GERMAN - MONGOLIAN INSTITUTE
FOR RESOURCES AND TECHNOLOGY

The present work was submitted to

the German-Mongolian Institute of Resource and Technology

FEASIBILITY ANALYSIS OF APPLYING LEAN MANUFACTURING TOOLS TO REDUCE WATER WASTE AND ENHANCE COST EFFICIENCY:

A CASE STUDY AT "MBC ASIA PACIFIC LLC"

Bachelor's Thesis

By

UYANGA Otgontsetseg

Study Program: Industrial Engineering

Student ID: B2200613

1st Supervisor/Examiner: Dr. Bolormaa Purevjav

2nd Supervisor/Examiner: Dr. Zolzaya Battsogt

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Statutory Declaration

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I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

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Abstract

The brewing industry is a water-intensive sector in which inefficient resource utilization leads to increased operational costs and environmental impact. This study evaluates the feasibility of applying Lean Manufacturing tools to reduce water waste and enhance cost efficiency at MBC Asia Pacific LLC.

The research is based on a case study approach, combining quantitative operational data from the 2025 reporting period with qualitative insights obtained through direct process observation during an internship. Value Stream Mapping (VSM) was used to analyze the current production system, followed by waste identification and root cause analysis using Fishbone diagrams and the 5 Whys method.

The results indicate that the current water consumption ratio of 3.72 hl/hl exceeds the internal target of 3.30 hl/hl, representing a performance gap of approximately 11%. Water usage is highly concentrated in the brewing process, accounting for approximately 73% of total consumption. Key inefficiencies were identified as inconsistent implementation of operational standards, limited process-level monitoring, process imbalance, and equipment-related losses.

Based on these findings, Lean-based improvements were proposed, including standardization (SOP), visual management, and continuous improvement practices. The future state analysis demonstrates a realistic reduction potential of 4.6%–6.5% within the scope of brewing and packaging processes, corresponding to an annual water saving of approximately 4,800–6,800 m^3.

Financial analysis confirms the economic feasibility of the proposed improvements. The estimated annual cost savings range from 24.6 to 34.8 million MNT, with a payback period of 0.43 to 0.61 years, a return on investment of 64% to 132%, and a positive net present value over the project lifetime.

Overall, the study demonstrates that Lean Manufacturing Tools provides a practical and financially viable approach to improving water efficiency in brewery operations, offering both operational and economic benefits.

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Chapter 1 Introduction

The brewing industry is one of the most water-intensive sectors within the food and beverage industry, where water is essential across all stages of production, including brewing, fermentation, packaging, and cleaning operations. In addition to being a primary ingredient, water is widely used in heating, cooling, and sanitation processes, making water management both an operational and economic concern (1)

Typical breweries consume between 4 and 7 hectoliters of water per hectoliter of beer produced, while efficient operations achieve levels below 4 hl/hl through systematic water management practices (1) (2). Despite these improvements, water inefficiency remains a challenge, with significant volumes of wastewater generated during production (1). At MBC Asia Pacific LLC, the current water consumption ratio is 3.72 hl/hl, exceeding the internal target of 3.30 hl/hl, indicating the presence of remaining inefficiencies despite operating within the general industry benchmark range.

Lean manufacturing is a management approach focused on eliminating waste and maximizing value from the customer's perspective (3). Originating from the Toyota Production System, it has been widely applied across industries, including food and beverage manufacturing (4). Lean tools such as Value Stream Mapping, Root Cause Analysis, Standard Work, and Kaizen provide structured methods to identify inefficiencies and improve resource utilization (5). Previous studies have shown that these approaches can improve operational performance and resource utilization in production systems, including brewery operations (6) (7).

From an economic perspective, inefficient water use increases costs through water procurement, energy consumption for heating and cooling, and wastewater handling. Therefore, improving water efficiency has both financial and environmental importance.

In this context, this study evaluates the feasibility of applying lean manufacturing tools to reduce water waste and improve cost efficiency at MBC Asia Pacific LLC by integrating process analysis with financial evaluation.

1.1 Problem Statement

Despite growing awareness of water efficiency in the brewing industry, many breweries continue to operate above best practice benchmarks, resulting in unnecessary resource use and higher operational costs (1) (2). Excessive water consumption in brewery operations is associated with non-value adding activities across cleaning, product

transfer, and packaging processes, many of which can be reduced without significant capital investment (8) (1).

Observations conducted during a professional internship at MBC Asia Pacific LLC identified several instances of inefficient water use across production processes. In the filtration area residual liquid discharge required repeated water flushing, extending cleaning duration. In the packaging area, glass breakage incidents were managed by water flushing after manual removal of larger fragments. Frequent mechanical breakdowns of the can washing machine resulted in uncontrolled water spillage during each repair period, while pasteurizer stoppages led to both water loss and reduced product shelf life. These findings indicate that inefficiencies exist across multiple process stages at MBC Asia Pacific LLC, driven by both operational practices and equipment reliability issues.

From a performance perspective, the current water consumption ratio of **3.72 hl/hl** exceeds the internal target of **3.30 hl/hl**, corresponding to a performance gap of approximately **11%**, which reflects excess water consumption within the production system. This indicates that a measurable portion of water use is non-value-adding and can be reduced through process improvement.

These findings demonstrate that inefficiencies are present across multiple process stages, driven by operational practices and equipment-related issues. Therefore, there is a need for a systematic and structured approach to identify and reduce water waste in brewery operations. This study addresses this gap by examining process inefficiencies and supporting improvements toward more efficient and sustainable water use.

1.2 Research Aim and Objectives

Research Aim

The aim of this study is to evaluate the feasibility of applying lean manufacturing tools to reduce water waste and improve cost efficiency in brewery operations at MBC Asia Pacific LLC.

Research Objectives

To achieve this aim, the study pursues the following objectives:

1. To analyze current water usage and identify sources of water waste in brewery operations at MBC Asia Pacific LLC.
2. To evaluate improvement opportunities for reducing water waste using lean manufacturing principles.

3. To assess the financial feasibility of proposed improvements through cost savings, payback period, return on investment, and cost benefit analysis.
4. To provide recommendations for improving water efficiency and supporting sustainable operations at MBC Asia Pacific LLC.

These objectives follow a logical sequence from diagnosis of current performance to development and evaluation of improvement strategies.

1.3 Research Questions

This study is guided by the following research questions:

1. How is water currently used across brewery processes at MBC Asia Pacific LLC?
2. Where do non-value-adding water losses occur within the production system?
3. What lean manufacturing approaches can be applied to reduce water waste?
4. What level of water reduction can be achieved through lean-based improvements, and are these improvements financially feasible?

1.4 Significance of the Study

This study is significant from both practical and academic perspectives. From the practical standpoint, the findings provide MBC Asia Pacific LLC with a systematic evidence-based assessment of water waste across its brewery operations, identifying specific areas of inefficiency and quantifying the potential financial benefits of lean-driven improvement. The proposed recommendations offer a practical roadmap for reducing water consumption and operational costs, supporting the brewery's long-term sustainability and cost efficiency objectives.

From an academic perspective, the study contributes to the application of lean manufacturing in resource management by linking process-level waste identification with financial feasibility analysis. By integrating technical and economic evaluation, the study provides a structured framework that can be applied to similar production environments seeking to improve efficiency and sustainability.

1.6 Scope and Limitations

This study is limited in scope to the water consumption and waste reduction feasibility at MBC Asia Pacific LLC. The analysis focuses on the brewing and packaging processes, as these were identified as the main contributors to water consumption. Other process areas, including utilities and cleaning operations, are considered outside the scope of this study.

The financial feasibility assessment is based on data collected during a defined period and projected savings are estimated using lean improvement literature rather than measured post-implementation results, as this study is a feasibility analysis and not an implementation study. The findings and recommendations are specific to MBC Asia Pacific LLC and may not be directly generalizable to other brewery operations due to differences in scale, technology, and operational context.

A key limitation is the absence of primary data collection through interviews or surveys due to restricted access. The analysis is based on operational records and direct process observation, which may limit detailed insight into process-level behavior.

1.7 Company Overview

MBC Asia Pacific LLC is a brewing company located in Bayanzurkh District, Ulaanbaatar, Mongolia. The company was established in 2007 as a production facility to manufacture Tiger beer for the domestic market following its initial importation. In 2021, it became a joint venture between APU Company, one of Mongolia's leading beverage producers, and Heineken International, a globally recognized brewing corporation, marking a significant expansion of its operations and brand portfolio.

The company operates with an annual production capacity of approximately 300,000 hectoliters and produces a diverse range of beer brands, including Heineken, Tiger, Sengur, and Borgio. These products are packaged in multiple formats, including glass bottles, cans, and kegs, serving both retail and hospitality markets across Mongolia.

As a large-scale brewing operation producing internationally recognized brands under strict quality standards, efficient resource management is a critical priority. In particular, water consumption plays a central role in both operational performance and sustainability. The scale of production and the complexity of multi-format packaging operations make the company a relevant and appropriate case for evaluating the feasibility of applying lean manufacturing tools to reduce water waste and improve cost efficiency.

Chapter 2 Literature review

2.1 Lean Manufacturing

2.1.1 Definition and Historical Background

Lean manufacturing is a management philosophy focused on the continuous elimination of waste and the maximization of value from the customer's perspective (9). Originating from the Toyota Production System developed in Japan, lean emerged in response to resource constraints and the need for more efficient production methods (4). It gained global recognition following the publication of *The Machine That Changed the World*, which demonstrated how lean production outperformed traditional mass production in efficiency, quality, and flexibility (3).

Since then, lean has evolved into a widely applied framework across industries, including food and beverage manufacturing (4). In resource-intensive sectors such as brewing, lean provides both a theoretical foundation and a structured approach for reducing waste and improving operational efficiency.

2.1.2 Core Principles of Lean Manufacturing

Lean manufacturing is structured around core principles aimed at maximizing customer value while systematically eliminating waste throughout production processes. Rather than focusing solely on cost reduction, lean emphasizes the redesign of production systems to improve value creation and resource efficiency (10).

Womack and Jones defined five key principles of lean manufacturing: specifying value, identifying the value stream, creating flow, establishing pull, and pursuing perfection (3). These principles form an integrated framework that supports continuous improvement and efficient resource utilization, particularly in resource-intensive industries such as brewing.

The first principle, **specifying value**, defines value from the customer's perspective, where any resource use beyond what is necessary to deliver that value is considered waste (3). The second principle, **identifying the value stream**, involves mapping all activities required to deliver a product, enabling the identification and elimination of non-value-adding processes (3).

The third principle, **creating flow**, ensures that value-adding activities proceed continuously without interruptions, reducing inefficiencies such as waiting and excess resource consumption (10). The fourth principle, **establishing pull**, aligns production

with actual customer demand, preventing overproduction and unnecessary resource use (3) (10).

The final principle, **pursuing perfection**, emphasizes continuous improvement through ongoing waste elimination, supported by Kaizen practices across all organizational levels (3) (10).

Overall, these principles provide a structured foundation for improving resource efficiency and reducing water waste in brewery operations.

2.1.3 Lean and Sustainability

Lean manufacturing and sustainability are increasingly recognized as complementary concepts, as both focus on waste elimination and efficient resource utilization. While lean primarily targets economic performance, studies confirm that lean initiatives also contribute positively to environmental and social sustainability performance (4). Sustainability is commonly framed through the Triple Bottom Line which encompasses economic, environmental, and social dimensions, all of which are supported through lean waste elimination and resource efficiency (4). Both lean and green practices share a fundamental objective of eliminating excess, where lean removes non-value-added activities and green targets inefficient resource use and environmental impact (11). This makes lean a practical catalyst for environmentally responsible operations, particularly in resource-intensive industries such as food and beverage manufacturing (11).

While lean manufacturing provides a strong theoretical basis for waste reduction, its application to resource-specific inefficiencies such as water consumption remains less explicitly developed in existing studies.

2.2 Waste in Lean Manufacturing

2.2.1 Definition of Waste

In lean manufacturing, waste refers to any activity that consumes resources but does not create value for the customer. Value is defined strictly from the customer's perspective, and therefore any use of resources that does not directly contribute to transforming a product in a way the customer is willing to pay for is considered waste (3). This concept is expressed through the Japanese term *muda*, describing any form of unnecessary resource consumption within a production process (3). Lean thinking further distinguishes between two categories of non-value-adding activities: those that are temporarily unavoidable due to current process constraints, and those that are completely unnecessary and should be eliminated immediately (3). Addressing both

categories is essential to improving operational efficiency and reducing unnecessary resource consumption in manufacturing systems.

2.2.2 The Eight Wastes

The Toyota Production System originally identified seven main types of waste within manufacturing processes. Over time, lean manufacturing practitioners and researchers expanded and refined this classification by adding an eighth waste (12). The eight types of waste in lean manufacturing include the following:

The first waste is **overproduction** -producing more than the customer demands or before it is needed, leading to excessive inventory, storage costs, and inefficient use of resources. The second waste is **defects** - producing products that fail to meet quality standards, resulting in rework, material waste, and extended production lead times. The third waste is **inventory** - maintaining unnecessarily high levels of raw materials, work-in-process, or finished goods, which increases storage costs and conceals production problems. The fourth waste is **transportation** - any movement of materials that does not add value to the product, resulting in longer cycle times and inefficient use of labor and space. The fifth waste is **waiting**- idle time for workers or machines caused by bottlenecks or inefficient production flow, during which no value is being created. The sixth waste is **motion** - unnecessary physical movements by workers that divert them from value-adding activities, often caused by poor workplace layout or ergonomics. The seventh waste is **over-processing** -performing more work on a product than the customer requires, consuming resources without adding customer value (12).

In addition to these seven process-related wastes, later lean manufacturing research introduced an eighth waste known as **non-utilized talent**, which occurs when organizations fail to fully use employees' skills, knowledge, and improvement ideas, resulting in lost opportunities for operational enhancement (13).

Lean manufacturing therefore emphasizes both the elimination of process waste and the effective utilization of human potential as essential foundations for continuous improvement and sustainable operational performance.

2.3 Water Usage in Brewing Industry

2.3.1 Overview of Brewing Process

Beer production is a multi-stage industrial process that transforms raw ingredients, primarily malted barley, water, hops, and yeast, into a finished beverage (1). The process generally consists of three main phases: brewhouse operations, fermentation, and packaging. During brewhouse operations, malted barley is milled and mashed with hot

water to extract fermentable sugars, which are then boiled with hops to produce wort (1). The wort is then cooled and transferred to fermentation vessels, where yeast converts sugars into alcohol and carbon dioxide (1). Following fermentation, the beer undergoes maturation, filtration, and pasteurization before being packaged into bottles, cans, or kegs (7).

