Master of Environmental and Energy Management

Master Thesis

Reducing the water consumption of a large-scale brewery

Author:

J.K.C. van der Tuin

Company supervisor:

S. Ladrak

University of Twente supervisors:

dr. K.R.D. Lulofs

dr. F.H.J.M. Coenen

UNIVERSITY OF TWENTE.

Grolsch

Abstract

Due to the increasing shortage of fresh water, companies must consider ways to make their water use more sustainable at a strategic level. This research focuses on identifying possibilities to reduce the water consumption of a brewery. The research objective in the master's thesis was to collect and analyse relevant data to make recommendations on how to reduce the water consumption of a large-scale brewery. Therefore, a case study was conducted at the Grolsch brewery in Enschede. Grolsch is one of the largest beer breweries in the Netherlands. For the production of beer, the brewery uses water from multiple sources in the region. Based on the research objective, the following research question has been formulated: "*Which initiatives can be taken to reduce the water consumption of a large-scale brewery?*"

To answer this question, multiple analyses were executed. First, existing water reduction methods for companies were analysed. Subsequently, the water-consuming processes within the brewery were analysed. Thereafter, it was determined which processes have the biggest potential for realising water reductions. Finally, possible solutions to reduce water consumption were investigated.

The production process within the brewery consists of several steps that take place in different areas of the brewery. The water used in the brewery leaves the brewery in different ways. Most of the water (65%) leaves the brewery via the effluent. This includes the water used for CIPs, bottle washers and pasteurisers. Besides, a large part of the water (26%) ends up in the beer. In addition, part of the water leaves the brewery via by-products (spent grains, trub etc.), through evaporation (brewhouse, cooling plant) and product losses.

Based on the benchmark analysis, the three areas with the most potential at Grolsch are: water treatment, filling lines (KL02, KL04 and KL07) and total refrigeration. Closing the gap between the water consumption of Grolsch in 2019 and the best-in-class consumption of equal L3 areas in other breweries results in a significant reduction of the water consumption. Besides, there are also a few areas that were not included in the benchmark analysis but that could be of interest. Beer processing and BBT/chemical are especially interesting because they fall within the top 10 consumers at level 3.

It appeared that initiatives could be taken on various fronts to reduce the water consumption of the brewery. According to the water management hierarchy (WMH), five options for water reduction can be distinguished: elimination (most preferred), reduction, direct reuse, regeneration reuse and freshwater usage (least preferred). During the research, various solutions were found to reduce the water consumption of the brewery. Using a dry conveyor belt lubrication system, adding a wort recovery system and reusing the last CIP rinse are some of the found possibilities. Besides, a concrete plan has been made to reduce the water consumption of filling line KL02. This approach mainly focuses on optimising the bottle washer, improving factory efficiency (FE), and reducing bottle losses at the empty bottle inspection (EBI). If it is possible to achieve the defined performance targets for this line, the consumption of the filling line could be reduced significantly. It is also possible for breweries to treat wastewater and reuse it in the factory. Grolsch is currently investigating this possibility.

Keywords: sustainability, water consumption

Acknowledgements

First, I would like to thank Grolsch for the opportunity to write my thesis at their company. My special thanks go to Susan Ladrak for being my internal supervisor. She was always willing to help during the project, and she taught me a lot about sustainability within the company. I would also like to thank all other people involved, especially Arjen Pille, who taught me a lot about the processes within the brewery. This project would not have been possible without the knowledge and ideas of these colleagues.

Secondly, I would like to thank Kris Lulofs for being my 1st supervisor at the University of Twente. With the help of his extensive feedback and suggestions, I was able to complete this graduation project successfully. Furthermore, I would like to thank Frans Coenen for being my 2nd supervisor and providing feedback in the final stage of writing the thesis.

Contents

List of Figures

List of Tables

List of Abbreviations

BSG	Brewer's Spent Grain
CEMWN	Cost-Effective Minimum Water Network
CIP	Cleaning-In-Place
GHGs	Greenhouse Gases
HTHW	High-Temperature Hot Water
IWA	International Water Association
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)
LCC	Limiting Composite Curve
NRB	Non-Returnable Bottles
PCW	Process Water
PDW	Product Water
PVPP	Polyvinylpolypyrrolidone
RB	Returnable Bottles
WBCSD	World Business Council for Sustainable Development
WMH	Water Management Hierarchy
WPA	Water Pinch Analysis
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

1. Introduction

The beverage industry is currently facing a challenge to reduce water consumption. This research focuses on identifying possibilities to reduce water use within a brewery. Therefore, a case study was conducted at the Grolsch brewery in Enschede.

1.1 Background

Since the industrial revolution, the influence of humans on the climate has grown rapidly. This growth is mainly due to the emission of greenhouse gases (GHGs) such as CO_2 and methane. Due to the emission of these GHGs, heat is retained, and the temperature on Earth rises (Rijksoverheid, 2021). In the Netherlands, the average temperature has increased by 1.7 °C since 1906 (Government of the Netherlands, 2016). One of the consequences is that humans and animals increasingly suffer from extreme weather (Rijksoverheid, 2021). In the past few summers, there were several drought-related problems in the Netherlands. The summer of 2018 was extremely dry, and the summers of 2019 and 2020 were also drier than average. The drought in 2018 had severe consequences for the shipping industry, farmers, and water managers. The total economic damage is estimated between 450 and 2080 million euros (KNMI, 2020). According to research by Utrecht University and the KNMI, dry summers (like the summer of 2018) are now more common in the inland than around 1950 due to climate change (Sluijter, Plieger, & van Oldenborgh, 2018). Drought problems are most severe in places with higher sandy soils, in the south and east of the Netherlands (Pol, 2020). In contrast to the clay soil in the west of the country, sand retains little water (Drost, 2020). Therefore, the water in sandy soils sinks into the ground more quickly. Additionally, there is less rainfall in these regions, and rivers do not replenish the water. As a result, the groundwater level in these areas is already lower than in the west of the country (Pol, 2020).

The Royal Netherlands Meteorological Institute (KNMI) developed several climate scenarios for a possible future climate for the Netherlands. The most recent scenarios show a picture of higher temperatures, a faster-rising sea level, heavier rainfalls, and a chance of drier summers. In two of the four climate scenarios, it will undoubtedly become drier in the Netherlands (KNMI, 2020). Deltares, an independent institute for applied research in the field of water, expects an increase in freshwater demand and a decrease in availability (Klijn, van Velzen, ter Maat, & Hunink, 2012). Due to the increasing shortage of freshwater, companies must consider ways to make their water use more sustainable at a strategic level. Sustainable use of water is the way for companies to anticipate on the reduced availability of water (VEMW, 2013).

A lot of sectors in the Netherlands are dependent on the availability of water for their production. According to the Dutch government, 16% of the economy in the Netherlands is dependent on freshwater (Rijksoverheid, 2015). Together, these sectors account for a turnover of more than 193 billion euros per year. An economy without sufficient water of the right quality is impossible. In the Netherlands, the beverage industry is one of the large water users. In 2019, the beverage industry used 13,8 million m^3 groundwater. This concerns 1.2% of the total amount of groundwater used in the Dutch economy (Centraal Bureau voor de Statistiek (CBS), 2021). The largest part of the water used by the beverage industry concerns groundwater. Besides that, the industry also makes limited use of tap water and surface water. The sector mainly uses the water for the products, cleaning of return bottles & process lines, and cooling (Panteia, 2009). In the past few years, the water consumption of the beverage industry decreased. Compared to 2017, the water consumption of the beverage industry has decreased by 5.5% in 2019 (Centraal Bureau voor de Statistiek (CBS), 2021).

The Dutch beer sector is an innovative sector that delivers an essential contribution to the Dutch economy (Nederlandse Brouwers, 2021). In 2020, the Netherlands was the largest exporter of beer in the European Union. Last year, more than 2 billion euros worth of beer was exported (Centraal Bureau voor de Statistiek, 2021). Globally, beer is the most popular alcoholic drink (Nelson, 2005). A distinction can be made between different types of beer. In the Netherlands, Pilsner is the most widely available beer type. Well-known breweries in the Netherlands that produce this beer are Grolsch, Heineken, and Hertog Jan (Statista, 2020). In recent years, the production of non-alcoholic beer has increased. The export value of non-alcoholic beer was almost twice as high in 2020 as in 2017. In this period, the export of non-alcoholic beer grew much faster (+83%) than the export of beer with alcohol (+11%) (Centraal Bureau voor de Statistiek, 2021).

Most major breweries are aware that their water consumption needs to be reduced and are taking action. For example, the members of "Nederlandse Brouwers" (umbrella organisation representing the interests of 13 breweries established in the Netherlands) took several actions in the past years. As a result, the breweries achieved a water reduction of 19% in 9 years (base year 2005) (Nederlandse Brouwers, 2021). Many large-scale breweries communicate about their ambitions & goals and publish their water-to-beer ratio. The water-to-beer ratio concerns the amount of water used to create the final product. The water use includes water used as input for the beer and water needed for other processes in the brewery (e.g., cleaning). Large regional breweries tend to have a water-to-beer ratio of 4 hl/hl, while breweries focused on sustainability typically have a water consumption of 3 hl/hl (Foster, 2020).

One of the largest beer breweries in the Netherlands is Grolsch. The company is part of the Japanese beverage group Asahi. In 2019, Grolsch distributed beer to over 60 countries and sold 2.8 million hectolitres of beer. In the Netherlands, Grolsch has a market share of 13%. The company has a broad portfolio of beers, including Radlers, Specialty beers, and Pilsners (Grolsch, 2019). To produce beer, Grolsch uses well water from multiple sources in the region. Grolsch endorses the importance of sustainable water use and aims to produce more beer with less water (Grolsch, 2020). In recent years, the company has taken various measures to reduce water consumption. In 2019, Grolsch used 3.36 hectolitres of water to produce one hectolitre of beer. Compared to 2005, Grolsch has achieved a water reduction of 30%. In 2020, due to production losses caused by COVID-19, the brewery's water consumption was 3.68 hl/hl (Grolsch, 2020). The ambition of the company is to use less than 3 hl/hl by 2025. Therefore, the water consumption of Grolsch must be reduced by 18.5% in 5 years. By 2025, all Asahi breweries in Europe aim to have an average water consumption of 2.75 hl/hl. Individual Asahi breweries in Europe must reduce their water consumption to at least 3 hl/hl by 2025 (Asahi, 2020).

In 2015, Grolsch performed a source vulnerability assessment to investigate water risks (quality and quantity). At the time, this assessment showed that the risks for Grolsch were low. An update of the assessment was carried out in 2020. During this assessment, the increase in volume and various climate scenarios were also considered. This assessment has shown that there is a significant risk for Grolsch. There is urgency for Grolsch to both reduce water consumption and make the water supply future-proof.

1.2 Goal and research questions

The research objective in the master's thesis is to collect and analyse relevant data to make recommendations on how to reduce the water consumption of a large-scale brewery. By providing a detailed analysis of the water-consuming processes, implementation of shared learnings and defining new optimisation opportunities, the aim is to provide a list with initiatives to reduce water consumption. Based on this research objective, the following research questions have been formulated:

Main question:

Which initiatives can be taken to reduce the water consumption of a large-scale brewery?

Sub-questions:

1. *What existing methods are there to reduce a company's water consumption?*
2. *For which applications is water used in the beer production process?*
3. *Which processes should be prioritised to achieve water savings?*
4. *What possible solutions are there to reduce the water consumption of the brewery?*

1.3 Approach and methods

This section describes the approach and methods that were used to provide answers to the sub-questions and main question.

1. ***What existing methods are there to reduce a company's water consumption?***

A water reduction project can be approached in many ways. The first sub-question was formulated to gain more insight into existing methods. This information was necessary to determine the approach of the project. To answer the 1st sub-question, various methods to reduce a company's water consumption were analysed. First, a secondary analysis (using existing data) was carried out. Therefore, diverse literature and documents from organisations were reviewed. Subsequently, an evaluation of the found methods was carried out. During this evaluation, the methods were assessed against the following criteria:

- The method includes chain perspective
- A concrete approach that can be used within the factory
- Method indicates required data
- The method includes priority-based option screening

By assessing the existing methods on the points mentioned, it has been determined to what extent the method can be used for a water reduction project at a brewery. Based on the results of the evaluation and short open discussions with the supervisors, it was determined which elements from the methods found could be integrated into the project.

2. ***For which applications is water used in the beer production process?***

First, it was investigated for which applications water is used within the entire production chain (see The water footprint of beer). Therefore, secondary analyses were used. For this study, it has been decided to limit the focus on investigating water reduction opportunities at the production plant of Grolsch in Enschede. Grolsch was selected as a case study because it is an interesting brewery for research. Grolsch is a large brewery and has been working on water reduction for years. Therefore, it is engaging to investigate which further optimisations are possible. Besides, it is possible that found improvements can also be applied at other breweries. In 2020, the beer/water efficiency at Grolsch was 3.68 hl/hl. Considering large-scale breweries as the population, Grolsch is an example of a typical case (Gerring & Cojocaru, 2016).

To determine how water is used in the production process, several qualitative and quantitative analyses were executed. First, semi-structured conversations were held with process specialists within the brewery, and internal documents were analysed to understand the production process within Grolsch. Accordingly, an analysis was made on how water is used in the production process. Therefore, qualitative data was collected by conducting several interviews and analysing internal documents. Quantitative data was extracted from the data warehouse (see section 4.2). Besides, a general water balance was made to gain insight into where the water is used and where it goes.

3. ***Which processes should be prioritised to achieve water savings?***

The 3rd sub-question has been formulated to gain insight into the processes that must be prioritised to achieve water savings. A Multi-Criteria Analysis (MCA) was used to determine which processes need to be prioritised. This analysis provides a systematic approach according to pre-determined objectives and criteria (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2021). To determine which processes should be prioritised, the following criteria were used:

- Absolute water consumption
- Benchmarks
- Process analysis

These criteria have been established based on the results of analyses of previous water-saving projects and discussions with the supervisors. To save as much water as possible, it would be considered logical to focus on processes whose absolute consumption is high and that deviate from benchmarks. There is a greater chance that these processes can be improved and that improvements lead to significant water reductions.

The first two mentioned criteria determine the ranking of the processes that should be prioritised to achieve water savings. Accordingly, process analyses were performed to determine which exact parts of the processes have the potential for improvement.

Figure 1 shows how the processes are prioritised based on the mentioned criteria.

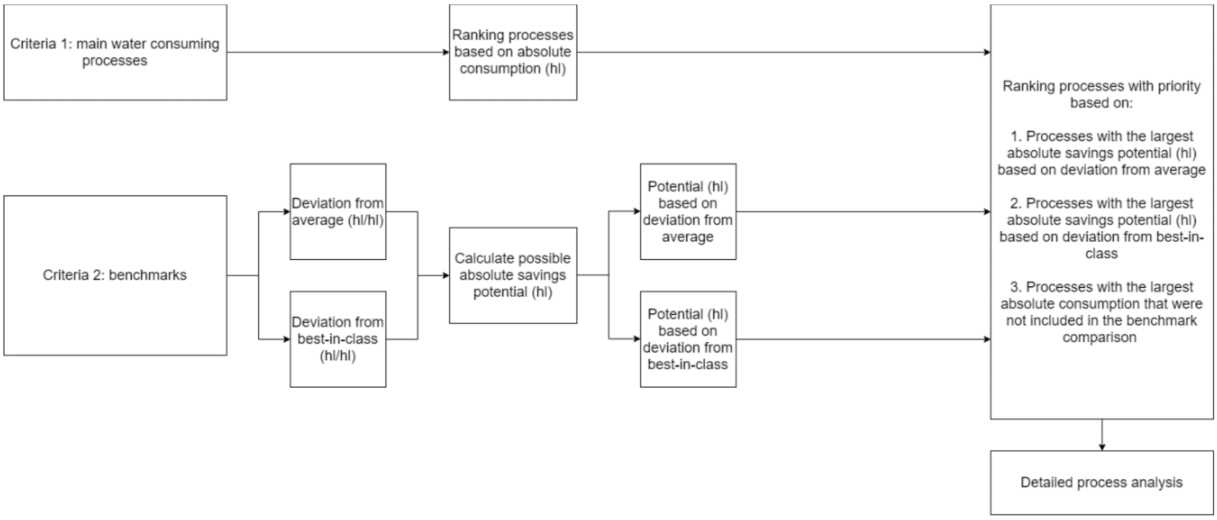

Figure 1: Method to determine which processes must be prioritised to realise water savings

Main water-consuming processes

First, processes were ranked based on absolute consumption. Within Grolsch, the water consumption is measured at four different levels: L1 (entire brewery), L2 (departments), L3 (production lines, production areas and utility installations) and L4 (individual machines). Data used for the analysis was retrieved from the data warehouse (see 4.2). It was decided to identify the main water-consuming processes at L3 and later perform a more detailed analysis on details. This decision was made based on the following arguments:

- Water consumption is not measured for all individual machines (L4).
- The categories on L3 are considered suitable for the benchmark comparison.
- Processes will be analysed later in the study. Many processes can influence each other; for this reason, it is important to understand the context. It is therefore considered that when processes at level 3 are analysed, the context will be better considered.

To get an overview of the L3 processes that consume the most water, a Pareto chart has been made. The Pareto chart provides a graphical display of the Pareto principle (Bird, Menzies, & Zimmermann, 2016). According to this principle, 80% of the benefit can be achieved by 20% of the effort (Loshin, 2013).

For the analyses, data from 2019 was used. In 2020, COVID-19 had a significant influence on the production circumstances. Therefore, data from 2020 could give a distorted picture of the situation, and it has been decided not to use this data as the starting point for the research. However, for some analyses, data from 2020 and 2021 will be used to provide insight into how the current consumption relates to historical consumption.

Benchmarks

Accordingly, a benchmark comparison was made to determine which processes have the largest potential for improvement. Therefore, data on the water consumption of 7 breweries in Italy, the Czech Republic, Poland, Romania, and Japan has been collected. The difference between the consumption of Grolsch and the average consumption of the other breweries and the consumption of the best-in-class brewery has been calculated for each L3 area. To determine which processes have the largest reduction potential, the absolute consumption and the difference with the average consumption of other breweries were considered. Therefore, the absolute savings potential has been calculated for each specific process. These savings were calculated by multiplying the possible water saving in a specific area (hl/hl) by the packed amount of beer in 2019 (hl).

It has been decided to first prioritise processes that have a large savings potential compared to the average water consumption. Subsequently, processes with a large reduction potential compared to the best-in-class brewery were prioritised.

Detailed process analysis

Based on the first two criteria, a ranking of L3 processes was created. Besides, detailed process analyses were performed to gain insight into which parts of the L3 processes have the potential for improvement. Therefore, several quantitative and qualitative analyses were performed. First, process descriptions were made based on information from interviews and internal documents. Accordingly, qualitative & quantitative data were used to describe the water applications within the processes. For this purpose, benchmark numbers, historical data on water consumption and knowledge about factors that influence water consumption were used.

