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A treatment train based on constructed wetlands for the treatment of zootechnical wastewater. A study case in Paute-Ecuador

Disciplinary Scientific Sector ICAR/03

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To Maria de Angeles. You are present in every step I take.

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I also want to thank my parents for encouraging me every single day.

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List of acronyms

% Percentage

°C Degrees centigrade

A Area

A_S Surface Area

BOD_5 Biological Oxygen Demand

C/N Carbon Nitrogen Relationship

C_x Concentration of pollutant

cm Centimeter

cm^3 Cubic Centimeter

COD Chemical Oxygen Demand

C_S Surface Load

CW Constructed Wetland

d Day

EPA United States Environmental Protection Agency

ETP Evapotranspiration

FWS Free flow systems

g Gram

GDP Gross Domestic Product

H Height

h Hour

Ha Hectares

HRT Hydraulic Retention Time

HSSF Horizontal Subsurface Flow

Kg Kilogram

K_s Conductivity

K_t Constant temperature

L Length

l Litters

m Meter

ɱ Removal rate

m^2 Square meter

m^3 Cubic meters

mg Milligram

ml milliliter

mm Millimeters

MPN More Probably Number

mS Microsiemens

N Nitrogen

n Porosity

NVP Net Present Value

P Phosphorus

pH Power of Hydrogen

Q Flow rate

R Percentage removal rate

s Seconds

Slp Slope

T Temperature

t Time

TKN Total Kendal Nitrogen

TN Total Nitrogen

TP Total Phosphorus

TSS Total Suspended Solids

TULSMA “Texto Unificado de Legislación Secundaria del Ministerio del Ambiente”

u Unit

UASB Up-flow Anaerobic Sludge Blanket

µm Micrometer

USD United States Dollar

V Volume

VSSF Vertical Subsurface Flow

W Width

WTP Willingness To Pay

CHAPTER I

INTRODUCTION

1.1 Problem

Ecuador is a country that has based its economy on the primary sector of production. At an international level, the most interesting product is oil, which contributes with 13% of the Gross Domestic Product (GDP), while in the domestic market animal husbandry stands out, for example it contributed to the GDP with 14% in 2013 [1].

Bovine cattle mainly represents the zootechnical activity in the country that according to national statistics, there are more than 4.1 million of livestock heads and 427514 production areas for their breeding and exploitation [2].

Of these 427514 production areas, 90.7% correspond to small and medium producers that are those that have little or absence of technology; not only to improve their production but also to treat all the types of wastes they generate.

Since in Ecuador, these production systems of small and medium producers are dominating, there are serious problems of environmental contamination as the generated wastewaters are discharged directly into the sewage system or into water bodies without any treatment that allow them to find the conditions that do not cause a risk for human health, ecosystems and the environment. It is known that in Ecuador, the 24% of the rural population drinks polluted water [3].

Given that breeding and exploitation of livestock is an important activity in Ecuador although it pollutes a lot, the aim of this thesis is to propose a treatment train that is effective to bring the wastewaters generated in this activity to the limits established by Ecuadorian environmental law. In addition, this treatment train should have low costs of implementation and operation, considering that the people who are dedicated to this activity have limited resources so constructed wetlands appear as an option as well as a solution.

Within the province of Azuay (which is the one that stands out nationally, both due to the number of cattle it has and for the number of production areas), in Paute canton, the Salesiano Education Center has a space dedicated to this activity. This production area has about 100 heads of cattle that remains almost unchanged throughout the year, in which cows are raised for marketing and for the production of milk. The production area is divided into two subareas: the stall and the milking area.

The wastewaters produced by this activity are not treated, those generated in the stall area are directly released into Paute River, and those that are generated in the milking area are conveyed into the sewage system and released to the same water body a few meters further on.

This production area has been taken as a study case to develop the proposal of this research.

1.2 Objectives

1.2.1 General Objective

To propose a treatment train based on constructed wetlands to purify zootechnical wastewaters generated in the production area of the Salesiano Education Center in Paute through the analysis of different executed models.

1.2.2 Specific Objectives

To analyze different scenarios of a treatment train including constructed wetlands through a literature review survey with different but similar applications to identify a favorable design to implement it in the production area of study.

To develop the design of a treatment train considering the different characteristics of the production area of Salesiano Education Center and the wastewater that is generated there to support its treatment.

To operate a pilot station of the proposed treatment train to evaluate the efficiency of its use in the treatment of this type of wastewaters by analyzing their quality before and after the treatment.

To carry out an analysis of the willingness of the population to pay the city for the proposed treatment train considering different factors.

1.3 Contributions

From the literature, there appears to be little evidence of the use of constructed wetlands for the treatment of zootechnical wastewater and its efficiency in decontamination processes [4].

In general, constructed wetlands are used mainly in the treatment of domestic wastewaters with very good efficiencies of up to 95% [5].

This thesis will contribute to the literature on constructed wetlands in terms of having a design to treat zootechnical wastewaters and assess its efficiency on their purification.

1.4 Methodology

The design of constructed wetlands depends on the concentration of organic matter as a key variable within the characteristics of the wastewater as it is described in Chapter II.

For this thesis, the methodology to be used for the design of the constructed wetlands is that adopted in the thesis of Jaime Lara Borrero [6] and developed by the United States Environmental Protection Agency (EPA) in its design manual for constructed wetlands [7].

The characteristics of the wastewaters to determine their status condition to be able to design the constructed wetlands and the waters that leave after the treatment in the pilot station to test its efficiency, will be evaluated with physical-chemical analyzes using the techniques specified in the Standard Methods for the Examination of Water and Wastewater [8].

Once the efficiency of the constructed wetlands in the removal of pollutants from the wastewater is obtained, the final step is to establish a cost study based upon the willingness of the population to pay the cost of the analysis of the construction of this system according to their interest on taking care of the environment following the methodology used by Verlicchi et al [9].

1.5 Structure of the Thesis

The following diagram shows the steps used to complete this thesis.

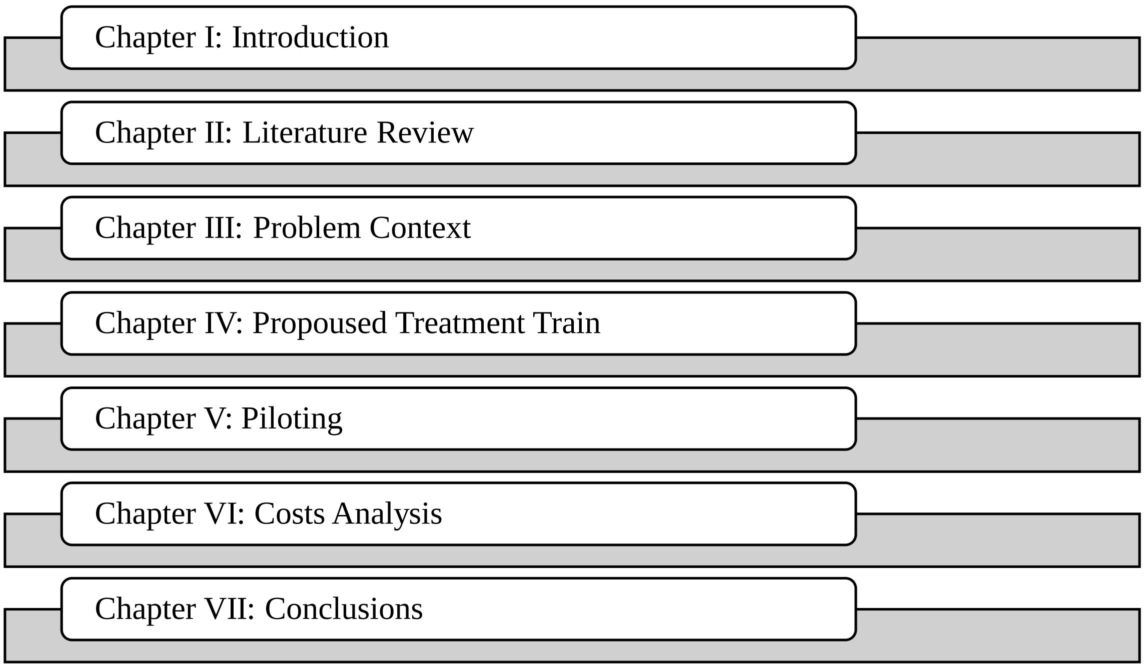


Figure 1 Structure of the Thesis

1.6 Scope and limitations

1.6.1 Scope

Given that in this thesis the main objective is to design a treatment train based on constructed wetlands that allows purifying zootechnical wastewaters, this treatment train constitutes one of the most appropriate alternatives due to its simplicity of operation and maintenance and the low construction and operational costs associated with it [10].

Constructed wetlands (CW) have been applied in the treatment of domestic wastewaters, especially in small communities[10] as secondary and tertiary treatment, where pollutants removal efficiencies of up to 95% have been demonstrated. A contribution of this thesis is to determine their efficiency in the treatment of zootechnical wastewaters.

1.6.2 Limitations

A limitation that I had was the fact that given the investigation involved collecting the data of the characteristics of the wastewater before and after the application of the treatment train, in order to evaluate some parameters and that the access to the laboratory of water of the Politécnica Salesiana University that is where the tests were developed is limited; as well as the analysis costs; the data of monitoring generated a small number of observations.

CHAPTER II

LITERATURE REVIEW

2.1 Zootechnical Wastewaters

2.1.1 Livestock wastes

Mainly there are three types of livestock wastes:

- Solid and semi-solid excreta: they are the excrements of the cattle and a proportion of the bed. They have less than 85% of water in their composition[11].

- Lisier: In its composition, the amount of water is greater than 85%. They are excrements and they contain little or nothing of bed as dilution waters [11].

- Purin: it is the liquid part of the excrement mixed with wash water, rainwater and drinking water leaks. More than a waste, they constitute a type of wastewater (zootechnical wastewater) because according to definitions of dictionaries, the purines are the mixture of manure and urine [11].

2.1.2 Zootechnical wastewaters characteristics

These are all wastewaters from livestock activities, which involve the breeding, production and exploitation of cattle, sheep, pigs, equines or goats, as well as poultry such as chickens, ducks, goats, quails and turkeys and small animals like rabbits and guinea pigs.

These types of wastewater are specially generated when the places where the animals are, or the production processes take place, are cleaned.

There is not a general scheme in terms of the characteristics of the zootechnical wastewaters, as we can find in the domestic wastewater.

However, they are characterized by a high concentration of suspended solids, grease, nitrogen and phosphorus compounds as well as a big number of pathogen agents [12]. Their values will depend on the level of intensification of the activity, the type of animal, number of animals, type of activity, cleaning practices, time of year, etc. [11].

As examples, wastewaters generated in dairy farms have average values of Biological Oxygen Demand (BOD_5) of 1500-8000 mg/l, which is 3-16 times higher than the BOD_5 concentrations in domestic wastewaters; wastewaters generated in slaughter industries have averages values of BOD_5 of 25000-30000 mg/l [4].

Some values of the main parameters in these type of wastewaters are shown in table N°1. The values were obtained in different case studies.

Table 1 Tested Parameters in zootechnical wastewater. Study cases

Parameter	Case Study						
	Pig Farm	Pig, cattle and poultry farm	Swine wastewater	Swine wastewater	Swine wastewater	Cattle and Dairy farm	Slaughter industry
BOD_5 mg/l	1000	30000-52000	no info	120	no info	1500-8000	2500-3000
COD mg/l	2000	no info	no info	373	no info	no info	no info
TSS mg/l	550	no info	no info	31.8	no info	no info	no info
TP mg/l	no info	no info	55	no info	no info	no info	no info
TN mg/l	no info	no info	no info	70	32-175	no info	no info
References	[13]	[14]	[15]	[16]	[17]	[4]	[4]

Some characteristics of these wastewaters made in some trials are the following [11]:

Table 2 Characteristics of zootechnical wastewater

Parameter	Value	Unit
Dry matter	3	%
TN	2	kg/t
$N-NH_4$	1.5	kg/t
P_2O_5	1.5	kg/t
K_2O	2.5	kg/t
C/N	5	kg/t
pH	7	

The amount of wastewaters generated by cows are on average the following [11]:

Table 3 Amount of zootechnical wastewaters generated by bovines

Type of animal	Value	Unit
Milk cow	12-18	m^3/cow head/year
Veal	7-9	m^3/cow head/year
Veals for meat	3-5	m^3/cow head/year

2.1.3 Environmental problems of zootechnical wastewaters

Decades ago, not all livestock wastes were considered a problem; rather they were used as fertilizers in the soil of the fields[12]. Because of the amount of the wastes that were generated, these could be assimilated and degraded in the environment.

Nowadays, the livestock systems are much bigger and intensified so that the amount of wastes that are produced, cannot be assimilated into the environment and they produce problems such as excessive accumulation of nutrients in the soil, water contamination, air contamination, and health problems due to microorganisms or accumulation of toxic components.

2.1.3.1 Excessive accumulation of nutrients in the soil

When these wastewaters are spread in the soil it carries the compounds they contain and the quantities of these compounds are not balanced, that is, they can incorporate into the soil greater quantities than it really needs. This alters the initial physical and chemical characteristics of the soil and can interfere with its fertility as well as cause damage to the plants and crops found in it[11].

Another consequence of an uncontrolled discharge is that the soil can be affected by the formation of surface crusts, reducing the permeability to water and air and therefore favoring erosion [17].

2.1.3.2 Water pollution

Water pollution is produced by infiltration and runoff causing degradation in the quality of the water resource mainly by nitrates without neglecting other compounds. The effects they produce on the quality of the water depends mainly on the volume of the incorporated wastewaters and the flow of the hydric body [11].

The affections of rivers and streams are not only by the direct discharge of the wastewaters on them, it is also due to the overflow of rafts or zootechnical wastewaters accumulation pits and the indirect discharges through municipal sewage systems [17].

One of the main problems is the eutrophication of waters that also generates problems of odors and loss of biodiversity. It should be noted, that there is also the presence of high concentrations of copper, iron and other metals and they can generate big problems considering their bio accumulative character [17].

2.1.3.3 Air pollution

Occurs due to the generation of gases and odors. The odors are the most perceived problem by the population and they are a product of the degradation of the organic matter present in these wastewaters while the gases are principally volatized and contribute to the greenhouse effect [11].

The greater amount of water used in the washing processes, the greater dilution and therefore the lower amount of gases and odors that are produced but also the greater volume of wastewater to treat [11].

2.1.3.4 Health problems or accumulation of toxic substances

Bacteria, parasites, viruses, heavy metals, drugs and other compounds present in livestock manure and diluted in the wash water, will still be present on it, causing diseases to other species [11] .

As an example, *Salmonella spp* in the zootechnical wastewaters of bovine origin survives 165 days in the environment and *E. Coli* from 27 to 60 days[11].

A list of the pathogens that can be transmitted by zootechnical wastewaters are presented in the following table [11].

Table 4 Microorganisms transmitted by zootechnical wastewaters

Microorganism	Zootechnical wastewater origin
Salmonella spp	cows, pigs, birds
Escherichia coli	Cows
Yersinia entercolitica	Pigs
Rotavirus	cows and pigs
Campylobacter spp	cows, pigs, birds
Cryptosporidium parvum	cows
Giardia lamblia	cows

2.1.4 Zootechnical Wastewaters treatability

For the treatment of these wastewaters there are two different approaches[11]:

- Hard technologies: they are the most efficient but they require a high-energy consumption, complex maintenance and high costs.

- Soft technologies: their efficiency is lower so they require more time to treat these wastewaters, however, energy consumption is low and their costs are accessible.

For both, the obtained effluent can be used in agricultural reuse, cleaning water in the stall or discharged in water bodies.

The treatment that is usually given to these wastewaters is[11]:

- Physical process: it is the separation between solid and liquid fractions.

- Chemical process: it consists upon the addition of certain chemical compounds to facilitate the physical processes or to avoid odor problems.

- Biological process: can be of two types: anaerobic or aerobic.

o Anaerobic digestion: a reactor is required and the generated biogas can be reused.

o Aerobic digestion: the lagooning is the main treatment, integrated by aerobic and sedimentation lagoons or a reactor in which air is provided to guarantee aerobic conditions.

2.1.4.1 Physical processes

It is the primary treatment that wastewaters have, and seeks the separation of the different phases present on them. Some of the types of physical processes are[11]:

- Sedimentation: the suspended solids in the wastewater are separated from the liquid fraction by gravity.

The infrastructure in which this process is carried out is a settler/sedimentation tank and its efficiency is determined by the time the wastewater remains in it. Some chemicals can be added to increase the efficiency of the sedimentation process such as aluminum and iron salts: $FeCl_2$, $Fe_2 (SO_4)_3$, $AlCl_3$, $Al_2 (SO_4)_3$, $CaCO_3$.

Some yields in the sedimentation process are presented:

Table 5 Removal efficiency in sedimentation processes

Type of wastewater	Sedimentation time (h)	TS out g/l	TSS out g/l	TS out %	TSS out %	TKN out g/l	TP out g/l
Pig	1	1.83	0.34		2		
Pig	1	5		31.3	54	16.2	45.4
Pig	1	10		43.8	4	19.02	60.9
Cow	0.5	41.7	32.9	55	60.5	24.4	27.8
Cow	1	41.7	32.9	60.8	71.5	24	37.7

- Filtration: the liquid and the particles of smaller size to the used filter pass through it, while the bigger solids retained are eliminated with rackets. Some efficiencies presented according to the filter size can be seen in the next table. The filters can be of sand, gravel or other material.

Table 6 Removal efficiency according to the filter size

Type of wastewater	Filter mm	TS g/l	TSS g/l	TSS g/l	TKN%	TP%
Pig	1.59	24.8	6.29	15.3	7.2	10
Pig	3.36	24.8	15.8	2.6		
Cow	3	71		56	49	49
Cow	1.5	38.3		62.6	49.2	53

- Centrifuging: with the centrifugal force, the particles present in the wastewater are separated, facilitating sedimentation. The efficiency depends on the centrifugal acceleration, drain volume, and retention time.

2.1.4.2 Deodorization

Its objective is to eliminate odors, and can be done through different procedures such as[11]:

- Addition of commercial products: substances can be added to inhibit biological fermentation processes or to inhibit the perception of odors; or there are some substances that act like odor maskers.

- Deodorization by aeration: air is applied to the effluent and aerobic fermentation is favored. The most common systems are aeration by laminar jet or bacterial bed, surface aeration by floating aerators, and aeration in the liquid with compressors.

- Deodorization by anaerobic fermentation: it generates efficiencies between 80 and 90% and the treated effluent has lower content of BOD_5 and total solids.

- Filtration: bio-filters that have fixed microorganisms are used to deodorize the effluent while eliminating the material in suspension.

2.1.4.3 Biological Treatments

A cultivation of microorganisms is created and they use for their feeding the organic matter present in the effluent through enzymes that act as catalysts of the process. In this type of treatment, the BOD_5 present in the effluent is reduced, odors are reduced and even disinfection takes place[11].

- Aerobic treatments: it is carried out in the presence of oxygen and the amount of BOD_5 is reduced; nitrates, sulfates, phosphates and carbon dioxide are formed. To generate the presence of oxygen, diffuse aeration systems or surface aeration systems are used. In some tests, up to 86% efficiencies have been obtained in the reduction of COD and 60% for Nitrogen. A separation process of the centrifuging type and a reactor with injection of air constitute the most used systems in France[11].

- Anaerobic treatments: the degradation of organic matter is carried out in the absence of oxygen, generating methane and carbon dioxide as main products. Reduces between 60 and 80% of the initial BOD_5 of the effluent. It is a process composed of four stages: hydrolysis, acid phase, lactogenic phase and methanogen phase. The reactors or digesters used in this type of treatment can be discontinuous or batch, semi-continuous or continuous. Depending on the degree of mixing, they can be full mixed or plug flow; and if the biomass is adhered they can be of anaerobic filter, expanded bed or fluidized, or up flow anaerobic sludge blanket (UASB) type [11].

- Lagooning: this consists of one or several lagoons that reduce the organic matter present in the effluent; algae and bacteria are those that carry out the treatment process. This process produces the deodorization of the effluent and it can be stored in the lagoon for long periods. There are some types of lagoons, such as [11]:

○ Aerobic lagoons: their use is limited in effluents with too high organic loads because they will reduce the amount of available oxygen and, if the effluent contains copper it is toxic to algae. Their depth goes from 0.4 to 0.6 m.

○ Anaerobic lagoons: act as a bio-digester and the organic matter is deposited in the bottom forming sludge. A partial treatment of stabilization of the organic matter or sedimentation units for subsequent aerobic treatments are considered. Their depth go from four to 6 m.

○ Facultative lagoons: they have an aerobic and an anaerobic stage and are widely used in countries such as Brazil where for example after a solid-liquid separation treatment, the effluent was placed in a lagoon of this type and subsequently apply the treated water in agricultural soils. Their depth go from one to two m.

- Constructed wetlands (CW): constituted by lagoons or shallow channels filled with some material and plants that grow on them. They are of interest to treat this type of effluents as final stages of treatment and a requirement is that the water being treated be of good quality. They require previous treatments and usually zoological effluents; anaerobic or facultative lagoons are used.

Different types of wetlands or a combination of them can be used, although in countries such as Ireland and the United States, horizontal subsurface flow constructed wetlands are the most widespread to treat zootechnical wastewaters [11].

2.2 Constructed wetlands

2.2.1 Definition

Constructed wetlands can be defined as a biological system confined by some type of waterproofing and filled with some material, which arises from the simulation of the mechanisms of natural wetlands for the purification of water [18]. Combinations of physical, chemical and biological processes occur when the wastewater interacts with soil, plants, microorganisms and atmosphere[19].

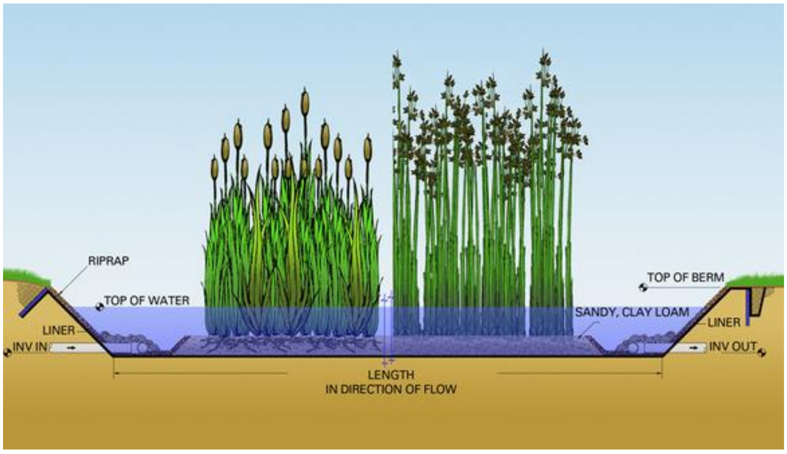


Figure 2 Constructed wetland

Constructed wetlands remove pollutants through various processes including sedimentation, microbial degradation, plant action, absorption, chemical reactions and volatilization.

The functioning of constructed wetlands is based on three principles: the biochemical activity of microorganisms, the supply of oxygen through the plants and the physical support of an inert bed, which serves as a support for rooting, in addition to serving as a filter. Together, these elements eliminate dissolved and suspended materials from wastewaters [20].

In a constructed wetland different mechanisms of removal of contaminants from the wastewater are developed. They can effectively treat high levels of biochemical oxygen demand (BOD_5), total suspended solids (TSS), and total nitrogen (TN), as well as significant levels of metals, organic trace compounds and pathogens.

In table 7, we see the main processes and mechanisms that occur in a constructed wetland and that allow the purification of the wastewater [21].

Table 7 Mechanisms that take place in a wetland

Parameter	Purification mechanisms
Total Suspended Solids	• Sedimentation • Filtration
Organic Matter	• Aerobic microbial degradation • Anaerobic microbial degradation • Sedimentation
Nitrogen	• Ammonification followed by microbial nitrification and denitrification. • Assimilation by plants • Volatilization of ammonia
Phosphorus	• Adsorption by the bed • Assimilation by plants
Metals	• Assimilation by plants • Ionic exchange

Pathogens	• Sedimentation • Filtration • Natural death • Ultraviolet irradiation • Excretion of antibiotics by the roots of macrophytes

2.2.2 Types of constructed wetlands

There are two types of constructed wetlands according to the flow that the water follows: surface flow constructed wetlands and subsurface flow constructed wetlands.

2.2.2.1 Surface flow constructed wetlands (FWS)

Surface flow systems are those where water is exposed to the atmosphere and circulates preferentially through the stems of the plants.

These type of constructed wetlands consist of channels of shallow (0.1 to 0.6 m) built on the ground with some type of barrier that confines the system and prevents leaks. They contain a bed of gravel or sand to support the roots of the emergent vegetation and through which wastewater circulates. These systems are mainly used for tertiary treatments and in some cases for secondary treatments[19] [22].

The exposure of water directly to the atmosphere makes the proper design of these systems crucial to avoid problems arising from a possible overload of the system, the appearance of odors and some insects[4].

In terms of landscape, this system is highly recommended for its ability to host different species of fish, amphibians, birds, and so on. They can be built in tourist places and in places of study of different disciplines by the complex biological interactions that are generated and established.

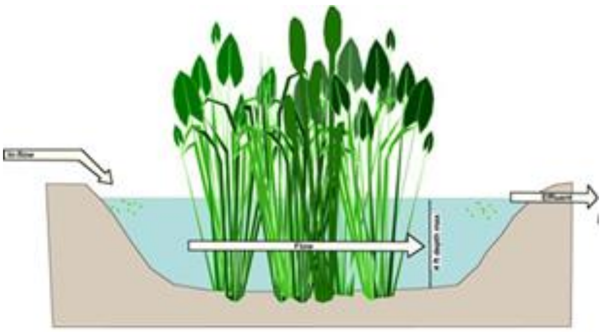


Figure 3 Surface constructed wetland

2.2.2.2 Subsurface constructed wetlands (SSF CW)

The subsurface flow constructed wetlands also consist of a raft or waterproofed channel from the outside. In these systems, the water circulation is done through a porous solid material that occupies almost the entire depth, which is generally of 0.6 m; wastewater circulates through the porous medium and always below the surface thereof. As a porous medium, sand, gravel or rocks o different diameters from 2 mm to 120 mm are usually used. The vegetation is planted in this granular medium and the water is in contact with the rhizomes and roots of the plants [4] [19].

The microorganisms that degrade the organic matter are found forming a biofilm around the gravel and the roots of the plants. Therefore, the larger the surface susceptible to be occupied by the biofilm, the greater the density of microorganisms and the greater the performance of the system.

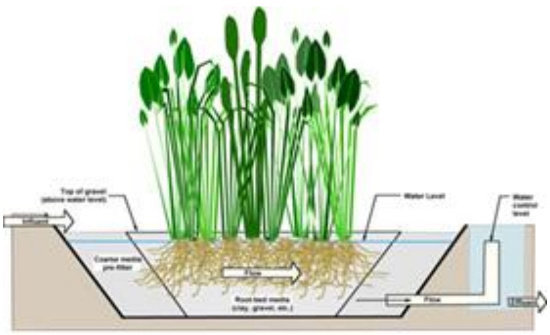


Figure 4 Subsurface flow constructed wetland

The main problem that might occur in a subsurface flow constructed wetland is surface and volume clogging caused by the accumulation of inorganic matter present in the wastewater as well as caused by an extreme biological mass growth [23].

If the subsurface flow bed is properly managed, clogging risk is low and the wastewater treatment plant can work continuously.

If clogging appears, the first action to take is to guarantee a rest period to the bed in order to allow the degradation of organic material accumulated on/in the bed.

For this reason, good practices are:

- To design different beds operating in parallel in order to put them alternatively in exercise or in maintenance (rest).

- To carry out sedimentation and precipitation steps before the subsurface flow systems to increase their lifespan.

- To wash the inflow feeding area in the subsurface flow system where the materials generally accumulate and cause over flooding.

There are two types of subsurface flow constructed wetlands:

- Horizontal subsurface flow (HSSF) system: these systems usually consist of a bed, of either sand or gravel, planted with aquatic macrophytes, in most cases with the common reed *(Phragmites australis).*

The entire bed is covered by a waterproof membrane (geo-membrane) to prevent leaks in the soil, but if there is clay, the waterproof membrane is not necessary. The depth of the bed ranges from 0.45 m to 1 m and has a slope of 0.5% to 1%. These systems work with a continuous feed made along one of the sides. The purified water is collected at the bottom of the opposite side of the feed [19] [4].

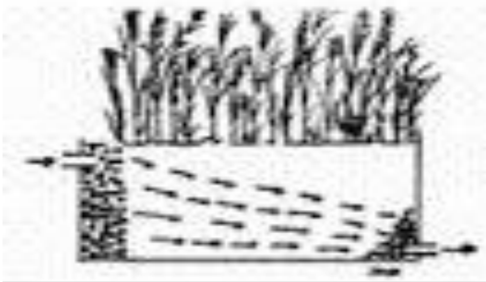


Figure 5 Horizontal subsurface flow constructed wetland

- Vertical subsurface flow (VSSF) system: Also known as intermittent filters, these types of constructed wetlands receive the wastewater from top to bottom, through a system of water application pipes. The feed is done evenly distributed and usually by loads. The waters infiltrate vertically through all the surface and the inert substrate (sands, gravel), after the waters are collected in a drainage network located at the bottom of the constructed wetland [19] [4].

In this system, there is a better approach between the wastewater and the air inside the pores; therefore, better yields in the aerobic mechanisms that had place due to a greater contribution of oxygen.

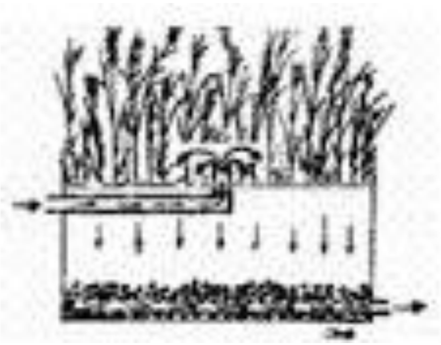


Figure 6 Vertical subsurface flow constructed wetland

2.2.3 Constructed wetlands design

There is an extensive literature, which describes the required conditions for a successful design [18]. Those include elements such as the construction site, hydrological analysis, water quality, macrophytes selection, soil characteristics and geological conditions. Accordingly, some criteria in the literature for designing constructed wetlands will be described below.

For good pollutant removal performance, pre-treatment is necessary, because different substances can alter the operation conditions of constructed wetlands and decrease their performance. Usually, the primary treatments used are traps for oils and settlers.

2.2.3.1 Design models for Free Flow Constructed Wetlands Systems (FWS)

2.2.3.1.1 Constructed wetlands and aquatic plant systems for municipal wastewater treatment

The following model is for low and moderate organic loads[7].

The organic load must be distributed over a portion of the area and not applied to a single point.

The depth of the water should be 0.6 m or less to ensure adequate distribution of oxygen, in the summer months, part of the effluent could be recycled to avoid evaporative losses in order to maintain oxygen levels and design flows.

A first order model has described the removal of BOD_5 in a constructed wetland as follows:

$$\frac{C_e}{C_o} = exp\,(-K_T * \, t) \qquad (1)$$

Where:

C_e = BOD_5 effluent, mg/l
C_o = BOD_5 influent, mg/l
K_T = first order reaction constant dependent on the temperature, d^{-1}
t = hydraulic retention time, d

The hydraulic retention time can be expressed as:

$$t = \frac{L * W * d}{Q} \qquad (2)$$

Where:
L = system length
W = system width
d = depth
Q = average flow (in and out)

In a free flow constructed wetland (FWS), a portion of the available volume will be occupied by vegetation; therefore, the actual dwell time will be a function of the porosity, which can be defined as the remaining cross-sectional area available for flow.

$$n = \frac{V_v}{V} \qquad (3)$$

Where:

n = porosity
V_v = spaces volume
V = total volume
Combining equations (2) and (3) with equation (1) yields:

$$\frac{C_e}{C_o} = A.exp\left(-0.7 * \ K_T * \ A_{V^{1.75}} * \frac{L*W*n}{Q}\right) \qquad (4)$$

Where:

A = BOD_5 not removed fraction as sedimentable solids near the system entrance, decimal fraction.
A_v = specific surface area for microbial activity, m^2/m^3

The velocity constant depending on the temperature is calculated from the velocity constant for 20 ˚C K_{20} and the correction factor 1.1. The velocity constant K_T (d^{-1}) at water temperature T (˚C) is defined by the following equation.

$$K_T = \ K_{20} * 1.1^{T-20} \qquad (5)$$

The other coefficients of equation (4) have been estimated.

A = 0.52
K_{20} = 0.0057 d^{-1}
A_v = 15.7 m^2/m^3
n = 0.75

2.2.3.1.2 Depuration of municipal wastewaters with constructed wetlands

The design models presented here have been presented by Jaime Lara [6], whose mentions were suggested by Sherwood C. Reed in his book Natural Systems for Wastewater Management and Treatment.

Hydraulic design

The flow of water in a FWS is described by the Manning equation, which defines the flow in open channels. The velocity of the flow in the wetland is described by equation (6); it depends on the depth of the water, the slope of the water surface and the density of the vegetation. Other applications of the Manning equation for open channels assume that frictional resistance only occurs at the bottom and the walls of the channel. In FWS, the resistance is distributed over the entire water column, as emergent plants and vegetation are present throughout the space. The Manning equation also assumes turbulent flow, which is not completely valid but is an acceptable approximation.

$$v = \frac{1}{n} * y^{\frac{2}{3}} * S^{\frac{1}{2}} \qquad (6)$$

Where:

v = flow rate, m/s

n = Manning Coefficient, m/s

y = depth of water in the wetland, m

S = hydraulic gradient or slope of the water surface, m/m

For constructed wetlands, the Manning coefficient (n) is a function of the water depth due to the resistance imposed by the emergent vegetation. The resistance also depends on the density of the vegetation and the layer of debris that may vary depending on the location or the season. The relationship is defined by:

$$x = \frac{a}{y^{\frac{1}{2}}} \qquad (7)$$

Where:

a = resistance factor, $s * m^{\frac{1}{6}}$

y = 0.4 for sparse vegetation y γ > 0.4 m

1.6 for moderately dense vegetation with y ≈ 0.3 m

6.4 for very dense vegetation with $\gamma \leq 0.3$m

In many situations, with typical emergent vegetation, it is acceptable to assume for design purposes values of a between one and four. Substituting equation (7) into equation (6), we have.

$$v = \frac{1}{a} * y^{\frac{7}{6}} * s^{\frac{1}{2}} \qquad (8)$$

To determine the length of the wetland the following definitions must be taken into account:

$$V = \frac{Q}{W*y} = \frac{Q}{A_T} \quad (9a) \quad W = \frac{A_S}{L} \quad (9b) \qquad S = \frac{m*y}{L} \quad (9c) \qquad t = \frac{A_{S*y*n}}{Q} \quad (9d)$$

Where:

Q: flow, m^3/d

m = slope of the wetland, % expressed as a decimal

W = width of the wetland, m

A_T = wetland cross-sectional area, m^2

A_s = wetland surface area, m^2

L = length of the wetland, m

Replacing the previous relations gives:

$$L = \left[\frac{A_S * y^{\frac{8}{3}} * m^{\frac{1}{2}}}{a*Q} 86400\right]^{\frac{2}{3}} \qquad (10)$$

The limiting pollutant removal design model first determines the surface area of the constructed wetland.