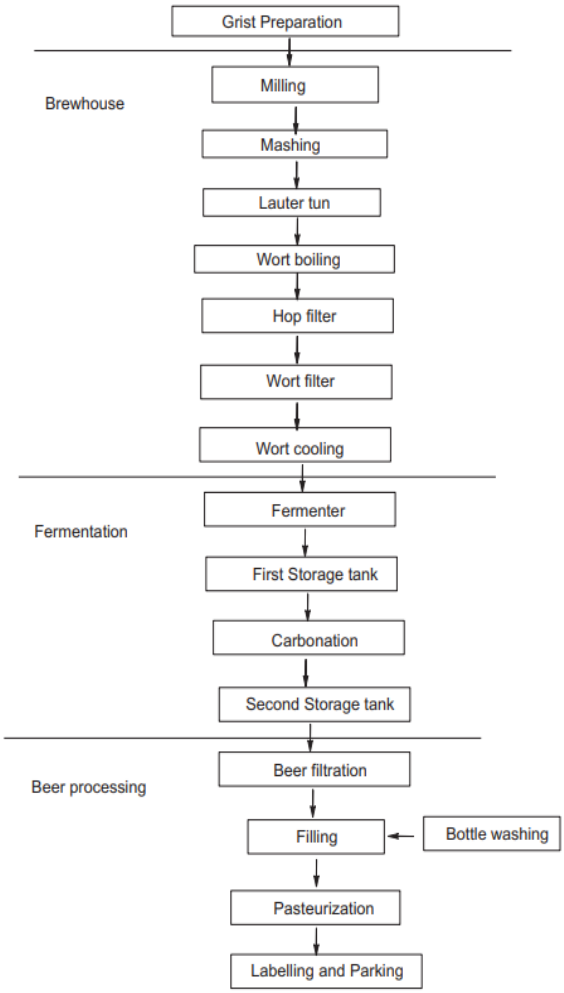

FIGURE 1 STAGES OF BEER PRODUCTION

2.3.2 Water Consumption in Brewery Process

The brewing industry is one of the largest industrial consumers of water in the food and beverage sector (1). In brewery operations, water serves two primary roles: as the main ingredient of beer, comprising approximately 90 to 95 percent of the final product by mass, and as a process utility used in heating, cooling, cleaning, and sanitation operations throughout the production system (1). The main water consuming areas of a

typical brewery include the brewhouse, fermentation cellars, filtration, packaging, and cleaning-in-place (CIP) operations (1). Water consumption levels vary depending on factors such as brewery size, packaging type, equipment age, and cleaning system efficiency, with modern breweries typically consuming between 4 and 7 liters of water per liter of beer produced (1) (2)

Studies on brewery water balance indicate that the largest portion of water consumption occurs not in the brewing process itself but in cleaning, packaging, and process support operations. Packaging processes, particularly bottle cleaning, filling, and pasteurization, represent one of the most significant areas of water consumption. A water balance study in brewery operations found that cleaning, filling, and pasteurization together accounted for approximately 51% of total plant water consumption (8). Pasteurization is identified as a particularly water-intensive process because it involves heating followed by rapid cooling, requiring significant volumes of water during each production cycle (2). In addition, chase water used to push beer from filtration to storage tanks has been identified as another major contributor to water consumption, accounting for approximately 41% of total water usage in the case study brewery (8). These findings indicate that the majority of water consumed in brewing is not incorporated into the final product but is instead used in cleaning, packaging, and product transfer operations, highlighting these areas as the most important targets for water efficiency improvement in brewery operations. It should be noted, however, that at MBC Asia Pacific LLC, the process-level analysis presented in Chapter 4 demonstrates that brewing operations account for 73% of total production water consumption, the dominant water-consuming stage across all three reporting years, while packaging accounts for 16 percent, reflecting the specific operational profile of this large-scale brewery.

2.3.3 Industry Benchmarks

Establishing water consumption benchmarks is essential for evaluating brewery performance and identifying opportunities for efficiency improvement. Water consumption efficiency in breweries is commonly measured using the water to beer ratio, expressed as hectoliters of water used per hectoliter of beer produced (hl/hl). This metric is widely used internationally to assess both operational efficiency and environmental performance in brewery. (1)

Water consumption levels vary significantly depending on brewery size, technology level, cleaning practices, and packaging methods, with modern breweries generally consuming between 4 and 7 hl/hl of beer produced (1) (2). However more recent industry data suggests that leading breweries are achieving significantly lower consumption rates, with

modern best practice benchmarks ranging from 3.7 to 4.7 hl/hl of beer sold (8). The industry average across commercial breweries has been reported at approximately 5 hl/hl, while world class performers have consistently achieved ratios below 4 hl/hl (6) (2).

Major global brewers have demonstrated that significant water reduction is achievable through targeted efficiency programs. AB-InBev achieved a water use ratio of 3.53 hl/hl, while Heineken reduced its specific water consumption to 3.6 hl/hl through detailed action plans and continuous monitoring (6) (8). SABMiller similarly improved its water efficiency from 4.6 hl/hl in 2008 to 3.2 hl/hl by 2016 through process improvements and technology upgrades (2). Research has shown that lean and six sigma continuous improvement methodologies have been applied in brewery operations to identify and eliminate waste, contributing to improvements in both operational efficiency and resource utilization (6) (7). These findings suggest that water consumption efficiency is largely influenced by operational management practices rather than brewing technology alone.

Based on reported industry data, brewery water efficiency can be broadly categorized into three performance levels, including inefficient breweries consuming more than 7 hl of water per hl of beer, average breweries operating between 4 and 7 hl/hl, and efficient breweries achieving water consumption below 4 hl/hl.

2.3.4 Water Waste Challenges

Despite technological advancements, water waste remains a persistent challenge in brewery operations. It has been estimated that approximately 3 to 10 liters of wastewater is generated per liter of beer produced, representing a substantial environmental and economic burden (1). A significant portion of this waste originates from cleaning operations, particularly bottle washing in the packaging area and cleaning-in-place CIP processes across the brewhouse, fermentation, and filtration areas, which are essential for maintaining hygiene and product quality standards (2).

Beyond technical factors, human and organizational barriers contribute significantly to water waste. Studies show that excessive consumption has been linked to a lack of targets, insufficient employee training, and limited awareness of water management practices at operational level.(8) Mental barriers such as resistance to operational changes and lack of accountability have been identified as major barriers to water reduction efforts, while inadequate monitoring systems limit breweries' ability to accurately measure and control water consumption across process areas (8) (2). Research indicates that breweries can reduce water consumption by 20 to 50 percent without significant capital investment through training, monitoring and process

reengineering, highlighting that water waste is largely a management and process control issue rather than a purely technological limitation (1).

These findings indicate that water inefficiencies are primarily operational rather than technological, highlighting the relevance of process-based improvement approaches.

2.4 Lean Tools

Lean manufacturing relies on a range of practical tools that operationalize its principles by systematically identifying and eliminating waste across production processes. Rather than functioning independently, lean tools are typically applied as part of a structured improvement methodology that includes process mapping, waste identification, root cause analysis, process standardization, performance monitoring, and continuous improvement (5). In this study, Value Stream Mapping, Fishbone Diagram, and 5 Whys are used as primary analytical tools to identify process inefficiencies and root causes of excessive water consumption. Standardized Work, Visual Management, and Kaizen are applied as supporting tools to implement, monitor, and sustain process improvements.

2.4.1 Value Stream Mapping

Value Stream Mapping (VSM) is a lean tool used to visually map the flow of production, representing both current and future state of processes in a way that highlights opportunities for improvement (5). A value stream encompasses all activities, both value-adding and non-value-adding, required to bring a product from raw material to the customer, including the flow of both materials and information across the entire production system (14). The ultimate goal of VSM is to identify all types of waste within the value stream and provide a structured basis for its elimination (14). The application of VSM typically involves three sequential steps: selecting the target product or product family, drawing a current state map that reflects existing process conditions, and developing a future state map that represents the improved system after waste reduction (14). Studies reviewed in the food manufacturing sector demonstrate the practical value of VSM in eliminating waste. VSM applied in a Finnish food manufacturing company helped analyze and eliminate unnecessary inventories and other forms of waste along the supply chain, resulting in cost reduction and increased customer satisfaction (15). Similarly, in a large-scale food production facility, VSM was found to improve production efficiency, product quality, and working environment when applied as part of a lean improvement program (15). In the context of this study, VSM will be applied to map water consumption flows across brewery processes at MBC Asia Pacific LLC, providing a systematic visual basis for identifying non-value-adding water usage throughout production stages.

2.4.2 Fishbone

The Fishbone Diagram, also known as the cause-and-effect diagram, is a lean tool that displays graphically the factors and underlying causes of a defect or problem, with causes drawn on lines radiating from a central line in a structure that resembles a fish skeleton (5). The diagram enables teams to systematically categorize and analyze potential causes of a problem across multiple dimensions such as people, methods, machines, materials, and environment, ensuring a comprehensive evaluation of contributing factors. (5). By organizing all potential causes visually, the Fishbone Diagram supports structured root cause analysis and helps prevent superficial solutions that address only the symptoms of a problem rather than its underlying causes of a problem (5). In this study, the Fishbone Diagram will be applied to identify and categorize the root causes of excessive water consumption across key brewery process areas at MBC Asia Pacific LLC.

2.4.3 5 Whys

The 5 Whys is a root cause analysis technique used to uncover the underlying cause of a problem or defect by repeatedly asking why something occurred, with each answer forming the basis for the next question, until the true root cause is identified (5). This iterative process moves beyond surface-level symptoms to expose the fundamental process failures that give rise to operational inefficiencies, ensuring that corrective actions target the true source of a problem rather than its visible manifestations (5). The 5 Whys is frequently used in conjunction with the Fishbone Diagram, where the diagram first maps all potential causes across categories and the 5 Whys technique then drills deeper into each identified cause to reach its root (5). In this study, the 5 Whys technique will be applied alongside the Fishbone Diagram to trace the root causes of water waste in specific brewery operations at MBC Asia Pacific LLC.

2.4.4 Standardized Work

Standard Work refers to documented procedures for manufacturing that capture best practices, including the time required to complete each task, serving as a living document that is easy to update as improvements are made (5). By establishing and consistently applying standardized procedures across operators and shifts, Standard Work eliminates process variation and inefficiency, forming a reliable baseline for future improvement activities (5). Research in the food sector has confirmed that the application of standard operations can generate measurable cost savings across production stages, with studies reporting cost reductions of 2 to 3 percent per actor in the food supply chain through the application of standard operations (15). In brewery operations, where

processes such as cleaning-in-place and equipment operation are highly repetitive and directly influence water consumption, Standard Work serves as a supporting tool for embedding water-efficient practices into daily operations and maintaining consistency across all process areas.

2.4.5 Visual Management

Visual Management refers to the use of visual indicators, displays, and controls throughout manufacturing plants to improve the communication of information, making the state and condition of manufacturing processes easily accessible and clear to everyone on the production floor (5). This tool supports operational awareness by ensuring that process conditions are immediately visible to all employees, enabling problems to be identified and addressed promptly (5). In brewery operations, where water consumption occurs across multiple simultaneous process areas, Visual Management serves as a supporting tool by making consumption levels, targets, and deviations visible to operational staff, supporting timely corrective action before excessive water use escalates into significant waste.

2.4.6 Kaizen

Kaizen is a lean strategy in which employees at all levels work together proactively to achieve regular, incremental improvements in the manufacturing process, combining the collective talents of an organization to create a continuous engine for eliminating waste (5). Kaizen events are focused; time-limited activities where cross-functional teams identify and implement specific process improvements within a defined area (5). In the food and beverage sector, the application of kaizen has been shown to improve production efficiency, product quality, and working environment in food manufacturing operations (15). In this study, Kaizen serves as a supporting tool that provides the overarching improvement philosophy connecting all other lean tools applied across brewery operations at MBC Asia Pacific LLC.

However, the effectiveness of these tools depends on their structured integration within a broader analytical framework rather than isolated application.

2.5 Financial Feasibility

2.5.1 Definition and Purpose

Financial feasibility analysis is an essential component in evaluating whether proposed process improvements are economically viable and justifiable. In the context of engineering and operations management, this process is defined as the formulation, estimation, and evaluation of the expected economic outcomes of alternatives designed

to accomplish a defined purpose (16). For the purposes of this study, financial feasibility analysis is applied to assess whether the implementation of lean manufacturing tools at MBC Asia Pacific LLC is economically justified through projected reductions in water consumption and associated cost savings.

The financial assessment of lean improvement initiatives is particularly important in resource-intensive industries such as brewing, where water represents both a significant production input and a major operational cost (1). Research has confirmed that lean manufacturing practices contribute positively to financial performance by reducing waste and lowering operational costs across production processes (15). This study applies four key financial evaluation tools, namely Cost-Benefit Analysis, Net Present Value, Payback Period, and Return on Investment, to assess the financial viability of lean-driven water waste reduction at MBC Asia Pacific LLC.

2.5.2 Cost Components of Water in Brewery Operations

Before financial benefits can be calculated, the full cost of water consumption should be established. In brewery operations, water related costs extend beyond the direct purchase price and include multiple components that together determine the overall financial impact of water use. These consist of direct costs, such as water purchase per cubic meter, as well as indirect costs, including energy consumption for water heating and cooling across brewing, fermentation, and cleaning processes. At MBC Asia Pacific LLC, wastewater treatment and discharge costs are not applicable as the facility does not discharge wastewater to the municipal system.

Understanding the full cost structure of water consumption at MBC Asia Pacific LLC is essential for accurately quantifying the financial impact of water waste and estimating potential cost savings associated with the implementation of lean manufacturing tools to reduce water consumption.

2.5.3 Financial Evaluation Methods and Calculations

This section outlines the financial evaluation methods applied in this study to assess the economic viability of implementing lean manufacturing tools to reduce water waste at MBC Asia Pacific LLC. The calculations follow a sequential structure in which the output of each step serves as the input for the next, ensuring a consistent and integrated financial assessment.

Total Annual Water Consumption Cost

The first step establishes the total annual cost of water consumption. This calculation quantifies the full financial burden of current water usage by combining all direct and

indirect water related costs identified in Section 2.5.2, including water purchase costs, energy required for heating and cooling, to produce a single total annual water cost figure expressed in Mongolian Tugrik (MNT). This baseline figure represents the starting point for all subsequent financial calculations in this study.

Projected Water Reduction

The projected reduction in water consumption is determined through Value Stream Mapping analysis, which identifies the non-value-adding water consumption at each brewery process stage at MBC Asia Pacific LLC. Rather than applying a generic industry reduction range, the reduction percentage in this study is derived directly from the VSM findings, reflecting the specific water waste profile of MBC's operations. The projected water reduction is calculated as the difference between current total water consumption and the estimated future water consumption after elimination of identified non-value-adding water use. Research confirms that brewery facilities can achieve significant reductions through process reengineering and training, with studies reporting potential reductions of 20 to 50 percent without significant investment (1), providing a benchmark against which the VSM-derived reduction estimate can be evaluated.

Projected Water Cost Savings

Based on the estimated reduction in water consumption, the projected annual cost savings are calculated by applying the water reduction percentage to the total annual water consumption cost established in the first step. This produces the estimated monetary saving in MNT per year that MBC Asia Pacific LLC could achieve through lean tool implementation, forming the primary benefit figure used in all subsequent financial evaluation metrics.

Cost-Benefit Analysis

Cost-Benefit Analysis (CBA) is defined as the comparison of the present worth of project benefits to the present worth of project costs (16). In this study, the projected annual water cost savings represent the benefit, while the total cost of implementing lean manufacturing tools represent the cost. A Benefit-Cost Ratio greater than one indicates that the financial benefits exceed the costs, confirming the economic viability of the proposed improvement at MBC Asia Pacific LLC.

Payback Period

The payback period is defined as the time required for the cumulative cash inflows to equal the initial investment (16). In this study, the payback period is calculated by dividing

the total lean implementation cost by the projected annual water cost saving, resulting in the number of years required to fully recover its investment through water savings. A shorter payback period indicates a more financially attractive improvement.

Return on Investment

Return on investment (ROI) is expressed as a rate of return, calculated as the ratio of net benefits to investment cost (16). In this study, ROI is used to measure the profitability of the lean implementation by comparing the annual savings to the total implementation cost. A positive ROI value indicates that the investment generates financial returns.

Net Present Value

Net Present Value, also referred to as present worth, is defined as the algebraic difference between the present worth of cash inflows and the present worth of cash outflows, discounted at a specified interest rate (16). This method incorporates the time value of money by converting future savings into present value terms. A positive NPV indicates that the proposed lean implementation at MBC Asia Pacific LLC generates net financial value over its lifetime, providing the most comprehensive measure of financial feasibility in this study.

2.6 Research Gap

Despite extensive research on lean manufacturing and water efficiency in brewery operations, several gaps remain.

First, existing studies often treat operational efficiency and environmental performance separately, with limited integration between lean-based process analysis and resource-specific outcomes such as water consumption.

Second, while lean tools such as Value Stream Mapping and root cause analysis are widely applied, their use in quantifying and reducing water waste in brewery-specific contexts remains limited.

Third, financial feasibility is often discussed conceptually but rarely integrated with process-level analysis in empirical case studies.

This study addresses these gaps by combining lean process analysis, water consumption evaluation, and financial feasibility assessment within a real industrial case study.

The following chapter translates these identified gaps into a structured methodology for analyzing water waste and evaluating improvement feasibility.