4. ***<u>What possible solutions are there to reduce the water consumption of the brewery?</u>***

In this part of the research, possible solutions and improvements were investigated. Solutions can be organisational and logistics aspects, machines and tools and rules and standards. To find possible solutions, secondary analyses are performed, and semi-structured discussions are held. Solutions were categorised using the water management hierarchy (WMH).

<u>Which initiatives can be taken to reduce the water consumption of a large-scale brewery?</u>

To answer the main question, the information gained by answering the sub-questions was combined. First, it will be answered which initiatives Grolsch can take to reduce their water consumption. Accordingly, it will be discussed whether initiatives might be interesting for other large breweries as well. There will also be a discussion that includes a reflection on the performed research. Finally, recommendations will be given to other researchers and Grolsch.

1.4 Thesis outline

Chapter 2 provides an overview of existing water reduction methods that can be used in companies. The various methods will be discussed in separate paragraphs, after which the 1st sub-question, *“What existing methods are there to reduce a company's water consumption?”* will be answered in section 2.6. Chapter 3 contains a context analysis. Section 3.1 provides information about the water footprint of beer. This section discusses water use throughout the entire beer production chain. After this, the analysis will focus on the situation within the Grolsch brewery. Section 3.2 discusses the production process at Grolsch. Section 3.3 provides information about how water is used in the brewery. Section 3.4 provides an answer to the 2nd sub-question, *“For which applications is water used in the beer production process?”*. Chapter 4 provides information about the processes that must be prioritised to achieve water savings. Also, this chapter also contains a more extensive analysis of the most important processes at Grolsch. At the end of chapter 4, an answer will be given to the 3rd sub-question, *“Which processes should be prioritised to achieve water savings?”*. Chapter 5 provides an overview of the solutions that are possible to reduce the water consumption of the brewery. In this chapter, the last sub-question, *“What possible solutions are there to reduce the water consumption of the brewery?”* will be answered. Chapter 6 contains the conclusions and recommendations of the study. In this chapter, the main research question: *“Which initiatives can be taken to reduce the water consumption of a large-scale brewery?”* will be answered.

2. Existing water reduction methods

This chapter aims to provide an answer to the question: *''What existing methods are there to reduce a company's water consumption?''* In this chapter, five methods that can be used for the reduction of water in a brewery will be discussed. Finally, in section 2.6, the methods will be compared, and a conclusion will be drawn.

2.1 Water footprint

The water footprint was created by Arjen Hoekstra as a metric to measure the amount of water consumed and polluted to produce certain services and goods along their full supply chain. The water footprint helps to understand how production and consumption choices are affecting natural resources (Water Footprint Network, 2020). Arjen Hoekstra described the water footprint as follows:

> *''The water footprint is an indicator of freshwater use that looks at both direct and indirect use of water by a consumer or producer. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business''* (Hoekstra A. Y., 2013, p. xiii)

It is possible to measure the water footprint for a single process (e.g., growing rice), for a product (e.g., jeans) or for an entire multinational company. For companies, the water footprint can help to determine where and when water is used in their business. A company's water footprint includes its direct (operational) and its indirect (supply-chain) footprint. Conducting a water footprint assessment can provide a new perspective for developing a corporate water strategy (Water Footprint Network, 2021). The water footprint consists of three components: green, blue, and grey.

- **Green water footprint** is water from precipitation that is stored in the root zone of the soil and transpired, evaporated, or incorporated by plants. This is particularly relevant for agricultural, forestry and horticultural products.
- **Blue water footprint** is water that has been drawn from the surface and/or groundwater resources and is either incorporated into a product, evaporated, or taken from one body of water and returned to another or returned at another time.
- **Grey water footprint** is the required amount of fresh water to assimilate pollution to meet specific water quality standards (Water Footprint Network, 2020).

A product's water footprint is the total volume of fresh water used directly or indirectly to produce the product. The water footprint can be estimated by considering the water consumption and pollution in all steps of the production chain. In recent years, many large companies have performed water footprint assessments (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011).

The water footprint assessment can be used to quantify and map green, blue and grey water footprints, assess the sustainability, assess the efficiency and equitability of water use and identify which actions should be prioritised. The water footprint assessment consists of four phases. In the first phase, the goals and scope of the water footprint study are set. The assessment can be tailored to meet the scope and goals of the study. The scope and goal will indicate the data that will be used, the approach for every step in the assessment and the level of detail that is required to achieve the desired result. Once the scope and goal of the assessment are clear, data can be collected to calculate the footprint of the relevant processes. Data can either be collected locally or can be gathered from global databases. Thereafter, it is assessed whether the water use is balancing the needs of nature and people, if water resources are being used efficiently and if the water is shared fairly.

The final stage of the assessment is response formulation. The information gained should be used to prioritise the response strategies for implementation. It is important that companies use the insights gained. Developing a water footprint will only make a difference if practical solutions to the problems are developed. The Strategies can range from investing in more accurate metering, investments in technology or changes in practices that will reduce the water footprint (Water Footprint Network, 2021).

2.2 The 5Rs approach

The 5Rs approach for water management was developed by The International Water Association (IWA). The World Business Council for Sustainable Development (WBCSD) gives the following definitions of the 5Rs:

- ***Reduce***: *reduce water losses and boost water efficiency*
- ***Reuse***: *reuse water, with minimal or no treatment, within and outside the fence for the same or different processes*
- ***Recycle***: *recycle resources and wastewater (treated by a membrane or reverse osmosis to very high quality) within and outside the fence*
- ***Restore***: *return water of a specific quality to where it was taken from*
- ***Recover***: *take resources (other than water) out of wastewater and put them to use* (World Business Council for Sustainable Development (WBCSD), 2017, p. 6)

According to the WBCSD, many companies already apply one or more of the 5Rs. Reducing water use, reusing water, and recycling wastewater will help to reduce water stress and result in lower investment and energy costs. Besides, treated wastewater can also deliver social and environmental benefits. Furthermore, the treatment of wastewater can ensure a reliable water supply throughout the whole year (World Business Council for Sustainable Development (WBCSD), 2017). The first step to implement the 5Rs is to identify drivers for reducing water use. Once the drivers have been identified, an evaluation decision tree can be used to evaluate the options for reducing water use, recycling water, or reusing water. Figure 2 shows the decision tree that can be used to assess the applicability of the 5Rs.

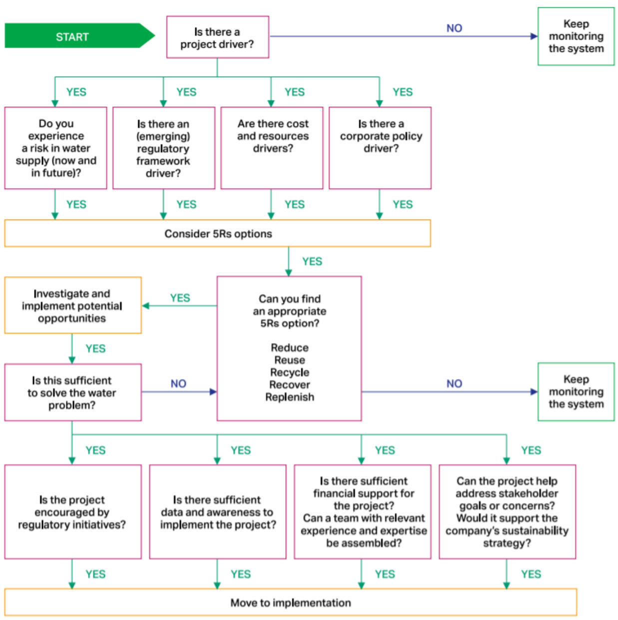

Figure 2: Decision tree to evaluate the applicability of the 5Rs (Business guide to circular water management: spotlight on reduce, reuse and recycle, 2017, p. 33)

2.3 Water Management Hierarchy

In 2006, Wan Alwi and Manan introduced the Water Management Hierarchy (WMH) (Wan Alwi & Manan, SHARPS: A New Cost-Screening Technique to Attain Cost-Effective Minimum Water Network, 2006). The WMH can be used as a guide for water minimisation and consists of 5 levels. The most preferred option is shown at the top of the hierarchy (L1), and the least preferred option is shown at the bottom (L5). Figure 3 shows the Water Management Hierarchy.

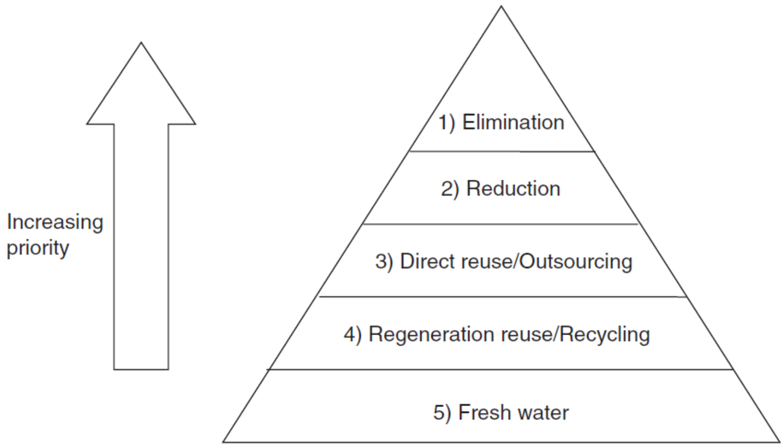

Figure 3: Water Management Hierarchy (Wan Alwi & Manan, SHARPS: A New Cost-Screening Technique to Attain Cost-Effective Minimum Water Network, 2006, p. 3982)

Source elimination (L1), which is shown at the top of the hierarchy, basically means complete avoidance of freshwater usage. In some cases, it is possible to eliminate water use instead of reducing, reusing, or recycling water. An example of elimination is the usage of an alternative cooling media instead of water. Although source elimination should be the goal, it is often not possible to eliminate water. If source elimination is not possible, the second-best option is source reduction (L2). Source reduction means that the amount of water being used at the source of water usage (for example, certain equipment or processes) is reduced. Wastewater recycling should be considered when it is not possible to eliminate or reduce fresh water at the source. Level 3 (direct reuse/outsourcing) and level 4 (regeneration reuse/recycling) both present a different variant of water recycling. Direct reuse means using process water directly within the process because the quality of the water is acceptable for the operation. Outsourcing means the usage of an external water source (rainwater or river water). Level 3 basically concerns the usage of spent water or an external water source for tasks for which water of lower quality can be used. In many industrial applications, regeneration (L4) may be necessary prior to recycling. Regeneration refers to the partial treatment of wastewater to obtain water with the desired quality for a certain task. Basically, there are two possibilities for regeneration. Regeneration-recycling means reusing treated water in the same process or equipment. Regeneration-reuse means reusing treated water in other equipment or processes. Level 5 is the least preferred option of the WMH. Fresh water usage (L5) should only be considered when it is not possible to recycle wastewater, or in case wastewater needs to be diluted to obtain a certain quality (Wan Alwi & Manan, SHARPS: A New Cost-Screening Technique to Attain Cost-Effective Minimum Water Network, 2006).

2.4 Water pinch analysis

The water pinch analysis (WPA) is a systematic technique of implementing a water minimisation strategy through the integration of processes for maximum water efficiency. The pinch refers to limits on productivity. The WPA proposes to reuse wastewater in a process that requires less pure water instead of discharging it to the wastewater treatment. The key message of WPA is as follows:

''Don't solve an end-of-pipe problem with an end-of-pipe solution. Unless you have explored the in-process solutions, your end-of-pipe solution could be the worst solution of your problem (Tainsh & R., 1996, p. 2).''

The water pinch analysis consists of five steps:

1. Analysis of the water network

First, the existing or base case water network should be analysed through plant auditing. According to (Liu, Lucas, & Mann, 2004), processes that consume high amounts of water, that generate high toxicity waste and that have disposal problems are good candidates for the implementation of water-saving projects. First, the overall water network of the plant should be obtained from process flow diagrams (PFD) and instrumentation diagrams (P&ID). A mass water balance needs to be made for all the water streams. The balance can be obtained from existing balances, routine measurements, earlier studies, and laboratory reports (Liu, Lucas, & Mann, 2004).

2. Data extraction

The 2nd step is the identification of water sources and water sinks that have the potential for reuse and recycling. After the water network is analysed, the processes can be grouped into plant sections. Information about the water sources, sinks flow rates, and quality requirements for each water-using process need to be gathered.

3. Setting minimum utility targets

The 3rd step is establishing the minimum water targets by using a targeting method. The three most widely used approaches are the Limiting Composite Curve, Source/Sink Composite Curve and Water Cascade Analysis Technique.

<u>Limiting Composite Curve (LCC)</u>

The LCC is only applicable for mass-transfer-based (MTB) operations, which are operations whereby species are transferred from a rich stream to water. Examples are cleaning and absorption processes. The LLC is a plot of the contaminant mass load vs contaminant concentrations. It is assumed that each water-using process has a fixed flow rate. Figure 4 is an example of a limiting composite curve.

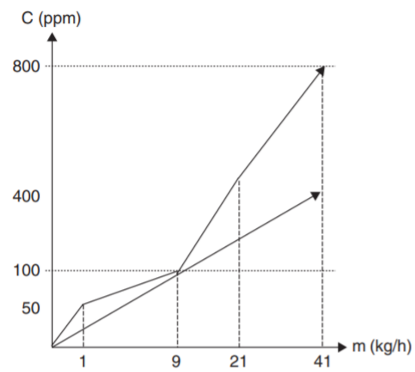

Figure 4: LCC (Wang & Smith, 1994, p. 987)

Each stream that has an inlet contaminant (C_{in}) and an outlet concentration (C_{out}) is plotted on the LCC. Accordingly, the streams are composited according to the concentration intervals. The minimum flowrate target for the system is given by the point where the fresh water supply line touches the composite curve. The point where the composite curve and supply line touch is called the pinch point.

<u>Source/Sink Composite Curve</u>

The source/sink composite curve can be used to set the target for the minimum usage of fresh resources for the material recycle/reuse network. First, the sinks are ranked in order of the maximum allowable contaminant concentration. Secondly, the sources are ranked in order of the maximum allowable contaminant concentration. Thereafter, the maximum mass load of each sink is plotted against its flow rate. Accordingly, a sink composite curve can be created. The next step is to plot the mass load of each source against its flowrate, after which a source composite curve can be created. Figure 5 is an example of a source/sink composite curve.

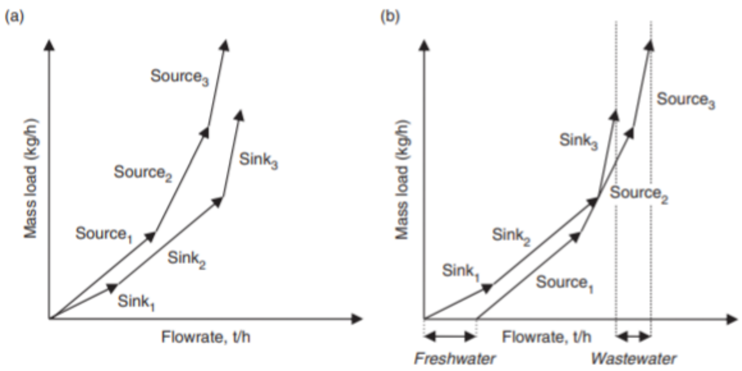

Figure 5: Source/sink composite curve (El-Halwagi, Gabriel, & Harrel, 2003, p. 4324)

The last step is to shift the composite stream until it touches the sink composite stream. The pinch is the point where the two curves touch.

<u>Water Cascade Analysis (WCA)</u>

The WCA is a method that can be used to establish the minimum water targets for a process after looking at the possibilities of using available water sources within a process to meet its water sinks. To achieve this goal, the net water flowrate, water surplus and deficit at different water purity levels within the process must be established. Therefore, (Manan, Tan, & Foo, 2004) introduced the Water Cascade Table (WCT). Figure 6 shows how the water cascading principle can minimise water needs and wastewater generation.

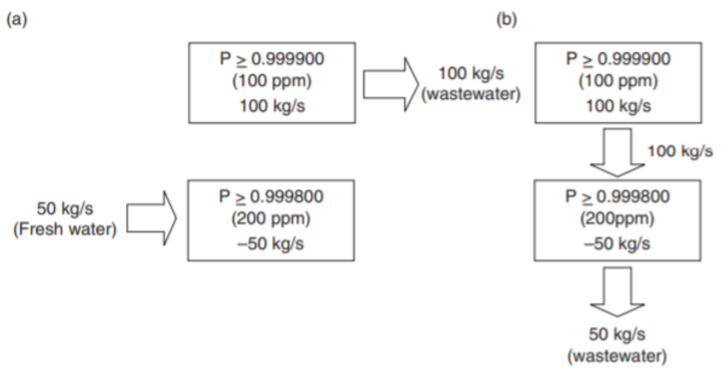

Figure 6: Water cascading principle (Manan, Tan, & Foo, 2004, p. 3174)

In section (a) of the figure, it is visible that 100 kg/s of wastewater is produced by a water source at a purity level of 100 ppm, and 50 kg/s water is needed by a water sink at a purity of 200 ppm. Without water reuse, 100 kg/s wastewater would be generated, while 50 kg/s fresh water would be needed. In section (b), it is shown that it is possible to avoid sending part of the water source directly to the effluent. By reusing water, not only the amount of wastewater will decrease, but also the fresh water will decrease. Figure 7 shows the general structure of a Water Cascade Table (WCT).

C	P	ΔP	ΣF_{SKi}	ΣF_{SRj}	$\Sigma F_{SKi} + \Sigma F_{SRj}$	ΣF	$\Delta P \times \Sigma F$	Cumulative ($\Delta P \times \Sigma F$)
			−1.2			F_{FW} = 2.0571		
0	10.99999			0.855.9	−0.4			
	0.999986	0.00001	−5.8			1.6571	0.00001657	
10	0.999975				−58			0.00001657
	0.999966	0.000004		1.4		−4.1429	−0.00001657	
14					5			0 (PINCH)
		0.000011				0.8571	0.00000943	
25					5.9			0.00000943
		0.000009				6.7571	0.00006081	
34					1.4			0.00007024
		0.999966				F_{WW} = 8.1571	8.15686551	
								8.15693576

Figure 7: General structure of a WCT (Manan, Tan, & Foo, 2004, p. 3174)

There are several steps that must be followed to create a WCT:

1. First, the contaminant concentration (C) needs to be listed for all the water-consuming processes. Duplicates need to be removed, and the contaminant concentration intervals need to be set up in ascending order, see Figure 7.
2. Accordingly, the purity of each concentration needs to be calculated. This can be done by using the formula below.

$$\text{Purity, } P = \frac{1{,}000{,}000 - C}{1{,}000{,}000}$$

Figure 8: Purity (P) calculation (Manan, Tan, & Foo, 2004, p. 3174)

In this formula, the C stands for the contaminant concentration in ppm.

