Fall 2021

Taking the Waste out of Wastewater: Evaluation and Implementation of Sustainability Measures at Base Aérea N.°5's Wastewater Treatment Plant

Abigail Monahan
SIT Study Abroad

Taking the Waste out of Wastewater:

Evaluation and Implementation of Sustainability Measures at Base Aérea N.°5's Wastewater Treatment Plant

Abigail Monahan

School for International Training

Portugal: Sustainability and Environmental Justice

Fall 2021

Table of Contents

Figures and Tables

Abstract

Wastewater treatment is a critical process by which the concentration of pollutants in wastewater are reduced to minimize the resulting effluent's impact on human health and the environment. Base Aérea N.°5, an airbase located in Monte Real, Portugal, is striving to enhance their wastewater treatment methods to decrease the impact of the treated effluent on the environment. They can reduce the effluent's impact by implementing more advanced wastewater treatment to decrease the concentration of micropollutants and pathogens in the effluent, and they can reuse the treated effluent to decrease the volume of freshwater they extract. This work seeks to evaluate the current wastewater treatment methods used at Base Aérea N.°5 and determine how advanced wastewater treatment and water reuse can be implemented. An evaluation of current wastewater treatment methods revealed that the overall effectiveness of nutrient removal is low due to the oversized nature of the treatment plant, the treatment plant's age, and the composition of the wastewater. Chlorination is the most financially feasible tertiary treatment method that would allow the effluent to be reused for several non-potable purposes. The ability to reuse treated wastewater would decrease the annual total cost of water extraction, offsetting the cost of implementing chlorination.

1. Introduction

Adequate wastewater treatment is imperative to sustainable human-environment interactions. Inadequate wastewater treatment can result in perturbations to the natural environment that have significant ecological consequences, as well as deplete freshwater resources critical to human life (Daims et al., 2006). Thus, wastewater treatment is imperative to eliminate pollutants, control nutrient levels, and diminish bacteria levels that could adversely affect the environment or human health (Emerging Technologies in Wastewater Treatment, n.d.; *Water Quality and Wastewater*, 2017). Treated wastewater is a valuable resource for protecting ecosystems, decreasing freshwater depletion, and can be reused for potable and non-potable purposes.

In Portugal, the vast majority of wastewater is treated (*Water: Urban Wastewater*, 2021). Typically, treatment takes place in a wastewater treatment plant (WWTP), and the degree of treatment is dependent on the type of raw influent, physical and financial resources of those treating the water, and local and national regulations (Emerging Technologies in Wastewater Treatment, n.d.). Primary treatment employs screens, grit chambers, and sedimentation tanks to physically remove almost two-thirds of total suspended solids (TSS) and decrease biological oxygen demand (BOD, used interchangeably with CBO_5) of the raw influent by one third (Emerging Technologies in Wastewater Treatment, n.d.). Secondary treatment removes more than 85% of TSS and BOD by using bacteria and aeration to decompose organic matter into non-toxic by-products (Emerging Technologies in Wastewater Treatment, n.d.). Tertiary treatment is a complex process that removes up to 99% of TSS, organic materials, nitrogen, phosphorous, metals, and pathogens (Gerba & Pepper, 2019; Emerging Technologies in Wastewater Treatment, n.d.). There are several forms of tertiary treatment such as ozonation, UV radiation, chlorination, and reverse osmosis (Mudge & Ball, 1964; Emerging Technologies in Wastewater Treatment, n.d.). Currently, the majority of wastewater generated in Portugal undergoes secondary treatment (76%), followed by tertiary treatment (15%), and primary treatment (7%), leaving less than 1% of wastewater untreated (*Water: Urban Wastewater*, 2021).

Wastewater treatment in Portugal is regulated by Directive 91/271/EEC and transposed into Portuguese legislation by Decree-Law 348/98 (*Water: Urban Wastewater*, 2021). This legislation details total nitrogen and phosphorus levels for effluent discharged by urban WWTPs (Decreto-Lei n.° 348/98, 1998). It stipulates that tertiary treatment should be used when necessitated by the receiving environment or water resources (*Water: Urban Wastewater*, 2021). Furthermore, given the ongoing water-scarcity crisis in Europe, which is being felt even more urgently in southern Europe, there are several national and regional water management plans in place; they include the National Water Plan (PNA), the National Program for the Efficient Use of Water (UNEP), the Strategic Plan for Water Supply and Water Sanitation (PENSAAR), and the Operational Program for the Sustainability and Efficiency in the Use of Resources (PO SEUR) (Rocha, 2020). These policies aim to minimize the risk of water scarcity by promoting efficient water use and reuse in industrial and urban sectors (Rocha, 2020).

Base Aérea N.°5's onsite WWTP is a relevant example of a Portuguese WWTP striving to become more sustainable. The base has a history of working to improve their environmental performance. On November 15, 2008, the Quality and Environment Office was created following the Air Force General's implementation of environmental policy in 2007 (Delgado, F., 2021). Base Aérea N.°5's commitment to sustainability is further evidenced by their acquisition of the European Union Eco-Management and Audit Scheme (EMAS) certification. This certification was developed by European commission as a method for organizations to complete an environmental audit using standards defined in ISO 14001. Organizations use the results of this audit to create an environmental statement and develop a strategic plan for continuously improving the base's environmental performance (*Eco-Management and Audit Scheme*, n.d.). The Quality and Environment Office on Base Aérea N.°5 worked for over six years to finally complete the certification in 2016 (Delgado, F., 2021). The sustainable initiatives put forth by the strategic plan cover all sectors of base activities, including wastewater treatment. Specifically, Axis II of strategic plan seeks to promote the reuse of treated wastewater with a goal of reusing 50% of treated wastewater (*Plano Estratégico de Sustentabilidade Ambiental da Base Aérea N.º 5(PESA BA5)*, 2020).

The goal of this paper is to evaluate the current wastewater treatment methods employed at Base Aérea N.°5 and determine what changes can be made to enhance the sustainability of the treatment process. First, all collected influent and effluent data from chemical, physical, and biological indicator testing will be analyzed and compared to Base Aérea N.°5's allowed effluent discharge conditions described in their license. This analysis will be used to identify current challenges and shortcomings of the current wastewater treatment method. Next, the advantages and disadvantages of several tertiary treatment methods will be presented in order to determine a ranking of tertiary treatment methods. Finally, potential areas for treated wastewater reuse will be identified in order to meet the goals outlined in Axis II of the Strategic Plan.

2. Background

2.1 Base Aérea N.°5's Wastewater Treatment Plant

Base Aérea N.°5, located in Serra Porto de Urso in the parish of Monte Real and municipality of Leiria, was inaugurated in 1959 (*Declaração Ambiental 2020*, 2020). The base was built over the Vieira de Leiria-Marinha Grande aquifier and occupies 482 hectares of national territory; the majority of the land comprised of forest and uncultivated land, while less than a third is occupied by infrastructure (Rocha, 2020). The population of Base Aérea N.°5 has declined significantly over the years, and currently only 600 civilians and Air Force members live and work on base (F. Delgado, personal communication, November 17, 2021). However, there is significant population variation over the course of the year, such as on community event days and when the base hosts visitors (Rocha, 2020).

The airbase's secondary decentralized WWTP, with the capacity to serve 3,000 people, opened in 1998 and is located on base (*Licença de Utilização dos Recursos Hídricos - Rejeição de Águas Residuais*, 2016). The 3,000-person capacity is equivalent to 530 m^3 of wastewater per day or 88.33 m^3 of wastewater per hour (F. Delgado, personal communication, November 17, 2021). The WWTP treats all the domestic and industrial wastewater, as well as rainwater collected on base (*Declaração Ambiental 2020*, 2020). There is significant variation in the volume of wastewater treated due to population fluctuations and rainfall which impacts the concentration of pollutants in the wastewater and the efficiency of the treatment (*Declaração Ambiental 2020*, 2020).

The WWTP is located at the lowest elevation relative to the rest of the base, so gravity is the primary force used to transport wastewater to the treatment plant. Additionally, there are three electric pump stations that increase the efficiency of the transport process (F. Delgado, personal communication, November 17, 2021). The raw influent enters the WWTP through a channel equipped with an automatic grid remover that removes large solids, which constitutes the primary treatment process (*Funcionamento da estação*, n.d.). The bypass channel is parallel to the main channel and allows influent to move directly into the aeration tank when the main channel overflows and the floodgates are activated.

Upon entering the aeration tank after passing through the main or bypass channel, the influent begins the secondary treatment process by being mixed with oxygen and aerobic microorganisms to undergo biological treatment (*Funcionamento da estação*, n.d). During this step, the microbial community transforms some dissolved pollutants and organic matter into biological flakes that are collected and removed as sediment. This phase of treatment is contingent on microbial community growth, so the conditions of the aeration tank must be optimized to enable this. These conditions are achieved by automatic aerators controlled by an oxygen probe or timer which maintains a dissolved oxygen concentration of 2 mg/L. Dissolved oxygen concentrations below this limit favor the predominance of filamentous microorganisms which hinder sludge sedimentation; concentrations above the limit do not significantly improve the sedimentation process and are therefore a waste of energy. An aerobic environment is maintained in the aeration tank, however, processes that require anaerobic conditions, specifically denitrification and sludge digestion, take place simultaneously in the aeration tank. The anaerobic conditions are a result of the mismatch between the population capacity the WWTP is designed to serve and the actual population on base. The aeration tank in tandem with the automatic grid remover aims to minimizes the suspended solids and incorporate the majority of organic matter into microorganisms and organic sediment, which is referred to as activated sludge. Once the concentration of activated sludge exceeds optimal value, the sludge is purged, and the influent moves to the decanter.

