UNIVERSIDAD DE INVESTIGACIÓN DE TECNOLOGÍA EXPERIMENTAL YACHAY

Escuela de Ciencias Biológicas e Ingeniería

Título: Design of an integral treatment system to reduce the impact of eutrophication in the Yahuarcocha lagoon

Trabajo de integración curricular presentado como requisito para la obtención del título de Biólogo

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Dedicatoria

Dedico este trabajo a mi madre que siempre está a mi lado apoyándome y subiéndome el ánimo para seguir adelante y superarme, a mi padre por el esfuerzo y arduo trabajo que realiza para entregarme las herramientas necesarias para alcanzar mis metas, a mis hermanos por ser ejemplos a seguir y una motivación para no quedarme atrás en el aspecto académico y profesional. En general a toda mi familia por siempre brindarme su apoyo cuando más lo necesite y por generar un ambiente lleno de unión.

Francisco Rafael León Chamorro

Agradecimiento

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Francisco Rafel León Chamorro

Resumen

Los niveles de eutrofización en la laguna de Yahuarcocha se han incrementado drásticamente en los últimos años debido a la acción antropogénica alrededor del cuerpo de agua, esto ha tomado la atención de los ciudadanos que viven cerca de la laguna y de las entidades públicas. En este proyecto se propondrá un modelo de Planta de Tratamiento de Agua para reducir el nivel de eutrofización en la laguna. Los primeros pasos de la planta son los habituales en las plantas de tratamiento de aguas residuales, como el tratamiento preliminar para eliminar los sólidos que pueden dañar el equipo en los siguientes tratamientos; el tratamiento primario para sedimentar los sólidos con mayor densidad que el agua; el tratamiento biológico mediante una piscina aireada para reducir la materia orgánica; el decantador secundario para recircular los lodos activados, y el tratamiento de lodos para obtener energía y reducir el volumen de lodos generados. Los pasos adicionales serán el tratamiento con luz UV-C para desinfectar el agua y matar las microalgas y cianobacterias sobrevivientes, implementación de un humedal artificial para reducir la cantidad de nutrientes utilizando dos fases, la primera es un humedal superficial con *Eichhornia crassipes* que tiene una tasa de crecimiento rápida y gran absorción de nutrientes, el exceso se utilizará como alimento para el ganado; la segunda fase es un humedal sub superficial con *Typha latifolia* para reducir los metales pesados y evitar las fugas de *Eichhornia crassipes*. Finalmente, el último paso es la implantación de tecnosuelos anti eutroficantes para eliminar los restos de nutrientes del agua. Todo este proceso reducirá la cantidad de nutrientes y algunos contaminantes del agua reduciendo el alimento disponible para el crecimiento de las microalgas y cianobacterias para restaurar el equilibrio en el ecosistema de la laguna.

Palabras clave: Eutroficación, Planta de Tratamiento de Agua, humedales artificiales, luz UV-C, tecnosuelos.

Abstract

Levels of eutrophication in the Yahuarcocha lagoon have increased drastically in the last few years because of anthropogenic action around the water body, this has taken the attention of citizens that live near to the lagoon and public entities. In this project will be propose a model of Water Treatment Plant to reduce the eutrophication level in the lagoon. The firsts steps of the plant are the common ones used in Waste Water Treatment Plants like preliminary treatment to remove solids that can damage the equipment of following treatments; primary treatment to settle solids with higher density that water; biological treatment using an aerated pool to reduce organic matter; secondary settler to remove activated sludge, and sludge treatment to obtain energy and reduce the volume of sludge generated. Additional steps will be a UV-C light treatment to disinfect water and kill the survival microalgae and cyanobacteria, implementation of an artificial wetland to reduce the amount of nutrients using two phases, the first one is a superficial wetland with *Eichhornia crassipes* which has a fast growth rate and the excess will be used as cattle food, the second phase is a sub superficial wetland with *Typha latifolia* to reduce heavy metals and avoid leaks of *Eichhornia crassipes*. Finally, the implementation of anti-eutrophication techno soils to remove the remaining nutrients from the water. This whole process will reduce the amount of nutrients and some contaminants from water reducing the available food for microalgae and cyanobacteria growth to restore the equilibrium into the lagoon ecosystem.

Key words: Eutrophication, Water Treatment Plant, artificial wetland, UV-C light treatment, techno soils.

Contents

Index of Figures

Index of tables

Annexes

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Chapter 1

Introduction

1.1. Background

Anthropic activities have caused a great impact on the environmental balance during the last decades, both in the continental and maritime part affecting one of the most limited and important resources for humanity, water, especially fresh water, which is indispensable for humans, animals and plants. In this context, the Yahuarcocha Lagoon has undergone a drastic change in the eutrophication levels in recent years due to poor environmental practices and anthropogenic activities near the lagoon and its tributaries. The most common activities that increase the eutrophication are tourism, agriculture, livestock, sports and recreational activities, leading to an increase in organic matter and nutrients in the water body. This causes an increase in phytoplankton growth which lead to a series of events like reduction of dissolved oxygen leading into asphyxia of aquatic animal, reduction of light in the water column leading in the dead of submerged aquatic plants that increase sediments, increasing the anaerobic activity that degrade the quality of the aquatic ecosystem. Lack of interest and poor management of this environmental situation can lead to a level of deterioration of the ecosystem with irreversible consequences such as the significant loss of the biotic part that depends on this resource (Oquendo, 2016). Because Yahuarcocha is part of the UNESCO Global Geopark (Imbabura), it is required to prioritize its remediation and take immediate action to set a good example of conservation of our Lakes and Lagoons. The purpose of this project is to propose a possible solution through a water treatment plant that focuses on reducing the amount of microalgae, organic matter and nutrients present in the lagoon.

1.2. Yahuarcocha Lagoon

Yahuarcocha is considered a micro-basin because its surface area is less than 10,000 ha (2574.55 ha). Figure 1 shows the location of the micro basin in the north of Ecuador in the province of Imbabura, San Miguel de Ibarra (0°22'N 78°06'W) and the closest towns to the micro basin are Priorato, Aloburo, Cachipamba, San Francisco, Yuracruz, Yuracrucito, Bellaurco, Olivo Alto and San Miguel de Yahuarcocha (GAD Municipal de San Miguel de Ibarra, 2018).

Among the main freshwater tributaries that enter the lagoon are the Manzano Huaycu, Polo Golo and San Antonio streams, but due to their low flow and intermittency they are not a significant contribution of water, but contribute nutrients and organic matter. In times of drought, leaf litter, garbage and population wastes accumulates, besides being close to agricultural areas the remains of fungicides, pesticides, fertilizer and animal feces run off in times of rain to the lagoon. On the other hand, the affluent coming from the Tahuando River is constant and is the main water source (GAD Municipal de San Miguel de Ibarra, 2018).