3. Methodology

3.1 Introduction

This chapter presents the research methodology adopted to investigate the feasibility of applying lean manufacturing tools to reduce water waste and enhance cost efficiency at MBC Asia Pacific LLC. The study employs a pragmatic research philosophy and a deductive approach, utilizing a case study design to examine brewery operations in a real industrial context. The methodology integrates process analysis, Value Stream Mapping, root cause analysis, and continuous improvement tools to systematically evaluate water consumption across production processes. The chapter then details the research design, data collection methods, analytical framework, and concludes with a discussion on the validity and reliability of the research.

3.2 Research Philosophy and Approach

Research philosophy refers to a system of beliefs and assumptions about the development of knowledge (17). This study adopts a pragmatic research philosophy, which argues that the most important determinant of the research philosophy is the research question, allowing the researcher to work within both positivist and interpretivist positions and select methods that best address the research problem (17). This approach integrates quantitative operational data with qualitative insights derived from direct process observation during the researcher's internship at MBC Asia Pacific LLC.

A deductive approach involves the application of existing theory to develop a structured framework that is tested within a specific context (17). This study adopts a deductive approach, applying established lean manufacturing principles to analyze and identify water waste within brewery operations at MBC Asia Pacific LLC.

3.3 Research Design

Research design is the general plan of how the research question will be addressed (17). It ensures coherence between the research philosophy, strategy, and methods adopted, serving as a blueprint that guides the entire research process toward effectively addressing the study objectives.

3.3.1 Mixed Methods Design

This study adopts a mixed methods research design, which combines quantitative and qualitative techniques within a single study (17). Quantitative data includes production volumes monthly and annually, water consumption by each process area, and internal target, as well as UBM target, covering three-year dataset from MBC Asia Pacific LLC. Qualitative insights are derived from direct process observation conducted during the

researcher's internship. This approach enables a contextual understanding of operational inefficiencies while ensuring that findings are grounded in actual production conditions. This approach enables a contextual understanding of operational inefficiencies while ensuring that findings are grounded in actual production conditions.

3.3.2 Case Study Strategy

This research employs a case study research strategy. A case study involves an empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidence (17). MBC Asia Pacific LLC is selected as the single case for this study as it represents a relevant and accessible industrial setting for examining water waste in brewery operations. This strategy is appropriate as it allows for an in-depth analysis of water consumption patterns, waste identification, and improvement feasibility within the specific operational environment of the brewery, where the boundaries between the phenomenon and its context are closely interrelated (17).

3.3.3 Time Horizon

This study adopts a cross-sectional time horizon. A cross-sectional study examines a phenomenon at a specific point in time (17). As this research focuses on analyzing current water consumption and waste within 2025 production data rather than tracking changes over time, a cross-sectional approach is appropriate and consistent with the scope of this study.

3.4 Data Collection Methods

Data collection methods are techniques used to gather data that will answer research questions (17). In this study, both primary and secondary data are collected to provide a comprehensive analysis of water consumption and waste in brewery operations. The use of multiple data sources enables triangulation, improving the reliability and validity of the findings (17).

3.4.1 Primary Data

Primary data are data collected specifically for the research project being undertaken (17). Primary data were collected through direct observation of brewery operations during the researcher's internship at MBC Asia Pacific LLC in 2025. Due to company restrictions, interviews and surveys were not able to be conducted. Observations focused on process flow, operational practices, equipment behavior, and water usage patterns

3.4.2 Secondary Data

Secondary data are data that were originally collected for some other purpose (17). This study draws on the following secondary data sources within 2023-2025:

- MBC Asia Pacific LLC internal production records and water consumption data
- Utility bills and water cost records
- Company operational reports and process documentation
- Published industry benchmarks for brewery water consumption from peer reviewed literature

Secondary data provides the quantitative baseline for analyzing current water consumption levels at MBC and comparing them against industry benchmarks established in the literature review.

3.4.3 Triangulation

Triangulation refers to the use of more than one data collection method or source of data in the study of a phenomenon (17). Triangulation was achieved by combining observational data with secondary data from company records and industry benchmarks, strengthening the validity of findings.

3.5 Analytical Framework

The analytical framework of this study is structured around six lean manufacturing tools applied sequentially to identify, analyze, and address water waste across brewery operations at MBC Asia Pacific LLC. The framework progresses from process mapping and waste identification through to root cause analysis, improvement development, and financial feasibility assessment, reflecting the systematic nature of lean-based improvement methodology.

3.5.1 Value Stream mapping

Value Stream Mapping is applied as the primary analytical tool to map the current state of water consumption flows across all brewery process areas at MBC Asia Pacific LLC. VSM documents each step and activity from start to finish, capturing processing time, waiting time, and material flow at each stage (5).

The current state map is constructed by walking through the entire brewery production process, from raw material reception through brewhouse operations, fermentation, filtration and packaging while incorporating water consumption data derived from operational records alongside process cycle times. By integrating water consumption

data into the Value Stream Map, the analysis enables the identification of process stages where water usage is excessive or inefficient.

By distinguishing between value-adding and non-value-adding water consumption at each process step, the current state map provides a comprehensive visual basis for identifying where excessive or unnecessary water use occurs across the production system. A future state map is then developed to represent the improved system after waste elimination, showing the target water consumption levels achievable through lean tool implementation (18). The gap between the current and future state maps defines the scope of improvement opportunities that are further investigated through subsequent analytical steps.

3.5.2 Water Consumption Analysis and Benchmark Comparison

Water consumption analysis is conducted to quantify water usage across different stages of brewery operations and to identify areas of excessive consumption within the production system. This analysis is based on secondary data obtained from MBC Asia Pacific LLC, including total water usage, production volumes, and process-level water consumption where available. Water efficiency is evaluated using the water-to-beer ratio, expressed as hectoliters of water used per hectoliter of beer produced (hl/hl), which is a standard performance indicator in the brewing industry (1).

The analysis focuses on examining water usage across key process areas, including brewhouse operations, fermentation, packaging, and cleaning-in-place processes. Particular attention is given to high-consumption activities such as brewing and packaging which have been identified as major contributors to water usage in brewery systems (2) (8)

To evaluate operational performance, the measured water consumption levels are compared against industry benchmarks reported in the literature. Efficient brewery operations typically achieve water consumption levels below 4 hl/hl while industry averages range between 4 and 7 hl/hl (1) (6).This comparison enables the identification of performance gaps between current operations at MBC Asia Pacific LLC and best practice standards.

3.5.3 Waste Analysis

Following the completion of Value Stream Mapping and water consumption analysis, the Eight Wastes framework of lean manufacturing is applied to classify the forms of water waste identified across brewery process areas at MBC Asia Pacific LLC. The Eight Wastes framework includes overproduction, defects, inventory, transportation, waiting,

motion, over-processing, and non-utilized talent, providing a structured approach to identifying inefficiencies within production systems. This step converts the findings from the VSM and consumption analysis into a structured lean classification, enabling clearer understanding of the nature and origin of each inefficiency prior to root cause analysis.

Based on the results of Value Stream Mapping and water consumption analysis, each stage of the brewery process is evaluated to determine the presence of waste, with particular attention given to activities that contribute to excessive water usage. In the context of this study, key forms of waste are expected to include over-processing such as excessive cleaning or rinsing beyond hygiene requirements, waiting caused by process delays between production stages, and unnecessary motion or handling during operations.

The classification of waste using the Eight Wastes framework enables a systematic understanding of how inefficiencies are distributed across the production process, providing the foundation for subsequent root cause analysis and the development of targeted improvement measures.

3.5.4 Root Cause Analysis

Root cause analysis is conducted using two complementary lean tools, the Fishbone Diagram and the 5 Whys technique, to identify the underlying factors contributing to excessive water consumption within brewery operations at MBC Asia Pacific LLC. These tools are used together to ensure that improvement recommendations address the fundamental sources of water waste rather than surface-level symptoms. This analysis builds on the results of Value Stream Mapping, water consumption analysis, and waste classification, focusing on the key areas where inefficiencies have been identified.

The Fishbone Diagram is first constructed for each major water waste area identified at MBC Asia Pacific LLC. The diagram displays graphically the factors and underlying causes of a problem, with causes drawn along branches radiating from a central line in a structure that resembles a fish skeleton (5). In this study, it is used to visually map and categorize potential causes of excessive water consumption across key brewery process areas, drawing on data collected through questionnaires, interviews, and process observation. This structured visual representation ensures that all contributing factors, including man, methods, machines, process and measurement, are systematically considered before corrective actions are developed.

Following this, the 5 Whys technique is applied to each cause identified within the Fishbone Diagram. This technique uncovers the root cause of a problem by repeatedly

asking “why”, with each answer forming the basis for the next question, until the underlying issue is identified (5). By drilling deeper into each identified cause, the 5 Whys moves beyond observable symptoms to reveal the fundamental process failures contributing to excessive water consumption at MBC Asia Pacific LLC.

The combined use of the Fishbone Diagram and 5 Whys enable a systematic and in-depth analysis of water waste causes, providing a clear basis for the development of targeted and effective improvement measures.

3.5.5 Financial Analysis

Total Annual Water Consumption Cost

The total annual water consumption cost was calculated by total production water excluding third-party and water-related costs at MBC Asia Pacific LLC. The formula applied was:

EQUATION 1 TOTAL ANNUAL WATER CONSUMPTION COST

$$Total\ Annual\ Water\ Cost(MNT) = \left[Water\ Consumption(m^3) \times Water\ Tariff(\frac{MNT}{m^3})\right] + Energy\ Cost\ for\ Heating\ and\ Cooling\ (MNT) + Wastewater\ Treatment\ Cost(MNT)$$

Water consumption data were obtained from MBC internal records, water tariff figures from utility bills, and energy bills from MBC operational records. This calculation established the financial baseline for all subsequent steps.

VSM-Based Water Reduction Rate

Rather than applying a generic industry reduction range, the water reduction rate in this study was derived directly from the Value Stream Mapping analysis conducted in section 3.5.1. The VSM identified non-value-adding water consumption at each brewery process stage, brewing, packaging, and fermentation processes. The reduction rate was calculated as follows:

EQUATION 2 REDUCTION RATE

$$Reduction\ Rate\ (\%) = \frac{Current\ Ratio - Future\ Ratio}{Current\ Ratio} \times 100$$

This approach produced a reduction rate specific to MBC Asia Pacific LLC's operational profile rather than relying on a generic literature estimate.

Projected Water Reduction

The projected annual water reduction was calculated by applying the VSM-based reduction rate to MBC's current annual water consumption. The formula applied was:

EQUATION 3 PROJECTED WATER REDUCTION

$$Projected\ Water\ Reduction(m^3) = Current\ Annual\ Water\ Consumption(m^3) \times VSM\ Based\ Reduction\ Rate(\%)$$

The projected future water consumption was then determined as:

EQUATION 4 FUTURE WATER CONSUMPTION

$$Future\ Water\ Consumption(m^3) = Current\ Annual\ Water\ Consumption(m^3) - Projected\ Water\ Reduction(m^3)$$

Projected Water Cost Savings

The projected annual water cost saving was calculated by applying the VSM-based reduction rate to the total annual water consumption cost established in the first step. The formula applied was:

EQUATION 5 PROJECTED ANNUAL COST SAVING

$$Projected\ Annual\ Cost\ Saving(MNT) = Total\ Annual\ Water\ Cost(MNT) \times VSM\ Based\ Reduction\ Rate(\%)$$

This figure represented the primary financial benefit of lean implementation and formed the input for all subsequent financial evaluation metrics.

Cost-Benefit Analysis

Cost-Benefit Analysis was applied to compare the total projected financial benefits of lean implementation against the total implementation costs at MBC Asia Pacific LLC (Blank & Tarquin, 2012, p.235). The Benefit-Cost Ratio was calculated using the following formula:

EQUATION 6 BENEFIT COST RATIO

$$Benefit\ Cost\ Ratio = \frac{Projected\ Annual\ Cost\ Saving(MNT)}{Total\ Implementation\ Cost(MNT)}$$

Total implementation costs included staff training, monitoring equipment installation, standard work documentation, and visual management systems. A Benefit-Cost Ratio greater than one confirmed that the financial benefits of lean implementation exceeded its costs.

Payback Period

The payback period was calculated to determine how many years MBC Asia Pacific LLC would require to recover its lean implementation costs through projected water savings (Blank & Tarquin, 2012, p.348). The formula applied was:

EQUATION 7 PAYBACK PERIOD

$$Payback\ Period(years) = \frac{Total\ Implementation\ Cost(MNT)}{Projected\ Annual\ Cost\ Saving(MNT)}$$

A shorter payback period indicated a more financially attractive improvement program.

Return on Investment

Return on investment was calculated to express the financial return of the lean improvement program as a percentage of the total investment made (Blank & Tarquin, 2012, p.173). The formula applied was:

EQUATION 8 ROI

$$ROI(\%) = \left[\frac{Projected\ Annual\ Cost\ Saving - Total\ Implementation\ Cost}{Total\ Implementation\ Cost}\right] \times 100$$

A positive ROI confirmed that the projected water savings exceeded the cost of lean implementation at MBC Asia Pacific LLC.

Net Present Value

Net Present Value was calculated to assess the long-term financial viability of lean implementation by accounting for the time value of money (Blank & Tarquin, 2012, p.131). The formula applied was:

EQUATION 9 NPV

$$NPV\ (MNT) = \Sigma\ \left[\frac{Annual\ Cost\ Saving}{(1+i)\text{^}t}\right] - Total\ Implementation$$

Where *i* represented the discount rate and t represented the year of the project lifetime. A positive NPV confirmed that the lean improvement program generated net financial value over its lifetime at MBC Asia Pacific LLC, providing the most comprehensive measure of financial feasibility in this study.

3.5.6 Validity and Reliability

This study ensures validity by using actual company data, including water consumption and performance indicators, which accurately reflect operational conditions at MBC Asia Pacific LLC. The application of Value Stream Mapping and root cause analysis further supports that the identified inefficiencies are directly linked to real process conditions.

Reliability is supported by the use of standardized analytical methods that can be applied in similar industrial settings. However, due to company restrictions, no interviews or surveys were conducted. Therefore, the analysis is based on observational data and company records, which may limit insight into operator-level practices.

Chapter 4 Case Study Analysis and Findings

4.1 Introduction

This chapter presents the case study analysis and findings for MBC Asia Pacific LLC, focusing on water consumption and process efficiency within the beer production system. The analysis is based on operational data from 2023 to 2025, supported by value stream mapping (VSM), waste identification, and root cause analysis.

The objective of this chapter is to evaluate current water usage performance, identify inefficiencies across process areas, and quantify the potential for improvement relative to internal targets and industry benchmarks. Based on these findings, Lean-based improvements are proposed and their expected impact is assessed through future state analysis and financial evaluation.

4.2 Current Brewery Process Overview

MBC Asia Pacific LLC operates a continuous large-scale brewing production system producing **262,619 hl**, **274,327 hl** and **270,568 hl of beers across the 2023**, **2024, and 2025** reporting periods respectively. The production system is structured across five principal process stages: brewing, fermentation and conditioning, filtration, packaging, and cleaning-in-place (CIP). Across these stages, water is utilized as both a direct production input and as a supporting process utility.

Over the three-year period, total water consumption decreased from **117,893 m³ to 104,811 m³**, representing a cumulative reduction of **11.1%**, while the overall water-to-beer ratio improved from **4.49 hl/hl to 3.87 hl/hl**. Despite this improvement, the 2025 ratio of **3.87 hl/hl remains 17.3% above** the internal target and UBM benchmark of **3.30 hl/hl** equivalent to an excess water consumption of 15,524 m³ per year. This indicates that significant non-value-adding water use persists across brewery operations Table 1 summarizes the process-level water consumption and water-to-beer ratios across all three reporting years, identifying brewing and cleaning-in-place (CIP) as the two process areas consistently operating above their respective benchmarks.