In the decanter, activated sludge settles to the bottom of the tank and is transported to the sludge collection point (*Funcionamento da estação*, n.d). Additionally, a bridge scraper moves sludge and scum from the surface of the water into a box that is connected to the sludge collection point. The decanter does not contain aerators, however, sludge is kept in aerobic conditions via purging to avoid the release of gas bubbles which could result in settled sludge re-suspending in the partially treated influent. Additionally, residual oxygen dissolved in the partially treated influent is maintained to prevent denitrification of the sludge which could also reduce the sludge's sedimentability. At the sludge collection point, sludge can be recirculated to the aeration tank if the concentration of microorganisms in the aeration tank is low, or it can be transported to a silo where gravity is used to remove the water from the sludge. Finally, the partially dried sludge is compressed in a band filter and lime is added to completely dehydrate the sludge; this treatment reduces the volume and disposal cost of the sludge by making it easier to transport. The dried sludge is collected in big bags that are disposed of or purchased by external companies to use as compost. After the sludge has been removed, effluent drains over the internal rim of the decanter to the effluent outlet where it is discharged into the surrounding forest and eventually joins Ribeira dos Tourões. The effluent outlet is equipped with a flow meter so the base can determine the amount of treated effluent produced each year. The hydraulic retention time (HRT) of the wastewater, defined as the average length of time that a compound remains in treatment plant, is estimated at about a day (Perry, 2020). The sludge collected at Base Aérea N.°5 has an estimated HRT of 75 days which is higher than the average range of between 15 and 30 days, likely due to the low organic load of the treatment plant (Perry, 2020). Figure 1 depicts a diagram of the wastewater treatment process at Base Aérea N.°5.

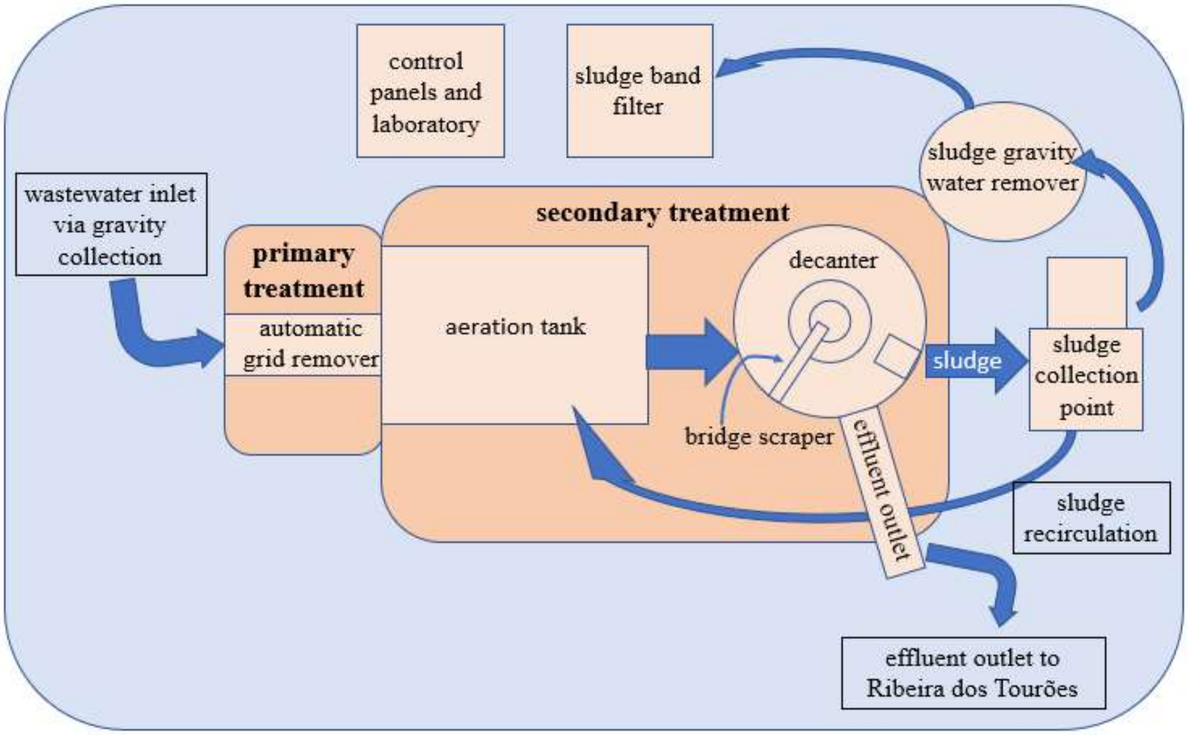

Figure 1. The flow of wastewater at the Base Aérea N.°5 wastewater treatment plant

In 2016, Base Aérea N.°5 obtained a five-year license to operate a domestic WWTP (*Licença de Utilização dos Recursos Hídricos - Rejeição de Águas Residuais*, 2016). The license characterizes the treatment as secondary biological treatment by activated sludge in prolonged aeration with the previously stated discharge limits. The discharge system is classified as "collected without protective work" indicating the effluent is discharged directly into the recipient medium, Ribeira dos Tourões (*Licença de Utilização dos Recursos Hídricos - Rejeição de Águas Residuais*, 2016). The license specifies the hydrographic region, basin, sub basin, and water body, and classifies their ecological status as reasonable. One of the general conditions of the license is that the Air Force must pay a Water Resource Fee of €600 annually to be authorized by the Portuguese Environmental Agency to discharge wastewater (F. Delgado, personal communication, November 17, 2021). Additionally, they general conditions state that the effluent can't change the quality of the receiving environment in a way that jeopardizes the resource or impacts its flow. Finally, the license lists effluent discharge conditions and self-monitoring programs that must be implemented to ensure the conditions are met. Currently, chemical, physical, and biological parameters are regularly monitored to ensure the effluent produced meets licensing standards (*Relatório de Sustentabilidade Ambiental 2020*, 2020).

2.2 Tertiary Treatment

Traditional secondary wastewater treatment methods, such as those used at Base Aérea N.°5, are designed to remove organic matter and suspended solids; unfortunately, there are several chemical contaminants and microorganisms that secondary treatment is not designed to effectively remove (Emerging Technologies in Wastewater Treatment, n.d.). As a result, these contaminants are discharged in effluent into rivers and creeks (Emerging Technologies in Wastewater Treatment, n.d.). These compounds include personal care products (PCPs), endocrine disrupting compounds (EDCs), pharmaceutically active compounds (PhACs), pesticides, disinfection by-products, and enteric pathogens such as viruses, bacteria, protozoa, helminths (Emerging Technologies in Wastewater Treatment, n.d.; Rocha, 2020; Khan, 2012). Currently, the full ramifications of these pathogens and micropollutants on the environment are not well understood. Furthermore, these contaminants are difficult to detect, requiring the use of advanced and expensive analytical chemistry equipment such as gas chromatography or high-performance liquid chromatography (Feier et al., 2018). Emerging research indicates that the discharge of these contaminants into the environment is worthy of our concern. Specifically, scientists are concerned about PhACs and EDCs promoting increased incidence of disease, antimicrobial resistance, exhibiting endocrine disrupting effects on fish, and negatively impacting biodiversity (Feier et al., 2018; electrobased tech for the contaminants remaining on soil). Additionally, is an inherent risk of surface and groundwater contamination, and subsequent contact with people, animals, and plants who come in contact with soil irrigated with wastewater; this is especially relevant when discussing microorganisms because at high enough concentrations, they can contaminate aquifers (Rocha, 2020; Khan, 2012). Finally, there are some pathogens that are resistant to disinfection, so there is always a risk of low concentrations of microbial pathogens in recycled water (Khan, 2012). As a result, in 2015, the European Union released the Surface Water Watch List which listed PCPs as contaminants of concern (CEC) due to their abundant usage and prevalence in aquatic environments (Emerging Technologies in Wastewater Treatment, n.d.).

Given the lack of data about the amount of micropollutants and pathogens currently released by WWTPs and what amount would pose a significant health threat to communities, the European Union has not set limits on concentrations of these compounds that can be released into the environment in effluent (Rocha, 2020). Thus, typically tertiary treatment is only employed when logistically necessary and financially reasonable. However, given the emerging research about the environmental risks of releasing these contaminants into bodies of water, environmental and human health consideration must be considered when evaluating the necessity of tertiary treatment implementation.

Tertiary treatment facilitates the removal of pathogens and micropollutants, decreasing the environmental and health risks associated with effluent reuse. Ideally, tertiary treatment kills all potential pathogens in the water without adding toxic compounds in a safe, easy, and affordable way (Emerging Technologies in Wastewater Treatment, n.d.). There are two components of tertiary treatment: filtration and disinfection (Rocha, 2020). The goal of filtration is to decrease the concentration of TSS in the water. Disinfection aims to reduce the number of pathogenic organisms to levels that enable safer reuse. The mechanisms of pathogen and micropollutant removal for a selection of relevant tertiary treatment methods are described in the following paragraphs.