3. After the calculation of the *P*, the purity differences (ΔP) can be calculated. This can be done by using the formula below.

$$\Delta P = P_n - P_{n+1}$$

Figure 9: Purity difference (ΔP) equation (Manan, Tan, & Foo, 2004, p. 3174)

4. The 4th step is to sum the flowrate of the water sinks (FSK) and sources (FSR) at each purity level. Water sources are written as positive values, while the water sinks are written as negative.
5. After this, the water sinks, and sources need to be summed up in the 6th column. In this column, a positive value means that there is a net surplus of water present at the respective purity level. A negative value means a net deficit of water. Water sources at a higher level can be used as input for water sinks with lower purity.
6. In the cumulative flowrate column (ΣF), water in the 6th column is cascaded. The first row in the cumulative flowrate column represents the estimated flow rates of fresh water required for the water-consuming processes. The estimated flow rate needs to be added to the value in the second row in the column to determine the cumulative water flow at every purity level. This process is continued until the last value in the column is added. The total cumulative water flowrate value in the final column is the total amount of wastewater generated in the process.

7. In the next column, the product of the purity difference and cumulative flow rate are calculated at every purity level. These values represent the pure water deficit or surplus in every region.
8. After this, the sum of $\Sigma F \times \Delta P$ needs to be calculated for every purity level. A negative value means that there will not be sufficient water purity in the network. In this situation, more fresh water needs to be added until all the values in this column are positive. The minimum freshwater target is the flow rate that results in zero cumulative water surplus in this column.
9. To ensure that there is enough water at all points in the network, a freshwater flowrate of the same magnitude as the value of the largest negative F_{FW} should be supplied at the highest purity level of a water cascade. The zero value that will appear is the pinch point.

After the targets are set by using one of the described methods, process modifications can be considered.

4. Water network design

The 4th step of the WPA is designing a water recovery network to realise the minimum water targets. A water network can be made using the Source-Sink Mapping Diagram by (Polley & Polley, 2000). In this diagram, the water sinks are aligned horizontally while all water sources are arranged vertically. Both need to be arranged according to increasing contaminant concentration. Figure 10 shows an example of a possible network design that was generated by source-sink mapping.

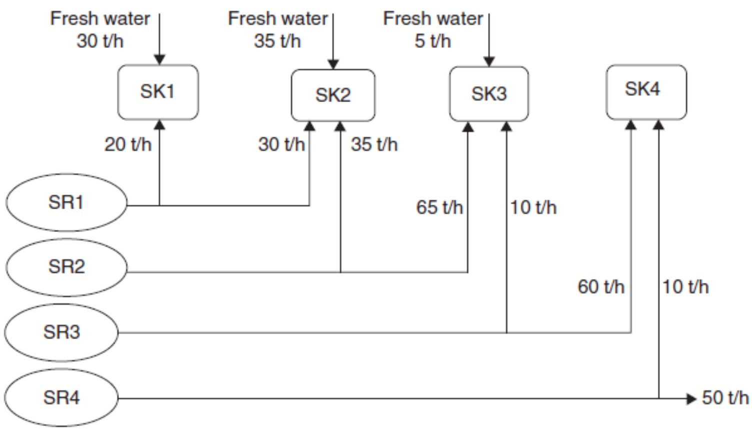

Figure 10: Network design by using a source-sink mapping diagram (Polley & Polley, 2000, p. 47)

A lot of times, there are several solutions possible to achieve the goals. Designers can influence the solution by imposing other constraints.

5. Economic evaluation

The last step is the evaluation of the economics of the water network. To calculate network costs, complex calculations can be used. However, the payback period is the most used criteria to assess the feasibility of a network solution. The payback period can be calculated using the equation that is visible in Figure 11.

$$\text{Playback period (years)} = \frac{\text{Net Capital Investment (\$)}}{\text{Net Annual Savings(\$/y)}}$$

Figure 11: Payback period equation (Wan Alwi & Manan, Water Pinch Analysis for Water Management and Minimisation: An Introduction, 2013, p. 373)

2.5 Holistic framework for the design of a cost-effective minimum water utilization network

The WPA is a well-established tool for designing a maximum water recovery (MWR) network. However, according to (Wan Alwi S. , Manan, Samingin, & Misran, 2008), MWR only partly addresses the water minimisation problem because it is primarily concerned with water recovery and regeneration. It is only possible to achieve minimum water targets when all minimisation options (see Figure 3) have been applied. Therefore, Wan Alwi and Manan developed a method to systematically and cost-effectively apply the WPA within the context of the WMH. This section describes the method for designing a cost-effective minimum water network (CEMWN) by (Wan Alwi S. , Manan, Samingin, & Misran, 2008). Figure 12 shows the holistic framework that can be used to achieve CEMWN.

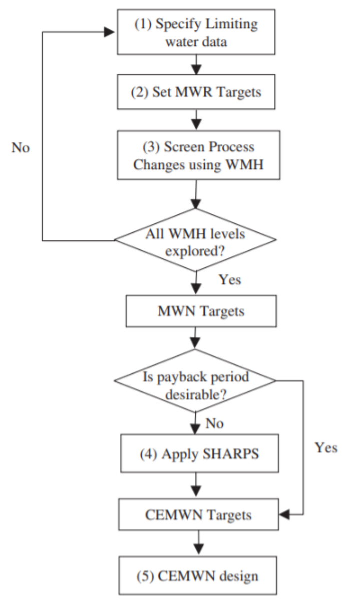

Figure 12: Holistic framework to achieve CEMWN (Wan Alwi S. , Manan, Samingin, & Misran, 2008, p. 223)

The framework consists of five key steps:

1. Specify the limiting water data

First, limiting water data need to be specified. This step involves line-tracing, establishing balances, and isolating the appropriate water sources and water demands that have the potential for integration. The water sources and demands need to be listed in terms of quality and quantity.

2. Determine maximum water recovery (MWR) targets

Secondly, base-case maximum water recovery targets need to be established. The base-case MWR targets only include the re-use and recycling levels of the WMH. The water cascade analysis (WCA) technique by Manan is a commonly used method to determine these targets.

3. WMH-guided screening and selection of options

To reduce the MWR targets and achieve the Minimum Water Network benchmark, changes can be made to the flow rates and concentrations of water sources and demands. The core of step 3 is the level-wise hierarchical screening and prioritisation of process changes using the WMH and four option-screening heuristics. These heuristics can be used to prioritise process changes at each level of the WMH. However, the four heuristics are not applicable at each level of the WMH.

Heuristic 1

Process changes need to start at the core of a process. High water usage at the core of the system will cause wastage at the outer layers. Improving the core of the system first will eliminate or reduce wastage downstream. Heuristic 1 only applies to the process change options at L1 and L2 of the WMH (see section 2.3). The appliance of heuristic 1 to source elimination options at L1 will lead to new targets. Once all elimination options are explored, heuristic one can be applied at L2 of the WMH.

Heuristic 2

All available demands with a concentration lower than the pinch point should be reduced, starting from the cleanest demand. If multiple demands exist at the same concentration, it is beneficial to start by reducing the demand that yields the most flow rate reduction. Heuristic 2 is applicable to L1 and L2 of the WMH.

Heuristic 3

Reduce the demands starting from the one giving the biggest flow rate reduction in case several demands exist at the same concentration. Heuristic 3 is only applicable to L1 and L2 of the WMH.

Heuristic 4

Regenerate wastewater or harvest outsourced water only as needed. Heuristic 4 only applies to L3 and L4 of the WMH.

4. Applying the SHARPS strategy

The 4th step is to use the Systematic Hierarchical Approach for Resilient Process Screening (SHARPS) strategy to economically screen inferior process changes. The SHARPS procedure is visible in the figure below.

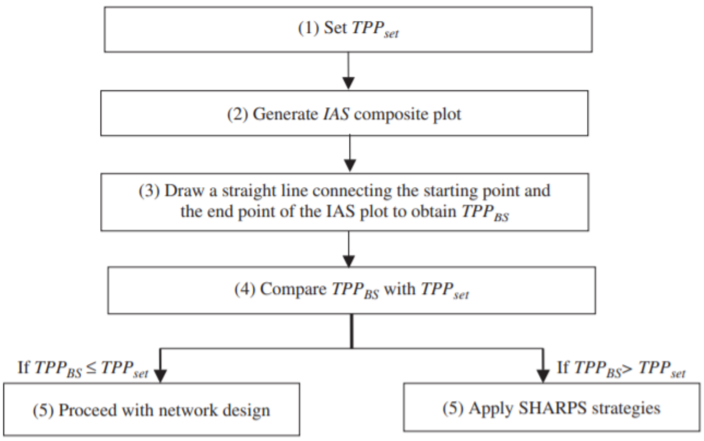

Figure 13: SHARPS procedure (Wan Alwi S. , Manan, Samingin, & Misran, 2008, p. 227)

1. First, the desired total payback period (TPP_{set}) needs to be determined. The desired payback period can be set by a plant owner.
2. An investment vs annual savings (IAS) composite plot needs to be generated. This plot needs to cover all the levels of the WMH. The gradient gives the payback period for each process change.
3. A straight line that connects the starting point and the end point of the IAS plot needs to be drawn. The gradient of the line is a preliminary cost estimate of the TPP for implementing all options. Figure 14 shows an example of an IAS plot.

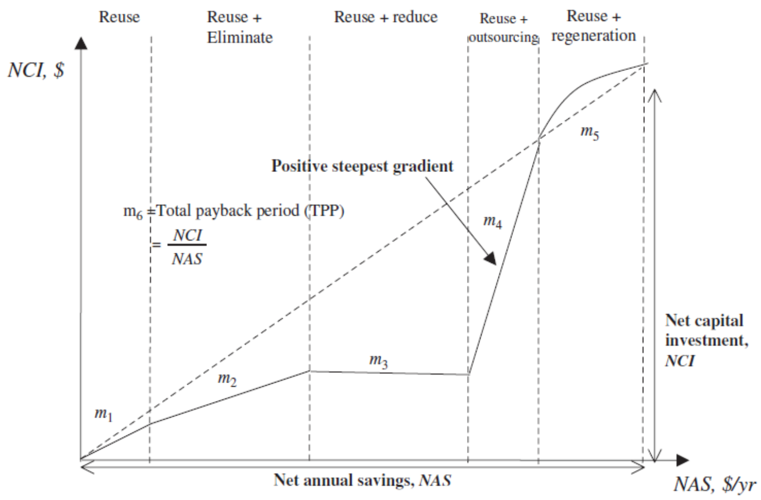

Figure 14: IAS plot covering all levels of WMH (Wan Alwi S. , Manan, Samingin, & Misran, 2008, p. 225)

4. The TPP_{BS} (total payback period before implementing SHARPS) needs to be compared to the TPP_{set}. The total payback period and the maximum desired payback period should match. The minimum water network can be tailored to the requirements of the plant owner. The comparison has two possible outcomes: $TPP_{BS} \leq TPP_{set}$ and $TPP_{BS} > TPP_{set}$.
5. If the outcome is $TPP_{BS} \leq TPP_{set}$, the network design can be continued.
6. In case the outcome is $TPP_{BS} > TPP_{set}$, there are two strategies that can be used. The first strategy involves replacing equipment that resulted in the steepest positive gradient with equipment that will cause a less steep gradient. The second strategy involves reducing the length of the steepest positive gradient until TPP_{AS} (which is the TPP after implementing SHARPS strategies) is equal to TPP_{set}.

5. Network design

When the CEMWN targets have been established, the network can be designed to achieve the CEMWN targets. This network could be developed using an established tool such as the Source-Sink Mapping Diagram (Polley & Polley, 2000).

2.6 Evaluation and conclusion

The aim of this chapter was to answer the 1st research question: *''What existing methods are there to reduce a company's water consumption?''*

Several methods can be used to reduce a company's water consumption. Some approaches are extensive and contain a detailed description of all the steps that must be followed, while others are more general/holistic. Some concepts (such as the categories for water-saving possibilities) were reflected in multiple approaches. Table 1 shows a comparison of the described methods.

Table 1: Methods comparison

Method	Includes chain perspective	A concrete approach that can be used within the factory	Indicates required data	Includes priority-based option screening
Water footprint	+	-	-	-
5Rs approach	-	+/-	-	-
Water management hierarchy	-	+/-	-	+
Water pinch analysis	-	+	+	-
Holistic framework	-	+	+	+

For companies, the water footprint assessment can help to gain insight into the use of water throughout the whole production chain. A supply chain perspective while doing a water footprint assessment makes sense for a company if it can influence other segments in the chain and is willing to do so. For this study, it has been decided to limit the focus on investigating water reduction opportunities at the production plant in Enschede. Therefore, the water footprint concept will only be used in this report to contextualise the research (see section 3.1).

The 5Rs approach and the water management hierarchy (WMH) have some similarities. Reducing, reusing, and recycling water are mentioned as options within both approaches. The 5Rs method is very general and does not contain a concrete approach. The WMH is more concrete; within this approach, the options are also ranked according to priority. The water pinch analysis (WPA) and the holistic framework for the design of a cost-effective minimum water utilization network are concrete methods that contain a detailed description. However, the WPA is primarily concerned with water recovery and regeneration. It is only possible to achieve minimum water targets when all minimisation options from the WMH have been applied. The holistic framework for the design of a cost-effective minimum water utilization network can be used to apply the WPA within the context of the WMH.

Looking at the methods described, there is not one method that completely fits within the research at the Grolsch brewery (considering the scope of the research and the desired results that the research must yield). To make the research as effective as possible and to keep it manageable, it was decided to first determine the most critical processes. This is done based on a benchmark comparison (see section 4.1). Only the processes with the most potential are analysed in detail. In chapter 4, the solutions found will be categorised according to the WMH.

3. Context analysis

This chapter provides context about the production process of beer and how water is used in this process. This chapter aims to provide an answer to the 2nd research question: *''For which applications is water used in the beer production process?''* Section 3.1 provides information about the water footprint of beer. Section 3.2 discusses the production process at Grolsch. Section 3.3 provides information about how water is used in the brewery. Finally, this chapter concludes with section 3.4.

3.1 The water footprint of beer

The water footprint was created by Arjen Hoekstra as a metric to measure the amount of water consumed and polluted to produce certain services and goods along their full supply chain (see section 2.1) (Water Footprint Network, 2020). This section provides information about the water footprint of beer.

Crop cultivation

The production of beer starts with the cultivation of crops. One of the most important materials for the production of beer is malt. Barley is the most common cereal used for the production of malt. According to (Mekonnen & Hoekstra, 2010), the global average water footprint of barley is 1420 litre/kg. Considering the amount of malted barley needed for the production of beer, the water footprint of the barley part in the beer is 298 litre water per litre of beer (85% green, 6% blue, 9% grey water footprint) (Mekonnen & Hoekstra, 2010). This is the sum of the water consumption (rain & irrigation water) and water pollution to make barley for 1 litre of beer. Hereby, the water footprint of other ingredients used in the production process (such as hops) is excluded. The water footprint of barley varies greatly per country. In the Netherlands, an average of 90 litres of water is needed per litre of beer. Part of the water is directly used for growing crops, water is used for the production of fertilizers, and there is water related to the energy use of farm machinery and the transport of the crops to the crop processing facilities (SABMiller, WWF-UK, GIZ, 2010).

Malting

Before barley is used for the production of beer, it is processed into malt. This process is called malting and includes the germination and drying of the barley. Malting usually takes place in a malt house (Gude, W; van Schaik, R, 2015). In the malting process, water is used for various purposes: part of the water is directly used for the process, there is water related to the energy used in the process, and there is water related to the energy used for the transportation of the malt to the brewery (SABMiller, WWF-UK, GIZ, 2010).

Brewery

In the brewery, water is used for various purposes. A case study conducted by SABMiller, WWF-UK and GIZ has shown that 5-9% of the water footprint of beer is attributable to brewing & bottling (SABMiller, WWF-UK, GIZ, 2010). Section 3.3 describes the applications of water in the brewery.

3.2 Production process

Beer is a collective name for different types of alcoholic drinks. Beer is obtained by fermenting an extract of malt and/or other cereals and by adding hops. For the production of beer, the following ingredients are used:

- Water
- Barley
- Hops
- Yeast (Gude, W; van Schaik, R, 2015)

Beer production is a classic example of a biotechnological process. The production process of beer can be divided into three parts: malting, brewing and fermentation (Wageningen University & Research, 2020). The first step in beer production is malting, which is done to convert barley into malt. Malting usually takes place in a malt house. The goal of malting is to modify the starch. This allows the starch to be processed by enzymes during brewing to convert it into sugar. The brewing process takes place in the brewhouse of the brewery. The purpose of the brewing process is to convert starch into fermentable sugars. After the brewing process, yeast is added to the wort, and the fermentation process will start. During the fermentation, yeast will convert the sugar into alcohol and CO_2. After fermentation, the beer will be temporarily stored so that the beer can mature. Finally, the beer will be filtered to make the beer clear (Gude, W; van Schaik, R, 2015). Figure 15 gives an overview of the beer production process.

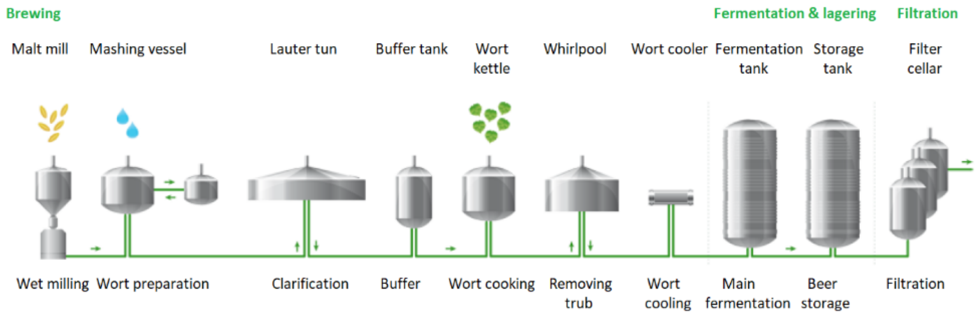

Figure 15: Beer production process (Gude, W; van Schaik, R, 2015, p. 41)

3.3 Water use in the brewery

This section provides information about how water is used within the brewery. Section 3.3.1 describes the water sources of Grolsch. Section 3.3.2 provides information about how water is used in the brewery. Section 3.3.3 gives an overview of the total water balance of the brewery.

3.3.1 Sources

Grolsch uses water from wells in Enschede and Hengelo as well as municipal water. Within the brewery, a distinction is made between 3 types of water: product water, process water and municipal water. Product and process water are extracted from multiple groundwater sources and treated to the required specification in water treatment plants. Municipal water is supplied by Vitens (drinking water company).

The groundwater that is used as product water in the brewery is extracted from 3 well fields in Enschede:

1. Schreurserve (5 wells)
2. Kotkamp (7 wells)
3. Lonnekerbleek (4 wells)

After the water has been extracted, it is transported to the brewery via a 7 km long pipeline. The groundwater that is used as process water is extracted from a well field in Hengelo. Figure 16 provides an overview of the brewery's water sources.

