Retrofitting of the Existing Wastewater Treatment Plant for Nutrients Removal in Cusco – Peru

A Capstone Project

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By

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This thesis was prepared for the School of Civil Engineering at the University of Sydney, Australia, and describes simulated models to retrofit Cusco's Wastewater Treatment Plant (Trickling Filters for secondary treatment) into Biological Nutrient Removal Plant. The opinions, conclusions and recommendations presented herein are those of the author and do not necessarily reflect those of the University of Sydney or any of the sponsoring parties to this project.

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ABSTRACT

This project presents how the wastewater is treated in Cusco – Peru, utilising practically new facilities (structures from 2014) that in the near future can surpass the discharge regulations. Moreover, treating only some parameters of wastewater effluents and leaving aside the treatment of the nutrients that contaminate the nearby rivers can produce algae growth and bad odours. Thus, the current discharge regulations do not contemplate the treatment of nutrients, or these have contradictions that generate gaps in the maximum permissible limits of the effluent parameters. In the present project, some processes are investigated to perform the treatment of nutrients biologically and to find a method that can use the existing trickling filters and would not incur higher operating costs.

A novel process was found (AnoxAn), which uses the existing structures to treat nitrogen and phosphorus biologically; the retrofitting needs to be done in the primary settlers, adapting them into an internal mixture of anaerobic, anoxic and aerobic reactors. It is required to vary the volume of these facilities to find the best solution for the biological nutrient removal; where ammonia can be oxidised into nitrites, nitrates and nitrogen gas. Moreover, Phosphorus Accumulating Organisms can be promoted to release phosphates in the anaerobic zones and phosphates uptake in the aerobic zones. In addition, the old secondary clarifier can be used in the process to receive the effluent of the primary trickling filters and kick it back to the secondary trickling filters. Hence, the whole process can achieve biological nutrient removal within international discharge regulations. Additionally, some sensitivity analysis of the current process and the new suggested process can be provided to the operator of the wastewater treatment plant; with these analyses, an early initiation of the third stage – expansion of the mentioned facilities – can be proposed to avoid future environmental issues and surpassed the discharge regulations.

CONTENTS

WORKING TERMINOLOGY

GLOSSARY OF TERMS (WATER_ENVIRONMENT_FEDERATION, 2017, TCHOBANOGLOUS ET AL., 2014, LINDEBURG, 2014)

Term	Definition
Trickling filter (TF)	It is an aerobic tank that contains rock or plastic media where sewage is watered for the biological treat`ment process. This process is also known as attached-growth or fixed-film process.
Eutrophication	Over-fertilisation of receiving waters
Anoxic process (AX)	This process occurs when there is no oxygen available, so microorganisms use another source such as nitrate and nitrate to obtain energy - metabolic reactions (e.g. denitrification).
Biochemical Oxygen Demand (BOD_5)	The BOD_5 is the amount of oxygen measured for the biochemical oxidation of carbonaceous source in wastewater. It is a standard procedure measure in specified conditions such as temperature and time (five days).
Chemical Oxygen Demand (COD)	The COD is the amount of oxygen measured for the chemical oxidation of organic material in the wastewater. It is a two-hour standard test that uses inorganic dichromate or permanganate salts as oxidants.
Total Suspended Solids (TSS)	The TSS is the portion of the total solids that are retained on a sieve (specified pore size), then this portion is dried at 105°C to obtain the dried weight.
Total organic carbon (TOC)	In a wastewater sample is the quantity of carbon attached to organic compounds. The amount of TOC shows a way to evaluate the degree of organic pollution.
Total oxygen demand (TOD)	It is the measured oxidisable material in the wastewater. Using high-temperature conditions to exhaust oxygen.
Autotrophic bacteria	The process of cell synthesis is done using inorganic carbon (CO_2). (e.g. Anammox bacteria - Anaerobic ammonium oxidation).
Heterotrophic bacteria	The process of cell synthesis is done using organic carbon.
Nitratation / Nitritation	Biological oxidation process (BOP) where nitrite is oxidised to nitrate/ammonia is oxidised to nitrite.

Term	Definition
Nitrification	BOP (second-step) where nitrogen (mostly in the form of ammonia) is oxidised to nitrite (Ammonia Oxidising Bacteria – AOB) and then to nitrate (Nitrate Oxidising Bacteria - NOB).
Denitritation/ Denitrification	A process where nitrite/nitrate is decreased to nitrogen gas and other nitrogen's gaseous end products.
Phosphorus accumulating organisms (PAOs)	Enhanced biological phosphorus removal process where heterotrophic bacteria storage high intracellular phosphorus.
Simulation model	Computational model (mathematical). It is a set of equations used to calculate the kinetics process and variations of sewage parameters. Analysing the performance of the model.

CHAPTER 1

1. BACKGROUND

Due to the eight Millennium Development Goals and subsequent Sustainable Development Goals proposed by the United Nations, Peru is making a great effort to accomplish them through investment in scholarships, research development, politics guidelines and public-private partnerships projects (INEI, Updated Set 2017). This research is focused on the sixth goal: Clean Water and Sanitation.

Wastewater treatment plants (WWTPs) in Peru have several years of operation. Therefore, many of these plants are more than 30 years old. This case study of the WWTP in Cusco-Peru, had quite a few stages of design, construction and operation; the first stage was carried out in 1985 when the wastewater treatment plant started its operation. This stage lasted almost 20 years and problems were found; firstly, a deficient process that did not fulfil the discharge regulations (Appendix I); secondly, the growing population (population demographics, more than two times from 1985 to 2006 (INEI)) produced an increment in the flow rate of wastewater; thirdly, Peru - as part of the UN – had been committed to reach the goal 7C of the eight Millennium Development Goals. Hence, an upgrade project (second stage) was developed and approved in 2006, which had to be restructured in 2012 by Nippon Koei LAC & COSAPI S.A and financed by The Japan International Cooperation Agency – JICA – and the Peruvian Government (Takahashi and Gibu, Updated Jun 2016). Finally, the construction phase was completed in 2014 and began its operation the same year (El_Diario_del_Cusco, Published on Jun 30, 2014).

After few years of operation of the second stage, some environmental issues occurred in the system such as **eutrophication** in the river due to nutrients in the effluent (Masco-Arriola, 2017), surpassing the **odour threshold**; additionally, lack of knowledge related to the circular economy leads to **inadequate management of biogas and biosolids**.

The problem of nutrients removal in the WWTP, indicated in the above paragraph, will be addressed in the subsequent investigation. Therefore, the next topic reports the issues from the design stage culminating in the operation of the WWTP.

1.1. Problem Description

The design of the WWTP of Cusco was approved in 2006 (El_Diario_del_Cusco, Published on Jun 30, 2014), although, new discharge regulations for the nutrients in the effluents were adopted in 2008 and the threshold of some parameters (BOD_5, COD and TSS) also changed in

2010 (both shown in Appendix I). Same parameters, in different years, had different values; showing inconsistency among them. For that reason, intermediate values were taken into account for the design of the plant. The facts mentioned above are shown in Table 1.1.

TABLE 1.1
SUMMARY DISCHARGE PARAMETERS

Parameter	Units	Standard Water Quality Type 1A3 (2008)	Discharge regulation (2010)	Design Values (2012)
Average flow / Peak flow	L/s	--	--	446/802
BOD_5	mg/L	10	100	30
COD	mg/L	30	200	90
TSS	mg/L	-	150	30
Faecal coliforms	MPN*/100 mL	20000	10000	1000
Oil and Grease	mg/L	1	20	30
Ammonia N	mg/L	3.7	--	30**
Phosphorus (total Phosphate)	mg/L	0.15	--	--

* Most Probable Number (MPN) ** Total Nitrogen

Type 1A3: groundwater that could be treated with an advanced process. Discharge Regulations tables in Appendix I

The WWTP was designed with the following stages of treatment (shown in Figure 1.1):

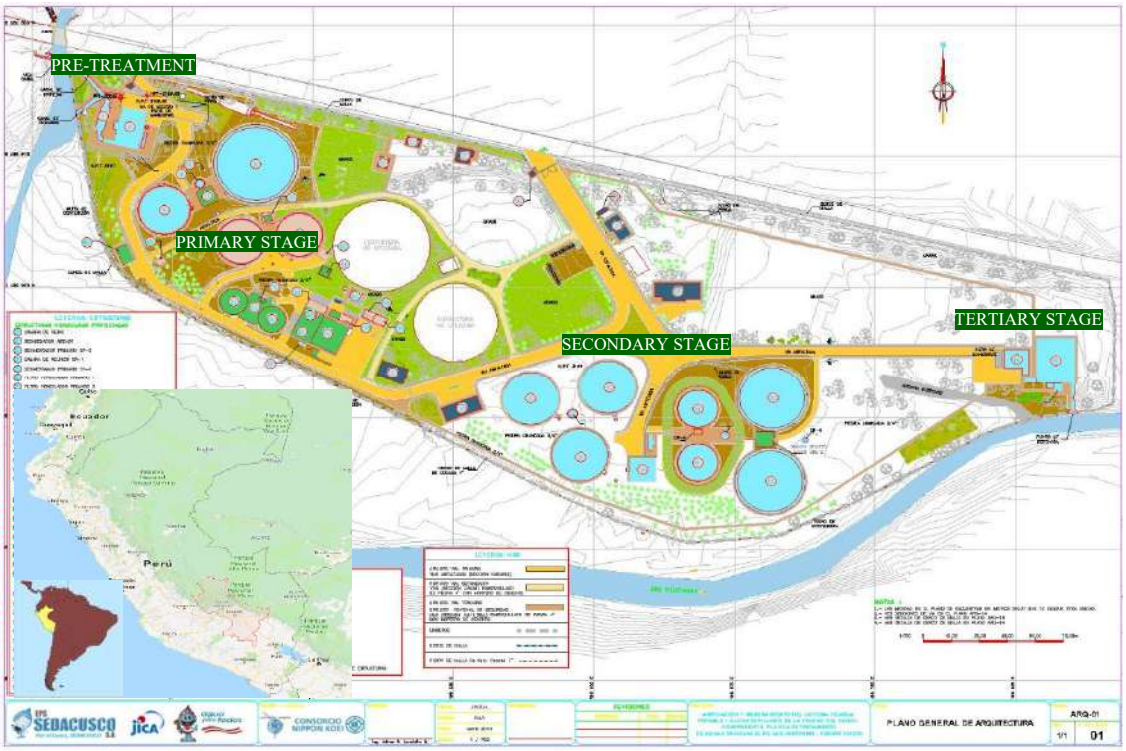


FIGURE 1.1 LAYOUT OF THE WWTP. (ADAPTED FROM GOOGLE EARTH AND WWTP PROJECT)

- Pre-treatment Stage: It consists of the preliminary process that includes coarse and fine screens to retain coarse materials, then an aerated grit chamber to eliminate oil and grease and grit particles.

- Primary Treatment Stage: The suspended solids of the flow are decanted in both Primary Settlers (PS). The liquid enters the PS vertically, and then through these, the liquid is separated from the suspended solids.

- Secondary Treatment Stage: Also known as biological treatment (Tchobanoglous et al., 2014). This stage is divided into two phases, one for liquids where the wastewater is treated aerobically by five trickling filters (three are primary and two are secondary), and then passing through two secondary clarifiers. The other phase is for solids, where solids go through two gravity sludge thickeners (dewatering process), the dewatered enter into an anaerobic bioreactor where is digested and produced biogas that is accumulated into a gasometer; culminating with a centrifuge process to obtain biosolids.

- Tertiary treatment Stage: It is done by chlorinating the treated water for final disinfection and subsequent discharge to the Huatanay River. All the stages are shown in Figure 1.2.

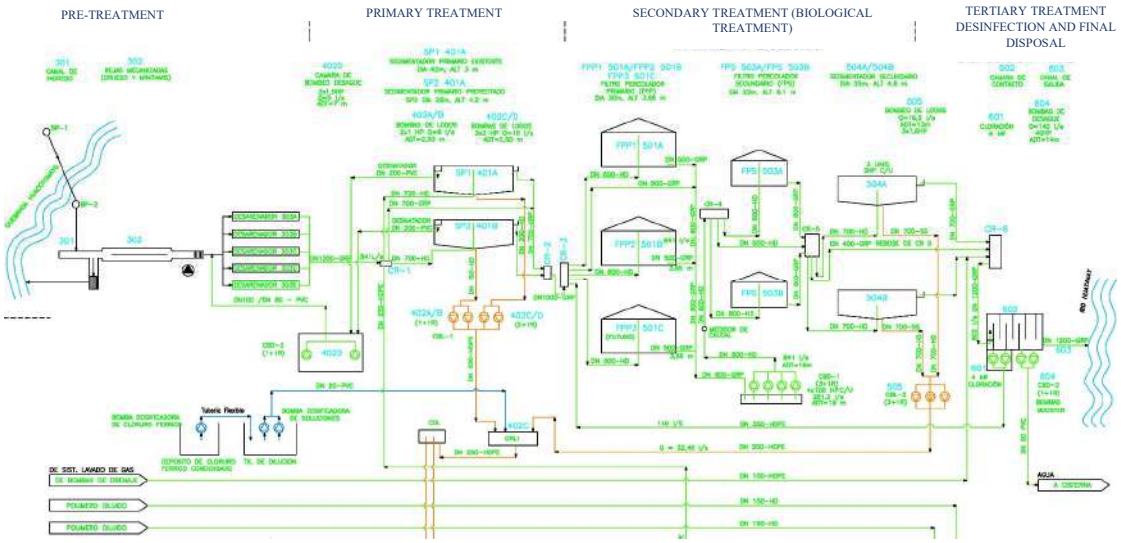


FIGURE 1.2 FLOW DIAGRAM OF THE WWTP - CUSCO

The operation of the WWTP is being carried out with the parameters approved in 2010. In that discharge regulation's document, the nutrients removal was not taken into account, that is why all measurements that are being developed by the WWTP operator do not take into consideration the phosphorus and nitrogen levels in the effluent which leads to the generation of eutrophication in the Huatanay river (Masco-Arriola, 2017). Regarding the **discharge**

regulations (Table 1.1) an international threshold for the effluent nutrients will be considered for this research – **TN = 15 mg/L, TP = 2 mg/L** – **(European_Union, 21 May 1991).**

As explained above, this WWTP works with Trickling Filters (liquid phase) and Anaerobic Reactors (solid phase) to treat the wastewater. Entailing that there is no process for nutrients removal (nitrogen and phosphorus). Hence, the main problem to be discussed, in this capstone project, is the new process configuration for the existing WWTP that would be able to remove nutrients without causing issues in other discharge regulation parameters.

1.2. Aim and Objectives

This research **aims to find an innovative process to remove the nutrients biologically** (nitrogen and phosphorus) of the wastewater that is generated from approximately 400 000 inhabitants of the city of Cusco. Hence, the following objectives need to be accomplished:

a) Create a model of the actual wastewater treatment plant and simulate its processes.

b) Check the designed life cycle and robustness of the actual WWTP.

c) Find a method to retrofit the WWTP – based on Trickling Filters – into a Biological Nutrient Removal plant and to minimise the construction investment in new reactors.

d) Create a simulation of the retrofitted WWTP in order to achieve the selected discharge regulation for TN and TP.

e) Check the robustness of the retrofitted WWTP.

CHAPTER 2

2. LITERATURE REVIEW

This chapter will introduce the basic concepts related to Wastewater Engineering emphasising the concepts of biological nutrients removal using Trickling Filters for the secondary treatment stage.

2.1. Nutrients

These are assimilated substances for the growth of microorganisms, plants and animals. Among all nutrients, the primary ones in the WWTPs are Nitrogen and Phosphorus (Tchobanoglous et al., 2014, Water_Environment_Federation, 2017). For a suitable biological aerobic process in a WWTP, the minimum ratio for BOD_5:N:P (100:5:1) is needed (Slade et al., 2011).

2.1.1. Nitrogen:

Nitrogen is a necessary element for the biological treatment of wastewater, due to its essential function in synthesising proteins. Minimum values of nitrogen must be ensured in the treatment of sewage (BOD_5:N:P 100:5:1). However, high amounts of this element in the effluents can promote algae growth in the receiving surface water. Therefore, levels within the range established by local regulations must be maintained (Tchobanoglous et al., 2014).

It is common to measure nitrogen in wastewater as ammonia (NH_3), nitrate (NO_3^-), nitrite (NO_2^-), and the total Kjeldahl nitrogen to estimate the organic nitrogen (Morgan, 1998). These elements are reported within total nitrogen, as shown in Table 2.1.

TABLE 2.1
TOTAL NITROGEN REPORT (TCHOBANOGLOUS ET AL., 2014)

Form of nitrogen	Abbrev.	Definition
Ammonia gas	NH_3	NH_3
Ammonium ion	NH_4	NH_4^+
Total ammonia nitrogen	TAN	$NH_3 + NH_4^+$
Nitrite	NO_2	NO_2^-
Nitrate	NO_3	NO_3^-
Total inorganic nitrogen	TIN	$NH_3 + NH_4^+ + NO_2^- + NO_3^-$
Total Kjeldahl nitrogen	TKN	Organic N + NH_3 + NH_4^+
Organic nitrogen	Organic N	TKN - (NH_3 + NH_4^+)
Total nitrogen	**TN**	**Organic N + NH_3 + NH_4^+ + NO_2^- + NO_3^-**

Depending on the pH of the sewage, it is possible to identify the state of ammonia. It can be found either as ammonium ion (aqueous solution) or ammonia gas (shown in Figure 2.1 Left).