Ozonation is the process by which ozone deactivates pathogens and chemical pollutants by transforming them into different final products (Emerging Technologies in Wastewater Treatment, n.d.). Mechanistically, this occurs via the breakdown of ozone into hydroxyl radicals that react with wastewater pollutants directly and non-selectively. The high oxidation potential of ozone forces the targeted chemical to give up an electron and become a radical that further reacts with other target chemicals. The targeted chemical radicals interact with each other effectively neutralizing and stopping the reaction. This method's effectiveness is dependent on the ozone concentration in the effluent, the susceptibility of the target chemicals to oxidation, and the amount of time the target chemicals are in contact with the ozone.

UV radiation uses electromagnetic energy to penetrate the genetic material of targeted cells of organisms to impede their ability to reproduce (Emerging Technologies in Wastewater Treatment, n.d.). The electromagnetic radiation is generated by an electric arc directed through mercury vapor that produces electromagnetic radiations that have wavelengths between 10 and 400 nm. The majority of energy output occurs at a wavelength inside the optimal germicidal range. This method inactivates organisms rather than removing them from the effluent, so sometimes it is used in combination with other filtration treatments. The effectiveness of UV radiation is dependent on the composition of the wastewater, intensity of the radiation, and the total time the radiation is employed.

Chlorination, like ozonation, oxidizes cellular material to impair target organisms (Emerging Technologies in Wastewater Treatment, n.d.). Several different forms of chlorine are effective in carrying out chlorination, including sodium hypochlorite, gaseous chlorine, and chloramines. Depending on the organism that is oxidized, several different hazardous and non-hazardous by-products could be formed; for example, when oxidized, amino acids can form aldehydes, nitriles, and dichloroacetonitirile. Concerns relating to the formation of hazardous by-products by the typical chlorine compounds used for chlorination have prompted scientists to look into alternative oxidizers that produce the same desired outcome without the harmful by-products. Two promising alternatives are chlorine dioxide and peracetic acid, which exhibit minimal formation of by-products (Emerging Technologies in Wastewater Treatment, n.d.; Rocha, 2020). Prior to releasing treated effluent into the environment, it is necessary to dechlorinate treated effluent because residual chlorine is toxic to aquatic organisms at any concentration (Emerging Technologies in Wastewater Treatment, n.d.).

Reverse osmosis is a pressure-driven process by which non-tertiary treated effluent moves through a semi-permeable membrane from a region of higher solute concentration to a region of lower solute concentration (Emerging Technologies in Wastewater Treatment, n.d.). Large, nonpolar, ionic, and toxic soluble pollutants are unable to travel through the membrane, removing up to 99% of total dissolved solids. There are several factors that affect the removal efficiency, including membrane porosity and morphology, and characteristics of the influent.

Activated carbon, typically in the form of granular activated carbon or powdered activated carbon, is treated to generate microfissures that increase the adsorptive surface area of the compound (Emerging Technologies in Wastewater Treatment, n.d.). Wastewater contaminants accumulate on the surface of the activated carbon compound. This tertiary treatment method requires large amounts of activated compound to be used to compete with any remaining organic matter in the wastewater. It has shown to be up to 95% effective at removing PhACs, however, this removal efficiency is dependent on the amount of organic matter still present in the influent and the frequency of activated carbon replacement.

Constructed wetlands can be used for primary, secondary, or tertiary wastewater treatment (Emerging Technologies in Wastewater Treatment, n.d.). This method has the ability to remove a variety of pollutants such as organic matter, pathogens and heavy metals using natural processes employed by microbiomes in the vegetation, soil, and water of wetlands. There are environmental benefits above and beyond those associated with discharging a tertiarily treated effluent into the environment, including carbon storage, biodiversity conservation, and the stabilization and protection of shorelands.

Electroremediation is a tertiary treatment method that applies low-level direct current to promote physiochemical changes in wastewater pollutants (Magro, 2019). Water undergoes electrolysis at the electrodes, generating hydrogen and hydroxyl radicals which causes pollutants to undergo electromigration, electrophoresis, and electroosmosis (Magro, 2019; Ferreira, 2018). Organic contaminants undergo anodic oxidation when they directly encounter the anode surface, or indirect oxidation by oxidants formed in surrounding liquid media (Magro, 2019). Hydrogen produced by the electrolysis of water can be collected and used as fuel for fuel cells, offsetting the energy-costs of the tertiary treatment.

2.3 Water Scarcity and Effluent Reuse

The United Nations stated that the majority of Mediterranean countries will have less freshwater available in 2050 than in 1990 (Lavrnić et al., 2017). Today, at least 11% of the population in countries in the European Union are facing water stress (Lavrnić et al., 2017). In Portugal specifically, one case study found that over the next 40 years, annual precipitation will decrease significantly, and temperature will increase (Quinteiro, 2019). This will cause greater atmospheric capacity for holding moisture, more flooding due to more frequent extreme precipitation events, and more heat waves. As a result, there will be less rainwater stored in topsoil that can be evaporated and transpirated by plants, effectively decreasing the groundwater recharge and runoff resources available (Quinteiro, 2019; Lavrnić et al., 2017). Mountain and coastal areas, especially the western coast of Portugal, are predicted to be the most affected by temperature increases and precipitation changes (Quinteiro, 2019; Lavrnić et al., 2017).

The water exploitation index (WEI) is calculated by determining the total volume of freshwater extracted per year expressed as a percentage of the maximum theoretical yearly amount of renewable water available to each person in a country (Lavrnić et al., 2017). A WEI value of less than 10% indicates low water stress. The WEI for Portugal is 12.31%, and the WEI for the sub-basin of Vouga, Mondego, and Lis where Base Aérea N.°5 is located is 2.64% (*Use of freshwater resources in Europe*, n.d.). Presently, 57.5% of mainland Portugal experiences water deficit, yet only about 10% of treated wastewater is reused. (Marecos do Monte, 2010).

In the region where Base Aérea N.°5 is located, 141 hm^3 of surface water and 14 hm^3 of groundwater is extracted annually. The largest consumer of freshwater in this region is the electricity, gas, steam, and air conditioning sector (*Use of freshwater resources in Europe*, n.d.). Base Aérea N.°5 extracts all water used on base from three well located inside the campus, then stores it in tanks where it is treated with chlorine. Extracting less freshwater would decrease the amount of wastewater discharged, thereby reducing water stress (Lavrnić et al., 2017). Treated wastewater reuse is an excellent solution to the challenges posed by the water scarcity crisis in Portugal because it enables the conservation of water resource reserves (Rocha, 2020). In addition, it expands the amount of constant water resources available presently and in the future. This proposition would enable a decrease in the volume of freshwater consumed for processes that don't require high quality water resources and lead to better management of effluent discharges.

Axis II of the Base Aérea N.°5's EMAS strategic plan sets forth a goal of reusing half of all treated wastewater, and the plan outlines several potential uses (*Plano Estratégico de Sustentabilidade Ambiental da Base Aérea N.º 5 (PESA BA5)*, 2020). Currently, aside from reusing some effluent for cleaning the WWTP, Base Aérea N.°5 discharges three to four thousand cubic meters of effluent into the surrounding forest each month, corresponding to a water reuse rate of less than 1% (*Plano Estratégico de Sustentabilidade Ambiental da Base Aérea N.º 5 (PESA BA5)*, 2020). This is indicative of a missed opportunity for sustainable water reuse on the base. One challenge to implementing treated wastewater reuse is the absence of adequate legislation and infrastructure necessary for reuse implementation (Rebelo, 2020). Other hurdles associated with wastewater reuse include costs associated with additional effluent treatment necessary to ensure safe reuse and the cost of infrastructure for pumping, storing, and distributing treated wastewater in separate plumbing from pipes containing potable water (Asano et al., 2007).

To capitalize on the potential for effluent reuse and reducing water shortages, the Portuguese government has implemented policy allowing reclaimed water to be used for non-potable purposes (Rebelo, 2020). Decree Law No. 226-A/2007 states that treated wastewater must be reused whenever possible for watering gardens, public spaces, and golf courses, however, the most relevant piece of wastewater reuse legislation is Decree Law No. 119/2019 which was created on August 21, 2019 (Decreto-Lei n.°119/19, 2019). The law defines the standards for the reuse of water that has undergone wastewater treatment, as well as outlining methods for conducting risk assessments to use the treated wastewater. Decree Law No. 119/2019 is a part of the Common Strategy for implementing the Water Framework Directive (Decree Law No. 152/97) that aims to achieve and maintain all bodies of water in Portugal in good condition so they can be used for agricultural irrigation. This legislation puts Portugal at the forefront of countries and international organizations developing strategies to support water reuse, such as the World Health Organization, the International Organization for Standardization, and the European Union Commission. Additionally, this legislation aligns with goals put forth in the Action Program for Adaption to Climate Change.

Under definitions put forth by Decree Law No. 119/2019, Base Aérea N.°5 produces urban wastewater that is treated in a decentralized system (Decreto-Lei n.°119/19, 2019). Since the water is not being reused by a third party, the water reuse proposal is subjected to a simplified risk assessment. The risk assessment requires the identification of physical, chemical, and biological hazards that could threaten people, soil, vegetation, animals, or water resources. Additionally, if the base were to want to transport the water in any way, additional documentation is needed under Decree Law No. 147/2003. The urban reuse water quality standards are mostly focused on ensuring pathogen levels are low to minimize risks associated with dermal contact, so they are less stringent standards than water being reused for agricultural irrigation must meet. Standards for reuse of water for potable purposes are not defined in Decree Law No. 119/2019.