Equation (10) allows the direct calculation of the maximum acceptable length of a wetland cell.

BOD_5 removal model

All constructed wetland systems can be considered as biological reactors and their performance may approximate that described by the first order kinetics of a plug flow reactor.

The model is based on the experience with systems applied on soil and percolating filters.

$$\frac{C_e}{C_o} = A * exp\left[- \frac{0.7* K_{T*} A_{v^{1.75}} * L*w*y*n}{Q}\right]^2 \qquad (11)$$

Where:

C_e = BOD_5 concentration in the effluent, mg/l
C_o = BOD_5 concentration in the influent, mg/l
A = BOD_5 fraction not removed as sedimentable solids near the system's entrance, decimal fraction
K_T = first order reaction constant dependent on the temperature, d^{-1}
A_v = specific surface area for microbial activitym^2/m^3
L = length of system, m
W = system width, m
y = average depth of system, m
n = system porosity, decimal fraction
Q = average flow of the system, m^3/d

Equation (11) is considered theoretically correct, but has the problem to evaluate factors A and A_v. The value of A_v recommended by some publications is 15.7 m^2 / m^3, since it is difficult to measure it in a functioning wetland. Depending on the level of treatment desired, factor A may take different values, for primary effluents 0.52, for secondary 0.75 and 0.90 for tertiary effluents.

Reorganizing the terms of equation (11) gives an expression to estimate the surface area required for the wetland in square meters (As).

$$A_s = \frac{Q(1nC_o - 1nC_e - 1nA)}{K_T * y * n} \qquad (12)$$

$$K_T = K_{20} * 1.06^{(T-20)} \qquad (13)$$

The value of K_{20} is 0.2779 d^{-1} and the porosity range, n, is 0.65 to 0.75.

Due to the difficulties in evaluating A and A_v, a second approach has been made from the analysis of the performance data of such systems in operation.

$$\frac{C_e}{C_o} = exp(-K_T * t) \qquad (14)$$

The equation (13) is used to calculate the coefficient K_T. The value of K_{20} is 0.678 d^{-1}.

The surface area of the wetland is determined as follows:

$$A_s = \frac{Q * (1nC_o - 1nC_e)}{K_T * y * n} \qquad (15)$$

Removal model for total suspended solids

In this system, the removal of solids is due to physical processes. Because the removal of TSS is faster compared to that of BOD_5, it is not considered as a design parameter.

A linear regression of data obtained in constructed wetlands in the United States provides the equations that can be used to estimate the concentration of TSS at the exit of the constructed wetland. These equations are valid for hydraulic loads between 0.4 and 0.75 cm/d, values that are not in this range may have incorrect results.

$$C_e = C_o * (0.1139 + 0.00213 * CH) \qquad (16)$$

$$CH = \frac{Q}{A_s} \qquad (17)$$

Where:

C_e = TSS Concentration in the effluent, mg/l
C_o = TSS Concentration in the influent, mg/l
Ch = hydraulic load, cm/d
Q = average flow's system, m^3/d
A_s = wetland surface area, m^2

Removal model for Nitrogen

The main source of oxygen for nitrification in these constructed wetlands is atmospheric aeration near the surface of the water and the carbon source for denitrification is the layer of vegetation that is submerged.

Nitrification: The recommended design model assumes that removal of ammonia is completely by nitrification. The following equations are applied for the removal of ammonia in FWS wetlands expressed in terms of ammonia concentrations.

$$\frac{C_e}{C_o} = exp(-K_T * t) \qquad (18)$$

$$A_s = \frac{Q * (1nC_o - 1nC_e)}{K_T * y * n} \qquad (19)$$

$$K_T = 0.1367 * 1.15^{(T-20)} \qquad (20)$$

$$K_T = 0.2187 * 1.048^{(T-20)} \qquad (21)$$

Where:

A_s = wetland surface area, m^2
C_e = concentration of ammonia in the effluent, mg/l
C_o = TKN concentration in the influent, mg/l
K_T = First order reaction constant dependent on the temperature, d^{-1}
y = depth of water in the wetland, m
t = hydraulic retention time, d

n = system porosity, decimal fraction
Q = average flow's system, m^3/d

Equation (20) is used for the temperature range between 1 and 10˚C and equation (21) for temperatures greater than 10˚C. The porosity for equation (19) must be from 0.65 to 0.75.

2.2.3.1.3 Free water surface system for wastewater treatment: a technology assessment

This is a hydraulic design [24]:

Hydraulic retention time. The theoretical hydraulic retention time is the ratio of the volume of the available constructed wetland to the flow, which includes the effects of volume reduction by vegetation (porosity) and flow.

$$t = \frac{V * \varepsilon}{Q_{AVE}} \qquad (22)$$

$$Q_{AVE} = \frac{Q_i + Q_o}{2} \qquad (23)$$

Where:

t = hydraulic retention time, [t]
ε = system porosity, decimal fraction
Q_{AVE} = average flow's system, $[l^3/t]$
Q_i = system input flow, $[l^3/t]$
Q_o = output flow in the system, $[l^3/t]$

Hydraulic load.

$$q = \frac{Q}{A} \qquad (24)$$

Where:

q = Hydraulic loading at the inlet, [l/t]
Q = Flow, $[l^3/t]$
A = Wetland surface area, $[l^2]$

2.2.3.1.4 Constructed wetlands treatment of municipal wastewaters

This model focuses on improving secondary treatment for domestic wastewater [25]:

Hydraulics

In order to treat a domestic wastewater, the main design variables are area, depth, hydraulic retention time, type of vegetation and, in general, the shape and dimensions of the constructed wetland.

From a design perspective, wetland hydraulics define the movement of water through the system. A FWS with poor hydraulic design can cause problems with effluent water quality. The volume of a free flow constructed wetland is the potential amount of water (without vegetation and debris) that could circulate in the system.

$$V_w = A_w * h \qquad (25)$$

Where:

V_w = wetlands volume
A_w = surface area
h = average depth of water

The flow rate to be managed in the wetland will be an average of the inflows and outflows in the system.

$$Q_{AVE} = \frac{Q_o + Q_e}{2} \qquad (26)$$

Where:

Q_{AVE} = average flow of wastewater to be treated
Q_o = inlet flow rate
Q_e = flow of effluent

The hydraulic retention time can be expressed as follows:

$$t = \frac{V_W * \varepsilon}{Q_{AVE}} \qquad (27)$$

Where:

t = hydraulic retention time

V_w = volume of the wetland

ε = porosity

Q_{AVE} = average flow of wastewater to be treated

The hydraulic load for this wetland can be written as follows:

$$q = \frac{Q_o}{A_W} \qquad (28)$$

Where:

q = Hydraulic load

Q_o = Inlet flow rate

A_w = Surface area

For FWS constructed wetlands, it is necessary to measure the loss of energy between the inlet and outlet of the system, since the constructed wetland must be designed to handle flows without creating significant problems of stagnation and flooding. The Manning equation defines open channel flow, and it can be adapted to estimate the energy loss in FWS constructed wetlands.

$$S^{\frac{1}{2}} = \frac{V}{1n * h^{\frac{2}{3}}} \qquad (29)$$

Where:

v = Average flow rate

n = Manning resistance coefficient

h = Average Wetland Depth,

S = Hydraulic gradient or slope of the water surface,

Fecal Coliform Removal Model

$$\frac{C_e}{C_o} = \frac{1}{(1+t * K_p)^N} \qquad (30)$$

$$K_p = 2.6 * 1.19^{T-20} \qquad (31)$$

Where:

C_e = Concentration of fecal coliforms in effluent, cfu/100ml

C_o = Concentration of fecal coliforms in the influent, cfu/100ml

N = Number of open water zones

t = Hydraulic retention time, HRT

K_p = Constant rate of fecal coliform removal, T^{-1}

T = Temperature, °C

Removal model for BOD_5.

$$\frac{C_e}{C_o} = \frac{1}{(1+t * K_p)^N} \qquad (32)$$

$$K_b = 0.15 * 1.04^{(T-20)} \qquad (33)$$

Where:

C_e = Concentration of BOD_5 in effluent, mg/l

C_o = Concentration of BOD_5 in the influent, mg/l

N = Number of open water zones

t = Hydraulic retention time, HRT

K_b = BOD_5 specific rate of removal constant, T^{-1}

T = Temperature, °C

2.2.3.2 Design models for subsurface flow constructed wetlands

2.2.3.2.1 Constructed wetlands and aquatic plant systems for municipal wastewater: horizontal subsurface flow constructed wetland (HSSF)

The following model is specially for BOD_5 removal [7]:

Removal of BOD_5

The subsurface flow system is designed to maintain the flow below the bed surface. The selection of the plant species is an important factor.

The removal of BOD_5 in subsurface flow systems can be described with the first order kinetics of a plug flow as described in equation (35) for free flow systems. Equation (35) can be rearranged and used to estimate the surface area of the subsurface flow constructed wetland.

$$\frac{C_e}{C_o} = exp(-K_T * t) \quad (34)$$

$$A_s = \frac{[Q*(In\, C_o - C_e]}{K_T*d*n} \quad (35)$$

Where:

C_e = BOD_5 effluent, mg/l
C_o = BOD_5 influent, mg/l
K_T = first order reaction rate constant, d^{-1}
t = hydraulic residence time HRT, d
Q = average flow through the system, m^3/d
d = depth, m
n = porosity of the bed, as a fraction
A_S = surface area of the system, m^2

The cross-sectional area for flow through a subsurface system is calculated according to the following equation:

$$A_C = \frac{Q}{k_S} * S \quad (36)$$

Where:

A_c = cross-sectional area of the wetland bed, perpendicular to the direction of flow, m^2
d = bed depth, m
W = bed width, m
K_S = hydraulic conductivity of the medium, $m^3/(m^2 \cdot d)$
S = slope of the bed, or hydraulic gradient (as a decimal fraction).

The width of the bed is calculated by the following equation

$$W = \frac{A_C}{d} \qquad (37)$$

The cross-sectional area and width of the bed are established by Darcy's law.

$$Q = k_S * A_S * S \qquad (38)$$

The cross-sectional area and bed width are independent of temperature and organic load since they are controlled by the hydraulic characteristics of the medium.

The value of K_T can be calculated using equation (5) and a known K_{20} for the subsurface flow system. The approximate value of K_{20} for media types ranging from medium to coarse sand is 1.28 d^{-1}. Based on European data and data from Santee, California, the value of K_{20} is presented in Table 8. The effect of using a medium-larger size (with a small porosity value), and low temperatures represents a system that has not been studied and the above equations cannot accurately predict the results. The porosities (n) and the hydraulic conductivity are shown in the following table.

Table 8 Characteristics of support material

Media	Max 10% Grain Size, mm	Porosity n	Hydraulic Conductivity, (k_s) $m^3/(m^2 * d)$	K_{20}
Middle Sand	1	0.42	420	1.84
Gross sand	2	0.39	480	1.35
Grave sand	8	0.35	500	0.86

2.2.3.2.2 Depuration of municipal wastewaters with constructed wetland: horizontal subsurface flow constructed wetland (HSSF)

Depending on the factor, some models are presented [6]:

Hydraulic design

Darcy's law describes the flow regime in a porous medium that is generally accepted for the design of subsurface flow type constructed wetlands using soil and sand as the bed medium. The highest level of turbulence in the flow occurs in beds that use very thick stone; then the Ergun equation is more appropriate for this case.

Darcy's law can give a reasonable approximation to the hydraulic conditions in the subsurface flow constructed wetland, if a medium or small size gravel is used; if the system is well constructed, if the system is designed to have minimal dependence on the hydraulic gradient, and if the system gains and losses are adequately recognized.

$$v = k_s * s \quad (39)$$

Given that:

$$v = \frac{Q}{Wy} \quad (40)$$

So:

$$Q = k_S A_C s \quad (41)$$

Where:

Q = average flow through the wetland, m^3/d $[(Q_o + Q_e)/2]$
K_s = hydraulic conductivity of a unit of constructed wetland area perpendicular to the direction of flow, $m^3/m^2/d$.
A_c = cross-sectional area perpendicular to the flow, m^2
s = hydraulic gradient or "slope" of the water surface in the system. m/m
v = Darcy velocity, the apparent flow rate across the entire cross-sectional area of the bed, m/d.

Substituting and rearranging the terms it is possible to develop an equation that will determine in an acceptable manner the minimum width of a subsurface flow constructed wetland cell that is compatible with the hydraulic gradient selected for the design, starting from:

$s = \frac{m*y}{L}$ (42a) $L = \frac{A_S}{W}$ (42b) $A_C = W * y$ (42c)

Where:

W = width of a wetland cell, m
A_S = surface area of the wetland, m^2
L = wetland length, m
m = slope of the wetland, % expressed as decimal
y = depth of water in the wetland, m

$$W = \frac{1}{y} * \left(\frac{Q * A_S}{m * k_S}\right)^{0.5} \quad (43)$$

The surface area of the wetland (A_s) is determined using the limiting design model for the removal of contaminants. Equation (43) allows to directly calculating the acceptable absolute width of a constructed wetland cell compatible with the selected hydraulic gradient. The m-value of the equation is usually between 5 and 20% of the potential load loss. It is advisable to take a value of the effective hydraulic conductivity (ks) β 1/3 and that m is not greater than 20% to have a sufficient safety factor against possible potential clogging, viscosity effects and other contingencies that may become unknown at the moment of design.

Equations (41) and (43) are valid when the flow is laminar along the void spaces of the medium, that is, when the Reynolds number is less than 10. The Reynolds number is a function of the velocity of the flow, the size of the void spaces and the kinematic viscosity of the water, as shown in equation (44). In many cases the Reynolds number will be much less than 10 and Darcy's law is valid. If the flow is turbulent, then the effective hydraulic conductivity would be significantly lower than that predicted by Darcy's law.

$$N_R = \frac{v*D}{\tau} \qquad (44)$$

Where:

N_R = Reynolds number, dimensionless
v = speed of Darcy, m/s
D = diameter of the empty spaces in the medium equal to the mean size of the medium, m
τ = kinematic water viscosity, m^2/s

The hydraulic conductivity varies directly with the viscosity of the water, which in turn is a function of the water temperature.

$$\frac{k_{sr}}{k_{d20}} = \frac{\mu_{20}}{\mu_T} \qquad (45)$$

Where:

k_s = Hydraulic conductivity at a temperature T y a 20ºC
μ = Dynamic viscosity of water at a temperature T y a 20ºC

Table 9 Physical water properties

Temperature (T), ˚C	Density (Þ), kg/m^3	Dynamic viscosity x10^3 (μ) $N*s/m^2$	Kinematic viscosity x10^6 (τ) m^2/s
0	999.8	1.781	1.785
5	1000.0	1.518	1.519
10	999.7	1.307	1.306
15	999.1	1.139	1.139
20	998.2	1.102	1.003
25	997.0	0.890	0.893
30	998.7	0.708	0.800
40	992.2	0.653	0.658
50	988.0	0.547	0.553
60	983.2	0.466	0.474

Viscosity effects may be significant in cold climates, with SSF constructed wetlands operating during the winter months. Hydraulic conductivity also varies with the number and size of empty spaces in the medium used for the wetland.

Table 10 presents different magnitudes estimated for a range of granular materials that could be used. It is recommended that hydraulic conductivity and porosity be measured in the laboratory before the final design.

Table 10 Characteristics of the medium

Type of material	Effective size D_{10}, mm	Porosity (ŋ), %	Hydraulic conductivity (ks), $m^3/(m^2*d)$
Gross sand	2	28-32	100-1000
Grave sand	8	30-35	500-5000
Fine Gravel	16	35-38	1000-10000
Medium Gravel	32	36-40	10000-50000
Thick rock	128	38-45	50000-250000

It is advisable that the porosity (ƞ) of the medium is also measured in the laboratory before making the final design. It is also possible to use a relationship based on the Ergun equation to estimate hydraulic conductivity when using coarse gravels or rocks:

$$k_s = n^{3.7} \qquad (46)$$

This equation, as well as the values presented in Table N 10, are useful only for a preliminary design or to estimate an order of magnitude. The final design of a subsurface flow constructed wetlands should be based on actual measurements of hydraulic conductivity and porosity.

BOD_5 removal model

The mechanisms of removal of the BOD_5 in a subsurface flow constructed wetland are the same described for the free flow constructed wetlands type. However, yield may be better in subsurface flow since they have a much larger submerged area that increases the biomass growth potential.

The equations presented first are also valid models for the design of subsurface flow constructed wetlands. The only difference is the magnitude of the porosity, which can be taken from Table 10 and from the temperature constant, K_{20}, which takes the value of 1,104 d^{-1}.

Model of total suspended solids removal

These mechanisms of total solids removal are mainly due to physical processes. Since the sedimentation distance for the particulate matter is relatively small and the residence time of the water in the wetland is very long, the effects of viscosity can be omitted, as well as the removal of total suspended solids in these type of systems are not a limiting parameter for the design and sizing of the constructed wetland.

A linear regression of data obtained in the USA constructed wetlands, provides equations that can be used to estimate the concentration of TSS at the exit of the wetland. These equations serve only to estimate the magnitude of the discharge but not as a design parameter. The equations described below are valid only for loads between 0.4 and 0.75 cm / day, since the values under or over these may give incorrect results.

$$C_e = C_o(0.1058 + 0.0014(CH)) \quad (47)$$

Where:

C_e = TSS concentration in the effluent, mg/l
C_o = TSS concentration in the influent, mg/l
CH = hydraulic load.

Design models for nitrogen removal

The major source of carbon to enable denitrification is the death and decomposition of roots and rhizomes, other organic residues or detritus and BOD_5 of wastewater, and the main source of oxygen in the subsurface flow constructed wetlands are the roots of plants. It is essential to ensure that the root system will penetrate to the full depth of the bed design.

Nitrification

There is no consensus on how much oxygen is transferred to the root zone by each type of vegetation, so it is not known how much oxygen is available at the root surface for biological activity. The nitrification depends on the depth of penetration of the roots present in the subsurface flow constructed wetland.

The oxygen available for nitrification per unit surface area ranges from 2.1 to 5.7 g/m^2d because the depth of root penetration varies in each of the plants. This suggests that at least for the three most commonly used species (*Scirpus*, *Phragmites* and *Typha*) the oxygen available for nitrification will be approximately the same, so nitrification depends on the depth of penetration of the roots present in the wetland. Equation (48) defines this relation.

$$K_{NH} = 0.01854 + 0.3922(rz)^{2.60\pi} \quad (48)$$

Where:

K_{NH} = nitrification constant at 20 ̊C, d^{-1}
rz = percentage of depth occupied by the root zone, decimal fraction (0 a 1).

Once the basic constant K_{NH} is defined it is possible to determine the removal of ammonia via nitrification using the following equations

$$\frac{C_e}{C_o} = exp(-K_T\, t) \qquad (49)$$

$$A_s = \frac{Q\, In(C_o/C_e)}{K_T y n} \qquad (50)$$

Where:

A_s = surface area of the wetland, m^2
C_e = concentration of ammonia in the effluent, mg/l
C_o = concentration of ammonia in the influent, mg/l
K_T = first order reaction constant dependent on Temperature, d^{-1}
y = depth of water in the wetland, m
t = hydraulic retention time, d
n = system porosity, decimal fraction
Q = average flow rate in the system, m^3/d

It is not acceptable to assume that the root zone automatically occupies the whole of the bed, except, if it is very shallow or if it uses very small gravel.

Denitrification

When the project requires nitrogen removal, it is necessary to consider the requirements for denitrification and to size the constructed wetland by considering them. Much of the nitrate production can be denitrified and removed within the intended nitrification area. The design model for estimating the removal of nitrates via denitrification corresponds to the following equations.

$$\frac{C_e}{C_o} = exp(-K_T\, t) \qquad (51)$$

$$A_s = \frac{Q\, In(C_o/C_e)}{K_T y n} \qquad (52)$$

$$K_T = 1.00 * 1.15^{(T-20)} \quad (53)$$

Where:

A_s = surface area of the wetland, m^2
C_e = concentration of nitrates in the effluent, mg/l
C_o = concentration of nitrates in the influent, mg/l
K_T = first order reaction constant dependent on Temperature, d^{-1}
y = depth of water in the wetland, m
t = hydraulic retention time, d
n = porosity of the system, decimal fraction,
Q = average flow rate in the system, m^3/d

Total Nitrogen

When denitrification is required, it is generally because there is a discharge limit for the total nitrogen TN. The determination of the area required to reach the specific TN level in the effluent is an iterative procedure using equations (50) and (52).

Assume a value for residual ammonia (C_e) and solve equation (49) to obtain the area required to nitrify, thus determining the hydraulic retention time.

Take the difference (C_o - C_e) as nitrate produced by nitrification and use this value as that of the tributary in equation (51). Determine the concentration of nitrates in the effluent with the same equation.

The TN concentration in the effluent is the sum of the values of C_e obtained in equations (49) and (51). If the required NT value is not reached, another iteration is required.

Removal model for Phosphorus

For the removal of phosphorus, the same model can be used as described, for a free flow constructed wetland.

2.4.3.3 Constructed wetlands treatment of municipal wastewater: horizontal subsurface flow constructed wetland (HSSF)

The following model calculates [25]:

Water level estimation

An important step in the design process is the estimation of the elevation of water through the subsurface flow constructed wetland. Darcy's law describes the relationship between the flow through the porous medium and the hydraulic gradient. This assumes laminar flow; no modifications are recommended as sufficient to estimate the water level within a free flow constructed wetland

$$Q = K * A_c * S = K * W * D_w \left(\frac{dh}{dL}\right) (54)$$

Or to define the length,

$$dh = \frac{Q * L}{K * W * D_w} (55)$$

$$A_c = W * D_w \ (56)$$

$$A_c = W * D_w \ (57)$$

Where:

Q = flow, m^3/d
K = hydraulic conductivity, $m^3/(m^2 \cdot d)$
Ac = cross-sectional area for residual water flow, m^2
W = width of the wetland, m
Dw = water Depth, m

Determination of surface area

$$A_s = \frac{Q * C_o}{ALR} \qquad (58)$$

Where:

As = surface Area of BOD_5 and TSS

ARL = surface loading speed, of BOD_5 and TSS

CO =c of the influent, mg/l

Q = flow, m^3/d

Determination of width.

The minimum width required to maintain the flow below the surface, using Darcy's equation, equation (60), but using the initial values of the treatment zone.

$$Li = \frac{A_{Si}}{W} \qquad (59)$$

$$W^3 = \frac{Q * A_{si}}{K_r * (dh_i) * D_{wo}} \qquad (60)$$

2.4.3.4 Constructed wetlands for civil wastewaters: vertical subsurface flow constructed wetland

These kind of systems are designed as the intermittent filters [26].

Surface area

It is calculated using the hydraulic load estimated for the population that will use the system. The values that the hydraulic load can have are from 40 to 50 l/m^2d

$$As = \frac{Hydraulic\ stimated\ load}{Hydraulic\ load} \qquad (61)$$

Length

It is calculated with the surface area and assuming values for width

$$L = \frac{As}{W} \ (62)$$

Depth

Values for depth can go from 0.4 to 0.6 m as in the horizontal subsurface flow constructed wetlands.

Distribution System

The number of pipes, the frequency of the dose that will feed the system, the holes in the pipes to feed the system and the number of holes by pipe must be calculated.

These values depend of the designer. Doses frequencies can go from two to 48 times a day. The number of pipes is related to the width of the bed and how separated the designer wants they to be.

$$\#pipes = \frac{W}{SL} \ (63)$$

Where:

W: width of the bed
SL: separation between pipes
Considering a surface organic load of 5 g/m^2d, it is calculated by:

2.3 Constructed wetlands to treat zootechnical wastewater

They are generally used as final stages of treatment in conjunction with other types of treatments (stabilization lagoons, vermifiltration, anaerobic digesters or activated sludge). Their choice depends on the type of effluent to be treated and the characteristics that are desired in the final effluent, either to discharge it directly into a water body or to reuse it as wash water in the farms for example [11].

They are an excellent treatment option to reduce organic matter, suspended solids, microbiological contamination, nitrogen and even some heavy metals and organic pollutants if their design and loading speeds are correct. The elimination of the phosphorus is partial and to improve it, other expensive systems are required or either to carry out a process of chemical precipitation[11].

The retention times that are recommended in some standards are no less than 12 days, loading rates between 7 g BOD_5/m^2d to 11 g BOD_5/m^2d[11].

The suspended solids are those that require more attention at the time of treating wastewater because they cause clogging problems in the system; for this purpose, constructed wetlands are usually accompanied by anaerobic or facultative lagoons[11].

In the case of nitrogen, horizontal subsurface flow wetlands facilitate denitrification while vertical subsurface flow wetlands facilitate nitrification processes. A combination of these systems can achieve a total elimination of the nitrogen present in the treated effluent[11].

In some countries, wastewaters are purified in the constructed wetlands without a prior treatment and good results have been verified in the reduction of organic matter but partial or reduced nitrification. For example, the efficiencies obtained in the reduction of BOD_5 were of 85% while TN of 53%[11].
A study carried out with zootechnical wastewaters of pig farms and in which vertical subsurface constructed wetlands with recirculation were proved, showed that these treatment stations have a high potential [12]. There are cases in which efficiencies of 99% of TSS, 99% of BOD_5, 93% of COD and 93% TN have been reached [11].
Another case with dairy effluents has reached a purification efficiency of 92% in BOD_5 and 80% in TN[11].

2.3.1 Application examples

The following section presents some examples of zootechnical effluents treated with constructed wetlands. It should be considered that the production of this type of wastewater in Europe is centered in Denmark, Holland, Belgium, France, Germany, Italy and Spain while in America it is centered in the United States [11].

2.3.1.1 Application of constructed wetland to effluent purification in a pig farm

From this case, it is recognized that constructed wetlands to treat sewage from intensive pig farms have many advantages such as qualified quality of outflow, little odor, cheap operation, and easy maintenance and management [13].

They are a good recommendation for intensive pig farms to treat the wastewater that these farms generate and the constructed wetlands could be built in various combinations (multi-stage series and/or parallel).

Table 11 Study Case 1

The application of constructed wetland to effluent purification in a pig farm	
Goals	Reduce the pollutant load of an effluent from a pig farm using a constructed wetland as a secondary treatment
Typology	Multistage system consisting of 4 cells
Stratigraphy and typology of filling medium	Units consisting of a gravel bed. The gravel bed was of 5-4 cm size in the first unit, 4-3 cm in the second, 3-2 cm in the third and 2-1 cm in the fourth, with a bed height of 0.5 m.
System Treatment	Sedimentation tank, Constructed Wetland, Oxidation pool (aerobic lagoon)
Vegetation	*Monochoria Vaginalis presl ex kunth*
Flow rate	80-100 l/d
Characteristics of the influent	1000 mg/l BOD_5; 2000 mg/l COD; 550 mg/l TSS
Characteristics of the effluent	124.1 mg/l BOD_5 ; 246.1 mg/l COD ; 51.5 mg/l TSS
Notes	The plant removes 80% TSS, 90% BOD_5

2.3.1.2 Wetland system for agriculture and animal industry

In this case, all the components of the system have been successful, and the system has offered the potential for recycling all nutrients. It has been seen the plant used (water hyacinth roots) has the ability to absorb and coagulate suspended material [14].

Table 12 Study case 2

Wetland system for agriculture and animal industry	
Goals	Purify the water of animal excreta especially of pork by a system of constructed wetlands
Typology	Multi-stage system with 2 cells, Retention time of 10 days,
Stratigraphy and typology of filling medium	Not specified
Treatment System	Sedimentation tank, Constructed Wetland
Vegetation	*Hyacinth (eichornia crassipes)*
Flow rate	5000 l/d
Characteristics of the influent	30000 - 52000 mg/l DOB_5
Characteristics of the effluent	3000 mg/l BOD_5

2.3.1.3 Performance of a constructed wetland for treating farm-yard dirty water

This study shows that the constructed wetland has achieved a high and consistent removal rate. It has five cells and the results show that the correct sizing is essential. It was also noted that the constructed wetlands operated as an excellent pollution control system during the summer period of the year when river flows tended to be low and vulnerable to farm yard runoff pollution [27].

Table 13 Study case 3

Performance of a constructed wetland for treating farm-yard dirty water	
Goals	Clean sewage from dairy farms
Typology	A multi-station horizontal subsurface flow constructed wetland system with 5 stations with a total area of 12510 m^2
Stratigraphy and typology of filling medium	Not specified
Treatment System	Not specified
Vegetation	*Phragmites australis ; Typha lutifolia ; Carex ; Sparganium erectum*
Flow rate	Not specified
Characteristics of the influent	2716 mg/l BOD_5
Characteristics of the effluent	8 mg/l BOD_5

2.3.1.4 Phosphorus removal from lagoon pretreated swine wastewater by pilot-scale surface flow constructed wetlands planted with *Miriophyllum aquaticum*

This case shows that the *M. aquaticum* used in a constructed wetland can remove phosphorus effectively from swine wastewater, with a mean removal efficiency of 70.1–89.4%. Phosphorus in the swine wastewater was removed mainly via absorption and precipitation by sediment in the constructed wetland 1 and via uptake and harvest of the plant *M. aquaticum* in constructed wetland 3 [15].

Table 14 Study case 4

Phosphorus removal from lagoon-pretreated swine wastewater by pilot-scale surface flow constructed wetlands planted with *Myriophyllum aquaticum*	
Goals	Treat sewage produced by pigs and pretreat from a lagoon through constructed wetlands.
Typology	A multi-station system composed of a surface flow constructed wetland of 3 cells. Dimensions 5 x 2 x 0.2 m, retention time of 33 days
Stratigraphy and typology of filling medium	Paddy soil
Treatment System	Constructed wetland
Vegetation	*M. aquaticum*
Flow rate	Not specified
Characteristics of the influent	High 55 mg/l ; Medium44.5 mg/l ; Low 25.5 mg/l TP
Characteristics of the effluent	High 17 mg/l ; Medium 8.1mg/l ; Low 3.4 mg/l
Notes	Removes 78-89% TP

2.3.1.5 Swine wastewater treatment by marsh-pond-marsh constructed wetlands under varying nitrogen loads

This study shows that the constructed wetlands removed an average of 35–51% of wastewater TSS, 30–50% of wastewater COD, 37–51% of total N, and 13–26% of total P. It was noted that the COD and total N treatment efficiencies were significantly lower during the winter experimental period compared to the summer [28].

Table 15 Study case 5

Swine wastewater treatment by marsh-pond-marsh constructed wetlands under varying nitrogen loads	
Goals	Investigate the efficiency of the marsh-pond-marsh to treat wastewaters from pig farms, varying the loads of nitrogen.
Typology	Multi-station system with 6 surface flow stations. With dimensions of 11 x 10 m and with a depth of 0.15 m at the beginning and at the end and in the central part a depth of 0.75 m.
Stratigraphy and typology of filling medium	Not specified
Treatment System	Storage tank, Anaerobic lagoon, Constructed Wetland
Vegetation	*Typha latifolium ischoenoplectus americanus*
Flow rate	Not specified
Characteristics of the influent	From the anaerobic lagoon 175 mg/l TN
Characteristics of the effluent	Not specified
Notes	Decrees 31-50% TSS, 30-50%COD,37-51% TN, 12-26% TP

2.3.1.6 Swine wastewater treatment using vertical subsurface flow constructed wetland planted with *Napier grass*

This case concludes that the *Giant* and *Dwarf Napier* grasses can be used in the VSF constructed wetlands to treat swine wastewater and that this constructed wetland has a prominent pollutant removal performance, especially for the BOD_5 and TKN [16].

The system reached the Thailand's swine wastewater quality standard and there is no statistically significant difference among the treatments that uses different retention times with different kinds of plants.

Table 16 Study case 6

<table>
<tr><td colspan="4">Swine wastewater treatment using vertical subsurface flow constructed wetland planted with Napier Grass</td></tr>
<tr><td>Goals</td><td colspan="3">Measure the efficiency of the pollutant reduction in wastewater of pig farms, using a constructed wetland.</td></tr>
<tr><td>Typology</td><td colspan="3">A multistate system of vertical subsurface flow bed. It is a circular tank of diameter 0.8 m and a depth of 0.8 m. With a retention time of 2 days and 5 days depending on the vegetation</td></tr>
<tr><td>Stratigraphy and typology of filling medium</td><td colspan="3">The bed consists of 10 cm of gravel, 40 cm of fine sand and 15 cm of medium sand.</td></tr>
<tr><td>Treatment System</td><td colspan="3">Not specified</td></tr>
<tr><td>Vegetation</td><td colspan="3">Pennisetum purpureum , King grass and Mott</td></tr>
<tr><td>Flow rate</td><td colspan="3">Not specified</td></tr>
<tr><td>Characteristics of the influent</td><td colspan="3">120 mg/l BOD_5 ; 373 mg/l COD, 31.8 mg/l TSS ; 70 mg/l N</td></tr>
<tr><td rowspan="5">Characteristics of the effluent</td><td>Retention time</td><td>Plant 1: Pennisetum purpureum cv King</td><td>Plant 2: Pennisetum purpureum cv Mott</td></tr>
<tr><td rowspan="2">2 days</td><td>11 mg/l BOD_5</td><td>16 mg/l BOD_5</td></tr>
<tr><td>10 mg/l TSS</td><td>11 mg/l TSS</td></tr>
<tr><td rowspan="2">5 days</td><td>21 mg/l BOD_5</td><td>22 mg/l BOD_5</td></tr>
<tr><td>11 mg/l TSS</td><td>15 mg/l TSS</td></tr>
<tr><td>Notes</td><td colspan="3">Removes 70% of BOD_5</td></tr>
</table>

2.3.17 Constructed wetland in wastewater treatment

The study results show that ammonia, total phosphorus, BOD_5, and organic matter were high indicating that macrophytes had an important role in removing these variables [29].

Table 17 Study case 7

Constructed wetland in wastewater treatment	
Goals	Determine the effectiveness of a constructed wetland to treat wastewater
Typology	Constructed wetland with dimensions of 70 x 1 x 0.3 m
Stratigraphy and typology of filling medium	Mud
Treatment System	Bio digester, constructed wetland
Vegetation	*Eichhornia crassipes, Alternanthera philoxerodos, Heteranthera reniformis, Hydrocoty leumbeliferae, Ludwigia elegan, Ludwigia sericea, Myriophyllum aquaticum and Thypha domingensis*
Flow rate	Not specified
Characteristics of the influent	Not specified
Characteristics of the effluent	4.3 mg/l BOD_5 , 28 mg/l TSS
Note	Not effective with Nitrogen

2.3.1.8 Zootechnical wastewater reuse: constructed wetland as a challenge for protozoan parasite removal

This case shows, to some extent, that constructed wetlands as complement to more conventional water treatment technologies are able to reduce the number of protozoa and thus reduces the potential risk of infection through contaminated aquatic environments [30].