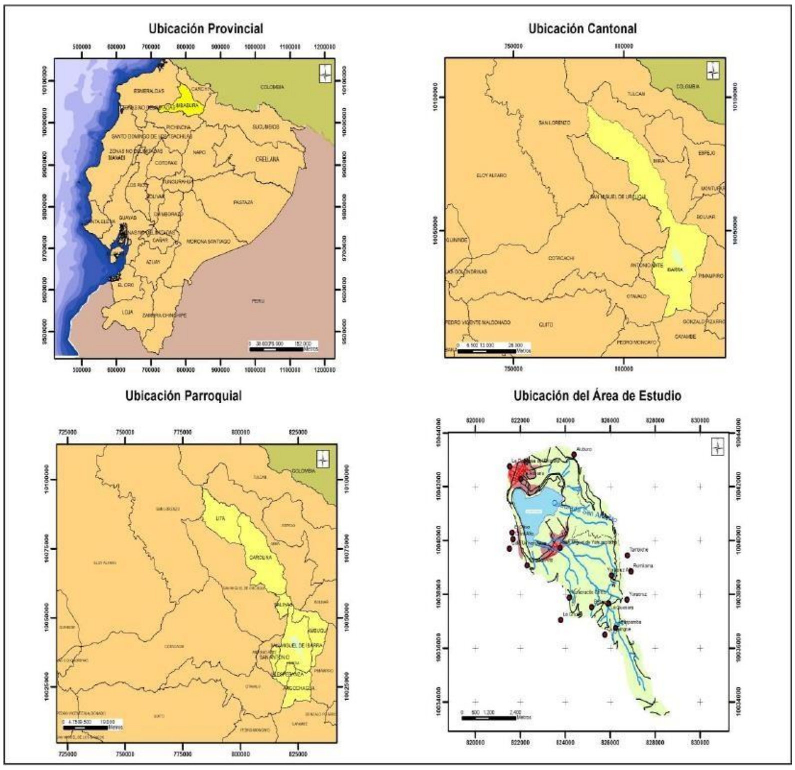

Figure 1. Geographical location of the Yahuarcocha Lagoon micro basin. Country Ecuador, canton Ibarra, parish Ibarra, micro basin Yahuarcocha. (GAD Municipal de San Miguel de Ibarra, 2018)

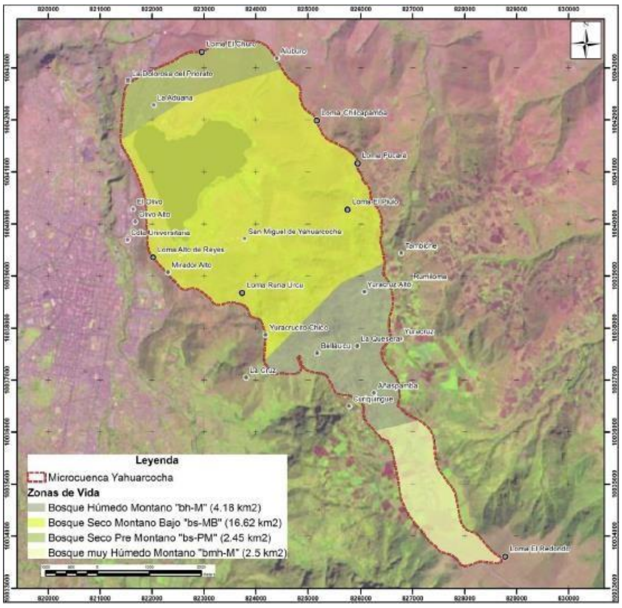

Figure 2. Life Zones Map of Yahuarcocha Lagoon micro basin. Here we can see the different kinds of weathers along the micro basin. (GAD Municipal de San Miguel de Ibarra, 2018)

The micro-basin is divided into three main zones: the high zone is a very humid montane paramo-type forest, the middle zone consists of humid montane forest, and the low zone is surrounded of dry montane forest; its maximum altitude is 3820 m.a.s.l, and the lowest elevation is 2200 m.a.s.l (Oquendo, 2016). The surface area of the lagoon is 2.6 km^2 and has a volume of approximately 13 million m^3, the temperature varies from 5°C to 20°C and has an annual precipitation of 750 mm (Table 1) (Saelens, 2015).

Table 1. General Characteristics of Yahuarcocha lagoon.

Parameter	Yahuarcocha
Latitude (N)	00°22'32,2"
Longitude (W)	078°06'6,5"
Altitude (m)	2192
Surficial area (km^2)	2.6
Maximum depth (m)	6.9
Mean depth (m)	4.9
Volume (m^3)	12.7*10^6
Annual precipitation (mm)	750
Catchment area (km^2)	23.71
Urban area (%)	6.07
Plantations (%)	1.86
Agricultural area (%)	25.64
Páramo (%)	1.64

Source: (Saelens, 2015)

1.3. Eutrophication

Eutrophication is a natural process that occurs in all bodies of water and consists of the increase of nutrients and detritus that serves as nutrient substrate in the water either by the organic waste of animals (feces and decomposition of dead animals) and plants of that ecosystem or by the entry of nutrients through rainfall which erodes the surrounding soils and washes away nutrients (Salcedo, 2019). In general, the aging process is very slow since the ecosystems have to be in homeostasis, and the loss of water bodies can take hundreds or thousands of years due to the accumulation of sediments by the decomposition of organic matter (Callisto, Molozzi & Etham, 2014). In the last decades this process has accelerated in an alarming way due to anthropic activities such as deforestation, tourism, agriculture, cattle raising, fishing, etc. These activities alter the balance of the ecosystem by increasing the amount of nutrients and organic matter entering the water body, thus accelerating the eutrophication process, and in some cases facilitating the colonization of species to alter this homeostasis (Ansari & Gill, 2014).

In the case of Yahuarcocha Lagoon, the main factors contributing to the acceleration of eutrophication are agriculture and tourism (Salcedo, 2019). Perhaps, the excessive use of pesticides, fungicides, fertilizers, and other supplements used for rapid crop production have drastically increased nutrient inputs into the lagoon. The lower and middle zone of the micro-basin are the main agricultural areas located near the lagoon's tributaries (GAD Municipal de San Miguel de Ibarra, 2018). On the other hand, the large number of tourists coming to the lagoon, especially on weekends, has led to an increase in the number of restaurants and recreational activities. The worst the wastes coming from these restaurants and from the town of Yahuarcocha used to reach a small wastewater treatment plant, but because it was not working properly, it was closed in 2013. (Saelens, 2015).

This increase in nutrients has unleashed an overgrowth of microalgae and cyanobacteria, especially of the genus *Cylindrospermopsis*, affecting the quality of the water. (Saelens, 2015). This leads to a reduction in the amount of dissolved oxygen (DO) in the water, directly affecting the animals that live in the lagoon as they could suffocate and die. Also, reduces the amount of light in the water column because phytoplankton absorbs light to do photosynthesis, which further reduces the amount of

DO in the water as submerged macrophytes cannot do photosynthesis and starts to die increasing the amount of organic matter in the lagoon (Yépez, 2016). Finally, increase the biochemical oxygen demand (BOD) to oxidase or degrade the organic matter and increase the anaerobic activity in the sediments that releases bad odors and toxic gases (Ongley, 1997).