TABLE 1 WATER CONSUMPTION BY PROCESS AREA 2023-2025

Process Area	2023 (m^3)	2024 (m^3)	2025 (m^3)	2023 (hl/hl)	2024 (hl/hl)	2025 (hl/hl)	Target (hl/hl)	UBM (hl/hl)
Brewing	81,850	79,095	73,481	3.12	2.88	2.72	2.10	2.13
Packaging	17,347	17,336	16,211	0.66	0.63	0.60	0.70	0.85
Utility	6,493	6,439	5,877	0.25	0.24	0.22	0.30	0.26
Cleaning-related	5,451	5,139	4,743	0.21	0.19	0.18	0.08	0.08
Total Production Water	111,142	108,006	100,308	4.24	3.94	3.72	3.30	3.30
Total Water	117,893	114,241	104,811	4.49	4.16	3.87	—	—

4.2.1 Brewing Process

The brewing process begins with malt preparation, where raw material is cleaned and processed through a wet milling system before being transferred to the mash tun. During mashing, water is used to convert starches into fermentable sugars at 62–72°C over approximately 90 minutes. The wort is then separated from spent grain in the lauter tun using hot water sparging and transferred to the wort kettle, where it is boiled at 95°C for 90 minutes with hops added for flavor development. After boiling, the wort passes through a whirlpool for clarification and is subsequently cooled from 95°C to 8–10°C using a heat exchange system before fermentation.

Water is utilized throughout these stages as a direct process input, a heat transfer medium, and for cleaning related operations. As shown in Table 1, brewing is the most water-intensive stage, accounting for approximately **73%** of total production water consumption across three reporting years. Annual brewing water consumption decreased from **81,850 m^3 in 2023** to **79,095 m^3 in 2024** and further to **73,481 m^3 in 2025**, reflecting a cumulative reduction of **12.7%**.

Despite this improvement, the brewing water-to-beer ratio recorded 3.12 hl/hl, 2.88 hl/hl, and 2.72 hl/hl across the three years respectively, remaining persistently above the internal target of 2.10 hl/hl and UBM benchmark of 2.13 hl/hl in every reporting period. Due to internal target, the performance gaps of 1.02, 0.78, and 0.62 hl/hl in 2023, 2024, and 2025 correspond to excess water consumption, confirming that brewing operations

contain substantial non-value-adding water usage and represent the primary focus area for improvement.

4.2.2 Fermentation, Conditioning Process and Filtration

Following the brewing stage, cooled wort (8-10°C) is transferred into fermentation and conditioning tanks, where yeast converts sugars into alcohol and carbon dioxide over approximately 14-18 days. The conditioned beer is then filtered to remove remaining yeast cells, proteins, and suspended particles before transfer to BBT.

Water consumption in these stages is primarily indirect and associated with cooling and cleaning-related activities, rather than direct product formation. These processes contribute approximately 10–12% of total production water consumption, largely through non-value-adding operations.

During the researcher's internship at MBC Asia Pacific LLC, filtration-related liquid spillage was observed on the production floor, which required additional water for cleaning. This represents a recurring source of non-value-adding water consumption, indicating potential inefficiencies in operational control.

4.2.3 Packaging Process

Beer from the BBT tank is filled into three packaging formats: bottles, cans, and kegs, across multiple packaging lines. Water is consumed across multiple packaging sub-processes including bottle and crate washing, pasteurization, conveyor lubrication, filling operations and line cleaning.

During the researcher's internship, several sources of inefficiency were identified, including glass breakage requiring floor cleaning, mechanical failures in the can washer leading to uncontrolled water discharge, and pasteurizer stoppages causing residual water loss.

As shown in the Table 1, packaging water consumption decreased slightly from **0.66 hl/hl in 2023 to 0.60 hl/hl in 2025**, accounting for approximately **15–20% of total production water usage**, making the packaging process, the second-largest contributor to water consumption. Although packaging operates below the internal target of 0.70 hl/hl and UBM benchmark of 0.85 hl/hl in all three reporting years. Despite performing within acceptable benchmarks, the observed operational waste sources indicate that non-value-adding water consumption exists within the packaging area beyond what is captured in the metered consumption data.

4.2.4 Utility Process

The utility water system at MBC Asia Pacific LLC supports facility operations including the evaporative condenser for refrigeration cooling, the reverse osmosis water treatment system, and the boiler for steam generation. Water is mainly used in boilers, cooling systems, and heat exchangers, these systems provide essential process support across all production stages but do not directly contact the beer product.

As shown in Table 1, utility water consumption decreased from 6,493 m^3 in 2023 to 5,877 m^3 in 2025, a cumulative reduction of 9.5%, with the ratio recording 0.25, 0.24, and 0.22 hl/hl across the three years, consistently below both the internal target and UBM target 0.26 hl. Utility water does not represent a priority area for lean manufacturing intervention in this study.

4.2.5 Cleaning—Related Water Consumption

Cleaning-related water consumption includes water used for equipment cleaning, floor washing, and general sanitation activities across the production system. These activities are essential for maintaining hygiene standards but do not directly contribute to product value.

As shown in Table 1, CIP water consumption decreased from **5,451 m^3 in 2023** to **4,743 m^3 in 2025**, with water intensity improving from **0.21 to 0.18 hl/hl**. However, these values remain significantly above the UBM benchmark of 0.08 hl/hl, exceeding the benchmark by more than 100% across all years. This makes cleaning-related operations represent a significant source of water consumption, accounting for approximately **4–6% of total production water usage** across the three reporting years, with a substantial portion classified as non-value-adding.

In summary, water consumption within the production system is heavily concentrated in the brewing stage, while non-value-adding usage is primarily observed in packaging and cleaning-related activities. Although improvements have been achieved over the three-year period, inefficiencies remain across several process areas. The following section presents a detailed analysis of water consumption patterns to identify specific sources of inefficiency and potential areas for improvement.

4.3 Current Water Consumption Analysis

This section presents a comprehensive analysis of water consumption patterns within the production system at MBC Asia Pacific LLC. The analysis focuses on evaluating total and production water usage, identifying process-level consumption patterns, and assessing water use efficiency relative to internal targets and industry benchmarks. The

objective is to identify areas of inefficiency and provide a quantitative foundation for waste identification and subsequent lean improvement.

4.3.1 Overview of Annual Water Consumption

Water consumption at MBC Asia Pacific LLC was analyzed across the 2023 to 2025 reporting period. Total water consumption decreased from **117,893 m³** to **104,811 m³,** representing a cumulative reduction of 11.1%. This reduction occurred alongside relatively stable production volumes, indicating an improvement in overall water use efficiency.

Production water accounts for the majority of total water consumption, with values of **111,142 m³ in 2023**, **108,006 m³ in 2024**, and **100,308 m³ in 2025**, representing approximately **94–96% of total water usage**, with the cumulative reduction of 9.7%. The remaining portion consists of non-production water, including third-party consumption such as canteen and facility services, which is excluded from further analysis.

As shown in Table 2 total water consumption decreased by 11.1% between 2023 and 2025, while production increased by 3.0%, resulting in a 13.8% improvement in overall water efficiency. Despite this improvement, the 2025 production water intensity of **3.72 hl/hl** remains above the internal target and UBM benchmark of **3.30 hl/hl**, indicating that further reduction potential exists within the production system.

TABLE 2 THREE YEAR WATER CONSUMPTION SUMMARY

Metric	2023	2024	2025	Change (2023-2025)
Production Volume (hl)	262,619	274,327	270,568	3.0%
Total Water (m³)	117,893	114,241	104,811	-11.1%
Production Water (m³)	111,142	108,006	100,308	-9.7%
3rd Party Water (m³)	6,751	6,235	4,503	-33.3%
Total water (hl/hl)	4.49	4.16	3.87	-13.8%
Production Water (hl/hl)	4.24	3.94	3.72	-12.3%
Internal target (hl/hl)	3.30	3.30	3.30	—
UBM benchmark (hl/hl)	3.30	3.30	3.30	—

4.3.2 Water Consumption by Process Area

Production water was disaggregated across four operational areas to identify the relative contribution and performance trend of each process area Table 3 presents the three-year breakdown by process area in both absolute volume m³ and percentage of total production water, while *Figure 2* illustrates the proportional distribution.

TABLE 3 WATER CONSUMPTION BY PROCESS AREA

Process Area	2023 m³	2024 m³	2025 m³	Change	2023 % of Total	2024 % of Total	2025 % of Total
Brewing	81,850	79,095	73,481	-10.20%	73.6%	73.2%	73.3%
Packaging	17,347	17,336	16,211	-6.50%	15.6%	16.1%	16.2%
Utility	6,493	6,439	5,877	-9.50%	5.8%	6.0%	5.9%
Cleaning-Related	5,451	5,139	4,743	-13.00%	4.9%	4.8%	4.7%
Total Production	**111,142**	**108,006**	**100,308**	**-9.70%**	**100%**	**100%**	**100%**

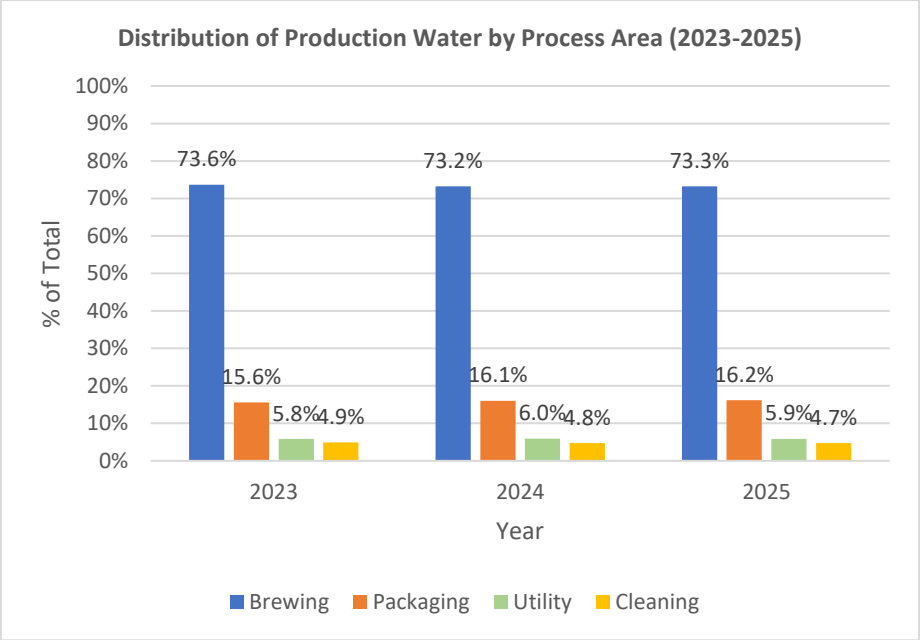

FIGURE 2 DISTRIBUTION OF PRODUCTION WATER BY PROCESS AREA 2023-2025

As shown in Table 3 and *Figure 2* brewing dominates water consumption, accounting for **approximately 73%** across three years. This consistency indicates that brewing water

usage is structurally embedded within the production system rather than driven by short-term variation.

Packaging represents the second-largest contributor, accounting for **15.6% in 2023, 16.1% in 2024, and 16.2% in 2025**, followed by utility water consumption at approximately **5.8–6.0%**, and cleaning-in-place at **4.7–4.9%**. Although all process areas show a reduction in absolute water consumption over the three-year period, their relative proportions remain largely unchanged. This suggests that overall efficiency improvements have occurred proportionally across all processes rather than through targeted reduction in specific high-consumption areas.

The dominance of brewing highlights its role as the primary driver of total water consumption, while packaging contributes a moderate but stable share. Cleaning-related water, although smaller in proportion, represents a category of consumption not directly linked to production output, indicating potential non-value-adding activities.

Overall, the analysis confirms that water consumption is highly concentrated in brewing operations, with additional contributions from packaging and cleaning-related activities. All three process areas targeted for lean intervention, showed improvement over the three-year period, yet the rate of improvement has been insufficient to close the gap against internal targets and UBM benchmarks.

4.3.3 Water-to-Beer Ratio Analysis

The water-to-beer ratio (hl/hl) is the primary performance indicator used to evaluate water efficiency, as it normalizes water consumption relative to production output. Table 4 presents the three-year ratios by process area alongside internal targets and UBM benchmarks.

TABLE 4 WATER-TO-BEER RATIO BY PROCESS AREA COMPARED TO TARGET AND UBM BENCHMARK (2023–2025)

Process Area	2023 hl/hl	2024 hl/hl	2025 hl/hl	Target	UBM	Gap vs Target	Status
Total water	4.49	4.16	3.87	3.3	3.3	0.57	❌
Brewing	3.12	2.88	2.72	2.1	2.13	0.62	❌
Packaging	0.66	0.63	0.6	0.7	0.85	-0.1	☑
Utility	0.25	0.24	0.22	0.3	0.26	-0.08	☑
Cleaning	0.21	0.19	0.18	0.20	0.08	-0.02	☑

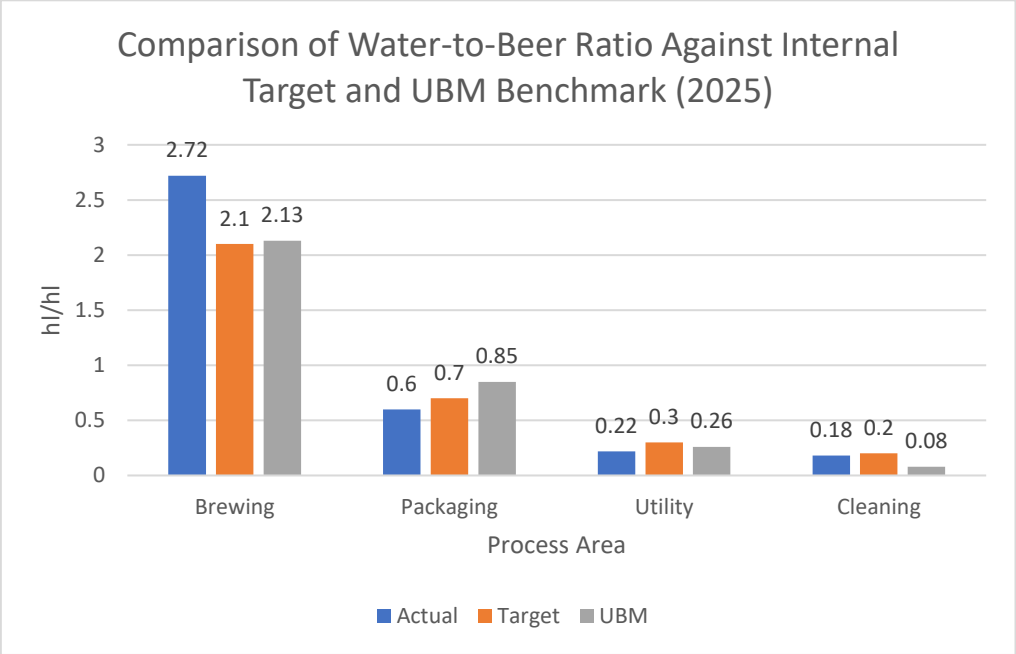

FIGURE 3 COMPARISON OF WATER-TO-BEER RATIO AGAINST INTERNAL TARGET AND UBM BENCHMARK (2025)

As shown in Table 4 and *Figure 3*, a clear performance gap exists between process areas. Brewing consistently exceeds both internal targets and industry benchmarks, while packaging and utility remain within acceptable limits.

In 2025, the brewing water ratio of **2.72 hl/hl** exceeds the UBM benchmark of **2.13 hl/hl** by approximately **27.7%**, indicating a substantial efficiency gap. Although improvement has been observed from **3.12 hl/hl in 2023**, the reduction rate remains insufficient to achieve target performance in the short term. This persistent gap suggests that brewing inefficiencies are structural rather than temporary.

Cleaning-related water consumption also exceeds expected operational levels, with a ratio of **0.18 hl/hl**, indicating inefficiencies associated with cleaning activities. Unlike brewing, this category reflects water usage that is not directly linked to production output, suggesting potential non-value-adding consumption.

In contrast, packaging and utility water consumption perform within acceptable ranges. Packaging recorded **0.60 hl/hl in 2025**, below both the internal target (**0.70 hl/hl**) and UBM benchmark (**0.85 hl/hl**), while utility water consumption remained consistently below target levels.

Overall, while MBC's total water consumption ratio of **3.87 hl/hl** falls within the global "world-class" range of below 4 hl/hl (1), this aggregated performance masks significant

process-level inefficiencies. In particular, brewing and cleaning-related activities represent critical areas for improvement.

