proceeding with the implementation of one of the two suggested treatment chains are listed below.

1. The chains need to be further examined regarding the following aspects:
    - Economics
    - Social aspect
    - Legal aspects
    - Environmental impact
    - Energy consumption
    - Thorough examination of the safety aspects, since it is only discussed in this project
2. The wastewater from Hurva need to be analyzed
3. The expanded WWTP need to be designed
4. Pilot tests need to be performed

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7 Appendix

7.1 DWTP Flows

Table 8: *Monthly mean and maximum values of the inflow and outflow from the Hurva DWTP*

	Mean out [m^3]	Mean in [m^3]	Max out [m^3]	Max in [m^3]
January	1638	1688	2001	2036
February	1517	1556	1791	1821
March	1738	1770	2185	2239
April	1712	1685	1909	1886
May	1893	1633	2136	2184
June	1827	1878	2523	2590
July	1896	1924	2183	2258
August	1751	1798	2025	2048
September	1536	1633	1709	1754
October	1656	1430	1899	1915
November	1360	1580	1800	1690
December	1453	1537	1671	1713

7.2 WWTP Flows

Table 9: *Monthly mean and maximum values of the outflow from the WWTP in Hurva*

Months	Mean in [m^3]	Min in [m^3]
January	9418	5637
February	10750	8239
March	8375	4565
April	5520	5509
May	4031	3844
June	2965	2726
July	2254	1933
August	2563	2519
September	2548	2142
October	3838	2330
November	4047	2267
December	6987	3633