3. Methods

3.1 Collection of Influent and Effluent Data

Data on several different chemical, physical, and biological indicators are collected periodically during the wastewater treatment process at Base Aérea N.°5. The collection points are as follows: (1) raw influent is collected before entering the treatment plant, (2) influent is collected from the aeration tank, (3) sludge is collected from the sludge collection point, (4) partially treated effluent is collected from the aeration tank and sludge recirculation point, and (5) treated effluent is collected from the effluent outlet. Figure 2 summarizes the indicators analyzed at each collection point. Samples collected at points (1), (3), and (5) are analyzed by an external laboratory, Laboratório Tomaz, in accordance with method described in ISO 5667-10:1992. Samples collected at points (2) and (4) are analyzed in the laboratory at the WWTP. I visited Base Aérea N.°5 from November 17 to November 19, 2021 to see the WWTP and to observe the on-base testing of samples collected at points (2) and (4).

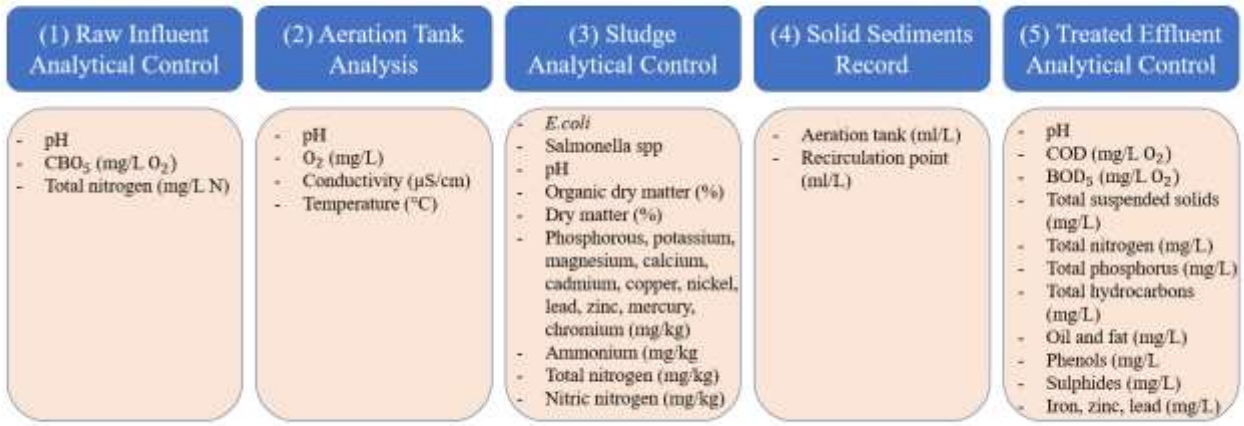

Figure 2. Summary of indicators assessed at each collection point

A sample of raw influent was collected quarterly and analyzed at Laboratório Tomaz in 2018 to determine the composition of wastewater entering the WWTP. This enabled the WWTP operators to quantitatively compare the influent to the treated effluent to determine what level of nutrient removal occurred. The pH of the influent is determined to ensure it falls within the optimal range for microbial growth and the function of metabolic enzymes so the wastewater can be efficiently treated in the aeration tank (F. Delgado, personal communication, November 17, 2021). Biological oxygen demand indicates the amount of oxygen demand the sample is consuming without chemical help, where higher values indicate lots of undesirable biological activity in the water (F. Delgado, personal communication, November 17, 2021). Total nitrogen is an indicator of the starting amount of nutrients in the solution.

A sample is collected from the aeration tank four times per month to verify that the influent is receiving adequate treatment. During my time at Base Aérea N.°5, I observed the WWTP operator sample the aeration tank and conduct indicator testing. First, the WWTP operator donned personal protective equipment due to the health risks associated with untreated wastewater. Then he used a metal bar attached to a plastic container to collect one liter of wastewater to sample. In the WWTP laboratory, he used probes to record the pH, conductivity, dissolved oxygen (DO), and temperature of the sample. If the DO is above or below 2 mg/L, the aerators in the aeration tank are be manually adjusted as necessary so filamentous microorganisms are not formed and energy is not unnecessarily wasted. Data was recorded in a table in their paper records.

Base Aérea N.°5 analyzed two sludge samples in 2016. Sludge is collected from the aeration tank and tested at Laboratório Tomaz to evaluate pathogen concentrations in the sludge; *E. coli* and Salmonella have been selected by Base Aérea N.°5 as the main indicators of pathogen levels. In addition, heavy metal levels are analyzed at this data collection point. Sludge collected from the WWTP goes on to be dehydrated and sold to a company to use as compost or disposed of. Thus, it is critical to know if there is a high concentration of pathogens or heavy metals in the sludge because it poses a health risk to those handling it or using it for farming purposes.

I also observed the analysis of solid sediments while I was on base. This analysis is conducted several times per month. A one-liter liquid sample is collected from the aeration tank and sludge recirculation point the same way the aeration tank sample was collected. This sample is transferred into an Imhoff test cone to determine the sedimentable solids (SS30) of the samples collected from two different collection points. After being transferred into the test cone, the sample is left for 30 minutes so the solid sediments settle to the bottom of the cone to determine the volume of sediment at each collection point. The sludge must be between 800 and 1000 ml/L and between 400 and 600 ml/L at the recirculation point and in the aeration tank, respectively. If there is not enough sediment in the aeration tank, the sludge at the recirculation point is recirculated instead of moving on to the gravity water remover.

Treated effluent is collected and analyzed at Laboratório Tomaz once per month to verify that the effluent's biological, chemical, and physical indicators are within ranges specified on their discharge license, so the effluent does not cause environmental harm. The pH of the effluent is analyzed to ensure that the effluent is relatively neutral, so it doesn't alter the pH of the receiving environment. The biological and chemical oxygen demand are assessed to verify that the effluent's oxygen demand will not create an anoxic environment in the receiving ecosystem. Total suspended solids are analyzed to make sure that enough sediment has been removed and the turbidity of the effluent will not alter the ability for light to pass through the receiving environment. Nitrogen and phosphorus levels are assessed to verify that the effluent won't increase nutrient levels of the receiving environment, promoting eutrophication. Hydrocarbon, oil, fat, phenol, and heavy metal levels are all indicators that allow Base Aérea N.°5 to further quantify the extent of the treatment and make sure the composition of the wastewater will not alter the composition of the receiving environment. The flow rate of treated effluent being discharged into the environment is determined by a flow rate sensor on the effluent outlet pipe.

3.2 Analysis of Previous Influent and Effluent Data Relative to Base Aérea N.°5's License Limits

I requested and received all previously collected biological, physical, and chemical indicator data collected at Base Aérea N.°5's WWTP between 2016 and 2018. This data was all hand-recorded and transferred to me by scanning the physical records. First, I digitized the data and organized it in tables in Excel. I then created graphs comparing indicator values of samples collected before and after wastewater treatment to quantify how effective the nutrient removal was. I also made graphs of indicator data for treated effluent to determine how the quality of effluent has changed over time.

3.3 Comparison of Tertiary Treatment Methods

A literature search was conducted primarily using Google Scholar, including a review of relevant case studies conducted at Base Aérea N.°5 to determine what tertiary treatment methods were infrastructurally and financially feasible for implementation. Advantages and disadvantages of each treatment method were identified and organized to allow for comparison. The two most feasible options were identified and compared further.

3.4 Determination of Areas of Possible Water Reuse and the Associated Financial Implications

Documents from the Base Aérea N.°5's audit of on-base water consumption were evaluated to identify possible areas of non-potable water reuse. Members of the Base Aérea N.°5 Quality and Environment Office were consulted to provide a rough estimate of the volume of water that could be reused for each identified non-potable purpose. The cost-benefit analysis of implementing water reuse at the proposed locations was calculated using the associated cost of using well water provided by members of the Quality and Environment Office.

4. Results and Discussion

4.1 Previous Base Aérea N.°5 Influent and Effluent Data

In 2018, Base Aérea N.°5 collected raw influent and treated effluent quarterly and determined their pH, CBO_5, and total nitrogen values. The average pH of raw influent and treated effluent samples collected were both within the acceptable license range of between six and nine. Wastewater treatment resulted in a 10% decrease in pH of the wastewater. The treated effluent had a pH closer to neutral than the raw influent. The average CBO_5 of influent in 2018 was significantly above the license limit. Wastewater treatment decreased the CBO_5 of the wastewater by 86%, resulting in effluent with a CBO_5 value below the license limit. Initially, the total nitrogen level of the wastewater was around three times the license limit. Wastewater treatment decreased the nitrogen level by 27%, however, the discharged effluent still had a nitrogen level about two times higher than the license limit. These results are reflected in Figure 3.