4.3.4 Monthly Water Consumption Analysis

Monthly water consumption data for 2025 was analyzed to assess variability and its relationship with production volume. Table 5 presents monthly production, water consumption, and corresponding water-to-beer ratios.

TABLE 5 MONTHLY WATER CONSUMPTION AND PRODUCTION DATA (2025)

Month	Production (hl)	Total m³	Brewing m³	Packaging m³	Cleaning m³	Total (hl/hl)
January	27,138	9,214	7,514	615	356	3.40
February	10,091	4,991	3,794	387	268	4.95
March	21,442	8,152	6,147	1,167	249	3.80
April	25,838	9,346	6,480	1,591	554	3.62
May	28,284	10,054	6,927	1,787	540	3.55
June	25,809	9,661	6,649	1,678	551	3.74
July	29,353	9,902	6,922	1,834	454	3.37
August	29,414	10,217	7,226	1,402	629	3.47
September	19,821	8,119	5,271	1,514	583	4.10
October	20,334	7,737	5,368	1,388	314	3.80
November	20,874	8,588	5,529	1,393	95	4.11
December	12,170	8,830	5,652	1,455	152	7.26
YTD	**270,568**	**104,811**	**73,481**	**16,211**	**4,743**	**3.87**

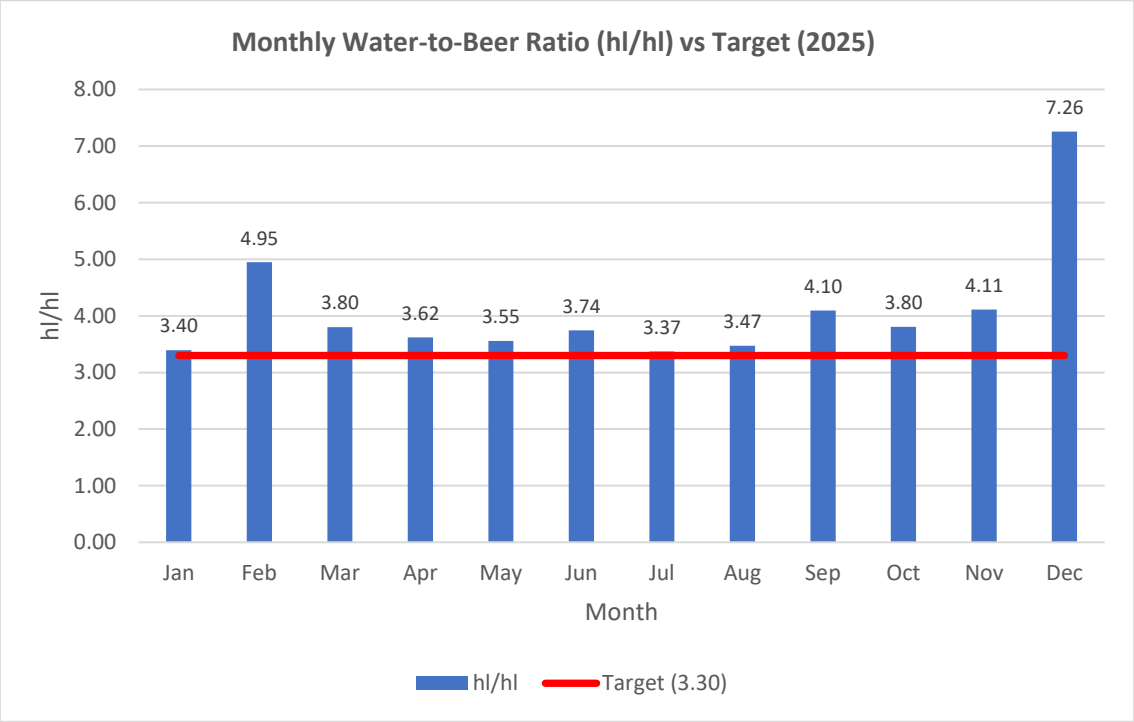

FIGURE 4 MONTHLY WATER-TO-BEER RATIO (HL/HL) VS TARGET (2025)

As shown in Table 5 and *Figure 4*, water efficiency varies significantly across months, with total water-to-beer ratios ranging from **3.37 hl/hl to 7.26 hl/hl**. A clear inverse relationship is observed, where higher production months consistently achieve lower water consumption ratios.

For example, July recorded the lowest ratio of **3.37 hl/hl**, corresponding to the highest production volume (**29,353 hl**), whereas February recorded a significantly higher ratio of **4.95 hl/hl** at the lowest production level (**10,091 hl**). This pattern indicates that a portion of water consumption is fixed and does not scale proportionally with production output.

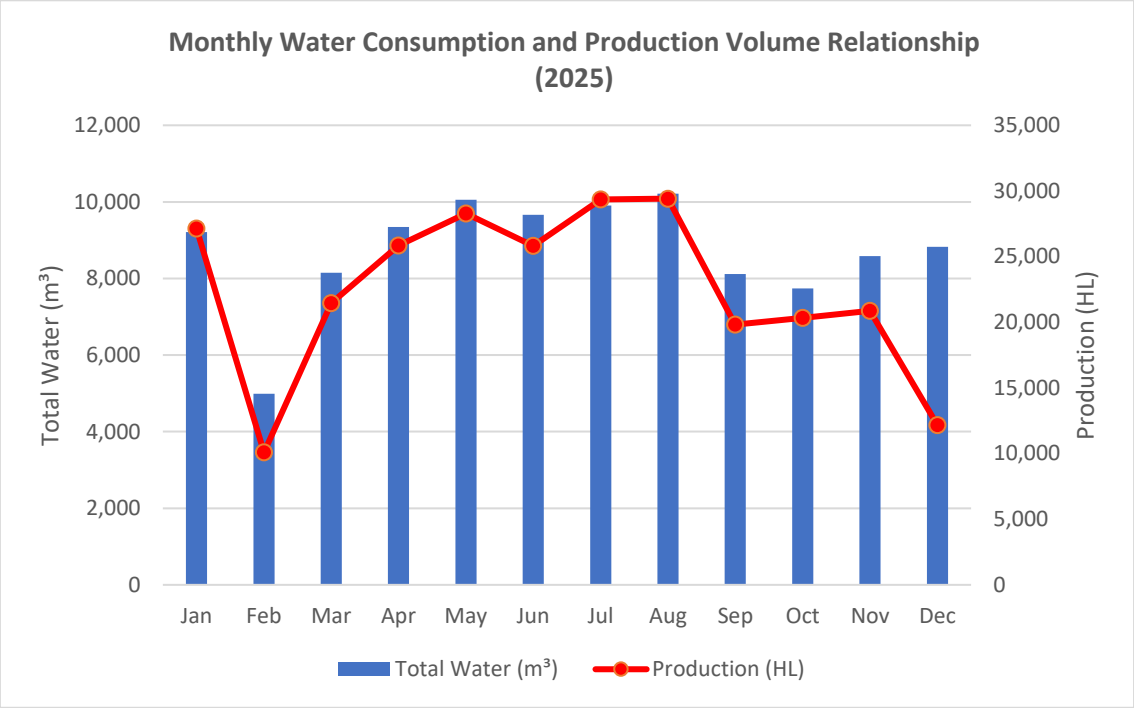

FIGURE 5 MONTHLY WATER CONSUMPTION AND PRODUCTION VOLUME RELATIONSHIP (2025)

Figure 5 further supports this relationship by illustrating that total water consumption remains relatively stable across months, while production volume fluctuates significantly. As a result, when production decreases, the water-to-beer ratio increases sharply, reflecting inefficiency.

A significant deviation is observed in December, where the ratio reached **7.26 hl/hl**, approximately **85% above the annual average**. This is primarily driven by reduced production (**12,170 hl**) while baseline water usage remains relatively constant.

These findings confirm that a substantial portion of water consumption is independent of production volume, indicating structural inefficiencies within the system.

4.3.5 Performance Gap Analysis and Improvement Potential

The performance gap between actual and target water consumption provides a quantitative basis for identifying inefficiencies and estimating reduction potential within the production system. In this study, the gap is defined as the difference between actual and target production water consumption expressed in hl/hl.

To evaluate its operational impact, the gap was converted to volumetric excess using

EQUATION 10 EXCESS WATER

$$Excess\ Water\ (m^3) = \frac{Gap\ (hl/hl) \times Production\ Volume\ (hl)}{10}$$

This conversion enables the magnitude of inefficiency to be expressed in practical terms and allows comparison across process areas.

TABLE 6 PERFORMANCE GAP AND REDUCTION POTENTIAL BY PROCESS AREA (2025)

Process Area	Actual (hl/hl)	Target (hl/hl)	Gap (hl/hl)	Excess Water (m³)	Reduction Priority
Brewing	**2.72**	**2.1**	**+0.62**	**16,775**	**Highest**
Packaging	0.60	0.70	-0.10	-	**Significant**
Utility	0.22	0.30	-0.08	-	**Low**
Cleaning-related	0.18	0.20	-0.02	-	**Low**
Total Production	**3.72**	**3.30**	**+0.42**	**11,364**	**11.06%**

As shown in Table 6, the total production water ratio of **3.72 hl/hl** exceeds the internal target of **3.30 hl/hl**, resulting in a gap of **0.42 hl/hl**. This corresponds to approximately **11,364 m³ of excess water consumption annually**.

When compared to total production water usage (**100,308 m³**), this represents a total water consumption reduction of approximately **11%**, indicating that a measurable portion of water consumption can be eliminated without affecting production output.

At the process level, inefficiency is highly concentrated in the brewing stage. Brewing alone contributes **8,078 m³**, accounting for approximately **73% of total excess water consumption**, making it the primary target for reduction. Packaging contributes **1,782 m³**, representing a secondary source of inefficiency with moderate improvement potential.

In contrast, utility and cleaning-related water consumption contribute relatively small portions of excess water, with **645 m³** and **546 m³**, respectively. These values indicate that while minor improvements are possible, they are not priority areas for intervention.

Overall, the analysis demonstrates that water inefficiency is not evenly distributed across the production system but is concentrated in a limited number of process areas.

Therefore, reduction efforts should be primarily focused on the brewing process, with secondary attention given to packaging operations.

These findings provide a clear quantitative basis for prioritizing improvement efforts and form the foundation for subsequent value stream mapping and waste identification in the following sections.

4.3.6 Summary of Key Findings

Water consumption at MBC Asia Pacific LLC improved between 2023 and 2025, with total water usage decreasing by **11.1%** while production increased by **3.0%**. Despite this progress, the 2025 production water ratio of **3.72 hl/hl** remains above the target of **3.30 hl/hl**, indicating remaining inefficiencies.

Water usage is highly concentrated in the brewing process, accounting for approximately **73% of total production water**, followed by packaging at **15–16%**. The distribution has remained stable over time, suggesting that improvements have not been specifically targeted at high-consumption areas.

The analysis identifies a total water reduction potential of approximately **11%**, equivalent to **11,364 m³**. This reduction is primarily driven by inefficiencies in **brewing**, with **packaging** contributing a smaller but relevant share. These two processes are therefore identified as the **main priority areas for improvement**.

Utility and cleaning-related water consumption remain within acceptable performance levels and are not considered priority areas.

Overall, water inefficiency is concentrated in a limited number of processes, particularly brewing and packaging, providing a clear focus for the subsequent value stream mapping and improvement analysis.

4.4 Current State Value Stream Map

This section presents the current state value stream map (VSM) of the beer production process at MBC Asia Pacific LLC. The VSM provides a visual and analytical representation of material and information flows, enabling the identification of inefficiencies, waiting times, and non-value-adding activities within the production system.

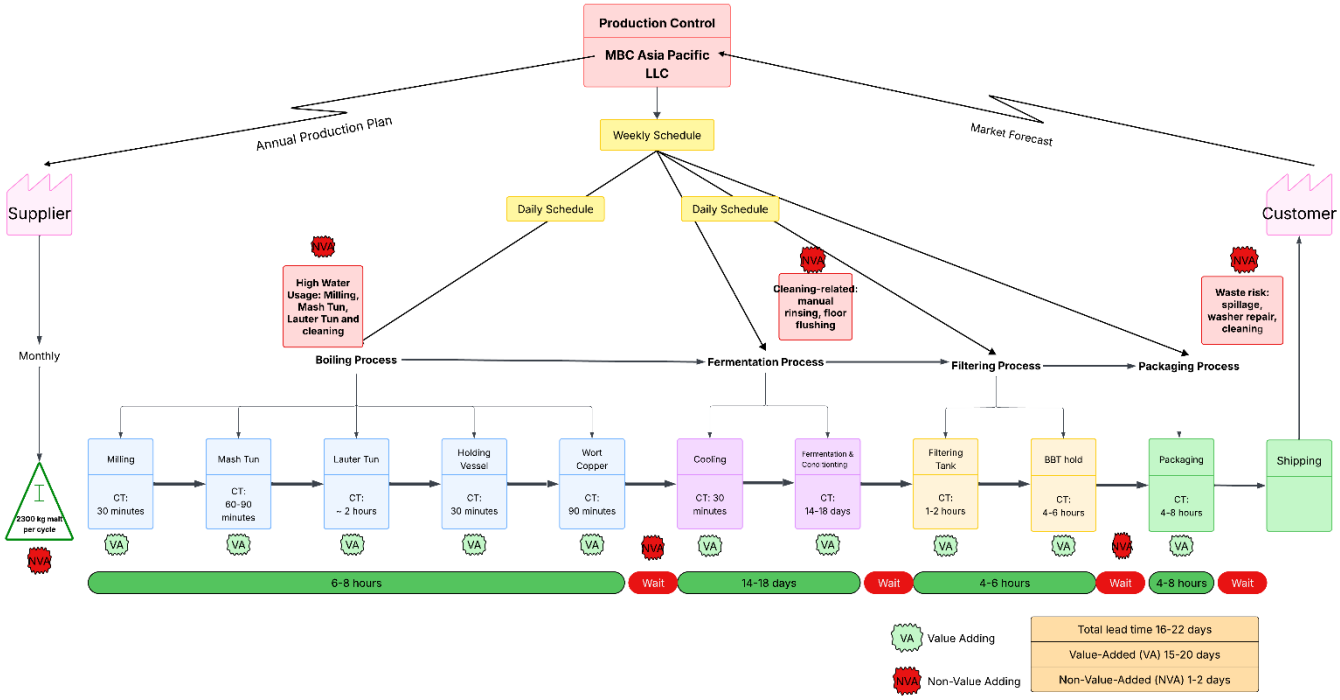

FIGURE 6 CURRENT STATE VALUE STREAM MAPPING

Current State Flow Description:

The production process begins with brewing operations (milling, mashing, lautering, and boiling), followed by fermentation and conditioning, filtration, and packaging. Production is controlled centrally through planning weekly schedule to daily scheduling, operating under a push-based system.

Value-Added and Non-Value-Added Analysis:

The VSM distinguishes between value-added (VA) and non-value-added (NVA) activities based on whether the process contributes directly to product transformation.

The majority of processing steps are classified as value-added activities, as they directly contribute to the transformation of raw materials into finished beer. The total value-added time is estimated at approximately **15–20 days**, primarily driven by the fermentation and conditioning process.

In contrast, non-value-added time consists of waiting periods, intermediate storage, and operational delays between processes. These include waiting before fermentation, holding in bright beer tanks, and delays prior to packaging. The total non-value-added time is estimated at approximately **1–2 days**.

Although non-value-added time represents a relatively small proportion of total lead time, it reflects inefficiencies in flow continuity and process synchronization.

Identification of Waste and Bottlenecks:

The current state VSM reveals several sources of inefficiency within the production system. The most significant observation is the concentration of waste within specific process areas, particularly brewing and packaging.

In the brewing stage, high water consumption is observed across milling, mashing, and lautering operations, as well as during cleaning activities. These represent forms of overprocessing and resource waste.

In the packaging stage, operational losses such as spillage, equipment downtime, and cleaning requirements contribute to additional non-value-adding activities. These inefficiencies not only affect productivity but also increase water consumption.

Furthermore, waiting times between major stages, particularly before fermentation and packaging, indicate the presence of process imbalance and limited flow synchronization. These delays contribute to extended lead times and reduced system efficiency.