7.3 Matlab Script for Waterbalance Estimation

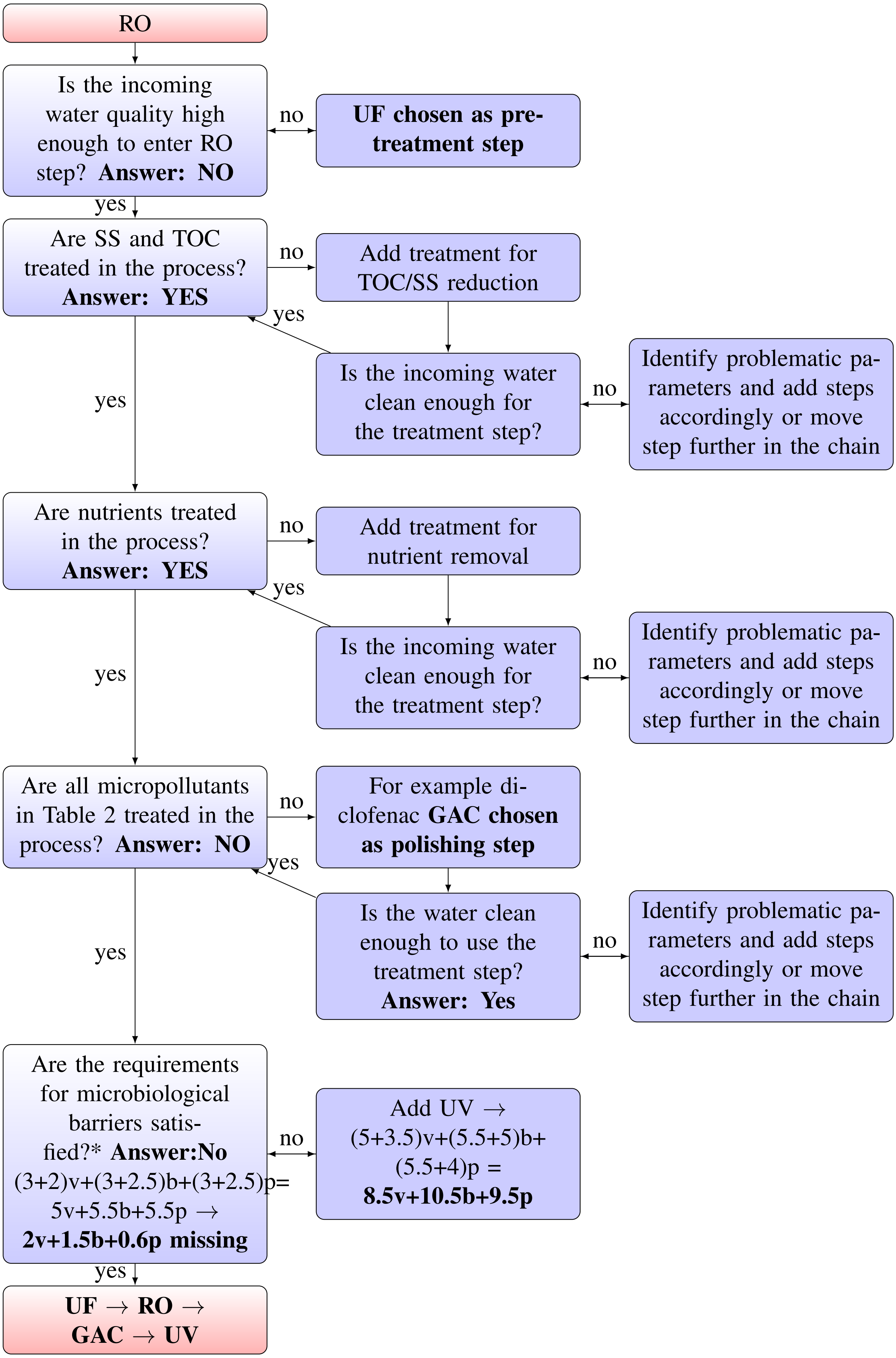
```
opts_WWTP=detectImportOptions('Hurva_WWTP_Flow.txt');
WW_flows_hourly=readtable('Hurva_WWTP_Flow.txt', opts_WWTP); % Imports the data for WWTP flow to a 19248x2 table
%with hours in the first column and hourly average flows in the second.
WW_flows_hourly_tt=table2timetable(WW_flows_hourly); % Transforms the table to a timetable
```

```

n=26;
WW_flows_hourly_tt(1:n,:) = []; %Deleting the first rows including headlines and data from one day in december 2017.
WW_flows_monthly_tt = (retime(WW_flows_hourly_tt,'monthly','sum')); %Creates a 28x1 timetable with total monthly flows [m^3/h]
WW_flows_monthly=table2array(WW_flows_monthly_tt); %Transforms timetable to array.
Months=WW_flows_monthly_tt.Datum(1:12); % Creates a datetime containing the 12 months
Months_20182019=WW_flows_monthly_tt.Datum(1:24); % Creates a datetime containing the months for which data is available from both plants.

opts_DWTP=detectImportOptions('Hurva_DWTP_Flow_.txt');
DW_flow=readtable('Hurva_DWTP_Flow_.txt',opts_DWTP); %Imports data from Hurva DWTP containing containing monthly total flows.
DW_flow_monthly=table2array(DW_flow(:,2));

DW_20182019=DW_flow_monthly(61:84,:); %Extracts data from relevant dates
WW_20182019=WW_flows_monthly(1:24); %Extracts data from relevant dates

WB_EQ_20182019=(WW_20182019./DW_20182019)';
ONE=ones(size(WB_EQ_20182019));

scatter(Months_20182019,WB_EQ_20182019, 'filled')
grid on
hold on
plot(Months_20182019,ONE)
xticks(Months_20182019);
xtickangle(55)
legend('(Q_{WWTP, out})/(Q_{DWTP, in})')
title({'Monthly inflow for Hurva WWTP divided ','by monthly inflow to Hurva DWTP (Jan 18 -Dec 19)'})
```

7.4 Selection of Treatment Chains

7.4.1 Treatment Chain 1 - RO for Treatment of Micropollutants

In treatment chain UF was chosen as pretreatment step before the RO treatment (Figure **??**). After the RO treatment hardness and pH adjustments need to be done. To achieve a high enough microbiological safety level and to make sure that there is a disinfection step UV was chosen as a last microbiolgoical treatment step before the water reaches the distribution network.