This research will propose a different application of the model of Waste Water Treatment Plants to reduce eutrophication in lakes, using this process like a giant filter. Actually, Water Treatment Plants treats the water that enters into the water body, removing garbage and contaminants coming from near cities, but don't remove all the remaining nutrients that can be generated in the process and ends in the lake contributing the eutrophication. Coupling steps that remove these nutrients like wetlands and technosoils the eutrophication can be reduce. Additionally, if the water of the lagoon is treated, can be avoided the accumulation of sediments that are generated by the effects of eutrophication and degrade the water quality.

1.4. Objectives

1.4.1. General objective

- Propose a plant treatment of water model to minimize the negative eutrophication effects in the Yahuarcocha Lagoon that has been affected by an enrichment of nutrients that triggers a bloom of phytoplankton, mostly *Cylindrospermopsis sp.*

1.4.2. Specific objectives

- Explain how eutrophication reduces water quality in fresh water bodies and why is important to take cautions.
- Describe step by step the water treatment plant process that is proposed to minimize eutrophication effects in the lagoon.
- Propose possible approaches for the generated for social and economical benefits.

Chapter 2

Treatments

One of the most common ways to reduce the amount of nutrients and contaminants that enter into a lagoon is using waste water treatment plants in the sources of water income, but I propose a water treatment plant for the water lagoon because of the long residence time or permanence of the water in the lake (12 years) (Yépez, 2016).

In order to reduce the level of eutrophication in the Yahuarcocha Lagoon, it is necessary to carry out several water purifications steps like preliminary treatment, primary and secondary treatment that are basic in a Waste Water Treatment Plant. Additional steps will be wetlands with *Eichhornia crassipes* and *Typha latifolia* that are described below and implementation of technosoils.

2.1. Preliminary treatment

In this step suspended solids of considerable size (> 5 mm) and inert matter are removed from the water flow to avoid damage or wear in the machinery of the subsequent steps.

2.1.1. Water intake pump

To take the water directly from the lagoon, a submersible pump is needed to move the water to a well where the water level will be controlled by floats,in this way when the water reaches the desired level the inlet pump will stop working until it is necessary to refill the well, this step is essential because if we send the water directly to the other stations and we could saturate the machines and present failures.

For this work, it is recommended to use a submersible centrifugal pump with an anti-clogging impeller, since it is not necessary that their performance is high and they suffer from few problems of clogging with solid materials (Fernández, 2016).

The disadvantage of using a centrifugal pump inside the lagoon is that it could drag some fish with it, so it is recommended to place a series of cages with slots of variable size, 4 cm and another of 2 cm, to avoid the entry of fish that could affect the operation of the pump. It should also be taken into account that the pump will be located at a distance of 15 m from the water outlet of the current treatment plant and at a depth of 1.5 m to suck the largest amount of microalgae and cyanobacteria possible, and by being far from the shore, the suction of large debris is avoided.

2.1.2. Retention pit

The well enables to control the amount of water entering the treatment process, it also serves as a small decanter because if solid material of high weight enters it will accumulate at the bottom of the well, it is important to clean it regularly to avoid fermentation processes and consequently bad odors. (Fernández, 2016).

2.1.3. Secondary Pump

This pump is responsible for carrying the water from the well to the screening stage, for which another submersible centrifugal pump can be used as the one used in the water intake to the well. We must take into account that a second centrifugal pump is required as a backup in case the first one gets clogged (Fernández, 2016).

2.1.4. Screening

The role of screening is to remove suspended and floating solids such as casings, wood, leaves, bottles and organic matter of considerable size (larger than 2 cm) that can damage the structures (pipes and pumps) of the subsequent steps in the decontamination process (Veloz, 2020). In the figure 3 we can see the screen mechanism that consists of a screen with uniform holes or a grid that has its rods inclined from 30 to 60° with a separation of less than 5 mm to allow the water to drain and the solids to slide down the screen for later collection (Valdez & Vázquez, 2003).

Figure 3.Hydroscreen with speciated rods of 5mm to separate solids from water (JUMAPAC, 2016)

2.1.5. Grit trap

Once the solids of significant size have been removed, it is necessary to remove the inert particles of small size such as sand and gravel as these can impair the performance of primary and secondary treatment by accumulating in the pipes, in the pumps and wear out the machines due to their abrasive effect. In addition, they can accumulate during the sludge treatment process, reducing the sludge capacity and thus reducing the time-consuming cleaning of the sludge tanks. (Fernandez, 2016). The grit traps work by means of selective settling, this can be carried out in channels with enough length to allow the heavier particles to settle and then be removed. A vortex effect also allows the heavier particles to remain at the bottom for later extraction using a suction pump and with the help of a water jet as shown in figure 4 light blue arrow.

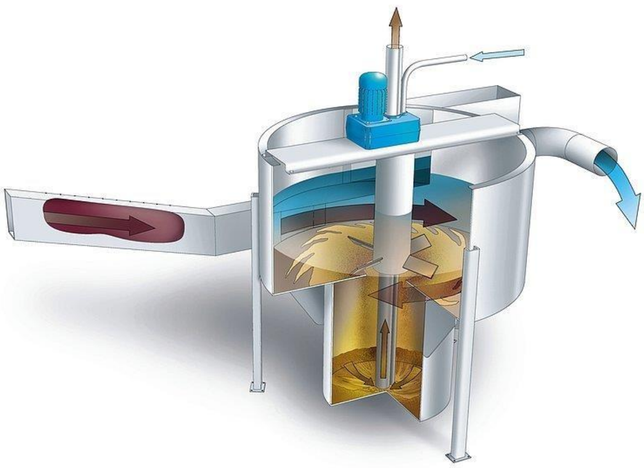

Figure 4. Vortex Grit Chamber to separate small solid matter from water. (Huber Technology Waste Water Solutions, 2010)

2.2. Primary Treatment

At difference of preliminary treatment, primary treatment has a longer retention time of water into the tank that allows to settle small particles.

2.2.1. Primary Settler

After removing the largest amount of large suspended solids in the preliminary treatment, the water reaches the primary settling tank. This equipment is designed to perform two important functions: to remove settleable organic matter that has a higher density than water, and to separate floating matter such as fats and oils that have a lower density than water (Valdez & Vázquez, 2003). Two types of designs are generally used for this process, one is in a horizontal flow rectangular tank as shown in figure 5, with sufficient length to allow the suspended solids to settle at the bottom of the tank, in addition allows the matter that is less dense than water to accumulate on the surface in the form of foam. In order to collect both the sediment and the foam generated, this model of settling tank is equipped with scrapers that remove the sludge in the bottom to its extraction point by means of suction pumps. While on the surface remove the accumulated fats and oils up to its collection point, which is a little before the outlet of the treated water (Valdez & Vázquez, 2003).