Table 18 Study case 8

Zootechnical wastewater reuse: Constructed wetland as a challenge for protozoan parasite removal	
Goals	Evaluate the removal of parasites through the use of a constructed wetland
Typology	A vertical subsurface flow constructed wetland, with dimensions corresponding to 13 x 6 m at the top with a depth of 1.9 m and a bottom of 11 x 4 m
Stratigraphy and typology of filling medium	Soil by 20%, sand and gravel
Treatment System	Not specified
Vegetation	*Arundo donax*
Flow rate	Not specified
Characteristics of the influent	Not specified
Characteristics of the effluent	2.4×10^4 MPN/100 ml BOD_5 ; 4.4×10^2 MPN/100 ml *E.coli*
Notes	Avoid bad odors and direct contact with the environment

2.3.1.9 Multistage hybrid subsurface flow constructed wetlands for treating piggery and dairy wastewater in cold climate

This case studied three-hybrid subsurface flow constructed wetlands and all of them were able to effectively treat high pollutants content in the wastewater in cold climate conditions [31].

The parameters TN, NH4-N, TP, COD, BOD_5, TSS, and *E. coli* had a removal efficiency of 70-86%, 40-85%, 71-90%, 91-96%, 94-98%, 84-97% and 70-97%, respectively.

Table 19 Study case 9

Multistage hybrid subsurface flow constructed wetlands for treating piggery and dairy wastewater in cold climate	
Goals	Evaluate the use of a constructed wetland system treating piggery and dairy wastewater
Typology and geometry	It is a subsurface hybrid system, consisting of 4 vertical flow units and one horizontal unit.
Stratigraphy and typology of filling medium	Pumice gravel; sand; gravel and clinker ash
Treatment System	Not specified
Vegetation	*Phragmites australis*
Flow rate	Not specified
Characteristics of the influent	Not specified
Characteristics of the effluent	COD was reduced from 91-96% and BOD_5 from 94-98%

2.3.1.10 Startup water purification performance of multistage vertical flow constructed wetland treating milking parlor and paddock run-off

This study shows that the water quality through the five stage units improves. The vegetation was planted in different ways in each unit, a vegetated zone, a half vegetated zone and a non-vegetated zone. The best performance is reached in the non-vegetated zone [32].

Table 20 Study case 10

Start-up water purification performance of multistage vertical flow constructed wetland treating milking parlor wastewater and paddock run-off	
Goals	Investigate the contribution of the treatment stages as well as the effect of the vegetation on the start-up purification performance of a constructed wetland system
Typology	A multistage vertical subsurface flow constructed wetland system of 5 units of 111 m^2
Stratigraphy and typology of filling medium	Large gravel, small gravel and gross sand
Treatment System	Not specified
Vegetation	*Phragmites australis*
Flow rate	Not specified
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	BOD_5 reduced until 60-80% in the three first units and in the last two 15%.

2.3.1.11 Intervention of rationalization of the use of water in milking operations and purification of wastewater through constructed wetlands

This study reveals that constructed wetlands are efficient reducing the TSS present in the wastewaters from milking operations [33].

Table 21 Study case 11

Intervention of rationalization of the use of water in milking operations and purification of wastewater through constructed wetlands	
Goals	To value the efficiency of constructed wetlands treating wastewater from milking operations.
Typology	A multistage constructed wetland system of 3 units of horizontal subsurface flow
Stratigraphy and typology of filling medium	Gravel
Treatment System	2 imoff tanks, filtration tank, horizontal subsurface flow constructed wetland
Vegetation	*Phragmites australis*
Flow rate	4-4.5 m^3/d
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Decreases TSS

2.3.1.12 Adapting socioeconomic, operational, and environmental challenges of dairy farm effluent in Uruguay through the use of surface flow constructed wetland

This study shows that the farmers who produce zootechnical wastewater are interested in the implementation of a constructed wetland and a constructed wetland that was built, showed a good efficiency with suspended solids [34].

Table 22 Study case 12

Adapting to socioeconomic, operational, and environmental challenges of dairy farm effluent in Uruguay through the use of surface flow constructed wetland	
Goals	To implement a surface flow constructed wetland using native plants and evaluate the willingness of the farmers to pay.
Typology	A multistage constructed wetland system of 3 units of horizontal subsurface flow
Stratigraphy and typology of filling medium	Gravel
Treatment System	Anaerobic lagoon 1710 m^3, facultative lagoon 2223 m^3, surface flow constructed wetland 736 m^2
Vegetation	*Scirpus americanus*
Flow rate	4-4.5 m^3/d
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Decreases TSS

2.3.1.13 7 Constructed wetlands to treat wastewater from dairy and swine operations

This article indicates that constructed wetlands are an option well defunded to treat the zootechnical wastewaters, although their efficacy depends on the characteristics of the wastewater and the climate [35].

Table 23 Study case 13

Constructed wetlands to treat wastewater from dairy and swine operations	
Goals	To review the use and efficiency of constructed wetlands in the zootechnical wastewaters treatment.
Typology	A horizontal subsurface flow constructed wetland, a vertical subsurface flow constructed wetland of 2 stages
Stratigraphy and typology of filling medium	Not specified
Treatment System	Not specified
Vegetation	Not specified
Flow rate	Not specified
Characteristics of the influent	1119 mg/l BOD_5
Characteristics of the effluent	71.4 mg/l BOD_5
Notes	Removes 74% BOD_5

2.3.1.14 Wastewater similar to domestic wastewater: "La Collina" company

This book explains how the constructed wetlands work and presents some examples of their application in some zootechnical wastewaters [36].

Table 24 Study case 14

Wastewater similar to domestic wastewater: "La Collina" company	
Goals	To show the application of a constructed wetland treating zootechnical wastewaters.
Typology	A vertical subsurface flow constructed wetland of 100 m^2
Stratigraphy and typology of filling medium	Not specified
Treatment System	Imoff tank, constructed wetland
Vegetation	Not specified
Flow rate	6 m^3/d
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Not specified

2.3.1.15 Wastewater similar to domestic wastewater: Da Capreria dairy

This book explains how the constructed wetlands work and presents some examples of their application in some zootechnical wastewaters [36].

Table 25 Study case 15

Wastewater similar to domestic wastewater: Da Capreria dairy	
Goals	To show the application of a constructed wetland treating zootechnical wastewaters
Typology	A horizontal subsurface flow constructed wetland od 104 m^2
Stratigraphy and typology of filling medium	Not specified
Treatment system	Constructed wetland
Vegetation	Not specified
Flow rate	4.16 m^3/d
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Not specified

2.3.1.16 Wastewater similar to domestic wastewater: Campogalliano milking parlor

This book explains how the constructed wetlands work and presents some examples of their application in some zootechnical wastewaters [36].

Table 26 Study case 16

Wastewater similar to domestic wastewater: Campogalliano milking parlor	
Goals	To show the application of a constructed wetland treating zootechnical wastewaters
Typology	A vertical subsurface flow constructed wetland of 32 m^2
Stratigraphy and typology of filling medium	Not specified
Treatment system	Constructed wetland
Vegetation	Not specified
Flow rate	2.4 m^3/d
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Not specified

2.3.1.17 Wastewaters assimilated to domestic wastewaters: Faieto milking parlor

This book explains how the constructed wetlands work and presents some examples of their application in some zootechnical wastewaters [36].

Table 27 Study case 17

Wastewaters assimilated to domestic wastewaters: Faieto milking parlor	
Goals	To show the application of a constructed wetland treating zootechnical wastewaters
Typology	A horizontal subsurface flow constructed wetland of 160 m^2, a retention time of 10 days
Stratigraphy and typology of filling medium	Not specified
Treatment system	Constructed wetland
Vegetation	Not specified
Flow rate	6 m^3/d
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Not specified

2.3.1.18 Wastewater similar to domestic: milk-bottling plant

This book describes how the constructed wetlands work and presents some examples of their application in some zootechnical wastewaters [36].

Table 28 Study case 18

Wastewater similar to domestic: milk bottling plant	
Goals	To show the application of a constructed wetland treating zootechnical wastewaters
Typology	A horizontal subsurface flow constructed wetland of 150 m^2
Stratigraphy and typology of filling medium	Not specified
Treatment system	Septic tank, Constructed wetland
Vegetation	Not specified
Flow rate	80 m^3/d
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Not specified

2.3.1.19 Industrial wastewaters: Santa Vittoria dairy

This book details how the constructed wetlands work and presents some examples of their application in some zootechnical wastewaters [36].

Table 29 Study case 19

Industrial wastewaters: Santa Vittoria dairy	
Goals	To show the application of a constructed wetland treating zootechnical wastewaters
Typology	A horizontal subsurface flow constructed wetland, a vertical subsurface flow constructed wetland, total area 4050 m^2
Stratigraphy and typology of filling medium	Not specified
Treatment system	Homogenization and oxygenation tank, a 4 stage horizontal subsurface flow constructed wetland, a vertical subsurface flow constructed wetland
Vegetation	Not specified
Flow rate	80 m^3/d
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Not specified

2.3.1.20 Livestock industrial wastewater: Carmignano del Brenta

This book explains how the constructed wetlands work and presents some examples of their application in some zootechnical wastewaters [36].

Table 30 Study case 20

Livestock industrial wastewater: Carmignano del Brenta	
Goals	To show the application of a constructed wetland treating zootechnical wastewaters
Typology	A horizontal subsurface flow constructed wetland, a vertical subsurface flow constructed wetland
Stratigraphy and typology of filling medium	Not specified
Treatment system	Physical separation, chemical separation, percolator filter, constructed wetland
Vegetation	*Phragmites australis, Iris psedaucorus, Typha latifolia*
Flow rate	4 m^3/d
Characteristics of the influent	48000 mg/l COD, 30000 mg/l BOD_5, 2150 mg/l N
Characteristics of the effluent	160 mg/l COD, 40 mg/l BOD_5, 15 mg/l N
Notes	Not specified

2.3.1.21 Industrial wastewater: Carpaneto Piacentino dairy

This book explains how the constructed wetlands work and presents some examples of their application in some zootechnical wastewaters [36].

Table 31 Study case 21

Industrial wastewater: Carpaneto Piacentino dairy	
Goals	To show the application of a constructed wetland treating zootechnical wastewaters
Typology	A horizontal subsurface flow constructed wetland, a vertical subsurface flow constructed wetland
Stratigraphy and typology of filling	Not specified
Treatment system	Constructed wetland
Vegetation	Not specified
Flow rate	80 m^3/d
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Not specified

2.3.1.22 Constructed wetlands applied to the treatment of wastewater in the milking area of cattle breeding

This article shows that the constructed wetlands are a worthy option for the treatment of wastewaters generated in milking spaces. It is also indicated that the costs of this type of treatment are accessible [37].

Table 32 Study case 22

Constructed wetlands applied to the treatment of wastewater in the milking area of cattle breeding	
Goals	To verify the efficiency of the constructed wetlands in reducing the polluting load of milking wastewaters.
Typology	A horizontal subsurface flow constructed wetland of 2 stages, 75 m^2 of area each one
Stratigraphy and typology of filling medium	Not specified
Treatment system	Imoff tank, constructed wetland
Vegetation	Not specified
Flow rate	4.5 m^3/d
Characteristics of the influent	700mg/l TSS, 1200mg/l COD, 450mg/l BOD_5
Characteristics of the effluent	Not specified
Notes	Removes 90% of BOD_5, COD and TSS; 50%N, 60%P

2.3.1.23 Effects of load fluctuations on treatment potential of a hybrid subsurface flow constructed wetland treating milking parlor wastewater

This document shows that even the load fluctuations of the pollutants in the wastewater, and the constructed wetlands systems are tolerant to them [38].

Table 33 Study case 23

Effects of load fluctuations on treatment potential of a hybrid subsurface flow constructed wetland treating milking parlor wastewater	
Goals	To evaluate the effects of load fluctuations on the treatment efficiencies in a hybrid subsurface flow constructed wetland
Typology	A vertical subsurface flow constructed wetland of 2 stages, a horizontal subsurface flow constructed wetland
Stratigraphy and typology of filling medium	Gravel and sand
Treatment system	Constructed wetland
Vegetation	*Phragmites australis*
Flow rate	Not specified
Characteristics of the influent	1259 mg/l TSS, 2114 mg/l BOD_5, 7085 mg/l COD, 243 mg/l TN, 41 mg/l TP
Characteristics of the effluent	Not specified
Notes	Removes 99% TSS, 95% BOD_5, 96% COD, 90% TN, 87% TP

2.3.1.24 Treatment of industrial effluents in constructed wetlands: challenges, operational strategies and overall performance

This document indicates that the constructed wetlands have a high tolerance to high organic loads and they are effective to treat the wastewater generated in the milking parlor/cheese industry [39].

Table 34 Study case 24

Treatment of industrial effluents in constructed wetlands: challenges, operational strategies and overall performance	
Goals	To evaluate how constructed wetlands work with high organic loads
Typology	A horizontal subsurface flow constructed wetland
Stratigraphy and typology of filling medium	Not specified
Treatment system	Sedimentation tank, anaerobic lagoon, constructed wetland
Vegetation	Not specified
Flow rate	Not specified
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Just the wetland removed 30% of organic matter The total system removed 91% BOD_5, 89% COD, 85% TSS

2.3.1.25 The use of constructed wetlands for the treatment of agro-industrial wastewater. A case study in a dairy cattle farm in Sicily (Italy)

The study indicates that the constructed wetlands are a good option for the treatment of agro-industrial wastewater and the treated wastewater can reach the legal requirements [40].

Table 35 Study case 25

The use of constructed wetlands for the treatment of agro-industrial wastewater. A case study in a dairy cattle farm in Sicily (Italy)	
Goals	To evaluate the pollutants removal efficiency of a constructed wetland treating the wastewater generated in a dairy cattle farm
Typology	A horizontal subsurface flow constructed wetland
Stratigraphy and typology of filling medium	Not specified
Treatment system	Degreaser, 2 imoff tanks, constructed wetland
Vegetation	*Phragmites australis*
Flow rate	Not specified
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Not specified

2.3.1.26 Effects of the hydraulic retention time on pig slurry purification by constructed wetlands and stabilization ponds

This study shows that the retention time in a constructed wetland can be a determining variable in its efficiency to eliminate pollutants from a wastewater. Even 3 days retention time is recommended in literature, a 7 day retention time is better [41].

Table 36 Study case 26

Effects of the hydraulic retention time on pig slurry purification by constructed wetlands and stabilization ponds	
Goals	To compare the efficiency of a constructed wetland varying the retention time.
Typology	A horizontal subsurface flow constructed wetland of 3 stages with 3-7 days of retention time.
Stratigraphy and typology of filling medium	80 cm of gravel, 20 cm of washed sand.
Treatment system	Storage tank, physical separation, stabilization lagoon, constructed wetland
Vegetation	*Phragmites australis*
Flow rate	Not specified
Characteristics of the influent	3233 mg/l COD, 3052 mg/l TSS, 2800 mg/l TN, 129 mg/l TP
Characteristics of the effluent	Not specified
Notes	Removes 30% COD

2.3.1.27 Performance evaluation of hybrid treatment wetland for six years of operation in cold climate

The document shows that the performance of the hybrid subsurface flow constructed wetland is excellent even though six years has passed [42].

Table 37 Study case 27

Performance evaluation of hybrid treatment wetland for six years of operation in cold climate	
Goals	To evaluate the efficiency removal of pollutant in six years using a hybrid subsurface flow constructed wetland.
Typology	A vertical subsurface flow constructed wetland of 2 stages (160 m^2 each one), a horizontal subsurface flow constructed wetland. (336 m^2)
Stratigraphy and typology of filling medium	Not specified
Treatment system	Sedimentation tank, constructed wetland
Vegetation	*Phragmites australis*
Flow rate	Not specified
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Removes 90% COD, 90% BOD_5, 90% TSS

2.3.1.28 Treatment of dairy wastewater using constructed wetlands and intermittent sand filters

This article shows that the constructed wetlands are usually used to treat this type of wastewater but they show a limitation with the organic load [43].

Table 38 Study case 28

Treatment of dairy wastewater using constructed wetlands and intermittent sand filters	
Goals	To evaluate the performance of constructed wetlands in the treatment of parlor wastewater treatment
Typology	2 vertical subsurface flow constructed wetland, a horizontal subsurface flow constructed wetland. (336 m^2)
Stratigraphy and typology of filling medium	Not specified
Treatment system	Anaerobic lagoon, constructed wetland
Vegetation	Not specified
Flow rate	Not specified
Characteristics of the influent	350 mg/l BOD_5, 400 mg/l TSS
Characteristics of the effluent	61 mg/l BOD_5, 100 mg/l TSS
Notes	Not specified

2.3.1.29 Wastewater treatment from milk processing. Santa Lucia di Casina Farm

This study shows how the produced wastewater in a stall where milk is transformed to cheese is treated through a constructed wetland system [44].

Table 39 Study case 29

Wastewater treatment from milk processing. Santa Lucia di Casina Farm	
Goals	To evaluate the efficiency of constructed wetlands treating wastewaters product of milk transformation.
Typology	2 horizontal subsurface flow constructed wetlands of 12.5 x 6 x 0.9 m
Stratigraphy and typology of filling medium	Gravel of 8-12 mm and gravel of 3-6mm
Treatment system	Imoff tank, intermittent filter, constructed wetland
Vegetation	*Phragmites australis*
Flow rate	Not specified
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Wastewaters matches to law and can be discharged.

2.3.1.30 Hybrid constructed wetlands plant for the treatment of pig wastewaters

This report shows how to treat swine wastewater with constructed wetlands. The constructed wetland systems area is around 130m^2 [45].

Table 40 Study case 30

Hybrid constructed wetlands plant for the treatment of pig wastewaters	
Goals	To treat swine wastewater through constructed wetlands
Typology	3 vertical subsurface constructed wetlands of 10 x 0.7 x 0.7 m, 1 horizontal subsurface constructed wetland 27 x 4 x 0.7 m
Stratigraphy and typology of filling medium	Washed gravel
Treatment system	Not specified
Vegetation	*Phragmites australis*
Flow rate	Not specified
Characteristics of the influent	Not specified
Characteristics of the effluent	Not specified
Notes	Not specified

Two tables are presented in which the characteristics of effluents treated with constructed wetlands are indicated as well as the results after applying the treatment [11].

Table 41 Characteristics of the wastewaters treated by constructed wetlands

Country	Spain	Australia	Connecticut	USA	Italy	Ireland	USA	Ireland
Water origin	milking parlor	farm	milking parlor	farm	milking parlor	farm	farm	milking parlor
Flow l/cow day	21.7	67	26.9		55	181		50
BOD_5 mg/l	1056	220	1000-13000	442	636	2629	517	954-2974
COD mg/l	3096		1284		1709			3000
TSS mg/l	1440		103	1111	1008	980		
TN mg/l	206	59	26		82			88-225
TP mg/l	35				18		21	

Table 42 Characteristics of the wastewaters after the treatment

Country	Spain	Australia	Connecticut	USA	Italy	Ireland	USA	Ireland
Water origin	Milking parlor	Farm	Milking parlor	Farm	Milking parlor	Farm	Farm	Milking parlor
Pretreatment		Lagoon	Septic tank		Imhoff tank			Septic tank
Constructed Wetland	HSSF	FWS/HSSF	HSSF	FWS/HSSF	2HSSF	HSSF	HSSF/VSSF	VSSF
Elimination efficiency	92-76 BOD_5	61 BOD_5	85 BOD_5		90 TSS	99 TSS	99 BOD_5	99 BOD_5
	76-83 TSS	27 TKN	94 TSS		90 COD	99 BOD_5		86 TN
		28 TP	68 TP		90 BOD_5			
			53 TKN		48.5 TKN			
					60.6 TP			
Retention time	2 to 7	10 to 14	41		10		10	
Effluent	11-27 BOD_5	90 BOD_5	692 BOD_5		28 BOD_5	20 BOD_5	5.2 BOD_5	
	30-36 TSS	49 TP	130 TSS		60 TSS	11 TSS		
			14 TP		98 COD			
					33 TKN			
					5 TP			

CHAPTER III

PROBLEM CONTEXT

3.1 Ecuador and its zootechnical sector

3.1.1 General aspects

Ecuador is a country located in the northern part of South America on the parallel with the same name, it has an extension of 283561 km^2; its geographical limits are to the north with Colombia, to the south and east with Peru, and to the west with the Pacific Ocean. It is divided into four natural regions: Coast, Mountains, Eastern and Galapagos Regions [46].

Figure 7 Ecuador's Localization and Map

The population of Ecuador is 16,750,253 people, 63% of them live in urban areas and 37% in rural areas. According to the index of dissatisfied basic needs, 31.8% of the population is poor [47].

65.2% of Ecuador's urban population is economically active and 94.3% are employed; while of the rural population, 74.7% belong to the economically active population and of this, 98.1% are employed [48].

Ecuador is a major exporter of oil, flowers, shrimps and cocoa; and the first banana exporter in the world. The country GDP is of 182.4 billion dollars (USA dollars), which places it in seventh place in the South American economy.

The Ecuadorian GDP is mainly due to the oil region, followed by the agro-zootechnical sector (including agriculture, livestock breeding, fishing and forestry). If we consider the enlarged agro-zootechnical sector (the one that incorporates the agro-food industry and its main branches), it is the first to support the GDP[1].

3.1.2 Zootechnical sector

Ecuador is a country with a high potential in agro-zootechnical activities (79% of its area has potential for this sector), however, only 34% of this area is used in the agro-zootechnical activities, the remaining 66% is in a conflict zone.

The importance of this sector for the economy of the country lies in the fact that in 2013, according to data from the Central Bank of Ecuador, it contributed to the GDP with 14% in the category of an enlarged agro-zootechnical sector.

The main products of the agro-zootechnical sector for the GDP are the bananas in the international market, while in the national market are the animals breeding, cereals, tubers and fruits. Animal husbandry contributed with $414,462 USD in 2013.

During 2007 and 2013 agro-zoo technical GDP generated employment for 62% -70% of the country's rural population. 1.5 million people (62%) from the rural area and 300,000 people from the urban area depended from this sector, which represents a quarter of the total number of employees at a national level.
Of the 841,045 zootechnical production areas in 2013, 24% were responsible for women, representing more than 200,000 women working in this sector [1].

3.1.3 Cattle

The bovine cattle with 4.1 million of heads mainly represent the zootechnical sector of Ecuador, even if pigs, poultry and smaller species are produced.

Table 43 Type of cattle and number

Type of cattle	Number of animals
Bovines	4,190,611
Pigs	1,115,473
Sheep	390,120
Horses	209,990
Donkeys	80,111

Mule	49,120
Goats	39,583
Roosters and Hens	13,406,254
Chickens	29,166,370

Of the 4.1 millions of bovine heads that exist nationwide, 73.23% are females and 29.77% are males.

The cattle breed that predominates is the "mixed" with 31.43%, followed by the creole breed with 27.79% and the Brahmin and Holstein breeds [2].

3.1.3.1 Bovine Cattle distribution at National level

At regional level, the mountain region is the one with the highest number of animals with 48.87% of the national total and the one with the highest milk production. However, at provincial level, Manabí is the province with the highest number of animals and Pichincha is the province that produces more milk (16.27% of the national total) [2].

Table 44 Bovines national distribution

Region	Number of cows	Milked cows	Milk production (litters)
National total	4,190,611	856,164	5,135,405
Mountains	2,048,097	550,596	3,915,587
Coast	1,773,500	256,803	1,009,644
Eastern	367,422	48,515	207,898
Unlimited areas	1,592	251	2,075

In the coastal region, the Manabí province is distinguished by the number of animals and the milk production.

Table 45 Bovines coast region distribution

Coast			
Province	Number of cows	Milked cows	Milk production (litters)
El Oro	186,544	15,051	110,030
Esmeraldas	309,469	33,077	128,874
Guayas	270,029	40,160	145,698
Los Rios	107,084	9,876	37,341
Manabí	896,476	158,505	587,252
Santa Elena	3,898	133	449

In the Mountain region, the Azuay province is distinguished by the number of animals while the Pichincha province excels in milk production.

Table 46 Bovines mountains region distribution

Mountains			
Province	Number of cows	Milked cows	Milk production (litters)
Azuay	323,735	94,961	482,401
Bolivar	188,680	46,533	197,040
Cañar	155,095	50,669	324,578
Carchi	99,803	34,801	360,598
Cotopaxi	254,709	63,932	514,759
Chimborazo	222,316	64,846	431,325
Imbabura	91,807	19,261	160,473
Loja	166,226	27,770	103,152
Pichincha	286,586	85,172	835,663
Tungurahua	106,133	34,103	297,060
Santo Domingo de los Tsáchilas	148,006	28,548	206,738

In the Eastern region, the main province in terms of the number of animals and milk production is Morona Santiago.

Table 47 Bovines Eastern region distribution

Eastern			
Province	Number of cows	Milked cows	Milk production (litters)
Morona Santiago	137,942	17,972	67,041
Napo	21,620	3,949	23,892
Orellana	29,576	2,960	18,754
Pastaza	11,815	1,992	11,223
Sucumbíos	86,565	8,918	33,446
Zamora Chinchipe	79,904	12,724	53,542

Dual-purpose systems (milk and meat) cover 69% of the production, 19% milk production and 12% meat production. 72.32% of the produced milk is destined for sale and marketing [1].

3.1.3.2 Pastures surface destined to bovine cattle

In the Coast region, the Manabí province is the one with the most quantity of areas occupied with pastes for cattle, followed by Esmeraldas province.

Table 48 Pastures surface coastal region

Coast	Natural pastes (Ha)	Cultivated pastes (Ha)	Total (Ha)
El Oro	139,901	17,976	157,877
Esmeraldas	217,319	626	217,945
Guayas	138,097	27,394	165,491
Los Ríos	47,628	21,415	69,044
Manabí	752,974	13,800	766,774
Santa Elena	5,704	298	6,002

In the Mountain region, the province that has the largest amount of areas occupied by pastures for livestock is Loja, followed by the Azuay province [2]; while in the Eastern region, the province with the largest number of areas occupied by cattle pastures is Morona Santiago, followed by Sucumbíos.

Table 49 Pastures surface mountains region

Mountains	Natural pastes (Ha)	Cultivated pastes (Ha)	Total (Ha)
Azuay	81,004	98,381	179,385
Bolívar	128,090	5,860	133,950
Cañar	37,601	41,009	78,610
Carchi	25,270	24,138	49,408
Cotopaxi	52,395	87,167	139,562
Chimborazo	49,955	55,189	105,144
Imbabura	25,350	22,730	48,081
Loja	82,260	115,574	197,834

Pichincha	96,053	57,284	153,337
Tungurahua	31,558	21,407	52,965
Santo Domingo de los Tsáchilas	11,578	26	113,604

Table 50 Pastures surfaceEastern region

Eastern	Natural pastes (Ha)	Cultivated pastes (Ha)	Total (Ha)
Morona Santiago	172,701	17,915	190,616
Napo	19,803	1,256	21,059
Orellana	33,591	8,072	41,663
Pastaza	12,841	23,688	36,529
Sucumbíos	100,664	384	101,048
Zamora Chinchipe	81,693	15,864	97,557

3.1.3.3 Zootechnical production areas for bovine cattle

The production areas have been classified according to the hectares they occupy, those of less than one hectare of land are the most numerous [2].

Table 51 Production areas according to size

Bovine	Production area size										
	Total	<1 Ha	1-2 Ha	2-3 Ha	3-5 Ha	5-10 Ha	10-20 Ha	20-50 Ha	50-100 Ha	100-200 Ha	>200 Ha
# Production areas	427514	93839	57747	40295	47143	52574	44793	51434	24803	9948	4939

The Mountain region is the one with the largest number of production areas dedicated to livestock.

In the Mountain region the Azuay province, in the coast the Manabí province and in the Eastern the Morona Santiago province.

Table 52 Production areas by region

Mountains Total: 339555		Coast Total: 56985		Eastern Total: 30975	
Azuay	6873	El Oro	6733	Morona Santiago	10918
Bolívar	26526	Esmeraldas	6778	Napo	2394

Cañar	21040	Guayas	12487	Pastaza	2145
Carchi	7984	Los Ríos	5733	Zamora Chinchipe	6725
Cotopaxi	37356	Manabí	25255	Sucumbíos	4117
Chimborazo	60548			Orellana	2705
Imbabura	16746			Galápagos	297
Loja	37178			Las Golondrinas	84
Pichincha	29767			La Concordia	613
Tungurahua	40536			Manga del Cura	727
				El Piedrero	249

3.1.3.4 Bovine production systems in Ecuador

Production systems are based upon the surface that the production area has [2].

Small and medium producers are considered those that have from one to 50 hectares in their production areas, with creole cattle and low or no technology because they use self-sufficiency practices and the farm resources they have. The number of bovine heads go from 1 to 100.

Big producers are those with more space, more than 50 hectares, semi-technician activities or good technology; they make genetic improvements with their animals. The number of bovine heads is over 100 heads.

According to this classification, it is determined that 90.7% of the production systems in Ecuador are from small and medium producers (with little or no technology) and 9.3% are of big producers (technically or semi-technically).

3.1.3.4.1 Big producers systems

The big producer systems in Ecuador represent 9.3% of the national total and are characterized by having the following features:

- Stall with access to water and electricity, good ventilation and good lighting

- Perimeter fence of the property
- Facilities for handling animals (fences, sleeves, mobilization ramps)
- Milking and animal waiting rooms away from the stall
- Facilities for the extraction of milk and slaughter of animals
- Tanks and storage facilities for milk and meat
- Systems for cleaning used structures and generated wastes (manure, sludge, sewage)
- Area for waste management far from the production area
- Septic tanks or sedimentation tanks for wastewater treatment
- Sites and facilities for the storage, handling, processing and disposal of manure and sludge
- Showers, toilets and walk-in closets for workers

3.1.3.4.2 Small and medium producers systems

These systems in Ecuador are distinctive because they are extensive, or they increase their size by incorporating new livestock or new extensions of production areas, but they do not increase their productivity with investments in new technologies and animal exploitation mechanisms.

Their main features are:

- Stall with access to water and occasionally electricity
- Perimeter fence of the property
- Milking and animal waiting rooms near or next to the stall
- Manual structures or mechanisms for milk extraction and slaughter of animals
- Poor systems for cleaning used structures and generated wastes (manure, sludge, sewage)
- Area for waste management close to the production area
- Sites for the storage of manure
- Toilets for workers

3.2 Study Area

3.2.1 Geographic location

Paute canton (2°16’44.4”S; 78°45’39.6”W) belongs to the Azuay province and is bordered on the north by Azogues city, on the south by Gualaceo canton, on the east by Sevilla de Oro canton and Guachapala canton and on the west by Cuenca city [49].

It has an area of 271 km^2 and is located at a height of 2100 msnm. It is divided into eight zones that includes: Paute as center , Bulán, Chicán, El Cabo, Guarainag, San Cristobal, Tomebamba and Dugdug [49].

Figure 8 Location of Paute

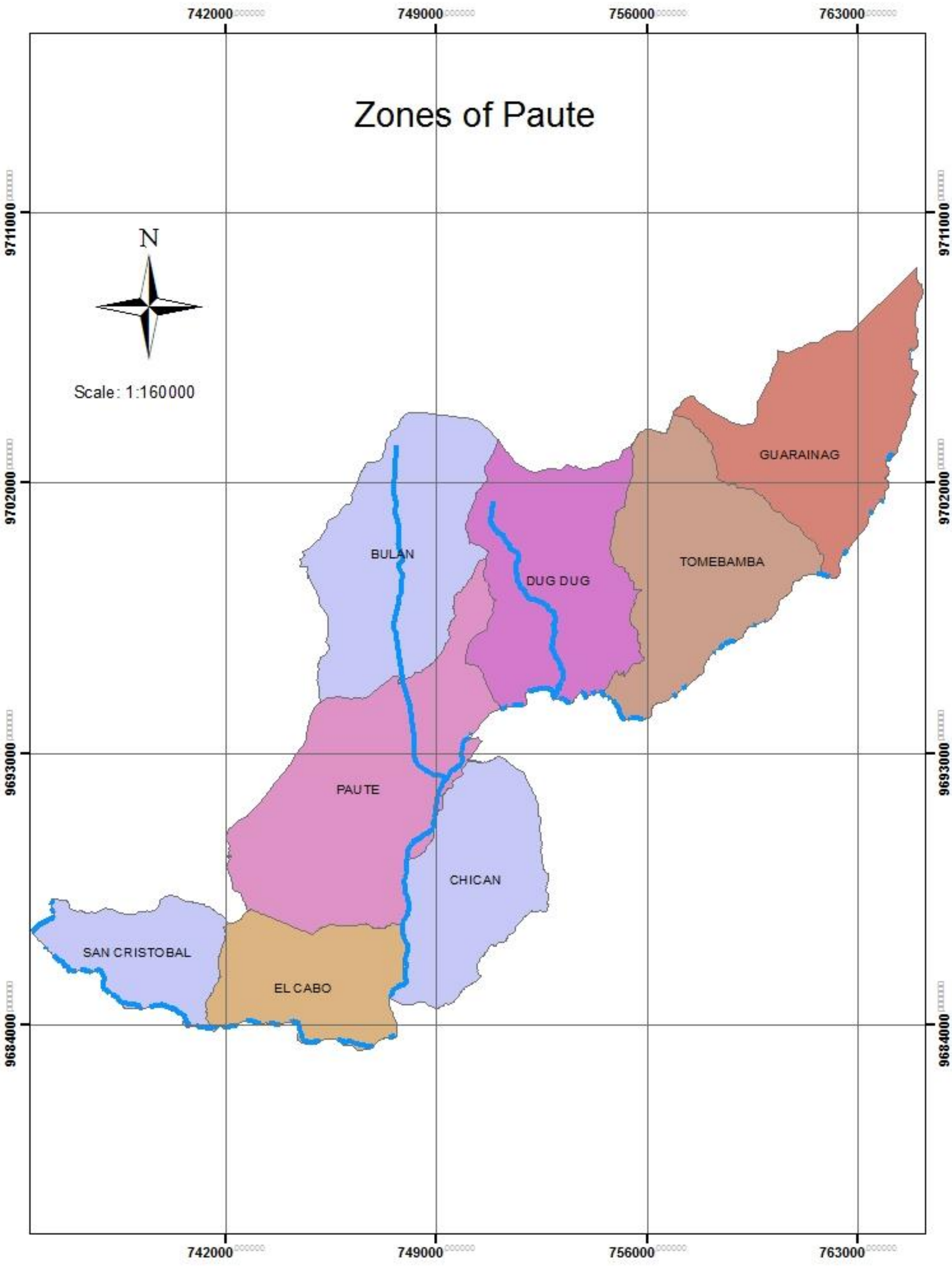


Figure 9 Zones of Paute

3.2.2 Population

Paute has a population of 25,494 inhabitants, each zone has [49]:

Table 53 Paute population by zones

Zone	Inhabitants
Paute as center	9850
Bulán	2173
Chicán	3644
El Cabo	3320
Guarainag	846
San Cristobal	2412
Tomembamba	1346
Dugdug	1902

3.2.3 Climate

Paute has a subtropical-temperate weather with an average annual temperature of 17 °C, a relative humidity of 83% and a precipitation of 852.4 mm per year [49].

3.2.3.1 Precipitation

The month with more precipitation is October while the driest are July and August [50].

Table 54 Precipitation

Month	Precipitation (mm)
January	97.6
February	118.9
March	49.8
April	102
May	53.3
June	49.4
July	40.6
August	32.2
September	14.2
October	147.8
November	90.1
December	56.5

3.2.3.2 Temperature

The hottest month is November while the coldest is August [50].