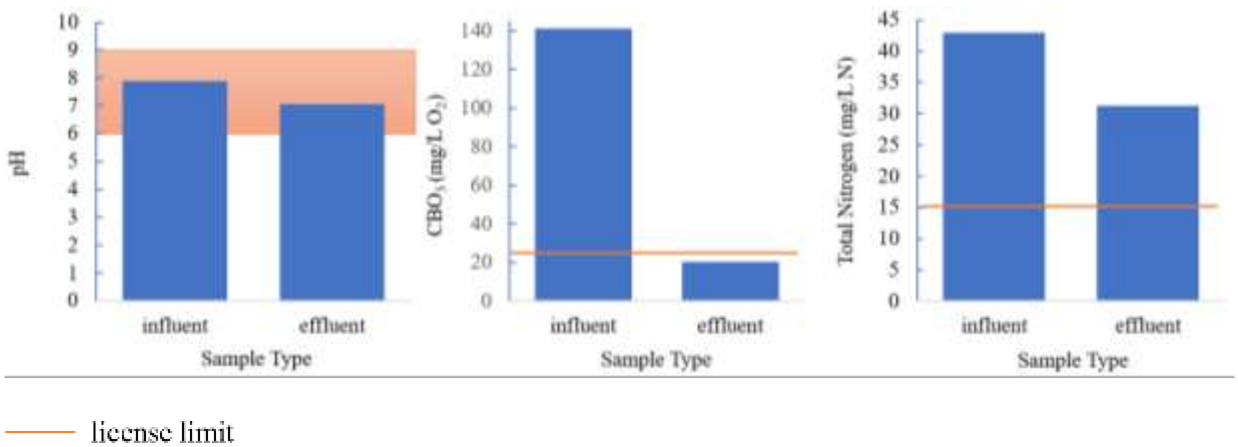

Figure 3. Influent and effluent pH, CBO_5, and total nitrogen values relative to license limit

All three data sets demonstrate that the indicator values did decrease as a result of wastewater treatment. However, wastewater treatment only resulted in the CBO_5 indicator decreasing to meet the license limit; the pH level of the raw influent was already below the license limit, and neither the total nitrogen level before nor after treatment were below the license limit. Thus, the two major issues that Figure 3 illustrates is that nutrient levels, specifically nitrogen levels, don't decrease significantly as a result of wastewater treatment, and they do not meet the license limits.

The primary reason inefficient nitrogen removal is observed is that the WWTP is oversized. It is operating at 20% of its intended capacity, and the predicted wastewater composition and organic matter volume does not correspond to the reality of the raw influent. The composition of the wastewater has a higher proportion of urine and lower levels of organic load than is intended for optimal treatment (F. Delgado, personal communication, November 17, 2021). This could be attributed to a significant portion of the base population living off base and not using the sanitary facilities as often as a larger population living on base would. Additionally, the low levels of organic load in the influent correspond to an average BOD level in the low 100 mg/L O_2 range. Domestic influent usually has a BOD between 100 and 1,000 mg/L O_2 where higher incoming BOD levels are more favorable because macronutrients are removed relative to BOD removal (F. Delgado, personal communication, November 17, 2021). Since 5 kg of nitrogen and 1 kg of phosphorus are removed for every 100 kg of BOD removed, nitrogen removal is hindered by low initial BOD levels.

Another reason that inefficient nitrogen removal is observed is because rainwater enters the system due to the gravity-fed nature of the treatment plant, further diluting the nutrients and decreasing the efficiency of the treatment (*Relatório de Sustentabilidade Ambiental 2020*, 2020). It is worth noting that according to Decree Law No. 236/98, it is not imperative for Base Aérea N.°5 to meet the nitrogen license limits because the WWTP is not located in a "sensitive area" as defined by the decree law (F. Delgado, personal communication, November 17, 2021). However, there are environmental consequences associated with discharging effluent with high levels of nitrogen into the environment, including promoting eutrophication.

One way to promote denitrification without increasing organic load levels is to implement an anoxic tank as a primary treatment step to decrease the nitrogen levels of the influent before it enters the aeration tank (Perry, 2020). The lack of oxygen in this tank would force the bacteria to use nitrogen as an energy source, thus decreasing nitrogen levels. A denitrification primary treatment step would result in the total nitrogen levels of the treated effluent being closer to or meeting the license limits.

Data on the pH, TSS, total nitrogen, and total phosphorus levels of the treated effluent were regularly collected between 2016 and 2018. When graphed relative to the acceptable range given in the license, the pH levels of the treated effluent have remained in the acceptable range from 2016 to 2018. The plotted pH levels of the effluent samples don't display any clear trend over the three years, and no samples fell outside the license range. The majority of samples collected between 2016 and 2018 have a TSS value below the license limit, but three samples had TSS levels above the license limits. The TSS level of the samples do trend upward towards the license limit. The majority of samples had a total nitrogen level above the license limit, though there were four times where the total nitrogen level was less than the license limit. The total nitrogen levels of the effluent samples trend upwards over time. Similarly, the total phosphorus levels of the effluent samples trend upwards over time. The total phosphorus levels of the collected samples all fall below the license limits. Total nitrogen is the only effluent indicator that was consistently higher than the license limit, although the TSS level did exceed license limits multiple times. Total suspended solids, total nitrogen, and total phosphorous levels all trended upwards over time. These findings are reflected in Figure 4.

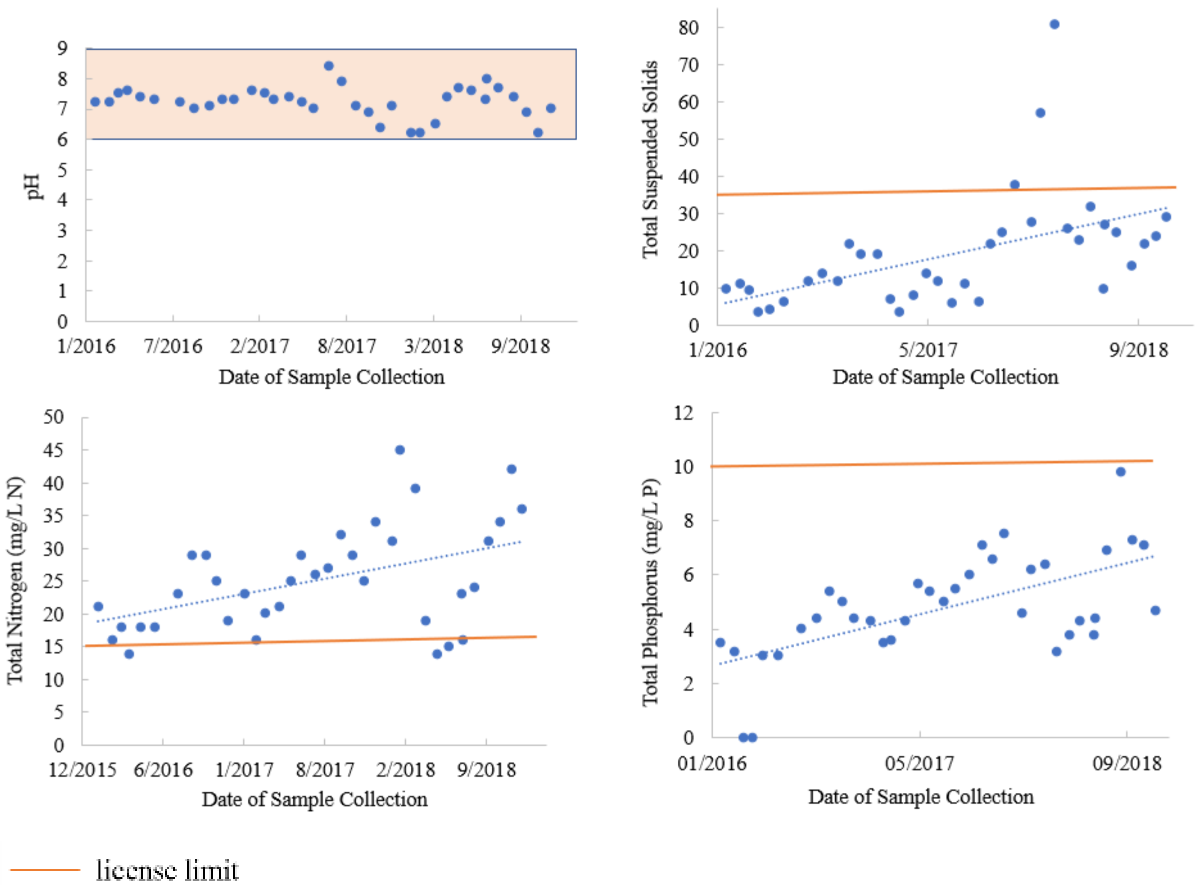

Figure 4. pH, total suspended solids, total nitrogen, and total phosphorus levels relative to license limits from 2016 to 2018

The biological oxygen demand (CBO_5) and chemical oxygen demand (COD) of treated effluent samples were regularly measured. The CBO_5 indicates the amount of oxygen necessary to carry out biological processes such as the degradation of organic compounds (Perry, 2020). The COD is a measure of the amount of oxygen needed to chemically oxidize organic compounds and inorganic compounds in the water sample (Perry, 2020). Between 2016 and 2018, CBO_5 and COD levels generally remained below the license limits, however, some samples had CBO_5 and COD levels that exceeded these limits. Similarly to the TSS, total nitrogen, and total phosphorous levels presented above, CBO_5 and COD levels trended upwards toward the license limit. These results are displayed in Figure 5.