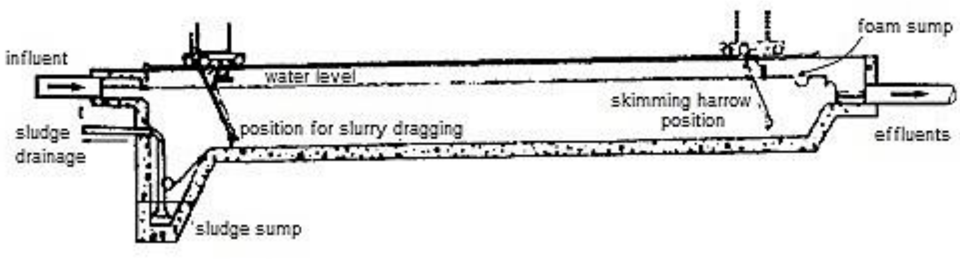

Figure 5. Rectangular settler scheme with the main parts, arrows show the flow of water (Valdez & Vázquez, 2003)

The other model of primary settler used is a circular one with radial flow that is shown in figure 6. In this model water enters through the lower central part, and as in the rectangular one, it has scrapers that are in constant movement along the surface and the base of the tank to collect the sludge and the foam generated (Valdez & Vázquez, 2003). It should be noted that the movement is slow to avoid re-suspending the sediments. Figure 7 shows the typical parameters used in the design of primary settling tanks.

Table 2. Design parameters for primary settling tanks

Parameter	Range	Typical Value
Detention time (h)	1.5 - 2.5	2.0
Overflow rate ($m^3/m^2.d$)	-	-
-At average flow	32 - 50	40
-At peak hourly flow	78 - 120	100
Weir loading rate ($m^3/m.d$)	125 - 500	260
Rectangular Tank (m)	-	-
-Length	15 - 90	25 - 40
-Width	3 - 24	5 - 10
-Depth	3 - 5	4.5
Circular Tank (m)	-	-
-Diameter	3 - 60	12 - 40
-Depth	3 - 5	4.5

Source: (Veloz, 2020).

During this process there are some variants that can affect the sedimentation performance such as a bad preliminary treatment implying the increase of large sediments that pass through the pumps and extraction pipes, wearing out the equipment and increasing the possibility of accumulation and clogging in the process. Temperature changes in the water which increase the viscosity generating density currents, swirling currents can also be generated by the entry of water or by the action of wind currents. Primary settler usually removes 50 to 60% of the suspended solids (Valdez & Vázquez, 2003).

The advantage of using water directly from the lagoon is that it does not enter a large amount of colloidal waste as in wastewater treatment plants, this drastically reduces the amount of sludge generated since most of it is expected to be microorganisms such as microalgae and cyanobacteria.

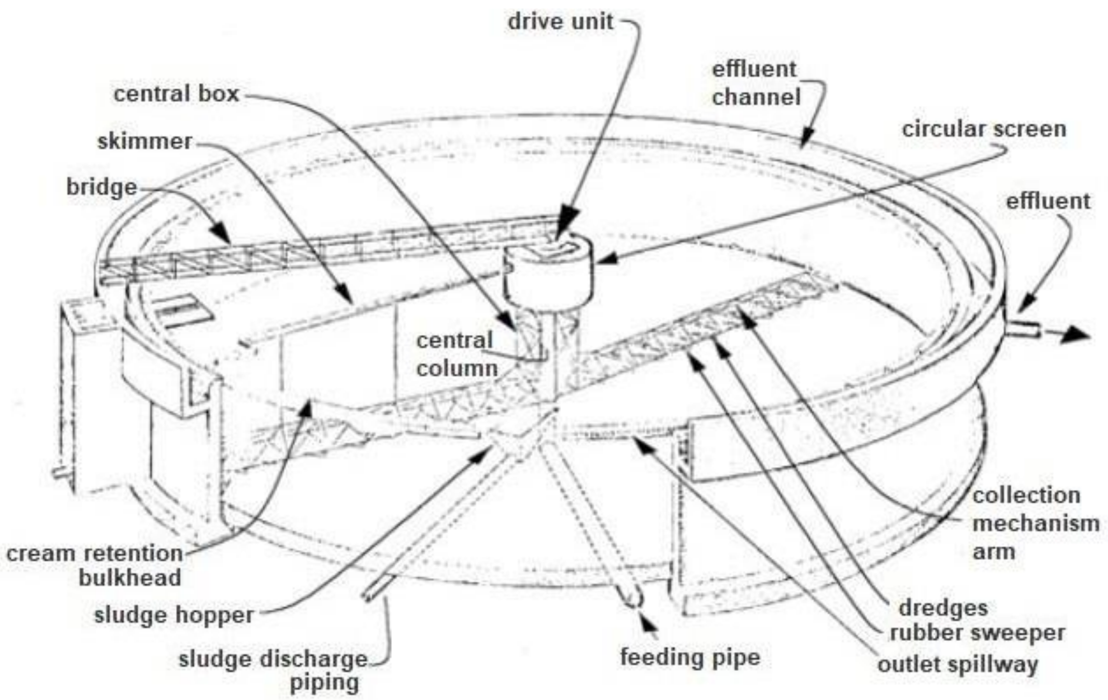

Figure 6. Circular settler with the main parts, water enters from the bottom and exits from the top (Valdez & Vázquez, 2003)

To boost the efficiency of the settling tanks, coagulating agents such as aluminum sulfate ($Al_2(SO_4)_3$) or ferric chloride ($FeCl_3$) can be added to increase the amount of settleable solids removed from the liquid (Veloz, 2020). However, since these coagulants can affect the lagoon ecosystem it is preferable avoid its use. If desired, natural organic coagulants can be used, such as the one extracted from tamarindseeds (*Tamarindus indica*), which achieves a removal rate of 85% under optimal conditions, (Ramirez, 2019) or the one extracted from the prickly pear plant (*Opuntia ficus-indica*), which has a removal rate of more than 50%, but if supplemented with aluminum sulfate can reach 95% removal rate. (Contreras et al, 2015). If a coagulant is used, it should be added before entering the primary settling tank in a mixing tank, where the exact amount should be added for the indicated volume to avoid reducing the effectiveness of the coagulant and increasing the amount of unnecessary matter entering the settling tank.

2.3. Secondary Treatment

Secondary treatment is mainly carried out by biological processes where millions of microorganisms use the remaining organic matter from the primary sedimentation as a food source, biological processes are cheaper and have a high efficiency (Valdez & Vázquez, 2003). During a biological process a great diversity of microorganisms are involved, which are in charge of consuming or transforming the remaining organic compounds of the treated water in the primary settler in order to produce more biomass and reduce the BOD. We do not have knowledge of all the metabolic processes that occur within the biological treatment since there is so much diversity that each microorganism uses the food source that most favors its development (Valdez & Vázquez, 2003).

Of the groups of microorganisms that we have greater knowledge of their metabolism and are more relevant are nitrifiers, responsible for converting the ammonia present in animal waste into nitrites and nitrates that are less toxic to aquaticfauna (Le, Yoshimura, & Fujii, 2017). Sulfur oxidizers, responsible for oxidizing sulfur compounds and converting them into sulfates; and those responsible for fixing carbon dioxide for the construction of cell mass (Moeller & Tomasini, 2017). During all this process an aerobic environment is required, so it is necessary to inject enough atmospheric oxygen to maintain an optimal environment for the development of microorganisms. Secondary treatment enhances the biological process that happens naturally in aquatic ecosystems, to reduce the time it takes to oxidize the organic matter that reaches this stage (Moeller & Tomasini, 2017).