Overall, the VSM highlights that while the production system is largely value-driven, inefficiencies arise from resource overuse, waiting, and operational losses. These findings provide a clear basis for further root cause analysis and the application of lean improvement tools in the subsequent sections.

4.5 Waste Identification

Following the construction of the current state Value Stream Map, the eight wastes framework of lean manufacturing was applied to systematically classify non-value-adding activities identified across brewery operations at MBC Asia Pacific LLC. Each identified inefficiency was examined and mapped to the relevant lean waste category to provide a structured classification that forms the basis for the root cause analysis in section 4.6.

Table 7 presents the waste classification results across all eight lean waste categories, based on VSM findings, water consumption data analysis, and observations recorded during the researcher's internship at MBC Asia Pacific LLC.

TABLE 7 IDENTIFICATION OF LEAN WASTES IN PRODUCTION SYSTEM

Lean Waste Type	Identified	Main Issue
Overprocessing	**Yes**	Excessive water usage in brewing operations (milling, mashing, lautering) and cleaning activities due to lack of standardized water control and monitoring
Waiting	**Yes**	Idle time before fermentation and packaging caused by process imbalance, batch production, and push-based scheduling system
Motion	**Yes**	Manual cleaning activities and unnecessary operator movement
Inventory	**Partial**	Temporary storage in BBT and holding vessels due to batch processing and lack of continuous flow between stages
Defects	**Partial**	Product spillage and breakage in packaging leading to re-cleaning, additional water usage, and minor production losses
Transportation	**No**	Process layout is relatively integrated; no significant unnecessary material movement observed between stages
Overproduction	**No**	Production is aligned with planned schedules, no evidence of producing beyond demand within observed scope
Non-Utilized Talent	**No**	Workforce utilization and skill-related inefficiencies were not evaluated within the scope of this study

The analysis identifies overprocessing, waiting, and motion are the main wastes, mainly in brewing and cleaning. Defects and inventory are minor and limited to packaging and storage, while other wastes are not significant. Overall, waste is concentrated in brewing and packaging, which are the focus of the root cause analysis.

The concentration of identified waste in overprocessing, waiting, and motion categories is consistent with the eight wastes framework established in the lean manufacturing literature (12), and aligns with (1), who identified cleaning operations and product transfer

as significant contributors to water waste in brewery operations. These findings directly inform the root cause analysis and lean improvement recommendations presented in the following sections.

4.6 Root Cause Analysis

This section identifies the underlying causes of the key wastes using a fishbone diagram and the 5 Whys method. The analysis focuses on high water consumption in brewing and packaging, supported by VSM results, quantitative data, and operational observations.

Fishbone Diagram Analysis:

The fishbone diagram groups causes under Man, Method, Machine, Measurement, and Process. Results indicate that inefficiencies stem mainly from execution gaps and process conditions rather than absence of systems.

- **Method**: Standards exist but are not consistently followed, cleaning practices are not optimized, leading to overuse of water.
- **Process**: Batch production and imbalance (long fermentation vs faster upstream) create waiting and repeated cleaning/flushing.
- **Measurement**: KPIs are tracked at aggregate level, with limited process-level visibility and real-time control.
- **Machine**: Minor leakage, uncontrolled discharge, and packaging spillage contribute to water loss.
- **Man**: Variation in operator practices and inconsistent adherence to SOPs.

Overall, excessive water use is driven by inconsistent implementation of standards, limited operational control, and process imbalance.

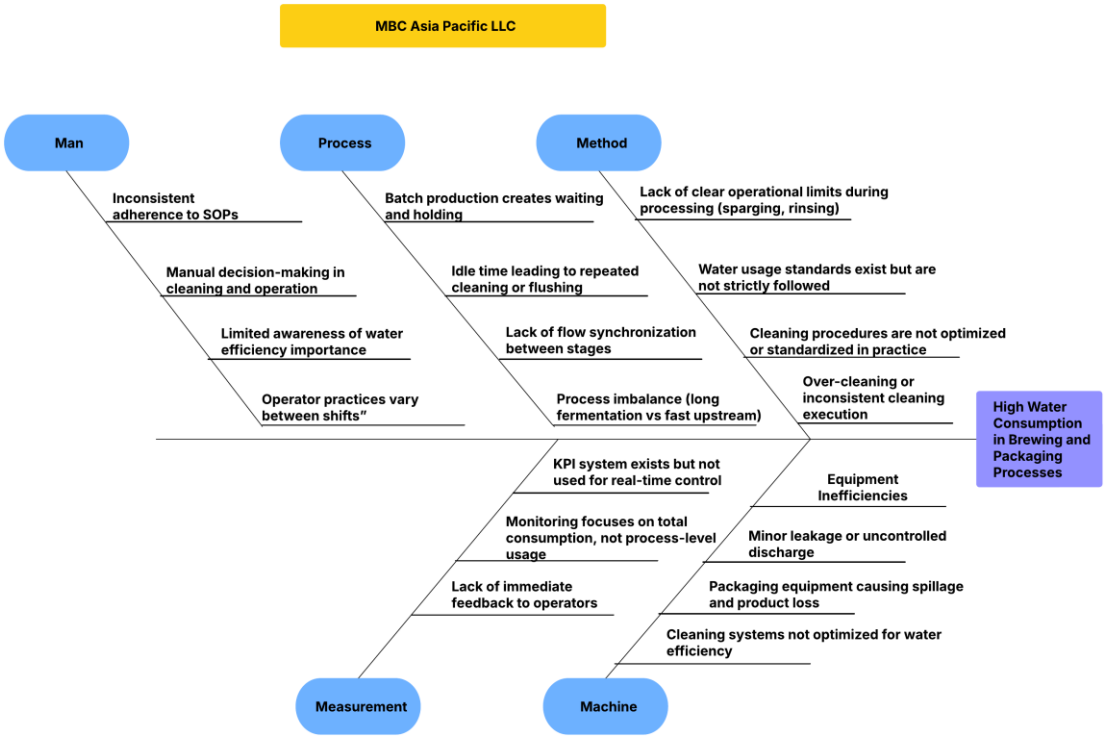

FIGURE 7 FISHBONE DIAGRAM

5 Whys Analysis:

The 5 Whys analysis was conducted as a structured analytical approach based on process observations, value stream mapping results, and quantitative performance data, rather than direct interviews, to identify the underlying causes of inefficiencies.

To further validate the root causes, the 5 Whys method was applied to the most critical issue: excessive water consumption in the brewing process.

Problem: High water consumption in brewing

1. Why is water consumption high?
   Because water is used excessively during processing and cleaning.
2. Why is water used excessively?
   Because cleaning and operational practices are not consistently controlled.
3. Why are practices are not consistently controlled?
   Because standards are not strictly followed and vary between operators.
4. Why are standards not strictly followed?
   Because monitoring and control are not implemented at the process-level.
5. Why is process-level control limited?

Because existing KPI systems focus on overall performance rather than real-time operational control.

The analysis indicates that the root cause lies in the gap between defined standards and actual operational execution, supported by limited real-time control.

A similar pattern is observed in the packaging process. Product spillage and minor defects lead to additional cleaning and water usage, which are also linked to equipment conditions and inconsistent operational practices. Therefore, although the specific activities differ, the underlying causes, inconsistent execution of standards and limited process-level control-remain consistent across both brewing and packaging processes.

4.7 Proposed Lean-Based Improvements for Water Efficiency

This section proposes targeted improvements to reduce water consumption and improve process efficiency at MBC Asia Pacific LLC. The proposals directly address the root causes identified in Section 4.6, inconsistent execution of standards, limited process-level control, and process imbalance and are prioritized based on the quantified performance gap in Section 4.3.5.

In 2025, the production water ratio is 3.72 hl/hl versus a target of 3.30 hl/hl, yielding a gap of 0.42 hl/hl, equivalent to approximately 11,364 m^3 of excess water. Of this, ~73% (8,078 m^3) originates from the brewing process and ~16% (1,782 m^3) from packaging. Accordingly, improvements focus on these two areas.

The Lean tools applied in this study include SOPs for standardization, visual management for monitoring, and Kaizen for continuous improvement. Table 8 presents the alignment between identified root causes, the corresponding Lean tools, and the expected outcomes of their implementation.

TABLE 8 PROPOSED LEAN TOOLS AND ROOT CAUSE LINKAGE

Root Cause	Proposed Lean Tool	Expected Outcome
Inconsistent implementation of water usage and cleaning standards	SOP (Standard Operating Procedures)	Consistent execution of water usage limits and reduction of over-cleaning, leading to lower water consumption
Limited process-level monitoring and control	Visual Management	Real-time visibility of water consumption (hl/hl), enabling quick detection and correction of deviations
Process imbalance and waiting between stages	Visual Management / Kaizen	Improved coordination between processes, reduced waiting time, and minimized unnecessary cleaning
Variability in operational practices between shifts	SOP / Kaizen	Standardized practices across operators, reducing variability in water usage
Packaging losses (spillage and minor defects)	Kaizen	Continuous identification and reduction of losses, decreasing additional cleaning and water usage

4.8 Future State Value Stream Map

This section presents the future state value stream map (VSM) developed based on the Lean-based improvements proposed in Section 4.7. The objective is to reduce non-value-added activities and improve water efficiency, with a primary focus on the **brewing and packaging processes**, where the highest inefficiencies were identified.

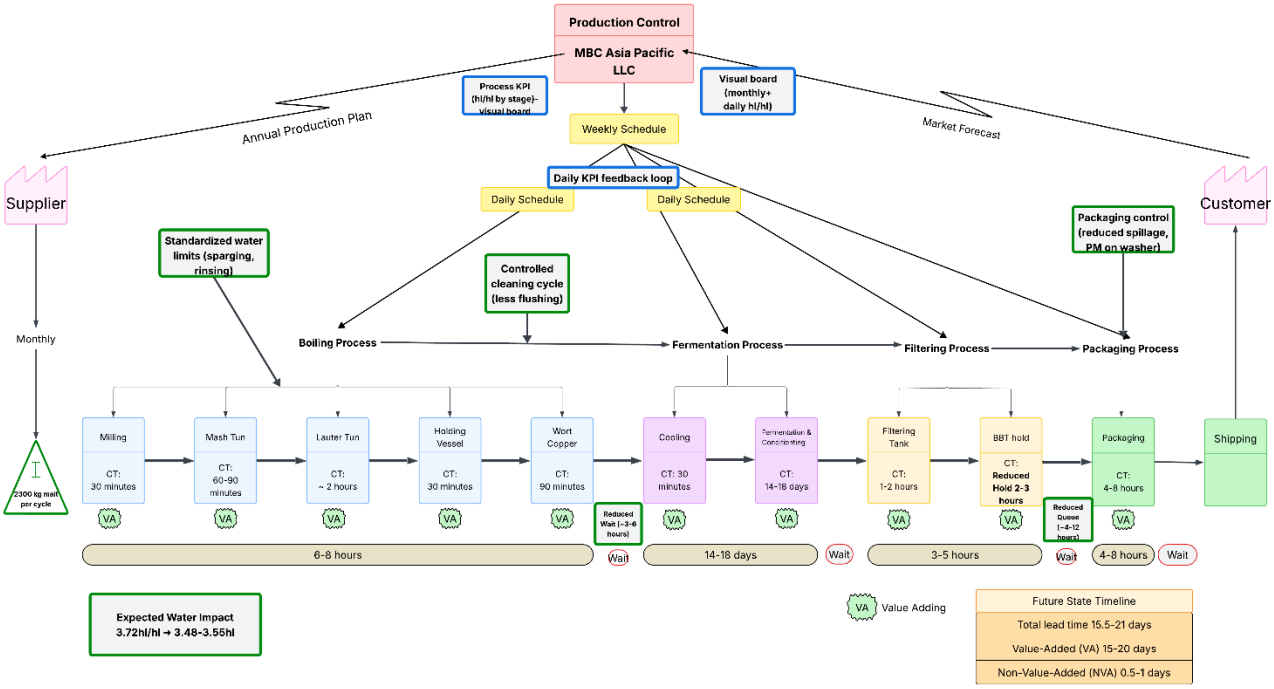

FIGURE 8 FUTURE VALUE STREAM MAP

The future state maintains the existing production structure while introducing targeted improvements in standardization, process control, and flow synchronization. In the brewing stage, water usage is regulated through defined operational limits and optimized cleaning practices, reducing excessive consumption. In the packaging stage, improvements in operational control and equipment condition reduce spillage and the need for additional cleaning.

From a process perspective, waiting and holding times are reduced to improve flow efficiency. The waiting time before fermentation and packaging is reduced to approximately **3–6 hours**, while the BBT holding time is reduced from **4–6 hours to 2–3 hours**. The filtering process remains unchanged at **1–2 hours**, as it is a value-added activity.

The current water consumption of **3.72 hl/hl** exceeds the internal target of **3.30 hl/hl**, representing a total performance gap of approximately **11%**. However, within the scope of this study, focusing on improvements in the brewing and packaging processes, the achievable reduction is estimated at **4.6%–6.5%**, corresponding to a decrease to **3.48–3.55 hl/hl**. This represents a partial but realistic reduction of the total gap, while the remaining reduction potential lies beyond the scope of this study.

In terms of time efficiency, the future state reduces non-value-added time from approximately **1–2 days to 0.5–1 day**, while total lead time decreases slightly due to the dominance of fermentation time as a value-added process. These improvements result in a more balanced and controlled production system.

Overall, the future state VSM demonstrates that targeted Lean-based interventions can significantly improve water efficiency and process performance, while providing a practical pathway toward achieving the company's long-term target.

4.9 Financial Feasibility Analysis

The financial feasibility of implementing lean manufacturing tools at MBC Asia Pacific LLC was assessed through a sequential series of calculations to determine whether the projected water cost savings justify the estimated implementation costs. As the reduction percentage is expressed as a range (4.6%–6.5%), the financial calculations are conducted using a low-case and high-case scenario to reflect variability in achievable outcomes. The analysis is based on 2025 operational data, as it represents the most recent and stable performance period, reflecting current production conditions and the effectiveness of recent efficiency improvements. All monetary values are expressed in Mongolian Tugrik (MNT). Water consumption figures are based on the 2025 reporting period data. Water tariff data is sourced from the Ulaanbaatar Water Supply Authority Director's Order dated October 31 2023, and electricity tariff data is sourced from the Mongolian Energy Regulatory Commission Category 1 rate schedule applicable to holders of alcoholic beverage production licenses. As MBC Asia Pacific LLC does not discharge wastewater to the municipal system, wastewater treatment costs are not included in the analysis.

Total Annual Water Consumption Cost:

The total annual water consumption cost at MBC Asia Pacific LLC was established by combining all direct water purchase costs and indirect energy costs associated with water use in production operations. Third party water consumed in non-production areas was excluded from the calculation as it falls outside the scope of lean manufacturing intervention in this study. Table 9 presents the cost components and their calculated values.

TABLE 9 TOTAL ANNUAL WATER CONSUMPTION COST 2025

Cost Component	Consumption	Tariff	Annual cost MNT
Water consumption without 3rd party water	104,811 m³	3,560 MNT/m³	373,127,160 MNT
Energy cost for cooling	562,500 kWh	285 MNT/kWh	160,312,500 MNT
Energy cost for heating	540,591 MJ	4 MNT/MJ	2,162,364 MNT
Total			**535,602,024 MNT**

The total annual water consumption cost of 535,602,024 MNT approximately 535.6 million MNT, establishes the financial baseline for all subsequent feasibility calculations. Table 9 represents the full annual cost burden of water-related operations at MBC Asia Pacific LLC and forms the primary input for projecting the cost savings achievable through lean tool implementation.

VSM-Based Reduction Rate:

The reduction rate applied in this financial analysis is derived from the future state VSM results presented in Section 4.8. The achievable reduction range of **4.3%–6.2%** reflects improvements in the brewing and packaging processes.