Nitrogen in domestic wastewater is usually measured as TKN (organic nitrogen and ammonia). The untreated influent enters the WWTP with a typical amount of 40 mg/L for TKN (15 mg/L of organic nitrogen and 25 mg/L of ammonia). Throughout biological treatment, bacteria used approximately 20 % of the influent nitrogen to growth; when bacteria die either is consumed by other microorganisms (endogenous respiration) or this nitrogen finishes as sludge (Water_Environment_Federation, 2017).

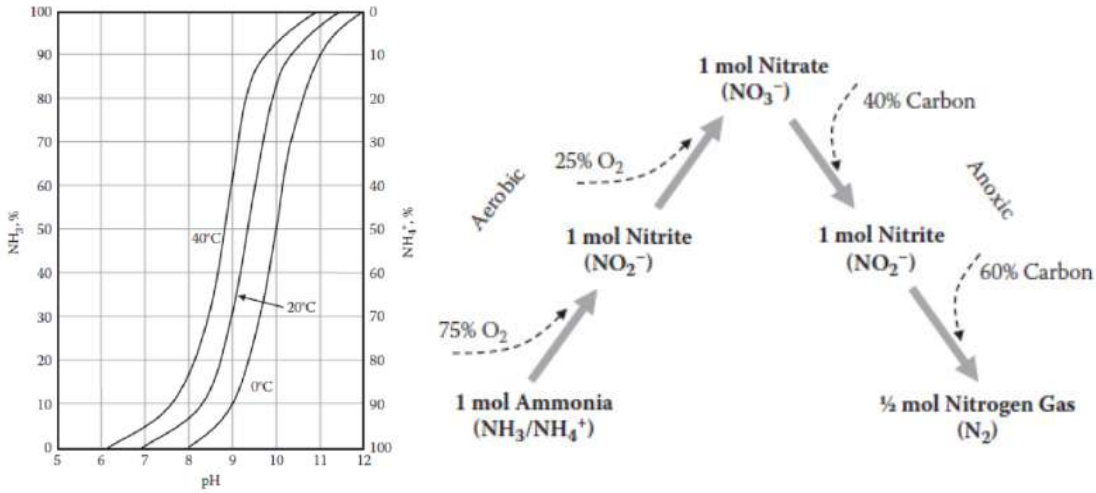


FIGURE 2.1 LEFT: DISTRIBUTION OF AMMONIA ACCORDING TO PH AND TEMPERATURE; RIGHT: SCHEMATIC OF NITRIFICATION-DENITRIFICATION PROCESS. SOURCE: (RIFFAT, 2013)

The process where ammonia is oxidised to nitrite and then to nitrate is called nitrification. Then, an anaerobic heterotrophic process (denitrification) occurs when nitrates are converted to nitrogen gas (Figure 2.1 Right). Both nitrite and nitrate are water pollutants; being toxic to fish and causing illness in infants (methemoglobinemia) (Lindeburg, 2014, Tchobanoglous et al., 2014).

2.1.2. Phosphorus:

This element is presented in wastewater due to human waste and from detergents (synthetic wastes) (Riffat, 2013). Similar to Nitrogen, low quantities of Phosphorus are necessary for the reproduction of bacteria (BOD_5:N:P 100:5:1). When the concentration of phosphorus exceeds 0.015 mg/L, the growth of plants (algae) in the surface water is promoted that leads to eutrophication (Parsons and Smith, 2008, Qiu et al., 2015).

In untreated municipal wastewater, the phosphorus concentration could be found in a range of 5-15 mg/L. In the primary settler, an approximate 10 % can be removed because that percentage of the total phosphorus is insoluble in the municipal wastewater (Lindeburg, 2014). Conservative measures of phosphorus in municipal wastewater have given the value of 3.7-

11 mg/L, according to Tchobanoglous et al.; in contrast, Parsons and Smith have shown 6-8 mg/L.

On the other hand, phosphorus is a marketable fertiliser that could be obtained from processing wastewater (the circular economy). Moreover, taking into account that in the next one hundred years there will be problems for the production of phosphorus as shown in Figure 2.2; the removal and recycling of phosphorus are of vital importance in the treatment of sewage (Qiu et al., 2015).

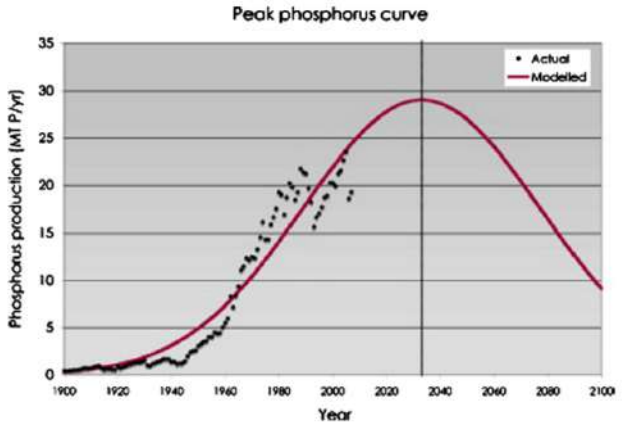


FIGURE 2.2 PEAK PHOSPHORUS CURVE INDICATING A PEAK IN PRODUCTION BY 2033. SOURCE: (QIU ET AL., 2015)

2.2. Nutrient Removal

The removal of nutrients dates back more than a century when the Danish parliament decided to drastically reduce the Nitrogen and Phosphorus levels of wastewater discharged into surface water (Morgan, 1998). In recent decades, according to regulators in Europe and the USA, the excess of nutrients continues causing low water quality, the trend is to control the levels of Nitrogen and Phosphorus more severely (Lema and Suarez, 2017).

For some ecoregions in the United States, the standard for nutrients discharge is lower than 10 mg N/L and 1 mg P/L; a similar situation is occurring in Europe where the rules are quite strict, like the Helsinki region in Finland where the values are 4.5 mg N/L and 0.3 mg P/L. The challenge for designers is to find an equilibrium between environmental issues (nutrient removal, greenhouse gas emissions and effluent parameters), economic aspects (limit of technology and cost) and social stakeholders (Lema and Suarez, 2017).

This tendency is quite similar in South America. In Peru, the Standard Water Quality and Discharge Regulations document (shown in Table 1.1) gives an idea about the permit limits of pollutants discharge in watersheds. Nevertheless, there are inconsistencies between these parameters; for that reason, the WWTP's operators take into account the last one (Discharge

Regulations of 2010) that is not severe. In the coming years, this gap will be closed. Therefore, stakeholders need to know how to deal with this nutrient removal issue.

2.2.1. Nutrient Removal by Air Stripping or Precipitation

In the case of Nitrogen, air stripping or biological processing could be used to remove ammonia. In the first method, pH is increased to about ten by adding lime in the wastewater and ammonium ions change into ammonia gas. The process continues blowing air at high rates that strips the ammonia gas out of the wastewater; if necessary, recarbonation finalised the process (Lindeburg, 2014, Water_Environment_Federation, 2017).

Another option to remove nutrients is by chemical precipitation that is the most commonly applied process for Phosphorous (Parsons and Smith, 2008). Frequently chemicals that are chosen might be aluminium sulphate, ferric chloride and lime depending on the phosphorous radical. Here are examples of literature showing different approaches; Parsons and Smith (2008) indicated that iron is preferred. Instead, Lindeburg (2014) argued that aluminium is desirable and do not generate additional precipitates such as lime. Regardless, all of them converged on downstream sludge issues such as less biogas production, dewatering, handling and the disposing of sludge. Qiu et al. (2015), suggested ferric-calcium complex precipitant as another method, understanding that ferric and calcium salt acting as single processes had "high treatment cost, low effluent pH and generated recycling of phosphorus problems" and "lead to an unacceptably high effluent pH of over 10" respectively.

The last one needs further research to understand the consequence between organic fraction and phosphorus removal; similarly, more investigation is needed to know the consequences of using the sludge in agriculture or the industry. There are many options to remove nutrients from wastewater; some of them are still in research, but one that was tested already and showed decreasing in the operational cost is the Biological Nutrient Removal (Lema and Suarez, 2017); the section 2.2.2 will be delivered this type of nutrient removal.

2.2.2. Biological Nutrient Removal

Nowadays, there is a tremendous interest in enhancing the productivity of Biological Nutrient Removal (BNR) in WWTP while lowering the operational cost (Lema and Suarez, 2017).

The **conventional process to remove Nitrogen** is to convert ammonia in nitrite and then into nitrate **(nitrification)**, followed by the conversion of nitrate to nitrogen gas **(denitrification)** which is released to the atmosphere. The advanced process tries to short-cut nitrogen removal or through the nitrite pathway by nitritation/denitritation or anammox (deammonification) (Water_Environment_Federation, 2017, Lema and Suarez, 2017). These required appropriate

control in temperature and pH due to the presence of two groups of autotrophic bacteria (ammonia-oxidising and nitrate-oxidising bacteria) (Van Hulle et al., 2007). Furthermore, Anammox process (from nitrite and ammonium to nitrogen gas) needs further operation research due to its high inhibition to noxious compounds and issues in biomass growth rate result in kick-off process (Lema and Suarez, 2017).

Table 2.2 shows the Stoichiometry and Kinetics rates of the biological nitrogen removal processes.

TABLE 2.2
STOICHIOMETRY AND MONO GROWTH KINETICS. ADAPTED FROM: (TCHOBANOGLOUS ET AL., 2014, WATER_ENVIRONMENT_FEDERATION, 2017, VAN HULLE ET AL., 2007)

Process	Stoichiometry	Kinetics rates
Nitritation (AOB)	$2\ NH_4^+ + 3\ O_2 \rightarrow 2\ NO_2^- + 4\ H^+ + 2\ H_2O$	$\mu_{AOB} = \mu_{max,AOB}\left(\frac{S_{NH}}{K_{NH}+S_{NH}}\right)\left(\frac{S_O}{K_{O,AOB}+S_O}\right) - b_{AOB}$
Nitratation (NOB)*	$2\ NO_2^- + O_2 \rightarrow 2\ NO_3^-$	$\mu_{NOB} = \mu_{max,NOB}\left(\frac{S_{NO}}{K_{NO}+S_{NO}}\right)\left(\frac{S_O}{K_{O,NOB}+S_O}\right) - b_{NOB}$
Nitrification (Total oxidation reaction) ****	$NH_4^+ + 2\ O_2 \rightarrow NO_3^- + 2\ H^+ + H_2O$	Where: $\mu_{AOB/NOB}$: specific growth rate $_{AOB/NOB}$ [d^{-1}] $\mu_{max\ AOB/NOB}$: maximum specific growth rate $_{AOB/NOB}$ [d^{-1}] b $_{AOB/NOB}$: specific endogenous decay rate $_{AOB/NOB}$ [d^{-1}] S $_{NH/NO}$: NH_4/NO_2^- concentration [mg/L] K $_{NH/NO}$: half velocity coefficient for NH_4^+/NO_2^- [mg/L] S_o: DO concentration [mg/L] $K_{o,\ AOB/NOB}$: half velocity coefficient for DO for $_{AOB/NOB}$ [mg/L]
Denitrification	NO_3^- + carbon + facultative bacteria → N_2 + CO_2 + H_2O + OH^- + new cells	Specific denitrification rate (SDNR) **[g NO_3/g MLVSS·d]** Preanoxic zones for domestic wastewater ≈ **0.04 to 0.25** Postanoxic tanks (endogenous decay) ≈ **0.01 to 0.03; or 5 to 10 times higher if supplemental substrate *** is added to the tank.**
Deammonification (Anammox bacteria)	$NH_4^+ + NO_2^- \rightarrow N_2 + 2\ H_2O$	0.06-0.07 d^{-1} ****

* Optimal process: pH ≈ 6.5 to 8, Temperature ≈ 35 to 45 °C, respectively.

** Design main issues: BOD, alkalinity (pH ≈ 7.5 to 8.0), temperature and potential for noxious compounds '(solvent organic chemicals, amines, proteins, tannins, phenolic compounds, alcohol, cyanates, ethers, carbamates and benzene)'. Nitrifying organisms also need CO_2 and phosphorus for cell growth.

*** Methanol, acetate, ethanol, glycerin, corn syrup, brewery, distillery and food processing waste.

**** Literature varies widely: 0.21 d^{-1} (30 °C) (Lotti et al., 2014); 0.55 to 3.38 d^{-1} (30 °C) (Loosdrecht et al., 2016); 0.062 d^{-1} (38 °C) (Van Der Star et al., 2008). That is why Tchobanoglous et al. (2014) is chosen.

Table 2.3 shows a comparison of capital and Operation & Maintenance (O&M) cost among the process mention above.

TABLE 2.3
CONVENTIONAL AND ADVANCED BIOLOGICAL NUTRIENT REMOVAL COMPARISON (LEMA AND SUAREZ, 2017)

`	Oxygen Requirements [kgO_2 / $kgN_{rem.}$]	COD Consumption [kgCOD / $kgN_{rem.}$]	Sludge Produced [kgVSS / $kgN_{rem.}$]	Total Treatment Cost [€ / $kgN_{rem.}$]
Nitrification / denitrification	4.33	2.86	1-1.2	3-5
Nitritation / denitritation	3.26	1.72	0.8-0.9	1.5-2.5
Deammonification	1.71	0	<0.1	1-2

The biological process to remove Phosphorus is also called enhanced biological phosphorus removal (EBPR). In contrast to chemical removal, this one reduces the operational cost (no use of reagents) and decreases the sludge production due to precipitants. The bacteria in charge to of EBPR process is named polyphosphate-accumulating organism (PAO could remove over 80 % of biological phosphorus). The first environment (anaerobic contact zone) for PAO stimulate them to storage a high quantity of orthophosphate and grow. The next phase might be a nitrate-rich or an anoxic phase (Water_Environment_Federation, 2017, Lema and Suarez, 2017, Tchobanoglous et al., 2014). This process is shown in Figure 2.3.

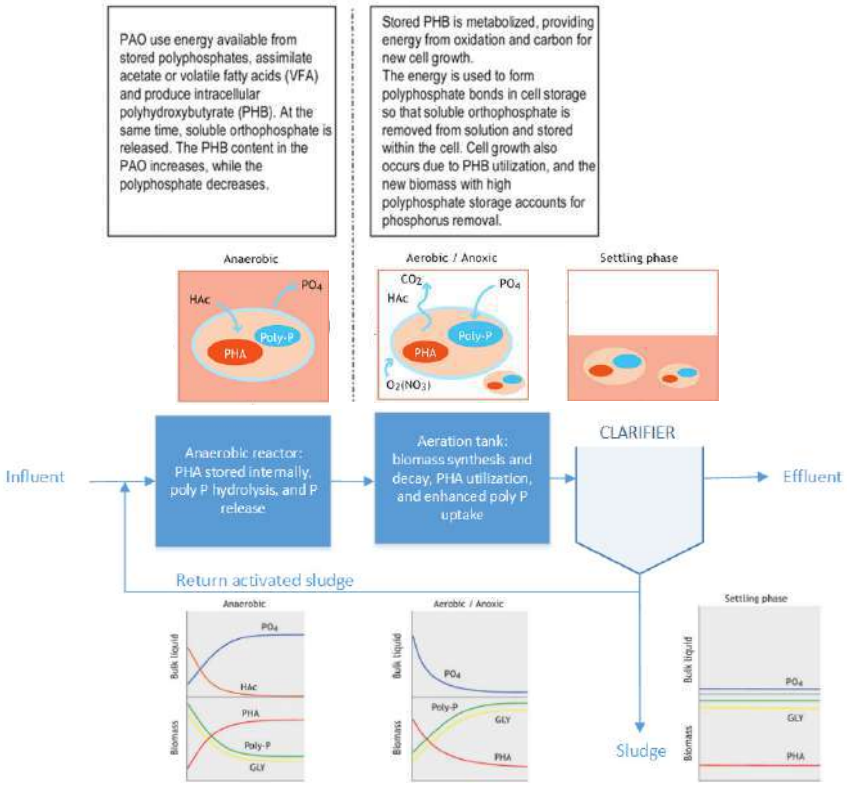


FIGURE 2.3 BIOCHEMICAL MODEL FOR PHOSPHORUS RELEASE AND REMOVAL BY PAO - GENERIC EBPR PROCESS. ADAPTED FROM: (TCHOBANOGLOUS ET AL., 2014, WATER_ENVIRONMENT_FEDERATION, 2017, LOOSDRECHT ET AL., 2016)

One option to save on aeration, diminish the production of sludge, and minimise readily biodegradable COD demands is to combine the process of denitrification and Phosphorus removal. This process requires the reduction of nitrite less than 2.0 g/m^3 (Tchobanoglous et al., 2014) in the influent to stop the generation of nitrous oxide (N_2O greenhouse gas) and to increase Phosphorus removal (Lema and Suarez, 2017).