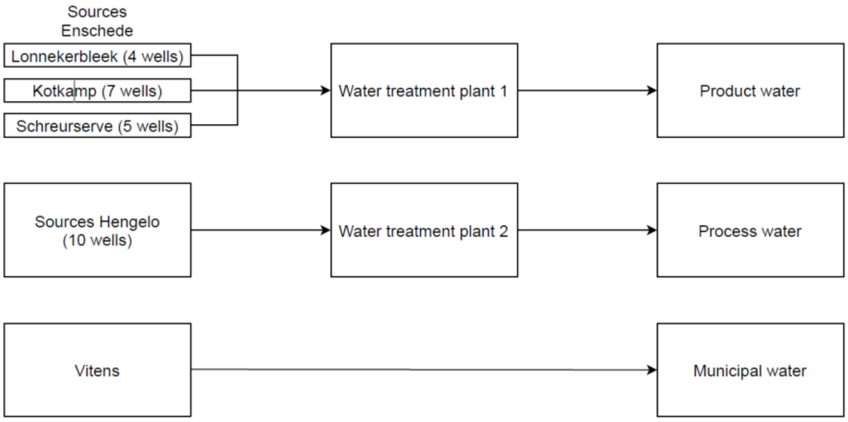

Figure 16: Water sources Grolsch

Product, process, and municipal water are used for different applications. Therefore, there are different requirements for each water type. Product and process water are both treated in a separate water treatment installation (WTP1 and WTP2). Most of the water used in the brewery is extracted from the well fields in Enschede and Hengelo. A small part of the water used in the brewery is supplied by Vitens. Figure 17 shows the distribution of Grolsch's water sources.

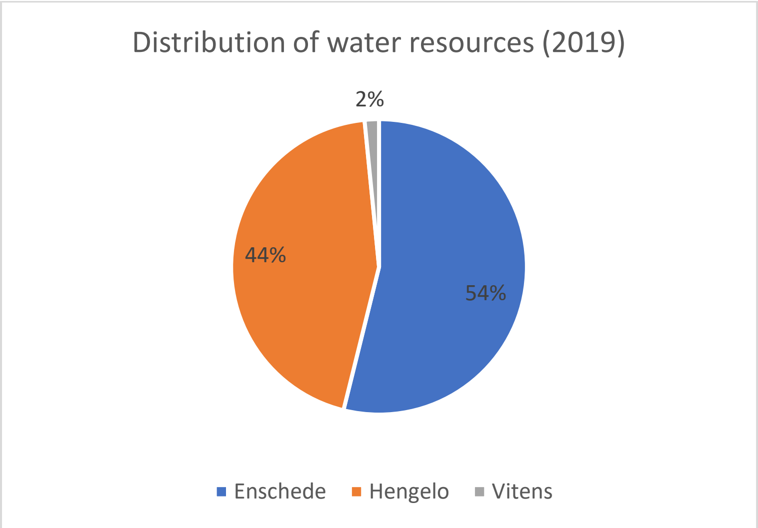

Figure 17: Distribution of water resources (Data warehouse Grolsch, 2019)

3.3.2 Applications

After treatment, the product and process water are distributed to the different departments within the brewery (brewing, packaging, and utilities). Within these departments, the water is used for a variety of applications. Municipal water is only used for sanitary facilities, offices, and fire hoses. The municipal water is (in principle) not used in the actual production process. Therefore, it is excluded from this research.

Product water

Before the extracted groundwater is used in the brewery, it is treated in a water treatment installation. A large part of the product water is used directly and ends up in beer, by-products or evaporates during the process. Besides, a part of the product water is used for cleaning, heating, and cooling applications. A large part of the product water ends up in the beer. The product water has a different composition than the process water. The main difference is the water hardness; product water contains a high amount of dissolved calcium and magnesium. Part of the product water undergoes an additional treatment in which oxygen is removed, producing degassed water. Most of this degassed water is used for blending. Besides, some of this water is used for flushing pipes at the end of a CIP treatment. There are a few process steps in which product water is directly used:

- Wet grinding of the malt
    - During this process, the starch is broken and reduced in size. Hereby water is added to ensure that the chaff remains intact.
- Mashing
    - Before the mashing begins, brewing water is mixed with malt in the mashing vessel.
- Mash separation
    - After separation, a large amount of the extract remains in the residue. In order to prevent losses, warm water is sprayed over the residue.
- Blending
    - Degassed water can be blended with beer at several moments within the process.

Depending on the application, the required temperature of the product water may vary. To ensure that the water has the right temperature, ambient product water and 85 °C product water are mixed in the right proportion.

Process water

Process water is extracted from the well field in Hengelo. Before it is used in the brewery, the water is treated in a separate water treatment installation. Due to the difference in treatment, the composition of the process water is different than the composition of product water. Unlike product water, the process water does not come in contact with the product. Within the brewery, process water is used for various cleaning, heating and cooling applications.

3.3.3 Water balance

This section provides an overview of the brewery's water balance.

After treatment, the product and process water are transported to the various consumers within the different departments (brewing, packaging, utilities). Figure 18 provides an overview of the brewery's water balance.

<<CONFIDENTIAL>>

Figure 18: Water balance brewery (Data warehouse Grolsch, 2019)

Figure 18 shows the sources of the incoming water, water-consuming processes, and outgoing flows. In 2019, a total of 9,229,847 hl of water was consumed in the brewery. The percentages shown for specific processes within the brewery indicate the amount of water used by a particular process relative to the total consumption. The percentages shown for outgoing flows indicate the amount of water in an outgoing stream relative to the total consumption. All calculations and percentages are based on data from 2019. The balance excludes water entering the brewery via chemicals and raw materials (malt, hops, et cetera).

Of all the water used in the brewery in 2019, 57% was used in the brewing department. Besides that, 29% of the water was used in the packaging department, and 12% was used in the utilities department. A large part of the water is used directly, which means that the water comes into contact with the product. Some of the water ends up in the beer, part evaporates during the boiling process, and some ends up in by-products (brewer's spent grain, trub etc.). Water is also used directly for the product during blending (after treatment to degassed water). According to calculations, 26% of the water entering the brewery in 2019 ended up in the beer. In addition, water is also lost through product losses. The water used for cleaning, heating, and cooling (water that does not evaporate in the condensers of the refrigeration installation) applications is treated in the wastewater treatment plant (WWTP). After treatment, the effluent will be sent to the sewage treatment plant. In 2019, 65% of the incoming water left the brewery as effluent.

3.4 Conclusion

This chapter provided information about the production process of beer and the use of water within this process. The chapter aimed to answer the 2nd research question: *''For which applications is water used in the beer production process?''*

The secondary analysis showed that water is consumed throughout the entire beer production chain, most of which is due to crop cultivation. However, the water footprint of barley varies greatly per country. The global average amount of water needed considering the amount of malted to produce beer is 298 litres of water/litre of beer, while in the Netherlands (with Dutch barley), 90 litres of water/litre of beer is needed (Hoekstra A. , 2019). A case study conducted by SABMiller, WWF-UK, and GIZ has shown that 5-9% of the water footprint of beer is attributable to the processes that take place in the brewery (SABMiller, WWF-UK, GIZ, 2010). Further research at Grolsch focuses explicitly on reducing water consumption within the brewery.

The production process within the brewery consists of several steps that take place in different areas of the brewery. Of all the water used in the brewery in 2019, 57% was used in the brewing department. Besides that, 29% of the water was used in the packaging department, and 12% was used in the utilities department. Dependent on the application, Grolsch uses product, process, and/or municipal water. Although the name product water suggests that this water is only used for the product itself, it is also used for other applications. Product and process water are treated in separate water treatment installations and differ in composition.

The water used in the brewery leaves the brewery in different ways. Most of the water (65%) leaves the brewery via the effluent. This includes the water used for CIPs, bottle washers and pasteurisers. Besides, a large part of the water (26%) ends up in the beer. In addition, part of the water leaves the brewery via by-products (spent grains, trub etc.), through evaporation (brewhouse, cooling plant) and product losses.

4. Priorities

This chapter aims to provide an answer to the 3rd research question: *''Which processes should be prioritised to achieve water savings?''* The first paragraph provides information about the criteria that are used to detect processes with potential for improvement. Section 4.2 contains information about the main water-consuming processes within the brewery. In section 4.3, Grolsch's water consumption is compared to other Asahi breweries. Section 4.4 contains analyses of the most critical processes. Finally, the conclusions indicating the processes that need to be prioritised are listed in 4.5.

4.1 Criteria

It is not possible and beneficial to analyse all processes within the brewery in detail; therefore, priorities must be set. A Multi-Criteria Analysis (MCA) will be used to determine which processes need to be prioritised. Therefore, the following criteria are taken into account:

- Absolute water consumption
- Benchmarks
- Process analysis

In order to save as much water as possible, it is beneficial to focus on processes whose absolute consumption is high, and that deviate from benchmarks. There is a greater chance that these processes can be improved and that improvements lead to significant water reductions.

Absolute water consumption

First, the processes will be ranked based on absolute consumption. Improvements that lead to savings for large consumers have the greatest impact. Therefore, processes that are large water users are good candidates for the implementation of water-saving projects (Liu, Lucas, & Mann, 2004).

Benchmarks

Benchmarking is a continuous improvement tool that makes it possible to have a more disciplined application of search for excellence through operational improvements (Passos & Haddad, 2013). The aim is to enable a company to close the gap between the current performance and superior performance (Rohlfer, 2002). Within various earlier performed studies on water savings, benchmarks were used to identify processes with potential for improvement. An example is a research by (Tokos & Glavič, 2007), in which benchmarks were used to identify critical processes for water savings in a brewery. For this research, data about the water consumption of specific processes within various breweries has been collected. This data has been used to determine the average consumption and best-in-class consumption for specific processes. The difference between Grolsch's current consumption and the average & best-in-class will be used to determine priorities. The idea is that the further Grolsch deviates from the average & best-in-class in terms of performance, the more there is to gain. The absolute savings potential is calculated for each specific process to determine the order in which processes need to be analysed in detail (see Figure 1 on page 13).

Process analysis

The ranking of processes that deserve priority is determined based on the first two criteria. However, processes need to be analysed in more detail to determine which exact part(s) can be improved. Therefore, more detailed quantitative and qualitative analyses are needed. More information about the approach and method of prioritising can be found in section 1.3 and Figure 1.

4.2 Main water-consuming processes

Within the brewery, the water consumption is measured at four different levels:

- Level 1: Water consumption of the entire brewery (main meters)
- Level 2: Water consumption of the individual departments (brewing, packaging, utilities, office and rest)
- Level 3: Water consumption of production lines, production areas and utility installations
- Level 4: Water consumption per individual machine (only available for large consumers)

Figure 19 provides an overview of the measurement levels.

<CONFIDENTIAL>

Figure 19: Measurements levels data warehouse (Data warehouse Grolsch, 2019)

Within the brewery, there are various flow meters that measure water consumption. However, water consumption is not measured for every L4 process. The consumptions measured in the brewery are visible in the data warehouse. The rest consumptions visible in the data warehouse are calculated. More information about the measurements of specific areas and machines can be found in section 4.4.

As described in section 1.3, information from the data warehouse was used to make balances. Within this research, the main water-consuming processes are identified at L3. The arguments for approaching the analysis from L3 can be found in section 1.3.

To get an overview of the water consumption, the figure below shows the consumption at level 2.

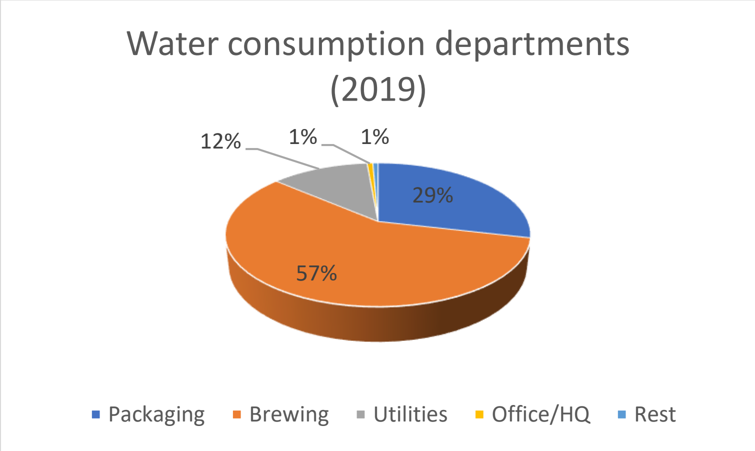

Figure 20: Water consumption departments (L2) (Data warehouse Grolsch, 2019)

Within the brewery, most of the water (57%) is used in the brewing department. A lot of water is also used in the packaging and utilities department. The office and rest only account for a very small percentage of the total water consumption.

To get an overview of the processes that consume the most water at L3, a Pareto chart has been made. This Pareto chart provides a graphical display of the Pareto principle (Bird, Menzies, & Zimmermann, 2016). According to this principle, 80% of the benefit can be achieved by 20% of the effort (Loshin, 2013). Figure 21 shows to what extent the different areas (L3) contributed to the total water consumption of the brewery in 2019.

<CONFIDENTIAL>

Figure 21: Pareto chart of water consumption (Data warehouse Grolsch, 2019)

Within the brewery, the eight largest consumers (at L3) are responsible for 80.5% of the water consumption.

4.3 Benchmarks

Grolsch is part of Asahi Europe & International. In total, Asahi owns 19 breweries in 8 production countries. Grolsch's water consumption has been compared to other breweries. Therefore, data on the water consumption of 7 breweries in Italy, the Czech Republic, Poland, Romania, and Japan has been collected. The following L3 areas are excluded from the comparison: filtration blend water, beer processing, BBT chemical, rest packaging, BBT and office rest. These areas have been excluded because it was not possible to collect benchmarks numbers for them. Table 2 shows the water consumption of Grolsch, the average water consumption of the other breweries and the water consumption of the best-in-class brewery.

Table 2: Water consumption comparison (Grolsch, 2021)

<CONFIDENTIAL>

Water consumption of the different units/installations is among others influenced by production volume, type of beer produced, efficiency and the design of the process. Investigating the factors that cause differences in detail is beyond the scope of this study. It should also be noted that benchmarks do not determine the true minimum target (or potential). If a previous achievement (such as the specific water consumption of a similar brewery) is used as a benchmark for improvement, the improvement is relative to a previous design achievement (Wan Alwi & Manan, Water Pinch Analysis for Water Management and Minimisation: An Introduction, 2013). Although it is difficult to make a completely fair comparison and benchmarks do not determine the actual savings potential, they do give an indication of areas that may have the potential for improvement. To determine which processes should be analysed first, both the absolute consumption and the difference with the consumption of other breweries must be considered. Therefore, based on the 2019 consumptions and data from Table 2, the absolute savings potential has been calculated for each specific process.

**The water consumption shown in the last row (best-in-class) is the consumption of the best performing brewery in a specific area.*

***The water consumption of the Grolsch returnable bottle filling line (RB) is the average value of all Grolsch RB filling lines.*

Figure 22 indicates the water reduction opportunity comparing the 2019 Grolsch performance with the average water consumption of equal L3 areas in other breweries.

<CONFIDENTIAL>

Figure 22: Absolute water savings compared to the average consumption (Data warehouse Grolsch, 2019)

Figure 23 indicates the water reduction opportunity comparing the 2019 Grolsch performance with the best-in-class consumption of equal L3 areas in other breweries.

<CONFIDENTIAL>

Figure 23: Absolute water savings compared to the water consumption of the best-in-class brewery (Data warehouse Grolsch, 2019)

The savings were calculated by multiplying the possible water saving in a certain area (in hl/hl) by the packed amount of beer in 2019 (hl). For the individual filling lines, the calculations are based on the consumption and the packed amount of beer on a specific filling line in 2019.

Closing the gap between the water consumption of Grolsch in 2019 and the average water consumption of other breweries (see Figure 21) results in a reduction of [redacted] hl/hl. Closing the gap between the water consumption of Grolsch in 2019 and the best-in-class consumption of equal L3 areas in other breweries results in a reduction of [redacted] hl/hl.

4.4 Process analyses

Now that a number of processes with potential have emerged from the analyses in section 4.2 and section 4.3, the most critical processes will be further analysed. The sequence in which the processes are described in this section were determined using the method in Figure 1. Processes with the largest savings potential based on the deviation from the average consumption will be analysed first.

4.4.1 Water treatment

This section describes the water treatment process, which is part of the utilities department.

4.4.1.1 Process description

As mentioned in section 3.3.1, extracted well water from Enschede en Hengelo are both treated in a separate water treatment installation (WTP1 and WTP2) to produce product and process water. The section below contains information about both treatments.

WTP1

In WTP 1, well water from Enschede wells is treated to product water. First, the water is aerated with air to dissolve the oxygen in the water. The oxygen and minerals that are present in the water form oxides, which are removed in the next step. Iron removal and manganese removal filters are used to remove the oxides. After filtration, the water is collected in a water storage tank. Part of the water is used as rinsing water to clean the iron and manganese removal filters. The remaining part of the water is further treated in the decarbonization plant. In this plant, the water flows through an ion exchange resin to remove calcium carbonate salts. For the quality of the beer, it is desired to leave some of the minerals in the water. Therefore, a part of the water bypasses the decarbonization step. Accordingly, other impurities will be removed by an activated carbon filter. Thereafter, CO2 will be removed from the water by a CO2 degasifier, and the water is stored in a storage tank. From this storage tank, the water is transported to the brewery. Part of the water undergoes an additional treatment in the filtration room (degassed water). This water is used as filtration blend water.

WTP2

The process water treatment has many similarities to the product water treatment, but there are also several differences. There is a difference in the order in which the steps take place. Within this treatment, the degasifier is placed after the iron removal filter. After the CO_2 is removed, the water is treated in the manganese removal filters and activated carbon filter. When these treatment processes are completed, the water is stored in a storage tank. Part of the water is pumped to the boilers, and part is pumped to a softening filter. After treatment, the water is stored in a tank and can be distributed throughout the brewery. CO_2 is added to the process water in utilities and in the filtration room.

The flow chart in which both processes are shown can be found in Appendix A: Flow chart water treatment.

4.4.1.2 Water applications

To obtain water of the right quality, the incoming water is treated by various filters. The different filters (iron removal, demanganization, activated carbon) within the installation must be cleaned. Currently, water is already being reused at the water treatment plant. A large part of the water is currently stored in a cellar and returned to a process water tank after reversed osmosis (RO) treatment.

4.4.1.3 Data

Figure 24 shows the water consumption of the water treatment area over the past few years.

<CONFIDENTIAL>

Figure 24: Water treatment trends water use (Data warehouse Grolsch, 2019)

The figure above shows that the water consumption of the water treatment area has increased in recent years. However, the amount of water used within this area is largely dependent on the amount of well water entering the brewery. The figure below shows how much water is consumed per hl water that enters the brewery.

<CONFIDENTIAL>

Figure 25: Water treatment water use (Data warehouse Grolsch, 2019)

According to the internal benchmark, the water used for water treatment should not exceed 7% of the incoming water volume. The figure above shows that this limit is not exceeded in the past few years.

