INDUSTRY PRIMER

DAIRY PROCESSING

CORRECT MANAGEMENT OF WASTEWATER IN THE AGRIBUSINESS SECTOR FOR IDB INVEST

Futuris SUSTAINABILITY ADVISORS

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Title & Reference	**Good Practice Note Wastewater Management for the Agribusiness Sector**	**Draft version V02**
For Client	João Paulo Diniz Abud, IDB Invest Natazha Valarezo, IDB Invest Paula Valencia, IDB Invest	jdinizabud@iadb.org PaulaVa@iadb.org natazhav@iadb.org
Prepared by	Mauricio Morera, Wastewater Expert Mónica Salas, Wastewater Expert	ma.morera@gmail.com msalas@auroraingenieria.com
Reviewed by	Natalia Benavides, Senior Consultant, Futuris Emma Tristán, General Director, Futuris	natalia@futurisconsulting.com emma@futurisconsulting.com
Futuris' Contact	Futuris Consulting S.A Tres Ríos, Cartago, Costa Rica	@ http://www.futurisconsulting.com +506 2279-3501

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Acronyms

BMP	Best Management Practices
BOD	Biochemical Oxygen Demand
BWMP	Best Wastewater Management Practices
CIP	Clean-In-Place
COD	Chemical Oxygen Demand
DAF	Dissolved Air Flotation
DO	Dissolved Oxygen
EC	Electrocoagulation
EP	Emerging Pollutants
FOG	Fats, Oils, and Greases
GPN	Good Practice Note
IDB	Inter-American Development Bank
ISO	International Organization for Standardization
KPIs	Key Performance Indicators
LAC	Latin America and the Caribbean
MET	Microbial Electrochemical Technology
MPN	Most Probable Number
UASB	Up flow Anaerobic Sludge Blanket
TDS	Total Dissolved Solids
UV	Ultraviolet
WBG	World Bank Group
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

1 Introduction

1.1 THIS INDUSTRY PRIMER AND THE GOOD PRACTICE NOTE

This industry primer has been prepared to complement the GPN for Wastewater Management for the Agribusiness Sector[1]. A reference to the GPN has been made in the following sections to reduce duplication whenever the information in the GPN complements what is presented in this industry primer.

It provides a comprehensive overview of BWMP for managing the environmental impacts of dairy processing wastewater, helping LAC companies to minimize environmental impact, ensure compliance with relevant regulations, promote sustainable practices that protect public health, and reduce operational costs. Section 2 describes the sector's characteristics, and Section 3 the BWMP, including pollution prevention BWMPs (Section 3.1) and wastewater treatment BWMPs (Section 3.2). Information regarding key performance indicators (KPIs) is linked to the specific regulatory frameworks of each country, and this information can be located in Section 2 and Annex I of the GPN. For further exploration of pollution prevention examples and BWMP in wastewater treatment, please refer to Section 4 and Section 5 of the GPN, respectively. More detailed monitoring information can be found in Section 6 of the GPN.

1.2 SOURCES OF INFORMATION

This industry primer on dairy processing wastewater has been developed using various sources of information. Primarily, it is built upon the foundation of the World Bank Pollution Prevention and Abatement Handbook (1998), which forms the underlying framework for the more specialized industry guidelines known as the Environmental, Health, and Safety Guidelines for Dairy Processing, published by the World Bank Group in 2007. A comprehensive compilation of references is available in Section 4. Moreover, insights from client-based interviews of IDB Invest have been incorporated.

2 Sector Characteristics and *Wastewater Production*

2.1 GENERAL OVERVIEW OF THE SECTOR

Dairy facilities process raw milk into consumer milk, butter, cheese, yogurt, condensed milk, dried milk (milk powder), and ice cream using chilling, pasteurization, and homogenization. Typical by-products include buttermilk, whey, and their derivatives. The effluents are generated from milk processing through milk spillage, drippings, discarded whey, and the wash water used for cleaning vats, equipment, floors, tanks, utensils, and bottles. The processing of milk generates wastes that are often discharged intermittently, and the nature and composition of wastes depend on the types of products produced and the size of the plants. Usually, wastewater contains various pollutants, including organic and inorganic matter, oils and greases, nutrients, and pathogens.