An efficient operation process of EBPR needs to be monitored and account for the following parameters: Temperature, pH, carbon source and volatile fatty acids (VFA). The control of this parameters must be strict because of the dependency among these and PAO; If conditions change, other bacteria such as glycogen accumulation organism (GAO) would compete with PAO and obtain a higher growth rate (Lopez-Vazquez et al., 2009). Around 20 °C is the optimal temperature for PAO and its maximum specific growth is 0.95 d^{-1} at that temperature (Tchobanoglous et al., 2014).

2.3. Process Configurations for Nitrogen and Phosphorus Removal

At present, some plants function with BNR processes for both nutrients (Nitrogen and Phosphorus); reducing the cost of chemicals used for coagulation or flocculation. Nonetheless, the configurations of the plants are getting complex (nested) regarding recycle streams and to maintain different growing conditions for each organism in various stages of the process (Water_Environment_Federation, 2017).

The Water Environment Federation (2017) classified the most commonly used processes configuration to remove nutrients as:

2.3.1. Three-stage Phoredox A^2/O process

Anaerobic reactor – Anoxic reactor – Aerobic reactor with a recycle stream to the previous anoxic tank – Secondary Clarifier with partial recycles of Waste Activated Sludge to the first anaerobic tank.

2.3.2. Five-stage Bardenpho process

Anaerobic reactor – Anoxic reactor – Aerobic reactor with a recycle stream to the previous anoxic tank – Anoxic reactor – Aerobic reactor – Secondary Clarifier with partial recycle of Waste Activated Sludge to the first anaerobic tank. Illustrated in Figure 2.4.

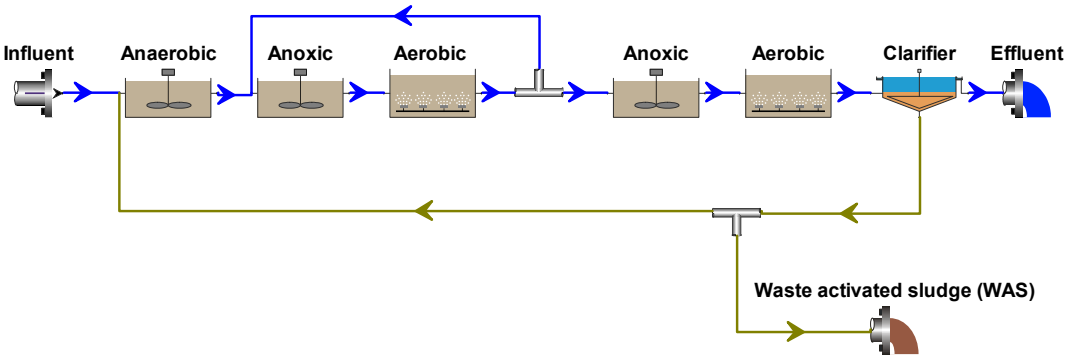


FIGURE 2.4 MODIFIED BARDENPHO PROCESS.

2.3.3. University of Cape Town (UCT) – Virginia Initiative Plant (VIP) [UCT – VIP Process]

Anaerobic reactor – Anoxic reactor with a recycle stream to the previous anaerobic tank – Aerobic reactor with a recycle stream to the previous anoxic tank – Secondary Clarifier with partial recycles of Waste Activated Sludge to the first anoxic tank.

2.3.4. Modified UCT

Anaerobic reactor – Anoxic reactor with a recycle stream to the previous anaerobic tank – Anoxic reactor – Aerobic reactor with a recycle stream to the previous anoxic tank – Secondary Clarifier with partial recycles of Waste Activated Sludge to the first anoxic tank. Shown in Figure 2.5.

2.3.5. Johannesburg and Modified Johannesburg Processes

Anaerobic reactor – Anoxic reactor – Aerobic reactor with a recycle stream to the previous anoxic tank – Secondary Clarifier with partial recycle of Waste Activated Sludge to a second anoxic tank – Kick back to the first anaerobic tank. Shown in Figure 2.6.

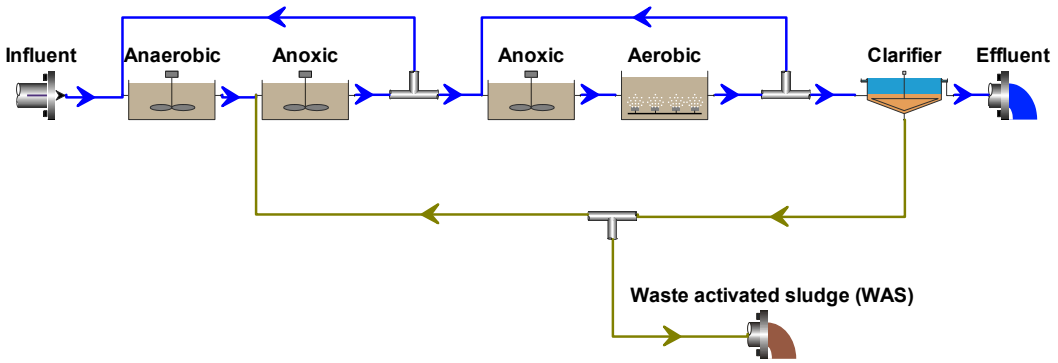


FIGURE 2.5 MODIFIED UCT

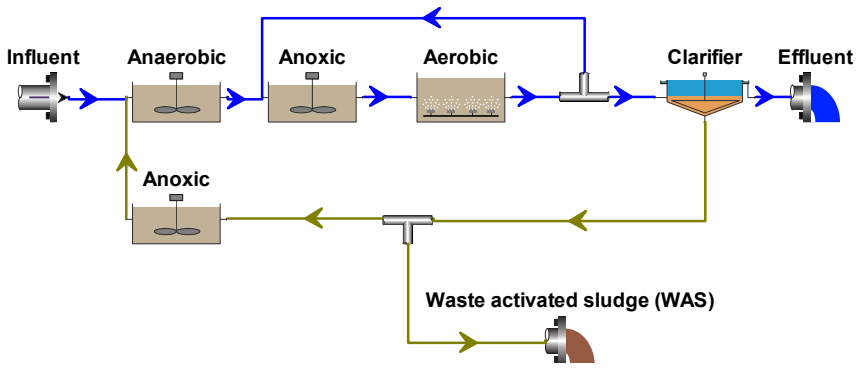


FIGURE 2.6 JOHANNESBURG PROCESS

Another way to fulfil the discharge regulations is to upgrade or retrofit an existing WWTP using BNR efficiently. An excellent example of that is Water 2020; its members are working on new technologies for side-stream and main-stream flows (Lema and Suarez, 2017). However, the majority of literature is based on the parameters of activated sludge and how to enhance its performance or retrofitting to BNR. That is why section 2.4 of this research is focused on upgrading or retrofitting Trickling Filters to obtain the BNR process within.

2.4. Processes within Trickling Filters

2.4.1. Background

These structures exist since the late 19th century; its research started in 1887 at the Lawrence Experimental Station (Massachusetts-USA). The biological treatment takes place in an Attached Growth Processes (AGP) that generally occurs in a non-submerged fixed film biological reactor. This tank uses rock or plastic media (packing); the sewage is spread over this media and that is when the biological treatment starts. Whence, this process requires low maintenance because is simple and involves low-energy to work (Tchobanoglous et al., 2014, Morgan, 1998); moreover, it has a resistance to toxic and loads with high fluctuations (Daigger and Boltz, 2011).

Further research of Trickling Filters (TF) divided AGP into five groups between aerobic process (AP) and activated sludge process (ASP) as shown in Table 2.4.

TABLE 2.4
GROUPS OF ATTACHED GROWTH PROCESSES FOR TRICKLING FILTERS

Aerobic Process (AP)	Activated Sludge Process (ASP)
1. Non-submerged attached growth	**4.** Sequential non-submerged attached growth
2. Partially submerged attached growth	**5.** with BioFilm carriers
3. Submerged attached growth	

These processes share similar characteristics such as bacteria population due to consumption of substrate occur on the fixed media, a secondary clarifier (SC) is needed after the TF, mechanical or natural ventilation (oxygen), the sewage needs to pass through the media surface area and a subchannel collects the treated effluent as shown in Figure 2.7 (Tchobanoglous et al., 2014, Daigger and Boltz, 2011). Likewise, sharing particular issues such as odour, filter fly and snail's proliferation; the last one causes clogging (Lindeburg, 2014, Morgan, 1998, Daigger and Boltz, 2011).

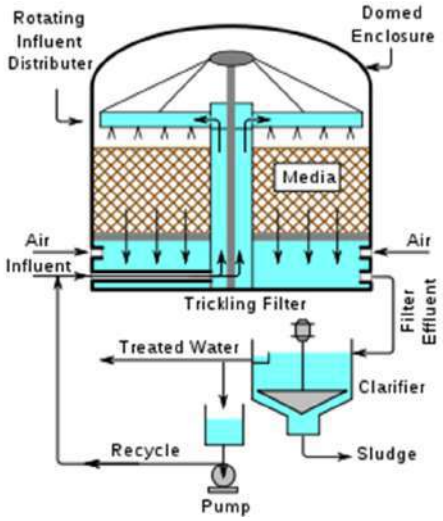


FIGURE 2.7 SCHEMATIC OF THE COMMON TRICKLING FILTER. FROM: HTTPS://WWW.REVOLVY.COM/PAGE/TRICKLING-FILTER

For the aim of this project, let us focus on Aerobic Process within non-submerged attached growth because the WWTP of Cusco uses that type of secondary treatment. For this type of operation, the literature suggests the efficiencies illustrated in Table 2.5.

TABLE 2.5
PARAMETERS REMOVAL EFFICIENCY (LINDEBURG, 2014).

Removing	Efficiency [%]
Suspended solids	70-90
BOD_5	65-85
Microorganism	70-95

Some designs incorporated a two-stage TF system to deal with higher BOD_5 or nitrification. This TF process uses combined structures for BOD_5 removal and nitrification and shows that nitrifying microorganisms will compete with the heterotrophic bacteria; the last one will proliferate because of its faster growth rate and higher biomass yield. The soluble BOD_5 needs to be below 2 to 10 mg/L to the proliferation of nitrifying microorganisms. To improve the efficiency of 90% ammonia removal is required a low surface loading rate (2 kg BOD/m^2·d).

Literature also determined that the effects of DO concentration, on nitrification rates, are superior to temperatures fluctuations (Tchobanoglous et al., 2014, Morgan et al., 1999).

Another way for nitrification in TF with plastic media is Tertiary Nitrification (TN). This process occurs afterwards the secondary treatment. Similar to the previous design, TN needs a minuscule amount of BOD to work correctly. Depending on the season, the level of ammonium could be less than 1 to 4 mg/L. The process needs some essential things to be considered during the design such as the packing form (media), forced draft air, hydraulic loading rates and recycle stream, and control of micro and macro-organisms (Daigger and Boltz, 2011, Tchobanoglous et al., 2014).

A synergy, among new processes and existing ones of the WWTP, needs to be reached. For that purpose, the following successful cases are taken into account such as the retrofitting of Selfs Point's WWTP to BNR in Tasmania (Morgan, 1998, Morgan et al., 1999); contemporary pilot (lab scale) and full-scale research of the state-of-the-art technologies and processes for treatment of municipal sewage (Hu et al., 2012); and the simulation of a WWTP in Spain to upgrade TF structures to BNR (Diez-Montero et al., 2019). The next topic is related to BNR in WWTP with Trickling Filters.

2.4.2. External Nitrification Biological Nutrient Removal Activated Sludge

The External Nitrification (EN) Biological Nutrient Removal Activated Sludge (ENBNRAS) system is comparable to the Biological Anoxic Phosphorus Removal (DEPHANOX) process when EN is required. Although, the ENBNRAS include a pre-anoxic tank between the secondary clarifier and the aerobic reactor (shown in Figure 2.8).

In the ENBNRAS the sewage flow goes to the Primary Settler which has a recycle stream to do the fermentation of the primary sludge. The next process (pre-anoxic and anaerobic reactors) is for Biological Phosphorus Removal (BPR) first phase (PAOs stored phosphate). This stream passes through an internal settler that bypasses the EN and redirects the sludge to an anoxic zone; besides, the liquid goes to the EN for nitrification and its effluent is mixed with the sludge of the internal settler. This liquor then goes to the anoxic zone for denitrification. The last process occurs in an aerobic tank that strips the nitrogen gas, treats the residual COD and finalising the BPR (Hu et al., 2012). This process based on TF for EN has nested recycled stream that accomplishes the requirements of treating Nitrogen and Phosphorus biologically.

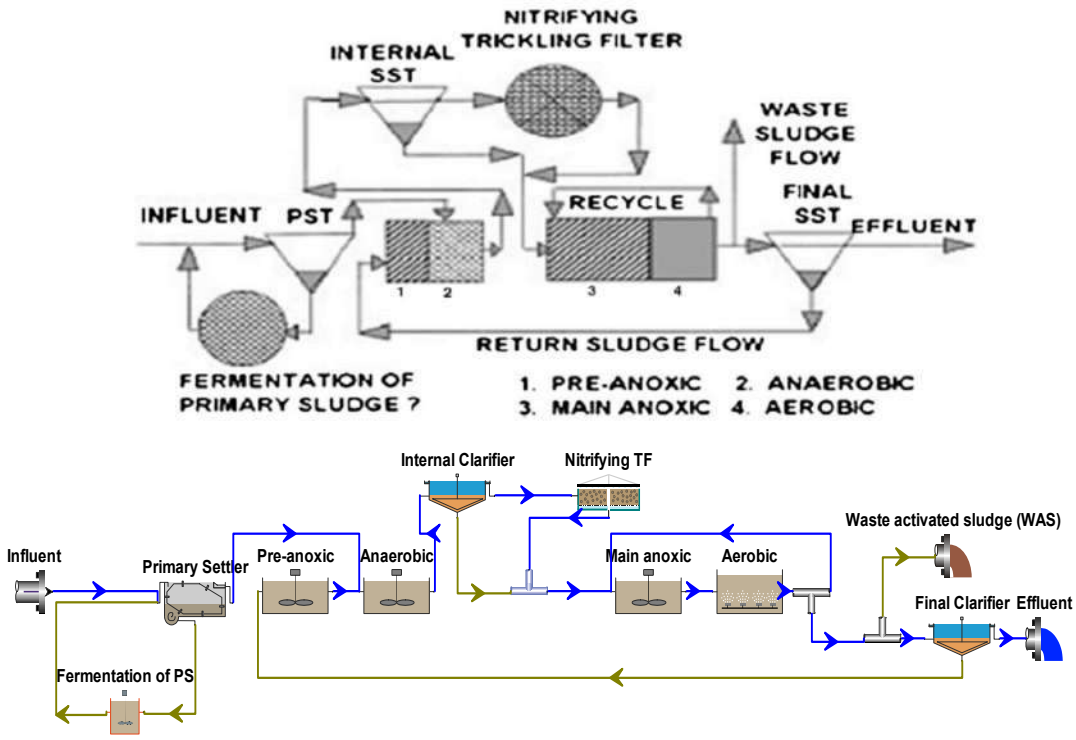


FIGURE 2.8 TOP: ENBNRAS PROCESS CONFIGURATION. TAKEN FROM: (HU ET AL., 2012); BOTTOM: ENBNRAS MODEL (BIOWIN).

2.4.3. Anaerobic-Anoxic Reactor TFs and Clarifiers within a WWTP

This configuration of WWTP works with the existing PS and retrofit it to obtain an anaerobic-anoxic reactor, as shown in Figure 2.9. The modification of the PS into the new reactor is called AnoxAn process and is illustrated in Figure 2.10 (Diez-Montero et al., 2019). These processes held the BNR without building major structures, do not need the input of chemicals nor external carbon source, and preserve the TFs without modification.

The upgraded reactor must run to offer a certain condition for denitrification and phosphate release. A central anaerobic section and an external anoxic compartment are contained in the new structure (Figure 2.10). Whilst, the TFs removes the residual organic matter (aerobic stage); also, phosphate uptake and nitrification process. The primary TF structures' functions are to remove organic matter and phosphate uptake; while, the process of the secondary TF is nitrification (Diez-Montero et al., 2019).