4.4.2 Filling lines

Within the packaging department, there are eight different filling lines. The benchmark comparison has shown that KL02, KL04, and KL07 have a higher water consumption than average and the best-in-class brewery. The water consumption of KL03 is lower than average but higher than the water consumption of the best-in-class brewery. In this section, the different filling lines are discussed.

4.4.2.1 Process description

The packaging process of beer consists of several steps and differs per filling line. Table 3 provides an overview of the different filling lines, types of beer that are filled, types of packaging used, and the machines whose consumption is measured.

Table 3: Filling lines (Gude, W; van Schaik, R, 2015)

Packaging line (L3)	**Type(s) of beer**	**Primary packaging**	**Secondary packaging**	**Equipment/machines measured (L4)**
KL01	Premium Lager, Miller, Lentebok, Herfstbok and Weizen	Returnable kegs (15-50 L)	Pallets	-
KL02	Special beers, Radler and Premium lager	Returnable bottles (RB) crown cap (30 cl)	6-packs and crates	Bottle pasteuriser Bottle washer Crate washer
KL03	Premium Lager	Returnable bottles (RB) crown cap (30 cl)	Crates	Bottle warmer Bottle washer Crate washer
KL04	Premium Lager	Returnable bottles (RB) swing-top (45 cl)	Crates, boxes, and 4-packs	Bottle washer Crate washer Bottle warmer
KL05	Premium Lager and Herfstbok	Magnum bottle / non-returnable bottle (NRB) - large (1,5 L)	Boxes	Bottle pasteuriser
KL07	Premium Lager, Export beers and Radler	Non-returnable bottle (NRB) crown cap (25 - 71 cl)	6-packs, 12-packs, and boxes	Bottle pasteuriser
KL08	Premium Lager, Export beers, Special beers, Radler	Cans (33/50 cl)	4/6/8/12/24-packs and trays	Can pasteuriser Rinser Filler
KL20 (unmeasured)	Premium Lager, Export beer	Tanks (80-120 hl)	-	-

The setup of each filling line is different and mainly depends on the type of beer and packaging used. The setup has a significant influence on water consumption. Water consumption is measured at both line-level (L3) and machine-level (L4). However, individual water consumption is not measured for every machine. Table 3 shows the machines whose water consumption is measured individually. A complete overview of the water-consuming processes (including unmeasured users) can be found in Table 4. The water consumption of filling line 20 (KL20) is not measured.

4.4.2.2 Water applications

Table 4 provides a complete overview of the processes within the filling lines that use water.

Table 4: Complete overview of water users filling lines (KL02, KL03, KL04 and KL07)

	KL02	KL03	KL04	KL07
Product water (85 °C)	*Measured* - Main meter (PDW) - Crate washer - Bottle washer - Retour (PDW)	*Measured* - Main meter (PDW) - Crate washer - Bottle washer - Retour (PDW)	*Measured* - Main meter (PDW) - Crate washer - Bottle washer - Retour (PDW)	*Measured* - Main meter (PDW) - Retour (PDW)
	Unmeasured - Water hose (11x) - Service unit (3x) - Hand washing unit - CIP set - Bottle filler	*Unmeasured* - Water hose (12x) - Service unit (3x) - Hand washing unit (2x) - CIP set - Bottle filler	*Unmeasured* - Water hose (11x) - Hand washing unit (5x) - Service unit (4x) - HWA - CIP set - Bottle filler - Swing-top washer - Swing-top closer (2x) - P (2x)	*Unmeasured* - Water hose (6x) - Service unit (3x) - Hand washing unit (3x) - CIP set - Rinser - Bottle filler
Process water	*Measured* - Main meter (PCW) - Crate washer - Bottle washer - Bottle pasteuriser	*Measured* - Main meter (PCW) - Crate washer - Bottle washer - Bottle warmer	*Measured* - Main meter (PCW) - Crate washer - Bottle washer - Bottle warmer	*Measured* - Main meter (PCW) - Pasteuriser
	Unmeasured - Water hose (9x) - Service unit (3x) - Hand washing unit - Full bottle control & sorting - Bottle labeller - CIP set - Bottle filler	*Unmeasured* - Water hose (11x) - Service unit (3x) - Hand washing unit (2x) - Bottle labeller - CIP set - Empty bottle inspection - Bottle filler - Machine LF56	*Unmeasured* - Water hose (8x) - Service unit (5x) - Hand washing unit (6x) - Bottle shower (2x) - Bottle opener - Ring changer (4x) - Swing-top cleaner - Leak detection - Conveyor belt (3x) - CIP set - Bottle filler - Labeller - Swing-top closer (2x)	*Unmeasured* - Water hose (6x) - Service unit (3x) - Hand washing unit (3x) - Bottle labeller - Bottle input - CIP set - Bottle filler

4.4.2.3 Data

Figure 26 shows the water consumption (hl/hl per line) of the filling lines with the highest water reduction potential and the average consumption from the benchmark analysis (blue dot).

<CONFIDENTIAL>

Figure 26: Water consumption filling lines (Data warehouse Grolsch, 2019)

The filling lines shown in the figure all performed better in the past in terms of water consumption. If it is possible to close the gap between the water consumptions of KL02, KL03, KL04, and KL07 in 2017 and 2019, this will yield a reduction of [redacted] hl/hl. In order to calculate the total possible saving in hl/hl, the absolute savings were calculated for every filling line. This was done by multiplying the difference (hl/hl) in consumption for each filling line (2017 – 2019) by the packed amount of a specific filling line in 2019.

Figure 27 shows how much water is used for different applications.

<CONFIDENTIAL>

Figure 27: Distribution water consumption filling lines (Data warehouse Grolsch, 2019)

In the figure, it is visible that the bottle washer is a large water consumer. On KL02, KL03, and KL04, beer is filled into returnable bottles (RB). These bottles must be cleaned and sterilised before beer can be filled. The bottle washer is used to clean bottles that have been returned to the brewery.

In order to reduce the water consumption of the filling lines significantly, the main focus will have to be on the bottle washers and the rest consumption of the filling lines. Based on historical performance, there is potential to improve these consumptions.

Bottle washer

Figure 28 gives an overview of the water consumption of the bottle washers (in hl/hl).

<CONFIDENTIAL>

Figure 28: Water consumption bottle washer (Data warehouse Grolsch, 2019)

Based on historical performance, the bottle washers have the potential for improvement. The table below shows the potential of the bottle washers based on historical performance.

Table 5: Water consumption bottle washer (ml/bottle)

<CONFIDENTIAL>

Table 6 shows what a certain saving on the water consumption of the bottle washer would yield on the total consumption of the brewery (in hl/hl).

Table 6: Savings bottle washer (hl/hl)

<CONFIDENTIAL>

For calculating the ultimate saving in hl/hl, use has been made of the quantities that were packed on the various filling lines in 2019. If it is possible to reduce the consumption of all three bottle rinsing machines to benchmark, this will reduce the total water consumption of the brewery by [redacted] hl/hl. However, such a huge saving does not seem realistic. In order to achieve [redacted] hl/hl for the bottle washer, the consumption of the bottle washer at line 2 must be reduced by [redacted]%, at line 3 by [redacted]% and at line 4 by [redacted]%. Based on historical consumption, a reduction of around [redacted]% should be realistic.

Rest consumption

The unmetered consumers are also responsible for a large part of the total consumption. This includes the vacuum pumps, fillers and service units that are in the line. Figure 29 shows the rest consumptions of the filling lines over the past few years.

<CONFIDENTIAL>

Figure 29: Water consumption filling lines rest (Data warehouse Grolsch, 2019)

A rest consumption is displayed for each filling line in the data warehouse. This rest consumption is calculated by subtracting the measured consumers from the measured overall consumption of the line. An overview of the unmeasured machines can be found in Table 4. A detailed overview of the rest consumption of the filling lines can be found in Appendix B: Water consumption filling lines rest. Table 7 shows the impact of a certain saving on the rest water consumption of a filling line on the total water consumption of the brewery (in hl/hl packed total).

Table 7: Savings rest (hl/hl)

<CONFIDENTIAL>

4.4.3 Total refrigeration

This section describes the refrigeration process, which is part of the utilities department.

4.4.3.1 Process description

The brewery's refrigeration system consists of a primary and secondary cooling system. In the primary system, liquid ammonia (NH_3) is cooled. The ammonia cools the secondary cooling system via heat exchange with aqueous propylene glycol. The glycol is distributed through the brewery and is used as a cooling medium for many processes. The primary system is only used in the utilities building. For the process, water is used to drive the condensers.

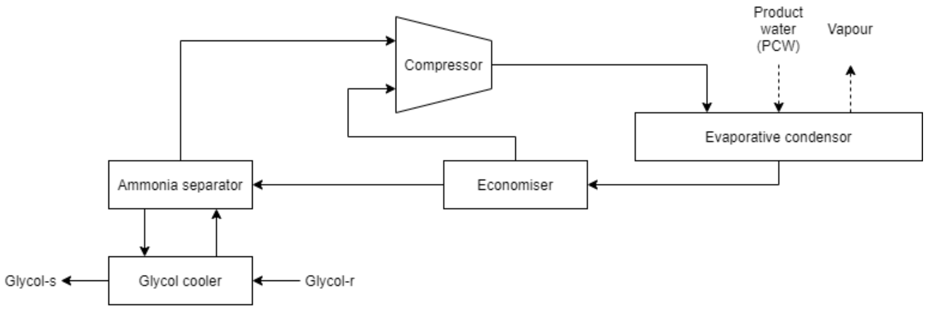

Figure 30: Flow diagram total refrigeration

4.4.3.2 Water applications

Within this area, water is used for the evaporative condenser.

4.4.3.3 Data

Figure 31 shows the water consumption of the total refrigeration area over the past few years.

<CONFIDENTIAL>

Figure 31: Trends water use total refrigeration (Data warehouse Grolsch, 2019)

The figure above shows that the water consumption of the total refrigeration area has increased in recent years.

4.4.4 Filtration

This section describes the filtration process, which is part of the brewing department.

4.4.4.1 Process description

After the beer is fermented and matured, filtration takes place to produce the so-called bright beer that is ready to be packed. The goal of the filtration process is to remove the last solids from the beer. Before and after the filtration, there is a possibility to add compounds to the beer. The addition of compounds is called standardisation in figure 35 below. Before the filtration process starts, the beer is cooled to a temperature of -1.5°C. The filtration process consists of multiple steps. Kieselguhr is used as a filtration material for the first tubular filter. This tubular filter removes solid particles from the beer. After a certain number of filtrations, the filter should be replaced. The second filter contains Polyvinylpolypyrrolidone (PVPP) and removes polyphenols from the beer. During the cleaning of the line, the PVPP is regenerated. After the PVPP filter, there is a trap filter. This filter removes all the filter particles that remained in the beer. After filtration, there is a possibility to standardise and/or pasteurise the beer. Finally, the beer will be sent to the Bright Beer Tanks (BBT). Figure 32 shows the process in the filtration area.

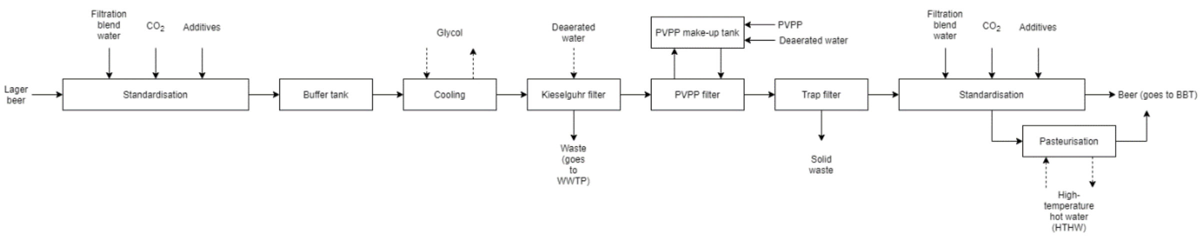

Figure 32: Flow diagram filtration area

4.4.4.2 Water applications

Within the filtration area, water is used for various cleaning treatments. Besides, the degassed water that is used for filling and flushing the pipes also falls under filtration.

4.4.4.3 Data

Figure 33 shows the water consumption of the filtration area over the past few years.

<CONFIDENTIAL>

Figure 33: Trends water use filtration (Data warehouse Grolsch, 2019)

In Figure 33, it is visible that the water consumption of the filtration area increased over the past few years. During discussions with experts, it emerged that this could partly be explained by an increase in the number of beer types and an increase in batch changes.

4.4.5 Brewhouse

This section describes the process that takes place within the brewhouse, which is part of the brewing department.

It was decided to analyse the brewhouse despite the fact that it did not emerge from the benchmark analysis as an area with potential. This choice was made because discussions with experts revealed that there is less insight into water consumption within the brewhouse than in other areas in the factory. Besides, the brewhouse remains the largest consumer of water in the brewery. Therefore, it is still considered realistic that possible improvements will have a significant impact.

4.4.5.1 Process description

The process starts with the transportation of malt to a malt mill, which is located at the entrance of the brewhouse. The malt is dosed into a steeping chute, where warm brewing water with a temperature of 63°C is added. This warm brewing water is obtained by mixing ambient product water (PDW-A) with hot product water (PDW-85°C) in the correct ratio. In the malt mill, the malt is crushed between rollers to decrease the size of the grains. This is done to improve the mashing rate and efficiency of the brewing process. The mixture of the warm brewing water and crushed malt is called mash. In the brewery, there are two identical brewing lines. After the mash has been obtained, the process will continue on one of these two brewing lines. First, the mash is pumped to a mashing tun. This is where the mashing process begins. During this process, the mash is heated to various temperatures using steam. In total, this process takes about 90 minutes. When the process is finished, the mash will be transferred to a lauter tun. In the lauter tun, the undissolved particles are removed from the mixture. The mash enters the lauter tun from the top, where the mash flows through a strainer. Some of the particles from the mash will form a (natural) filter for the mash. When the filtration is done, hot PDW will be used to rinse the filter. This is done to extract the remaining substances from the solids. The water that is used to rinse the filter will end up in the filtrate, which is called wort. The solid residue that remains in the lauter tun is called brewer's spent grain (BSG). The next step in the process is wort boiling. First, the wort will be preheated to 98°C in a heat exchanger. After this, the wort will be transported to a wort boiler. In this boiler, the wort is boiled for 40 minutes, and hops are added. During this process, the proteins will flocculate. These insoluble parts are called trub and will later be removed from the wort. During the boiling process, a part of the water will evaporate. As a result, the sugar content of the wort will increase. The water that evaporates during the process will be condensed in a condenser. After boiling, the wort is treated in a whirlpool. The whirlpool is a round insulated cylindrical tank. The wort enters the whirlpool through two openings in the wall. As a result of the tangential supply of the wort, a vortex is created. This vortex causes the trub to end up on the bottom, which makes it possible to remove the trub from the wort. When this process is finished, the wort will be cooled from 90°C to 9°C by a heat exchanger. Subsequently, the wort will be aerated. Thereafter, the wort will be transferred to the fermentation tanks in the beer processing area (Gude, W; van Schaik, R, 2015).

Figure 34 is a schematic representation of the process that takes in the brewhouse.

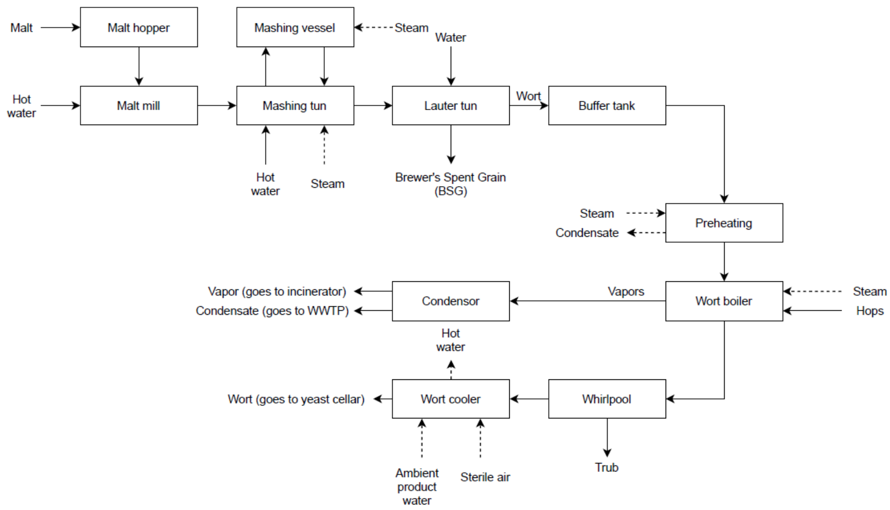

Figure 34: Flow diagram brewhouse

4.4.5.2 Water applications

Within the brewhouse, a distinction can be made between water that is used directly (comes in contact with the product) and water that is used for other applications.

Water that is directly used

A large amount of the water that is used in the brewhouse comes in contact with the product. Most of this water ends up in the beer, some evaporates during the boiling process, and some ends up in by-products. Figure 35 is a mass balance of the water used for the product in the brewhouse.

<CONFIDENTIAL>

Figure 35: Overview of directly used water

The values that are shown in the figure are based on calculations. The section below provides more information about these calculations.

- Wort

Grolsch Premium Pilsner contains a large amount of water. However, part of this water is added to the beer later during the process (filtration blend water). Within Grolsch, the brewed volume is measured.

- By-products: BSG & trub

BSG and trub are by-products that are created during the brewing process. In breweries, BSG accounts for 85% of the total by-product generation. BSG contains a high amount of proteins (15.3–24.7%) and polysaccharides (Loannidou, et al., 2020). Fresh BSG has a high-water content, which lies around 70-85% (Jackowski, Niedzwiecki, Jagiełło, Uchanska, & Trusek, 2020). The average measured water content of the BSG in the brewery of Grolsch is 79%. According to literature, fresh trub has a water content of 86.9% (Santos Mathias, Fontes Alexandre, Cammarota, de Mello, & Sérvulo, 2015). At Grolsch, the BSG and trub are combined and sold as animal feed. It is known that Grolsch sold [redacted] kg BSG and trub as animal feed in 2019. In order to calculate the amount of water that ended up in the by-products, data on the amount of sold by-products and the measured water content of BSG were used. In 2019, according to calculations, [redacted] hl water ended up in the by-products. In reality, the amount of water that ended up in the by-products may be even higher because the sold animal feed also contains a small amount of trub (trub has a higher moisture content than BSG).

- Evaporation

During the wort boiling, a part of the water will evaporate. The water that evaporates will be condensed in a condenser. This water will later be treated in the WWTP of the brewery. According to (Santonja, Panagiotis, Stubdrup, Brinkmann, & Roudier, 2019), 4% is the lowest evaporation rate documented by breweries as sufficient. A reduced evaporation rate brings some potential quality risks; therefore, brewers frequently monitor these risks (Santonja, Panagiotis, Stubdrup, Brinkmann, & Roudier, 2019).

Water used for other applications

In the brewhouse, water is also used indirectly. This water is used for various cleaning, heating, and cooling applications. Within Grolsch, an estimation is made of the amount of CIP used in the brewhouse. In 2019 it was estimated that [redacted] hl of water was used for the CIP treatments in the brewhouse.