The LAC dairy market is experiencing significant growth, primarily driven by expanding distribution channels for dairy products. New markets, like supermarkets and hypermarkets in the region, support this expansion. Brazil, Argentina, and Colombia are among the leading countries in the region; these countries have demonstrated their prowess in milk production and continue to play a pivotal role in driving the industry forward. Milk production is anticipated to expand in Argentina, Colombia, Chile, and Uruguay[2], indicating a rise in the export of dairy products and serving as a key trend that guides the overall growth of the LAC dairy industry.

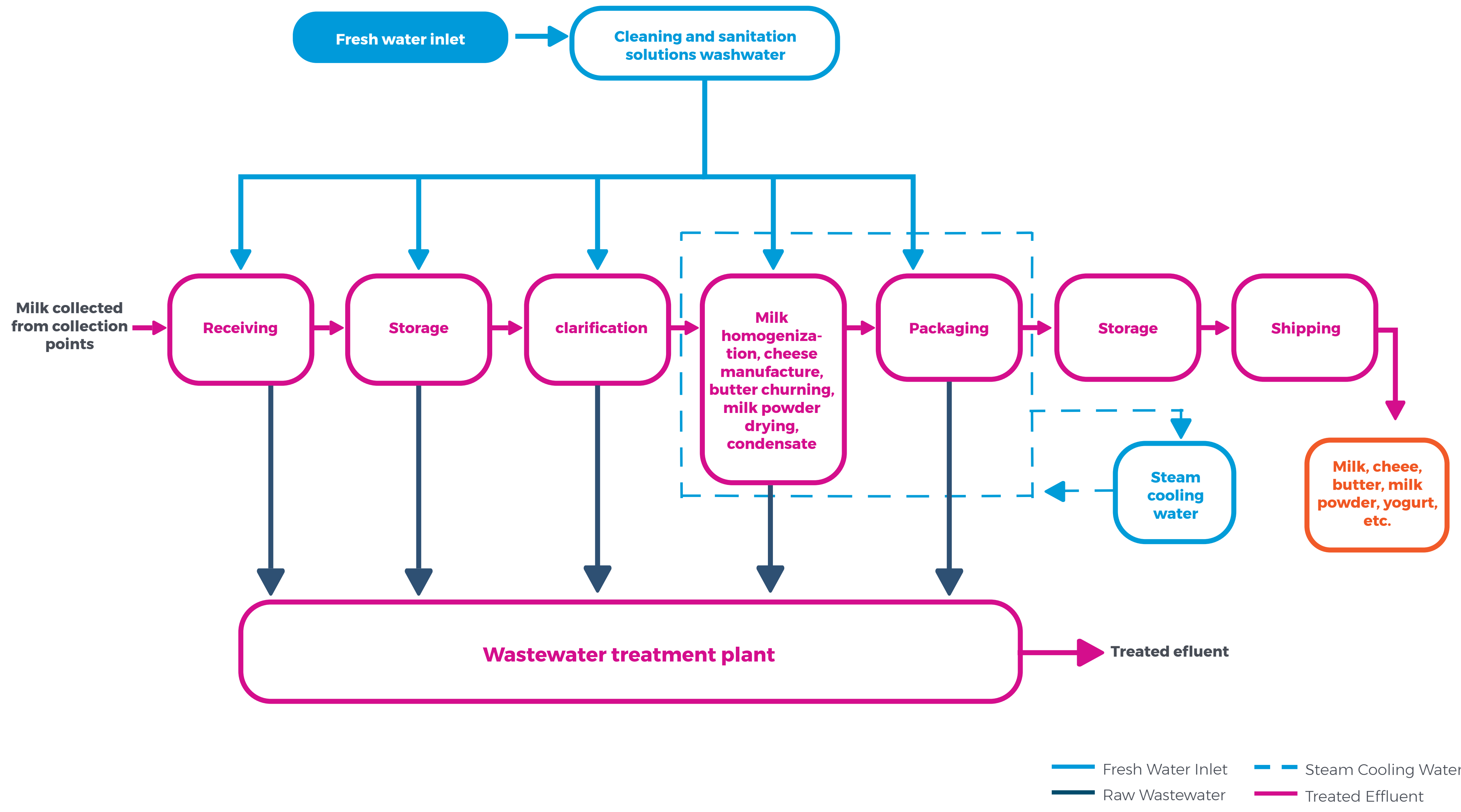
2.2 WATER USE WITHIN THE INDUSTRIAL PROCESS

Consumption of water in the general dairy industry is illustrated in Figure 1. Water is used at every step of the processing lines, including cleaning and sanitation, heating, and cooling, and it is also present in multiple milk products. **Most dairy plants consume from 1 to 10 m3. of water per every cubic meter of milk processed**; values depend on the country and the dairy derivates produced. **While milk powder is the lowest water consumer, with discounts, as little as 1.5-1.7 L_{water}/L_{milk}, ice cream production is the greater consumer, with values of 6.5-10.3 $L_{water}/kg_{product}$[3].**

Water used in milk products should meet the requirements of at least drinking water quality[4], so water must meet or exceed applicable national acceptability standards or, in their absence, the current edition of WHO Guidelines for Drinking-Water Quality. Depending on the source and quality of water and the technical requirements of use, this water must be further adjusted to suit regulated parameters, such as removal of color, softening, or the addition of chlorine to minimize the count of potential spoilage microorganisms or the use of UV radiation to disinfect stored water directly before use as an ingredient [5].

Understanding the water consumption patterns within dairy processing is critical for promoting sustainable wastewater management practices while ensuring compliance with relevant regulations. As further described in Section 2.2., the efficiency and intricacy of clean-in-place (CIP) systems play a crucial role in minimizing water usage in dairy processing.

FIGURE 1 Flowchart for consumption of water in a general dairy industry



2.3 GENERAL REVIEW OF WASTEWATER GENERATION

2.3.1 PRIMARY POLLUTANTS AND THEIR SOURCES