Table 55 Temperature

Month	Temperature (°C)
January	17.8
February	17.4
March	17.2
April	17.3
May	16.5
June	16.7
July	15.6
August	15.4
September	15.9
October	17.4
November	18.2
December	17.8

3.2.3.3 Evapotranspiration

Paute evapotranspiration was obtained by the Thornthwaide method [51]:

$$\boldsymbol{ETP = \frac{16t^{a}}{I}}$$

Where:

ETP= evapotranspiration

t= temperature

i= monthly caloric index

$i = \frac{t^{1,514}}{5}$

I= annual caloric index

$$\boldsymbol{\Sigma\left(i = \frac{t^{1.514}}{5}\right) = 76.16}$$

$a = 6.75e - 7I3 - 7.71e - 5I2 + 1{,}79E - 2I + 0.49239$

Corrected evapotranspiration

$$ETP\ c = ETP\frac{N}{12}*\frac{d}{30}$$

Where:

N= maximum number of hours= 12

d= number of day in the month

Table 56 Evapotranspiration

Month	Temperature °C	Precipitation mm	I	a	ETP mm	Corrected ETP mm
January	17.8	97.6	6.84	2.60	145.77	150.63
February	17.4	118.9	6.61	2.60	137.40	128.24
March	17.2	49.8	6.49	2.60	133.33	137.77
April	17.3	102	6.55	2.60	135.35	135.35
May	16.5	53.3	6.10	2.60	119.66	123.65
June	16.7	49.4	6.21	2.60	123.47	123.47
July	15.6	40.6	5.60	2.60	103.41	106.86
August	15.4	32.2	5.49	2.60	99.99	103.33
September	15.9	14.2	5.76	2.60	108.66	108.66
October	17.4	147.8	6.61	2.60	137.40	141.98
November	18.2	90.1	7.07	2.60	154.45	154.45
December	17.8	56.5	6.84	2.60	145.77	150.63

3.2.4 Water Resources

Paute is part of the water system of Santiago River; the city is distributed into six sub-basins: Paute, Cuenca, Jadán, Magdalena, Santa Bárbara and Pindilig sub-basins. The Paute sub-basin is the most extensive [49].

The water quality level is poor because there are direct wastewater discharges to the rivers as well as zootechnical activities that are carried out in areas of water bodies or are very close to them [49].

3.2.5 Environmental Sanitation

3.2.5.1 Drinking water

58.82% of Paute population have access to drinking water, being it divided by zones in the following manner [49]:

Table 57 Percentage of population with access to drinking water by zones

Zone	%
Paute as center	71.71
Bulán	52.78
Chicán	77.31
El Cabo	54.04
Guarainag	39.04
San Cristobal	41.35
Tomembamba	37.17
Dugdug	58.82

The remaining 41.18% of the population that do not have access to drinking water obtain it from the rivers and water bodies, rain water or from the public car which distributes it.

3.2.5.2 Sewage wastewater

36.33% of Paute population have access to the sewage system for the wastewater, being it divided by zones in the following manner [49]:

Table 58 Percentage of population with access to sewage system

Zone	%
Paute as center	66.79
Bulán	1.97
Chicán	19.32
El Cabo	34.59
Guarainag	9.02
San Cristobal	3.89
Tomembamba	7.44
Dugdug	25.84

The remaining 63.67% of the population empty their wastewaters by septic tanks, latrines or by direct discharge in rivers or water bodies.

3.2.6 Zootechnical sector

In Paute, 80% of the land is dedicated to zootechnical production. There are 4003 zootechnical production areas, which include all types of cattle: bovines, pigs, sheep, horses, donkeys, mule, goats, roosters, hens and chickens [49].

The most important animal according to consumption and commercialization are cows. There are 19327 heads of bovines [49].

42.47% of the economic active population work in the zootechnical sector in Paute of which [49]:

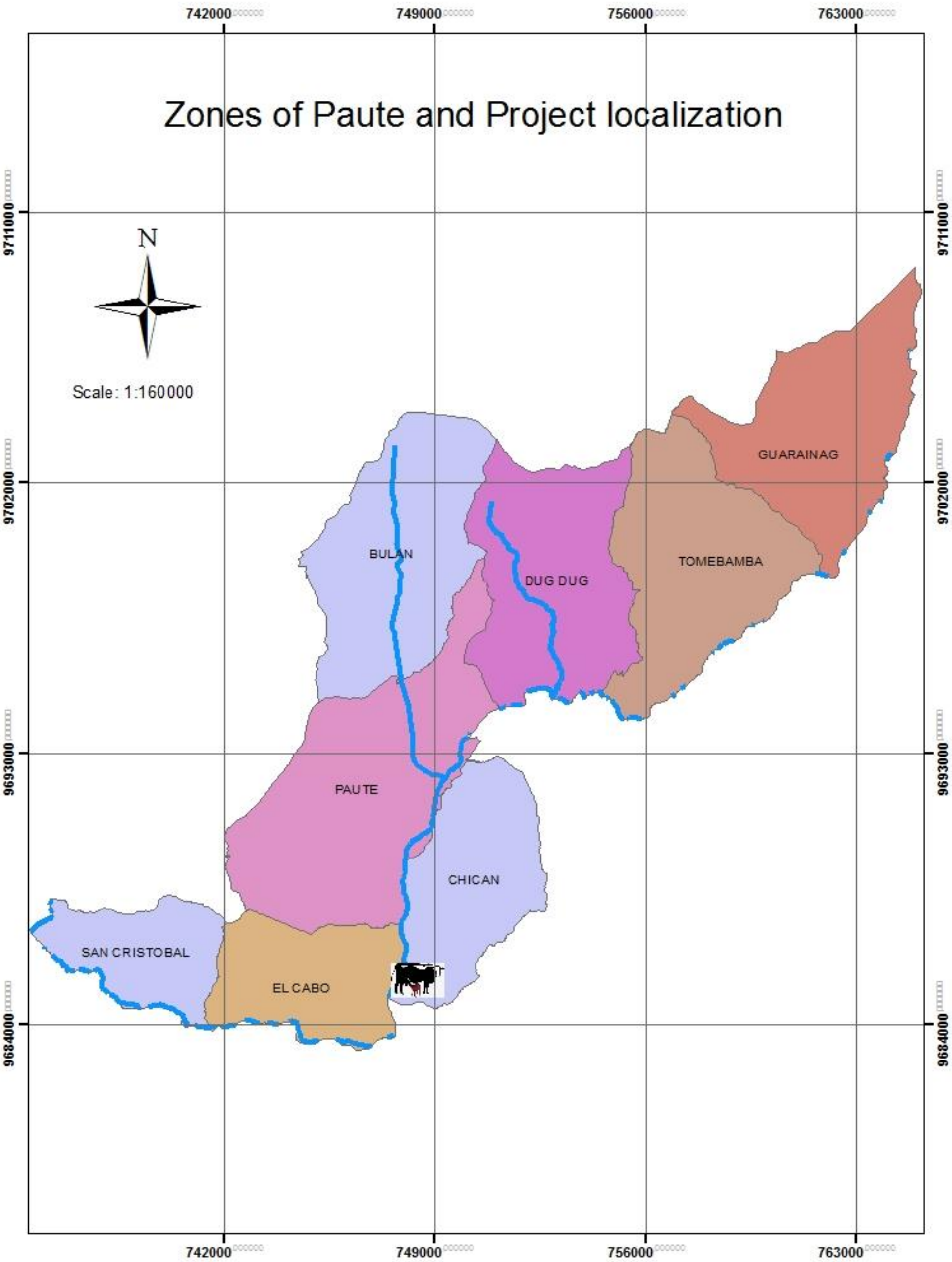
Table 59 Percentage of population dedicated to zootechnical sector by zones

Zone	%
Paute as center	15.64
Bulán	31
Chicán	12.7
El Cabo	10.94
Guarainag	4
San Cristobal	4
Tomembamba	10.59
Dugdug	15.64

3.2.7 Salesiano Education Center Production Area

The production area of the Salesiano Education Center is located in Paute, in the area of Chicán.

It has a stall and a milking area. The herd of cattle is composed of 100 heads whose presence in the stall is constant, that is to say that during the year, the number of cows present in this production area is the same.



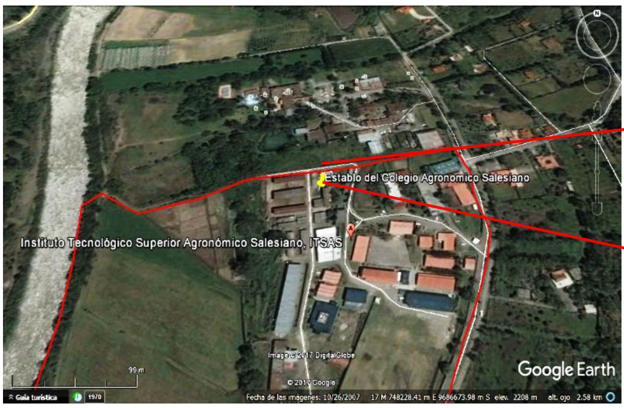


Figure 10 Salesiano Education Center Production Area

The cows are distributed as follows:

Table 60 Cows types and quantities

Type of animal	Number
Milking cow	76
Milking young cow	14
Young cow	10
TOTAL	100

The characteristics of the production system described above in the Bovine production systems in Ecuador that can be found in this creation area are:

- Stall with access to water and occasionally electricity
- Milking and waiting rooms for animals next to the stall
- Machines for mechanical milking
- Poor systems for cleaning used structures and generated wastes
- Toilets for workers

The generated wastes and their final destination in this production area are:

- Manure: with an amount of five kg/cow/day and a total production of 500 kg/day, is removed with shovels from the stall and from the milking area. Then, it is accumulated in an open space close to the stall and close to the agricultural crops, to be later disposed of them as a kind of fertilizer.

- Wastewater: is a product of the cleaning operations in the stall as well as in the milking area. Both the stall and the milking area are washed every day with a regularity of twice a day. In the stall, there are 59 l/cow/day of wastewater generated while in the milking area, 60 l/cow/day are generated. The wastewater generated in the stall, is directed and discharged into Paute River; and the wastewater generated in the milking area is directly discharged into the sewage system, which similarly performs its evacuation a few meters later to the same water body.

CHAPTER IV:

PROPOSED TREATMENT TRAIN

4.1. Characteristics of the wastewaters

There are two areas where wastewaters are generated: the stall and the milking area. In these two areas, wastewaters are generated twice a day in the washing process.

Figure 11 Washing process and wastewaters generation

The washing of the stall is done from 12 to 13 hours and from 13 to 14 hours while the washing of the milking area is completed from 9 to 10 hours and from 17 to 18 hours.

A sampling of the generated wastewaters was carried out during a period of six months. This sampling was carried out from January 2017 to June 2017. The sampling frequency was conducted once a week during 4 weeks throughout the month in different days of the week for January, February, March and April, while for May and June, the frequency was of once a week each 2 weeks in different days of the week.

The sampling frequency of once a week was established in this way because of the limited access to the water analysis laboratory and the analysis costs.

In each weekly sampling, the samples from the stall as well as from the milking area were taken in each hour of production of wastewaters that is to say in one day there were two samples collected from the stall and two samples from the milking area.

As in each hour of production of the wastewaters both in the stall and in the milking area, their characteristics (pollutant concentrations) and flow rates are different; a mass balance was made to obtain the characteristics of the wastewaters on that specific day of sampling. With these final characteristics of the 20 samplings carried out and their means, the wastewaters general characteristics were obtained.

The evaluated parameters were flow rate; BOD_5, COD, TSS, TN and TP. Microbiological analysis were not made because of the costs.

The procedures used for the determination of BOD_5, COD, TSS, TN, TP were those specified in the Standard Methods for the examination of water [8]. The flow rate measurement was done with the volumetric method [52].

4.1.1.1 Stall

An example of how the daily characteristics were obtained is presented for the first sample. All daily samples characteristics obtaining results are in Appendix N°1.

Table 61 Stall wastewaters characteristics obtaining, sample 1

Parameter	First Hour Characteristics	Second Hour Characteristics	Daily Characteristics	Obtaining of final Characteristics
Flow rate (Q)	Q_1	Q_2	Q_f	$Qf = Q1 + Q2$
	2.1 m^3/h	1.72 m^3/h	3.82 m^3/d	
Pollutant	C_1	C_2	C_f	$\mathrm{Cf} = \frac{(C1 * Q1 + C2 * Q2)}{Q1 + Q2}$
BOD_5	761 mg/l	589 mg/l	684 mg/l	
COD	1720 mg/l	1188 mg/l	1480 mg/l	
TSS	796 mg/l	686 mg/l	746 mg/l	
TN	120 mg/l	112 mg/l	116 mg/l	
TP	33 mg/l	24 mg/l	29 mg/l	

The daily characteristics for the stall wastewaters are:

Table 62 Stall daily characteristics of the wastewaters, 20 samples

Sample	Flow rate m^3/d	BOD_5 mg/l	COD mg/l	TSS mg/l	TN mg/l	TP mg/l
1	3.82	684	1480	746	116	29
2	5.76	382	780	401	90	24
3	4.61	219	530	244	54	29
4	5.40	329	782	320	49	35
5	5.18	1102	2580	1183	16	54
6	6.41	2166	5204	2353	139	74
7	6.34	500	1020	568	194	63
8	7.92	623	1397	601	89	36
9	9.00	262	529	243	77	20
10	4.97	632	1272	558	98	29
11	5.54	1042	2089	1603	114	37
12	4.46	863	1734	623	103	46
13	5.83	1427	2079	1071	288	47
14	4.97	328	693	421	136	35
15	5.33	310	734	345	77	24
16	6.12	1070	2159	996	171	27
17	6.70	373	748	329	73	72
18	8.64	1823	3673	1588	295	77
19	7.92	1189	2377	1591	151	62
20	4.25	2127	4292	2627	182	58
Mean	5.96	872.51	1807.62	920.48	125.47	43.81
Minimum	3.82	219.43	528.50	242.5	16.05	19.50
Maximum	9.00	2165.84	5203.99	2627	294.63	77.10
Standard deviation	1.45	614.27	1307.22	702.52	72.71	18.36

The flow rate varied between 3.82 m^3/d and 9m^3/d; this variation can be explained by the quantity of water that is used in the cleaning processes and how dirty the stall area is.

The BOD_5 rates were from 219.4 to 2165.8 mg/l and the COD rates from 528.5 to 5203.9 mg/l. The values of TSS were also high; the maximum was of 2627 mg/l and the mean of 920.48 mg/l. It can be associated to the poor procedures in the cleaning process while the manure is removed.

4.1.1.2 Milking area

An example of how the daily characteristics were obtained is presented using the first sample. All samples of the daily characteristics obtained results are in Appendix N°2.

Table 63 Milking area wastewaters characteristics obtaining, sample 1

Parameter	First Hour Characteristics	Second Hour Characteristics	Daily Characteristics	Obtaining of final Characteristics
Flow rate(Q)	Q_1	Q_2	Q_f	$Qf = Q1 + Q2$
	2.6 m^3/h	2.8 m^3h	5.4 m^3/d	
Pollutant	C_1	C_2	C_f	$Cf = \frac{(C1 * Q1 + C2 * Q2)}{Q1 + Q2}$
BOD_5	1210 mg/l	1102 mg/l	1154 mg/l	
COD	3292 mg/l	3100 mg/l	3192 mg/l	
TSS	1620 mg/l	1280 mg/l	1444 mg/l	
TN	91 mg/l	85 mg/l	88 mg/l	
TP	35 mg/l	35 mg/l	35 mg/l	

The daily characteristics for the milking area wastewaters are:

Table 64 Milking area daily characteristics of the wastewaters, 20 samples

Sample	Flow rate m^3/d	BOD_5 mg/l	COD mg/l	TSS mg/l	TN mg/l	TP mg/l
1	5.4	1154	3192	1444	88	35
2	5.5	2289	5579	1286	103	59
3	6.6	1000	3053	1220	82	59
4	6.5	1296	4115	987	205	25
5	5.5	1629	4219	1197	227	18
6	6.7	2623	5704	1221	225	22
7	5	3964	7993	1509	214	20
8	6	4877	8983	1485	203	18
9	5.5	2739	3123	978	96	46
10	7.5	4148	7926	1150	85	45
11	6.9	1184	3222	994	50	43
12	6.5	3762	7110	1371	89	39
13	6.6	1125	3340	1715	221	38
14	6.2	2419	5336	1288	105	56
15	6	1310	3974	1756	219	58
16	7	1286	3253	1008	214	54
17	6.2	2257	5220	1236	83	26
18	5.5	2272	5163	1312	95	32
19	6.4	4800	9812	1620	218	61
20	6.7	1398	3052	1934	230	62
Mean	6.21	2376.64	5168.49	1335.5	152.51	40.84
Minimum	5.00	1000.00	3051.58	978	50.00	18.00
Maximum	7.50	4877.00	9812.00	1934.00	230.39	61.96
Standard deviation	0.65	1283.86	2142.81	270.8	67.72	15.64

The flow rate in this area varied from 5 to 7.5m^3/d. There was a big concentration of organic matter that can be seen in the BOD_5 rates and in the COD rates. The BOD_5 rates were from

1000 mg/l to 4877mg/l and the COD from 3051.5 mg/l to 9812mg7l. The TSS were high with values from 978 to 1934 mg/l.

4.2 Legal Constraints for the Wastewaters Discharge

The main legal body in environmental matters for Ecuador is the “Texto Unificado de Legislación Secundaria del Ministerio del Ambiente (TULSMA)”; this is divided into nine books, and the sixth book deals with the issue of environmental quality. In Appendix I of the sixth book of this text, the effluent discharge limits are established according to the final destination they will have [53].

In the study case that is being analyzed, the effluents are discharged to a water body so the limits of discharges to water bodies that are established in the TULSMA, Appendix I, will be taken as a final reference. There are presented some effluents discharge limits applied in other countries to have an idea of how restrictive the ones established by the Ecuadorian law are.

Table 65 Legal Constrains for the wastewater discharge

Parameter	Unit	TULSMA ECUADOR	NT DISCHARGE HONDURAS	NOM-001-SEMARNAT MEXICO	TUA Lgs152/06 ITALY	EPA REGULATIONS USA
TN	mg/l	15	30	25	≤15	25
TP	mg/l	10	5	10	≤10	–
BOD_5	mg/l	100	50	60	≤40	40
COD	mg/l	250	200	–	≤160	120
TSS	mg/l	100	100	60	≤35	–
References		[53]	[54]	[55]	[56]	[57]

As you can see, the Ecuadorian effluents discharge limits are the least restrictive while the ones presented by Italy and the United States are the most restrictive.

The discharged wastewaters characteristics and the Ecuadorian law limits are presented below:

Table 66 Comparison between Ecuador's regulations and wastewaters

Parameter	Unit	TULSMA	Stall	Milking Area
TN	mg/l	15	125.47	152.51
TP	mg/l	10	43.81	40.84
BOD_5	mg/l	100	872.51	2376.64
COD	mg/l	250	1807.62	5168.49
TSS	mg/l	100	920.48	1335.5

As notorious, the discharged wastewaters do not match with the Ecuadorian limits laws.

4.3 Treatment Train

Considering the literary review described in Chapter II, in which it is stated that it is necessary to treat these type of wastewaters, the following treatment train has been proposed.

A physical step is necessary before carrying out the biological step, and usually another type of biological step precedes the constructed wetland system, as a result, we have:

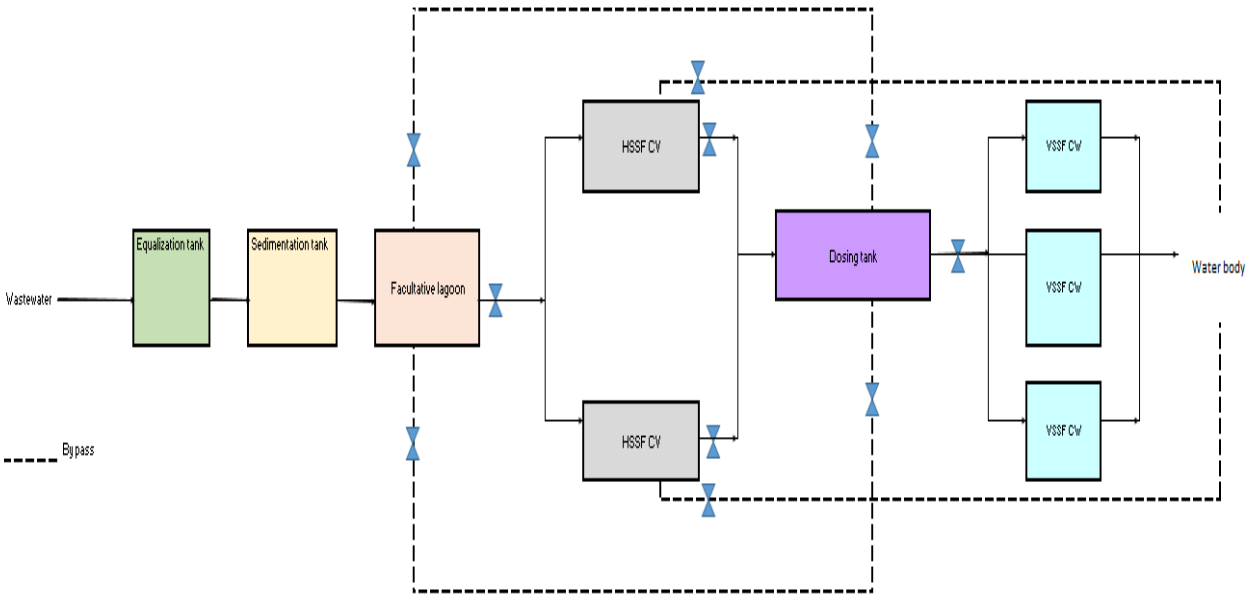


Figure 12 Treatment train scheme

4.3.1 Equalization tank

It is considered to be an important step for the treatment of these wastewaters, with this, it is intended to:

- Have a constant flow rate that feeds the following treatment train since both places (stall and milking area) generate the wastewaters at different times and only two hours a day (intermittent production of wastewaters).

- Collect the wastewaters of stall with the wastewaters of the milking area in the same place having them able to come together into the subsequent treatment stage.

The starting point for the design of the equalization tank where the collected data of flow rates obtained in each hour of the twenty samplings carried out in the stall and in the milking areas.

Data referring to the stall are presented in table N° 67.

Table 67 Sampling data for the stall

Sample	1st hour flow rate m^3/h	2nd hour flow rate m^3/h	1st hour COD concentration mg/l	2nd hour COD concentration mg/l	1st hour TSS concentratio n mg/l	2nd hour TSS concentration mg/l
1	2.1	1.72	1720	1188	796	686
2	3.35	2.41	798	755	405	395
3	2.77	1.84	550	500	254	228
4	3.15	2.25	792	768	320	320
5	2.65	2.53	2600	2560	1300	1060
6	3.66	2.75	5210	5196	2550	2090
7	3.69	2.65	1022	1017	572	563
8	4	3.92	1401	1392	700	500
9	4.5	4.5	540	517	255	230
10	3.02	1.95	1300	1228	550	570
11	3.5	2.04	2092	2084	1820	1230
12	2.4	2.06	1745	1722	647	595
13	3	2.83	2083	2075	1100	1040
14	2.75	2.22	709	673	510	310
15	3.13	2.2	747	716	320	380
16	3.6	2.52	2206	2092	1070	890
17	3.75	2.95	754	740	325	380
18	5	3.64	3872	3400	1900	1160
19	4.07	3.85	2385	2369	1980	1180
20	2.8	1.45	4360	4160	2900	2100

As it can be seen, the flow rates related to the first hour and the second hour are comparable. The values in the first hour are a bit higher and it could be because at the beginning of the cleaning process in the stall the area was dirtier.

The milking area data is described in the next table:

Table 68 Sampling data for the milking area

Sample	1st hour flow rate m^3/h	2nd hour flow rate m^3/h	1st hour COD concentration mg/l	2nd hour COD concentration mg/l	1st hour TSS concentration mg/l	2nd hour TSS concentration mg/l
1	2.6	2.8	3292	3100	1620	1280
2	2.8	2.7	5550	5610	1080	1500
3	3.5	3.1	3100	3000	1194	1250
4	3.5	3	4000	4250	710	1310
5	3	2.5	4176	4270	870	1590
6	3.2	3.5	5600	5800	1560	912
7	2.8	2.2	7850	8174	1430	1610
8	3	3	8956	9010	1520	1450
9	2.9	2.6	3080	3170	950	1010
10	4	3.5	7841	8024	1016	1304
11	3.5	3.4	3330	3110	983	1005
12	3.5	3	6948	7300	1258	1502
13	3.3	3.3	3100	3580	1830	1600
14	3.4	2.8	5160	5550	1286	1290
15	3	3	3848	4100	1932	1580
16	4	3	3216	3302	984	1040
17	3.5	2.7	5226	5214	1140	1360
18	3.1	2.4	5150	5180	1190	1470
19	3.2	3.2	9912	9712	1850	1390
20	3.5	3.2	3000	3108	1937	1932

As it can be seen, the date is almost the same. The data in the second hour in the milking area is a bit higher and it can be because the final cleaning of the day was done with more emphasis.

With these data, a small program in Excel was done to simulate:

- The entrance of these two types of wastewaters in the same place
- Their mixing

- The daily flow rate
- A constant flow rate in the exit of the process with the daily flow rate
- The maximum volume of the remaining, if a constant flow rate leaves the tank
- COD and TSS concentrations in the tank effluent each hour

The simulations were done for the 20 samplings. An example of this simulation for COD and TSS is presented for the first sample.

Table 69 Simulation example for COD

Hour	Interval	Dt h	Q in m^3/h	COD in mg/l	Q out m^3/h	Total inflow m^3	Total outflow m^3	Stored m^3	COD out mg/l
9	1	1	**2.6**	**3292**	0.38	2.6	0.38	2.22	3292
10	2	1	0	0	0.38	2.6	0.77	1.83	3292
11	3	1	0	0	0.38	2.6	1.15	1.45	3292
12	4	1	0	0	0.38	2.6	1.54	1.06	3292
13	5	1	**2.1**	**1720**	0.38	4.7	1.92	2.78	2248
14	6	1	**1.72**	**1188**	0.38	6.42	2.31	4.12	1843
15	7	1	0	0	0.38	6.42	2.69	3.73	1843
16	8	1	0	0	0.38	6.42	3.07	3.35	1843
17	9	1	**2.8**	**3100**	0.38	9.22	3.46	**5.76**	2416
18	10	1	0	0	0.38	9.22	3.84	5.38	2416
19	11	1	0	0	0.38	9.22	4.23	4.99	2416
20	12	1	0	0	0.38	9.22	4.61	4.61	2416
21	13	1	0	0	0.38	9.22	4.99	4.23	2416
22	14	1	0	0	0.38	9.22	5.38	3.84	2416
23	15	1	0	0	0.38	9.22	5.76	3.46	2416
24	16	1	0	0	0.38	9.22	6.15	3.07	2416
1	17	1	0	0	0.38	9.22	6.53	2.69	2416
2	18	1	0	0	0.38	9.22	6.92	2.31	2416
3	19	1	0	0	0.38	9.22	7.30	1.92	2416
4	20	1	0	0	0.38	9.22	7.68	1.54	2416
5	21	1	0	0	0.38	9.22	8.07	1.15	2416
6	22	1	0	0	0.38	9.22	8.45	0.77	2416
7	23	1	0	0	0.38	9.22	8.84	0.38	2416
8	24	1	0	0	0.38	9.22	9.22	0.00	2416

Table 70 Simulation example for TSS

Hour	Interval	Dt h	Q in m³/h	TSS in mg/l	Q out m³/h	Total inflow m³	Total outflow m³	Stored m³	TSS out mg/l
9	1	1	**2.6**	**1620**	0.38	2.6	0.38	2.22	1620
10	2	1	0	0	0.38	2.6	0.77	1.83	1620
11	3	1	0	0	0.38	2.6	1.15	1.45	1620
12	4	1	0	0	0.38	2.6	1.54	1.06	1620
13	5	1	**2.1**	**796**	0.38	4.7	1.92	2.78	1073
14	6	1	**1.72**	**686**	0.38	6.42	2.31	4.12	925
15	7	1	0	0	0.38	6.42	2.69	3.73	925
16	8	1	0	0	0.38	6.42	3.07	3.35	925
17	9	1	**2.8**	**1280**	0.38	9.22	3.46	**5.76**	1087
18	10	1	0		0.38	9.22	3.84	5.38	1087
19	11	1	0		0.38	9.22	4.23	4.99	1087
20	12	1	0		0.38	9.22	4.61	4.61	1087
21	13	1	0		0.38	9.22	4.99	4.23	1087
22	14	1	0		0.38	9.22	5.38	3.84	1087
23	15	1	0		0.38	9.22	5.76	3.46	1087
24	16	1	0		0.38	9.22	6.15	3.07	1087
1	17	1	0		0.38	9.22	6.53	2.69	1087
2	18	1	0		0.38	9.22	6.92	2.31	1087
3	19	1	0		0.38	9.22	7.30	1.92	1087
4	20	1	0		0.38	9.22	7.68	1.54	1087
5	21	1	0		0.38	9.22	8.07	1.15	1087
6	22	1	0		0.38	9.22	8.45	0.77	1087
7	23	1	0		0.38	9.22	8.84	0.38	1087
8	24	1	0		0.38	9.22	9.22	0.00	1087

The simulations' data of maximum accumulated volume (Stored) and resulting concentrations for COD and TSS (COD out and TSS out) for the 20 samples are presented below. The BOD_5 data were obtained considering the relationship that exists between COD and BOD_5 according to the sampling results and it is about 2.4:1.

The resulting concentrations of COD and TSS when the last feeding to the system takes place (9th interval and after), are the ones considered for the design process because they represent the third quartile of the whole data in each sample.

Table 71 Data after equalization process

Sample	Flow rate m^3/d	Volume m^3	Results COD concentration mg/l	Results TSS concentration mg/l	Results BOD_5 concentration mg/l
1	9.22	5.76	2416	1087	1007
2	11.26	7.04	2921	854	1217
3	11.21	7.01	1934	801	806
4	11.90	7.44	4447	746	1853
5	10.68	6.68	3361	1285	1400
6	13.11	8.19	5457	1706	2274
7	11.34	7.09	3685	945	1535
8	13.92	8.6	4238	918	1766
9	14.50	9.06	1328	473	553
10	12.47	7.79	5140	944	2142
11	12.44	7.78	2652	1278	1105
12	10.96	6.85	4824	1081	2010
13	12.43	7.77	2778	1356	1158
14	11.17	6.98	3151	867	1313
15	11.33	7.08	2381	995	992
16	13.12	8.2	2703	1007	1126
17	12.90	8.06	2644	742	1102
18	14.14	8.84	4132	1522	1722
19	14.32	8.95	5275	1523	2198
20	10.95	6.84	3571	2208	1488
Mean	12.17	7.60	3452	1117	1438
Maximum	14.50	9.06	5457	2208	2274
Minimum	9.22	5.76	1328	473	553
Standard Deviation	1.4	0.87	1168.41	399.35	486.9

The mean of maximum accumulated volume (7.6 m^3) and the mean of daily flow rate were used for the design process as well as the mean, maximum and minimum resulting concentrations of BOD_5 and TSS developing three scenarios.

As it is recommended to add a 20% to the volume for safety to the design, the maximum volume for which the equalization tank will be designed is 9.12 m^3 and finally it is considered 9.5 m^3 (this volume includes also the maximum stored volume calculated in the simulations).

The flow rate that will be sent out from the equalization tank each hour corresponds to the mean flow rate of generated wastewaters (12.17 m^3/d) and it is of 0.507 m^3/h.
The height and the width of the equalization tank are imposed and their values are 1 m and 2 m respectively, so the known data is:

Table 72 Equalization tank known data

Equalization Tank			
Data	Symbol	Value	Unit
Height	H	1	m
Volume	V	9.5	m^3
Width	W	2	m

4.3.1.1 Area

It is calculated by the following formula:

$$A = \frac{V}{h} \quad (64)$$

$$A = \frac{9.5\ m^3}{1\ m} = 9.5\ m^2$$

4.3.1.2 Length

It is calculated by the following formula:

$$L = \frac{A}{W} \quad (65)$$

$$L = \frac{9.5\ m^2}{2\ m} = 4.75\ m$$

4.3.1.3 Summary

The equalization tank summary is presented below:

Table 73 Equalization tank summary

Equalization Tank Summary		
Criteria	Value	Unit
Shape	Rectangular	-
Length	4.75	M
Width	2	M
Height	1	M
Volume	9.5	m^3

The design plan is presented in Appendix N°3

4.3.2 Sedimentation Tank

The design model that was taken as reference is the one proposed by Melcalf and Eddy [21] and applied by Alejandro Hammeken [58] in his thesis.

Metcalf and Eddy proposed hydraulic surface load values for average daily flow rates of 30 to 50 m^3/m^2d, and for this design, a value of 30 m^3/m^2d will be taken.

In the same way, it is proposed that the sedimentation tanks have a depth of 3 to 4 m. For this design, a depth of 3 m was considered.