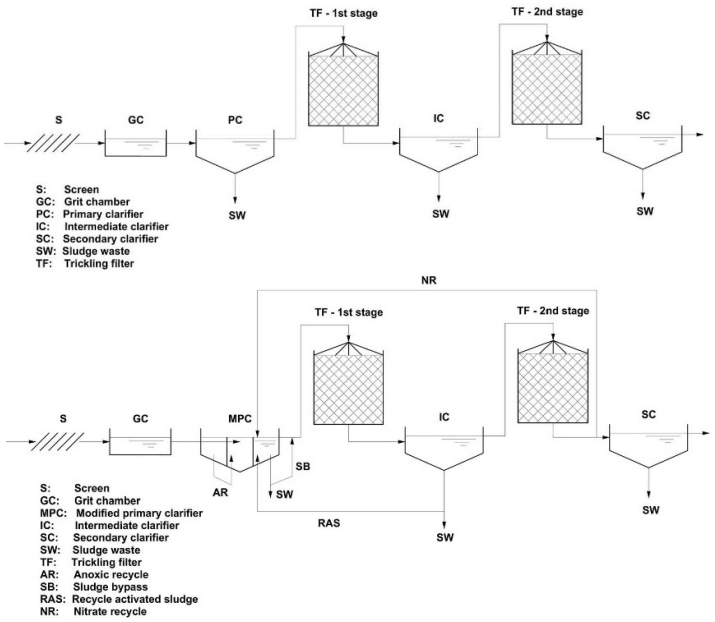


FIGURE 2.9 TOP: SCHEME OF THE EXISTING WWTP; BOTTOM: MODIFIED SCHEME OF THE WWTP (DIEZ-MONTERO ET AL., 2019)

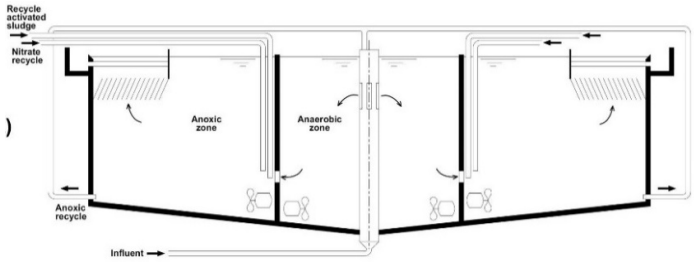


FIGURE 2.10 ANOXAN PROCESS IN THE MODIFIED PS (DIEZ-MONTERO ET AL., 2019)

The process begins when the wastewater flow (influent) goes to the anaerobic zone (inside the modified PS), and converged with the recycled sludge of the anoxic compartment. The produced stream (mixed liquor) goes through windows in the anaerobic zone's wall (upper part) to the anoxic zone. The anoxic compartment receives two streams; one from the secondary TF (nitrate-rich flow), and other from the (IS) intermediate settler's recycled activated sludge. The outlet stream passes through lamellas (work as a clarification zone and also retain the biomass) to finally be collected by submerged tubes. This modified structure gives two alternate environments to bacteria; promoting the denitrifying PAO. Likewise, a percentage between 0 to 50 % of the anoxic zone's activated sludge might go to the primary TF to give the aerobic environment to the PAO (enhancing the phosphorus removal process). This aerobic zone could be taken into account inside the anoxic zone to achieved an EBPR; the literature suggests 9.8 % to 78.2 % of the anoxic zone volume (Diez-Montero et al., 2019).

CHAPTER 3

3. METHODOLOGY

3.1. Case Study

Nitrogen and Phosphorus (nutrients) are polluting the downstream streams and catchments nearby Cusco's WWTP.

The methodology to address the problem of nutrients in wastewater was the simulation of the WWTP in different scenarios. These models were developed in the BioWin 5.3 software.

There is another issue related to the processing capacity, as explained in section 1.1. in Table 1.1 the design values of the flow rate of the WWTP, until 2022, were 446 L/s (38 534 m^3/d average discharge) and 802 L/s (69 293 m^3/d peak flow). The average influent now is 489 L/s (42 202 m^3/d) putting the process to its limits. The growth of the population in Cusco is leading to press forward a new stage of the WWTP.

The following sections show the process that was followed to obtain the different studied scenarios.

3.2. Data collection and processing

The first step of the investigation was the gathering of the characteristics of the WWTP of Cusco. Parallel with the collection of the mentioned data, Chapter 2 (Literature review) was developed, where the regulations for the discharges of wastewater into rivers are set out, as well as the environmental problems that this practice entails.

For the modelling purpose, the dimensions and the operation scheme of the structures are needed. The public company SEDACUSCO provided these through its engineering, operation and maintenance office of the WWTP. These are detailed below.

- Pre-treatment: This stage has an inlet channel, screening structure, and four parallel grit chambers with aerators,

- Primary treatment stage (PT): This one has two Primary Settlers (PS):

    a. PS1: This one was retrofitted in 2014 of the very first wastewater treatment plant that was built in 1985. The diameter is 42 m and 3 m for height (Figure 3.1).
    b. PS2: The structure was built in 2014. The diameter is 26 m and 4.2 m for height (Figure 3.2).

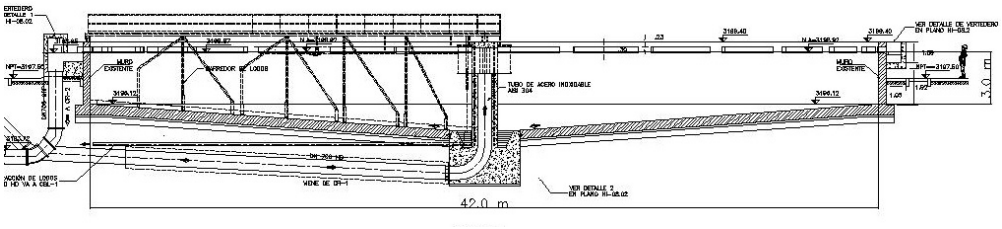


FIGURE 3.1 PRIMARY SETTLER 1. D=42 M, H=3.0 M (UNSCALED)

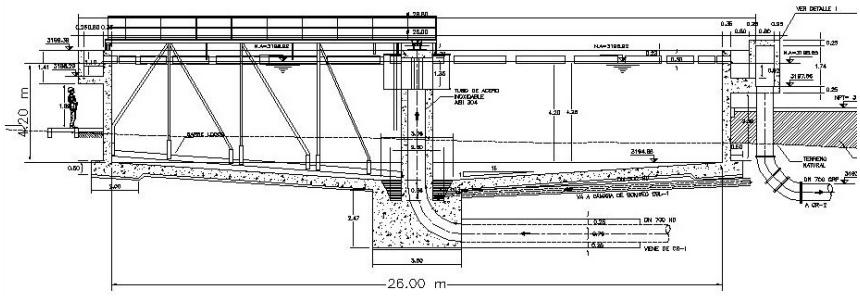


FIGURE 3.2 PRIMARY SETTLER 2. D=26 M, H=4.2 M (UNSCALED)

- Secondary or biological treatment stage (BT): Here is where the wastewater is treated (a vital part of the process). The structures within this stage are three Primary Trickling Filters (PTF), two Secondary Trickling Filters (STF), and two Secondary Clarifiers (SC).

    a. PTF: These three constructions are similar in shape with a Diameter of 30 m and 3.65 m of height (Figure 3.3).

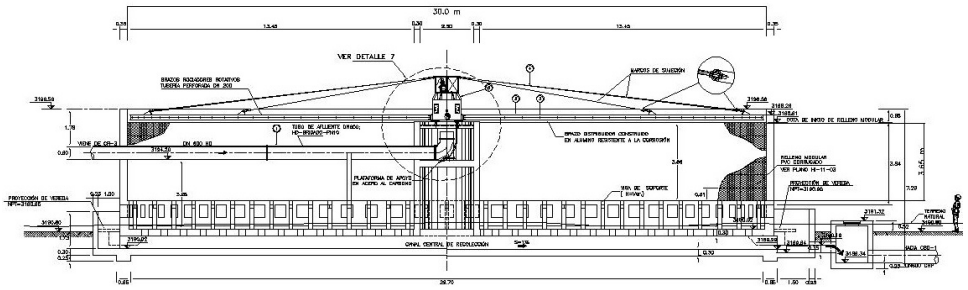


FIGURE 3.3 PRIMARY TRICKLING FILTER 1, 2 AND 3. D = 30 M, H = 3.65 M (UNSCALED)

    b. STF: Two structures with the same dimensions. The diameter of 22 m and a height of 6.1 m (Figure 3.4).
    c. SC: Two units with the same geometry. The diameter of 35 m and a height of 4.8 m (Figure 3.5).

- Tertiary treatment and disinfection (disposal of treated water to the mainstream): It has a chlorine chamber, a mixing structure, and a Parshall channel that discharge to an apron (concrete and riprap - protection structure).

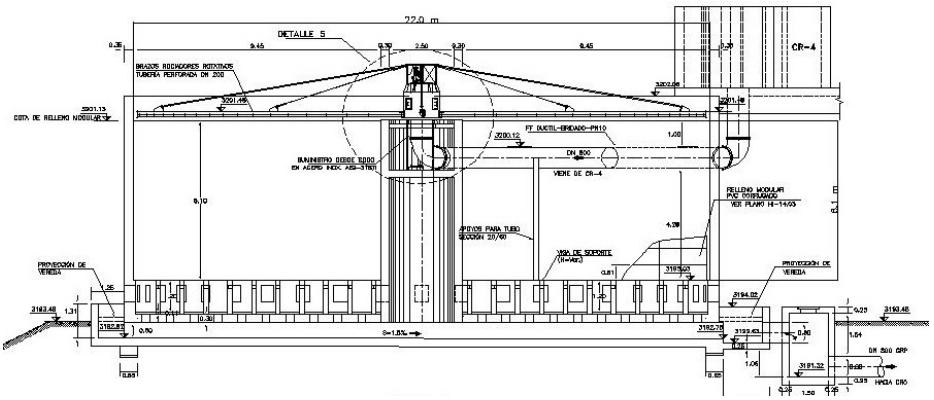


FIGURE 3.4 SECONDARY TRICKLING FILTER 1 AND 2. D = 22 M, H = 6.1 M (UNSCALED)

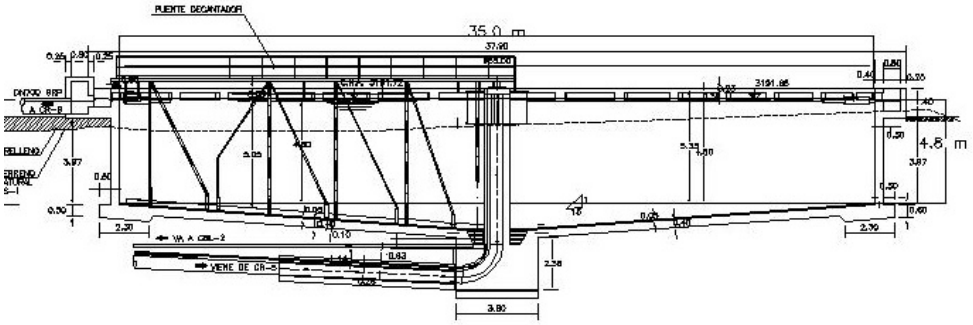


FIGURE 3.5 SECONDARY CLARIFIER 1 AND 2. D = 35 M, H = 4.8 M (UNSCALED)

The characteristics of the structures that are required for modelling the WWTP are synthesised in Table 3.1. Technical structure drawings are shown in Appendix III.

TABLE 3.1
CHARACTERISTIC OF THE WWTP STRUCTURES

Stage	Structure	Diameter [m]	Height [m]	Surface Area [m^2]	Volume [m^3]
PT	PS 1	42	3.0	1385.4	4156.3
PT	PS 2	26	4.2	530.9	2229.9
BT	PTF 1, 2, 3	30	3.66	706.9	2580.0
BT	STF 1, 2	22	6.1	380.1	2318.8
BT	SC 1, 2,	35	4.8	962.1	4618.14

The next step was to obtain the operational data of the WWTP. For that purpose, the governmental company in charge of the operation and maintenance processes provided the information and gave full permission to a third party (laboratory) to get samples of the wastewater. The raw data and its statistics are shown in Appendix IV. The consolidated operational values of BOD5, TN, TP, TSS and flow rate are shown in Table 3.2. This process is within the rule (BOD_5:N:P = 100:5:1) for a proper biological aerobic treatment showed in section 2.1. The WWTP has the ratio of 100:11.4:1.6 for influent BOD_5:N:P; 63:1 for BOD_5:P; of 0.071 TKN/TCOD, and 0.009 for TP/TCOD.

TABLE 3.2
EXISTING WWTP PARAMETERS (AVERAGE ANNUAL)

Parameters	unit	Influent	Effluent
Flow rate	m^3/d	42 202	41 607
BOD_5	mg/L	371.1	25.6
COD	mg/L	756.4	80.1
pH		7.6	7.3
TSS	mg/L	416.7	30.4
Temperature	°C	19.3	19.6
TKN	mg/L	42.4*	33.6*
TP	mg/L	5.9**	-**

* TN was not measured by SedaCusco. ** Unique value obtained for P in the influent, P was not measured by SedaCusco.

3.3. Process description

The raw data was received with different units. The shown data (Table 3.2) was normalised in order to ensure consistency. The software works with the SI units.

The physical facilities arrangement of the existing WWTP gave the designers limitations to propose a different kind of secondary treatment. From the beginning of the operation in 1985, the biological stage was defined to work with TF (in that case with rock media type – Figure 3.6). The upgraded WWTP finished in 2014 also took into account two stages of TF within its biological treatment; retrofitting some structures and leaving behind others such as the old TF that worked with rock media and a secondary clarifier. The wastewater treatment scheme of the existing WWTP is shown in Figure 3.7.

FIGURE 3.6 OLD TRICKLING FILTER (ROCK MEDIA). THE PHOTO WAS TAKEN ON 2012

For those reasons, the constraint of this case study is the space within its layout design (shown in Appendix III Layout WWTP).

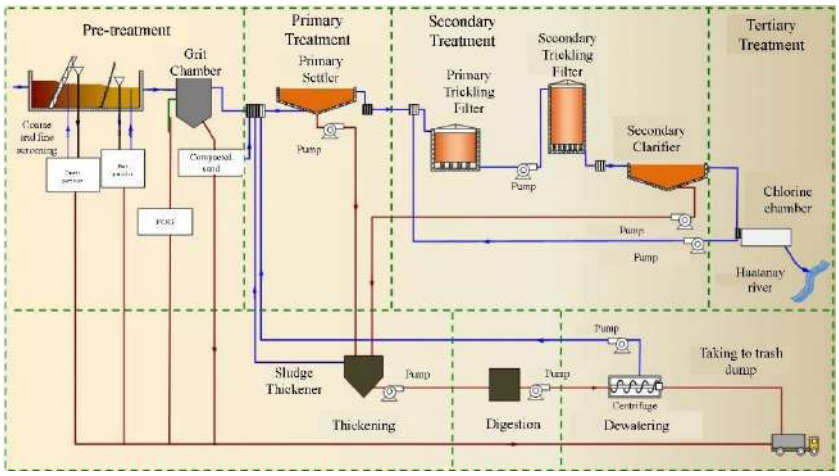


FIGURE 3.7 EXISTING WWTP SCHEME

Knowing the space constraints to biological treat the wastewater of the study case and analysing the possible solutions discussed in section 2.4. The one that fit the aim of nutrient removal without building new tanks or reactors is the AnoxAn process (discussed in section 2.4.3). Furthermore, this process does not involve chemicals addition or external carbon source.

On the other hand, the existing WWTP (Figure 3.8 Top) does not have an intermediate clarifier that is needed in the AnoxAn process. The solution is to use the old secondary clarifier (OSC) that is located near the primary TF (Figure 3.8 bottom - details in Appendix III) to solve that issue. Some minor work is needed to connect the OSC to the new system.

FIGURE 3.8 TOP: VIEW OF THE TFS AND SCS OF WWTP: BOTTOM: VIEW OF OSC (PHOTOS 2016)

The AnoxAn process needs the anaerobic-anoxic modified primary settler (MPS) to provide the bacteria with the conditions to realise phosphate and to hold the process of denitrification (consuming organic matter). Whilst, the primary and secondary TFs are going to work as aerobic reactors and the biomass hold there will consume the remaining substrate (PTFs), phosphate uptake and nitrification (STFs).

The influent goes first to the anaerobic zone in the MPS, where it will form a mixed liquor with the activated sludge that is recycled from the anoxic zone. This liquor will flow to the anoxic zone through windows located at the top of the interior wall. Two other streams would be mixed in the anoxic zone, the first one is the nitrate-rich flow from the secondary TF and the other is from the retrofitted OSC. The effluent passes through lamellas to avoid the loss of biomass from the MPS.

3.4. Modelling & Simulation

Three models, two for the existing biological treatment of the WWTP and one model for BNR, were simulated in BioWin Process Simulator v5.3 (EnviroSim Associates Ltd., Ontario, Canada). The models' option used in all biological unit processes is BioWin integrated ASDM (General Activated Sludge/Anaerobic Digestion). The BioWim ASDM has over eighty process expressions and approximately fifty state variables. The biological process simulations use these expressions to define what is usually taking place in the WWTP. Further information related to these processes should be found in BioWin user manual (BioWin).

The **first two models** had the same input data for the influent (Table 3.2), PSs (Ideal primary settling tank in BioWin), PTFs, STFs and SCs (Ideal clarifier) and the geometric parameters were taken from Table 3.1 and Table 3.3. The value 62.03 % TSS removal for the PS was taken from the raw data of the WWTP (Appendix IV). R. Diez-Montero et al. suggested to adjust some parameters to avoid over-optimistic result, these values are shown in Figure 3.9 (Diez-Montero et al., 2019). Additional values of the influent were assumed from BioWin default parameters.