It has been estimated that the amount of wastewater is approximately 1.5 - 2.5 times higher than that of processed milk in volume units. Still, the amount and characteristics of the wastewater depend largely on the facility size, applied technology, effectiveness, and complexity of CIP methods and BMP. dairy processing contains elevated levels of COD, BOD, inorganic and organic particles like carbohydrates, proteins, and grease or oil, and nutrients like Total Nitrogen (N), Total Phosphorous (P), and Potassium (K)[6]. The wastewater may also contain a microbiological load, pathogenic viruses, and bacteria.

Dairy effluents are also the basis for numerous emerging pollutants (EP), especially estrogenic compounds containing hormones that end up in the environment with industrial discharges[7]. More detailed information about wastewater quality is described in Section 1.4.

Sources of these pollutants come from milk or milk products lost in the technological cycles, for example, spilled milk, spoiled milk, skimmed milk, and curd pieces; starter cultures used in manufacturing milk products, by-products of processing operations (whey, milk, and whey permeate); chemical reagents applied in CIP procedures and sanitary needs. TAmong these pollutants, whey is the primary one due to its elevated organic content[8]. Other pollutants may come from additives added during manufacturing, such as the salting process in cheese production, which can lead to elevated salinity levels in wastewater.

Settleable solids in dairy wastewaters may clog sewage pipes, so preventing flushing down the drain is vital. These them solids are usually of protein origin, namely particles of solid milk processing (such as pieces of cheese, coagulated milk, cheese, curd fines, milk film or flavoring agents) and other impurities (soil, sand) that get into the sewage system during equipment washing or packaging[8].

2.3.2 MAIN ENVIRONMENTAL IMPACTS

An untreated effluent from dairy processing strongly impacts the environment. A direct discharge to water bodies implies large volumes of wastewater with high organic and nutrient loading and extreme pH variations. The untreated effluent would lead to pollution problems, including rapidly DO depletion that results in anaerobic conditions and the release of volatile toxic substances such as acetic acid ($C_2H_4O_2$) and propionic acid ($C_3H_6O_2$), as well as gases like methane (CH_4) and hydrogen sulfide (H_2S)[8].