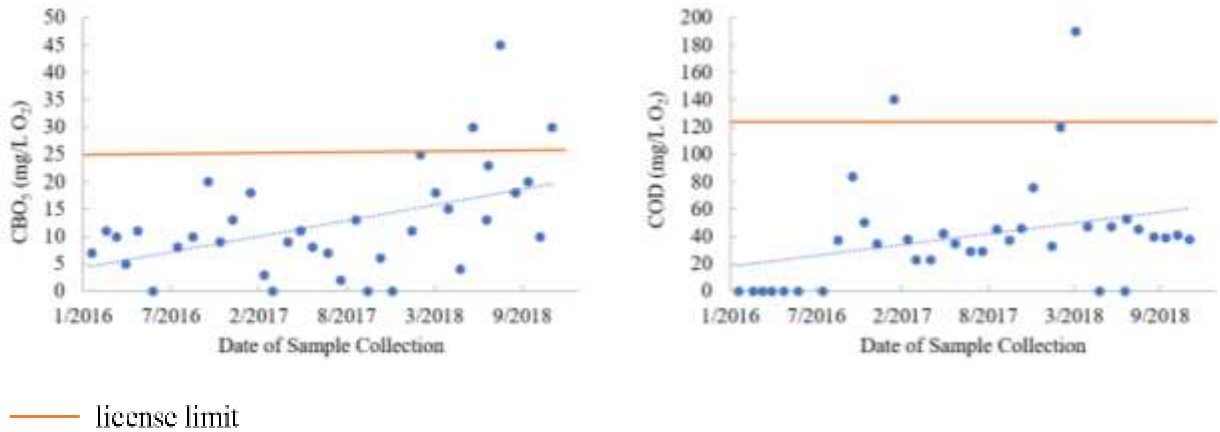

Figure 5. CBO_5 and COD levels relative to license limits from 2016 to 2018

Since CBO_5 correlates to the amount of oxygen necessary for the degradation of organic matter, and the COD represents the amount of oxygen used to chemically oxidize the organic and inorganic matter, the ratio of CBO_5 to COD is a useful indicator for determining the effectiveness of biological treatment (Perry, 2020). A CBO_5 to COD ratio grater than 0.5 indicates that the biodegradable fraction is high, and biological treatment has the potential to be successful. A CBO_5 to COD ratio between 0.5 and 0.3 suggests that the non-biodegradable fraction is significant, so further testing should be conducted to determine if biological treatment has the potential to be successful. When the CBO_5 to COD ratio is less than 0.3, biological treatment is unlikely to be successful. Analysis of the CBO_5 to COD ratio of effluent produced between 2016 and 2018 shows that the majority of samples had a ratio less than 0.5, and a significant amount were less than 0.3, as depicted in Figure 6. This indicates that the biological process occurring at the Base Aérea N.°5 WWTP is inefficient.

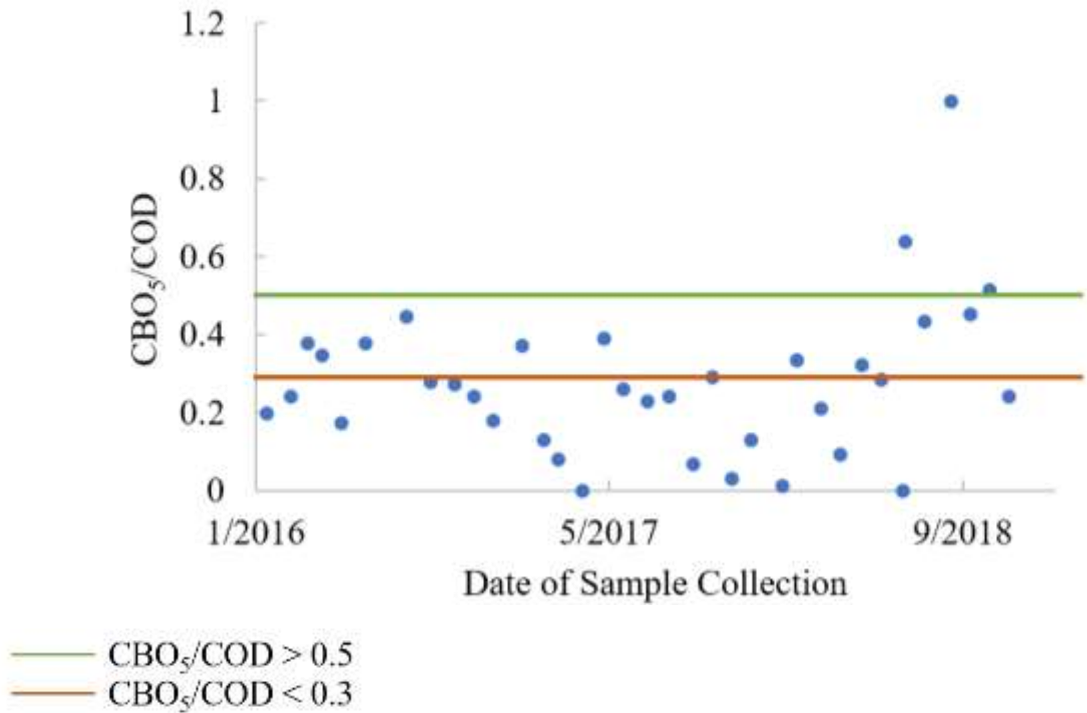

Figure 6. CBO_5 to COD ratio for all samples collected between 2016 and 2018

Analysis of effluent indicator reveals that TSS, nitrogen, phosphorus, CBO_5, and COD levels are trending upwards, suggesting that less nutrients are being removed by the treatment process over time. This could be attributed to the age of the treatment plant; the plant has been in operation since the late 1990's and has not received any significant intervention since its inception. Additionally, the decrease in efficiency of nutrient removal could be attributed to the decline of Base Aérea N.°5's population over the years, increasing the impact of the issues described earlier in this section. Wastewater treatment efficiency could be improved by implementing the recommendations given previously.

4.2 Analysis of Potential Tertiary Treatment Methods

It is logical to assume that members of Base Aérea N.°5 use PCPs, PhACs, EDCs, pesticides, and disinfection products. Additionally, they likely shed pathogens into water they encounter. The implementation of tertiary treatment would enhance the sustainability of Base Aérea N.°5's WWTP by preventing these micropollutants and pathogens from entering the environment. Additionally, the better the wastewater is treated, the more reuse purposes it can serve, further enhancing the sustainability and financial benefits to the base overall.

Table 1 presents the advantages and disadvantages of a selection of tertiary treatment methods. Several methods, including ozonation, UV radiation, reverse osmosis, and activated carbon cite the lack of chemicals or residues used in their treatment method as an advantage. Alternatively, some claim chemical chlorine is advantageous because this treatment method results in residual disinfectant that prolongs disinfection and hinders recontamination. A common disadvantage of several tertiary treatment methods is the complicated and expensive equipment system.

Table 1. A selection of tertiary treatment methods and relevant advantages and disadvantages

Treatment	Advantages	Disadvantages
Ozonation[1]	-more efficient than chlorine -10-30-minute contact time -no chemicals or residues -ozone can be produced onsite -treatment elevates dissolved oxygen levels, eliminating the need for reaeration -decreases taste and odor issues	-complicated equipment and system -strong oxidizer makes it most effective on effluents with low levels of TSS, BOD, and COD -high cost of treatment (electricity and infrastructure)
UV Radiation[1]	-effective disinfectant against pathogens including chlorine resistant pathogens -no chemicals or residues -inexpensive and easy to use equipment -not equipment intensive -20-30 second contact time	-low dose may be ineffective -repairing and reversing the effects of treatment is possible in some organisms -high turbidity can harm the effectiveness of UV disinfection -can't measure immediate success due to lack of residual disinfectant
Chlorination[1]	- chlorination already used to treat well water on base -residual disinfectant prolongs disinfection against recontamination -cost-effective -effective against a wide range of pathogenic organisms -can eliminate odors -can adjust dose to accommodate influent volume changes	-any concentration of chlorine is toxic to aquatic organisms; dechlorination after treatment may be necessary -complex microorganism are not exterminated by chlorine -some chlorination by-products are hazardous with long-term effects
Reverse Osmosis[1]	-no chemicals or residues -high-quality treated effluent -easily added to existing WWTP infrastructure	-costs associated with discharge of by-products (concentrate/brine) -effluent quality decreases over time due to membrane fouling -high operation and maintenance costs
Activated Carbon[1]	-no chemicals -relatively low cost and maintenance needs -enhances effluent odor/taste -efficient for filtering carbon-based chemicals and some microorganisms	-not efficient in removing chemicals not attracted to carbon -prone to clogging -requires adequate contact with the filter -can be ineffective or harbor some bacteria and viruses

Constructed Wetlands[1]	-the base has available land -low operation and maintenance costs -provides habitat for wetland organisms	-large land requirement -less consistent performance and longer hydraulic retention times relative to conventional treatment -negatively impacted by changing environmental conditions and wastewater volumes -toxic chemicals can hinder biological components
Electrochemical methods[2, 3]	-possible associate hydrogen production -no chemicals -stable under corrosive conditions -relatively more efficient at higher contaminant concentration	-relatively expensive

[1] *Emerging Technologies in Wastewater Treatment*, n.d.
[2] Ferreira, 2018
[3] Chaplin, 2018

When evaluating which of these advantages and disadvantages are most relevant, it is critical to consider what barriers to tertiary treatment exist. The largest barriers to implementation is funding; the base operates under a strict budget. Since the treatment plant has not received any significant intervention since it was built, any money allocated to improving the wastewater treatment plant would likely be used for maintenance and updates to enable all effluent produced to meet nutrient limits outlined in the license. Additional logistical limitations include the military hierarchy which requires that all decisions involving financial implications be presented to leading members of the air force. Furthermore, there is no full-time airforce member dedicated soley to the operation of the wastewater treatment plant, so implementing new infrastructure that requires a lot of maintenance and upkeep is not feasible. Additionally, significant alterations to the existing WWTP infrastructure or having to buy new equiptment or chemicals could be costly and logistically challenging. Finally, ensuring that tertiary treatment is operating effectively could require a lot of labor and financial resources to adjust treatment methods, as well as testing the water to verify that it was adequately treated and no hazardous by-products were formed.