Model parameter	Default value	Adjusted
OHO anoxic yield	0.54	0.90
P in biomass AOB, NOB, OHO (mgP mgCOD^{-1})	0.022	0.012
P in endogenous residue (mgP mgCOD^{-1})	0.022	0.012
AOB maximum specific growth rate μ (d^{-1})	0.9	0.5
AOB half-saturation coefficient K_N (mgN L^{-1})	0.7	1.0

OHO = ordinary heterotrophic organisms; AOB = ammonia oxidizer bacteria; NOB = nitrite oxidizer bacteria.

FIGURE 3.9 MODEL PARAMETERS ADJUSTMENT (DIEZ-MONTERO ET AL., 2019)

3.4.1. First model

This model of the WWTP was developed with the same number of structures (parallel flows). It is common to design constructions that would work in parallel; the reason for this is to have a backup line of the process in case of maintenance, upgrading or retrofitting of structures. Illustrated in Figure 3.10.

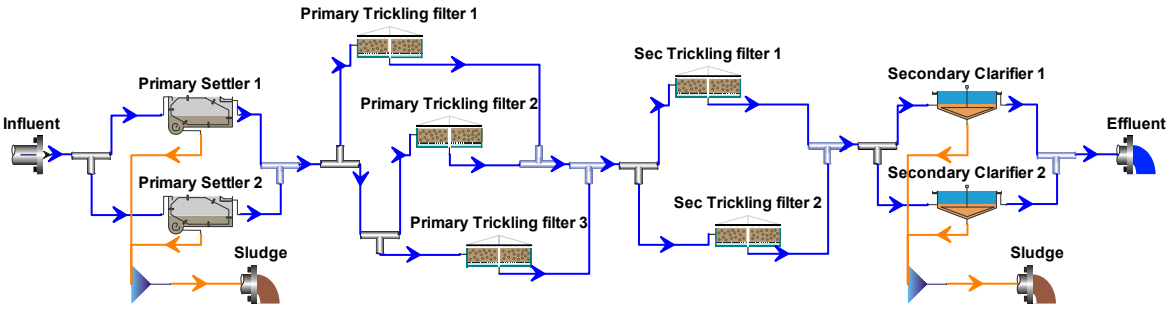


FIGURE 3.10 FIRST MODEL OF WWTP (PARALLEL FLOWS)

3.4.2. Second model (Consolidated)

The **second model** of the WWTP is a **consolidated** one. This scenario was built integrating paralleling structures, the analysis for the PSs, TFs and SCs was made to increase the performance of the software. Reducing the number of elements in the matrices; the software solved them in less time without compromising the results.

In this model, the surface area of the parallel constructions is added to obtain a consolidated value, and take the average height of the structures. Table 3.3 summarises the obtained data (Table 3.1). This consolidated model is illustrated in Figure 3.11.

TABLE 3.3
CONSOLIDATED DATA FROM PARALLEL STRUCTURES

Structure	Average height [m]	Consolidated surface area [m^2]
PS	3.6	1 916.3
PTF	3.66	2 120.6
STF	6.10	760.2
SC	4.80	1 924.2

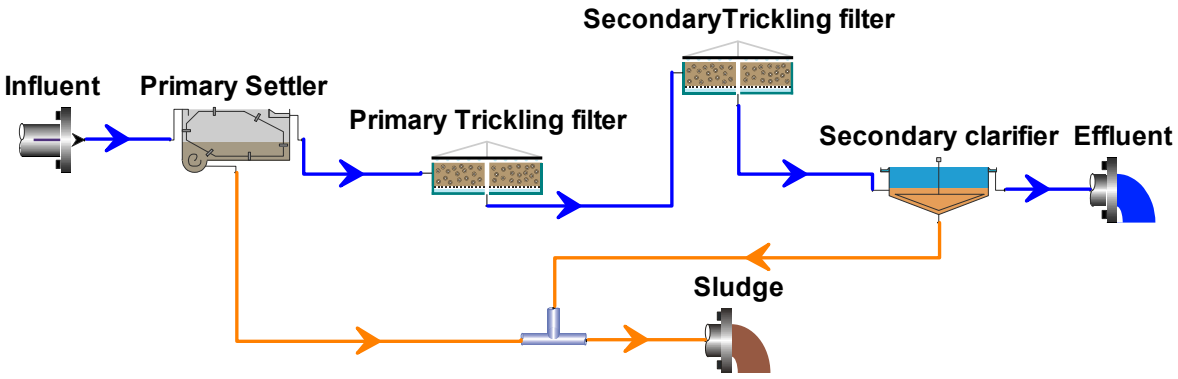


FIGURE 3.11 CONSOLIDATED MODEL OF THE WWTP

The values obtained from the two different models were similar as shown in Figure 3.12, further details are illustrated in CHAPTER 4 and Appendix V. The second model (consolidated one) has been validated with the results shown in the figure below. This model will be used from now on.

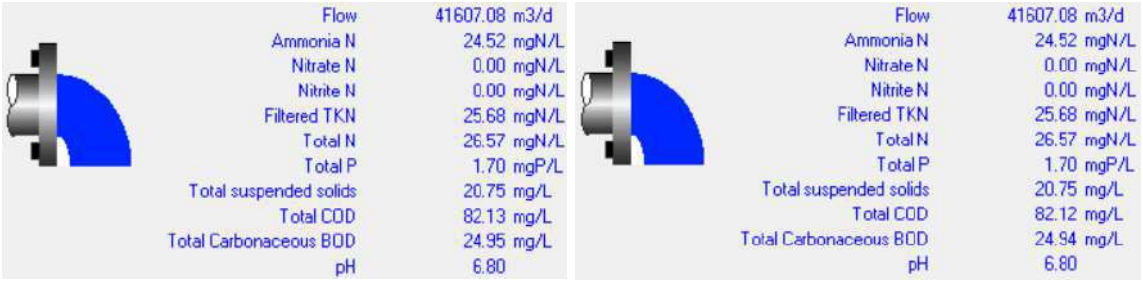


FIGURE 3.12 SIMILAR EFFLUENT DATA OBTAINED FROM THE SIMULATION OF THE TWO MODELS (APPENDIX V)

The consolidated model was created by simplifying the first model into one that works as a serial process (Water_Environment_Federation, 2014). This model was created anticipating that recycle streams of BNR for the retrofitted model are more complex to solve due to nested flows.

Before modelling the **retrofitted WWTP (third model)**, the consolidated model was tested to obtain its performance in twenty-five different scenarios. The first one was the base scenario (BS) and the flow rate (-10% to 61%), BOD_5 (-10% to 20%), P (-20% to 20%) and N (-20% to 20%) had six scenarios each. These setups showed a **robust model**. The processed data is shown in CHAPTER 4.

3.4.3. Third model (AnoxAn)

The **third model** of the WWTP was developed using the AnoxAn process and represented the suggested retrofit for BNR. This model was built using the consolidated model as seed scenario without modifying its parameters nor the influent characteristics.

Diez-Montero et al. suggested in their paper, the optimal percentages for the recycle streams and volume of the MPS:

- The Sludge Bypass (SB) stream from the anoxic zone and Recycle Activated Sludge (RAS) from Intermediate Settler as the 30 % of the influent flow rate;
- the anoxic recycle as two times the influent flow rate;
- the nitrate recycle from STF as three times the influent flow rate;
- and AV varies between 34 - 49 % of the total anoxic volume – these values are for the optimum scenario of the third model simulation –.

The dimensions of the MPS in the WWTP of Cusco are 3026.9 m^3 for the anaerobic volume and 3832.8 m^3 for the anoxic and aerobic total volume. The characteristics of the MPS are summarised in Table 3.4 and Table 3.5. This model is shown in Figure 3.13.

TABLE 3.4
RECYCLE FLOWS

Stream	Percentage of influent [%]	Optimal percentage of influent [%]	Optimal flow rate [m^3/d]
Anoxic Recycle (AR)	200	200	84 404
Sludge Bypass (SB)	0-50	30	12 661
Recycle Activated Sludge (RAS)	0-50	30	12 661
Nitrate Recycle (NR)	300	300	126 606

TABLE 3.5
PARAMETERS OF THE MODIFIED STRUCTURES

Structure	height [m]	Volume [m^3]
MPS/Anaerobic	3.6	3 026.9
MPS/Anoxic	3.6	1 978.9 - 2525.8
MPS/Aerobic	3.6	1 307 - 1 854.0
Intermediate Settler (IS)	3.0	4 871.5

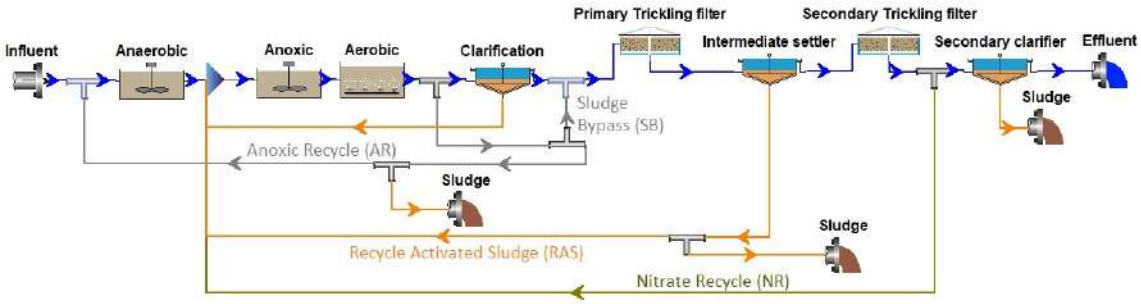


FIGURE 3.13 ADAPTED ANOXAN PROCESS FOR CUSCO'S WWTP

The retrofitted WWTP was tested in thirty different scenarios, being the first one for the base scenario; moreover, varying its flow rate in eleven setups (starting from -50% to 61%), and for BOD_5 (-49% to 20%), P (-20% to 20%) and N (-20% to 20%) in six scenarios each; those results are presented in CHAPTER 4.

CHAPTER 4

4. RESULTS

The secondary treatment stage (biological) of the WWTP was tested in different scenarios, using computational simulation. The existing biological process was consolidated in the second model; the first model and the consolidated one converged in results. The AnoxAn process showed satisfactory outputs compare to the discharge regulation. In the following sections, the results will be shown.

4.1. First Model results

This model of the WWTP was developed to show the completed process (parallel). Table 4.1 and Figure 4.1 showed the obtained results of this first simulation of the wastewater treatment.

The WWTP has a ratio of 100:11.4:1.6 for the influent BOD_5:N:P. This ratio is a useful parameter to take into account for biological aerobic treatment; it indicates a suitable environment to treat nutrients biologically – the minimum ratio is 100:5:1 - (Slade et al., 2011).

TABLE 4.1
INPUT AND OUTPUT VALUES OF THE FIRST SIMULATION (DETAILS IN APPENDIX V)

Elements	Flow [m^3/d]	Total N [mg/L]	Total P [mg/L]	TSS [mg/L]	Total BOD_5 [mg/L]
Influent	42202.08	42.40	5.90	416.60	370.50
PS1	20853.54	36.83	4.08	160.06	247.50
PS2	20853.54	36.83	4.08	160.06	247.50
PTF1	13902.36	36.77	4.08	236.20	190.13
PTF2	13902.36	36.77	4.08	236.20	190.13
STF1	20853.54	36.69	4.08	258.74	161.92
STF2	20853.54	36.69	4.08	258.74	161.92
SC1	20803.54	26.57	1.70	20.75	24.95
SC2	20803.54	26.57	1.70	20.75	24.95
Effluent	41607.08	26.57	1.70	20.75	24.95

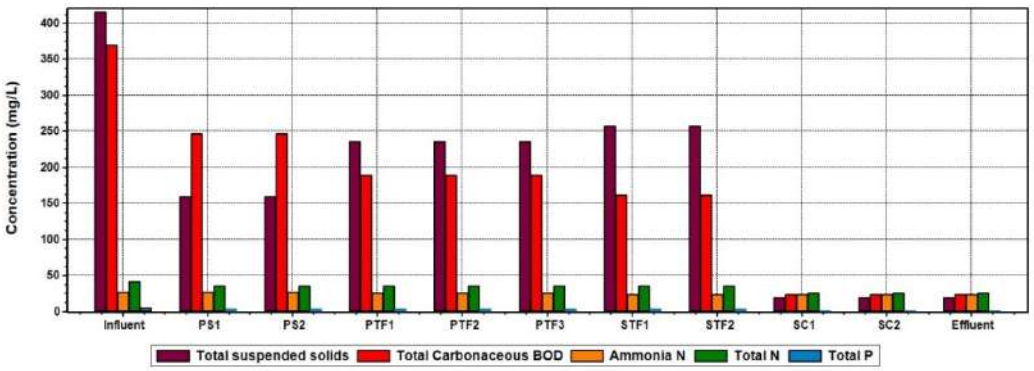


FIGURE 4.1 FIRST MODEL - PARAMETERS CONCENTRATION IN THE INFLUENT, REACTORS AND EFFLUENT

The output values are within the statistics – confidence level of 95% – of the real process (Table 4.2 and Appendix IV). The influent value for P was obtained from the parameter reported in the contract of the second stage of the WWTP, and the influent TN was supposed to be equal to the influent TKN. Even though the concentration of TN was requested, SedaCusco had only the TKN values of six months because these effluent parameters (P and N) are not required in the discharge regulation.

TABLE 4.2
COMPARISON BETWEEN REAL AND SIMULATED INPUT AND OUTPUT PARAMETERS (CONFIDENCE LEVEL 95 %)

Elements	Flow [m^3/d]	Total N [mg/L]	Total P [mg/L]	TSS [mg/L]	Total BOD_5 [mg/L]
Real Influent	42202 ± 6532	42.36 ± 6.13	5.90*	416.68 ± 94.64	371.10 ± 52.78
Simulated Influent	42202.08	42.40	5.90	416.60	370.50
Real Effluent	39072 ± 6875	No measured data **	No measured data **	30.38 ± 15.96	25.61 ± 7.45
Simulated Effluent	41607.08	26.57	1.70	20.75	24.95

* Unique value obtained for P (APPENDIX I). ** SedaCusco have not measured these values in the effluent (TN can be compared with TKN = 33.6 ± 5.3 mg/L)

4.2. Consolidated model results

The consolidated model was created by simplifying the first model into one that works as a serial process. The effluent values showed in Table 4.1 and Figure 4.1 are similar to the ones

shown in Table 4.3 and Figure 4.2; the consolidated model results and the first model outcomes converge.

TABLE 4.3
OUTPUT VALUES OF THE CONSOLIDATED SIMULATION (DETAILS IN APPENDIX V)

Elements	Flow [m^3/d]	Total N [mg/L]	Total P [mg/L]	TSS [mg/L]	Total BOD_5 [mg/L]
Influent	42202.08	42.40	5.90	416.60	370.50
PSs	41707.08	36.83	4.08	160.06	247.50
PTFs	41707.08	36.77	4.08	236.20	190.13
STFs	41707.08	36.69	4.08	258.74	161.92
SCs	41607.08	26.57	1.70	20.75	24.94
Effluent	41607.08	26.57	1.70	20.75	24.94

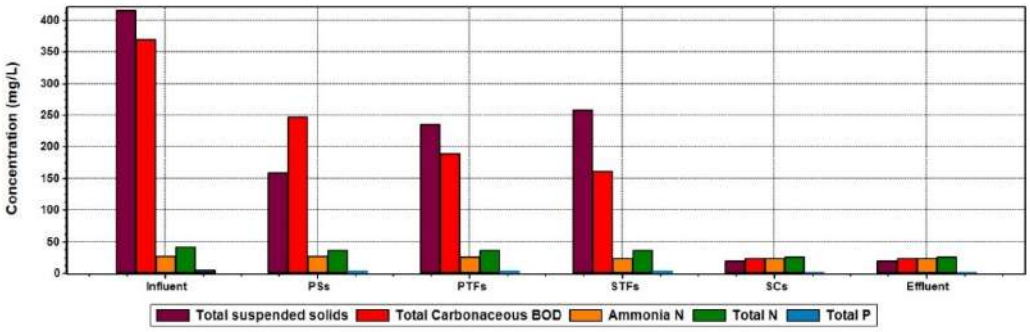


FIGURE 4.2 FIRST MODEL - PARAMETERS CONCENTRATION IN THE INFLUENT, REACTORS AND EFFLUENT

4.2.1. Sensitivity analysis for the consolidated model

A sensitivity analysis was made to validate this model (base scenario – 1), taking into account fluctuations in the influent wastewater stream, BOD5, TKN and P. Spreadsheets are detailed in Appendix VI.