The reduction rate is calculated based on the change in the water-to-beer ratio (hl/hl) as follows:

$$Reduction\ Rate\ (\%) = \frac{Current\ Ratio - Future\ Ratio}{Current\ Ratio} \times 100$$

Where:

- Current Ratio = **3.72 hl/hl**
- Future Ratio = **3.48–3.55 hl/hl**

Applying this:

- Low case:

$$\frac{3.72 - 3.55}{3.72} = 4.6\%$$

- High case:

$$\frac{3.72 - 3.48}{3.72} = 6.5\%$$

For consistency with the analysis in Section 4.8, the reduction range of **4.6%–6.5%** is applied in subsequent financial calculations.

Projected Water Reduction:

The projected annual water reduction is calculated by applying the reduction rate derived in Section 4.9.2 to the current annual water consumption.

Low Case (4.6%):

$$Projected\ Water\ Reduction\ (m^3) = 104{,}811 \times 0.046 = 4{,}821\ m^3$$

High Case (6.5%):

$$Projected\ Water\ Reduction\ (m^3) = 104{,}811 \times 0.065 = 6{,}813\ m^3$$

Future Water Consumption:

Low Case:

$$Future\ Water\ Consumption(m^3) = 104{,}811 - 4{,}821 = 99{,}990\ m^3$$

High Case:

$$Future\ Water\ Consumption(m^3) = 104{,}811 - 6{,}813 = 97{,}998\ m^3$$

The projected water reduction is estimated at approximately **4,800–6,800 m³ per year**, based on a reduction rate of **4.6%–6.5%** derived from the future state performance analysis.

Projected Water Cost Savings:

Low Case (4.6%):

$$Projected\ Annual\ Cost\ Saving(MNT) = 535{,}602{,}024 \times 0.046 = 24{,}637{,}693\ MNT$$

High Case (6.5%):

$$Projected\ Annual\ Cost\ Saving(MNT) = 535{,}602{,}024 \times 0.065 = 34{,}814{,}132\ MNT$$

The projected annual cost saving is calculated by applying the reduction rate to the total annual water-related cost. Based on a reduction rate of 4.6%–6.5%, the estimated savings range between approximately 24.6 million MNT and 34.8 million MNT per year, reflecting the combined reduction in water and energy-related costs.

Cost-Benefit Analysis:

The cost-benefit analysis evaluates the economic feasibility of the proposed Lean-based improvements by comparing the projected annual cost savings with the total implementation cost. The implementation cost is treated as an estimated input based on the Lean tools proposed in Section 4.7. The cost includes SOP documentation, staff training, visual management updates, monitoring improvements, and Kaizen activities.

Low Case:

$$\text{BCR} = \frac{24.6 \text{ million MNT}}{15 \text{ million MNT}} = 1.64 \text{ million MNT}$$

High Case:

$$\text{BCR} = \frac{34.8 \text{ million MNT}}{15 \text{ million MNT}} = 2.32 \text{ million MNT}$$

The calculated BCR values are greater than 1 in both cases, indicating that the financial benefits of the proposed improvements exceed the associated costs. This confirms that the Lean-based water reduction measures are economically feasible.

Payback Period:

The payback period measures the time required to recover the implementation cost through the annual cost savings generated by the proposed improvements.

Low Case (4.6%):

$$Payback\ Period\ (years) = \frac{15{,}000{,}000}{24{,}637{,}693} \approx 0.61\ years$$

High Case (6.5%):

$$Payback\ Period\ (years) = \frac{15{,}000{,}000}{34{,}814{,}132} \approx 0.43\ years$$

The results indicate that the payback period ranges between approximately 0.43 and 0.61 years, equivalent to 5–7 months. This demonstrates that the investment required for implementing the Lean-based improvements can be recovered within a very short period.

Return on Investment:

Return on Investment (ROI) measures the profitability of the proposed Lean-based improvements relative to the implementation cost.

Low Case (4.6%):

$$ROI\ (\%) = \frac{24{,}637{,}693 - 15{,}000{,}000}{15{,}000{,}000} \times 100 = 64.25\%$$

High Case (6.5%):

$$ROI\ (\%) = \frac{34{,}814{,}132 - 15{,}000{,}000}{15{,}000{,}000} \times 100 = 132.09\%$$

The ROI ranges between approximately 64% and 132%, indicating that the proposed improvements generate substantial financial returns relative to the investment required.

A positive ROI significantly greater than zero confirms that the Lean-based water reduction measures are financially attractive and provide strong economic justification for implementation.

Net Present Value:

Net Present Value (NPV) is used to evaluate the long-term financial viability of the proposed Lean-based improvements by considering the time value of money.

Present Value Factor (5 years, 12%):

$$PVF = \frac{1 - (1 + 0.12)^5}{0.12} \approx 3.605$$

Low Case NPV:

$$NPV = (24{,}637{,}693 \times 3.605) - 15{,}000{,}000$$

$$NPV \approx 88{,}800{,}000 - 15{,}000{,}000 = 73{,}800{,}000\ MNT$$

High Case NPV:

$$NPV = (34{,}814{,}132 \times 3.605) - 15{,}000{,}000$$

$$NPV \approx 125{,}500{,}000 - 15{,}000{,}000 = 110{,}500{,}000\ MNT$$

The NPV values are strongly positive in both cases, ranging from approximately 73.8 million MNT to 110.5 million MNT. This indicates that the proposed Lean-based improvements generate substantial financial value over the project lifetime.

A positive NPV confirms that the project is financially viable and contributes net economic benefit to MBC Asia Pacific LLC.

4.9.1 Financial Analysis Summary

The financial analysis confirms that the proposed Lean-based improvements at MBC Asia Pacific LLC are both technically effective and economically feasible.

The total annual water-related cost was estimated at **535.6 million MNT**, forming the baseline for the evaluation. Based on the future state VSM analysis, a realistic reduction rate of **4.6%–6.5%** was applied, resulting in an annual water saving of approximately **4,800–6,800 m³**.

This reduction translates into projected annual cost savings of approximately **24.6–34.8 million MNT**, considering both water and energy-related costs. Given the relatively low implementation cost of **15 million MNT**, the financial indicators demonstrate strong performance.

The **Benefit-Cost Ratio (1.64–2.32)** confirms that the financial benefits exceed the investment. The **payback period (0.43–0.61 years)** indicates that the investment can be recovered within less than one year. Furthermore, the **Return on Investment (64%–132%)** and **positive Net Present Value (73.8–110.5 million MNT)** demonstrate substantial financial returns over the project lifetime.

Overall, the results indicate that the proposed improvements provide a **low-risk, high-return investment**, supporting their practical implementation and contributing to improved operational efficiency and cost performance.

4.10 Summary of Findings

The analysis identified that water consumption at MBC Asia Pacific LLC improved between 2023 and 2025, but the 2025 production water ratio of 3.72 hl/hl remains above the target of 3.30 hl/hl. Brewing accounts for approximately 73% of total production water consumption and is the primary source of inefficiency. The total reduction potential is estimated at 11%, with a realistic achievable reduction of 4.6%–6.5% within the scope of brewing and packaging improvements.

Chapter 5 Discussion

5.1 Introduction

This chapter interprets the findings of Chapter 4 in relation to the theoretical framework established in the literature review and the five research questions guiding this study. The discussion examines water consumption performance, waste identification, root cause analysis, proposed lean improvements, and financial feasibility, connecting empirical findings from MBC Asia Pacific LLC with existing knowledge in the lean manufacturing and brewery water management literature.

5.2 Water Consumption Findings

The water consumption analysis presented in Chapter 4 demonstrates that MBC Asia Pacific LLC achieved consistent improvement in water efficiency. Water consumption decreased from 117,893 m³ to 104,811 m³ between 2023 and 2025. At the same time, the water-to-beer ratio improved from 4.49 to 3.87 hl/hl. This improvement trajectory is consistent with findings reported by (6), who identified that breweries implementing systematic water management programs achieve annual water ratio improvements of 3 to 7 percent. MBC's observed improvement rate of approximately 6.5 percent annually places it at the upper end of this range.

Despite this progress, the 2025 production water ratio of 3.72 hl/hl remains 12.7 percent above the internal target of 3.30 hl/hl, a gap of 0.42 hl/hl equivalent to approximately 11,364 m³ of excess water consumption per year. This persistent gap is consistent with findings reported by (2), who identified that many brewery operations maintain consumption ratios significantly above best practice levels despite year-on-year improvement, attributing the persistence of this gap to structural operational inefficiencies that incremental improvement alone cannot resolve. The deceleration of MBC's improvement rate across three consecutive years further supports this conclusion and strengthens the case for a structured lean-based intervention.

The total water ratio of 3.87 hl/hl positions MBC within the world class range of below 4 hl/hl as identified by (1), a finding that reflects the operational influence of Heineken International's global water management framework. However, this headline performance masks significant process-level inefficiencies, a pattern identified by (8), who noted that aggregate performance indicators frequently conceal process-specific waste that requires targeted analysis to identify and address.

The monthly consumption analysis revealed that a substantial portion of MBC's water consumption is fixed in nature, independent of production volume. The December ratio

of 7.26 hl/hl, recorded during the lowest production month, demonstrates the disproportionate impact of fixed water use during low-volume periods. This finding has important implications for lean intervention design, as it confirms that water savings achieved through process standardization will be consistent across all production volumes rather than diminishing during lower-output periods.

5.3 Waste Identification

The eight wastes framework analysis identified overprocessing, waiting, and motion as the primary waste categories present in MBC's production system, consistent with the waste classification framework established by (11). The classification of brewing water over-consumption as overprocessing waste is particularly significant. In the lean manufacturing context, overprocessing refers to consuming more resources than the process standard requires (5). The brewing ratio of 2.72 hl/hl, consuming 0.62 hl/hl more than the internal target of 2.10 hl/hl, directly reflects this definition.

The concentration of waste in brewing operations, which account for 73 percent of total production water and 73% of total excess water consumption at 8,078 m³, is consistent with the broader lean manufacturing literature on waste distribution in process manufacturing. (8) Identified that excessive brewery water consumption is frequently attributable to operational practices rather than inherent process requirements, supporting the conclusion that reduction is achievable through standardization and process control rather than capital investment.

The identification of cleaning-related water consumption at 0.18 hl/hl, exceeding the UBM benchmark of 0.08 hl/hl by more than 100 percent, as a persistent source of overprocessing waste aligns with findings reported by (2), who identified CIP operations as one of the most significant sources of preventable water waste in brewery operations. The persistence of this over-consumption across all three reporting years at MBC confirms its structural nature.

Packaging water consumption of 0.60 hl/hl, while below the internal target of 0.70 hl/hl based on metered data, was identified as a secondary waste area through direct operational observation. Glass breakage flushing, can washer breakdown spillage, and pasteurizer stoppage discharge represent unmetered non-value-adding water losses that contribute to packaging's 1,782 m³ share of excess consumption. This finding underscores the importance of supplementing metered data analysis with qualitative operational observation, a methodological approach supported by (1), who highlighted

that certain forms of brewery water waste are not captured by standard metering systems.

5.4 Root Cause Analysis

The Fishbone Diagram and 5 Whys analyses identified three fundamental root causes of excessive water consumption at MBC Asia Pacific LLC, the absence of process-level water consumption standards, the lack of sub-process water monitoring, and the absence of formalized preventive maintenance and breakdown response procedures. These findings converge on a single systemic finding: water management at MBC is monitored at the facility level only, without the process-level standards, visibility, and accountability necessary to drive targeted reduction in priority waste areas.

The identification of absent process-level standards as the primary root cause is consistent with findings reported by (8), who found that excessive brewery water consumption is frequently attributable to a lack of operational targets and limited process-level awareness rather than technical factors. The 5 Whys analysis revealed that this absence is systemic, water consumption has not been established as a measurable process-level target with defined operator accountability, a conclusion consistent with (2), who identified the shortage of adequate monitoring systems as a key structural barrier to water efficiency improvement in brewery operations.

The identification of equipment breakdown frequency as a contributing root cause is consistent with the defect and waiting waste categories identified through the eight wastes analysis. The reactive approach to equipment maintenance observed at MBC reflects a pattern identified by (14), who found that food manufacturing operations frequently lack formalized preventive maintenance systems, resulting in recurring unplanned failures that generate both production losses and resource waste. This finding has direct implications for the lean improvement recommendations, as Standard Work procedures addressing equipment breakdown response could generate water savings beyond those achievable through process standardization alone.

5.5 Proposed Improvements

The three lean tools proposed in Chapter 4, Standard Work, Visual Management, and Kaizen, were selected based on their direct alignment with the identified root causes and their established effectiveness in food and beverage manufacturing environments. This selection is consistent with findings reported by (14) who identified Standard Work and Kaizen as among the most frequently and successfully applied lean tools in food

manufacturing, generating measurable improvements in process consistency and resource efficiency.

Standard Work addresses the primary root cause by establishing documented water usage procedures for each brewing sub-process, eliminating the operator-dependent variability identified as the fundamental source of brewing water over-consumption. (5) identifies Standard Work as a foundational lean tool for reducing process variability and establishing measurable operating standards. In the context of MBC's brewing operations, where 8,078 m³ of excess water is attributable to the absence of standardized water volumes, Standard Work represents the highest-priority and highest-impact intervention.

Visual Management addresses the secondary root cause by creating process-level consumption visibility at the production floor. (5) identifies Visual Management as a critical enabler of Standard Work compliance, providing real-time feedback that supports behavioral adherence to documented procedures. In the MBC context floor-level consumption displays would bridge the gap between facility-level monitoring and process-level accountability.

Kaizen provides the continuous improvement framework within which Standard Work and Visual Management are sustained over time (5) (14). Regular team reviews of consumption data ensure that improvements are embedded in operational culture rather than treated as isolated initiatives.

The future state analysis estimates an achievable water reduction of 4.6 to 6.5 percent of current production water consumption, corresponding to a reduction of approximately 4,800 to 6,800 m³ per year and a future ratio of 3.48 to 3.55 hl/hl. This estimate is deliberately conservative relative to the 20 to 50 percent reduction potential reported by (1) for brewery facilities implementing training and process reengineering, reflecting the partial scope of the study targeting brewing and packaging only. The conservatism of this estimate strengthens the credibility of the financial conclusions by ensuring that projected savings are grounded in MBC's specific operational data.

5.6 Financial Feasibility

The financial feasibility assessment confirms that lean implementation at MBC Asia Pacific LLC is economically justified across all evaluation metrics. The total annual water-related cost of 535,602,024 MNT establishes a substantial financial baseline that directly justifies investment in water reduction measures. The projected annual savings of 24.6 to 34.8 million MNT, based on a reduction rate of 4.6 to 6.5 percent, provide a credible

and conservative estimate of the financial benefit achievable through lean tool implementation within the study scope.

The Benefit-Cost Ratio of 1.64 to 2.32 confirms that the financial benefits of lean implementation exceed its costs under both scenarios, consistent with the cost-benefit evaluation framework established by (15), who identify a BCR greater than 1.0 as the threshold for financial viability. The conservative BCR of 1.64 demonstrates that even under the most cautious reduction assumptions lean implementation remains financially justified, providing a robust foundation for management decision-making.

The payback period of 0.43 to 0.61 years, equivalent to 5 to 7 months, is particularly noteworthy. This sub-one-year payback period reflects the low capital requirements of the proposed lean tools, Standard Work, Visual Management, and Kaizen, which primarily require staff time and minimal equipment investment rather than significant capital expenditure. This finding is consistent with (1) observation that significant water reductions in brewery operations are achievable without significant capital investment, a conclusion directly reflected in the implementation cost of 15 million MNT estimated in this study.

The ROI of 64 to 132 percent and five-year NPV of 73.8 to 110.5 million MNT under both scenarios provide strong evidence of long-term financial viability. The substantially positive NPV values confirm that the lean improvement program generates net financial value significantly exceeding its implementation cost over the project lifetime, making lean implementation not merely financially viable but financially compelling for MBC Asia Pacific LLC.

The discount rate of 12 percent applied in the NPV calculation reflects a conservative assumption for industrial improvement projects in the Mongolian context, ensuring that the positive NPV result is robust even under higher-than-average cost of capital assumptions.

5.7 Summary

The discussion confirms that water inefficiency at MBC Asia Pacific LLC is primarily structural, rather than operational variability. Despite consistent improvement, the performance gap remains due to process-level inefficiencies concentrated in brewing and packaging.