While they do produce high quality effluents, ozonation, reverse osmosis, and electrochemical methods are costly and require the installation and maintenance of expensive and complicated equiptment. Thus, these treatment methods are not likely to be implemented due to budgetary constraints and the absence of personnel available to oversee this treatment method. The disadvantages of implementing activated carbon also outweigh the advantages, making it an impractical tertiary treatment method. While activated carbon is a low-cost and chemical-free tertiary treatment method, it is unable to filter out things that aren't attracted to carbon and the activated carbon filter tends to harbor bacteria and viruses. These associated risks do not warrant the investment into this tertiary treatment method. Additionally, the activated carbon filter is prone to clogging, which would render the tertiary treatment system completely unusable for periods of time. Constructed wetlands are not well designed for the specific characteristics of this treatment plant; changing environmental conditions and population variations would result in less effective wastewater treatment. Additionally, the wastewater treatment plant is already located at the edge of the Base Aérea N.°5 perimeter, so the large land requirement would pose a challenge. Thus, chlorination and ozonation are the two most promising contenders as they do not pose the barriers that the other treatment methods do.

Chlorination and UV radiation are both cost-effective tertiary treatment methods that require minimal equipment and maintenance and are effective against a wide range of pathogens, overcoming the two major barriers of cost and maintenance and infrastructure. Additionally, chlorine acts as a residual disinfectant that continues protecting treated effluent from recontamination, and UV radiation does not use any chemicals and is effective against some pathogens that chlorine can't combat. Both methods have some common disadvantages, such as they are not effective against all organisms and do not filter the effluent. Furthermore, any concentration of chlorine is toxic to aquatic life, so dechlorination would need to be investigated, as well as the potential for chlorine to form hazardous by-products such as trihalomethanes (*Emerging Technologies in Wastewater Treatment*, n.d.). UV radiation implementation would require the purchase and installation of new UV light infrastructure and optimization research to ensure an effective dose is being administered. Furthermore, as TSS levels in the effluent increase over time as the upward trend in the indicator suggests, UV radiation will become less effective. A summary of the comparison of these two treatment methods is provided in Figure 7.

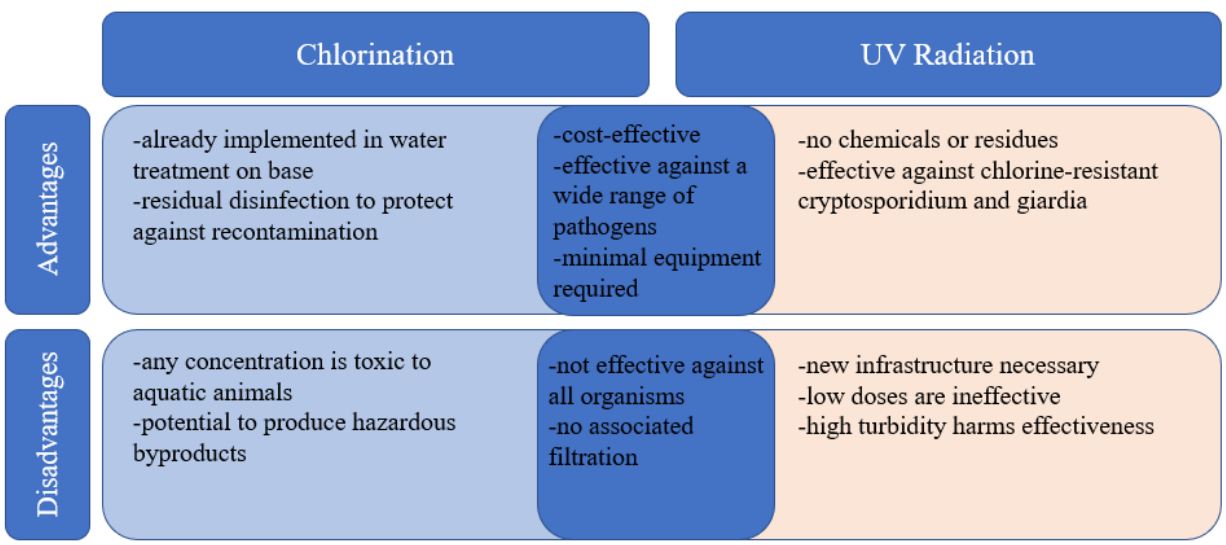

Figure 7. Comparison of the similarities and differences of chlorination and UV radiation

When chlorination and UV radiation are compared, chlorination stands out as the more advantageous tertiary treatment method. This is because chlorine is already being used on base to treat the extracted well water, so they already have the infrastructure and knowledge in place for implementing chlorine use. The associated risks of chlorine use, specifically hazardous by-product formation and toxicity to aquatic animals could be rectified by using an alternative to chlorine such as chlorine dioxide or peracetic acid (*Emerging Technologies in Wastewater Treatment*, n.d.; Rocha, 2020). Chlorine dioxide is a promising alternative to chlorine because it does not react with ammonia or aromatic organic compounds to produce trihalomethanes, making it less likely to form chlorinated organics. Peracetic acid is a mixture of hydrogen peroxide, acetic acid, and water that has similar oxidative properties to chlorine with minimal formation of by-products (Rocha, 2020).

4.3 Effluent Reuse and Financial Feasibility

Table 2 summarizes all moderate and significant water consumption activities on base listed in the internal audit. Using the definitions put forth by Decree Law No. 119/2019, it lists the standards the treated water would need to meet to be used for the given activity. The adequate treatment column refers to the primary, secondary, and tertiary designations. Reuse volume estimates were made by the Quality and Environment Office. Several water consuming activities did not fall into the categories provided in Decree Law No. 119/2019, specifically any type of potable reuse and instances of reuse that have high risk of dermal contact such as washing clothes.

Table 2. Summary of moderate and significant water consuming activities and reuse evaluation

Water Consuming Activities	Current Consumption	Reuse Standards	Adequate treatment	Estimated annual reuse volume (m^3)
Washing aircrafts	Significant	pH: 6-9 Turbidity: ≤5 *E. coli*: ≤10	Not stated in (9/19	50
Washing clothes	Significant	No standards outlined in DL119/19		0
Aircraft maintenance	Significant	No standards outlined in DL119/19		0
Maintenance of vehicles and equipment	Significant	No standards outlined in DL119/19		0
Laboratory work	Moderate	No standards outlined in DL119/19		0
Cleaning of facilities, equipment, and vehicles	Significant	pH: 6-9 Turbidity: ≤5 *E. coli*: ≤10	Not stated in DL119/19	100

Accommodation and housing	Significant	No standards outlined in DL119/19		0
Sanitary facilities	Significant	pH: 6-9 CBO_5: ≤25 Turbidity: ≤5 Ammonium (mg NH_4/L): ≤10 *E. coli*: ≤10	More advanced than secondary	7,085[1, 2]
Wastewater treatment	Moderate	Already implemented	secondary	
Maintenance of green spaces	Moderate	pH: 6-9 CBO_5: ≤25 Turbidity: ≤5 Ammonium (mg NH_4/L): ≤ 5 Total phosphate (mg/L): ≤ 2 *E. coli*: ≤10	More advanced than secondary	10,000
Infrastructure maintenance	Moderate	No standards outlined in DL119/19		0
Food confection	Significant	No standards outlined in DL119/19		0
Fire fighting	moderate	pH: 6-9 CBO_5: ≤ 25 Turbidity: ≤5 *E. coli*: ≤10	More advanced than secondary	dependent
Firefighting training	Significant	pH: 6-9 CBO_5: ≤ 25 Turbidity: ≤5 *E. coli*: ≤10	More advanced than secondary	100
Virus transmission prevention	significant	No standards outlined in DL119/19		0

[1] *Residential End Uses of Water*, n.d.

[2] *EU GPP Criteria for Flushing Toilets and Urinals*, n.d.

All of the activities where water reuse is possible listed above require the water undergoes some form of tertiary treatment, except for washing aircrafts and cleaning facilities, equipment, and vehicles where the adequate treatment level is not stated. The financial benefits of water reuse can help offset the cost of implementing tertiary treatment. Table 3 presents all currently identified possible places to implement water reuse for non-potable uses. The financial benefit of implementing water reuse for these activities is calculated using the cost of energy consumption associated with pumping the water out of the wells and treating it with chlorine; this associate cost comes to a total of €0.10/m^3. Reusing treated wastewater to fill toilet cisterns would require the installation of infrastructure to separate treated wastewater from freshwater.

Table 3. Financial benefits incurred by water reuse

Water Reuse Purpose	Annual Financial Benefit
Maintenance of green spaces	€1,000
Sanitary Facilities*	€708.50
Cleaning of facilities, equipment, and vehicles	€10
Firefighting training	€10
Washing aircrafts	€5

*requires installation of infrastructure to transport effluent

All of these activities, except for the cleaning of vehicles which can be driven down to the WWTP, require the transport of treated effluent to the location where it will be reused. This poses a challenge because installing piping and pumps to transport this water would pose a significant cost that would not be offset by the financial benefit of implementing water reuse. Thus, an alternative solution to installing piping for water reuse that would enable all proposed water reuse activities, except for water reuse in sanitary facilities, is using firetrucks to transport water from the treatment plant to the location where it will be reused. Implementing the water reuse activities suggested above will help Base Aérea N.°5 achieve the goals outlined in Axis II of their strategic plan as well as the guideline given in Decree Law No. 226-A/2007 that states that wastewater should be reused whenever possible for non-potable purposes.