The results of the first six scenarios (2 to 7) are illustrated in Table 4.4 and Figure 4.3 and have shown that an increment in the flow rate above 9% generated an increment of BOD_5, surpassing the maximum permissible limits – MPL - (BOD_5 = 30 mg/L); moreover, TP and TN are increased by 11% and 2%, respectively. The peak flow (flow +60.9%) is the critical scenario, where an increment of 62%, 25% and 8% were found for BOD_5, TP and TN, respectively. On the other hand, TSS decreased due to the sedimentation process. The fluctuation of the influent flow rate showed a linear response to the effluent TN, TP, TSS and BOD_5.

TABLE 4.4
SENSITIVITY ANALYSIS OF CONSOLIDATED MODEL – FLOW RATE FLUCTUATION

Scenario	Flow	Flow rate [m3/d]	TN [mg/L]	TP [mg/L]	TSS [mg/L]	Total BOD_5 [mg/L]
2	**-10 %**	37386.9	26.14	1.40	20.79	20.79
3	**-5 %**	39497.0	26.35	1.55	20.79	22.66
1	**BS**	41607.1	26.57	1.70	20.75	24.94
4	**+10 %**	45827.3	26.99	1.91	20.59	30.32
5	**+15 %**	47937.4	27.20	1.97	20.47	33.40
6	**+20 %**	50047.5	27.41	2.02	20.34	36.70
7	**+60.9 %**	68697.8	28.92	2.28	18.99	64.83

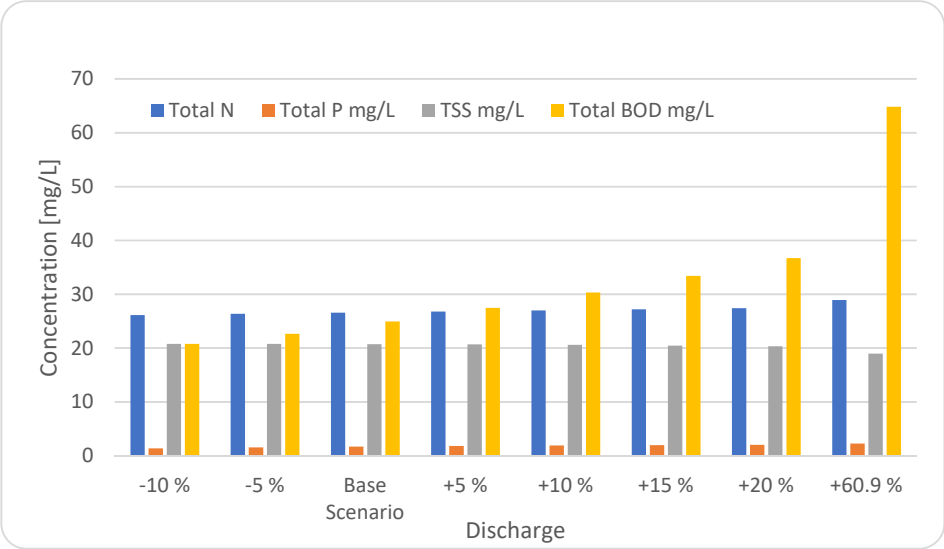


FIGURE 4.3 FLOW RATE FLUCTUATION - CONSOLIDATED MODEL

The effects of influent BOD_5 fluctuations (six scenarios – 8 to 13) on the effluent parameters are shown in Table 4.5 and Figure 4.4. It was found that an increment above 7.21% in the inlet BOD_5 generated an effluent BOD_5 higher than the MPL. The adverse scenario (+20% influent BOD_5) generated the following variations in the effluent 7%, -3%, 13% and 41 % of TP, TN, TSS and BOD_5, respectively. The fluctuation of the influent BOD_5 showed a linear response to the following effluent parameters TP, TSS and BOD_5; on the other hand, an inverse correlation is presented, regarding the influent BOD_5 and the effluent TN.

TABLE 4.5
SENSITIVITY ANALYSIS OF CONSOLIDATED MODEL – BOD_5 FLUCTUATION

Scenario	BOD_5 Fluctuations	Influent BOD_5 [mg/L]	TN [mg/L]	TP [mg/L]	TSS [mg/L]	Total BOD_5 [mg/L]
8	**-10 %**	333.0	27.11	1.56	18.99	19.48
9	**-5 %**	351.7	26.85	1.60	19.86	22.00
--	**BS**	370.5	26.57	1.70	20.75	24.94
10	**+5 %**	389.1	26.32	1.78	21.60	28.29
11	**+10 %**	407.5	26.10	1.80	22.42	32.15
12	**+15 %**	426.6	25.92	1.81	23.22	36.89
13	**+20 %**	445.0	25.77	1.82	23.94	42.23

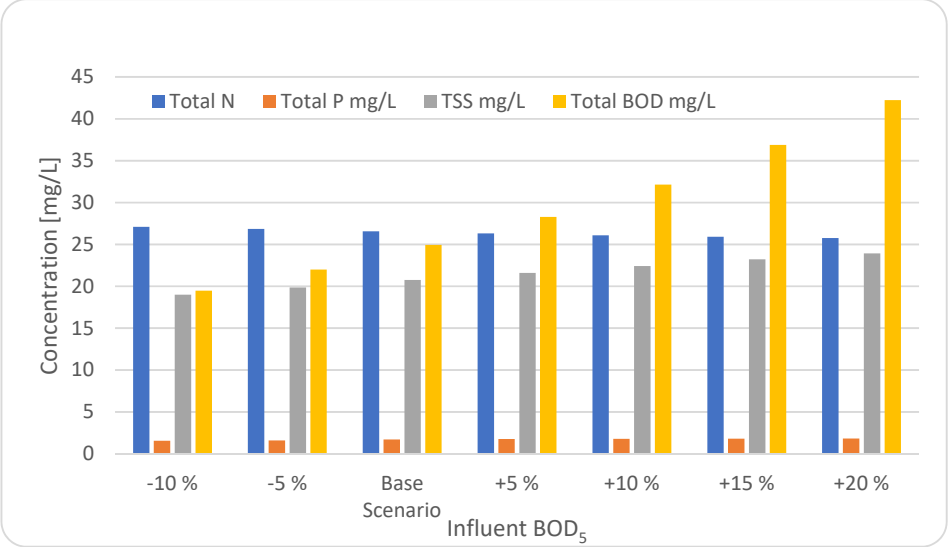


FIGURE 4.4 INFLUENT BOD_5 FLUCTUATION - CONSOLIDATED MODEL

The six setups (14 to 19) fluctuations of the TP were evaluated and their results are shown in Table 4.6 and Figure 4.5. The effluent TP showed variations of -56% to 27% when the influent TP was varied from -20% to 20%. The other parameters maintained their values in the evaluated scenarios, demonstrating that there is no correlation between the influent TP and the following effluent parameters TN, TSS and BOD_5.

TABLE 4.6
SENSITIVITY ANALYSIS OF CONSOLIDATED MODEL –TOTAL P FLUCTUATION

Scenario	TP Fluctuation	Influent Total P [mg/L]	TN [mg/L]	TP [mg/L]	TSS [mg/L]	Total BOD_5 [mg/L]
14	**-20 %**	4.72	26.57	1.09	20.73	24.99
15	**-10 %**	5.31	26.57	1.39	20.74	24.96
16	**-5 %**	5.61	26.57	1.55	20.75	24.95
--	**BS**	5.90	26.57	1.70	20.75	24.94
17	**+5 %**	6.20	26.57	1.86	20.75	24.94
18	**+10 %**	6.49	26.57	2.02	20.75	24.94
19	**+20 %**	7.08	26.57	2.33	20.75	24.93

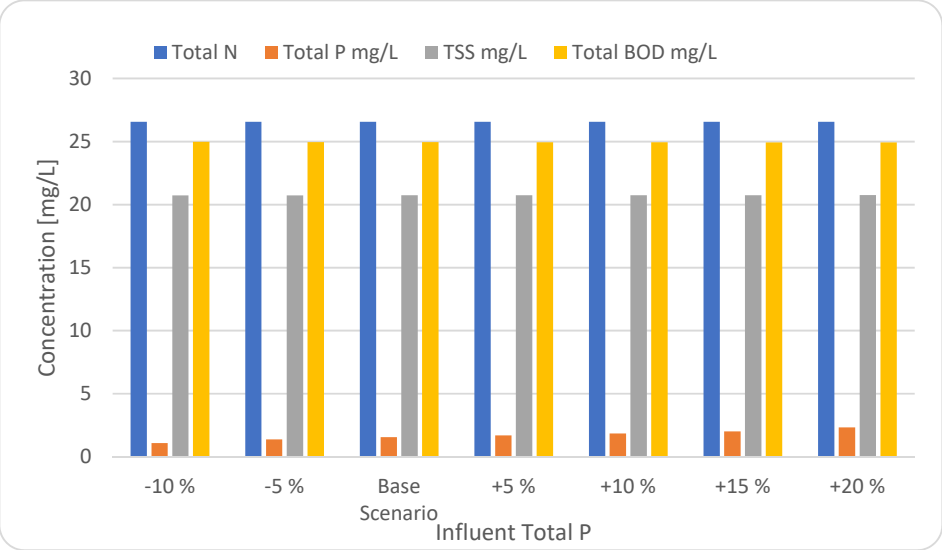


FIGURE 4.5 INFLUENT TOTAL P FLUCTUATION - CONSOLIDATED MODEL

The six scenarios (20 to 25) showed in Table 4.7 and Figure 4.6 reflected the variation of the influent TKN. This parameter was changed from -20% to 20% obtaining a fluctuation of -38% to 21% for the effluent TN, respectively. The discharge parameters TP, TSS and BOD_5 did not change in the evaluated setups; indicating that the mentioned effluent parameters did not correlate with the influent TKN. The effluent TN depicted a direct correlation with the influent TKN.

TABLE 4.7
SENSITIVITY ANALYSIS OF CONSOLIDATED MODEL –TKN FLUCTUATION

Scenario	TKN Fluctuation	Influent TKN [mg/L]	TN [mg/L]	TP [mg/L]	TSS [mg/L]	Total BOD_5 [mg/L]
20	**-20 %**	33.92	19.3	1.7	20.75	24.96
21	**-10 %**	38.16	22.93	1.7	20.75	24.95
--	**-5 %**	40.28	24.75	1.7	20.75	24.95
22	**BS**	42.40	26.57	1.7	20.75	24.94
23	**+5 %**	44.52	28.39	1.7	20.75	24.94
24	**+10 %**	46.64	30.20	1.7	20.75	24.94
25	**+20 %**	50.88	33.84	1.7	20.75	24.93

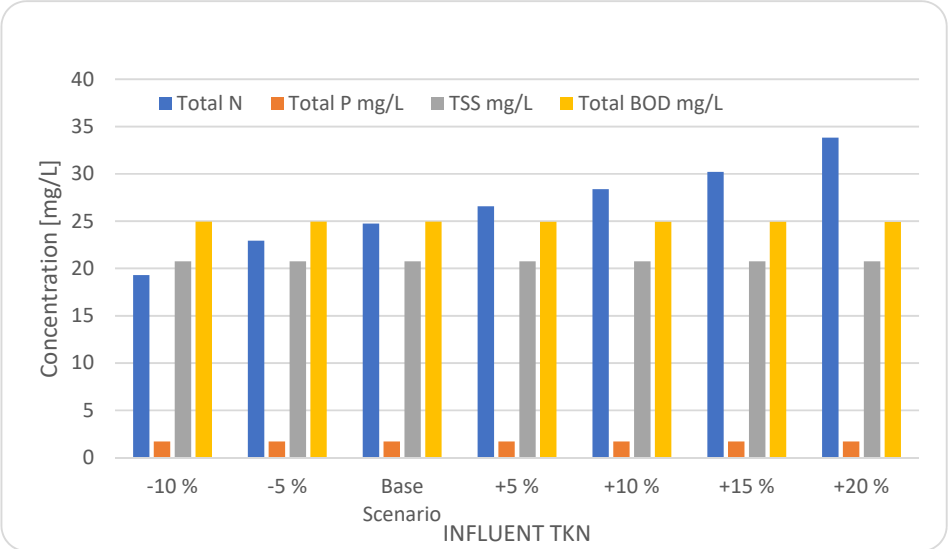


FIGURE 4.6 INFLUENT TKN FLUCTUATION - CONSOLIDATED MODEL

4.3. Third model results (AnoxAn)

The AnoxAn model was simulated in thirty different scenarios. The scenarios based on the Modified Primary Settler (MPS) without aerobic zone and with fluctuations of the SB (from 0 to 50 % of the influent flow rate). These showed that the effluent BOD_5 was reduced significantly when the Sludge Bypass (SB) was set to zero; TSS decreased abruptly due to the lamella action to retain biomass. The other simulations showed decrement values as far as -24% of effluent BOD_5 when SB was set to 50% of the influent. A reasonable value that keeps a regular substrate and biomass is 30% of the influent flow rate.

The subsequent simulations included the AV and changed its volume from 34.1% to 75 % of the anoxic zone and the SB (from 25 % to 35 % the influent flow rate). There was a point, in each scenario, where the treatment of TP stopped; it was when the AV had values outside the range of 44.1% and 48.4% of the anoxic zone. In order to minimise the utilisation of oxygen, the lower percentage was taken as the optimum value.

The values for the chosen scenario are: SB = 30% of the influent and volume AV of 44.1 % of the total anoxic volume; the other parameters were set as same as the consolidated model. The simulated parameters are shown in Table 4.8.

TABLE 4.8
OUTPUT VALUES OF THE ANOXAN MODEL (DETAILS IN APPENDIX V)

Element	Flow [m^3/d]	Ammonia [mg/L]	Nitrate [mg/L]	Nitrite [mg/L]	Soluble PO4-P [mg/L]	TSS [mg/L]	BOD_5 [mg/L]
Influent	42202.08	27.98	0	0	2.95	416.6	370.50
Anaerobic	126606.24	17.58	0	0	4.87	14122.8	4833.81
Anoxic	265972.24	12.74	0	0	4.88	20959.7	7107.12
Aerobic	265972.24	9.80	0.16	0.15	0.46	20959.5	7084.74
Lamella	168312.46	9.80	0.16	0.15	0.46	41.9	16.60
PTF	180973.08	8.57	1.26	0.16	0.09	1504.1	507.37
IS	168263.08	8.57	1.26	0.16	0.09	129.4	45.03
STF	168263.08	7.83	1.98	0.18	0.05	128.9	43.84
SC	41607.08	7.83	1.98	0.18	0.05	10.3	4.52
Effluent	41607.08	7.83	1.98	0.18	0.05	10.3	4.52

As expected, the concentration of ammonia was reduced in the MPS and converted into nitrite and nitrate; a nitrate-rich stream from the STF was kicked back to the anoxic zone (2AX) of the MPS; where it is reduced to nitrogen gas with the carbon source. These processes are depicted in Table 4.8, Figure 4.7 and Figure 4.8.

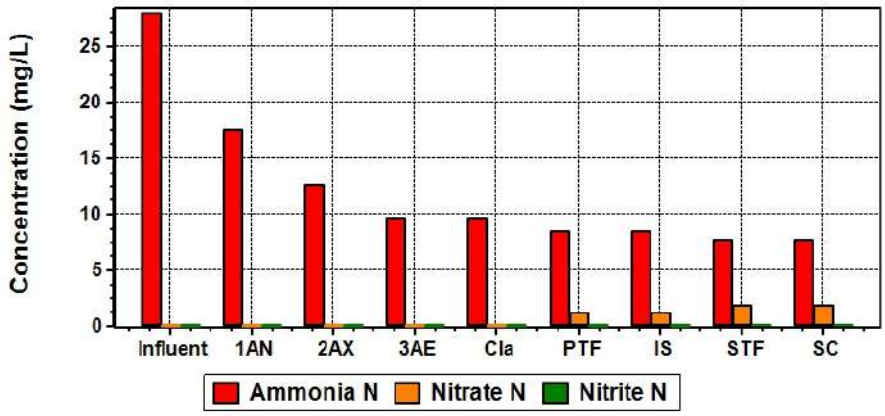


FIGURE 4.7 NITROGEN REMOVAL (1AN: ANAEROBIC, 2AX: ANOXIC AND 3AE: AEROBIC REACTORS)

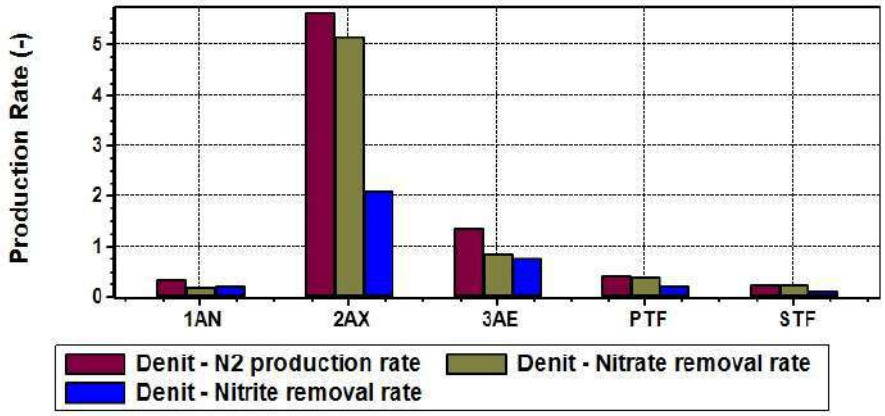


FIGURE 4.8 PRODUCTION AND REMOVAL RATES OF NITROGEN (1AN: ANAEROBIC, 2AX: ANOXIC AND 3AE: AEROBIC REACTORS)

The PAOs behaviour are depicted in Figure 4.9. It is shown that the phosphate release took place in the MPS (1AN and 2AX) to continue the EBPR of phosphate uptake in the aerobic reactor (3AE), PTF and STF; it also illustrates the nitrogen oxidation stage. Hence, this process represented the BNR in the simulated WWTP.