Discharges of organic matter cause the growth of algae and bacteria that can consume oxygen from water bodies potentially, leading to fish's gradual disappearance. Bacteria and other pathogens present in dairy wastewater have the potential to spread diseases that can be harmful. Milk waste contains significant quantities of soluble organics and suspended solids that may release gases, spread odors, and impart turbidity and color to the discharged effluents[7].

2.4 DESCRIPTION OF RAW WASTEWATER QUALITY

Due to the requirement for separate processing lines for each milk product, the composition of dairy raw wastewater can vary significantly, resulting in complex and diverse constituents. Numerous factors influence the pollutant concentration and composition of the raw wastewater, namely, the product type, the production program, the operating procedures, the design of the processing plant and the level of water management being employed, and consequently, the amount of water being conserved. Typical ranges of quality parameters are reported for wastewater in the dairy industry, as seen in Table 1.

TABLE 1 Ranges of quality parameters for dairy processing raw wastewater[9].

Parameters	Cheese processing factories	Milk/milk powder processing factories	Whey processing factories
COD (mg/L)	5,000-60,000	2,000-6,000	68,800
BOD (mg/L)	2,300-30,000	1,200-4,000	35,000
TSS (mg/L)	2,000-12,000	350-1,000	1,300
Total N (mg/L)	100-170	100-170	1,400
Total P (mg/L)	40-100	50-60	370-640
pH	3.5-5.5	8-11	4.6
FOGs (mg/L)	0.5-2.3	3-5	0.8

3 Best Wastewater *Management Practices*

3.1 POLLUTION PREVENTION BWMP

Increasing the use of technologies such as water recirculation and pollution prevention management techniques to achieve sustainability is essential. Staying updated on technological advancements and scientific research is important to attain this goal. To effectively manage wastewater, the dairy processing industry implement pollution prevention BWMPs, to prevent pollutants from entering a treatment plant; further pollution prevention information is described in Section 4 of the GPN. Examples in Table 2 should encourage pollution prevention at the source in a dairy processing facility.

TABLE 2 Management techniques for wastewater pollution prevention in dairy processing

Management Techniques for Pollution Prevention	Description of controls
Water re-usage does not directly interact with derived products, including hot water, steam production, cleaning activities and membrane cleaning[8].	• Monitor, at least quarterly, water quality parameters such as pH, conductivity, TDS, and microbial counts to ensure the water is safe for reuse. Ensure that it always complies with national regulations for reuse. • Where suspended solids can cause scaling and corrosion of equipment, use filtration, sedimentation, or chemical treatment before reusing hot water or for steam production. • Incorporate the reuse of water into the overall process controls of the dairy processing plant. • Store and distribute reused water separately from other water sources.
Prevent milk leakage in pipelines and product spillage (World Bank, 1999).	• Provide maintenance of fittings, valves, and seals at least once every six months. • Equip fillers with drip and spill savers. • Use proper seals on pumps and line connections.
Prevent flushing down the drain of solid materials (such as particles of solid milk and other impurities described in Section 4.3. of the GPN)[10].	• Provide bins or other receptacles for solid waste disposal and ensure employees understand what materials should be collected and treated as solid waste. • Install equipment such as screens, filters, and traps in the processing plant. • Implement daily maintenance and cleaning of this equipment to prevent solid materials from entering the drainage system. • Inspect daily to ensure that solid waste is not entering the wastewater treatment plant (WWTP).
Reduce pollution levels in the influent of wastewater treatment[9].	• Allow adequate time to drain pipes, tanks, and transport tankers before rinsing with water. • Use approved chemicals or detergents with less hazardous substances for cleaning and washing. • Periodic cleaning with appropriate chemical or bacterial preparations to avoid formation of protein and fat deposits on the inside of the pipes; using bacteria has an advantage, as they continue acting in the next stages of wastewater treatment.

3.2 WASTEWATER TREATMENT BWMP

In dairy processing, water treatment usually include preliminary treatment, primary or physical-chemical treatment, secondary treatment, and methods for managing sludge. Other emerging technologies for treating dairy wastewater include electrochemical advanced oxidation and membrane technologies. Also, there are emerging technologies for treating dairy wastewater, such as electrochemical advanced oxidation processes, and membrane technologies. Examples of technologies are listed in Table 3.