5. Conclusion

Effective wastewater treatment is critical to positive human-environment interactions that protect both the environment and human health. The goal of this paper was to evaluate ways that the sustainability of Base Aérea N.°5's WWTP could be improved. I first looked at what wastewater treatment method was implemented, and available biological, chemical, and physical indicator data that presented a clear picture of the effectiveness of the treatment method. Due to the oversized nature of the wastewater treatment plant and the composition of the wastewater, coupled with the treatment plant's age, the effectiveness of nitrogen removal is low, and the effectiveness of nutrient removal in general is decreasing. Tertiary treatment would be environmentally beneficial because it would decrease reliance on freshwater extraction and decrease the discharge of micropollutants and pathogens into the environment. Effluent that has undergone tertiary treatment can be reused for many purposes at Base Aérea N.°5 which would help offset the cost of implementing the treatment. Chlorination implementation would have several advantages and face the least hurdles in terms of financial implications and maintenance and infrastructure challenges. Wastewater reuse should be implemented for maintaining green spaces, sanitary facilities, cleaning facilities, equipment, and vehicles, firefighting training, and washing aircrafts. This water reuse would result in a financial benefit of over €1,700.

Following an evaluation of how to improve the sustainability of Base Aérea N.°5's WWTP, my recommendations are as follows:

- Implement an anoxic chamber during primary treatment where denitrification can occur so nitrogen levels of Base Aérea N.°5's effluent decrease
- Implement tertiary treatment via chlorination
- Implement water reuse for the purposes listed above
- Look into other areas where wastewater can be reused on base
- Investigate and apply for external European Union funding for WWTP improvement

There are several limitations associated with the recommendations presented. Firstly, these recommendations depend on access to funding and approval from the Portuguese Air Force hierarchy. Secondly, the age of the wastewater treatment plant could become limiting if appropriate interventions are not made to ensure its continued ability to treat wastewater effectively. Thirdly, successful implementation of chlorination relies on laboratory testing to determine what amount of chlorine should be added, if dechlorination is necessary, and if hazardous by-products are being formed. Finally, the water reuse depends on the ability to transport the water from the treatment plant to where it will be reused; if it is not possible to use firetrucks or another transport method, water the majority of water reuse proposed will not be possible.

Future research should investigate the financial and physical feasibility of adding an anoxic chamber to the wastewater treatment plant. Furthermore, it should investigate the minimum amount of chlorine that can be used to achieve elimination of micropollutants and pathogens. Additionally, research will be needed to determine if dechlorination is necessary to protect aquatic environments that the effluent is discharged into. Advanced analytical techniques such as gas chromatography and high-performance liquid chromatography should be used to determine if any hazardous by-products are being formed as a result of tertiary treatment of Base Aérea N.°5's wastewater via chlorination. If the cost of dechlorination makes chlorination not cost-effective or if hazardous by-products are formed, peracetic acid and chlorine dioxide should be investigated further. Finally, based on the purity of the treated effluent, more reuse opportunities could be evaluated.

Base Aérea N.°5 already stands as a leader in the Portuguese Air Force for their implementation of sustainable measures across all activities on base. Implementing more sustainable practices in their wastewater treatment methods enables them to decrease their environmental impact across several planes. Furthermore, and perhaps most importantly, they could encourage other air force bases to enhance the sustainability of their own bases, including their WWTPs, exponentially increasing their impact.

6. Acknowledgements

I would like to extend my sincerest gratitude to Filipe Delgado for being my advisor for this project. Thank you for hosting me on base, answering my never-ending questions, and being such a wealth of knowledge on all things wastewater. Thank you to Cátia Margo for helping advise me on this project and sharing your expertise and resources on electrochemical methods. Thanks to Joana Dionisio for advising me on this project and sharing your wisdom and resources related to tertiary treatment methods. A special big thank you to Cátia and Joana for encouraging me to explore my interests; your passion and support provided me with clarity on my on my future as a scientist.

7. References

Agência Portuguesa do Ambiente. (2016). *Licença de Utilização dos Recursos Hídricos - Rejeição de Águas Residuais.*

Asano, T. et al. (2007). *Water Reuse: Issues, Technologies, and Applications*. Metcalf & Eddy.

Base Aérea N.°5. (2020). *Declaração Ambiental 2020*. https://www.emfa.pt/paginas/certificacaoambiental_infinstitucional_fap/ficheiros/Declara%C3%A7%C3%A3o%20Ambiental%202020.pdf

Base Aérea N.°5. (2020). *Plano Estratégico de Sustentabilidade Ambiental da Base Aérea N.º 5 (PESA BA5)*. https://www.emfa.pt/paginas/infinstitucional_fap/ficheiros/2021/PESA%20B A5.pdf

Base Aérea N.°5. (2020). *Relatório de Sustentabilidade Ambiental 2020.* https://www.emfa.pt/paginas/fap/ficheiros/Documentos/Relat%C3%B3rio%20de%20Sustentabilidade%20Ambiental%202020.pdf

Base Aérea N.°5. (n.d.). *Funcionamento da estação.*

Chaplin, B. P. (2018). Chapter 17- Advantages, Disadvantages, and Future Challenges of the Use of Electrochemical Technologies for Water and Wastewater Treatment. In C. A. Martínez-Huitle, M. A. Rodrigo, O. Scialdone (Eds.), *Electrochemical Water and Wastewater Treatment* (451-494). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-12-813160-2.00017-1

CEMOWAS2. (n.d.). *Emerging Technologies in Wastewater Treatment.*

Daims, H., Taylor, M. W., Wagner, M. (2006). Wastewater treatment: a model system for microbial ecology. *Trends in Biotechnology*, *24*(11), 483-489. https://doi.org/10.1016/j.tibtech.2006.09.002

Decreto-Lei n.°119/19. (2019). https://dre.tretas.org/dre/3824634/decreto-lei-119-2019-de-21-de-agosto#anexos

Decreto-Lei n.° 348/98. (1998). https://files.dre.pt/1s/1998/11/259a00/59825983.pdf

Delgado, Filipe. (2021, September 24). *Defense & Sustainability: Air Base 5, Portuguese Air Force* [Lecture]. SIT Portugal Fall 2021 Excursions. Base Aérea N.°5.

European Commission. (n.d.). *Eco-Management and Audit Scheme.* Environmental Commission Europa. https://ec.europa.eu/environment/emas/index_en.htm

European Environment Agency. (n.d.) *Use of freshwater resources in Europe.* European Environment Agency Europa. https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-3/assessment-4

European Union Green Public Procurement. (n.d.). *EU GPP Criteria for Flushing Toilets and Urinals.*

Feier, B. et al. (2018). Electrochemical detection and removal of pharmaceuticals in waste waters. *Current Opinions in Electrochemistry, 11*, 1-11.

Ferreira, A. R. L. (2018). Electro-based technologies for contaminants removal from soil and effluents targeting further reuses. [Doctoral dissertation, Universidade Nova de Lisboa]. Repositório Universidade Nova.

Gerba, C.P. & Pepper, I.L. (2019). *Environmental and Pollution Science: Municipal wastewater treatment*. Academic Press. https://doi.org/10.1016/B978-0-12-814719-1.00022-7

Khan, M. Z. K. (2012). Micro-pollutant risks associated with using recycled water. *Journal of Civil Engineering, 40*(1), 11-22.

Lavrnić, S., Zapater-Pereyra, M., Mancini, M.L. (2017). Water Scarcity and Wastewater reuse Standards in Southern Europe: Focus on Agriculture. *Water Air Soil Pollution, 228*, 251. DOI 10.1007/s11270-017-3425-2.

Magro, C. J. C. (2019). Advances in applied electrokinetics: Treatment, by-products reuse and sensors' system. [Doctoral dissertation, Universidade Nova de Lisboa]. Repositório Universidade Nova.

Marecos do Monte, H. (2010, October 19-20). *Water Reuse in Portugal: Regulations and Practice* [Conference Session]. Conferencia Internacional de la Asociación Española de Reutilización Sostenible del Agua, Madrid.

Mayer, P. W. & DeOreo, W. B. (n.d.). *Residential End Uses of Water.* AWWA Research Foundation.

Mudge, S. & Ball, A. (1964). *Environmental Forensics: Sewage.* Academic Press. https://doi.org/10.1016/B978-012507751-4/50025-2

Perry, T.A. (2020). *Avaliação da Remoção de Azoto por Nitrificação e Desnitrificação Simultânea Caso de Estudo: ETAR da Base Aérea nº5*. [Master's thesis, Universidade Nova de Lisboa]. Repositório Universidade Nova.

Quinteiro, P. et al. (2019). Mapping green water scarcity under climate change: A case study of

Portugal. *Science of the Total Environment*, *696*, 1-9. https://doi.org/10.1016/j.scitotenv.2019.134024

Rebelo, A. et al., (2020). Water reuse in Portugal: New legislation trends to support the definition of water quality standards based on risk characterization. *Water Cycle.* 1, 41-53. https://doi.org/10.1016/j.watcyc.2020.05.006

Relatório do Estado do Ambiente (2021). *Water: Urban Wastewater.* https://rea.apambiente.pt/content/urban-wastewater?language=en

Rocha, B. F. S. (2020). *Valorização de Efluentes Urbanos. Caso de Estudo Base Áerea N.º 5, Monte Real.* [Master's thesis, Universidade Nova de Lisboa]. Repositório Universidade Nova.