The removal constants of BOD_5 and TSS established by Crites and Tchobanoglus [59] are:

Table 74 BOD_5 and TSS constants

Parameter	a	b
BOD_5	0.018	0.020
TSS	0.0075	0.014

The known data is the following:

Table 75 Sedimentation tank known data

Sedimentation Tank			
Data	Symbol	Value	Unit
Daily Flow Rate*	Q	12.17	m^3/d
Surface Load	C_S	30	m^3/m^2 d
Height	H	3	m
Length-Width relationship	L:W	4:1	

*It is guaranteed a constant daily flow rate by the equalization tank

4.3.2.1 Surface Area

It is calculated by the following formula:

$$As = \frac{Q}{C_s} \qquad (66)$$

$$As = \frac{12.17\ m^2/d}{30\ m^3/m^2 d} = 0.41\ m^2$$

4.3.2.2 Width

It is calculated by the following formula assuming that the sedimentation tank will be rectangular and considering the proposed relationship length: width of 4:1:

$$A = 4L^2 \qquad (67)$$

$$W = \sqrt{\frac{A}{4}}$$

$$W = \sqrt{\frac{0.41\ m^2}{4}} = 0.32\ m$$

4.3.2.3 Length

It is calculated by the following formula:

$$L = W * 4 \quad (68)$$

$$L = 0.32\ m * 4 = 1.28\ m$$

4.3.2.4 Volume

It is calculated by the following formula:

$$V = L * W * h \quad (69)$$

$$V = 1.28\ m * 0.32\ m * 3\ m = 1.23\ m^3$$

4.3.2.5 Corrected Area

It is calculated by the following formula:

$$A = L * W \quad (70)$$

$$A = 1.28\ m * 0.32\ m = 0.40\ m^2$$

4.3.2.6 Real surface load

It is calculated by the following formula:

$$C_s = \frac{Q}{A} \quad (71)$$

$$C_s = \frac{12.17\ m^3/d}{0.40\ m^2} = 29.7\ m^3/m^2d$$

4.3.2.7 Hydraulic retention time

It is calculated by the following formula:

$$HRT = \frac{V}{Q} \quad (72)$$

$$HRT = \frac{1.23\ m^3}{12.17\ m^3/d} = 0.10\ d = 2.42\ h$$

4.3.2.8 Pollutant removal

Scenario N°1

Table 76 Scenario 1 Sedimentation tank

Sedimentation Tank			
Data	Symbol	Value	Unit
BOD_5 concentration	C BOD_5	1438	mg/l
TSS concentration	C TSS	1117	mg/l

Removal percentage of BOD_5

It is calculated by the following formula:

$$R = \frac{HRT}{a+(b*HRT)} \quad (73)$$

$$R = \frac{2.42\ h}{0.018 + (0.020 * 2.42\ h)} = 36.46\%$$

Removed BOD_5

It is calculated by the following formula:

$$C_rBOD_5 = C\ BOD_5 * R \ (74)$$

$$C_rBOD_5 = 1438\ mg/l * 0.3646 = 524.28\ mg/l$$

Removal percentage of TSS

It is calculated by the following formula:

$$R = \frac{HRT}{a+(b*HRT)} \ (75)$$

$$R = \frac{2.42\ h}{0.0075 + (0.014 * 2.42\ h)} = 58.5\%$$

Removed TSS

It is calculated by the following formula:

$$C_rTSS = \mathrm{C}\ TSS * R \ (76)$$

$$C_rTSS = 1117\ mg/l * 0.585 = 653.35\ mg/l$$

Scenario N°2

Table 77 Scenario 2 Sedimentation tank

Sedimentation Tank			
Data	Symbol	Value	Unit
BOD_5 concentration	C BOD_5	2274	mg/l
TSS concentration	C TSS	2208	mg/l

Removal percentage of BOD_5

It is calculated by the following formula:

$$R = \frac{HRT}{a+(b*HRT)} \text{ (77)}$$

$$R = \frac{2.42\ h}{0.018 + (0.020 * 2.42\ h)} = 36.46\%$$

Removed BOD_5

It is calculated by the following formula:

$$C_r BOD_5 = C\ BOD_5 * R \text{ (78)}$$

$$C_r BOD_5 \ = 2274\ mg/l * 0.3646 = 829.08\ mg/l$$

Removal percentage of TSS

It is calculated by the following formula:

$$R = \frac{HRT}{a+(b*HRT)} \text{ (79)}$$

$$R = \frac{2.42\ h}{0.0075 + (0.014 * 2.42\ h)} = 58.5\%$$

Removed TSS

It is calculated by the following formula:

$$C_r TSS\ Rem = \mathrm{C}\ TSS * R \text{ (80)}$$

$$C_r TSS = 2208\ mg/l * 0.585 = 1291.61\ mg/l$$

Scenario N°3

Table 78 Scenario 3 Sedimentation tank

Sedimentation Tank			
Data	Symbol	Value	Unit
BOD_5 concentration	C BOD_5	553	mg/l
TSS concentration	C TSS	473	mg/l

Removal percentage of BOD_5

It is calculated by the following formula:

$$R = \frac{HRT}{a+(b*HRT)} \quad (81)$$

$$R = \frac{2.42h}{0.018 + (0.020 * 2.42\ h)} = 36.46\%$$

Removed BOD_5

It is calculated by the following formula:

$$C_r BOD_5 = C\ BOD_5 * R \quad (82)$$

$$C_r BOD_5 = 553\ mg/l * 0.3646 = 201.62\ mg/l$$

Removal percentage of TSS

It is calculated by the following formula:

$$R = \frac{HRT}{a+(b*HRT)} \quad (83)$$

$$R = \frac{2.42h}{0.0075+(0.014*2.42\ h)} = 58.5\%$$

Removed TSS

It is calculated by the following formula:

$$C_r TSS = \mathrm{C}\, TSS * R \text{ (84)}$$

$$C_r TSS = 473\ mg/l * 0.585 = 276.69\ mg/l$$

4.3.2.9 Sedimentation tank summary

The sedimentation tank summary is presented below:

Table 79 Sedimentation tank summary

Sedimentation Tank Summary			
Scenario	Criteria	Value	Unit
General	Shape	Rectangular	-
	Length	1.28	m
	Width	0.32	m
	Height	3	m
	Volume	1.23	m^3
	Hydraulic Retention time	2.42	h
Scenario N°1	Initial BOD_5 concentration	1438	mg/l
	Final BOD_5 concentration	914.03	mg/l
	Initial TSS concentration	1117	mg/l
	Final TSS concentration	463.55	mg/l
Scenario N°2	Initial BOD_5 concentration	2274	mg/l
	Final BOD_5 concentration	1444.6	mg/l
	Initial TSS concentration	2208	mg/l
	Final TSS concentration	916.39	mg/l
Scenario N°3	Initial BOD_5 concentration	553	mg/l
	Final BOD_5 concentration	351.7	mg/l
	Initial TSS concentration	473	mg/l
	Final TSS concentration	196.31	mg/l

The design plan is presented in Appendix N°3

4.3.3 Facultative Lagoon

With reference to domestic wastewaters, they are generally designed with observed criteria in which the surface organic load factor is the most important with an efficiency removal of about 30-50% for BOD_5 and not more of a 70% for TSS [9] [26]. However, this criterion is not considered for this study case with zootechnical wastewaters because applying it in extensive areas and very long retention times are required and that will generate odor problems.

For the design of this stage of the treatment train, a hydraulic retention time of 15 days is required, a depth of 1.8m was used; and from these, the respective sizing calculations were made.
The known data are:

Table 80 Facultative lagoon known data

Facultative Lagoon			
Data	Symbol	Value	Unit
Daily Flow Rate*	Q	12.17	m^3/d
Height	H	1.8	m
Hydraulic Retention time	HRT	15	d
Length-Width relation	L:W	4:1	
Length	L	20	m

*It is guaranteed a constant daily flow rate by the equalization tank

4.3.3.1 Volume

It is calculated by the following formula:

$$V = Q * HRT \ (85)$$

$$V = 12.17\ m^3/d * 15\ d = 182.55\ m^3$$

4.3.3.2 Area

It is calculated by the following formula:

$$A = \frac{V}{h} \quad (86)$$

$$A = \frac{182.55\ m^3}{1.8\ m} = 101.41\ m^2 = 0.01\ ha$$

4.3.3.3 Width

It is calculated by the following formula:

$$W = \frac{A}{L} \quad (87)$$

$$W = \frac{101.4\ m^2}{20\ m} = 5.07\ m$$

4.3.3.4 Pollutants removal

Scenario N° 1

Table 81 Scenario 1 Facultative lagoon data

Facultative Lagoon			
Data	Symbol	Value	Unit
BOD_5 concentration	C BOD_5	914	mg/l
TSS concentration	C TSS	463.55	mg/l

Final BOD_5

It is assumed a 40% of BOD_5 removal (ɱ)

$$C_f\ BOD_5 = C\ BOD_5 * (1 - \text{ɱ})\ (88)$$

$$C_f\ BOD_5 = 914\ mg/l * (1 - 0.4) = 548.4\ mg/l$$

Final TSS

It is assumed a 50% of TSS removal(ɱ)

$$C_f\ TSS = C\ TSS * (1 - \text{ɱ})\ (89)$$

$$C_f\ TSS = 463.55\ mg/l * (1 - 0.5) = 231.7\ mg/l$$

Scenario N° 2

Table 82 Scenario 2 Facultative lagoon known data

Facultative Lagoon			
Data	Symbol	Value	Unit
BOD_5 concentration	C BOD_5	1444.67	mg/l
TSS concentration	C TSS	916.39	mg/l

Final BOD_5

It is assumed a 40% of BOD_5 removal (ɱ)

$$C_f\ BOD_5 = C\ BOD_5 * (1 - \text{ɱ})\ (90)$$

$$C_f\ BOD_5 = 1444.6\ mg/l * (1 - 0.4) = 866.8\ mg/l$$

Final TSS

It is assumed a 50% of TSS removal (ɱ)

$$C_f\ TSS\ = \mathrm{C}\ TSS * (1 - \text{ɱ})\ (91)$$

$$C_f\ TSS = \ 916.39\ mg/l * (1 - 0.5) = 458.19\ mg/l$$

Scenario N°3

Table 83 Scenario 3 Facultative lagoon known data

Facultative Lagoon			
Data	Symbol	Value	Unit
BOD_5 concentration	C BOD_5	351.7	mg/l
TSS concentration	C TSS	196.3	mg/l

Final BOD_5

It is assumed a 40% of BOD_5 removal (ɱ)

$$C_f\ BOD_5 = C\ BOD_5 * (1 - \text{ɱ})\ (92)$$

$$C_f\ BOD_5 = 351.7\ mg/l * (1 - 0.4) = 211.03\ mg/l$$

Final TSS

It is assumed 50% of TSS removal (ɱ)

$$C_f\ TSS\ = \mathrm{C}\ TSS * (1 - \text{ɱ})\ (93)$$

$$C_f TSS\ = 196.3\ mg/l * (1 - 0.5) = 98.16\ mg/l$$

4.3.3.5 Facultative Lagoon Summary

The facultative lagoon summary is presented below:

Table 84 Facultative lagoon summary

Facultative Lagoon Summary			
Scenario	Criteria	Value	Unit
General	Shape	Rectangular	-
	Length	20	m
	Width	5.1	m
	Height	1.8	m
	Volume	180	m^3
	Hydraulic Retention time	15	d
Scenario N°1	Initial BOD_5 concentration	914	mg/l
	Final BOD_5 concentration	548.42	mg/l
	Initial TSS concentration	463.55	mg/l
	Final TSS concentration	231.77	mg/l
Scenario N°2	Initial BOD_5 concentration	1444.6	mg/l
	Final BOD_5 concentration	866.8	mg/l
	Initial TSS concentration	916.39	mg/l
	Final TSS concentration	458.19	mg/l
Scenario N°3	Initial BOD_5 concentration	351.71	mg/l
	Final BOD_5 concentration	211.03	mg/l
	Initial TSS concentration	196.31	mg/l
	Final TSS concentration	98.15	mg/l

The design plan is presented in Appendix N°3

4.3.4 Constructed Wetlands

Because the design of the constructed wetland will be carried out for the removal of BOD_5, scenario N ° 2 is taken for its development considering that, it is the one, in which the highest BOD_5 concentration exists and in this way, the other two scenarios (1 and 3) will be covered.

4.3.4.1 Horizontal Subsurface Flow Constructed Wetland

The model for the horizontal subsurface flow constructed wetland design was based on the one proposed by the EPA [7] and applied by Jaime Lara Borrero [6].

The height of 0.6 m and a slope of 1% are recommended for these stages. The kinetic degradation constant of BOD_5 is calculated with the minimum temperature registered in the zone, in this case it is of 15 °C [49]. The filling medium of the constructed wetland bed will be fine gravel which porosity is 35% and which hydraulic conductivity is of 10000 m^3/m^2d [26].

The BOD_5 that is expected to be obtained corresponds to the maximum limit of the Ecuadorian regulations, which is of 100 mg/l of BOD_5 [14].

The known data are in the table below:

Table 85 Horizontal subsurface flow constructed wetland known data

Horizontal subsurface flow constructed wetland			
Data	Symbol	Value	Unit
Daily Flow rate*	Q	12.17	m^3/d
Slope	Slp	0.01	%
Height	H	0.6	m
Temperature	T	15	°C
Medium	Medium	Fine gravel	
Porosity	N	0.35	
Hydraulic conductivity	K_s	10000	m^3/m^2d
Initial BOD_5 concentration	C BOD_5 in	866.8	mg/l
Initial TSS concentration	C TSS in	458.1	mg/l

*It is guaranteed a constant daily flow rate by the equalization tank

4.3.4.1.1 Temperature constant

The kinetic degradation constant of BOD_5 at 20 °C is 0.19 m/d and for θ is 1.1 [26].

$$K_T = K_{20} * (\theta)^{T-20} \text{ (94)}$$

$$K_T = 0.19 * (1.1)^{-5} = 0.12$$

4.3.4.1.2 Surface Area

It is calculated by the following formula:

$$As = \frac{Q(lnC\ BOD_5 in - lnCf\ BOD_5 out)}{K_T * h * n} \text{ (95)}$$

$$As = \frac{12.17\ m^3/d\ (ln866.8\ mg/l - ln100\ mg/l)}{0.12 * 0.6\ m * 0.35} = 1061\ m^2$$

4.3.4.1.3 Hydraulic Retention time

It is calculated by the following formula

$$HRT = \frac{As * h * n}{Q} \text{ (96)}$$

$$HRT = \frac{1061\ m^2 * 0.6\ m * 0.35}{12.17\ m^3/d} = 18\ d$$

4.3.4.1.4 Width

It is calculated by the following formula

$$W = \frac{1}{h} * (\frac{Q * A_S}{Slp * K_S})^{0\ 5} \quad \text{(97)}$$

$$W = \frac{1}{0\ 6\ m} * \left(\frac{\frac{12.17\ m^3}{d} * 1061\ m^2}{0.01 * \frac{10000\ m^3}{m^2 d}} \right)^{0\ 5} = 18.9\ m = 20\ m$$

4.3.4.1.5 Length

It is calculated by the following formula

$$L = \frac{A_s}{W} \quad (98)$$

$$L = \frac{1061\ m^2}{20\ m} = 53\ m$$

4.3.4.1.6 Final BOD_5

According to the study cases presented in Chapter II, it can be assumed that the BOD_5 removal can be from 80-90%. It is taken 80% of BOD_5 removal (ɱ).

$$C_f\ BOD_5 = C\ BOD_5 * (1 - ɱ) \quad (99)$$

$$C_f\ BOD_5 = 866.8\ mg/l * (1 - 0.8) = 173.3\ mg/l$$

4.3.4.1.7 Final TSS

According to the study cases presented in Chapter II, it can be assumed that the TSS removal is from 80 to 90%. It is assumed 80% of TSS removal (ɱ).

$$C_f TSS = \mathrm{C}\ TSS * (1 - ɱ) \quad (100)$$

$$F\ TSS = 458.19\ mg/l * (1 - 0.8) = 91.63\ mg/l$$

4.3.4.1.8 Applied organic Load

It is stated that the applied organic load has to have a maximum value of 10 g/m^2d

$$Aplied\ organic\ load = \frac{Daily\ organic\ load}{As} \quad (101)$$

$$Aplied\ organic\ load = \frac{10548.9\ g/m^3}{1061\ m^2} = 9.9\ g/m^2d$$

4.3.4.1.9 Horizontal subsurface flow constructed wetland summary

The horizontal subsurface flow constructed wetland summary is presented below:

Table 86 Horizontal subsurface flow constructed wetland summary

Horizontal subsurface flow constructed wetland		
Criteria	Value	Unit
Slope	0.01	%
Height	0.6	m
Width	20	m
Length	53	m
Hydraulic Retention Time	18	d
Medium	Fine gravel	
Plant	*Phragmites australis*	
Initial BOD_5 concentration	866.8	mg/l
Final BOD_5 concentration	173.3	mg/l
Initial TSS concentration	458.19	mg/l
Final TSS concentration	91.63	mg/l

This constructed wetland will be divided in two beds of the following dimensions: 26.5 m x 20 m x 0.6 m.

The design plane is presented in Appendix N°3

4.3.4.2 Vertical Subsurface Flow Constructed Wetland

This part of the treatment train is designed from the organic load and taking as reference the example developed by Masotti e Verlicchi [26].

The known data are the following:

Table 87 Vertical subsurface flow constructed wetland known data

Vertical subsurface flow constructed wetland			
Data	Symbol	Value	Unit
Daily Flow Rate*	Q	12.17	m^3/d
Height	H	0.6	m
Width	W	10	m
Medium	Medium	Fine gravel	
Porosity	n	0.35	
Hydraulic conductivity	K_s	10000	m^3/m^2d
Feeding dose	D	24	
Initial BOD_5 concentration	C BOD_5 in	173.3	mg/l
Initial TSS concentration	C TSS in	91.63	mg/l

*It is guaranteed a constant daily flow rate by the equalization tank

4.3.4.2.1 Surface Area

Considering a surface organic load of 5 g/m^2d, it is calculated by:

$$A_s = \frac{Daily\ organic\ load}{Superficial\ organic\ load} \qquad (102)$$

$$A_s = \frac{173.3\ g/m^3 * 12.17m^3/d}{5g/m^2d} = 421.9\ m^2 = 422\ m^2$$

4.3.4.2.2 Length

It is calculated by the following formula:

$$L = \frac{As}{W} \ (103)$$

$$L = \frac{422\ m^2}{10\ m} = 42.2\ m = 42\ m$$

4.3.4.2.3 Number of pipes

It is recommended to have a 0.5 m separation between the pipes that will distribute the water through the constructed wetland

$$\#pipes = \frac{W}{separation} \ (104)$$

$$\#pipes = \frac{10\ m}{0.5\ m} = 20\ pipes$$

4.3.4.2.4 Hole in pipes

The holes will have a diameter of 3 mm and it is known that with a standard pressure of 1.5m, its flow rate is of 1.6 l/min in 0.56 min and the dosing volume is 0.9 l

4.3.4.2.5 Dose volume

It is calculated by the following formula:

$$Vdose = \frac{Daily\ Volume}{Feeding\ dose} \ (105)$$

$$\text{Vdose} = \frac{12170\ \text{l}}{24} = 666.6\ \text{l}$$

4.3.4.2.6 Number of holes

It is calculated by:

$$\#\text{holes} = \frac{\text{Vdose}}{\text{Dosing volume}} \ (106)$$

$$\#\text{holes} = \frac{666.6\ \text{l}}{0.9\ \text{l}} = 740$$

4.3.4.2.7 Holes by pipe

It is calculated by:

$$\text{Holes by pipe} = \frac{\#\text{holes}}{\#\text{pipes}} \ (107)$$

$$\text{Holes by pipe} = \frac{740}{20} = 37$$

4.3.4.2.8 Pipes total length

It is calculated by:

$$\text{PL} = \text{L} * \#\text{pipes} \ (108)$$

$$\text{PL} = 42\ \text{m} * 20 = 840\ \text{m}$$

4.3.4.2.9 Holes separation

It is calculated by:

$$\text{H Separation} = \frac{\text{PL}}{\#\text{holes}} \ (109)$$

$$\text{H Separation} = \frac{840\ \text{m}}{740} = 1.13\ \text{m}$$

4.3.4.2.10 Hydraulic Retention Time

It is calculated by:

$$\mathrm{HRT} = \frac{\mathrm{As} * \mathrm{h} * \mathrm{n}}{\mathrm{Q}} \quad (110)$$

$$\mathrm{HRT} = \frac{422\ \mathrm{m}^2 * 0.6\ \mathrm{m} * 0.35}{12.17\ \mathrm{m}^3/\mathrm{d}} = 7.91\ \mathrm{d} = 8\ \mathrm{d}$$

4.3.4.2.11 Final BOD_5

It is known from the study cases analyzed in Chapter II that the BOD_5 removal can be from 80-90%. It is assumed an 80% of BOD_5 removal(ɱ).

$$C_f\ \mathrm{BOD}_5 = \mathrm{C}\ \mathrm{BOD}_5 * (1 - ɱ) \quad (111)$$

$$C_f\ \mathrm{BOD}_5 = 173.3\ \mathrm{mg/l} * (1 - 0.8) = 34.6\ \mathrm{mg/l}$$

4.3.4.2.12 Final TSS

It is known from the study cases analyzed in Chapter II that the TSS removal can be from 80-90%. It is assumed an 80% of TSS removal (ɱ).

$$C_f \mathrm{TSS} = \mathrm{C}\ \mathrm{TSS} * (1 - ɱ) \quad (112)$$

$$C_f \mathrm{TSS} = 91.63\ \mathrm{mg/l} * (1 - 0.8) = 18.32\ \mathrm{mg/l}$$

4.3.4.2.13 Dosing tank

The dosing tank corresponds to the 0.5 to 1 times the daily volume to be treated. It will be a tank of 6 to 12.17 m^3. It is a big tank considering that the constructed wetland will be divided in 2 or 3 beds working constantly so it is reduced to three m^3. It will be of 2 m x 1.5 m x 1 m.

4.3.4.2.13 Vertical subsurface flow constructed wetland summary

The vertical subsurface flow constructed wetland summary is presented below:

Table 88 Vertical subsurface flow constructed wetland summary

Vertical subsurface flow constructed wetland		
Criteria	Value	Unit
Height	0.6	m
Width	10	m
Length	42	m
Hydraulic Retention time	8	d
Medium	Fine gravel	
Plant	*Phragmites australis*	
Initial BOD_5 concentration	173.3	mg/l
Final BOD_5 concentration	34.6	mg/l
Initial TSS concentration	91.63	mg/l
Final TSS concentration	18.32	mg/l
Dosing tank		
Height	1	m
Width	1.5	m
Length	2	m

This constructed wetland will be divided in three beds of the following dimensions: 14 m x 10 m x 0. 6 m

The design plan is presented in Appendix N°3

4.3.5 General Treatment Train Schemes

There are two schemes presented that represent the proposed treatment train

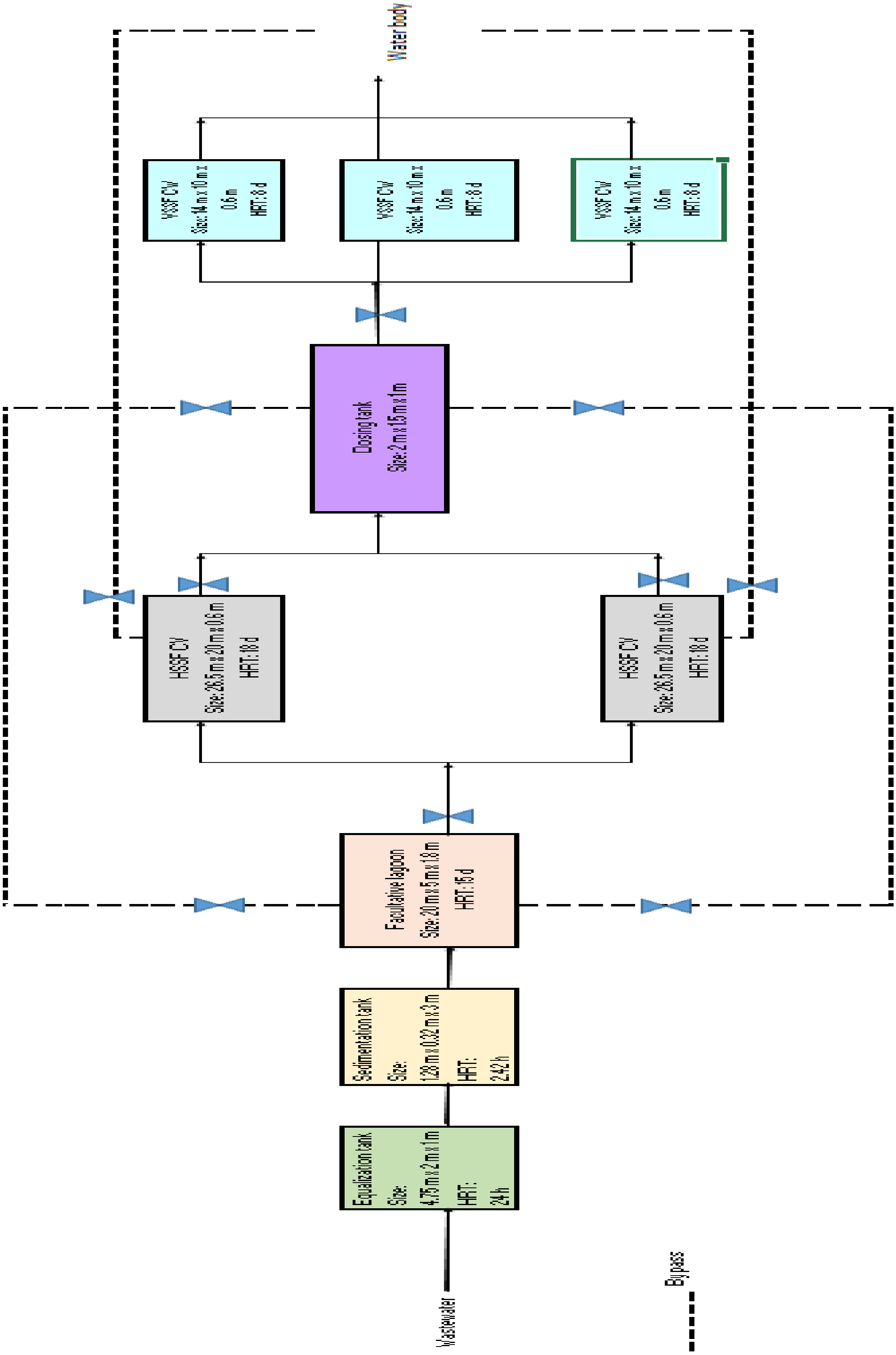


Figure 13 Treatment train sizing

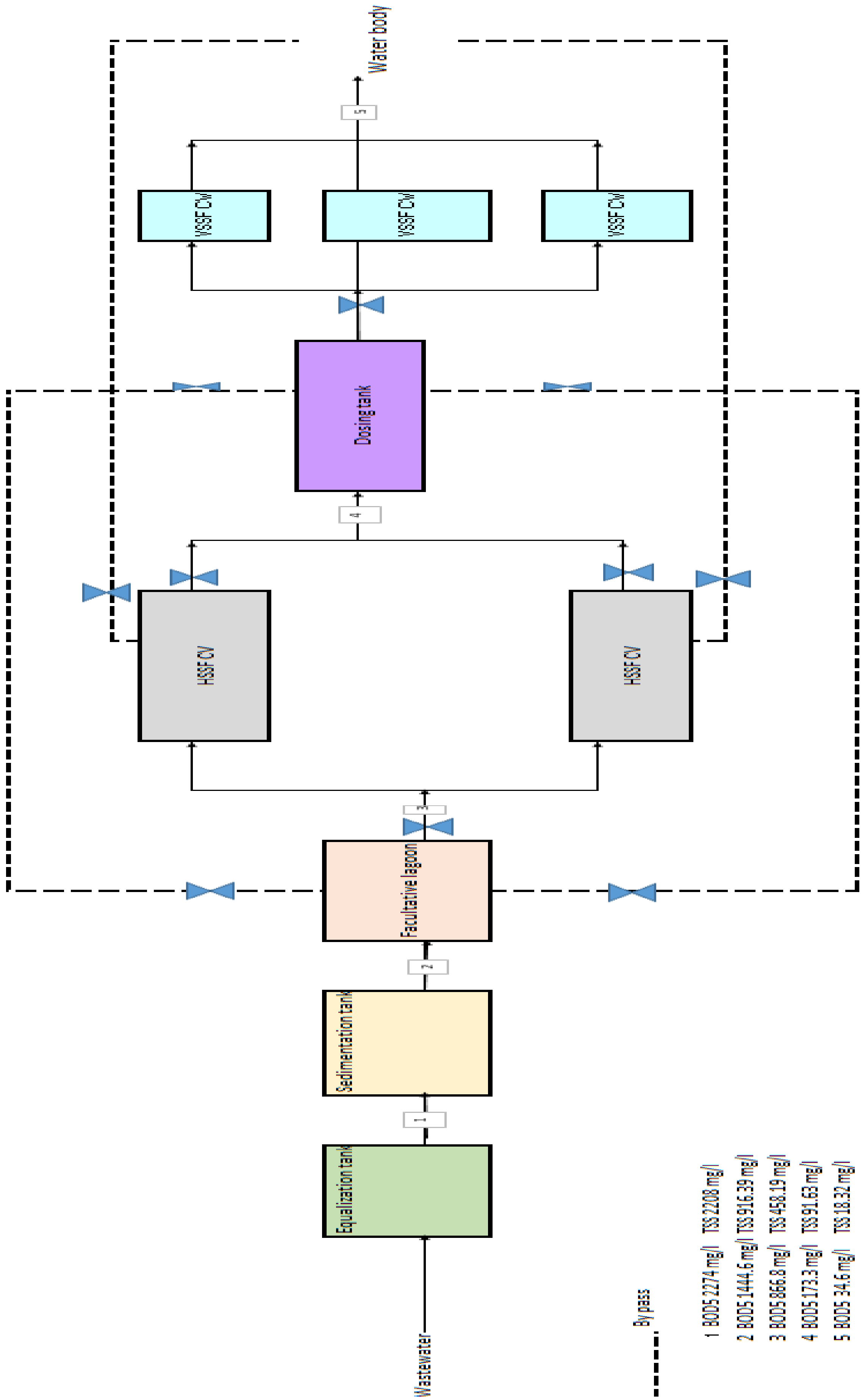


Figure 14 Treatment train pollutants removal

As it can be seen, in theory the final effluent will have a BOD_5 of 34.6 mg/l and a TSS of 18.3 mg/l. Both of them, matches the Ecuadorian regulations, which limits are for BOD_5 100 mg/l and for TSS 100 mg/l.

A bypass pipeline is designed from the facultative lagoon to the VSSF constructed wetlands in the case that the HSSF constructed wetlands are not working; and another bypass pipeline from the HSSF constructed wetlands to the water body in case the VSSF constructed wetlands are not working.

4.4 Waterproofing

As the elements to be built in the treatment train (facultative lagoon and constructed wetlands) are underground elements, it is necessary to perform an analysis of the type of soil in which they will be placed to assess the waterproofing and avoid contamination problems. An analysis of the soils where the treatment train can be implemented was carried out, obtaining the following results:

Table 89 Soil analysis

Parameter		Value	Methodology
Hydraulic sat. conductivity (cm/h):		2,54 (7x 10^{-6} m/s)	Inverted well
Hydraulic conductivity (cm/h):		0,35	Minidisk
pH (1:2,5)		7,73	Potentiometer. 1:2,5
Electric conductivity (mS/cm) (1:5)		0,31	Conductivity meter 1:5
Saturation point	Gravimetric (g/g)	0,41	Unaltered sample-Suction tables
	Volumetric (cm^3/cm^3)	0,52	
Field capacity	Gravimetric (g/g)	0,36	Unaltered sample-Suction tables
	Volumetric (cm^3/cm^3)	0,45	
% Porosity		45,09	Real and apparent density ratio
% Organic matter		9,15	Calcination
Structure:		Block	FAO’s guide
Consistence:	Clay<2µm (%)	22,59	Hydrometer Method
	Silty 2-63µm (%)	61,07	
	Sand 63-2000µm (%)	16,34	
Structural type:		Sitly loam	Texture triangle

The hydraulic sat conductivity is of 7 x 10^{-6} m/s and makes the soil require a waterproof operation [26].

4.5 Costs

The construction costs as well as the maintenance and operational costs have been calculated. It has been considered that the treatment train has a lifespan of 20 years.

4.5.1 Construction costs

They have been calculated considering the prices that the Civil Engineering Association in Cuenca city uses. These prices include labor and machinery; taxes are also considered and they are for the 2018 year [60]. It should be noted that these prices are referential prices and they are just for the civil infrastructure. Pipeline prices should be calculated and considered.

Table 90 Construction costs

Item	Unit	Quantity	Price USD	Total USD
Equalization Tank				**1434.78**
Mechanical excavation in soil 0-2 m depth	m^3	17.10	1.78	30.44
Compacted fill	m^3	0.95	4.39	4.17
Collection of material	m^3	16.15	1.14	18.41
Transport of material	m^3	16.15	2.42	39.08
Stone bed	m^2	9.50	8.01	76.10
Material/Installation: Electro welded Mesh	m^2	44.60	4.96	221.22
Concrete	m^3	4.80	150.44	722.49
Plastering and waterproofing	m^2	18.45	13.49	248.89
Painting	m^2	18.45	4.01	73.98

Sedimentation tank				**586.96**
Mechanical excavation in soil 0-2 m depth	m^3	0.98	1.78	1.75
Mechanical excavation in soil 2-4 m depth	m^3	0.74	2.14	1.58
Compacted fill	m^3	0.04	4.39	0.18
Collection of material	m^3	1.68	1.14	1.91
Transport of material	m^3	1.68	2.42	4.06
Stone bed	m^2	0.41	8.01	3.28
Material/Installation: Electro welded Mesh	m^2	22.81	4.96	113.14
Concrete	m^3	1.76	150.44	265.06
Plastering and waterproofing	m^2	11.20	13.49	151.09
Painting	m^2	11.20	4.01	44.91
Facultative lagoon				**2636.75**
Mechanical excavation in soil 0-2 m depth	m^3	240.00	1.78	427.20
Mechanical excavation in soil 2-4 m depth	m^3	36.00	2.14	77.04
Compacted fill	m^3	10.00	4.39	43.90
Collection of material	m^3	266.00	1.14	303.24
Transport of material	m^3	266.00	2.42	643.72
Material/Installation: Geo-membrane	m^2	215.00	5.31	1141.65

HSSF CW (2 beds)				**3.312.41**
Mechanical excavation in soil 0-2 m depth	m^3	1.272.00	1.78	2.264.16
Compacted fill	m^3	106.00	4.39	465.34
Collection of material	m^3	1.166.00	1.14	1329.24
Transport of material	m^3	1.166.00	2.42	2821.72
Material/Installation: Gravel	m^3	636.00	25.97	16516.92
Material/Installation: Geo-membrane	m^2	1.264.60	5.31	6715.03
Acquatic Plants	u	400.00	0.50	200.00
VSSF CW (3 beds)				**12641.96**
Mechanical excavation in soil 0-2 m depth	m^3	504.00	1.78	897.12
Compacted fill	m^3	42.00	4.39	184.38
Collection of material	m^3	462.00	1.14	526.68
Transport of material	m^3	462.00	2.42	1118.04
Material/Installation: Gravel	m^3	252.00	25.97	6544.44
Material/Installation: Geo-membrane	m^2	578.40	5.31	3071.30
Acquatic Plants	u	600.00	0.50	300.00

Dosing tank				**674.77**
Mechanical excavation in soil 0-2 m depth	m^3	3.20	1.78	5.70
Compacted fill	m^3	0.30	4.39	1.32
Collection of material	m^3	2.90	1.14	3.31
Transport of material	m^3	2.90	2.42	7.02
Stone bed	m^2	3.00	8.01	24.03
Material/Installation: Electro welded Mesh	m^2	24.00	4.96	119.04
Concrete	m^3	2.20	150.44	330.59
Plastering and waterproofing	m^2	10.50	13.49	141.65
Painting	m^2	10.50	4.01	42.11
SUBTOTAL				**47612.86**
TAX				**5713.54**
TOTAL				**53326.40**

4.5.2 Operational and maintenance costs

The activities that are considered in the operational and maintenance costs as well as the frequency have been imposed. The prices are the ones used in Ecuador and they include labor and machinery as well as taxes. Administration costs are also included.

Table 91 Operational and maintenance costs

Activity	Frequency	Price USD	Subtotal USD
Plantation	2 times/year	10	20
Cleaning	48 times/year	10	480
Sludge management	12 times/year	5	60
Cutting of vegetation	12 times/year	10	120
Maintenance of civil infrastructures	24 times/year	10	240
Wastewater analysis	4 times/year	300	1200
Administration costs	1 time/year	500	500
TOTAL			**2620**

The operational and maintenance costs are of $ 2620.00 USD.

4.6 Design Guidelines

According to the study case developed in this research, the following recommendations to treat similar wastewaters have been generated.