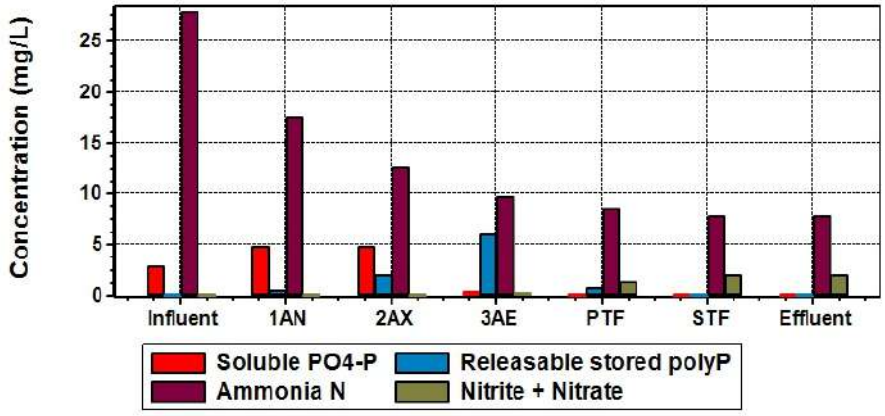


FIGURE 4.9 BIOLOGICAL NUTRIENTS REMOVAL (1AN: ANAEROBIC, 2AX: ANOXIC AND 3AE: AEROBIC REACTORS)

4.3.1. Sensitivity analysis for the AnoxAn model

This section was prepared to analyse the sensitivity of the influent parameters of the model (base scenario – 1), fluctuating the influent wastewater stream, BOD_5, P and TKN. Furthermore, the scenarios were simulated with the same values for AR, NR and reducing the amount of DO in the aerobic zone to control the operational cost of the biological process. For this reason, the selected combination of the anoxic zone (SB = 30%, AV = 44.1% Total anoxic-aerobic volume) was simulated in different DO scenarios. As explained by Diez-Montero et al. in their paper "Model-based evaluation of a trickling filter facility upgrade to biological nutrient removal", there is a range of values for DO where the Biological Nutrient Removal (BNR) stopped; in this process, the range goes between 0.75 mg/L to 2 mg/L. Less than 0.75 mg/L of DO decreased the efficiency of BNR and surpassed the MPL of TN (15 mg/L). Hence, 1.75 mg/L of DO was selected to have a safety factor. Spreadsheets and additional tables are shown in APPENDIX VI.

The results of the eleven first scenarios (2 to 12) for the AnoxAn process are shown in Table 4.9. This table showed that an increment of more than 12% in the flow rate could stop the simulation process due to a low Hydraulic Retention Time (HRT less than 1 hour) of the modified structures. No biological process occurs with a low HRT because of a flushing process (the biomass does not have enough time to process the substrate). The ninth scenario was the critical one, where a 12% increased influent flow rate represented 8%, 5%, 7% and 7% increment of the effluent TN, TP, TSS and DBO_5, respectively. The results showed a positive correlation between the fluctuation of the influent flow rate and the effluent TN, TP, TSS and DBO_5 (Figure 4.10 and Table 4.9).

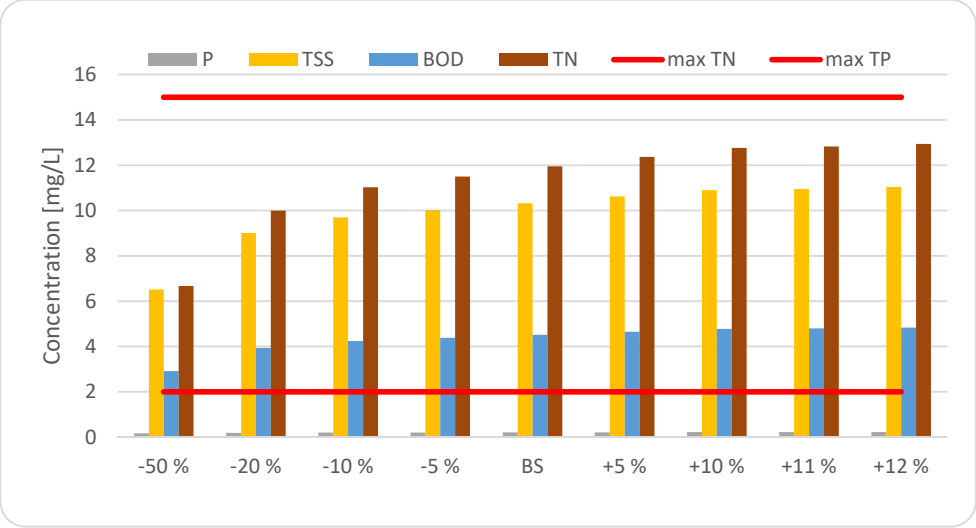


FIGURE 4.10 ANOXAN MODEL - FLOW RATE FLUCTUATIONS

TABLE 4.9
SENSITIVITY ANALYSIS OF ANOXAN MODEL – FLOW RATE FLUCTUATION

Set-up	BOD_5 Fluctuation	Influent BOD_5 mg/L	Ammonia mg/L	Nitrate mg/L	Nitrite mg/L	TN mg/L	TP mg/L	TSS mg/L	BOD_5 mg/L
2	**-50 %**	20506	2.82	1.95	0.13	6.67	0.17	6.51	2.91
3	**-20 %**	33167	5.84	2.10	0.17	10.00	0.19	9.01	3.94
4	**-10 %**	37387	6.87	2.05	0.17	11.03	0.20	9.70	4.24
5	**-5 %**	39497	7.37	2.02	0.18	11.50	0.20	10.02	4.38
1	**BS**	41607	7.83	1.98	0.18	11.95	0.21	10.32	4.52
6	**+5 %**	43817	8.28	1.94	0.18	12.37	0.21	10.62	4.65
7	**+10 %**	45927	8.69	1.90	0.18	12.76	0.22	10.90	4.78
8	**+11 %**	46349	8.77	1.89	0.18	12.83	0.22	10.95	4.80
9	**+12 %**	46982	8.89	1.88	0.18	12.94	0.22	11.04	4.84
10	**+15 %**	48037	NO SOLUTION FOUND						
11	**+20 %**	50147	NO SOLUTION FOUND						
12	**+61 %**	68798	NO SOLUTION FOUND						

The next scenarios (13 to 18) evaluated the reaction of the effluent parameters when the influent BOD_5 were changed (Figure 4.11and Table 4.10). A positive fluctuation of BOD_5 in the influent produces an increment in the effluent parameters (TP, TSS and BOD_5 – positive correlation), but reducing the amount of the effluent TN (indirect correlation). A 20% increase of BOD_5 produced 45%, 12%, 14% and -25% of TP, TSS, BOD_5 and TN, respectively. A variation below -20% of the influent BOD_5 generated more than 15 mg N/L in the effluent, exceeding the MPL.

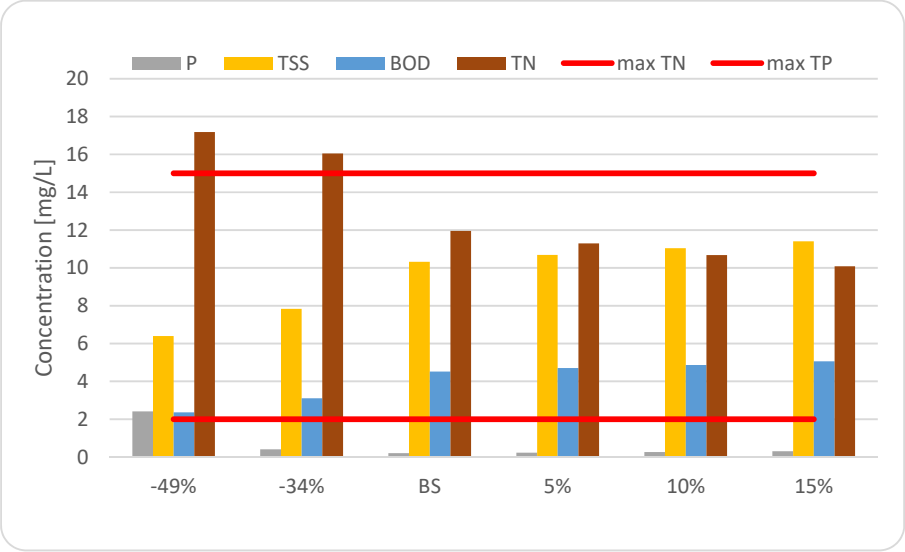


FIGURE 4.11 INFLUENT BOD_5 FLUCTUATIONS

TABLE 4.10
SENSITIVITY ANALYSIS OF ANOXAN MODEL – BOD_5 FLUCTUATION

Set-up	BOD_5 Fluctuation	Influent BOD_5 mg/L	Ammonia mg/L	Nitrate mg/L	Nitrite mg/L	TN mg/L	TP mg/L	TSS mg/L	BOD_5 mg/L
13	**- 49%**	189.3	10.40	4.86	0.28	17.18	2.41	6.40	2.36
14	**- 34%**	245.8	10.91	3.13	0.25	16.05	0.41	7.84	3.11
--	**BS**	370.5	7.83	1.98	0.18	11.95	0.21	10.32	4.52
15	**+ 5%**	389.1	7.33	1.81	0.17	11.29	0.23	10.69	4.7
16	**+ 10%**	407.5	6.86	1.65	0.16	10.68	0.26	11.04	4.87
17	**+ 15%**	426.6	6.42	1.48	0.16	10.08	0.31	11.40	5.06
18	**+ 20%**	445.0	6.00	1.33	0.15	9.54	0.38	11.75	5.23

The simulated scenarios (19 to 24) evaluated the behaviour of the process when the influent TP fluctuated from -20 % to +20% (Shown in Table 4.11 and Figure 4.12). A reduction of TP in the influent generated an adverse environment for PAO, which leads to an increase in the amount of TP in the effluent. On the other hand, an increase of TP would keep a similar environment for PAO. A 20 % decreasing of TP in the influent produced an increment of 52% of TP in the effluent (indirect correlation). The other effluent characteristics remained similar when the influent TP changed in the mentioned scenarios.

TABLE 4.11
SENSITIVITY ANALYSIS OF ANOXAN MODEL – PHOSPHOROUS FLUCTUATION

Set-up	TP Fluctuation	Influent TP mg/L	Ammonia mg/L	Nitrate mg/L	Nitrite mg/L	TN mg/L	TP mg/L	TSS mg/L	BOD_5 mg/L
19	**- 20 %**	4.72	7.88	1.83	0.18	11.81	0.44	10.24	4.48
20	**- 10 %**	5.31	7.80	1.92	0.18	11.83	0.27	10.30	4.50
21	**- 5 %**	5.61	7.80	1.95	0.18	11.88	0.23	10.31	4.51
--	**BS**	5.90	7.83	1.98	0.18	11.95	0.21	10.32	4.52
22	**+5 %**	6.20	7.59	2.07	0.18	11.80	0.20	10.33	4.53
23	**+10 %**	6.49	7.95	2.04	0.18	12.13	0.20	10.34	4.54
24	**+20 %**	7.08	8.04	2.09	0.18	12.30	0.21	10.35	4.55

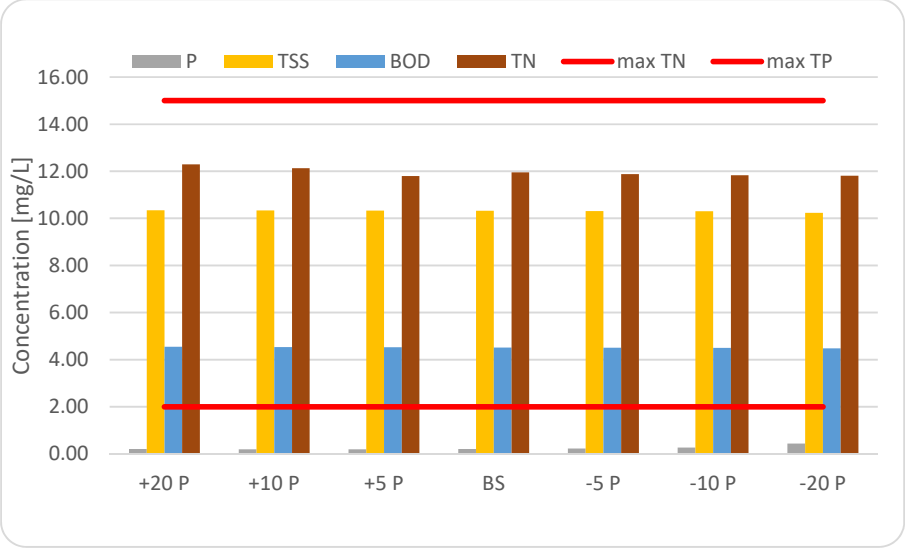


FIGURE 4.12 INFLUENT PHOSPHOROUS FLUCTUATION

The next scenarios (25 to 30) showed the analysis for the influent TKN and how this variation could affect the effluent parameters (shown in Table 4.12 and Figure 4.13). The fluctuation of TKN in the influent produces increment in the TN of the effluent as displayed in the 30th scenario, where an increment of 20% in the influent TKN produced a variation of 56% in the effluent TN (direct correlation). The other parameters stayed similar to the base scenario, showing no correlation between them. Increasing more than 10% of the influent TKN affected the effluent TN, giving it a value higher than 15 mg/L (exceeding the MPL).

TABLE 4.12
SENSITIVITY ANALYSIS OF ANOXAN MODEL – TKN FLUCTUATION

Set-up	TKN Fluctuation	Influent TKN mg/L	Ammonia mg/L	Nitrate mg/L	Nitrite mg/L	TN mg/L	TP mg/L	TSS mg/L	BOD_5 mg/L
25	**-20 %**	33.92	3.86	1.20	0.14	6.98	0.21	10.31	4.51
26	**-10 %**	38.16	5.59	1.64	0.16	9.25	0.21	10.32	4.52
27	**-5 %**	40.28	6.63	1.82	0.17	10.54	0.21	10.32	4.52
--	**BS**	42.40	7.83	1.98	0.18	11.95	0.21	10.32	4.52
28	**+5 %**	44.52	8.85	2.18	0.19	13.22	0.21	10.33	4.52
29	**+10 %**	46.64	11.43	2.02	0.20	15.62	0.20	10.39	4.47
30	**+20 %**	50.88	13.94	2.37	0.21	18.65	0.21	10.33	4.52

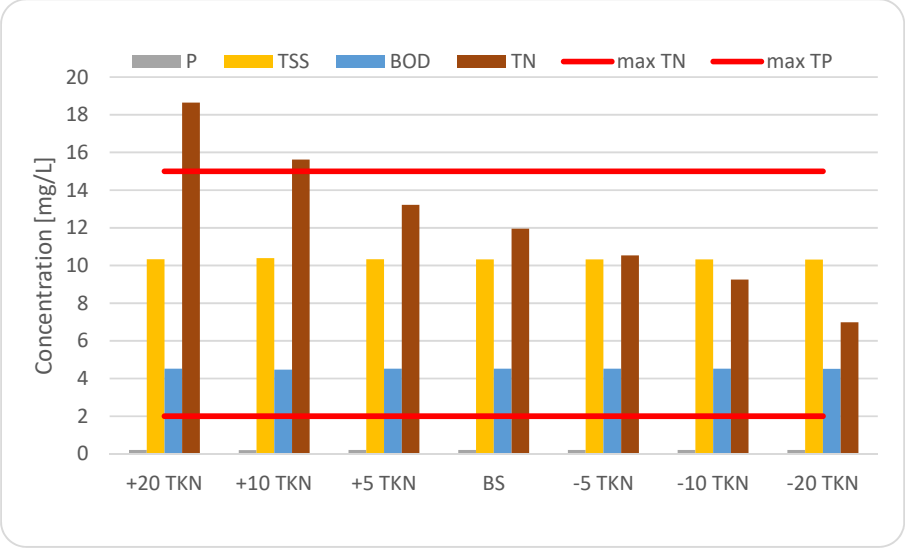


FIGURE 4.13 INFLUENT TKN FLUCTUATION

CHAPTER 5

5. DISCUSSION

5.1. Current Process

The Operation and Maintenance office of The Wastewater Treatment Plant of Cusco mentioned that the WWTP has a robust design and treatment process related to the discharge regulations of Peru. Regarding that affirmation, the obtained models were tested in different scenarios, as is explained in the following paragraphs.