PRELIMINARY TREATMENT

Involves the removing coarse solids, oils, and fats from the wastewater and the equalizing volumetric and mass flow changes. It helps reduce part of the concentration of suspended solids. Common pre-treatment technologies include clarifiers, screens, sedimentation tanks, and dissolved air flotation (DAF). Also, grease traps, skimmers, or oil water separators can separate floatable solids.

SECONDARY TREATMENT

Due to their reliability and capacity to effectively degrade highly biodegradable pollutants, anaerobic and aerobic reactors are preferred. This treatment involves using microorganisms to remove organic matter, nutrients, and pathogens from the wastewater. Common biological treatment technologies include activated sludge, trickling filters, and lagoons.

It is essential to consider that fatty acids from milk fat in wastewater may cause an inhibitory action during anaerobic treatment mainly due to decreased pH. Aerobic processes are highly-energy intensive and should be combined with anaerobic processes to achieve discharge standards. Up flow anaerobic sludge blanket reactor (UASB) is a typical and suitable configuration due to its ability to treat large volumes relatively quickly. Also, anaerobic filters are commonly applied in the anaerobic stage[11]. Sequencing batch reactors (SBR) and moving bed biofilm reactor (MBBR) are standard in aerobic treatment because of their various loading capabilities and effluent flexibility[8]. One phase of the anaerobic digestion process involves the degradation of organic matter by microorganisms without oxygen. It leads to biogas, a mixture of carbon dioxide (CO_2) and methane (CH_4), and biomass formation, a valuable and renewable energy source used for heating and producing electrical energy.

PRIMARY TREATMENT OR PHYSICAL AND CHEMICAL TREATMENTS

Primary treatments remove suspended solids, nutrients, and pathogens that biological treatment may not effectively remove. Common physical and chemical treatment technologies include coagulation, flocculation, sedimentation, and disinfection. These treatments effectively remove emulsified compounds by reducing milk fat and protein colloids; however, reagent addition increases water treatment costs. DAF is an effective treatment method because it reduces organic loading via protein and fat colloid destabilization with coagulants and flocculants. Still, this method implies using expensive and synthetic chemicals that can result in environmental issues such as releasing harmful chemicals into the environment, pollution of water bodies, and potential harm to aquatic life[8].

SLUDGE MANAGEMENT

Large quantities of dairy processing sludge are produced during primary, and secondary treatment. Several potentially harmful compounds, like antibiotics, heavy metals, pesticides, or microplastics, may enter the milk processing chain through various routes and accumulate in the sludge. The sludge needs to be evaluated on a case-by-case basis to establish whether it constitutes hazardous waste that should be disposed of in compliance with local regulatory requirements or non-hazardous waste that can be used as a fertilizer in land applications [12]. Common sludge management technologies include dewatering and anaerobic digestion, which can also produce biogas.

TABLE 3 Common treatment technologies used for treating dairy wastewater

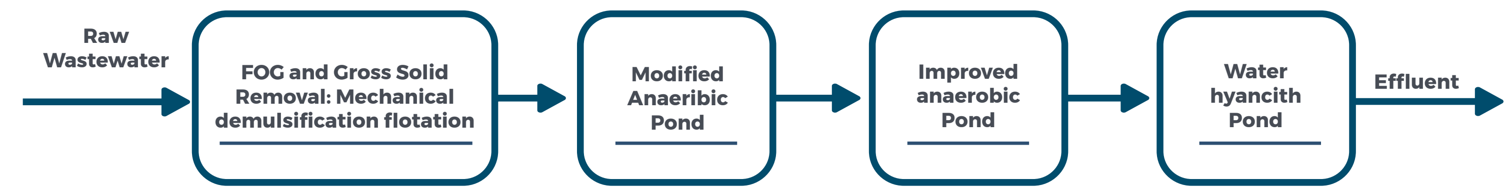
Industry	Preliminary treatment	Primary treatment	Secondary Treatment	Tertiary Treatment	Sludge treatment	Emerging technologies
Dairy processing	Flow equalization, screens, mechanical filters, grease traps, skimmers, or oil water separators.	Coagulation and Flocculation, DAF, and pH regulation (if needed).	Aerobic/Anaerobic biological treatments include aerobic/anaerobic lined ponds, aerobic reactors, anaerobic filters, UASB, SBR and biofilters.	Chlorine, ozone, UV (if pathogens are present).	Sludge produced in primary and secondary treatment should be dewatered before disposal using sludge drying beds, centrifuges, or decanters. It is encouraged to dry the sludge further to produce biosolids that can be repurposed.	Microbial electrochemical technologies (METs)[7] Electrocoagulation (EC) and electrochemical advanced oxidation process[13] Membrane technologies include microfiltration, nanofiltration, ultrafiltration, reverse osmosis, and electrodialysis 7.