4.6.1 Wastewater characteristics

Zootechnical wastewaters are wastewaters with very high pollutant loads, although they are produced in small daily volumes and in defined time intervals. The BOD_5 load can vary from 200 mg/l to 10000 mg/l as well as for COD. There are also high loads of Nitrogen and microorganisms.

The high presence of organic matter is associated with natural biological processes such as the digestion of animals (feeding and deposition) and milking processes. The presence of nitrogen is related to the urea that is also generated in the excretion.

There are many suspended solids due to the cleaning processes in the stalls. The generated manure is removed as much as possible but even so, it remains; its mixture with the residual wastewater generates a lot of suspended solids.

4.6.2 Wastewater treatment train

Due to the characteristics of the wastewaters described above, it is not possible to carry out a single treatment as it is currently done in Ecuador (in few production areas) only with the sedimentation process since the wastewater would not comply with the limits established in law. There is a need of a biological treatment because of the high organic loads that are present in these types of wastewaters.

The presented guidelines can be applied in zootechnical activities with similar characteristics to the study case developed.

Bigger production areas have more wastewaters production and more pollutants concentrations so other criteria should be applied in terms of sizing making the proposed treatment train appropriate to them.

Smaller production areas (from 5 to 20 cattle heads) do not justify the construction of a treatment train like the one proposed; it can be reduced to a sedimentation tank and a facultative lagoon.

4.6.2.1 Sedimentation

It must be carried out with a sedimentation tank because it guarantees the elimination of a large quantity of suspended solids and a part of the organic matter. It is not recommended that this process be carried out with imhoff tanks or septic tanks because the zootechnical wastewaters are very loaded and would generate more problems of odors than they already have.

As the design of a sedimentation tank is made from the surface load, it is recommended to take a surface load of 30 m^3/m^2d considering that the design is made for the mean flow rate.

The depth of the sedimentation tanks can be from three to 4.5 m. It is recommended to work with a depth of 3 m due to the odor problems that this type of effluents generate.

If the sedimentation tank is small, it is not necessary to install structures such as mechanical scrapers for the removal of generated sludge, it is just as important to have a good slope in the bottom of the tank to guarantee that the sludge will go to the area designed for its collection.

4.6.2.2 Lagooning

It is recommended that the facultative lagoon be used because in a single installation there are benefits offered by aerobic and anaerobic lagoons, although the anaerobic lagoons are discarded due to the problems of odors that they would produce with this type of effluent (zootechnical wastewaters).

As it is known, these lagoons are designed through an empirical criterion that takes into consideration the surface organic load factor of BOD_5 for domestic wastewaters, which in turn depends on the temperature of the area where these would be build. Following this model, large areas are required to treat this type of effluents and long hydraulic retention times so this design criterion is discarded for zootechnical wastewater due to the necessary surfaces dealing with small flow rates and the odor problems that it would generate.

An inverse design that considers the hydraulic retention time first and then calculates the necessary area, offers better scenarios in terms of required space.

The maximum retention time that is proposed is 15 days, thus avoiding the generation of bad odors; and the removal efficiency is still decent.

Although the applied organic loads may still be high, it is not determined as a problem since the treated effluent will not yet be sent to a water body and it will go to the constructed wetlands stages.

4.6.2.3 Constructed Wetlands

Between the two types of constructed wetlands that exist: surface and subsurface wetlands, the use of subsurface wetlands is recommended because:
- Area: surface wetlands require more area for their operation

- Odors: surface wetlands cause odor problems and as it has been seen the characteristics of these wastewaters are not the best to avoid this problem.

- Organic load: the surface wetlands operate well with low organic loads and these wastewaters have high organic loads

Once selected the subsurface constructed wetland, the use of hybrid stages is recommended, that is the combination of horizontal and vertical subsurface flow constructed wetlands.

The horizontal subsurface flow wetland will be responsible for the degradation of organic matter while the vertical subsurface flow wetland will be responsible for the nitrification of ammonia, which as seen in the description of zootechnical wastewaters, has a high presence.

No recirculation processes are necessary because the odor problems have been resolved avoiding them in the previous treatment stages.

Although the vertical subsurface flow constructed wetland design is based on the hydraulic loads, it must be done with the organic load because it makes the design more restrictive for the required characteristics to be obtained.

The intermittency that is required in feeding the vertical wetland of 24 times is recommended because the vertical subsurface flow constructed wetland works every hour and allows a worthy presence of oxygen along the day.

Fine gravel is considered a good filling medium for the constructed wetlands beds because it has not presented problems and the efficiency of the constructed wetlands have been adequate. The porosity associated to this filling medium that can be considered for the design is of 35% and the hydraulic conductivity of 10000 m/d. In the same way, small walls of thicker material in the feeding zone are suitable to face suspended solids and avoid possible clogging.

Even the suspend solids have been treated, there are still problems and risks with them because they have not been totally removed yet so it is important that the designed constructed wetlands are divided into two or three beds working in parallel allowing maintenance procedures if these problems occur and do not halt the work of the wastewater plant. In addition, these avoid the use of extensive areas in their implementation.

Praghmites australis shows a very good adaptability to this type of wastewater with high organic loads.

CHAPTER V:

PILOTING

5.1 Generalities

An experimental campaign was carried out in Ecuador in order to:

1. Verify the design of the proposed treatment train (subsurface constructed wetlands)
2. Collect data of the removal efficacy of BOD_5 (design parameter)
3. Evaluate how efficient they are (subsurface constructed wetlands) with zootechnical wastewaters.

As it was difficult to work out with the entire treatment train in a pilot scale for reasons of money and space, just the constructed wetlands steps (HSSF CW and VSSF CW) were built because this research made emphasis on their use.

A synthetic wastewater was prepared to feed the constructed wetlands because it was not possible to use real wastewaters due to the limited access to the area where they are produced.

The constructed wetlands were designed using the BOD_5 removal model, so the pilot station evaluated this parameter to validate the application of this model with zootechnical wastewaters with the current design, even predictions of TSS removal were established in Chapter IV.

5.2 Sizing and construction

The constructed wetlands pilot station was developed to treat the 5% of the expected flow rate so a scale factor of the 0.95 was used in order to build it.

Considering this factor, the size was obtained with the following formula:

$$Pilot\ size = Real\ size - (Real\ size\ x\ 0.95)\ (113)$$

The constructed wetlands pilot station sizes are presented in Table N° 92.

Table 92 Pilot station dimensions

Step	Real flow rate m^3/d	Pilot flow rate m^3/d	Real length m	Pilot length m	Real width m	Pilot width m	Real height m	Pilot height m	Hydraulic retention time d	Material	Plant
HSSF CW	12,17	0,60	53	2,65	20	1	0,6	0,6	18	Fine gravel	*Praghmites australis*
VSSF CW	12,17	0,60	42	2,1	10	0,5	0,6	0,6	8	Fine gravel	*Praghmites australis*

After establishing the sizes of the pilot scale constructed wetlands, they were built (HSSF CW and VSSF CW). The construction of the pilot station started December 4, 2017. The structures were built in glass.

Figure 15 Pilot station construction HSSF CW

Figure 16 Pilot station construction VSSF CW

For the pilot HSSF CW feeding, a hole was made in one of the width faces of the HSSF CW at a height of 0.30 m and pipe was introduced in it and then the synthetic wastewater passed through it.

The feeding system for the pilot VSSF CW was made taking as example an irrigation system. The used pipes were perforated to assure the whole distribution of the wastewater in the pilot VSSF CW, and then were placed on top of the bed.

One hole was made in the bottom-left side of the opposite width face where the feeding took place in both structures (HSSF CW and VSSF CW) to allow the treated wastewater goes out from them. A pipe was also introduced in the hole and in this way the wastewater left the pilot stations.

The gravel which was the filling medium was washed and the disposed in a height of 0.5 m, 0.1 m of agricultural soil where also added to the bed as feeding material to assure the plants stability and development. The pilot constructed wetlands where of 0.7 m of height with an effective height of 0.6 m. An empty space of 0.1 m was left.

For reasons of time, the used plants were mature plants, there was no need to make them grow but to make them adapt to the pilot station and the used wastewater.

Figure 17 Pilot HSSF CW

Figure 18 Pilot VSSF CW

5.3 Synthetic wastewater

The wastewater to be used must have a high amount of organic matter. Theoretically, the wastewater enters the HSSF with a concentration of 866.5 mg/l of BOD_5 and 458.19 mg/l of TSS as can be seen in Chapter IV.

Blood powder is a material that has been used to prepare synthetic wastewater in the laboratory practices that are carried out at the Politécnica Salesiana University. It is obtained from the dehydration of the blood that is produced in animal slaughterhouses in order to give a new use to the waste and not producing higher wastewaters volumes with them. It is used for the production of balanced food for dogs and cats.

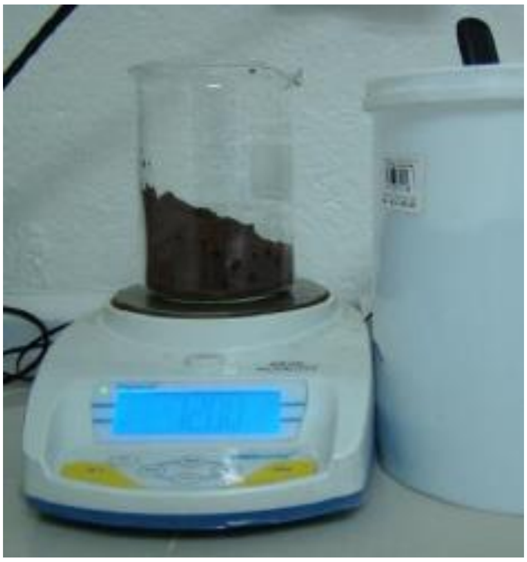


Figure 19 Blood powder for synthetic wastewater

In order to determine the quantity of blood powder necessary to produce similar characteristics in the synthetic wastewater that the real wastewaters will go to the constructed wetlands stages have, some tests were carried out.

Two, four and six grams of blood powder were dissolved in 500 ml of water obtaining the values presented below:

Table 93 BOD_5 concentrations with blood powder

Quantity of blood powder (g)	BOD_5 mg/l	BOD_5 mg/l mean
2	647.71	
2	665.14	656.42
4	925.7	
4	870.06	897.88
6	1284.39	
6	1300.5	1292.4

The ones with four grams of blood powder are those best matches with the real wastewaters characteristics that go to the constructed wetlands stages in terms of BOD_5 which is the analyzed parameter.

5.4 Pilot Station Star-up

Before putting to work the constructed wetlands pilot station, an adaptation of the plants to the wastewater was made.

They were planted on December 11th, 2017 and were watered seven days with pure water, seven days with a 50-50 mixture of synthetic wastewater and pure water, and seven days with synthetic wastewater.

No problems of wilting or death of the plants were observed, so the pilot station was fed and started to work. This process began on January 2nd, 2018 and finished August 31st, 2018.

As the pilot station was small, just one feed was done while the hydraulic retention time was passing, so during the 8 months that the experimental campaign took place, 13 analyzes were done as the pilot station worked in a batch.

Cleaning processes of the filling medium and the pilot constructed wetlands were done for each of the 13 analyzes before they started to work; these were made to avoid clogging problems.

The space where the experiment took place has similar environmental conditions where the wastewater is produced. This is 20 kilometers far from the production area of this study.

5.5 Results

The results of the 13 analyses made during the experimental campaign are presented below.

Table 94 Experimental campaign results

Experiment	Synthetic wastewater BOD_5 mg/l in	BOD_5 mg/l out HSSF CW	BOD_5 mg/l out VSSF CW
1	894.02	152.1	38.02
2	903.3	132	27.72
3	905.26	167.3	33.47
4	928.33	173.6	38.19
5	890.74	143.5	37.38
6	913	127.8	25.56
7	923.25	129.2	28.4
8	910.48	140.8	40.8
9	877.26	152.3	32.2
10	922.1	117	40
11	900.04	148.2	25.7
12	914.1	127.6	33
13	872.91	141.25	32.8
Mean	904.21	142.51	33.32
Maximum	928.33	173.6	40.8
Minimum	872.91	117	25.56
Standard Deviation	17.05	16.28	5.31

The synthetic wastewater that fed the constructed wetlands pilot station had a mean concentration of BOD_5 of 904.21 mg/l, reaching at the end of the treatment a mean value of 33.32 mg/l of BOD_5, which matches with the Ecuadorian regulations and allows the wastewater to be discharged to a water body.

Graphics of the pilot HSSF CW results for the 13 samples are presented below.

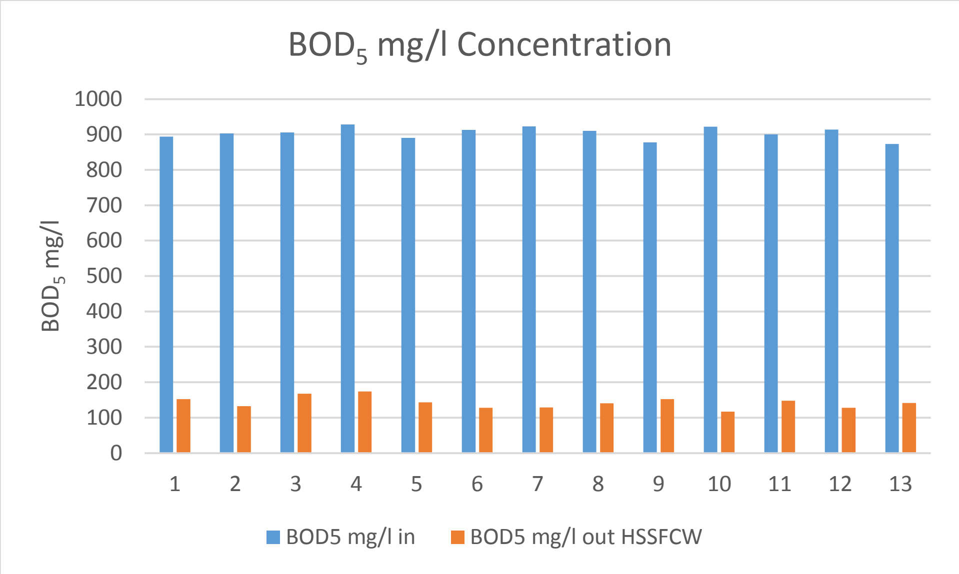


Figure 20 Initial and Final BOD_5 concentration pilot HSSF CW

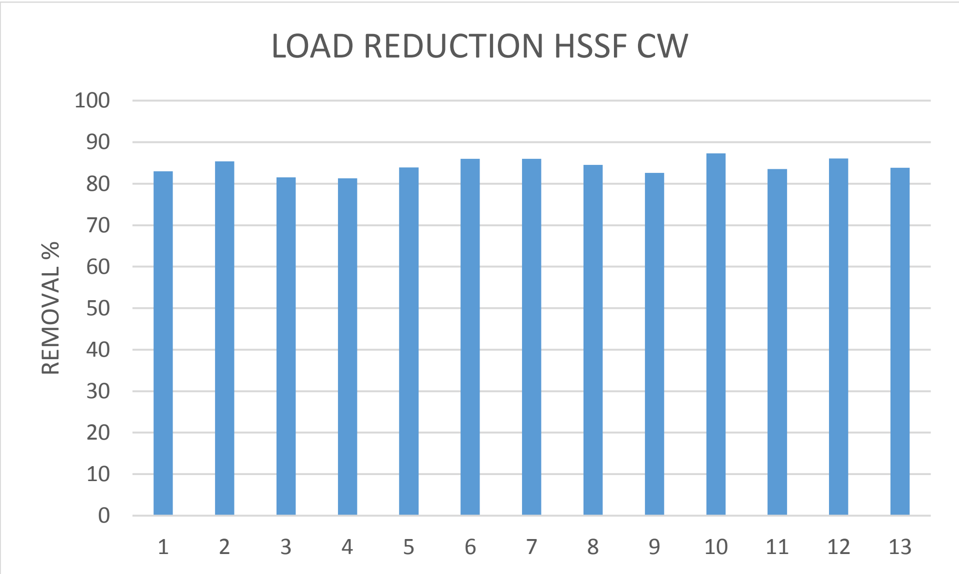


Figure 21 Removal % of BOD_5 pilot HSSF CW

There was a significant reduction of BOD_5 concentration, which initially had a mean value of 904.21 mg/l of BOD_5. Out of the pilot HSSF CW, there was a mean concentration of BOD_5 of 142.51 mg/l.

The efficiency removal varied from 80 to 87%. There was a higher efficiency removal when the wastewater had a higher concentration of BOD_5 even though it is not too significant.

Graphics of the pilot VSSF CW results for the 13 samples are presented below.

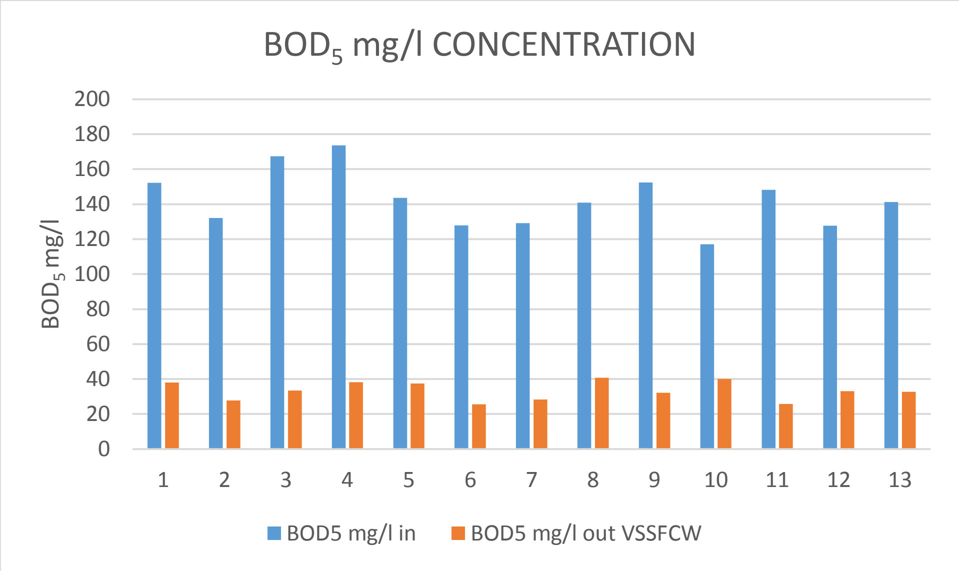


Figure 22 Initial and Final BOD_5 concentration pilot VSSF CW

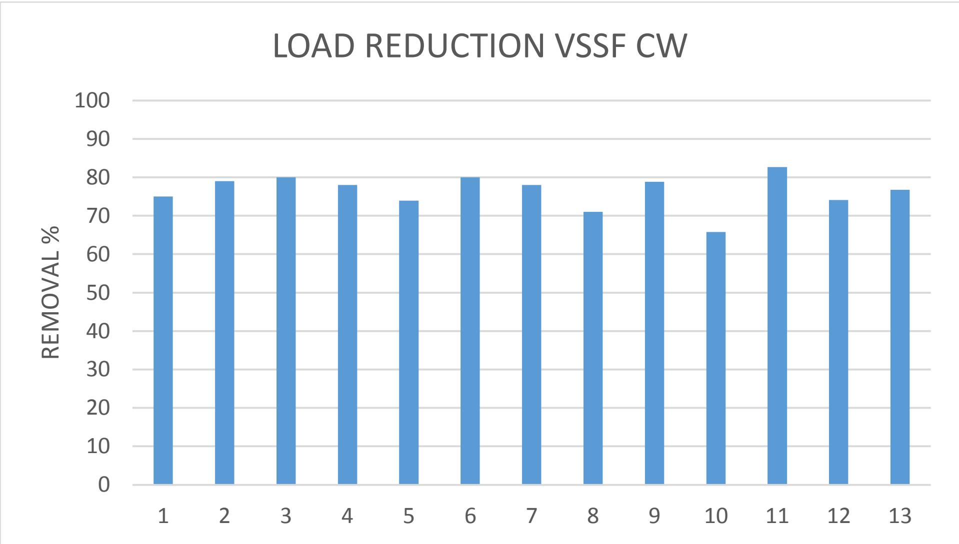


Figure 23 Removal % BOD_5 pilot VSSF CW

There was a suitable reduction of BOD_5 concentration in the pilot VSSF CW. Initially the BOD_5 was of 142.51 mg/l and at the end there was of 33.3 mg/l. The efficiency removal varied from 70 to 82%.

The HSSF CW has higher efficiency than the VSSF CW; it can be assumed that this occurs because the HSSF CW works better with organic matter while VSSF CW works better with nitrogen.

From the experimental campaign, it can be concluded that constructed wetlands are efficient to treat this type of wastewaters and the designs calculations were well done.

CHAPTER VI:

COSTS ANALYSIS

6.1 Willingness to pay analysis

The willingness to pay (WTP) is a methodology that estimates the ability to pay of a social group for a certain intervention; and it gives as a result the monetary amount that a social group could hypothetical have for it. It is being widely used in cost-benefit and in decision-making analysis [61].

The WTP uses a survey method that presents the respondent people a questionnaire related to the intervention that is intended to be evaluated. The survey consult the participants, how much they would be willing to pay for this intervention [61].

Two examples where the WTP has been applied in Latin America are presented below.

Table 95 Study cases for WTP in Latin America

Title	Results	Reference
A constructed wetland systems for residential grey water reuse: Economic feasibility of, and willingness to pay for	This study was carried out in Brazil, and it shows that wastewater treatment systems are financial feasible. 63% of the respondents are willing to pay for the project.	[62]
Willingness to pay for improvements in wastewater treatment: application of the contingent valuation method in Puno, Peru.	This study was done in Peru and it shows that the respondents (60.8%) have the willingness to pay for improvements in the wastewater treatment system.	[63]

A WTP analysis was carried out in Paute to know the monetary amount that the population could have for the treatment train developed to treat zootechnical wastewaters in this thesis, showing them the environmental benefits that they would have if the project were to be built.

The used questionnaire and the WTP study were made taking as reference the one developed by Verlicchi et al[9], where the WTP for a recreational benefit in a wastewater reuse project in Ferrara-Italy and adapting it to the study scenario. The questionnaire is in Appendix N°4. The study was conducted specifying that the WTP amount represents a family opinion.

6.1.1 Questionnaire

The questionnaire consisted of three parts:

The first part evaluated how involved the population is with environmental topics. It evaluated how much they think the environmental protection is important, how great the environmental quality of the study zone is, and their knowledge about a wastewater treatment plant and the specific treatment train proposed in this thesis.

If the people did not know the treatment train stations, they were clarified about them. The explanation included working procedures, their impacts, their benefits, their construction and as well as their investment and operational costs. Some schemes and photos of the treatment train stations were shown.

The second part was to collect the respondent's opinion regarding the project. This part consisted on the evaluation of the amount of money that they would contribute to the construction of the proposed treatment train. Some monetary amounts were established but to reduce bias, an option that allowed them to propose an amount was also presented. The proposed quantities are presented in the following table and they are expressed in USD.

Table 96 Proposed USD amounts for WTP study

1	15	35	60	100	300
2	20	40	70	150	500
5	25	45	80	200	700
10	30	50	90	250	1000
Other (specify)					

The third part was a general information data collection where information such as age, education level, job title and annual income where asked in order to relate the WTP with demographic and socioeconomic variables.

6.1.2 Sample

Considering that the population of Paute is of 25494 inhabitants and that a family is composed by 4 people [47], the universe is of 6374 families.

The number of respondents was defined by the Slovin's formula:

$$n = \frac{N}{1 + Ne^2} \quad (114)$$

Where:

N: is the universe of interest

e: is the desired margin of error.

The sample number was

$$n = \frac{6374}{1 + 6374 * 0.05^2} = 376\, respondents$$

To increase the reliability of the sample, 510 surveys were conducted and they represent 510 families, corresponding to the 8% of the whole universe.

As previously reviewed in Chapter IV, Paute is divided into eight zones and with different population present in them. The surveys were conducted in each of these eight zones and in proportion to the population with the following distribution.

Table 97 Surveys by Zone

Zone	Population	Surveys
Paute as center	9850	198
Bulán	2173	43
Chicán	3644	73
El Cabo	3320	66
Guaraignag	840	17
San Cristobal	2412	48
Tomebamba	1346	27
Dugdug	1903	38

resident population distribution is reported in Figure N°7 .

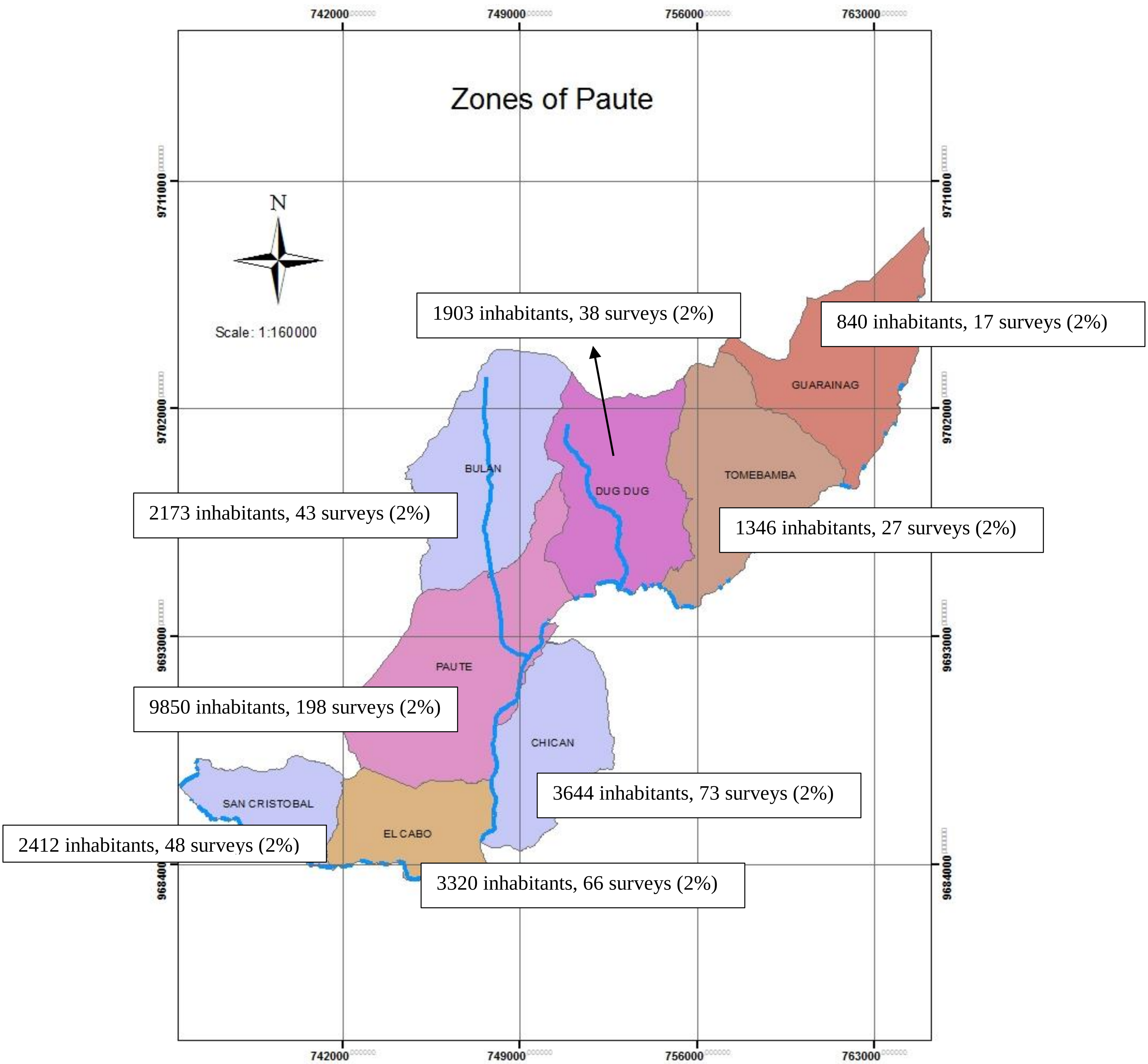


Figure 24 Zones of Paute with the corresponding inhabitants, number of surveys and the percentage of respondent families involved in the survey.

6.1.3 General Information Results

The following table reports the main characteristics of the respondents about gender, age, education level, job title and yearly family income.

Fifty six percent of the responders are male and the forty four percent are female. The largest number of respondents are between 31 and 60 years of age, representing 357 people, which is equivalent to 70% of the surveyed population.

The majority of the respondents have a high school education level (42%), followed by those who have a primary school certificate (34%). Very few people have a university degree that represents 12% of the respondents.

The 35% of the respondents are full time workers and 30% are mid time workers, 6% are retired and 2% are unemployed. Students and housewives represent 13% of each one.

Finally referring to the annual family income, most of the respondents have an annual family income ≤ 12000, which represents the 85%.

Table 98 General survey results

Description	Number	%
Gender		
Male	284	56
Female	226	44
Age		
≤30	85	17
31-40	130	25
41-50	139	27
51-60	88	17
61-70	58	11
>70	10	2
Education level		
None	60	12
Primary	174	34
Secondary	215	42
University	61	12
Job title		
Full time worker	180	35
Mid time worker	154	30
Retired	32	6
Unemployed	10	2
Student	66	13
Housewife	f68	13

Annual family income (USD)		
≤ 12000	432	85
12000 to 20000	57	11
20001 to 30000	18	4
30001 to 40000	2	0
40001 to 50000	1	0
> 50000	0	0

6.1.4 Environmental perception and treatment train knowledge

The respondents think that the protection of the environment has a high importance (56%). They mostly (38%) consider that the environmental quality of the area is good.

The 72% of the respondents consider that the community should take care of the environment.

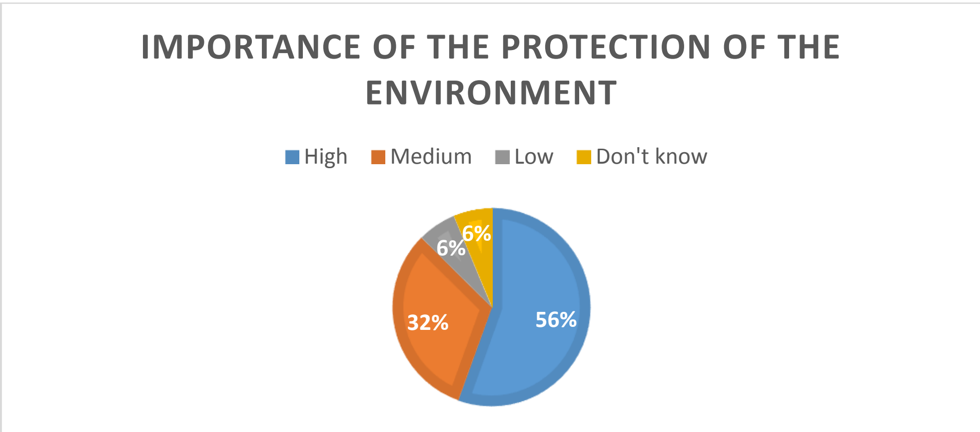


Figure 25 Respondents perception of environmental protection

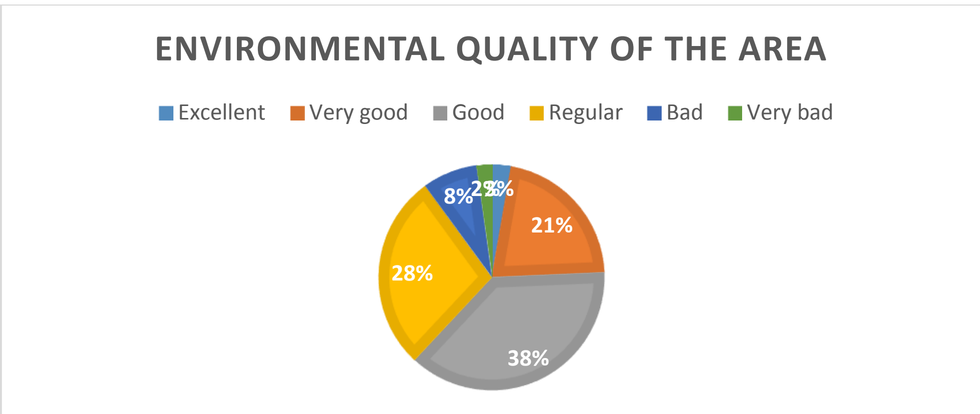


Figure 26 Respondents perception of the quality of the study area

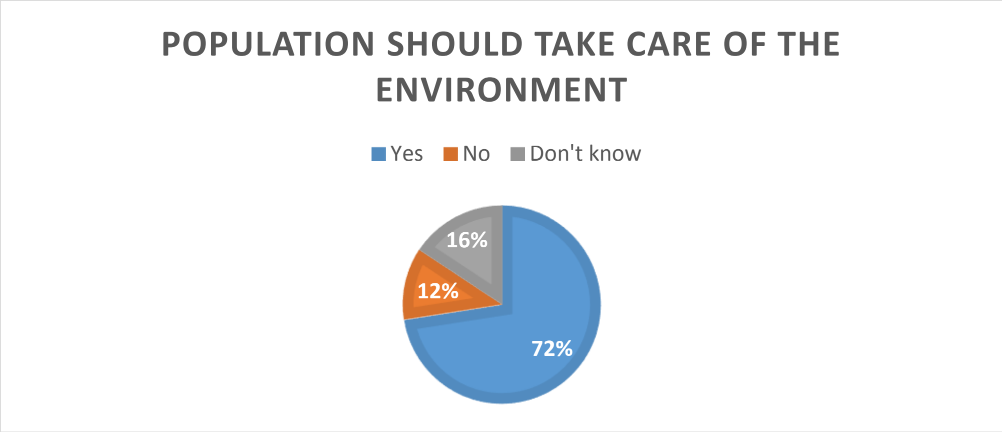


Figure 27 Respondents perception of taking care of the environment

The 78% of the respondents (398 people) do not know how a constructed wetland system to treat wastewaters is, however, once explained how they work and all the proposed treatment train stages to treat zootechnical wastewaters, 65% of the respondents agree with their construction.