There are several mechanisms used for biological treatment such as trickling filters, bio-towers and biological discs that act as adherent culture systems. On the other hand, there are activated sludge that work as suspended culture systems and are the most used actually (Valdez & Vázquez, 2003).

2.3.1. Activated sludge

This process involves the accumulation of active microorganisms capable of stabilizing the waste in an aerobic way, the wastewater obtained from the primary treatment is used and mixed with the activated sludge from the secondary settler or secondary clarifier, which will be discussed later, this mixture enters the aeration tank as shown in figure 7, where the organisms and the wastewater are mixed thanks to the movement generated by air bubbles allowing the oxidation and absorption of the waste which generates new microbial cells by using the energy obtained from the oxidation of the waste. (Valdez & Vázquez, 2003). The air that enters the tank comes from air pumps that reach the tank and are expelled by diffusers that generate many small air bubbles which facilitate the oxidation of suspended matter.

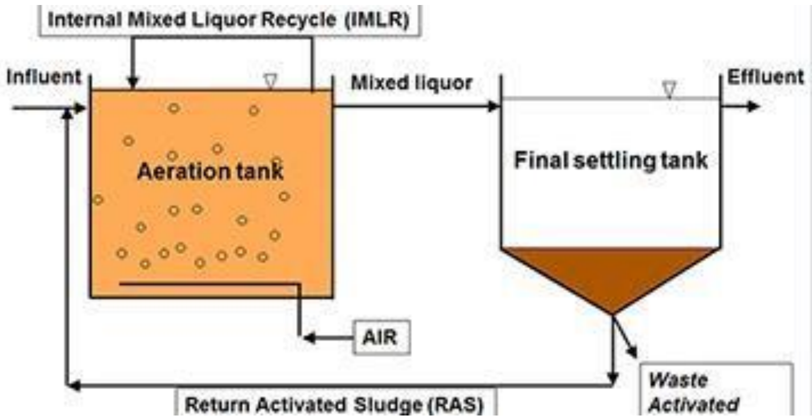

Figure 7. Activated sludge process (Smith, 2016).

2.3.2. Secondary settler

Secondary settler has the same function of primary settler, but this focus in the remaining sludge from biological treatment. The water coming out of the aeration tank contains a large amount of activated sludge (beneficial microorganisms) that need to be removed from the effluent to ensure that the water coming out of this process complies with the country's official standards. (Valdez & Vázquez, 2003). The sludge is of a flocculant nature will facilitates its collection; a large part of the collected sludge goes back to the aeration tank while the rest goes to the sludge treatment. The purpose of return activated sludge to biological treatment is to avoid the loss of young microorganisms, that have a higher performance in the oxidation of organic material, also, to avoid the accumulation of a large amount of old microorganisms which have a lower performance.

The resulting water comes out with a low level of dissolved organic matter but with a considerable amount of nutrients. An additional advantage provided by the secondary settler is that the water comes out with a reduced flow rate which favors the performance of the next step, which is disinfection (Valdez & Vázquez, 2003).

2.4. Sludge Treatment

The objective of treating the sludge obtained from the primary and secondary settler is to reduce the sludge population and stabilize the organic matter, the first step to achieve this is to enter the sludge to an anaerobic digester where the sludge consumes each other thanks to conversion processes carried out by anaerobic bacteria (Licera, 2016). This process is carried out at a temperature of 36° so it is necessary to apply heat energy to maintain the temperature. One of the most important things of this process are the by- products that are generated as biogas (methane) that can be collected in a tank and then be reused to cover part of the energy required for this process (Licera, 2016). Once the sludge is stabilized, it goes to a thickener where as much water as possible is extracted and then the excess sludge is sent to a belt filter (permeable belt) where the remaining water is extracted. The dry sludge obtained is rich in nutrients and can be reused in the agricultural sector or simply sent to a sanitary landfill (Licera, 2016).

2.5. Short wavelength Ultra Violet (UV-C) light treatment

UV-C light treatment is a disinfection process that kill a long range of microorganisms. After secondary settler, disinfection is usually performed using gaseous chlorine in channels before the effluent outlet (Licera, 2016). Since the water will return to the lagoon and chlorine can be harmful to aquatic fauna, it is preferred to use a treatment with UV-C light that treats the water of possible pathogens and especially reduces microalgae and cyanobacteria that could not be removed during the primary and secondary process. UV-C light is used because it has a wavelength of 200 nm to 280 nm, a range in which it affects cell structure, genetic material, photosynthetic system, nitrogen fixation and assimilation. (Li et al, 2020).

As part of the water treatment is crucial to remove as many cyanobacteria as possible because they produce cyanotoxins that can be harmful to aquatic fauna and to humans who come into direct contact with them during recreational activities in the lagoon. The most common cyanotoxin that is harmful to humans is microcystin, produced by the genera *Microcystis, Anabaena* and *Cylindrospermopsis* (Sedan & Andrinolo, 2011). Microcystin is responsible for producing Caruaru Syndrome, in the worst cases, the symptoms of this syndrome are general malaise, weakness, abdominal pain, myalgia, headache, visual difficulties, lethargy, gastrointestinal bleeding, jaundice, symptomatic hypoglycemia, nausea and vomiting (Sedan & Andrinolo, 2011).

Due to this public health risk, it is necessary to apply a system that is as effective as possible, as shown in figure 8, one of the most abundant cyanobacteria in the lagoon is currently of the genus *Cylindrospermopsis* and may represent a long-term problem. According to Li et al (2020) the removal efficiency of *Cyanophyta (Microsistis aeruginosa* and *Anabaena variabilis*) is 75 to 80% using UV-C light irradiation at high doses (200 mJ/L). As reported by Sedan & Andrinolo (2011), it could be inferred that UV-C light treatment would also be effective in removing cyanobacteria of the genus *Cylindrospermopsis,* that are the main generators of microcystin and the most abundant in the Yahuarcocha lagoon at present.

The disadvantage of this process is that microorganisms have to be exposed to the light as much time as possible. This requires a considerable amount of UV-C lamps depending on the size of the chamber that will be needed. Water must be exposed to this light both above and below, also the lamps used in the filters of ornamental ponds can be used, but the flow would be low and many would have to be placed in series. On the other hand, a concrete chamber can be made with a glass base in which lower lamps would be installed and the channel should be in the form of a fold to make better use of the space in the chamber. On the other hand, the energy demand is higher than that of a normal light bulb.