Waste identification and root cause analysis demonstrate that excessive water use is driven by inconsistent implementation of standards, limited process-level monitoring, and

process imbalance. These findings are consistent with existing lean manufacturing and brewery water management literature.

The proposed lean tools directly address these root causes and are supported by both theoretical and empirical evidence. The financial analysis further confirms that implementation is economically feasible, with strong returns and low investment risk.

Chapter 6 Conclusions and Recommendations

6.1 Conclusion

This study investigated the feasibility of applying lean manufacturing tools to reduce water waste and enhance cost efficiency at MBC Asia Pacific LLC, a large-scale brewing operation in Ulaanbaatar, Mongolia. The research addressed five research questions covering current water usage patterns, sources of non-value-adding water loss, suitable lean manufacturing approaches, achievable reduction levels, and financial feasibility.

The water consumption analysis established that MBC Asia Pacific LLC consumed 100,308 m³ of production water in 2025 at a ratio of 3.72 hl/hl, 12.7 percent above the internal target of 3.30 hl/hl, despite consistent improvement over three years. Brewing operations dominated consumption at 73 percent of total production water with a ratio of 2.72 hl/hl against a target of 2.10 hl/hl. Cleaning-related operations recorded a ratio of 0.18 hl/hl more than double the UBM benchmark of 0.08 hl/hl. Together these two areas account for the majority of the 11,364 m³ of total excess water consumption identified.

The current state Value Stream Map and waste identification analysis classified excessive brewing and cleaning water consumption as overprocessing waste the dominant lean waste category in the production system. Root cause analysis identified three fundamental causes: the absence of process-level water standards, lack of sub-process monitoring, and absence of formalized preventive maintenance procedures converging on the systemic finding that water management at MBC operates at facility level only without process-level standards or accountability.

Three lean tools were proposed Standard Work, Visual Management, and Kaizen, each directly addressing an identified root cause. The future state analysis projects an achievable water reduction of 4.6 to 6.5 percent corresponding to 4,800 to 6,800 m³ per year, improving the production ratio from 3.72 to 3.48 to 3.55 hl/hl.

The financial assessment confirms that lean implementation is economically feasible. Based on a total annual water cost of 535,602,024 MNT and a projected annual saving of 24.6 to 34.8 million MNT, the BCR of 1.64 to 2.32, payback period of 5 to 7 months, ROI of 64 to 132 percent, and five-year NPV of 73.8 to 110.5 million MNT collectively demonstrate that the proposed improvements represent a financially compelling low-risk investment for MBC Asia Pacific LLC.

In conclusion this study demonstrates that lean manufacturing implementation targeting brewing and packaging water waste at MBC Asia Pacific LLC is both technically justified and financially feasible. The persistent performance gap against targets across three

consecutive reporting years cannot be resolved through continued incremental improvement alone a structured intervention through Standard Work, Visual Management, and Kaizen is necessary and economically sound.

6.2 Recommendations

Based on the analysis conducted in this study, several targeted recommendations are proposed to improve water efficiency and operational performance at MBC Asia Pacific LLC. These recommendations are directly derived from the identified performance gaps, waste patterns, and root causes.

1. Establish Process-Level Water Consumption Standards

It is recommended that MBC develop and implement standardized water usage limits for each sub-process within the brewing stage, including mashing, lautering, and cleaning operations.

The analysis showed that brewing accounts for approximately 73% of total production water consumption and exhibits a performance gap of 0.62 hl/hl relative to the internal target. Root cause analysis identified the absence of clearly defined and enforced process-level standards as a primary driver of excessive water usage. Establishing measurable standards will reduce variability in operator practices and directly address overprocessing waste.

2. Implement Process-Level Monitoring and Control Systems

MBC should introduce monitoring systems that track water consumption at the process or sub-process level rather than relying solely on facility-level indicators.

The current monitoring system provides aggregate performance data but lacks real-time visibility into specific process stages. This limitation was identified as a key root cause of inefficiency, as it prevents timely identification and correction of excessive water use. Process-level monitoring will enable data-driven decision-making and improve operational control.

3. Strengthen SOP Implementation and Operational Compliance

Existing procedures related to water usage and cleaning should be standardized and consistently implemented across all shifts. This includes formal training programs, regular audits, and clear accountability mechanisms.

The findings indicate that inconsistencies in execution, rather than the absence of procedures, are a major source of inefficiency. Variability in operator practices contributes to excessive water consumption, particularly in brewing and cleaning

activities. Strengthening compliance will improve process stability and reduce non-value-adding water use.

4. Improve Preventive Maintenance Practices

It is recommended that MBC implement structured preventive maintenance programs for key equipment, particularly within packaging operations.

Observations identified equipment failures such as can washer malfunction, pasteurizer stoppages, and product spillage as contributors to water waste. These issues lead to additional cleaning and increased water consumption. Establishing preventive maintenance schedules and standardized response procedures will reduce defects and associated resource losses.

5. Implement Continuous Improvement through Kaizen

MBC should adopt a structured continuous improvement approach, such as Kaizen, to regularly review water consumption performance and identify further improvement opportunities.

The analysis demonstrates that water inefficiency is partly driven by process imbalance and operational practices that evolve over time. Continuous improvement mechanisms will ensure that implemented solutions are sustained and refined based on ongoing performance data.

6.3 Limitations and Future Research

This study has several limitations that should be acknowledged when interpreting the findings. These limitations also provide opportunities for future research.

1. Limited Availability of Process-Level Data

The analysis was based on available company data, which primarily consisted of aggregated water consumption figures. Detailed sub-process or real-time water consumption data were not available.

As a result, some inefficiencies were identified through indirect analysis and observation rather than direct measurement. While the findings are supported by consistent patterns in the data and literature, more detailed measurement would improve accuracy.

2. Absence of Primary Data Collection

The study did not include interviews or surveys with operators, engineers, or management personnel, as the company did not grant access for conducting primary data collection through these methods.

As a result, the root cause analysis was conducted using Value Stream Mapping, operational observations during the internship, and available quantitative data. While this approach is valid and widely applied in lean manufacturing studies, the absence of direct input from employees limits the depth of insight into behavioral and operational factors influencing water consumption.

Incorporating interviews or surveys in future research would provide additional validation of the identified root causes and enable a more comprehensive understanding of process-level practices.

3. Limited Scope of Improvement Analysis

The study focused primarily on brewing and packaging processes, as these were identified as the main contributors to water inefficiency.

However, the total reduction potential of approximately 11% indicates that additional inefficiencies exist in other process areas, such as cleaning and utilities. Therefore, the results represent a partial optimization rather than a full-system improvement.

Future Research Directions:

Future studies can build upon this research by addressing its limitations and expanding the scope of analysis.

- Conduct detailed process-level measurement using real-time monitoring systems to improve the accuracy of water consumption analysis.
- Incorporate qualitative methods such as interviews and surveys to validate root causes and understand behavioral factors influencing water use.
- Extend the analysis to include all process areas, enabling evaluation of the full reduction potential across the production system.
- Explore the relationship between water efficiency and other sustainability indicators, such as energy consumption and emissions, to support integrated resource management.

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Appendix

2025 Dataset: Monthly Water Consumption by Process Area							
month	unit	total water	production water	brewing	packaging	utility	cleaning
january	m^3	9,214.0	8,974.0	7,514.2	615.0	489.0	355.8
february	m^3	4,991.0	4,822.0	3,794.4	387.0	373.1	267.5
march	m^3	8,152.0	8,005.0	6,147.0	1,167.0	441.6	249.4
april	m^3	9,346.0	9,151.0	6,480.3	1,591.0	526.2	553.5
may	m^3	10,054.0	9,821.0	6,927.1	1,787.1	567.2	539.6
june	m^3	9,661.0	9,451.0	6,649.0	1,678.0	573.3	550.7
july	m^3	9,902.0	9,722.0	6,922.2	1,834.0	512.1	453.7
august	m^3	10,217.0	9,887.0	7,226.2	1,402.0	630.0	628.8
september	m^3	8,119.0	7,891.0	5,271.3	1,514.0	522.4	583.3
october	m^3	7,737.0	7,528.0	5,368.3	1,388.0	462.0	314.2
november	m^3	8,588.0	7,406.0	5,529.1	1,393.0	389.0	94.9
december	m^3	8,830.0	7,650.0	5,652.1	1,455.0	391.1	151.8
YTD	m^3	104,811.0	100,308.0	73,481.2	16,211.1	5,877.0	4,743.2

FIGURE 9 2025 DATA SET MONTHLY WATER CONSUMPTION BY PROCESS AREA M^3

2024 Dataset: Monthly Water Consumption by Process Area							
month	unit	total water	production water	brewing	packaging	utility	cleaning
january	m^3	10,460.0	10,038.0	8,442.2	646.0	565.0	386.0
february	m^3	5,694.0	4,953.0	3,861.3	406.0	386.7	300.0
march	m^3	9,113.0	8,748.0	6,775.3	1,218.0	498.9	256.0
april	m^3	9,998.0	9,605.0	6,682.0	1,727.0	576.2	618.0
may	m^3	11,123.0	10,715.0	7,482.0	1,987.1	629.1	618.0
june	m^3	10,113.0	9,893.0	6,881.0	1,786.0	624.4	601.0
july	m^3	10,790.0	10,595.0	7,499.4	2,049.0	556.3	492.0
august	m^3	11,364.0	10,995.0	8,142.0	1,473.0	717.2	663.0
september	m^3	8,766.0	8,519.0	5,790.0	1,589.0	539.0	600.0
october	m^3	8,513.0	8,279.0	5,912.1	1,509.4	513.0	345.0
november	m^3	9,094.0	7,663.0	5,666.0	1,478.0	413.1	106.0
december	m^3	9,213.0	8,003.0	5,962.1	1,468.0	420.0	153.0
YTD	m^3	114,241.0	108,006.0	79,095.4	17,336.5	6,438.9	5,138.0

FIGURE 10 2024 DATA SET MONTHLY WATER CONSUMPTION BY PROCESS AREA

2023 Dataset: Monthly Water Consumption by Process Area							
month	unit	total water	production water	brewing	packaging	utility	cleaning
january	m^3	10,199.0	9,700.0	8,095.0	665.0	532.0	407.0
february	m^3	6,607.0	5,780.0	4,593.8	440.1	439.8	306.0
march	m^3	9,238.0	8,846.0	6,834.2	1,246.0	472.1	294.0
april	m^3	10,468.0	10,057.0	7,211.4	1,649.0	564.3	632.0
may	m^3	11,102.0	10,641.0	7,433.3	1,944.0	643.6	619.0
june	m^3	10,818.0	10,572.0	7,527.5	1,764.0	615.0	665.0
july	m^3	10,783.0	10,592.0	7,518.1	1,983.0	585.0	506.0
august	m^3	11,738.0	11,330.0	8,418.2	1,491.0	705.3	715.0
september	m^3	8,951.0	8,688.0	5,851.3	1,598.0	596.2	644.0
october	m^3	8,230.0	7,985.0	5,660.1	1,468.2	485.4	372.0
november	m^3	10,015.0	8,611.0	6,520.0	1,534.0	441.1	115.0
december	m^3	9,744.0	8,340.0	6,187.3	1,565.0	413.4	176.0
YTD	m^3	117,893.0	111,142.0	81,850.2	17,347.3	6,493.2	5,451.0

FIGURE 11 2023 DATA SET MONTHLY WATER CONSUMPTION BY PROCESS AREA

2025 Data set: Monthly Water Consumption by Process Area (hl/hl)							
month	unit	total water	production water	brewing	packaging	utility	Cleaning
january	hl/hl	3.40	3.31	2.77	0.23	0.18	0.13
february	hl/hl	4.95	4.78	3.76	0.38	0.37	0.27
march	hl/hl	3.80	3.73	2.87	0.54	0.21	0.12
april	hl/hl	3.62	3.54	2.51	0.62	0.20	0.21
may	hl/hl	3.55	3.47	2.45	0.63	0.20	0.19
june	hl/hl	3.74	3.66	2.58	0.65	0.22	0.21
july	hl/hl	3.37	3.31	2.36	0.62	0.17	0.15
august	hl/hl	3.47	3.36	2.46	0.48	0.21	0.21
september	hl/hl	4.10	3.98	2.66	0.76	0.26	0.29
october	hl/hl	3.80	3.70	2.64	0.68	0.23	0.15
november	hl/hl	4.11	3.55	2.65	0.67	0.19	0.05
december	hl/hl	7.26	6.29	4.64	1.20	0.32	0.12
YTD	hl/hl	3.87	3.71	2.72	0.60	0.22	0.18

Figure 12 2025 Data set Monthly water consumption by process area hl

2024 Data set: Monthly Water Consumption by Process Area (hl/hl)							
month	unit	total water	production water	brewing	packaging	utility	Cleaning
january	hl/hl	3.74	3.59	3.02	0.23	0.20	0.14
february	hl/hl	5.76	5.01	3.91	0.41	0.39	0.30
march	hl/hl	4.17	4.00	3.10	0.56	0.23	0.12
april	hl/hl	3.83	3.68	2.56	0.66	0.22	0.24
may	hl/hl	3.82	3.68	2.57	0.68	0.22	0.21
june	hl/hl	3.92	3.83	2.67	0.69	0.24	0.23
july	hl/hl	3.53	3.47	2.46	0.67	0.18	0.16
august	hl/hl	3.79	3.67	2.71	0.49	0.24	0.22
september	hl/hl	4.47	4.34	2.95	0.81	0.28	0.31
october	hl/hl	4.15	4.03	2.88	0.74	0.25	0.17
november	hl/hl	4.36	3.67	2.72	0.71	0.20	0.05
december	hl/hl	7.65	6.65	4.95	1.22	0.35	0.13
YTD	hl/hl	4.16	3.94	2.88	0.63	0.24	0.19

FIGURE 13 2024 DATA SET MONTHLY WATER CONSUMPTION BY PROCESS AREA HL

2023 Data set: Monthly Water Consumption by Process Area (hl/hl)							
month	unit	total water	production water	brewing	packaging	utility	Cleaning
january	hl/hl	3.99	3.79	3.16	0.26	0.21	0.16
february	hl/hl	6.41	5.61	4.46	0.43	0.43	0.30
march	hl/hl	4.52	4.33	3.35	0.61	0.23	0.14
april	hl/hl	4.21	4.04	2.90	0.66	0.23	0.25
may	hl/hl	4.00	3.83	2.68	0.70	0.23	0.22
june	hl/hl	4.31	4.22	3.00	0.70	0.25	0.27
july	hl/hl	3.86	3.79	2.69	0.71	0.21	0.18
august	hl/hl	4.02	3.88	2.89	0.51	0.24	0.25
september	hl/hl	4.60	4.47	3.01	0.82	0.31	0.33
october	hl/hl	4.21	4.08	2.89	0.75	0.25	0.19
november	hl/hl	4.79	4.12	3.12	0.73	0.21	0.06
december	hl/hl	8.49	7.27	5.39	1.36	0.36	0.15
YTD	hl/hl	4.49	4.23	3.12	0.66	0.25	0.21

FIGURE 13 2023 DATA SET MONTHLY WATER CONSUMPTION BY PROCESS AREA HL

Production Volume across three-year period						
	Production Volume (hl)			Production Volume (m^3)		
Month	Year 2023	Year 2024	Year 2025	Year 2023	Year 2024	Year 2025
January	25593	27952	27138	2559.3	2795.2	2713.8
February	10301	9884	10091	1030.1	988.4	1009.1
March	20430	21869	21442	2043	2186.9	2144.2
April	24870	26092	25838	2487	2609.2	2583.8
May	27775	29134	28284	2777.5	2913.4	2828.4
June	25093	25802	25809	2509.3	2580.2	2580.9
July	27970	30533	29353	2797	3053.3	2935.3
August	29170	30000	29414	2917	3000	2941.4
September	19463	19615	19821	1946.3	1961.5	1982.1
October	19572	20534	20334	1957.2	2053.4	2033.4
November	20904	20868	20874	2090.4	2086.8	2087.4
December	11478	12044	12170	1147.8	1204.4	1217
YTD	262619	274327	270568	26261.9	27432.7	27056.8

FIGURE 14 PRODUCTION VOLUME ACROSS 2023-2025