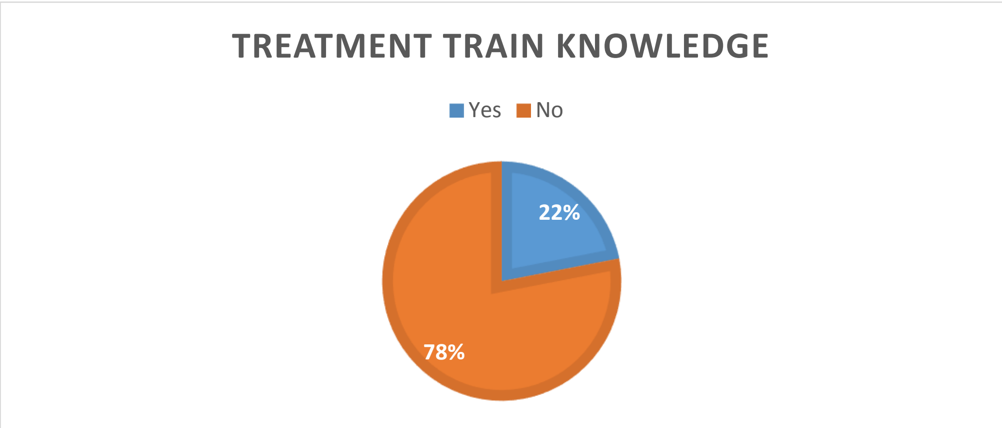


Figure 28 Respondents knowledge of the proposed treatment train and constructed wetlands

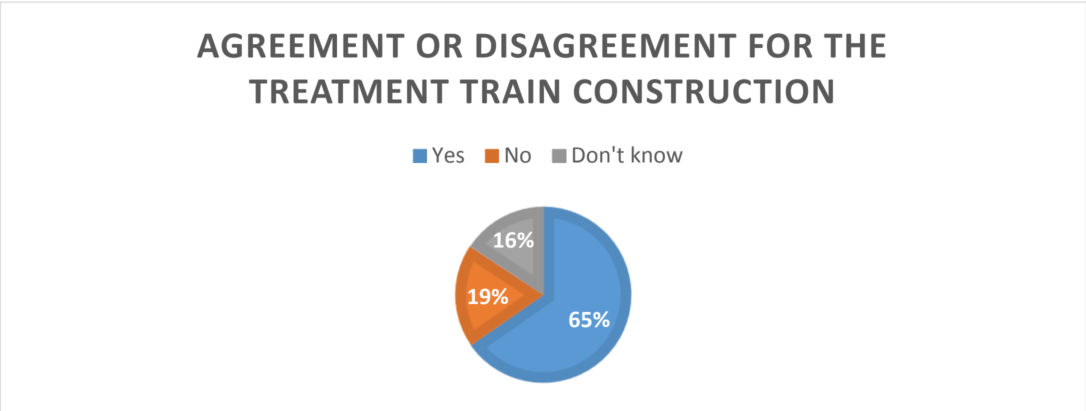


Figure 29 Respondents agreement with the construction of the treatment train

Some reasons were raised to know respondents might disagree with the construction of the treatment train, since the indifference to the problem is the main reason with 29%.

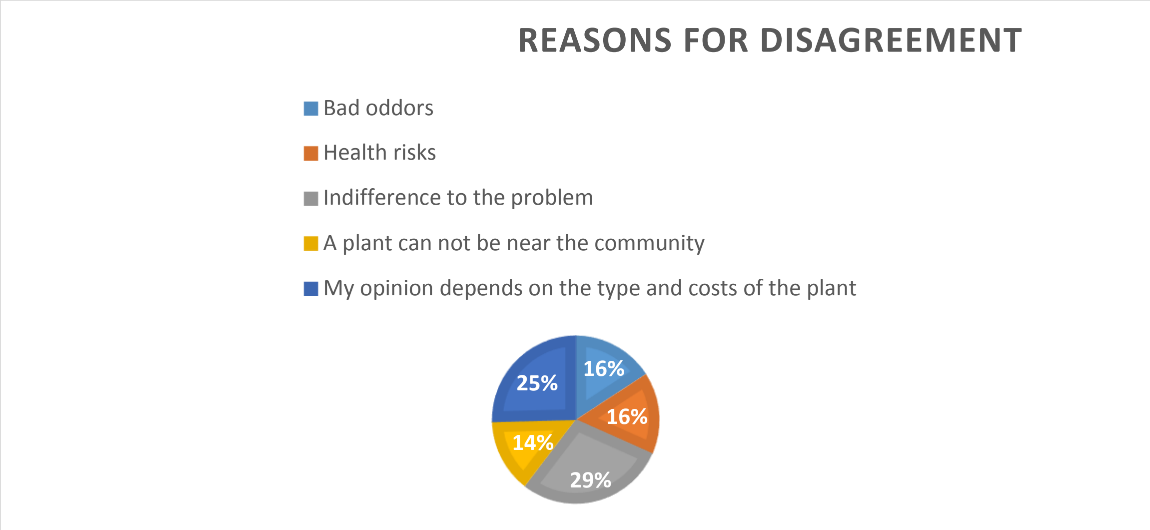


Figure 30 Respondents reasons for disagreement

Explaining more clearly how the project would be carried out and its benefits specially related to the improving of the environmental quality, agreement or disagreement for the construction of the system was another question asked. Eighty-two percent of the respondents that first did not agree or did not know, accepted the construction of the proposed treatment train.

The respondents that still do not agree with the construction of the treatment train explain that their main reason for disagreement are the negative impact that the treatment train has in the zone and the indifference to the problem.

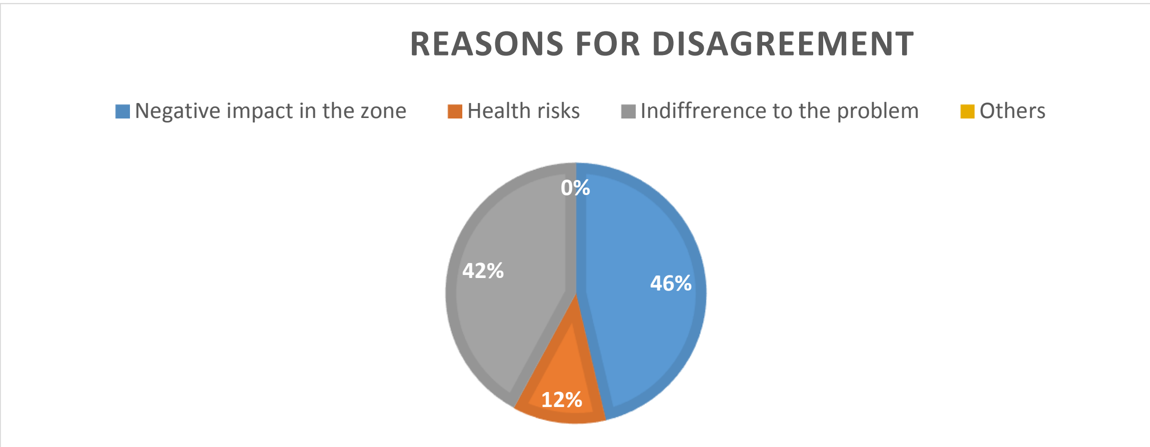


Figure 31 Respondents reasons for disagreement

6.1.5 Willingness to pay estimation

In the following lines, results referring to the WTP estimation are presented.

Considering that in the questionnaire it was specified that there would be just one single quota (*una tantum*) to support the construction of the treatment train to treat zootechnical wastewaters and that the amount represents the family's contribution, the WTP was calculated.

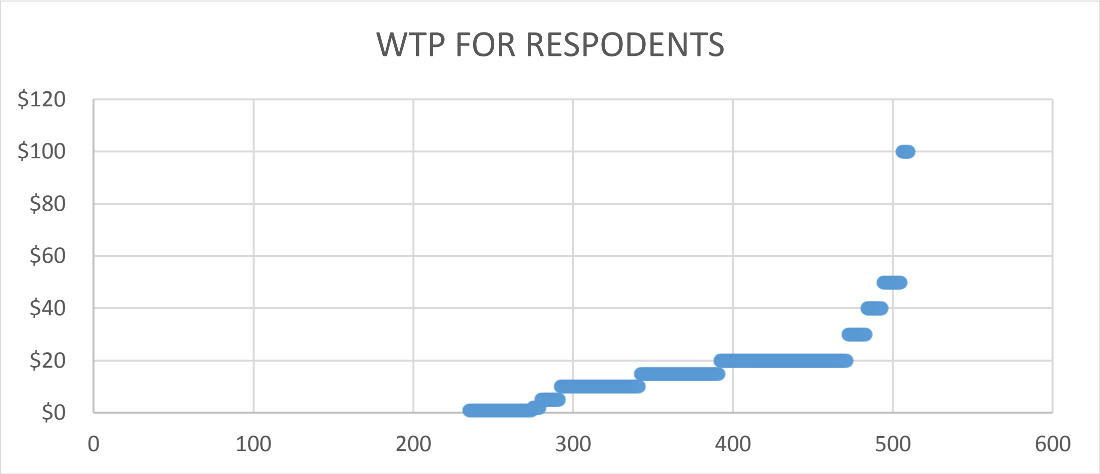


Figure 32 Respondents Willingness to pay for the project

Two hundred thirty four (45%) of the respondents have no willingness to pay for this project; the 55% of the respondents are willing to pay for the project. More respondents have an availability to pay 20 USD. Five respondents would give 100 USD for the project, which is the maximum amount of money to give for this project.

The willingness to pay for the responders (510 families) is of $4820.00 USD. In Paute, approximately the WTP for each family is $9.4 USD, as in the zone, there are 6374 families the total WTP is of $59,915.00 USD.

The higher the educational level, the higher WTP. People with a University degree WTP on average is of $11.00 USD.

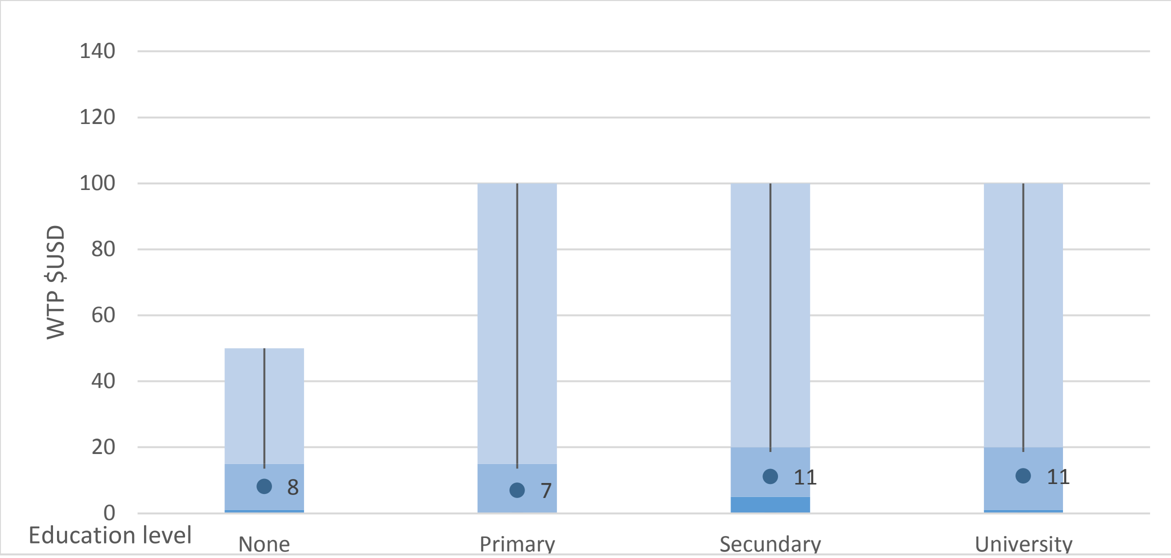


Figure 33 WTP vs. Education level

People with annual income in the range 120001 to 20000USD, in average have a WTP of $13 USD. The higher the annual family income is, the lower the WTP becomes.

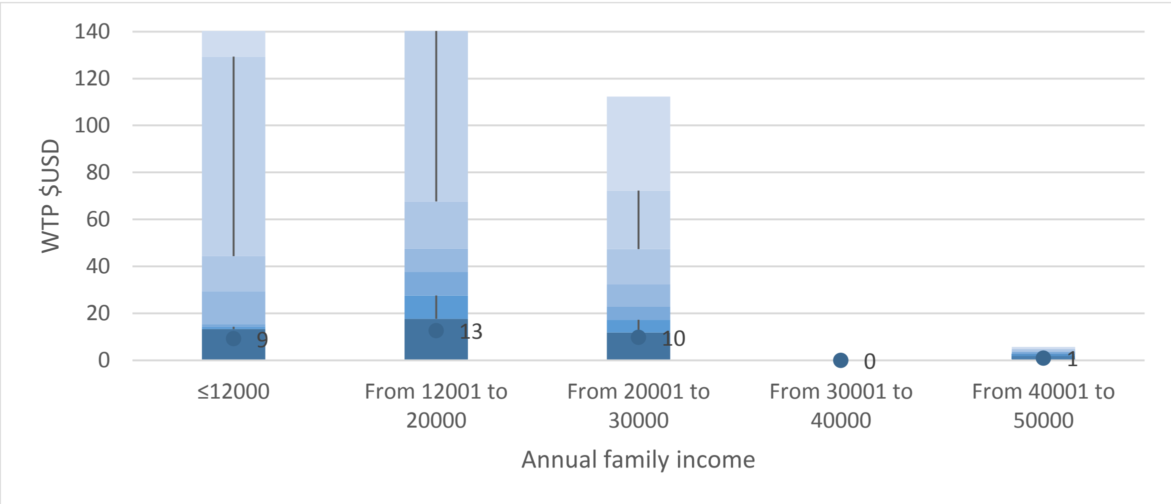


Figure 34 WTP vs. Annual family income

Full time workers and mid time workers are those with highest WTP. On average, it is of $10 USD.

Students also have a WTP of 10 USD as full time workers and mid time workers; it is related with the educational level sensitive.

Retired people are in second place of WTP with an average of $9 USD, it could be because people do not have big economic responsibilities.

Figure 35 WTP vs. Type of job

People from 31 to 50 years old are the ones with highest WTP; it is because they correspond to the working population and they consider a priority the construction of the treatment train for the zootechnical wastewater cause they mainly work in this sector.

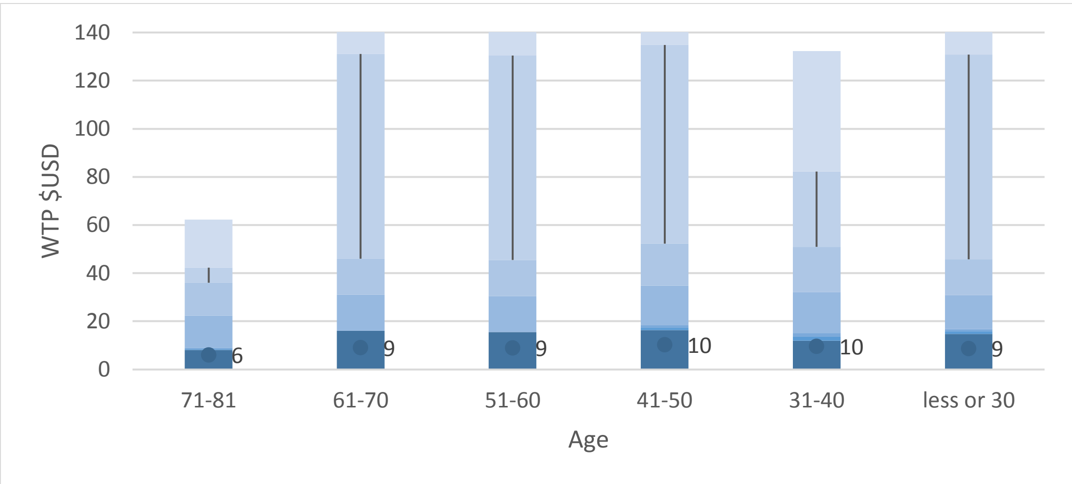


Figure 36 WTP vs. Age

According to the living zone, there is a high WTP in the zone where the project theoretically would be implemented taking as a reference the study area used in this thesis (Chicán) and the nearest zones (Paute as center, Bulán, El Cabo) because people living in Chicán and nearest zones are directly affected with the zootechnical wastewaters discharges.

The population of Chicán have an average WTP of 15 USD while the population of Dugdug (the most distant zone) have an average WTP of 2 USD.

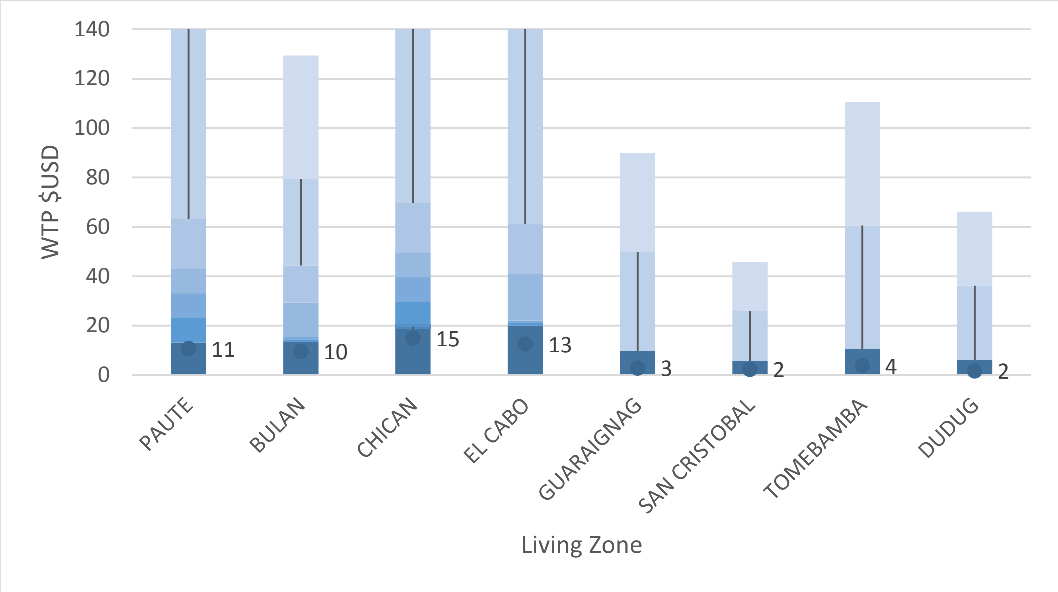


Figure 37 WTP vs. Living zone

6.2 Cost- Benefit estimation

The cost-benefit analysis is used to estimate if a project is or not feasible to be executed under a financial point of view. It assigns a monetary value to each input and output resulting from the project. If the benefits values are greater than the costs values, the project is deemed adequate and its implementation is possible [64].

Some studies have been done to evaluate if domestic wastewater treatment and reuse projects are feasible or not from a financial point of view [65] [66].

The construction of the proposed treatment train will guarantee the release of a treated effluent with low concentrations of BOD_5 and TSS. The experimental campaign showed the good removal achieved and that the effluent matches with the Ecuadorian legal requirements making the project feasible to be executed under an environmental point of view, so the financial feasibility of the project was evaluated.

6.2.1 Costs

Assuming that the treatment train can be constructed in one year, an estimation of all costs (Investment, operation and maintenance costs of the treatment train) involved is reported in the following table. The treatment train has hypothetically a lifespan of 20 years.

Table 99 Estimation of costs

Costs	Value
Construction Costs	
Treatment train (equalization tank, sedimentation tank, facultative lagoon, HSSF CW, VSSF CW, dosing tank)	53326.40 USD
Operation and maintenance costs	
Operation and maintenance costs (plantation and cutting of vegetation, cleaning, sludge management, maintenance of civil infrastructures, wastewater analysis, administration costs)	2620 USD/year

6.2.2 Benefits

The thesis under investigation features two main benefits: financial benefit and social benefit.

6.2.2.1 Financial benefit

The financial benefit is considered because the Ecuadorian Environmental Regulations impose fines for pollution towards water bodies.

In the Ecuadorian Law: *"Ley Orgánica de Recursos Hídricos, Usos y Aprovechamientos del Agua"*, it is established as a very serious violation to discharge contaminated waters without treatment in the water bodies with fines between 51 to 150 basic salaries ($386 USD) [67].

The competent environmental authority periodically carries out the controls to see if irregularities are being done. Each activity is controlled every 5 years.
Considering a fine that takes 100 unified basic salaries (an intermediate fine), it would be of $38,600.00 USD.

6.2.2.2 Social benefit

The social benefit has been calculated through the WTP analysis described above. The people of Paute have seen that the quality of the environment and the water as well as their health, would increase if the treatment train were built.

Returning to the data previously exposed, the WTP for the total zone families is of 59915 USD with a familiar WTP on average of 9.4 USD.

Table 100 Estimation of Benefits

Benefits	Value	Method
Financial Benefit (fines)	38600	Cost saving method
Social Benefit	59915	WTP

6.2.3 Cost-Benefit Calculation

Assuming that:

1. The real discount rate is equal to 3%
2. The lifespan of each treatment train step is of 20 years
3. The fine of 38600 USD is inflicted every 5 years and its amount is distributed in this period of time
4. The basis of previous analysis of costs (investment and operation and maintenance costs) as well as benefits (WTP)

The following table evaluates the net present value (NPV) for the treatment train. If the NPV>zero, the proposed treatment train is feasible from a financial point of view.

Table 101 Cost- Benefit analysis

Year	Costs C_k, [$]	Benefits B_k, [$]		Discount rate r	Sn=1/(1+r)^n	Present costs [$]	Present benefits [$]	Present Annual cash flow, [$]	Accumulated present anual cash flow [$]	NPV [$]
0	53326	59915	6589	0.03	1	53326	59915	6589	6589	82464
1	2620	7720	5100		0.971	2544	7495	4951	11540	
2	2620	7720	5100		0.943	2470	7277	4807	16347	
3	2620	7720	5100		0.915	2398	7065	4667	21015	
4	2620	7720	5100		0.888	2328	6859	4531	25546	
5	2620	7720	5100		0.863	2260	6659	4399	29945	
6	2620	7720	5100		0.837	2194	6465	4271	34216	
7	2620	7720	5100		0.813	2130	6277	4147	38363	
8	2620	7720	5100		0.789	2068	6094	4026	42389	
9	2620	7720	5100		0.766	2008	5917	3909	46298	
10	2620	7720	5100		0.744	1950	5744	3795	50093	
11	2620	7720	5100		0.722	1893	5577	3684	53777	
12	2620	7720	5100		0.701	1838	5415	3577	57354	
13	2620	7720	5100		0.681	1784	5257	3473	60827	
14	2620	7720	5100		0.661	1732	5104	3372	64199	
15	2620	7720	5100		0.642	1682	4955	3273	67472	
16	2620	7720	5100		0.623	1633	4811	3178	70650	
17	2620	7720	5100		0.605	1585	4671	3086	73736	
18	2620	7720	5100		0.587	1539	4535	2996	76732	
19	2620	7720	5100		0.570	1494	4403	2908	79640	
20	2620	7720	5100		0.554	1451	4274	2824	82464	

As the NVP>zero with a value of 82.4, the project is feasible from financial point of view. It emerges that the "*una tantum*" WTP is greater than the investment cost and since the first year of construction, the costs are less than the benefits.

6.3 Sensitivity analysis

In this section the main parameters (investment costs, fine probability and WTP) will be changed in order to evaluate how they influence the cost-benefit analysis.

6.3.1 Investment costs

The investment costs (53326 USD) could be underestimated and by this analysis it is needed to evaluate which is the investment cost corresponding to a NPV=zero.

Table 102 Cost-benefit analysis (Investment variation)

Year	Costs C_k, [$]	Benefits B_k, [$]		Discount rate r	Sn=1/(1+r)^n	Present costs [$]	Present benefits [$]	Present Annual cash flow, [$]	Accumulated present anual cash flow [$]	NPV [$]
0	136496	59915	-76581	0.029	1	136496	59915	-76581	-76581	0
1	2620	7720	5100		0.972	2546	7502	4956	-71625	
2	2620	7720	5100		0.944	2474	7291	4817	-66809	
3	2620	7720	5100		0.918	2405	7086	4681	-62128	
4	2620	7720	5100		0.892	2337	6886	4549	-57579	
5	2620	7720	5100		0.867	2271	6692	4421	-53158	
6	2620	7720	5100		0.842	2207	6503	4296	-48862	
7	2620	7720	5100		0.819	2145	6320	4175	-44687	
8	2620	7720	5100		0.796	2084	6142	4057	-40629	
9	2620	7720	5100		0.773	2026	5969	3943	-36686	
10	2620	7720	5100		0.751	1969	5800	3832	-32855	
11	2620	7720	5100		0.730	1913	5637	3724	-29131	
12	2620	7720	5100		0.710	1859	5478	3619	-25512	
13	2620	7720	5100		0.690	1807	5324	3517	-21995	
14	2620	7720	5100		0.670	1756	5174	3418	-18577	
15	2620	7720	5100		0.651	1706	5028	3322	-15255	
16	2620	7720	5100		0.633	1658	4886	3228	-12027	
17	2620	7720	5100		0.615	1612	4748	3137	-8890	
18	2620	7720	5100		0.598	1566	4615	3049	-5842	
19	2620	7720	5100		0.581	1522	4485	2963	-2879	
20	2620	7720	5100		0.565	1479	4358	2879	0	

If the investment cost increases to 136496 USD which means an 255.996% from the baseline value, the NVP=0, thus the project is not convenient financially to be executed.

6.3.2 Fine Frequency

Assuming that the probability that a fine is inflicted is lower.

Table 103 Cost-benefit analysis (Fine frequency variation)

Year	Costs C_k, [$]	Benefits B_k, [$]		Discount rate r	Sn=1/(1+r)^n	Present costs [$]	Present benefits [$]	Present Annual cash flow, [$]	Accumulated present annual cash flow [$]	NVP [$]
0	53326	59915	6589	0.03	1	53326	59915	6589	6589	0
1	2620	2177	-443		0.971	2544	2114	-430	6159	
2	2620	2177	-443		0.943	2470	2052	-417	5742	
3	2620	2177	-443		0.915	2398	1992	-405	5336	
4	2620	2177	-443		0.888	2328	1934	-394	4943	
5	2620	2177	-443		0.863	2260	1878	-382	4561	
6	2620	2177	-443		0.837	2194	1823	-371	4190	
7	2620	2177	-443		0.813	2130	1770	-360	3830	
8	2620	2177	-443		0.789	2068	1719	-350	3480	
9	2620	2177	-443		0.766	2008	1669	-339	3141	
10	2620	2177	-443		0.744	1950	1620	-330	2811	
11	2620	2177	-443		0.722	1893	1573	-320	2491	
12	2620	2177	-443		0.701	1838	1527	-311	2180	
13	2620	2177	-443		0.681	1784	1482	-302	1879	
14	2620	2177	-443		0.661	1732	1439	-293	1586	
15	2620	2177	-443		0.642	1682	1397	-284	1302	
16	2620	2177	-443		0.623	1633	1357	-276	1026	
17	2620	2177	-443		0.605	1585	1317	-268	758	
18	2620	2177	-443		0.587	1539	1279	-260	498	
19	2620	2177	-443		0.570	1494	1242	-253	245	
20	2620	2177	-443		0.554	1451	1205	-245	0	

It was found that if the interval between the fine is ≥17.73 years, it is not convenient to build the treatment train from a financial point of view.

6.3.3 WTP amount

Assuming that the WTP could be affected by a great uncertainty and the amount changes to 0, it means that the population of the zone has no WTP.

Table 104 Cost-benefit analysis (WTP variation)

Year	Costs C_k, [$]	Benefits B_k, [$]		Discount rate r	Sn=1/(1+r)^n	Present costs [$]	Present benefits [$]	Present Annual cash flow, [$]	Accumulated present annual cash flow [$]	NVP [$]
0	53326	0	-53326	0.034	1	53326	0	-53326	-53326	19817
1	2620	7720	5100		0.967	2534	7466	4932	-48394	
2	2620	7720	5100		0.935	2451	7221	4770	-43624	
3	2620	7720	5100		0.905	2370	6983	4613	-39011	
4	2620	7720	5100		0.875	2292	6754	4462	-34549	
5	2620	7720	5100		0.846	2217	6532	4315	-30234	
6	2620	7720	5100		0.818	2144	6317	4173	-26061	
7	2620	7720	5100		0.791	2073	6109	4036	-22026	
8	2620	7720	5100		0.765	2005	5908	3903	-18122	
9	2620	7720	5100		0.740	1939	5714	3775	-14348	
10	2620	7720	5100		0.716	1875	5526	3651	-10697	
11	2620	7720	5100		0.692	1814	5344	3531	-7167	
12	2620	7720	5100		0.670	1754	5169	3414	-3752	
13	2620	7720	5100		0.647	1696	4999	3302	-450	
14	2620	7720	5100		0.626	1641	4834	3194	2744	
15	2620	7720	5100		0.606	1587	4675	3089	5832	
16	2620	7720	5100		0.586	1535	4522	2987	8819	
17	2620	7720	5100		0.566	1484	4373	2889	11708	
18	2620	7720	5100		0.548	1435	4229	2794	14502	
19	2620	7720	5100		0.530	1388	4090	2702	17204	
20	2620	7720	5100		0.512	1342	3956	2613	19817	

It was found that even if WTP is of 0, and assuming the same values defined in the baseline scenario (investment costs and fine frequency), NPV>0 and the investment is feasible (accepted).

As a conclusion, it is important to mention that in the study area by assuming the probability of a fine inflicted every five years, the treatment train is an investment that is financially feasible.

CHAPTER VII: DISCUSION AND CONCLUSIONS

After describing and analyzing the different results obtained in this research, it is now necessary to carry out some discussions and conclusions that serve to consolidate the obtained results, at the same time it supposes a future line for new investigations.

7.1 Discussions

7.1.1 Constructed wetlands system discussion

The purpose of this thesis was to identify an adequate treatment train based on natural systems (constructed wetlands) for zootechnical wastewater and to evaluate its removal efficiency, especially with regard to the concentration of organic matter through the BOD_5 concentration. This investigation was based on an in-depth survey of the technical literature and in the simulation of different scenarios which could occur with this kind of wastewater, as well as on a pilot plant fed with a similar real zoo technical wastewater.

It has been possible to appreciate that the constructed wetlands allow obtaining positive results regarding the treatment of zootechnical wastewaters in what refers to BOD_5 concentration that was the factor for which the system was designed.

In previous studies presented in Chapter II, it is highlighted that the constructed wetlands have a removal efficiency in the range of 90%. In this study, it was found that the removal efficiencies for BOD_5 were in the range 70 and 87%.

It has been said that horizontal subsurface flow wetlands are more efficient to treat organic matter than vertical ones, which is verified by finding greater efficiencies in BOD_5 removal in the horizontal systems in the pilot tests developed in Ecuador.

It has been mentioned that the retention times should not be less than 12 days, however it has been seen that with shorter times (8 days) than the values recommended in Chapter II, high removal efficiencies for BOD_5 can also be found.

7.1.2 Willingness to pay discussion

The two analyzed studies developed in Latin America for WTP and reported in Table 95 show that wastewater treatment projects have a WTP from the population of 60.8% and 63% each one. These studies have evaluated domestic wastewater treatment projects. It was found in this study that for the proposed zootechnical wastewater treatment train there is also WTP but in a less percentage (55%) in comparison with the mentioned studies.

As was reported in the study that was used as the basis for this analysis, WTP is higher for people with a higher level of education, people who are full-time workers, people of working age and people who live in an area close to the area that the project would directly impact.

It is not verified what is found in literature that the higher the annual income is, the higher the WTP is.

7.1.3 Cost-benefit discussion

As mentioned in Chapter VI, domestic wastewater treatment and reuse projects are feasible from the financial point of view. It was found in this study that the proposed treatment train for zootechnical wastewaters is also feasible from a financial point of view.

7.2 Conclusions

The zootechnical area used for this study belongs to the so called “production systems of small and medium producers” according to the classification presented in Chapter III and Chapter IV, however, the wastewaters produced in it, are characterized by high concentrations of pollutants and are being directly discharged to a water body causing in this a very serious environmental problem such as water deterioration and pollution.

Results of this thesis indicate that a treatment train including constructed wetlands could be considered an efficient solution for zootechnical wastewaters treatment. The effluent from the constructed wetlands (pilot station) has concentrations of the investigated parameter (BOD_5) lower than the permissible discharge limit to a water body established in the Ecuadorian regulations (100mg/l) that make the systems feasible to use.

The adoption of constructed wetlands generates environmental benefits since they reduce pollution caused by the direct release of untreated zootechnical wastewaters into water bodies or in certain cases their spread on the soil.

Some parameters such as surface organic loads and retention times as well as specific characteristics of each site where the system would be implemented must be known to develop the specific design. The criteria followed to design the treatment train in this thesis are those adopted in the design of treatment of civil and industrial wastewaters. In any case tests on pilot plants are useful to verify specific parameters and to simulate the behavior of the real wastewater before developing the design for the full scale plant.

The preliminary experimental campaign carried out allowed establishing efficiencies between 70 and 87% in the removal of BOD_5 that was the design parameter of the system. Removals of other pollutants (TSS, COD, TN, TP, microorganisms) should be evaluated in future studies even though theoretical TSS final concentrations have been calculated.

The cost-benefit analysis makes it feasible for the construction of this project only considering social and financial benefits. This study could be amplified, making analysis of environmental, agricultural and other social benefits in greater depth. The feasibility of this project from a financial point of view is strictly correlated to the fact that labor and materials in Ecuador have a low cost and because the environmental fines established in the new Ecuadorian regulations are strong and severe. For these reasons, the project seems to be feasible even if WTP is not considered.