Figure 36 shows the distribution of water for different applications in the brewhouse.

<CONFIDENTIAL>

Figure 36: Distribution of water in the brewhouse

The largest part of the water used in the brewhouse ends up in the wort. The displayed residual value is calculated by subtracting the estimated consumption of the displayed consumers from the measured total consumption.

4.4.5.3 Data

Figure 37 shows the water consumption of the brewhouse over the past few years.

<CONFIDENTIAL>

Figure 37: Trends water use brewhouse

In the figure, it is visible that there has been some variation in water consumption in recent years. However, the deviations in water consumption are not very large. There is an internal benchmark for the use of CIP. This is set at [redacted] hl/hl; in 2019, the consumption of the CIP was [redacted] hl/hl.

4.5 Conclusion

This chapter provided information about the most important water-consuming processes within the brewery. The chapter aimed to answer the 3rd research question: *''Which processes should be prioritised to achieve water savings?''*

For Grolsch, it is important to focus on the areas where the most water can be reduced. The benchmark analysis has shown that there are several areas of which the water consumption at Grolsch is higher than at other Asahi breweries. Based on the benchmark analysis, the three areas with the most potential are:

1. **Water treatment** (L3)
2. **Filling lines**
    a. KL02 (L3)
    b. KL04 (L3)
    c. KL07 (L3)
3. **Total refrigeration** (L3)

Closing the gap between the water consumption of Grolsch in 2019 and the average water consumption of other breweries (see Figure 21) results in a reduction of [redacted] hl/hl. Closing the gap between the water consumption of Grolsch in 2019 and the best-in-class consumption of equal L3 areas in other breweries results in a reduction of [redacted] hl/hl. Besides, there are also a few areas that were not included in the benchmark analysis but that could be of interest. Beer processing and BBT/chemical are especially interesting because they fall within the top 10 consumers at level 3 (see Figure 21). Filtration blend water also falls under the major users but is not interesting from a water-saving point of view because this water enters the product directly.

It has been found that the areas with the biggest potential have all performed better in the past. However, it is also possible that Grolsch has started to consume more in certain areas due to stricter rules, more in-depth focus on hygiene, changes in product types and compliance with new standards. Figure 38 shows how much the total water consumption can be reduced if the consumptions of areas with potential are reduced to the historically lowest measured consumption (as of 2017).

<CONFIDENTIAL>

Figure 38: Water use (after reduction to best historical consumption)

If it is possible to reduce the areas with the most potential to the lowest historical consumption, the total consumption would be reduced to [redacted] hl/hl.

5. Initiatives

This chapter aims to provide an answer to the 4th research question: *"What possible solutions are there to reduce the water consumption of the brewery?"*

This chapter describes existing solutions to reduce the water consumption of a brewery. In order to find these solutions, the following actions have been taken:

- Conversations with experts within Grolsch
- Analysing literature and documents on possible solutions

The different solutions are categorised according to the levels of the water management hierarchy (WMH) (see section 2.3). The WMH can be used as a guide for water minimisation and consists of 5 levels. The most preferred option is shown at the top of the hierarchy (L1), and the least preferred option is shown at the bottom (L5). The WMH consists of the following five levels:

1. Elimination
2. Reduction
3. Direct reuse
4. Regeneration reuse
5. Freshwater usage

5.1 Elimination

Source elimination (L1) basically means complete avoidance of freshwater usage. In some cases, it is possible to eliminate water use instead of reducing, reusing, or recycling water.

5.1.1 Dry conveyor belt lubrication

Area: BBT/chemical (L3)

Within the packaging department, water is used for conveyor belt lubrication. Conveyor lubrication is used to reduce friction to enable traffic flow to encourage throughput (Diversey Holdings, 2021). Water-based solutions are very commonly used on beverage packaging lines to lubricate conveyors. However, water-based solutions can create hygiene issues & safety hazards and waste valuable water (Diversey Holdings, 2021). In the data warehouse, this consumption is allocated under BBT/chemical. In 2019, [redacted] hl water was used for conveyor belt lubrication.

Dry conveyor belt lubrication systems are available. From a water-saving perspective, it is desirable to replace the system with a dry conveyor belt lubrication system. Theoretically, complete elimination of water use for line lubrication will lead to a reduction of [redacted] hl/hl. Other important benefits include improvements in safety and hygiene as floors are drier and biological growth is minimal (Diversey Holdings, 2021).

However, there are many things that need to be investigated to determine whether it is actually possible and beneficial for the brewery to (partly) replace the existing system. The following matters, among others, should be considered:

- On which lines (or parts of lines) is it possible to replace the current system with a dry conveyor belt lubrication system
- Impact on production (what are the implications for cleaning, safety, efficiency, etc.)
- Costs

The risks and consequences must be carefully determined. For example, it must be determined whether the (partial) replacement of the system does not lead to extra water consumption for cleaning. It would be interesting to talk to a supplier to explore the possibilities. Audits could be carried out to determine the actual possibilities for Grolsch.

5.1.2 Dry vacuum pump

Area: packaging (L2)

Within the packaging department, there are vacuum pumps at the various filling lines. The vacuum pump is used in the filling process. In the bottle filling process, the air is first expelled from the bottle. After this, the bottle is brought to the correct pressure (slightly lower than the beer pressure) using carbon dioxide. Accordingly, the bottle is filled with beer which has approximately the same pressure as the pre-pressure. This makes it possible to prevent foaming (Gude, W; van Schaik, R, 2015). The water consumption of the vacuum pump is not measured separately. In the data warehouse, the water consumption of the vacuum pump falls under the rest consumption of the filling line.

A liquid ring vacuum pump utilises water as the sealant. Due to the sealing water inside the pump, the pump runs cool (Gardner Denver, 2021). In addition to vacuum pumps that use water, there are vacuum pumps that do not use water. According to an article by the Food Engineering Magazine, there is a brewery that uses a rotary screw vacuum pump in the beer bottling process. This rotary screw vacuum pump uses a foam-dampening water trap to capture water & foam during the process (Labs, 2018). Further research is needed to determine whether it is possible to replace current pumps. The following should be considered in this regard:

- Hygiene
- Reliability
    - All steps in the brewing process are interrelated; devices that do not function properly can have major consequences on the production
- Costs
- Possible saving

The first step to determine whether there is an opportunity here is to determine the water consumption of the pump. This can be done by (temporarily) installing a mobile flow meter.

5.2 Reduction

Source reduction means that the amount of water being used at the source of water usage (for example, certain equipment or processes) is reduced.

5.2.1. Bottle washer optimisation

Area: Packaging (L2) – KL02, KL03, KL04 (L3)

Within the filling lines, the bottle washer is the largest water consumer. The bottle washer is used to clean bottles that return to the brewery. An investigation can be started to reduce the water consumption of this machine. The things that need to be taken into account during research can be found in the action list for filling line KL02 (see Appendix D: Overview of filling line KL02).

5.2.2. CIP optimisation

Within the factory, a lot of water is used for the CIP treatments. A typical CIP process requires a large amount of water, chemicals and energy. For CIP optimisation, several initiatives can be taken:

- Changing chemical concentration
- Adjusting time taken for a certain stage of the CIP process
- Improving CIP automation

Filtration

Within the filtration area, a lot of water is used to clean the various filters. During the research, it was found that planning has a major influence on the frequency with which CIPs are performed. Team leaders receive information from the planning about the products that need to be filtered on the different lines. The frequency with which CIPs must be performed depends on the production time. However, each product change on a line also requires a CIP treatment. Because there are many product changes on the lines, the maximum production time (before a CIP has to be performed) is often not achieved. The setup of the planning is mainly based on demand. Research into the possibilities of optimising the planning in filtration to reduce water consumption could potentially lead to significant water savings.

5.3 Direct reuse

Direct reuse means using process water directly within the process because the quality of the water is acceptable for the operation.

5.3.1 Wort recovery

Area: brewhouse

In the production process, the wort is treated in a whirlpool (a round insulated cylindrical tank). Wort enters the whirlpool through two openings in the wall. As a result of the tangential supply of the wort, a vortex is created. This vortex causes the trub (insoluble parts) to end up on the bottom, making it possible to remove the trub from the wort. It is estimated that per brew (850 hl), about [redacted] hl of trub is produced (Gude, W; van Schaik, R, 2015). Based on this, it is calculated that in 2019 about [redacted] kg of trub was produced. Fresh trub has a water content of 86.9% (Santos Mathias, Fontes Alexandre, Cammarota, de Mello, & Sérvulo, 2015). At Grolsch, trub and BSG are combined and sold as animal food.

Alfa Laval (process equipment supplier) has a system that can be used for wort recovery. Figure 39 provides an overview of how this system works.

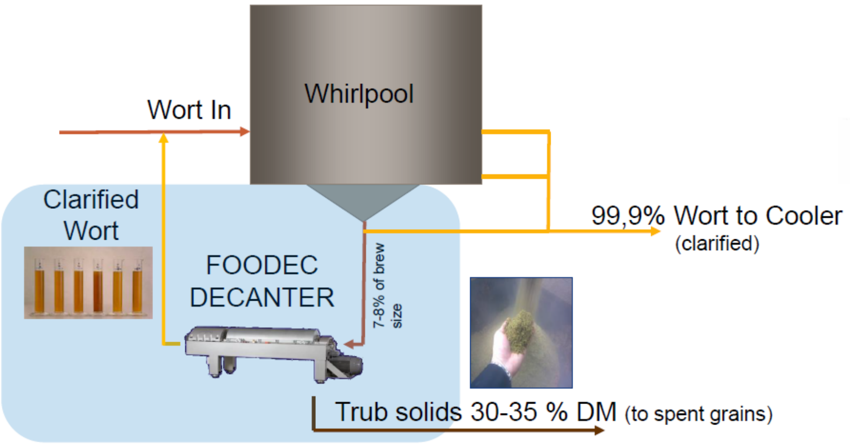

Figure 39: Wort recovery (Podobnikar & Visser, 2020)

With the wort recovery system, a decanter loop is added to the existing whirlpool. The decanter loop works in parallel with the whirlpool process. It is added to remove solids from the whirlpool during the whirlpool process. The solids collected in the cone at the bottom of the whirlpool tank are pumped to a decanter centrifuge. This machine makes use of centrifugal forces to separate solids from the liquid (Podobnikar & Visser, 2020). Within the brewery, a decanter centrifuge can be used to dewater various by-products. Information about dewatering the by-product BSG can be found in Appendix C: Spent grains dewatering.

Within the wort recovery system, the decanter is used to separate clear wort from the trub solids. Clear wort will be pumped to the whirlpool or downstream to the wort cooler line (to the same brew). This is done before the whirlpool is completely empty. After the trub solids are separated by the decanter, they can be transported to a storage tank (Alfa Laval, 2021). Because the solids are pumped from the whirlpool to the decanter centrifuge during the process (and so before the whirlpool is emptied completely), there are no remaining solids in the bottom of the whirlpool.

The main advantage of the system is the reduction of whirlpool losses. According to Alfa Laval, whirlpool losses can be reduced to max. 0.1% and thus increase the brewing yield by 1-3%. An increase in the brewing yield leads to both water and energy savings. Besides, water is also saved because water is no longer needed to rinse away the remaining trub (trub is already removed during the whirlpool process). According to an article by BRAUWELT International, water savings (due to reduced whirlpool flushing) of 0.02 hl/hl to 0.2 hl/hl can be achieved (Hambach, Podobnikar, & Jurado, 2015). In addition, a drier trub is produced. This extends the shelf life of the trub and reduces the costs for the transport of the trub (Alfa Laval, 2021).

Further research is needed to find out to what extent the solution can actually benefit Grolsch. The following should be examined in this regard:

- Possible savings
    - Wort
    - Water
    - Energy
    - Cost savings (savings in costs by reducing water and energy use and savings by reducing the volume of trub that has to be transported)
- Costs
    - Equipment investment cost
    - Costs associated with the use of the machine (energy, maintenance, etc.)
- Necessary adjustments to the current process to enable integration of the solution
- Influence on the production process (production times, quality of wort, cleaning, etc.)
- Payback time

5.3.2 Reuse of final rise

Area: brewhouse & filtration

In some cases, it is possible to install a tank to recycle the final rinse of the CIP treatment for the pre-rinse stage (Brewers Association, 2012). The last rinsing water of a cleaning cycle has a very good quality. By collecting the last rinsing water of the cleaning process and reusing it for the first flush of the next cycle, it is possible to save water. A lot of times, the initiative can be implemented without any major modifications and investments (World Business Council for Sustainable Development (WBCSD), 2017).

It might be possible to reuse the final rinse of the CIP treatment in the brewhouse. There is currently already a recovered CIP tank in the brewing department. Research into the possibilities for reusing the final rinse in the brewhouse can be included in the scope of a CIP optimisation project.

5.4 Regeneration reuse

Regeneration-reuse means reusing treated water in other equipment or processes.

5.4.1 Water recycling plant

There are breweries that treat wastewater to produce water with a quality that can be reused within the brewery. This year, a brewery in Denmark opened a water recycling plant that recycles 90% of the process water. This enables the brewery to halve its water consumption from the current 2.9 hl/hl to 1.4 hl/hl (Carlsberg Group, 2021). Within Grolsch, concrete research is currently being conducted to investigate this possibility.

5.5 Conclusion

This chapter aims to provide an answer to the 4th research question: *''What possible solutions are there to reduce water consumption in the brewery?''*

There are a lot of possibilities for water reduction. From a water-saving perspective, technical solutions such as a dry conveyor belt lubrication system and a dry vacuum pump are highly desirable. If it is possible to actually use these solutions, part of the water consumption is eliminated. However, these solutions are complex and cannot be applied immediately from one day to the next. Additional research needs to be performed to determine whether it is possible to replace the current systems and determine consequences, costs and how much it would actually yield. The same applies to the found solutions in which water is reused directly (wort recovery, reuse of final rinse). Solutions to reduce water consumption (optimisation of CIP, planning or certain machines) are easier to apply. For filling line 2 (KL02), a concrete overview has been made of the goals and actions that can be taken to reduce the water consumption of this line. This approach mainly focuses on optimising the bottle washer, improving factory efficiency (FE), and reducing bottle losses at the empty bottle inspection (EBI). If it is possible to achieve the defined performance targets for this line, the consumption of the filling line could be reduced from the current [redacted] hl/hl to [redacted] hl/hl. An overview of the plan can be found in Appendix D. Finally, it is also possible for breweries to treat wastewater and reuse it in the factory. Grolsch is currently investigating this possibility.

6. Conclusion, discussion and recommendations

This chapter includes the answers to each sub-question and the main question, a reflection on the approach and findings of the research and recommendations for other researchers and the company.

6.1 Conclusion

The research objective in the master's thesis was to collect and analyse relevant data to make recommendations on how to reduce the water consumption of a large-scale brewery.

Sub-questions:

1. *What existing methods are there to reduce a company's water consumption?*

Several methods can be used to reduce a company's water consumption. During this research, the following five methods were reviewed:

1. Water footprint
2. The 5Rs approach
3. Water Management Hierarchy (WMH)
4. Water pinch analysis
5. Holistic framework for the design of cost-effective minimum water utilization network

Some approaches are extensive and contain a detailed description of all the steps that must be followed, while others are more general/holistic. Some concepts (such as the categories for water-saving possibilities) were reflected in multiple approaches. For companies, the water footprint assessment can help to gain insight into the use of water throughout the whole production chain. Nevertheless, developing a water footprint will only make a difference if practical solutions to the problems are developed. The 5Rs method distinguishes five options for minimising water consumption. However, this method is quite general and does not contain a concrete approach to detect possibilities. Within the WMH, a distinction is also made between options for water minimisation. In addition, the WMH also distinguishes priority between the options. The water pinch analysis (WPA) and the holistic framework for the design of a cost-effective minimum water utilization network are straightforward methods that contain a detailed description. However, the WPA is primarily concerned with water recovery and regeneration. To achieve the minimum water targets, all minimisation options from the WMH must be applied. The holistic framework for the design of a cost-effective minimum water utilization network can be used to apply the WPA within the context of the WMH.

2. *For which applications is water used in the beer production process?*

The secondary analysis showed that water is consumed throughout the entire beer production chain, most of which is due to crop cultivation. A case study conducted by SABMiller, WWF-UK, and GIZ has shown that 5-9% of the water footprint of beer is attributable to the processes that take place in the brewery (SABMiller, WWF-UK, GIZ, 2010).

The production process within the brewery consists of several steps that take place in different areas of the brewery. Of all the water used in the Grolsch brewery in 2019, 57% was used in the brewing department. Besides that, 29% of the water was used in the packaging department, and 12% was used in the utilities department. Dependent on the application, Grolsch uses product, process, and/or municipal water. The water used in the brewery leaves the brewery through several streams. Most of the water (65%) leaves the brewery via the effluent. This includes the water used for CIPs, bottle washers and pasteurisers. Besides, a large part of the water (26%) ends up in the beer.

In addition, part of the water leaves the brewery via by-products (spent grains, trub etc.), through evaporation (brewhouse, cooling plant) and through product losses.

3. *Which processes should be prioritised to achieve water savings?*

For Grolsch, it is important to focus on the areas where the most water can be reduced. The benchmark analysis has shown that there are several areas of which the water consumption at Grolsch is higher than at other Asahi breweries. Based on the benchmark analysis, the three areas with the most potential are:

1. Water treatment (L3)
2. Filling lines
   a. KL02 (L3)
   b. KL04 (L3)
   c. KL07 (L3)
3. Total refrigeration (L3)

Closing the gap between the water consumption of Grolsch in 2019 and the average water consumption of other breweries (see Figure 21) results in a reduction of [redacted] hl/hl. Closing the gap between the water consumption of Grolsch in 2019 and the best-in-class consumption of equal L3 areas in other breweries results in a reduction of [redacted] hl/hl. Besides, there are also a few areas that were not included in the benchmark analysis but that could be of interest. Beer processing and BBT/chemical are especially interesting because they fall within the top 10 consumers at level 3 (see Figure 21). Filtration blend water also falls under the major users but is not interesting from a water-saving point of view because this water enters the product directly.

It has been found that the areas with the biggest potential have all performed better in the past. However, it is also possible that Grolsch has started to consume more in certain areas due to stricter rules, more in-depth focus on hygiene, changes in product types and compliance with new standards. If it is possible to reduce the areas with the most potential to the lowest historical consumption, the total consumption could be reduced to [redacted] hl/hl.

4. *What possible solutions are there to reduce the water consumption of the brewery?*

There are several possibilities for water reduction. From a water-saving perspective, technical solutions such as a dry conveyor belt lubrication system and a dry vacuum pump are very interesting. If it is possible to actually implement these solutions, part of the water use can be eliminated. However, these solutions are complex and cannot be applied immediately from one day to the next. Additional research needs to be performed to determine whether it is possible to replace the current systems and determine consequences, costs and how much it would actually yield. The same applies to the found solutions in which water is reused directly (wort recovery, reuse of final rinse). Solutions to reduce the water consumption of the brewery (optimisation of CIP, planning or certain machines) are easier to apply. For filling line 2 (KL02), a concrete overview has been made of the goals and actions that can be taken to reduce the water consumption of this line. Finally, it is also possible for breweries to treat wastewater and reuse it in the factory. Grolsch is currently investigating this possibility.