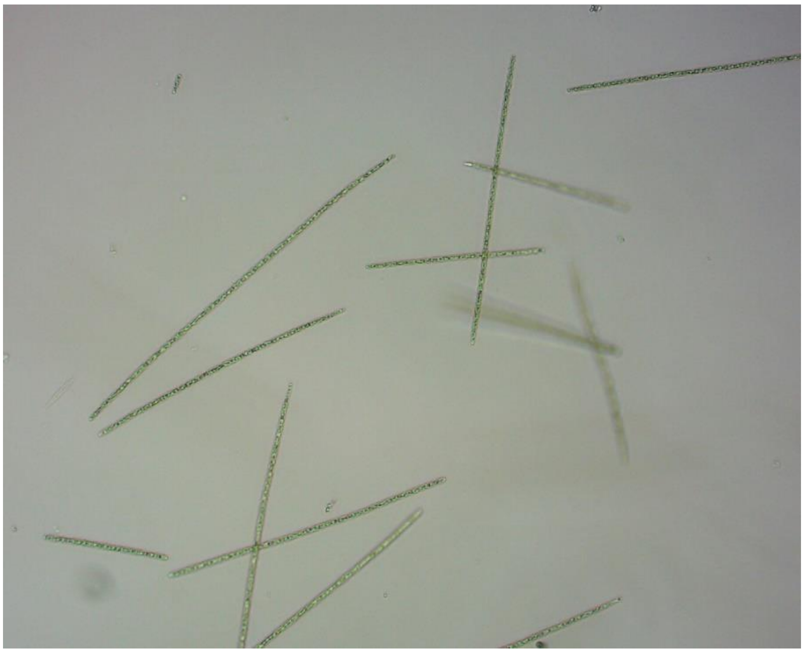

Figure 8. Photo in the microscope with 400x of a sample taken from the Yahuarcocha Lagoon. Cylindrospermopsis sp. is the most abundant phytoplankton.

2.6. Phytoremediation

Phytoremediation consists in approaching plants and their microbial rhizosphere to degrade and absorb the remaining nutrients in water (Odjegba & Fasidi, 2007). Once the water has been disinfected with the help of UV-C light, its needed to remove the organic and inorganic nutrients that remain in the water, since the secondary treatment doesn't remove all the nutrients. If they are not removed from the effluent and return to the lagoon they will be used by the microalgae and cyanobacteria to continue proliferating. Phytoremediation also has the potential to store or reduce some of the heavy metals present in the water due to poor management of agricultural and industrial wastes. (Odjegba & Fasidi, 2007). The problem of heavy metals in the lagoon has increased in recent years and is affecting aquatic fauna, specifically crayfish (*Procambarus clarkii)* and tilapia (*Oreochromis mossambicus)* where have been see the bioaccumulation of heavy metals in their tissues (Galarza & Pérez, 2019). Implying that people in the area who use tilapia as food source are also exposed to heavy metals. During a study conducted by Galarza & Perez (2019) 327 inhabitants of the San Miguel de Yahuarcocha neighborhood which is located next to the Lagoon, were interviewed to get information on the use of lagoon resources, 48.6% do not use any lagoon resources, 21.7% use lagoon animals as a source of food and trade especially fish, 12.2% use plant material such as cattails (*Typha latifolia*) for handicrafts such as mats, 8.3% use it for recreational activities within the lagoon and 9.1% of respondents use two or more resources such as irrigation of plants, food and handicrafts (Galarza & Pérez, 2019). This translates into an increase in cases of heavy metal poisoning from eating contaminated food. Heavy metals tend to accumulate quickly in the kidneys causing nephropathy that can result in renal failure (Barbier et al, 2005).

To prevent future intoxications, it is necessary to implement a phase in the decontamination system in which heavy metals are removed from the wastewater. This process can be carried out by physical-chemical methods such as addition of activated carbon or selective membranes, but as mentioned above, it increases the cost, so it is preferable to use phytoremediation.

2.6.1. Artificial Wetlands

This phytoremediation method consists of replicate natural wetlands that serve as a water filter due to their self-purifying potential (Llagas & Guadalupe, 2006). Wetlands are not considered aquatic or terrestrial environments due to their complexity since they have submerged vegetation, emergent vegetation and floating vegetation (Llagas & Guadalupe, 2006). By constructing them artificially water bodies can be treated approaching the cleaner potential of plants. Physical removal process is one of the main advantages of wetlands, because the laminar flow of water in wetlands is very slow due to the resistance created by roots and aquatic plants (Llagas & Guadalupe, 2006). This allows the remaining suspended fine particulate matter to sediment and then be used in biological removal processes. Biological process removes nutrients such as nitrates, ammonium and phosphates that are used by plants for their growth (Llagas & Guadalupe, 2006). On the other hand, microorganisms are also responsible for capturing and storing some nutrients and pollutants but only in the short term due to their short life cycle. In the sediments are anaerobic reactions that reduce the amount of nutrients that sediment because microorganisms use carbonated waste as a source of energy and convert it into gases such as carbon dioxide (CO_2) and methane (CH_4) (Llagas & Guadalupe, 2006). There are also specialized bacteria such as *pseudomonas sp.* which metabolically transform nitrates into nitrogen gas (N_2) (Llagas & Guadalupe, 2006). Chemical removal process is more related to the type of soil present in the wetland, especially in sub superficial wetlands because water pas through a bed of gravel or clay that facilitates adsorption and precipitation of contaminants (Llagas & Guadalupe, 2006). For example, clays facilitate the binding of cations such as ammonium (NH_4^+) to their surface, allowing the immobilization of certain nutrients and contaminants (Llagas Chafloque & Guadalupe Gómez, 2006).

In figure 9 we can see the three types of artificial wetlands that are most frequently used, superficial flow,sub superficial flow and free flow. To improve the performance of nutrient absorption, the mixed application of these techniques is recommended (Fernández, 2002). It will be described in Chapter 3.

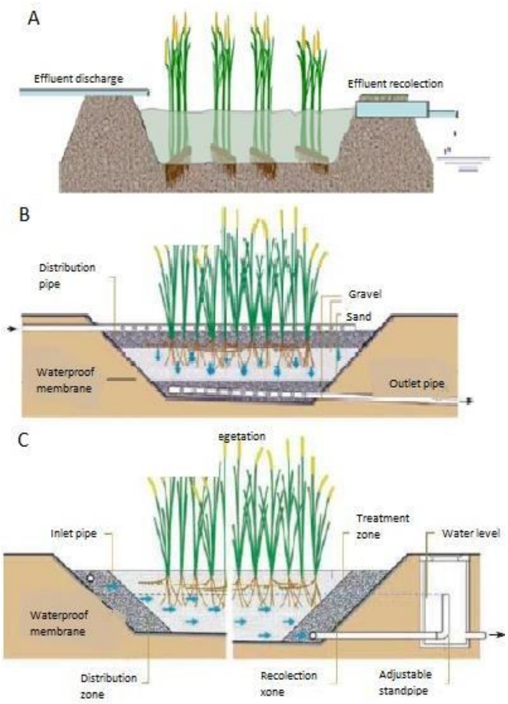

Figure 9. Types of artificial wetlands. A) Superficial wetland, B) Sub superficial wetland with horizontal flow, C) Sub superficial wetland with horizontal flow. Modified from (Galarza Guzmán & Pérez García, 2019).

The disadvantage of applying artificial wetlands is that they require a large space for this process to be effective since the longer the channel through which the water passesthe greater the amount of nutrients removed. Away to reduce the space used is to design them in the form of folds, leaving enough space for the entry of maintenance personnel between each fold. On the other hand, the construction cost is not high, for a sub-superficial of 1 275 m^3 the estimated value is $12 997 (Galarza & Pérez, 2019). The building value of a superficial wetland is about $7 000 because gravel is not needed.