APPENDIX

Appendix N°1: Stall wastewaters analysis

First Production Hour Analysis

Sample	Flow rate m^3/h	BOD_5 mg/l	COD mg/l	SST mg/l	TN mg/l	TP mg/l
1	2.1	761	1720	796	120	33
2	3.35	390	798	405	93	28
3	2.77	235	550	254	60	31
4	3.15	346	792	320	62	37
5	2.65	1105	2600	1300	18	66
6	3.66	2183	5210	2550	152	82
7	3.69	510	1022	572	203	71
8	4	633	1401	700	95	38
9	4.5	260	540	255	85	22
10	3.02	643	1300	550	108	31
11	3.5	1052	2092	1820	118	40
12	2.4	873	1745	647	110	51
13	3	1452	2083	1100	300	51
14	2.75	340	709	510	150	39
15	3.13	315	747	320	86	28
16	3.6	1105	2206	1070	181	31
17	3.75	375	754	325	82	81
18	5	1838	3872	1900	306	83
19	4.07	1207	2385	1980	179	72
20	2.8	2133	4360	2900	192	61

Second Production Hour Analysis

Sample	Flow rate m^3/h	BOD_5 mg/l	COD mg/l	SST mg/l	TN mg/l	TP mg/l
1	1.72	589	1188	686	112	24
2	2.41	372	755	395	85	19
3	1.84	196	500	228	46	25
4	2.25	304	768	320	30	31
5	2.53	1098	2560	1060	14	41
6	2.75	2143	5196	2090	122	63
7	2.65	486	1017	563	181	52
8	3.92	612	1392	500	82	33
9	4.5	264	517	230	68	17
10	1.95	615	1228	570	82	25
11	2.04	1026	2084	1230	108	32
12	2.06	851	1722	595	95	40
13	2.83	1400	2075	1040	275	42
14	2.22	314	673	310	118	31
15	2.2	304	716	380	63	19
16	2.52	1020	2092	890	156	22
17	2.95	370	740	334	61	61
18	3.64	1803	3400	1160	279	69
19	3.85	1169	2369	1180	121	51
20	1.45	2115	4160	2100	163	52

Daily Wastewaters Characteristics

They were obtained with the first and second hour characteristics by:

$$Qf = Q1 + Q2 \qquad \text{Cf} = \frac{(C1 * Q1 + C2 * Q2)}{Q1 + Q2}$$

Where

Q_1: flow rate in the first hour

C_1: pollutant concentration in the first hour

Q_2: flow rate in the second hour

C_2: pollutant concentration in the second hour

Sample	Flow rate m^3/d	BOD_5 mg/l	COD mg/l	SST mg/l	TN mg/l	TP mg/l
1	3.82	684	1480	746	116	29
2	5.76	382	780	401	90	24
3	4.61	219	530	244	54	29
4	5.4	329	782	320	49	35
5	5.18	1102	2580	1183	16	54
6	6.41	2166	5204	2353	139	74
7	6.34	500	1020	568	194	63
8	7.92	623	1397	601	89	36
9	9	262	529	243	77	20
10	4.97	632	1272	558	98	29
11	5.54	1042	2089	1603	114	37
12	4.46	863	1734	623	103	46
13	5.83	1427	2079	1071	288	47
14	4.97	328	693	421	136	35
15	5.33	310	734	345	77	24
16	6.12	1070	2159	996	171	27
17	6.7	373	748	329	73	72
18	8.64	1823	3673	1588	295	77
19	7.92	1189	2377	1591	151	62
20	4.25	2127	4292	2627	182	58

Appendix N°2: Milking area wastewaters analysis

First Production Hour Analysis

Sample	Flow rate m^3/h	BOD_5 mg/l	COD mg/l	SST mg/l	TN mg/l	TP mg/l
1	2.6	1210	3292	1620	91	35
2	2.8	2640	5550	1080	103	58
3	3.5	1000	3100	1194	80	57
4	3.5	1250	4000	710	192	22
5	3	1562	4176	870	224	16
6	3.2	2736	5600	1560	226	23
7	2.8	3888	7850	1430	211	18
8	3	4964	8956	1520	198	18
9	2.9	2586	3080	950	95	41
10	4	4120	7841	1016	82	45
11	3.5	1148	3330	983	50	43,8
12	3.5	3550	6948	1258	87	35
13	3.3	1200	3100	1830	220	38
14	3.4	2410	5160	1286	100	54
15	3	1420	3848	1932	215	57
16	4	1200	3216	984	205	49
17	3.5	2146	5226	1140	78	23
18	3.1	2190	5150	1190	91	29
19	3.2	4920	9912	1850	218	60
20	3.5	1350	3000	1937	228	61

Second Production Hour Analysis

Sample	Flow rate m^3/h	BOD_5 mg/l	COD mg/	TSS mg/l	TN mg/l	TP mg/l
1	2.8	1102	3100	1280	85	35
2	2.7	1926	5610	1500	103	60
3	3.1	1000	3000	1250	84	61
4	3	1350	4250	1310	220	29
5	2.5	1710	4270	1590	230	21
6	3.5	2520	5800	912	224	21
7	2.2	4060	8174	1610	217	23
8	3	4790	9010	1450	208	18
9	2.6	2910	3170	1010	97	52
10	3.5	4180	8024	1304	88	46
11	3.4	1222	3110	1005	50	43
12	3	4010	7300	1502	91	43
13	3.3	1050	3580	1600	221	38
14	2.8	2430	5550	1290	112	58
15	3	1200	4100	1580	222	59
16	3	1400	3302	1040	225	61
17	2.7	2400	5214	1360	90	29
18	2.4	2378	5180	1470	100	37
19	3.2	4680	9712	1390	218	61
20	3.2	1450	3108	1932	233	63

Daily Wastewaters Characteristics

They were obtained with the first and second hour characteristics by:

$$Qf = Q1 + Q2 \qquad Cf = \frac{(C1 * Q1 + C2 * Q2)}{Q1 + Q2}$$

Where

Q_1: flow rate in the first hour

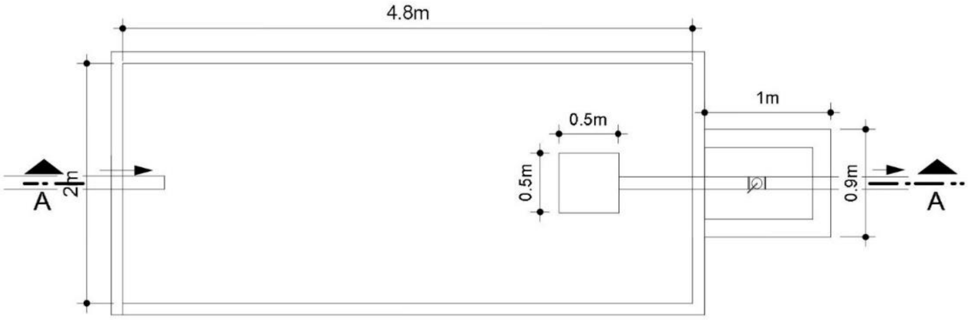
C_1: pollutant concentration in the first hour

Q_2: flow rate in the second hour

C_2: pollutant concentration in the second hour

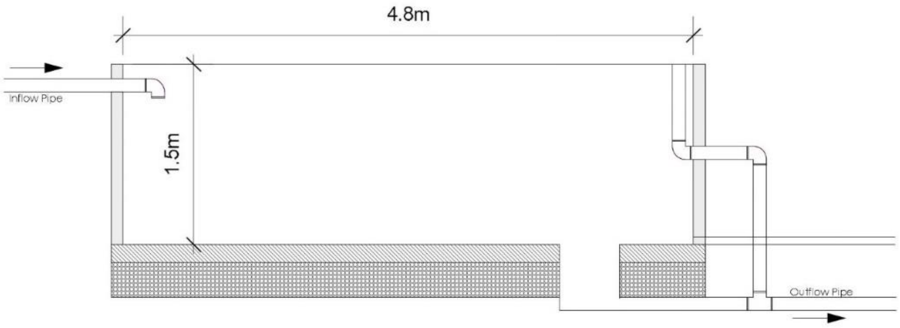
Sample	Flow rate m^3/d	BOD_5 mg/l	COD mg/l	SST mg/l	TN mg/l	TP mg/l
1	5.4	1154	3192	1444	88	35
2	5.5	2289	5579	1286	103	59
3	6.6	1000	3053	1220	82	59
4	6.5	1296	4115	987	205	25
5	5.5	1629	4219	1197	227	18
6	6.7	2623	5704	1221	225	22
7	5	3964	7993	1509	214	20
8	6	4877	8983	1485	203	18
9	5.5	2739	3123	978	96	46
10	7.5	4148	7926	1150	85	45
11	6.9	1184	3222	994	50	43
12	6.5	3762	7110	1371	89	39
13	6.6	1125	3340	1715	221	38
14	6.2	2419	5336	1288	105	56
15	6	1310	3974	1756	219	58
16	7	1286	3253	1008	214	54
17	6.2	2257	5220	1236	83	26
18	5.5	2272	5163	1312	95	32
19	6.4	4800	9812	1620	218	61
20	6.7	1398	3052	1934	230	62

Appendix N°3: Treatment train planes



EQUALIZATION TANK

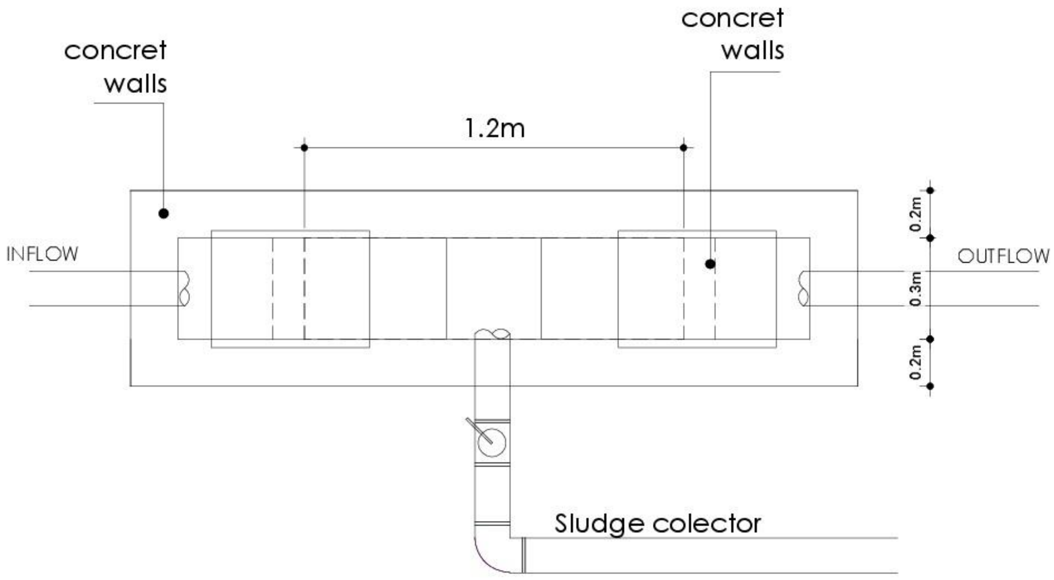
SCALE 1:50



A - A

SCALE 1:50

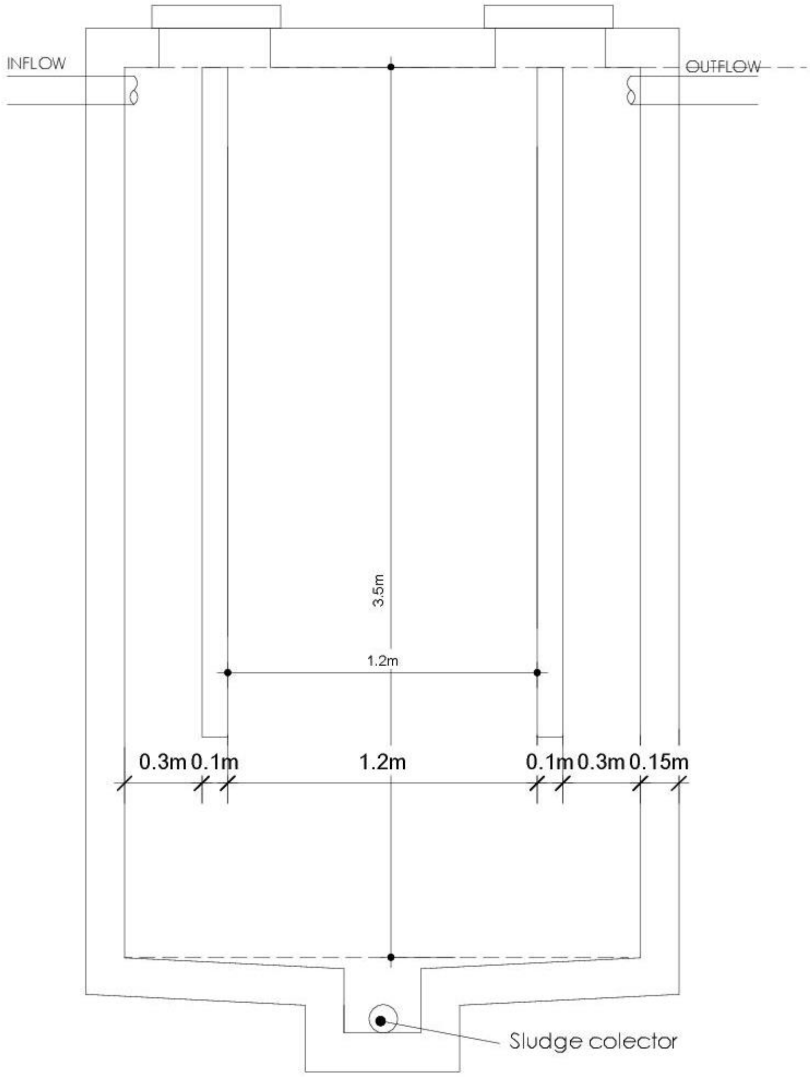
University of Ferrara Treatment Train for zootechnical wastewater	**Content:** Equalization tank	
Name: Estefanía Avilés Sacoto	**Scale:** unscaled	**Date:** November 2018



SEDIMENTATION TANK

SCALE 1:20

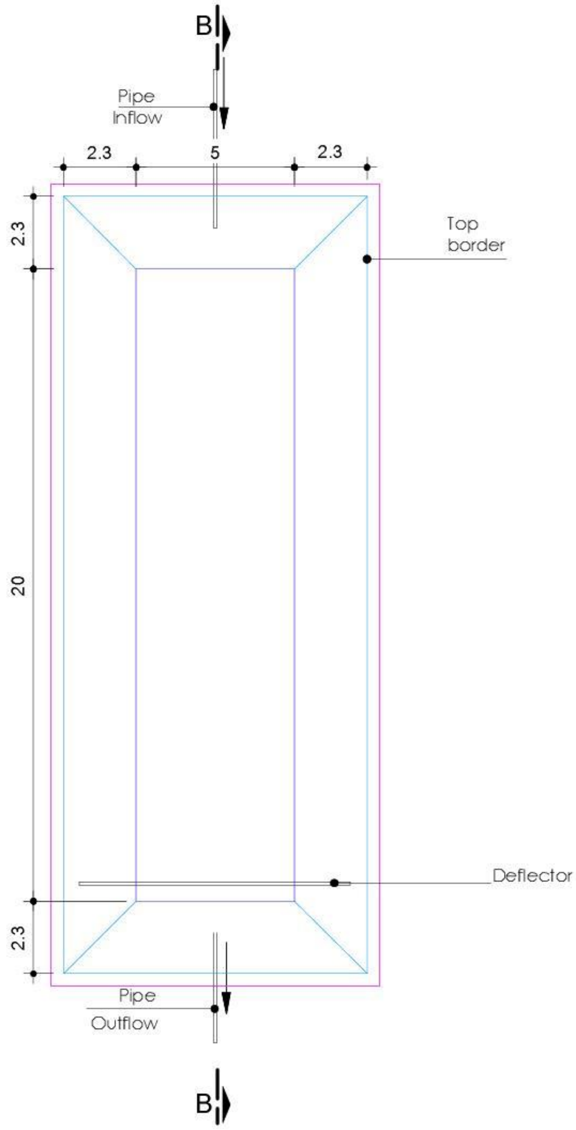
University of Ferrara Treatment Train for zootechnical wastewater	**Content:** Sedimentation tank	
Name: Estefanía Avilés	**Scale:** 1: 20	**Date:** November 2018



A - A

SCALE 1:25

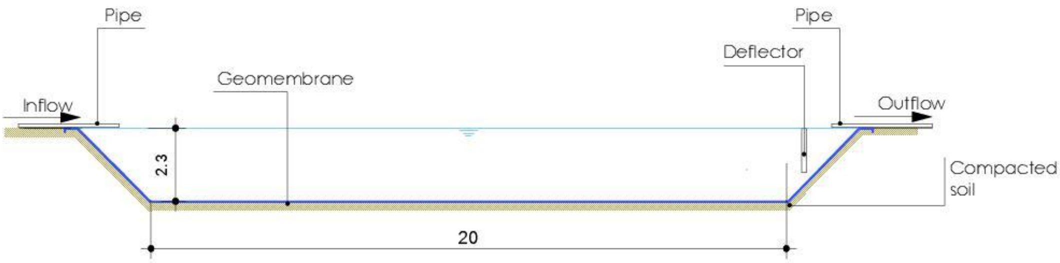
University of Ferrara Treatment Train for zootechnical wastewater	**Content:** Sedimentation tank	
Name: Estefanía Avilés Sacoto	**Scale:** 1: 25	**Date:** November 2018



FACULTATIVE LAGOON

SCALE 1:200

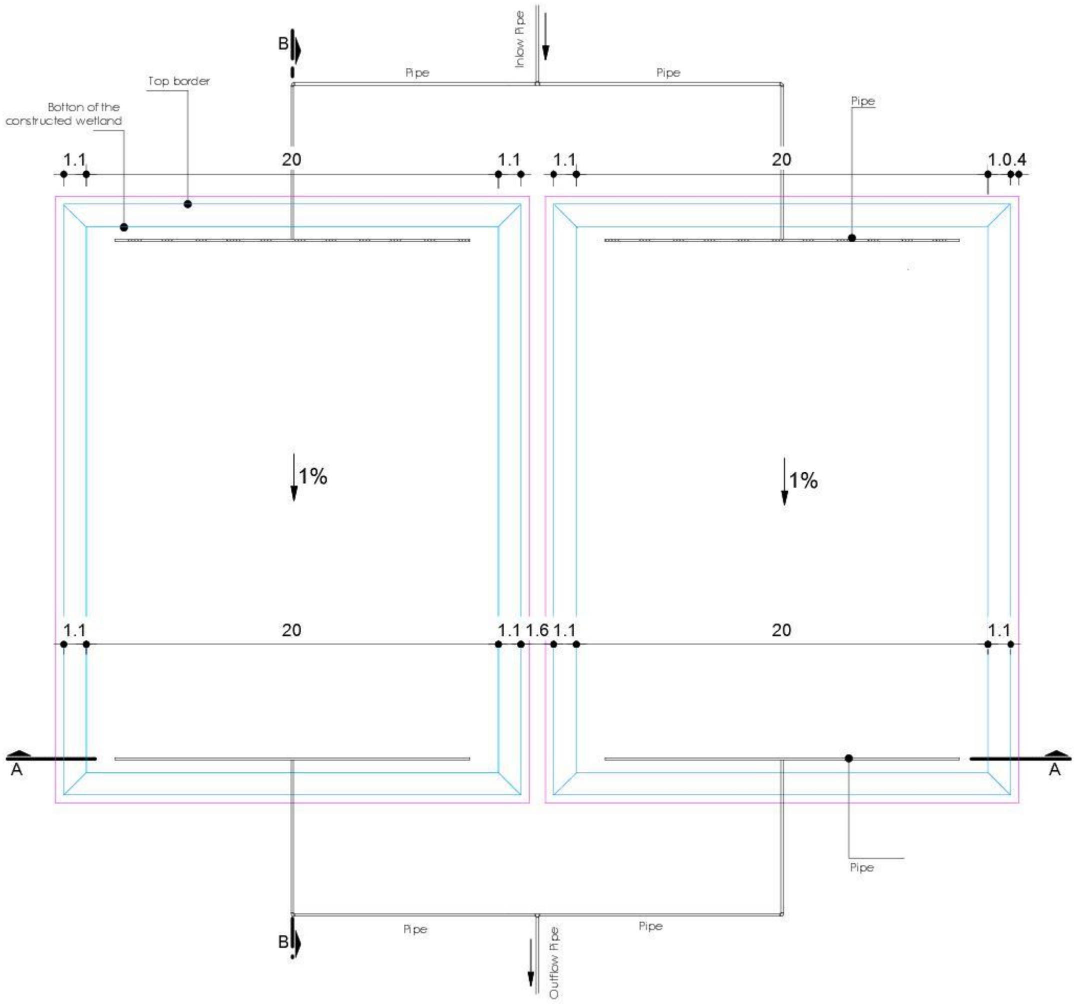
University of Ferrara Treatment Train for zootechnical wastewater	**Content:** Facultative Lagoon	
Name: Estefanía Avilés Sacoto	**Scale:** 1:200	**Date:** November 2018



A - A

SCALE 1:200

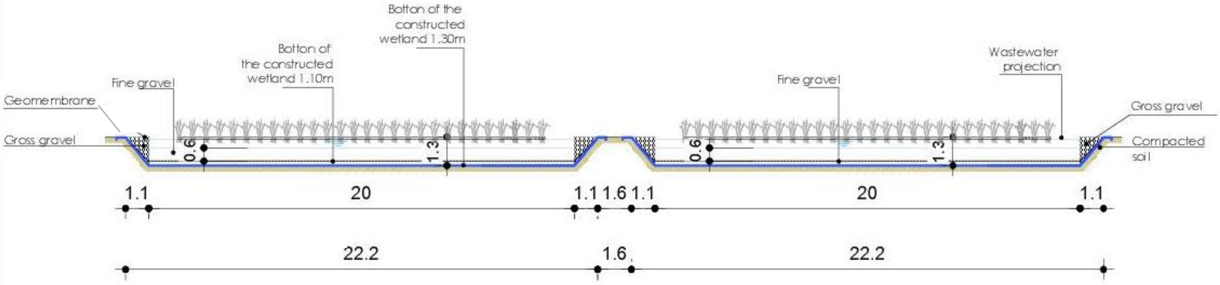
University of Ferrara Treatment Train for zootechnical wastewater		Content: Facultative Lagoon	
Name:	Estefanía Avilés Sacoto	**Scale:** 1:200	**Date:** November 2018



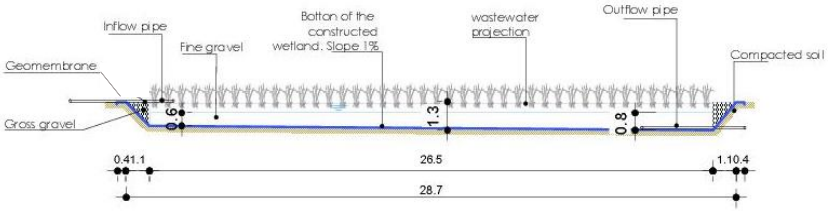
HORIZONTAL SUBSURFACE FLOW
CONSTRUCTED WETLAND

SCALE 1:300

University of Ferrara Treatment Train for zootechnical wastewater	**Content:** Horizontal subsurface flow constructed wetland	
Name: Estefanía Avilés Sacoto	**Scale:** 1 : 300	**Date:** November 2018

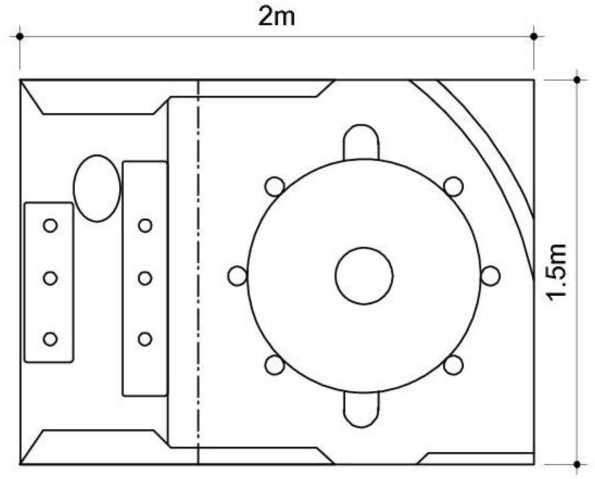


A - A
SCALE 1:300



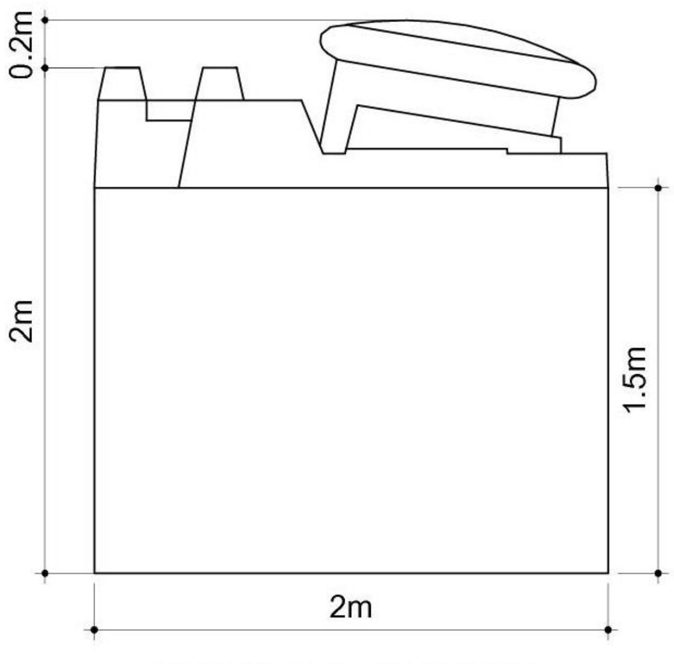
B - B
SCALE 1:300

University of Ferrara Treatment Train for zootechnical wastewater	**Content:** Horizontal subsurface flow constructed wetland
Name: Estefanía Avilés Sacoto	**Scale:** 1:300 / **Date:** November 2018



DOSING TANK

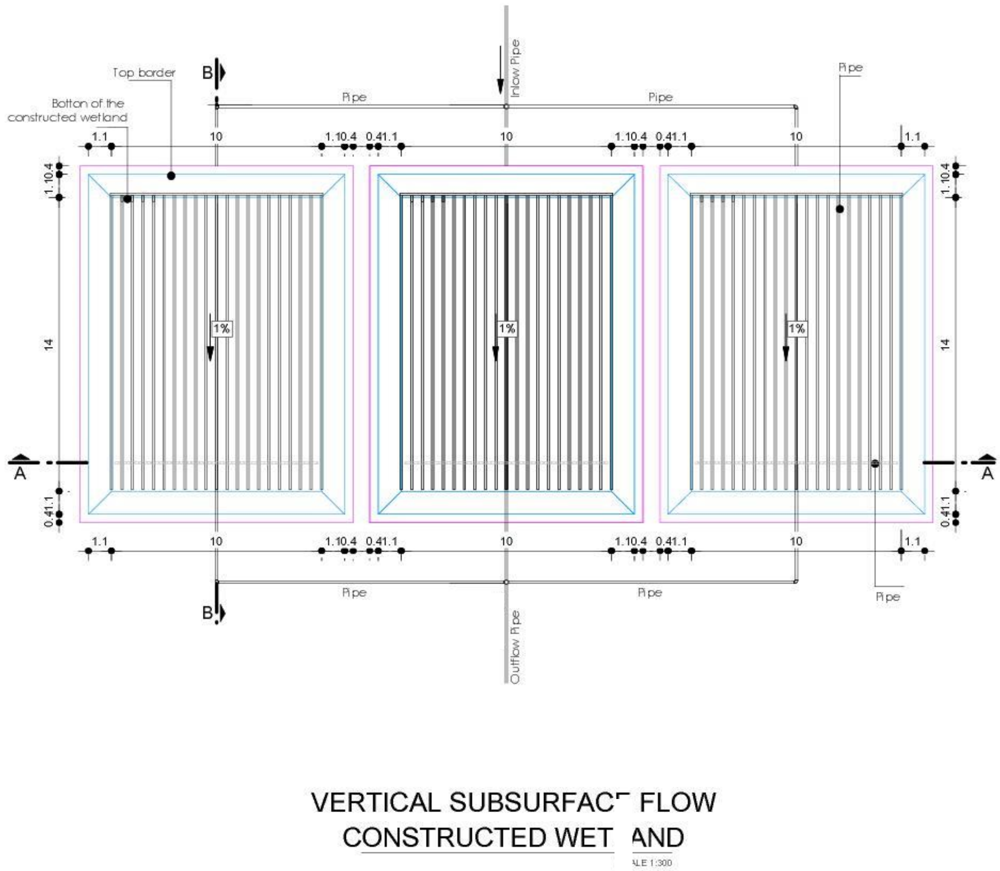
SCALE 1:20



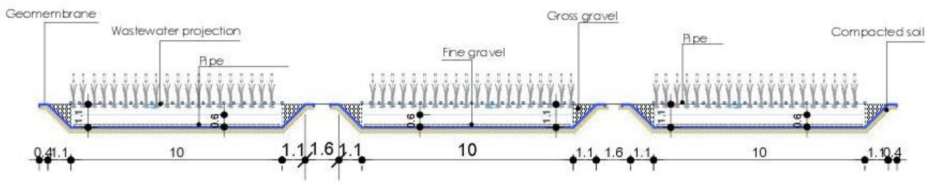
FRONT ELEVATION

SCALE 1:25

University of Ferrara Treatment Train for zootechnical wastewater	**Content:** Dosing tank	
Name: Estefanía Avilés Sacoto	**Scale:** 1:25	**Date:** November 2018

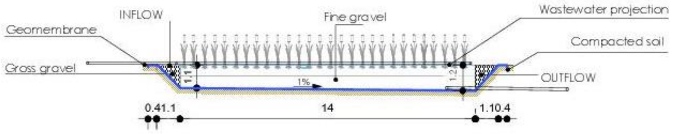


University of Ferrara Treatment Train for zootechnical wastewater	Content: Vertical subsurface flow constructed wetland	
Name: Estefanía Avilés Sacoto	**Scale:** 1: 300	**Date:** November 2018



A - A

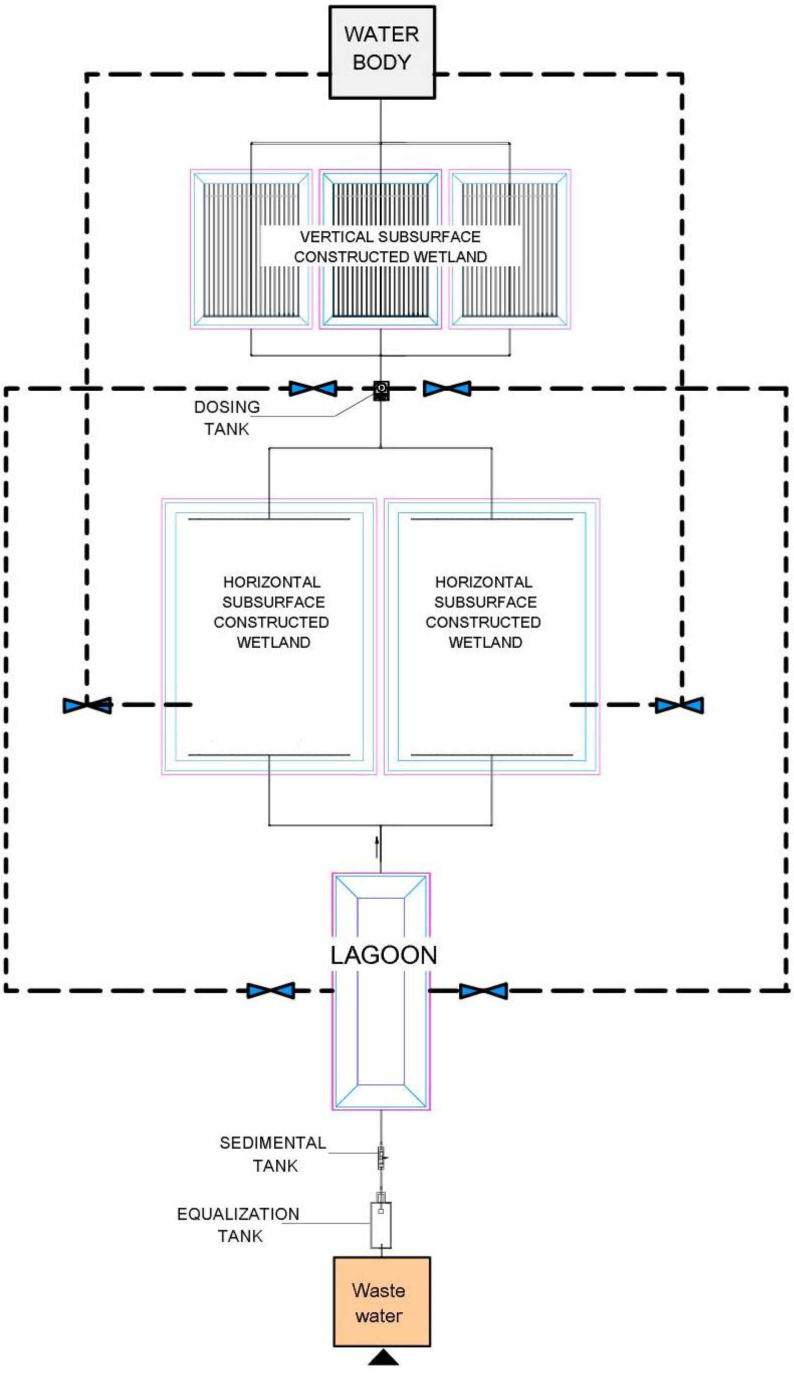
SCALE 1:200



B - B

SCALE 1:300

University of Ferrara Treatment Train for zootechnical wastewater		**Content:** Vertical subsurface flow constructed wetland	
Name:	Estefanía Avilés Sacoto	**Scale:** 1:300	**Date:** November 2018



University of Ferrara Treatment Train for zootechnical wastewater	**Content:** Treatment train scheme	
Name: Estefanía Avilés Sacoto	**Scale:** unscaled	**Date:** November 2018

Appendix N°4: Questionnaire

Good Morning

This survey is part of a scientific research project of the Politécnica Salesiana University with the objective of measuring the importance that the citizens of Paute give to the protection of water resources and the environment.

We would be very pleased if you could agree to participate in this study, the questionnaire lasts approximately 10 minutes.

Before proceeding, we assure you that all the information delivered will be exclusively used for research purposes guaranteeing absolute anonymity.

Section A

1. How much importance is the protection of the environment?

High Medium Low Don't know

2. How is the environmental quality of Paute?

Excellent Very good Good Regular Bad Very bad

3. In your opinion, should the community take care of the environment?

Yes No Don't know

4. Do you know what and how is a wastewater treatment plant?

Yes No

Explanation of the proposed train treatment (equalization, sedimentation, lagooning, constructed wetlands; benefits, impacts, construction, costs).

5. Do you agree with the construction of this system to treat zootechnical wastewaters? It hypothetically can be placed in the zone of Chicán where the Salesiano Education Center has a production area.

Yes (go to section B) No Don't know

6. What are the reasons that best represent your decision of not or not knowing whether to build this system?

Bad odors

Health risks

Indifference to the problem

A plant cannot be near a community

My criteria depends on the type and cost of the system

7. Suppose that natural techniques are adopted for the zootechnical wastewaters treatment and that they give the possibility to discharge the wastewaters to the river under regulations,

improving the quality of the environment and reducing risks to people, animals and environmental in general. Would you agree with this project considering that this means a revaluation of the environment and the natural landscape of Paute?
Yes (Go to section B) No Don't know

8. For what reasons do you not agree with the construction of this system (Select one and go to section C)

Negative impact with the odors in the area

Health risks

Indifference to the problem

Other specify

Section B

You have declared to be in agreement with the realization of the hypothetical project to treat zootechnical wastewaters, but the entire costs cannot be faced by the local administration.

9. Hypnotizing that there are no funds to carry out this project, that the only alternative is the voluntary private donation just one time (*una tantum*), and that the amount of money represents your family, Would you be willing to pay a monetary contribution exclusively to carry out and maintain the proposed treatment train system? Consider that it is a hypothetical situation and that no one will come to ask for a contribution in the event that your response is positive.

Yes No (Go to question 11) Do not know (Go to question 11)

10. Among the following quantities expressed in dollars, which is the maximum figure that on behalf of your family would be willing to donate for the wastewater treatment train system.

1	15	35	60	100	300
2	20	40	70	150	500
5	25	45	80	200	700
10	30	50	90	250	1000
Other (specify)					

11. What is the reason why you do not agree with the eventuality of voluntarily donating a amount of money for the construction of this wastewater treatment train system?

The realization of this project does not concern me to the point of justifying a payment from me

The realization of this project is not as important /priority as other things

It is considered better to place taxes on citizens

I do not trust that the money is effectively and efficiently used for the realization of the project

I do not think that this project should be done now

I would like to donate something but at this moment, I cannot do it

I do not have enough information about the project and the money management program

Other specify

Section C

12. How old are you?

≤30

From 31 to 40

From 41 to 50

From 51 to 60

From 61 to 70

>70

13. Gender

Male Female

14. What is your study level?

None Primary school Secondary school University

15. What is your type of job?

Full-time worker

Mid-time worker

Retired

Unoccupied

Student

Housewife

17. In which of the following classes of the average annual income is your family

≤12000

Between 12001 and 20000

Between 20001 and 30000

Between 30001 and 40000

Between 40001 and 50000

>50000

Thank you for your kind cooperation

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31
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A treatment train based on constructed
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A treatment train based on constructed
Tutore: Prof. (Cognome e Nome)
Verlicchi Paola
Settore Scientifico Disciplinare (S.S.D.) Indicare il settore della tesi. Ad esempio, BIO/01
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constructed wetland, zootechnical,
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(data)

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Visto: Il Tutore
Si approva
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