Main question:

Which initiatives can be taken to reduce the water consumption of a large-scale brewery?

The research has shown that initiatives can be taken on various fronts to reduce the water consumption of the brewery. According to the water management hierarchy (WMH), five options for water reduction can be distinguished: elimination, reduction, direct reuse, regeneration reuse and freshwater usage (freshwater usage should only be considered when it is not possible to recycle wastewater or in case wastewater needs to be diluted to obtain a certain quality).

Elimination

Within Grolsch, there are a number of options for minimising water consumption through elimination. The most important possibility for this is the use of a dry conveyor belt lubrication system. Within the packaging department, water is used for conveyor belt lubrication. Conveyor lubrication is used to reduce friction to enable traffic flow to encourage throughput (Diversey Holdings, 2021). Dry conveyor belt lubrication systems are available. However, additional research is needed to assess whether it is actually beneficial and possible for the brewery to replace the existing system. Within the brewery, the possibilities always depend on the existing structure of the system, and it is important that the possible consequences, costs and feasibility of implementation are properly investigated.

Reduction

For the reduction of water, there are various initiatives that can be taken. A concrete plan has been made to reduce the water consumption of filling line KL02. This approach focuses on optimising the bottle washer, improving factory efficiency (FE) and reducing bottle losses at the empty bottle inspection (EBI). If it is possible to achieve the defined performance targets for this line, consumption could be reduced to [redacted] hl/hl. Besides, there are also additional initiatives that can be taken to reduce the water consumption of this filling line. There are multiple water hoses at filling line KL02 that are used for various cleaning activities. In order to decrease the amount of water used for the water hoses, the cleaning procedures have to be standardised. Therefore, an optimal procedure needs to be determined. Besides, the amount of CIPs of the filler can be reduced by improving the maintenance. In addition, it emerged during the study that the water consumption of the filtration area is highly dependent on the existing planning. A study into the optimisation of the planning could potentially lead to a significant water reduction.

Direct reuse

In the production process, the wort is treated in a whirlpool (a round insulated cylindrical tank). There is a system that can be used for wort recovery, which can save water. It is expected that by using the system, whirlpool losses can be reduced to max. 0.1% and thus increase the brewing yield by 1-3%. An increase in the brewing yield leads to both water and energy savings. Besides, water is also saved because water is no longer needed to rinse away the remaining trub (trub is already removed during the whirlpool process). Further research is needed to find out to what extent the solution can actually benefit Grolsch.

Regeneration reuse

There are breweries that process the wastewater into the water of a quality that can be reused within the brewery. Within Grolsch, concrete research is currently being conducted to investigate this possibility.

6.2 Discussion

Approach

One of the components of this research was a benchmark comparison. Benchmarking is a continuous improvement tool that makes it possible to have a more disciplined application of search for excellence through operational improvements (Passos & Haddad, 2013). Within various earlier performed studies on water savings, benchmarks were used to identify processes with potential for improvement. In this study, data about the water consumption of specific L3 areas of other breweries were collected. However, the research did not include a detailed analysis of the factors that could cause differences between breweries. The water consumption of the different units/installations is influenced by a lot of factors (such as production volume, type of beer produced, efficiency and the design of the process). Therefore, it is difficult to make an entirely fair comparison. Besides, benchmarks do not determine the actual minimum target (or potential). Whenever a previous achievement is used as a benchmark for improvement, the improvement is always relative to a prior design achievement (Wan Alwi & Manan, Water Pinch Analysis for Water Management and Minimisation: An Introduction, 2013). It is certainly possible that there are areas that did not emerge as areas with potential for improvement but do have the potential for improvement. For example, it is possible that a solution that has never been used before can be applied within a certain area. Despite the fact that the use of benchmarks also has disadvantages, the benchmark comparison in this study did help to identify areas for improvement.

Because the scope of the research was quite large and the research did not focus on investigating one specific process, the analyses were limited to a certain level of detail. For example, the study did not investigate the influence of people on water consumption in many processes. However, people can have a significant influence on the water consumption of the brewery. Correctly dealing with processes that use water (following standards), awareness about the influence of choices on the water consumption of the brewery and responding appropriately to escalation are of great importance for reducing water consumption. When processes are analysed in more detail, even more possibilities will undoubtedly emerge.

Findings

During the research, possibilities for water reduction were found in various areas. The applicability of possible solutions within other breweries depends on many factors. The applicability of the technical solutions at other breweries mainly depends on the budget, the process set-up and the possible savings. It is very likely that a number of solutions found are also interesting for other large-scale breweries. Basic points for improvement (such as factory efficiency, bottle loss, optimisation of machines and improving maintenance) to reduce water consumption are relevant for every brewery in any case.

6.3 Recommendations

General recommendations

Improve benchmarking

According to (Karlöf, 2002), benchmarking means calibrating the efficiency of an organisation against other organisations, getting inspiration, and building on the experiences of people. However, it can be difficult to make fair comparisons between breweries, areas and machines. Comparing breweries is especially useful if the context is also taken into account. By including information about the equipment, type of beer, type of packaging, production schedules etc., benchmarking can be developed into bench learning. This makes comparisons more meaningful because breweries can learn more from them.

Developing new solutions

In order to keep water consumption as low as possible, it is essential to continuously look for new solutions. In addition, it is also essential that breweries have contact with equipment suppliers to develop new solutions. Sharing knowledge between both parties can make an important contribution to making the industry more sustainable.

An example of this is the processing of the by-product BSG. It would be interesting for breweries to investigate for which possible applications brewer's spent grain (BSG) can be sold in the future and how the processing process of BSG should be set up to obtain such a product (see Appendix C: Spent grains dewatering). It is relevant here to examine to what extent the dewatering of BSG at the brewery would fit within such a future processing process. In addition, it must also be examined whether it is possible to set up the process in such a way that the water from the BSG can also be reused (either directly reuse or reuse after treatment) within the brewery. The brewing process can be made more sustainable by devising new processes and applications.

Reducing water consumption outside the brewery

Besides the great importance of reducing the water consumption within the brewery, it is also important that the water that is used for the other processes in the production chain is reduced. It would be interesting to research to what extent breweries can influence this and how the water consumption in the rest of the chain can be reduced.

Recommendations for Grolsch

Improvement bottle washers

Within Grolsch, there are multiple bottle washers. The bottle washer is the largest water consumer within a filling line. To detect opportunities to reduce the consumption of the bottle washer, additional research is needed. Because there are bottle washers on several filling lines, possible improvements will probably yield a lot in terms of water reduction. A number of directions for further research are described in section Appendix D: Overview of filling line KL02.

Follow-up research on technical solutions

During the research, several technical solutions were found that could possibly be applied at Grolsch. The possibilities for wort recovery and dry conveyor belt lubrication systems are especially interesting. However, more research is needed to determine to what extent these solutions can benefit Grolsch. The list of considerations (described earlier) can be expanded to determine whether the possibilities are beneficial. Suppliers can be contacted to collect more information about the possibilities.

Data management

During the research, it has become apparent that insight into the water consumption in the brewhouse can be improved. There is currently a large rest consumption in the data warehouse for the brewhouse area. It is possible to further break down this consumption. Data from a number of sub-meters within the brewhouse are not visible in the data warehouse. If these measurements are added, it will be possible to further break down the consumption and increase insight.

References

1Twente Enschede. (2019, May 7). *Zoveel water is nodig voor jouw Grolsch-biertje*. Opgehaald van YouTube: https://www.youtube.com/watch?v=BdhNaehgpf4

Alfa Laval. (2005). *Alfa Laval Foodec decanter centrifuges in breweries.* Opgehaald van Alfa Laval: https://www.alfalaval.com/globalassets/documents/products/separation/centrifugal-separators/decanters/foodec_application_brewery.pdf?_ga=2.47060839.1518778327.1603331339-234127439.1571697156

Alfa Laval. (2021, July 18). *Intelligent Whirlpool System*. Opgehaald van Alfa Laval: https://www.alfalaval.com/products/process-solutions/brewery-solutions/wort-modules/intelligent-whirlpool-system/

Asahi. (2020, March 16). *Sustainable Water Resources*. Opgehaald van Asahi: https://www.asahigroup-holdings.com/en/csr/environment/water.html

Barth, R. (2013). *The Chemistry of Beer: The Science in the Suds.* Hoboken, New Jersey: John Wiley & Sons,.

Bird, C., Menzies, T., & Zimmermann, T. (2016). *Community Data for OSS Adoption Risk Management.* Morgan Kaufmann.

Bird, C., Menzies, T., & Zimmermann, T. (2016). *The Art and Science of Analyzing Software Data.* Morgan Kaufmann.

Brewers Association. (2012). *Water and Wastewater: Treatment/Volume.* Opgehaald van Brewers Association: https://www.brewersassociation.org/attachments/0001/1517/Sustainability_-_Water_Wastewater.pdf

Business guide to circular water management: spotlight on reduce, reuse and recycle. (2017, June 6). Opgehaald van World Business Council for Sustainable Development: https://www.wbcsd.org/contentwbc/download/3437/44956/1

Carlsberg Group. (2021). *Carlsberg opens water recycling plant and becomes the world's most water efficient brewery.* Opgehaald van Carlsberg : https://www.carlsberggroup.com/newsroom/carlsberg-opens-water-recycling-plant-and-becomes-the-world-s-most-water-efficient-brewery/

Carpenter, J. (2011). *Project Management in Libraries, Archives and Museums.* Chandos Publishing.

Centraal Bureau voor de Statistiek (CBS). (2021, June 18). *Watergebruik bedrijven en particuliere huishoudens; nationale rekeningen*. Opgehaald van Centraal Bureau voor de Statistiek (CBS): https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82883NED/table?fromstatweb

Centraal Bureau voor de Statistiek. (2021, July 26). *Nederland grootste bierexporteur in de Europese Unie*. Opgehaald van Centraal Bureau voor de Statistiek: https://www.cbs.nl/nl-nl/nieuws/2021/29/nederland-grootste-bierexporteur-in-de-europese-unie

Data warehouse Grolsch. (2019, December 12). L2 data water consumption. Enschede, Overijssel, The Netherlands.

de Jongh, J., Tramper, A., & Soosaipillaj, S. (2020). *Nationaal Bieronderzoek.* Amsterdam: Nederlandse Brouwers.

Dhole, V., Ramchandani, N., Tainsh, R., & Wasilewski, M. (1996). Make your process water pay for itself. *Chemical Engineering 103*, 100-103.

Diversey Holdings. (2021, July 22). *Wet, Dry and Semi-dry Conveyor Lubrication Solutions to Optimize your Packaging Lines*. Opgehaald van Diversey Holdings: https://diversey.com/en/solutions/food-and-beverage-production/conveyor-lubrication

Drost, S. (2020, July 12). *'Oosten van Nederland heeft impuls nodig om droogte te bestrijden'*. Opgehaald van NOS: https://nos.nl/artikel/2340487-oosten-van-nederland-heeft-impuls-nodig-om-droogte-te-bestrijden.html

E. I. El-Shafey, M. L. (2004). Dewatering of Brewer's Spent Grain Using a Membrane Filter Press: A Pilot Plant Study . *Separation Science and Technology, 39:14*, 3237-3261.

El-Halwagi, M., Gabriel, F., & Harrel, D. (2003). Rigorous graphical targeting for resource conservation via material reuse/recycle networks. *Ind Eng Chem Res 42*, 4319–4328.

El-Shafey, E; Gameiro, M; Carvalho, J. (2004). Dewatering of Brewer's Spent Grain Using a Membrane Filter Press: A Pilot Plant Study. *Separation Science and Technology Volume 39*, 3237 - 3261.

Fillaudeau, L., Blanpain-Avet, P., & Daufin, G. (2006). Water, wastewater and waste management in brewing industries. *Journal of Cleaner Production*, 463-471.

Foster, K. (2020, January 29). *Changing Tides — How Breweries are Combating Water Shortages and Working Towards Sustainability*. Opgehaald van Good Beer Hunting: https://www.goodbeerhunting.com/blog/2020/1/27/changing-tides-how-breweries-are-combating-water-shortages-and-working-towards-sustainability

Gardner Denver. (2021, July 29). *Liquid Ring Vacuum Pump Technology*. Opgehaald van Gardner Denver: https://www.gardnerdenver.com/en-nl/nash/technologies-by-nash/technology-of-liquid-ring-vacuum-pumps

Gerring, J., & Cojocaru, L. (2016). Selecting Cases for Intensive Analysis: A Diversity of Goals and Methods. *Sociological Methods & Research Vol. 45 (3)*, 392 - 423.

Government of the Netherlands. (2016, November 16). *Temperature trends: the Netherlands and worldwide, 1906-2015*. Opgehaald van Government of the Netherlands: https://www.clo.nl/en/indicators/en022612-temperature-trends-the-netherlands-and-worldwide#:~:text=Temperature%20increase%20in%20the%20Netherlands,over%20the%20last%2020%20years.

Grolsch. (2019, December 1). *DVO verslag Grolsch 2019.* Opgehaald van Grolsch: https://www.koninklijkegrolsch.nl/sites/default/files/200416%20DVO%20verslag%20Grolsch%202019%20Final.pdf

Grolsch. (2020). *DVO Jaarverslag 2019.* Opgehaald van Grolsch: https://www.koninklijkegrolsch.nl/sites/default/files/200323%20DVO%20Jaarverslag%202019.pdf

Grolsch. (2020). *Reduceren van watergebruik en veiligstellen van de beschikbaarheid ervan*. Opgehaald van Grolsch: https://www.koninklijkegrolsch.nl/duurzaamheid/water-dutch

Grolsch. (2021, August 4). Data warehouse. *Data warehouse*.

Grolsch. (2021, July 22). Internal information Grolsch.

Gude, W; van Schaik, R. (2015, January 15). Basiskennis over Grolsch. *Ingrediënten / Mouten / Brouwen*. Enschede, Overijssel, Nederland: Afdeling Hospitality Services.

Hambach, H., Podobnikar, R., & Jurado, J. (2015). A decanter used as Intelligent Whirlpool System. *BRAUWELT International*, 290 - 296.

Hoekstra, A. (2019, October 21). *In memoriam of Arjen Hoekstra*. Opgehaald van Twitter: https://twitter.com/AYHoekstra/status/1186272754837966848

Hoekstra, A. Y. (2013). *The water footprint of modern consumer society.* London, UK: Routledge.

Hoekstra, A., Chapagain, A., Aldaya, M., & Mekonnen, M. (2011). *The Water Footprint Assessment Manual.* Washington: Earthscan.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2021, July 23). *Multi-Criteria Analysis (MCA)*. Opgehaald van Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services: https://ipbes.net/policy-support/tools-instruments/multi-criteria-analysis-mca

Jackowski, M., Niedzwiecki, Ł., Jagiełło, K., Uchanska, O., & Trusek, A. (2020). Brewer's Spent Grains—Valuable Beer Industry By-Product. *Biomolecules*, 16-69.

Karlöf, B. (2002). Benchmarking. In H. Bidgoli, *Encyclopedia of Information Systems* (pp. 65 - 80). Academic Press.

Klijn, F., van Velzen, E., ter Maat, J., & Hunink, J. (2012). *Zoetwatervoorziening in Nederland.* Delft: Deltares.

KNMI. (2020, March 19). *Droogte*. Opgehaald van KNMI: https://www.knmi.nl/kennis-en-datacentrum/uitleg/droogte

KNMI. (2020, March 19). *KNMI-klimaatscenario's*. Opgehaald van KNMI: https://www.knmi.nl/kennis-en-datacentrum/uitleg/knmi-klimaatscenario-s

Labs, W. (2018, October 12). *Brewery saves 5,000 gallons of water per day with new pump*. Opgehaald van Food Engineering: https://www.foodengineeringmag.com/articles/97839-brewery-saves-5000-gallons-of-water-per-day-with-new-pump

Laerd Statistics . (2020, March 29). *Pearson Product-Moment Correlation*. Opgehaald van Laerd Statistics : https://statistics.laerd.com/statistical-guides/pearson-correlation-coefficient-statistical-guide.php

Leech, N. L., & Onwuegbuzie, A. J. (2007). An array of qualitative data analysis tools: A call for data analysis triangulation. *School Psychology Quarterly, 22(4)*, 557-584.

Liu, Y. A., Lucas, B., & Mann, J. (2004). Up-to-date tools for water-system optimization. *Chemical Engineering Magazine*, 30 - 41.

Loannidou, S., Pateraki, C., Ladakis, D., Papapostolou, H., Tsakona, M., Vlysidis, A., . . . Koutinas, A. (2020). Sustainable production of bio-based chemicals and polymers via integrated biomass refining and bioprocessing in a circular bioeconomy context. *Bioresource Technology Volume 307*, 123093.

Loshin, D. (2013). *Business Intelligence.* Morgan Kaufmann.

Lynch, K., Steffen, E., & Arendt, E. (2016). Brewers' spent grain: a review with an emphasis on food and health. *J. Inst. Brew., 122*, 553 - 568.

Manan, Z., Tan, Y., & Foo, D. (2004). Targeting the Minimum Water Flow Rate Using Water Cascade Analysis Technique. *American Institute of Chemical Engineers*, 3169-3183.

Mekonnen, M., & Hoekstra, A. Y. (2010). *The green, blue and grey water footprint of animals and animal products.* Delft, the Netherlands: Unesco-IHE Institute for Water Education.

Nederlandse Brouwers. (2021, July 26). *De biersector*. Opgehaald van Nederlandse Brouwers: https://www.nederlandsebrouwers.nl/biersector/

Nederlandse Brouwers. (2021, July 19). *Water*. Opgehaald van Nederlandse Brouwers: https://www.nederlandsebrouwers.nl/biersector/duurzaamheid-en-ketenbeheer/water/

Nelson, M. (2005). *The Barbarian's Beverage: A History of Beer in Ancient Europe.* 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN: Routledge.

Panteia. (2009). *Industriewater in Nederland.* Zoetermeer: Panteia.

Passos, C., & Haddad, R. (2013). Benchmarking: A tool for the improvement of production management. *IFAC Proceedings Volumes Volume 46*, 577-581.

Philip, S., Kew, S., van der Wiel, K., Wanders, K., & van Oldenborgh, G. (2020). *Attributie van de droogte van 2018 in Nederland.* KNMI. Opgehaald van https://www.knmi.nl/kennis-en-datacentrum/achtergrond/attributie-van-de-droogte-van-2018-in-nederland

Podobnikar, R., & Visser, C. (2020, April 16). Brewery decanters. *Presentation of Alfa Laval*. Alfa Laval.