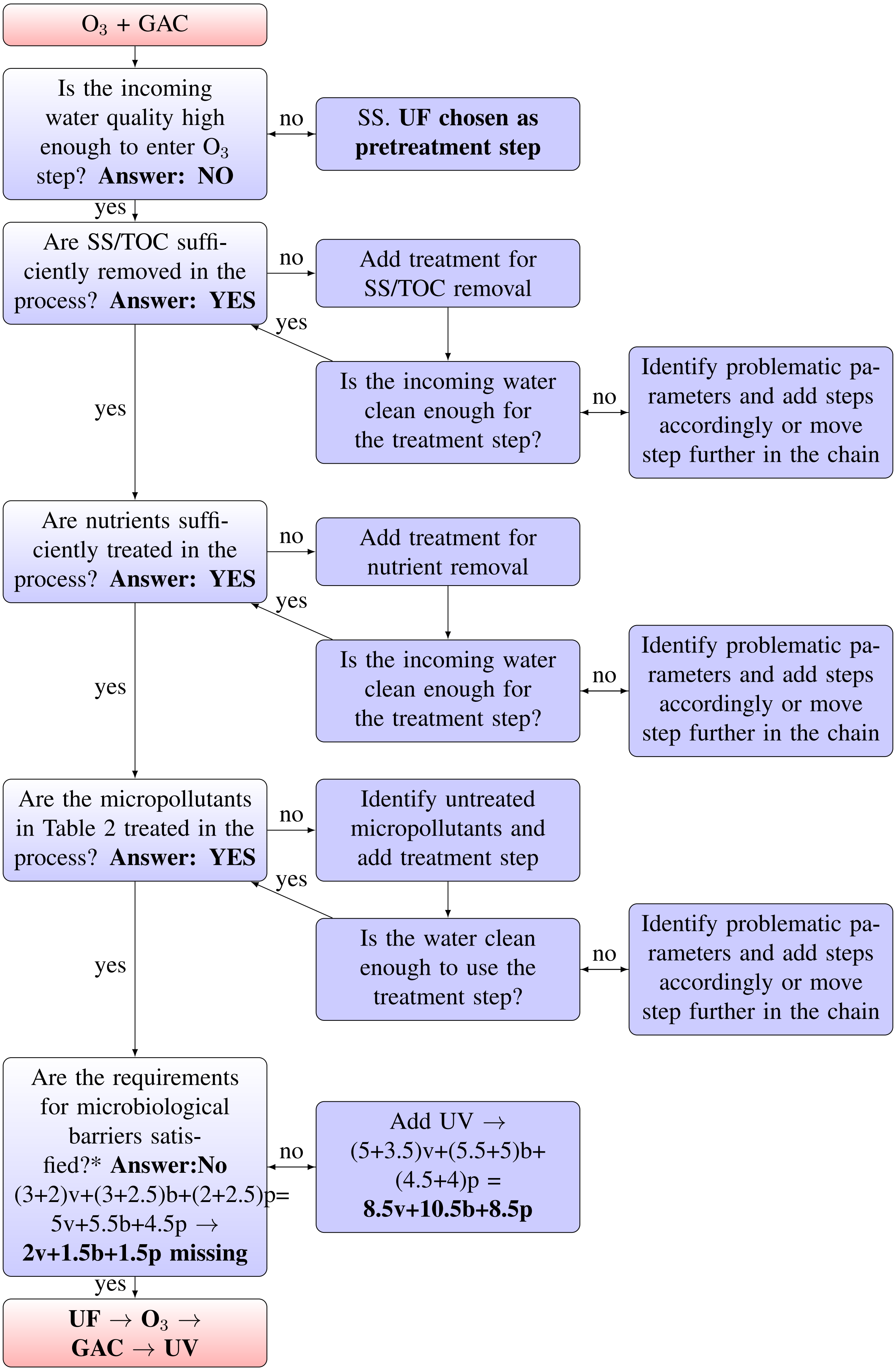


**According to the simplified MBA described in Section 3.2.5. Place the microbial barrier in such a way that the quality of the incoming water to the barrier is high enough.*

Figure 18: *Design of treatment chain 1*

7.4.2 Treatment Chain 2 - GAC+O_3 for Treatment of Micropollutants

In treatment chain 2 the combination of O_3 and GAC is used for removal of micropollutants. UF was chosen as pretreatment step before entering the ozonation step. To achieve a high enough microbiological safety level an to make sure that there is one disinfection barrier UV was chosen as a complementing last microbiological treatment step before the water reaches the distribution network.



**According to the simplified MBA described in Section 3.2.5. Place the microbial barrier in such a way that the quality of the incoming water to the barrier is high enough.*

Figure 19: *Design of treatment chain 2*