2.7. Tecnosoles

Tecnosoles or technosoils are a way to modify soils according to specific needs, the word comes from Greek where techno means technology and sol means soil (Caballero & Velázquez, 2014). From here are born the soils à la carte because, if someone needs to compensate the lack of some nutrient in their land, they can ask for some soil rich in that nutrient or with some specific physical characteristic such as better water absorption. The disadvantage of this process is the elaboration of the technosoils, they cannot be made with all types of soils, so it is necessary to carry out a study of the performance of technosoils created with soils of the country (Caballero & Velázquez, 2014). Otherwise, it would be necessary to import them and it would increase drastically the cost of this method.

Chapter 3

Plant Treatment Process of Water

Development of a detailed model of a treatment plant requires precise information on the water to be treated like: chemical oxygen demand (COD), temperature (T), pH, alkalinity, total phosphorus, Kjedahl total nitrogen, BOD, total suspended solids, acetic acid and lactic acid, soluble fraction of COD and BOD (Pazmiño Arias, 2017). Figure 10 shows some of the parameters necessary to carry out the simulations in the Design and Simulation of Activated Sludge System (DESASS) program to model the secondary treatment, where the sludge treatment is the most complex because of the anaerobic reactions that occur. Additionally, the standard mathematical equations for the simulation of anaerobic reactions are shown in table 3 with the description of each variable in table 4. In this project only the scheme of the water decontamination process of the Yahuarcocha lagoon was elaborated because was not possible to obtain all the parameters to run off the simulation. Scheme is detailed below and can be seen in the Annex 1.

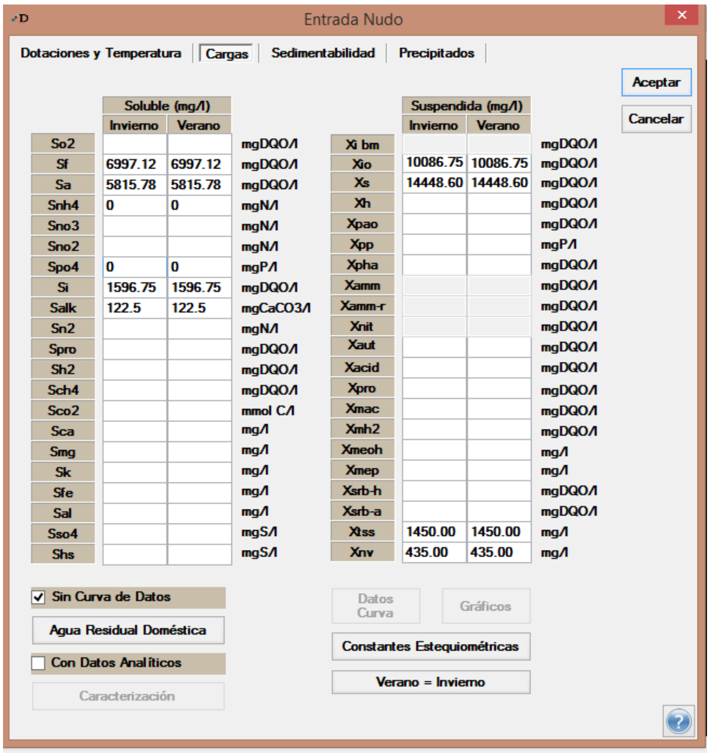

Figure 10. Soluble and particulate parameters considered for the characterization of the DESASS treatment influent (Pazmiño Arias, 2017).

Table 3. Biological Activated Sludge Model 1 equations to simulate aerobic and anaerobic activity in activated sludge

Compound → i process ↓ j Process	S_S	S_{NO}	S_{NH}	P_j, j = process for the n-th tank
1. Aerobic growth of heterotrophs	$\frac{1}{Y_H}$	0	$-i_{XB}$	$\hat{\mu}_H\left(\frac{S_S}{K_S+S_S}\right)\left(\frac{S_O}{K_{OH}+S_O}\right)X_{BH}$
2. Anoxic growth of heterotrophs	$-\frac{1}{Y_H}$	$\frac{1-Y_H}{2.86Y_H}$	$-i_{XB}$	$\hat{\mu}_H\left(\frac{S_S}{K_S+S_S}\right)\left(\frac{K_{OH}}{K_{OH}+S_O}\right)\left(\frac{S_{NO}}{K_{NO}+S_{NO}}\right)\eta_g X_{BH}$
3. Aerobic growth of autotrophs	0	$\frac{1}{Y_A}$	$-i_{XB}-\frac{1}{Y_A}$	$\hat{\mu}_A\left(\frac{S_{NH}}{K_{NH}+S_{NH}}\right)\left(\frac{S_O}{K_{OA}+S_O}\right)X_{BA}$
4. Hydrolysis	1	0	0	$k_h X_{BH}\left(\frac{X_s/X_{BH}}{K_x+X_s/X_{BH}}\right)\left[\left(\frac{S_O}{K_{OH}+S_O}\right)+\eta_h\left(\frac{K_{OH}}{K_{OH}+S_O}\right)\left(\frac{S_{NO}}{K_{NO}+S_{NO}}\right)\right]$

Source: (Plessis & Tzoneva, 2012)

Table 4. Activated sludge model 1 parameters, description of the abbreviations used in equation of table 3.

Symbol	***Meaning***
Y_A	Autotrophic biomass yield
Y_H	Heterotrophic biomass yield
i_{XB}	Nitrogen mass per mass of COD in biomass
u_A	Maximum specific growth rate of autotrophic biomass
u_H	Maximum specific growth rate of heterotrophic biomass
K_S	Half-saturation coefficient for heterotrophic biomass
K_{OH}	Oxygen half-saturation coefficient for heterotrophic biomass
K_{NO}	Nitrate for denitrifying heterotrophs
K_{NH}	Ammonium half-saturation coefficient for autotrophic biomass
K_{OA}	Oxygen half-saturation coefficient for autotrophic biomass
n_g	Correction factor for uh under anoxic conditions
nh	Correction factor for hydrolysis under anoxic conditions
k_h	Maximum hydrolysis rate
K_X	Half-saturation coefficient for hydrolysis of slowly-biodegradable substrate

Source: Modified from (Plessis & Tzoneva, 2012)**.**

3.1. Process

The idea of this research is to complement the general process of a wastewater treatment plant, this due to the urgency of reducing the advancing of pollution of the Yahuarcocha lagoon, since the amount of nutrients and pollutants entering the water body has drastically accelerated its level of eutrophication (Oquendo, 2016). The first problem arises from the incomplete wastewater treatment process of San Miguel de Yahuarcocha, which only removes suspended solids and reduces some toxic compounds to less toxic ones, but does not remove them from the water, which then returns to the lagoon (GAD Municipal de San Miguel de Ibarra, 2018). Allowing microalgae and cyanobacteria to continue proliferating. There are several options to remove nutrients within a treatment plant, but normally it involves the use of chemicals such as the addition of metallic salts to remove phosphorus, taking this into account, in this research tried to improve the plant with more environmentally friendly methods that have a good performance in removing nutrients from the water and the largest amount of microalgae and cyanobacteria.