Pol, G. v. (2020, June 26). *'Droogteproblematiek gaat me aan het hart. Ik huil een beetje bij elk beest dat omkomt bij natuurbranden'*. Opgehaald van de Volkskrant: https://www.volkskrant.nl/nieuws-achtergrond/droogteproblematiek-gaat-me-aan-het-hart-ik-huil-een-beetje-bij-elk-beest-dat-omkomt-bij-natuurbranden~bbaf44aa/

Polley, G., & Polley, H. (2000). Design better water networks. *Chemical Engineering*, 47–52.

Rijksoverheid. (2015). *Nationaal Waterplan 2016-2021.* Rijksoverheid.

Rijksoverheid. (2021, March 19). *Klimaatverandering en gevolgen*. Opgehaald van Rijksoverheid: https://www.rijksoverheid.nl/onderwerpen/klimaatverandering/gevolgen-klimaatverandering

Rohlfer, S. (2002). Benchmarking Concepts in the UK and Germany: Between Standardisation and Local Variation? *Warwick Papers In Industrial Relations 69*, 2.

SABMiller, WWF-UK, GIZ. (2010). *Water Futures.* UK: Water Futures.

Sachowski, J. (2016). *Implementing Digital Forensic Readiness.* Syngress.

Santonja, G. G., Panagiotis, K., Stubdrup, K. R., Brinkmann, T., & Roudier, S. (2019). *Best Available Techniques (BAT) Reference Document for the Food, Drink and Milk Industries. Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control).* 3 E-41092 Seville, Spain: Publications Office of the European Union.

Santos Mathias, T. R., Fontes Alexandre, V. M., Cammarota, M. C., de Mello, P. P., & Sérvulo, E. F. (2015). Characterization and determination of brewer's solid wastes composition. *The Institute of Brewing & Distilling*, 400-404.

Sluijter, R., Plieger, M., & van Oldenborgh, G. (2018). *De droogte van 2018: Een analyse op basis van het potentiële neerslagtekort.* De Bilt: KNMI.

Statista. (2020). *Beer Report 2020.* Statista.

Statista. (2020, June). *Which beers do you drink at least once per month?* Opgehaald van Statista: https://www.statista.com/statistics/585138/beer-consumption-in-the-netherlands-by-beer-type/

Tainsh, R. A., & R., R. A. (1996). Practical techniques and methods to develop an efficient water management strategy. *Linnhoff March International*, 2.

Tokos, H., & Glavič, P. (2007). Minimisation of freshwater consumption in brewery. *University of Maribor*, -.

VEMW. (2013). *Duurzaam industrieel watergebruik.* Woerden: De Vereniging voor Energie, Milieu en Water (VEMW).

Verschuren, P., & Doorewaard, H. (2010). *Designing a Research Project.* The Hague: Eleven International Publishing.

Vincent Corporation. (2006, June 1). *Spent Grain*. Opgehaald van Vincent Corporation: https://vincentcorp.com/content/spent-grain/

Wageningen University & Research. (2020, 18 March). *Voorbeeld van klassieke biotechnologie: bier*. Opgehaald van Wageningen University & Research: https://www.wur.nl/nl/Onderwijs-Opleidingen/Bachelor/BSc-opleidingen/BSc-Biotechnologie/Meer-over/Bier.htm

Wageningen University & Research. (2021, July 16). *Protein Valorisation from Brewers Spent Grain*. Opgehaald van Wageningen University & Research: https://www.wur.nl/nl/Onderzoek-Resultaten/Onderzoeksprojecten-LNV/Expertisegebieden/kennisonline/Protein-Valorisation-from-Brewers-Spent-Grain.htm

Wageningen University & Research. (2021, July 12). *Protein Valorisation from Brewers Spent Grain*. Opgehaald van Wageningen University & Research: https://www.wur.nl/nl/Onderzoek-Resultaten/Onderzoeksprojecten-LNV/Expertisegebieden/kennisonline/Protein-Valorisation-from-Brewers-Spent-Grain.htm

Wan Alwi, S. R., & Manan, Z. A. (2006). SHARPS: A New Cost-Screening Technique to Attain Cost-Effective Minimum Water Network. *AIChE Journal*, 3981-3988.

Wan Alwi, S. R., & Manan, Z. A. (2013). Water Pinch Analysis for Water Management and Minimisation: An Introduction.

Wan Alwi, S., Manan, Z., Samingin, M., & Misran, N. (2008). A holistic framework for design of cost-effective minimum water utilization network. *Journal of Environmental Management 88*, 219–252.

Wang, Y., & Smith, R. (1994). Wastewater minimisation. *Chemical Engineering Science 49*, 981-1006.

Water Footprint Network. (2020, May 17). *Water footprint*. Opgehaald van Water Footprint Network: https://waterfootprint.org/en/water-footprint/

Water Footprint Network. (2020, May 17). *What is a water footprint?* Opgehaald van Water Footprint Network: https://waterfootprint.org/en/water-footprint/what-is-water-footprint/#:~:text=Irrigated%20agriculture%2C%20industry%20and%20domestic,meet%20specific%20water%20quality%20standards.

Water Footprint Network. (2021, June 3). *Business water footprint*. Opgehaald van Water Footprint Network: https://waterfootprint.org/en/water-footprint/business-water-footprint/

Water Footprint Network. (2021, June 5). *What is Water Footprint Assessment?* Opgehaald van Water Footprint Network: https://waterfootprint.org/en/water-footprint/water-footprint-assessment/

World Business Council for Sustainable Development (WBCSD). (2017). Business guide to circular water management: spotlight on reduce, reuse and recycle. Switzerland: World Business Council for Sustainable Development (WBCSD).

Yildirim, F., Hasçelik, B., Yumru, Ş., & Palamutcu, S. (2018). Analysis of water consumption and potential savings in a cotton textile dye house in Denizli, Turkey. In S. Muthu, *Water in Textiles and Fashion* (pp. 115-134). Woodhead Publishing.

Appendix A: Flow chart water treatment

<CONFIDENTIAL>

Figure 40: Flow chart water treatment (Grolsch, 2021)

Appendix B: Water consumption filling lines rest

<CONFIDENTIAL>

Figure 41: KL02 rest (Data warehouse Grolsch, 2019)

<CONFIDENTIAL>

Figure 42: KL03 rest (Data warehouse Grolsch, 2019)

<CONFIDENTIAL>

Figure 43: KL04 rest (Data warehouse Grolsch, 2019)

<CONFIDENTIAL>

Figure 44: KL07 rest (Data warehouse Grolsch, 2019)

Appendix C: Spent grains dewatering

During the research, technology was found that makes it possible to extract water from the by-product BSG. In breweries, brewer's spent grain (BSG) accounts for 85% of the total by-product generation (Loannidou, et al., 2020). The average measured water content of the BSG in the brewery of Grolsch is 79%. According to literature, around 20 kg of BSG is produced per hl beer (Lynch, Steffen, & Arendt, 2016). Based on this data, it is estimated that around [redacted] hl of water ended up in the BSG in 2019.

There are various methods that can be used to extract water from the BSG. One of the options is the usage of a decanter centrifuge. This machine makes use of centrifugal forces to separate solids from the liquid (Podobnikar & Visser, 2020). According to Alfa Laval (process equipment supplier), it is possible to obtain BSG with a dry matter content of > 38% using this centrifuge. If it is possible to increase the dry matter content of the BSG from 21% to 38%, Grolsch could extract about [redacted] hl water per year.

According to Alfa Laval, there are dozens of breweries that use a decanter centrifuge to remove water from the BSG. The decanter can be used in various ways in the process. The first option is to only use the decanter centrifuge as separation equipment, see the figure below.

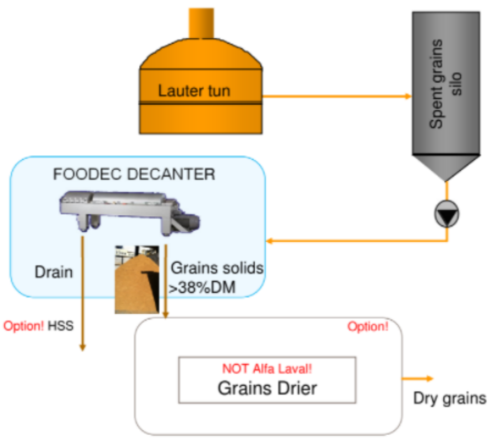

Figure 45: Spent grains dewatering (Podobnikar & Visser, 2020)

Besides, it is also possible to first use a screw press to dewater the BSG. Typically, a screw press can reduce the moisture content of the BSG to 64% to 70% (Vincent Corporation, 2006). When a screw press is used, it is possible to use a decanter to clarify the liquid fraction that comes from the screw press.

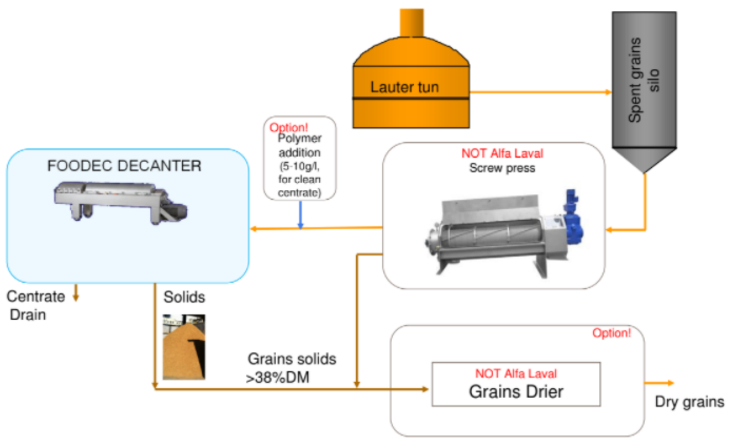

Figure 46: Using a screw press and decanter for dewatering BSG (Podobnikar & Visser, 2020)

As described, there are various options for extracting water from the BSG. However, there are currently no breweries (as far as known) that reuse the water for other processes within the brewery. This is probably partly due to the composition and quality of the extracted water. The breweries that currently extract water from the BSG treat the extracted water as wastewater. By treating the wastewater, it is possible to produce more biogas. However, the consequence is also that more water will go to the sewage treatment plant (RWZI). If the extracted water is not reused (either direct reuse or reuse after treatment) for other applications within the brewery, this technology cannot be regarded as a water-saving solution.

However, extracting water from BSG does have a number of advantages and may have more potential in the near future. Because of its high moisture and sugar content, BSG becomes an environmental problem after a relatively short time (El-Shafey, E; Gameiro, M; Carvalho, J, 2004). Dewatering BSG will lead to prolonged shelf life. Besides, dewatering of BSG will reduce the volume that has to be transported. This reduces the impact on the environment and also reduces transport costs (Podobnikar & Visser, 2020).

At the moment, a lot of research is being conducted into possible new applications of BSG. Most breweries currently sell their BSG as low-value animal feed. According to (Wageningen University & Research, 2021), BSG has potential in the food market and is currently underutilised. In 2019, a study was launched into Protein Valorisation from Brewers Spent Grain (funded by the Ministry of Agriculture, Nature and Food Quality) (Wageningen University & Research, 2021). According to this research, upgrading BSG to the food market will significantly contribute to preventing future protein shortages.

It would be interesting for breweries to further investigate for which possible applications BSG can be sold in the future and how the processing process of BSG should be set up to obtain such a product. It is relevant here to examine to what extent the dewatering of BSG at the brewery would fit within such a future processing process. In addition, it must also be examined whether it is possible to set up the process in such a way that the water from the BSG can also be reused (either directly reuse or reuse after treatment) within the brewery.

Appendix D: Overview of filling line KL02

The benchmark analysis has shown that KL02 has the most potential of all filling lines. Therefore, an overview has been made of the current situation and the actions that can be taken to reduce water consumption.

Line layout

On KL02, GPP and speciality beer is filled in 30 cl bottles. Figure 47 shows an overview of the filling process on KL02.

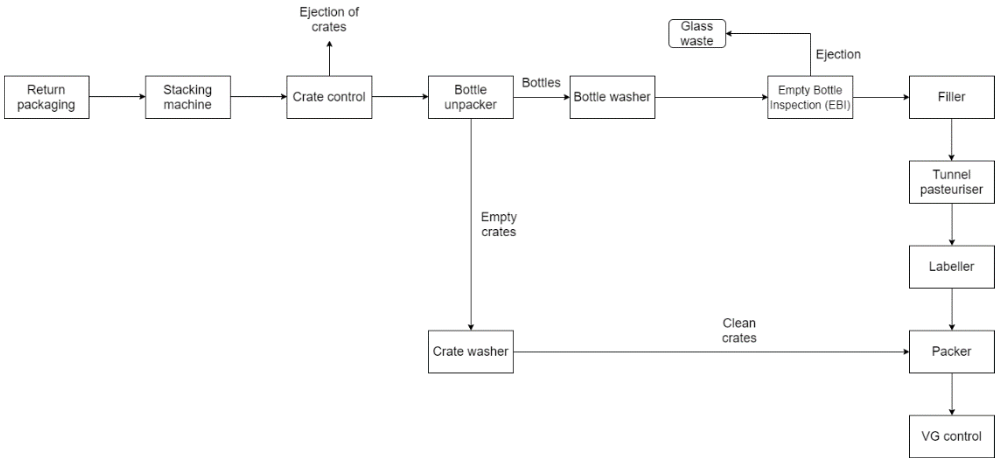

Figure 47: Overview KL02

In addition to the machines that are directly used for the filling process (which are visible in the figure above), there are also other machines that belong to the line. An overview of all machines at the line that use water can be found in Table 4. There are three machines within the line whose water consumption is measured individually: bottle washer, pasteuriser and crate washer. The unmetered water consumers within the line include (among other things) the vacuum pump and the filler. The figure below gives an overview of how much these machines have consumed in recent years.

<CONFIDENTIAL>

Figure 48: Distribution water consumption KL02 (Grolsch, 2021)

Benchmarks

There are several benchmark numbers that are relevant to KLO2. Table 8 gives an overview of the current situation, the benchmark numbers and the goals for 2025.

Table 8: Performance, benchmarks and goals of KL02

<CONFIDENTIAL>

The current performance of the line still deviates far from the benchmark numbers. To achieve these benchmark values, far-reaching adjustments to the process are required. These adjustments will also affect other processes and the investment budget. In consultation with experts from Grolsch, target values for 2025 have been determined. It is expected that these values can be achieved through targeted optimisations and continuous improvement.

Opportunities

There are several possible solutions to reduce the water consumption of KL02.

1. *Reduction of bottle loss EBI*

Bottles are checked during the empty bottle inspection (EBI). Bottles can be ejected due to the presence of contaminants, imperfections or defects. Bottles ejected at the empty bottle inspection (EBI) have already been treated by the bottle washer. If the ejection percentage of bottles is high, this also means that there are many bottles that have been treated by the bottle rinsing machine but which are not (directly) used to fill beer. Therefore, the amount of ejected bottles affects the water consumption of a line. It has been calculated how much a reduction in ejection will yield in terms of water savings.

Table 9: Potential savings when ejection is reduced

<CONFIDENTIAL>

For the calculation of the possible savings (hl/year), it has been assumed that the same number of bottles will be filled on the line as in 2020.

In 2021, [redacted]% of the bottles were ejected. In 2020, the percentage of bottles ejected was [redacted]%. This equates to a [redacted]% increase in bottle ejection. Based on historical data, it should be possible to reduce the ejection by [redacted]%. If it is possible to reduce the ejection by [redacted]%, this will reduce the total consumption of the line by [redacted] hl/hl.

The target set for 2025 is a [redacted]% ejection rate ([redacted]% reduction). Reducing the ejection rate to [redacted]% will result in a reduction of the total consumption of [redacted] hl/hl (for KL02). The figure below shows how much can be saved if the losses at the EBI are reduced every year.

<CONFIDENTIAL>

Figure 49: Reduction absolute consumption through EBI loss reduction

2. *Bottle washer optimisation*

The largest water consumer of the filling line is the bottle washer. According to the benchmark, the water consumption of this machine should be [redacted] ml/bottle. In 2021, the consumption of this machine was [redacted] ml/bottle. If it is possible to bring the water consumption of this machine to the benchmark level, this will save [redacted] ml/bottle. However, a consumption as low as the benchmark has never been achieved in the past. In recent years, the lowest consumption was about [redacted] ml/bottle. If this can be achieved, the consumption will be reduced by [redacted] hl/hl. Realising a water use of [redacted] ml/bottle for the bottle washer will result in a reduction of [redacted] hl/hl.

The figure below shows how much can be saved if the water consumption of the bottle washer is reduced every year.

<CONFIDENTIAL>

Figure 50: Reduction absolute consumption through BW optimisation

When calculating the consumption visible in the graph, it is assumed that the same amount is produced every year.

There are several things that can be done to optimise the bottle washer. When researching the optimisation of the bottle washer, the following should, in any case, be taken into account:

- Optimising process parameters (e.g., water temperature)
- Possibilities to optimise/replace spray nozzles
- Check for leaks
- Implementation of shared learnings about the bottle washer
- Cascade bottle washer/crate washer
- Short interval control
    - Taking actions in time (hourly check of consumption)
    - Quick response to an escalation

3. *Improvement of factory efficiency (FE)*

The factory efficiency (FE) has a significant influence on the water consumption of a line. It is considered realistic that the FE could be increased to [redacted]% by 2025 (based on previous research and historical performance). Previous internal research has shown that theoretically, a [redacted]% improvement in FE should lead to a [redacted] hl/hl decrease in water consumption (for KL02 specific). The figure below shows how much can be saved if FE is improved every year.

<CONFIDENTIAL>

Figure 51: Reduction absolute consumption through improvement FE

When calculating the consumption visible in the graph, it is assumed that the same amount is produced every year.

4. *Other opportunities*

Besides reducing the bottle losses (EBI), improving the bottle washer and improving the factory efficiency, there are more opportunities to reduce water consumption.

Replacing vacuum pumps for dry pumps

According to Grolsch employees, vacuum pumps consume significant amounts of water. However, the water consumption of these machines is not measured individually. To gain insight into the amount of water consumed by the pump, it would be possible to temporarily install a flow meter. It would then be interesting to investigate whether it is possible to replace the vacuum pump with a dry pump and to assess how much this yields.

Water hose usage

There are multiple water hoses at filling line KL02 that are used for various cleaning activities. The use of this falls under the residual consumption of the line. In order to decrease the amount of water used for the water hoses, the cleaning procedures have to be standardised. Therefore, an optimal procedure needs to be determined first. Then standards can be written that operators can use. It is, of course, essential that standards are clear, that operators are trained and that they are monitored for compliance.

Filler CIP optimisation

It is also possible to optimise the filler CIP. Replacing the filler taps has a major impact on the number of CIPs performed. By improving the maintenance (through better standards and controls), it is possible to reduce the amount of CIP and thus save water.

Total overview

The figure below provides an overview of the influence that the initiatives (reducing EBI bottle losses, optimisation of bottle washer and improvement of the efficiency) jointly have on the water consumption of KL02.

<CONFIDENTIAL>

Figure 52: Reduction of water consumption KL02

If it is possible to both improve ejection and reduce the water consumption of the bottle washer (both to historical levels), this will result in water consumption of [redacted] hl/hl (which is below the average of other breweries).