3.3 EXAMPLE OF WASTEWATER TREATMENT BWMP

An example of an existing WWTP in a Mexican cheese manufacturing industry is presented by Hung & Britz (2006).

The WWTP was operating above the discharge thresholds, prompting the need for an upgrade. The factory sought a treatment system that would be more effective, utilize pre-existing installations to reduce initial investment costs, and have low operational costs. The factory produced an average wastewater flow of 500 m^3/day, with an average composition (mg/L) of 4,430 COD, 3,000 BOD, 1,110 TSS, and 754 Fat, Oil, and Grease (FOG). The final process after the upgrade is described in ***Figure 2***. The modified wastewater treatment process resulted in an overall removal efficiency of 98% BOD, 96% COD, 98% TSS, and 99.8% FOG.

FIGURE 2 Flow diagram of the final process in a Mexican cheese plant[9].



Source: Own ellaboration based on Hung & Britz (2006).

3.4 KEY PERFORMANCE INDICATORS AND MONITORING

Each country has specific rules for managing and reusing wastewater, with regulations setting allowable water quality thresholds for different situations, such as the discharge into water bodies, coastal zones, and sanitary sewer systems, as well as the reuse of treated wastewater. The GPN in Section 2.2. includes a comparison of the quality parameters established in different countries. Table A-1 in Annex I provides a comprehensive overview of the legislative framework for wastewater management in the LAC region.

The World Bank Group (WBG) EHS Guidelines for Dairy Processing establish the maximum allowable discharge limits in water bodies for the parameters listed below in Table 4[14]. These must be achievable under normal operating conditions in appropriately designed and operated facilities and can be used as KPI of wastewater treatment. New projects must comply with WBG's EHS Guidelines, or national regulations (Annex I of the GPN), whichever is more stringent.

TABLE 4 Permissible limits for discharges into water bodies[15]

Pollutant	Guideline Value
pH	6-9
BOD_5	50 mg/L
COD	250 mg/L
Total N	10 mg/L
Total P	2 mg/L
Oil and Grease	10 mg/L
TSS	50 mg/L
Temperature increase	< 3 °C
Total coliform bacteria	400 MPN/100 mL

To prevent environmental and social impacts, monitoring effluent quality regularly and providing appropriate feedback mechanisms is crucial. More information is provided in Section 6 of the GPN for correctly managing of wastewater in the agribusiness sector. It is essential to develop and implement a program with sufficient resources and management oversight to achieve a monitoring program's objective(s) for wastewater and water quality. Table 9 of the GPN describes the sampling points and analytical requirements for process water and wastewater samples, and recommends a sampling frequency. Local regulations and other requirements for monitoring wastewater and water quality should always be the top priority and supersede any general guidelines or recommendations. While the suggested sampling frequency may be a good starting point, it is essential to understand and comply with the local regulations and requirements set forth by regulatory agencies.

In the case of dairy wastewater, monitoring parameters such as pH, DO concentration, turbidity, temperature, and water flow of the treated effluent should be conducted at a frequency that can provide representative data (for more information, check Section 6.5. of the GPN). The recorded information should include the date, time, measurement results, adjustments made, and other relevant data. It is necessary to use calibrated equipment and ensure trained operators conduct the measurements. A laboratory space at the treatment plant is also required for this task. Record-keeping procedures should be in place to document the monitoring results. External certified laboratories (preferably ISO 17025) shall provide monitoring records for microbial and physicochemical analysis, and frequency will depend on the regulatory frameworks of each region. The recommendation is to do it at least quarterly.

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