The preliminary treatment is the same as a conventional treatment plant, the step of removing the heavier suspended solids is essential to maintain the efficiency of the subsequent steps (Fernández, 2016). A retention well will be used to control the entry of water and also to sediment the heavier solids. Then the medium sized solids will be removed using a commercial hydro-screen as in figure 3 which saves time in cleaning since the removed solids go directly into a container which can be easily emptied. The final step of the preliminary treatment is to remove the inert settleable solids that have a lower weight using a vortex type desander as in figure 4.

Once the suspended solids that can damage the pumps and clog the primary treatment pipes have been removed, the water enters the primary settler. Here, water remains for a specific time that allows most of the suspended particles to settle for later collection by the scrapers that slowly move the sludge formed to the collection point. Also, during this time it allows the particles of lower density than the water (fats and oils) to reach the surface and be removed by another group of scrapers as in figure 6. The removed sludge is sent to the sludge digester and the collected fats and oils are collected in special containers and then disposed of responsibly.

The water that reaches the aeration tank undergoes a biological treatment that reduces or transforms the organic matter and nutrients considerably (Valdez & Vázquez, 2003). Here it is very important to use diffusers that expel bubbles of a diameter of less than 1 mm so that the gas exchange in the water is the greatest possible (Valdez & Vázquez , 2003). This favors the performance of aerobic microorganisms that are responsible for consuming the dissolved organic matter as food.

The treated water leaving the biological treatment contains a large amount of activated sludge that needs to be recovered and returned to the aeration tank, for this purpose the water passes through the secondary settler similar to figure 6, that removes the sludge and sends back most of the sludge to the aeration tank inlet, the rest is sent to the sludge treatment along with the sludge collected in the primary settler. These sludges are digested by anaerobic bacteria in a closed tank at a temperature of 36° to enhance the process (Licera, 2016). As the anaerobic bacteria consumes the organic matter present in the sludge, they generate CO_2 and CH_4 as main products; part of the CH_4 is used as fuel to generate energy and compensate the plant's expenses, while the excess is stored in a tank that withstands high pressures (Licera, 2016).

To improve the quality of the water, after this process we proceed to disinfect it using UV-C light to kill possible pathogens, microalgae and cyanobacteria that could not be removed during the previous processes, but the water will still contain a considerable amount of nutrients that returned to the water. To reduce the remaining nutrients water will be treated with phytoremediation. Taking into account the recommendation of Fernández (2002), it was proposed to use an artificial surface wetland as in figure 9A with water hyacinth (Eichhornia crassipes) as a first step. Due to its fast growth, high productivity, easy management, survivability in environments with high levels of nitrogen, phosphorus, and other pollutants such as heavy metals, which it removes from the water through its roots and then accumulates in the aerial vegetative part. (Guevara Granja & Ramírez Cando, 2015). Considering that plants will receive already treated water, the stress due to excess of pollutants will be lower and their growth will be favored. Also, the amount of heavy metals dissolved in the water will be lower since most of them sediment in the primary and secondary treatment. The low levels reduce the negative effect in the growth of the plants, allowing them to spread quickly through the surface wetland and increasing the consumption of nutrients. Since plants will cover the wetland in a short time, it is necessary to periodically remove excess vegetation. Its preferably remove flowering plants to avoid reproduction by seeds, which could reach the lagoon and increase the risk of propagation, so only young plants that multiply preferably by stolons are preserved (Simpson & Sanderson, 2002). Removing the plant biomass excess, also prevents the nutrients from returning to the water, since the plants can begin to die due to lack of space. On the other hand, all the excess plant biomass can be used for the elaboration of multinutritional blocks for cattle consumption (Rodríguez, Marcano & Salazar, 2005). According to Rodríguez et al (2005), water hyacinth contains 8.31% of crude protein, 39.02% of carbohydrates, 20.48% of crude fiber and 13.06% of minerals. Making it feasible to use this plant as a supplement for cattle feeding, since after processing, multinutritional blocks containing up to 26.74% of crude protein are obtained (Rodríguez et al, 2005).

As this is a stage in which sediments will be generated, a periodic extraction must also be carried out to avoid their accumulation and possible bad odors. Remember that one of the objectives of this process is to prevent the sediments generated by the suspended matter in the water from accumulating in the lagoon, because the option of dredging the bottom of the lagoon is not possible because it would re-suspend many nutrients and contaminants in the water column, which would favor a bloom of microalgae and cyanobacteria, drastically affecting the macrofauna of the lagoon (Saelens, 2015).

To enhance the take out of nutrients, a subsurface artificial wetland of horizontal flow as in figure 9B will be created where cattails (*Typha latifolia*) will be placed. Cattail fulfills the characteristics as phytoremediation, the difference with water hyacinth is that it has a slower growth, but is very resistant in contaminated aquatic environments. (Galarza & Pérez, 2019). The purpose of using a horizontal flow wetland is that it allows us to add clay between the gravel at the inlet and outletof the water flow, this allows us to retain a small amount of additional nutrients (Llagas & Guadalupe, 2006). Similar to water hyacinth, the excess cattail should be removed to prevent plants from dying or birds such as herons from creating nests in the wetland. The excess that is removed can be used in the creation of handicrafts such as fans, baskets, etc.

To ensure that all nutrients have been removed from the water, permeable bags with anti-eutrophying technosoils will be placed in the effluent water outflow. According to

Caballero & Velázquez (2014), by applying anti-eutrophying technosoils they were able to reduce 90% of the presence of *Cylindrospermopsis raciborskii* and *Microcystis aeruginosa* in the eutrophicated Lake Ypacaraí. In this way, applying the technosoils at the outlet of the artificial wetland can ensure that all the nutrients have been removed from the water and thus begin to reduce the level of eutrophication of the lake. When technosoils are saturated, are replaced with new ones, and those already used can be used in the agricultural sector since they are rich in nutrients (Bolaños et al, 2014).

Conclusions and Recommendations

- The scheme developed in this research could have a great potential to reduce the amount of nutrients, contaminants and future sediments in the Yahuarcocha Lagoon.
- A complete test of the lagoon water quality is needed in order to carry out a good simulation and make an accurate model for the lagoon requirements. Perform water quality tests on a regular basis is recommended in order to have updated information at all times.
- Cases of illnesses caused by heavy metals and cyanotoxins in people who are in constant contact with the lagoon water should be monitored more closely.
- It is necessary to carry out a complete study (geographical, biological and physicochemical) of the state of the streams that reach the lagoon, in order to implement environmental actions to reduce the amount of pollutants that reach them.
- To enhance the reduction of nutrient inputs to the lagoon, it is suggested that technosoils be applied at the inlet of the lagoon's tributaries.
- Due to the ongoing pandemic and lack of equipment it was not possible to take the necessary data to perform the modeling of the plant to optimally fit the lagoon parameters.

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Annex

Annex 1. Scheme of the water treatment plant process, blue arrow shows the flow of the water that enters into the plant and then returns into the lagoon like a light green arrow. Red arrows represent the solid wastes generated in the process. Yellow arrows represent the untreated sludge collected from primary and secondary treatments. Dark green arrows represent the subproducts generated in the sludge treatment.

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