Slade et al. suggested the minimum ratio – BOD5:N:P = 100:5:1 – for a suitable biological aerobic process. This one was checked for the current process and the obtained ratio (100:11.4:1.6) is within the range to have a proper aerobic bacteria behaviour.

The first simulation showed that the obtained effluent parameters converge to the raw data. Additionally, an adaptation method was utilised to convert the first model into the consolidated one. This method helps to minimise the mathematical processes within the iterations to solve the simulation. Thereby, both models showed the same parameters inside the biological treatment. This consolidated model displayed 20.75 mg TSS/L and 24.94 mgBOD_5/L for the effluent, fulfilling the actual permissible limits of BOD_5 and TSS (both 30 mg/L). **The first objective of this research was reached with the simulation of the consolidated model.**

Previous versions of the Discharge Regulations set values of nutrients such as 3.7 mg/L for Ammonia N and 0.15 mg/L for total Phosphate. Nevertheless, recent documents do not take into account these values. Hence, for this research, the benchmark parameters are 15 mg/L for TN and 2 mg/L for TP (giving by European regulation Directive 91/271/EEC). Due to these fixed parameters, the consolidated model that had annual average values of 26.57 mg N/L and 1.7 mg P/L for TN and TP, respectively; exceeded one of the maximum permissible limits (MPL).

The sensitivity analysis reinforced what was explained in Section 3.1 of the Methodology, that the WWTP is working above its limits regarding the design (average flow rate of 38 534 m^3/d and peak flow rate of 69 293 m^3/d). Indeed, the WWTP showed to be robust and worked 9.5% (42 202 m^3/d) above its designed average flow rate. Nevertheless, the sensitivity analysis demonstrated that the WWTP process is susceptible to fluctuations higher than 9% for the influent flow rate and 7% for the influent BOD_5; giving results beyond the MPL for the effluent nutrients. This analysis also showed that the effluent nutrients (TP and TN) were sensitive to

fluctuations in the influent TP and TKN, respectively. **Therefore, the second objective of this research was achieved with the results of the sensitivity analysis**.

This process is robust for the actual conditions and its wastewater treatment achieve the actual discharge regulations of Peru. The statement mentioned by the operator of the WWTP in the first paragraph of this section can be asseverated with the previous results. Hence, the first two objectives of this research were achieved with the BioWin simulation. However, a third stage of the WWTP needs to be designed and built to ensure the treatment of the future increased wastewater flow rate. This new stage has to take into account the BNR; the AnoxAn option is discussed in the following section.

5.2. AnoxAn Process

This process was chosen to retrofit the WWTP to a BNR plant because it will use the existing structures, change the PS into a mixed anaerobic, anoxic and aerobic reactor; and adapt the old existed secondary clarifier to receive the flow from the PTFs and kick it back to the STFs. The process works with ratios of 0.071 and 0.009 for influent TKN:TCOD and TP:TCOD, respectively (Diez-Montero et al., 2019); similar ratios (TKN/TCOD = 0.056 and TP:TCOD = 0.008) were obtained for the current WWTP that worked for the AnoxAn process. Furthermore, the literature suggests the minimum ratio of 20:1 for BOD_5:TP (Curtin et al., 2011) for PAOs appropriate environment and behaviour; the current WWTP has a higher ratio (63:1) which is useful for PAOs growth. **Consequently, this method fulfils the statement of the third objective of this research.**

The scenarios based on the MPS without aerobic zone showed that the effluent BOD_5 was reduced significantly when the SB was set to zero; the TSS declined due to the lamella function that retains biomass and suspended solids. A practical value for SB, as mentioned in the literature (Diez-Montero et al., 2019) that keeps a regular BOD_5 (carbon source) and biomass, is 30% of the influent flow. These parameters are essential in this type of BNR.

More scenarios were simulated varying the aerobic volumes (AV) within the anoxic zone. The range, where the treatment of TP occurred, was from 44.1% to 48.4% of the anoxic zone (outside this range no P was treated). In order to minimise the utilisation of oxygen, the rate of 44.1% of the anoxic zone was taken as the optimum value for the AV.

Using less DO in the aerobic zone can reduce the cost of the biological process. The simulation showed that less than 0.75 mg/L of DO in the AV could decrease the efficiency of BNR and surpassed the MPL of TN (15 mg/L). For this reason, the DO in the AV was set to 1.75 mg/L

to have a safety factor. **Hence, the fourth objective was satisfied with the design and simulation of the AnoxAn process.**

The sensitivity analyses were conducted by changing the influent parameters such as flow rate, BOD_5, TP and TKN. Similarly to the examination of the consolidated model, this simulation showed that this biological process is sensitive to more than 12 % increase in the average flow rate due to a low value of HRT (a value less than one hour generates an adverse environment to bacteria proliferation). Moreover, the MPL for the effluent TN is surpassed when the BOD_5 in the influent is more 15 % regarding its base scenario, or when the influent TKN went up 10% of its base scenario value. **This process examination showed a robust design; therefore, the fifth objective was achieved with the sensitivity analysis of the AnoxAn process.**

The AnoxAn process worked as mention in the literature. The oxidising nitrogen processes were held in the anoxic zone, helped by the nitrate-rich stream that was kicked back from the STF. Furthermore, the behaviour of PAO showed that the phosphate release took place within the anaerobic and anoxic zones to continue the phosphate uptake in the aerobic reactor, PTF and STF. (completing the EBPR). **Hence, this process represents the BNR in the simulated WWTP and achieves the main aim of this research.**

5.3. Error Analysis overview

This research is based on mathematical simulations that run iterations of mass balance with nested streams; utilising statistical characteristics of wastewater based on monthly measurements. Two types of errors are considered in this research:

5.3.1. Raw Data error

The measurement of the concentration of phosphorous and nitrogen in the wastewater was an issue since the beginning of the research due to those nutrients are not in the Discharge Regulations. The concentration of TP was taken from the construction contract of the actual WWTP (Appendix I). The value of TN was assumed as equal to TKN in the influent; even though the concentration on TN was requested to SedaCusco, the sent values were TKN (6 months). Two years data were utilised for the simulation because of the WWTP, in previous years, was in a commissioning phase.

5.3.2. Systematic error

The cause for this error is related to issues in the measurement equipment or gaps in the experiment design.

This error might appear if the laboratories do not calibrate their tools and equipment.

The source code of the software might have some assumption or simplifications that the user does not take into account leading to systematic errors. Those are not realised in the simulation until an expert in the field analysis the results. However, some parameters (section 3.4) were adjusted to avoid over-optimistic outcomes, as was suggested in the literature (Diez-Montero et al., 2019).

The first error could be absorbed by the sensitivity analysis; working with different scenarios and fluctuation of the influent parameters; however, it is still a data error. The second one is more difficult to reduce due to its nature.

5.4. Future Research

This research is focussed in the BNR in the liquid phase of the WWTP. A scaled model might be needed to test and validate the obtained result of the AnoxAn process.

There are still some issues related to biosolids and biogas such as disposal of treated "dried cake" and burning of biogas. Furthermore, investigations on a small scale are suggesting that wastewater streams have a vast amount of potential energy. This one could be harvested using electrochemistry (Shizas and Bagley, 2004, Heidrich et al., 2011, Aquino Neto et al., 2018, Lu et al., 2018, Mohan et al., 2016). These are an enormous opportunity to further investigation, taking into account the circular economy and zero waste theory.

CHAPTER 6

6. CONCLUSION

Due to issues such as eutrophication and more strict discharge regulations, the retrofitting of Cusco's Wastewater Treatment Plant to a Biological Nutrient Removal process is considered. This process was selected due to its low operational cost and the option for upgrading the existing structures, such as primary settlers and trickling filters, to reduce the construction footprint. Several simulations were run to characterise the current and the proposed WWTP.

Models of the existing process were simulated to obtain mathematical representations that fulfil the biological treatment stage meticulously. A consolidated model was tested and effluent parameters values within the statistics of the real output stream's characteristics of the process were obtained. The obtained data was the base scenario for the sensitivity analysis and it was found, as was mentioned by the WWTP operator, that future issues might occur if the flow rate is increased by ten per cent as the effluent's parameters may exceed the discharge regulations. Thus, this may lead to environmental problems near the discharge area and monetary fines to the operator. The process is also sensitive to a nine per cent increase of the BOD_5; hence, the influent for this WWTP may contain a low concentration of BOD_5, such as that from municipal wastewater.

Among the BNR processes, the AnoxAn one was selected because it would require an additional clarifier between two sequential trickling filters and a modified primary settler. The intermediate clarifier would be retrofitted from the 1985 existing structure. The process requires nested recycle streams that would promote the growth of different bacteria (PAO, AOB and NOB); these organisms can biological remove the nutrients. Various percentages of the recycle streams, aerobic volumes and DO were simulated, obtaining for this case study the following values SB of 30%, AV of 44.1% of the combined anoxic-aerobic zone and DO of 1.75 mg/L for the aerobic zone. This process is sensitive to a 12% increase in the flow rate due to the reduction of HRT below to one hour that would generate issues to the biomass growth; Moreover, the BOD_5 and TKN fluctuations above 20% and 10%, respectively, would exceed the TN of the European discharge regulation that was taken as a benchmark (TN = 15 mg/L, TP = 2 mg/L). In this research, the errors generated by the data collection and the systematic error could not be decreased.

REFERENCES

AQUINO NETO, S., REGINATTO, V. & DE ANDRADE, A. R. 2018. Chapter 12 - Microbial Fuel Cells and Wastewater Treatment. *In:* MARTÍNEZ-HUITLE, C. A., RODRIGO, M. A. & SCIALDONE, O. (eds.) *Electrochemical Water and Wastewater Treatment.* Butterworth-Heinemann.

BIOWIN. *BioWin Help Manual* [Online]. Available: http://www.envirosim.com/downloads/BW5Manual.pdf [Accessed 2019].

CURTIN, K., DUERRE, S., FITZPATRICK, B. & MEYER, P. 2011. Biological Nutrient Removal. *Minnesota Pollution Control*.

DAIGGER, G. T. & BOLTZ, J. P. 2011. Trickling filter and trickling filter-suspended growth process design and operation: A state-of-the-art review. *Water Environment Research,* 83**,** 388-404.

DIEZ-MONTERO, R., CASTRILLO, M., CASAO, M. & TEJERO, I. 2019. Model-based evaluation of a trickling filter facility upgrade to biological nutrient removal. *Science of the Total Environment,* 661**,** 187-195.

EL_DIARIO_DEL_CUSCO. Published on Jun 30, 2014. SedaCusco treinta años de servicio y permanente compromiso de mejorar la vida de los habitantes del Cusco.

EUROPEAN_UNION 21 May 1991. *Council Directive 91/271/EEC concerning urban wastewater treatment*, Official Journal L 135, 30/05/1991.

HEIDRICH, E., CURTIS, T. P. & DOLFING, J. 2011. Determination of the Internal Chemical Energy of Wastewater. *Environmental Science & Technology,* 45**,** 827-832.

HU, Z., HOUWELING, D. & DOLD, P. 2012. Biological Nutrient Removal in Municipal Wastewater Treatment: New Directions in Sustainability. *Journal of Environmental Engineering,* 138**,** 307-317.

INEI. *Poblacion 2000 al 2015* [Online]. Available: https://proyectos.inei.gob.pe/web/poblacion/ [Accessed 2018].

INEI. Updated Set 2017. *Increment of 80.9% to 87.8% of drinking water in the last five years* [Online]. Available: https://www.inei.gob.pe/prensa/noticias/acceso-al-agua-por-red-publica-en-los-hogares-se-incremento-de-809-a-878-en-los-ultimos-cinco-anos-9972/ [Accessed 2018].

LEMA, J. M. & SUAREZ, S. 2017. *Innovative wastewater treatment & resource recovery technologies: impacts on energy, economy and environment,* London, UK, IWA Publishing.

LINDEBURG, M. R. 2014. *Civil engineering reference manual for the PE exam Fourteenth Edition,* Belmont, Profesional Publications, Inc.

LOOSDRECHT, M. C. M. V., NIELSEN, P. H., LÓPEZ VÁZQUEZ, C. M. & BRDJANOVIC, D. 2016. *Experimental methods in wastewater treatment,* London, IWA Publishing.

LOPEZ-VAZQUEZ, C. M., OEHMEN, A., HOOIJMANS, C. M., BRDJANOVIC, D., GIJZEN, H. J., YUAN, Z. & VAN LOOSDRECHT, M. C. M. 2009. Modeling the PAO–GAO competition: Effects of carbon source, pH and temperature. *Water Research,* 43**,** 450-462.

LOTTI, T., KLEEREBEZEM, R., LUBELLO, C. & VAN LOOSDRECHT, M. C. M. 2014. Physiological and kinetic characterization of a suspended cell anammox culture. *Water Research,* 60**,** 1-14.

LU, L., GUEST, J. S., PETERS, C. A., ZHU, X., RAU, G. H. & REN, Z. J. 2018. *Wastewater treatment for carbon capture and utilization*, Nature Sustainability.

MASCO-ARRIOLA, M. L. 2017. *Determinación de Contaminantes Tensioactivos Tipo Ácido Dodecilbenceno Sulfónico Lineal en Aguas del Río Huatanay - Cusco.* DOCTORIS SCIENTIAE EN CIENCIA, TECNOLOGÍA Y MEDIO AMBIENTE, UNIVERSIDAD NACIONAL DEL ALTIPLANO.

MOHAN, S. V., BUTTI, S. K., AMULYA, K., DAHIYA, S. & MODESTRA, J. A. 2016. Waste Biorefinery: A New Paradigm for a Sustainable Bioelectro Economy. *Trends in Biotechnology,* 34**,** 852-855.

MORGAN, S. 1998. *Upgrading a Trickling Filter Wastewater Treatment Plant to Biological Nutrient Removal Standard.* Master of Environmental Studies, University of Tasmania.

MORGAN, S., FARLEY, R. & PEARSON, R. 1999. Retrofitting an existing trickling filter plant to BNR standard - Selfs Point, Tasmania's first. *Water Science and Technology,* 39**,** 143-150.

PARSONS, S. A. & SMITH, J. A. 2008. Phosphorus Removal and Recovery from Municipal Wastewaters. *Elements,* 4**,** 109-112.

QIU, L., ZHENG, P., ZHANG, M., YU, X. & ABBAS, G. 2015. Phosphorus removal using ferric–calcium complex as precipitant: Parameters optimization and phosphorus-recycling potential. *Chemical Engineering Journal,* 268**,** 230-235.

RIFFAT, R. 2013. *Fundamentals of Wastewater Treatment and Engineering*, Boca Raton, Fla. : CRC Press ; London : Co-published by IWA Publishing.

SHIZAS, I. & BAGLEY, D. M. 2004. Experimental determination of energy content of unknown organics in municipal wastewater streams. *Journal of Energy Engineering,* 130**,** 45-53.

SLADE, A. H., THORN, G. J. S. & DENNIS, M. A. 2011. The relationship between BOD:N ratio and wastewater treatability in a nitrogen-fixing wastewater treatment system. *Water Science and Technology,* 63**,** 627-632.

TAKAHASHI, Y. & GIBU, J. Updated Jun 2016. *Sector: Water and Sanitation* [Online]. Available: https://www.jica.go.jp/peru/espanol/activities/c8h0vm00009rmewp-att/activity05_03.pdf [Accessed 2018].

TCHOBANOGLOUS, G., STENSEL, H. D., TSUCHIHASHI, R., BURTON, F. L., ABU-ORF, M., BOWDEN, G., PFRANG, W., METCALF & EDDY 2014. *Wastewater engineering: treatment and resource recovery,* New York, NY, McGraw-Hill Education.

VAN DER STAR, W. R. L., MICLEA, A. I., VAN DONGEN, U. G. J. M., MUYZER, G., PICIOREANU, C. & VAN LOOSDRECHT, M. C. M. 2008. The membrane bioreactor: A novel tool to grow anammox bacteria as free cells. *Biotechnology and Bioengineering,* 101**,** 286-294.

VAN HULLE, S. W. H., VOLCKE, E. I. P., TERUEL, J. L., DONCKELS, B., VAN LOOSDRECHT, M. C. M. & VANROLLEGHEM, P. A. 2007. Influence of temperature and pH on the kinetics of the Sharon nitritation process. *Journal of Chemical Technology and Biotechnology,* 82**,** 471-480.

WATER_ENVIRONMENT_FEDERATION 2014. *Wastewater treatment process modeling,* McGraw-Hill Education: New York, Chicago, San Francisco, Athens, London, Madrid, Mexico City, Milan, New Delhi, Singapore, Sydney, Toronto, WEF Press Water Environment Federation.

WATER_ENVIRONMENT_FEDERATION 2017. *Operation of water resource recovery facilities, Manual of Practice No. 11,* New York, McGraw-Hill Education.

Appendix I

PARAMETERS OF INFLUENT AND EFFLUENT OF WWTP

El Río Huancaro, aguas arriba, recibe como efluente al Río Chocco el cual ha tenido poca influencia de contaminantes, en comparación a los demás.

A fin de tener un perfil completo, en los siguientes textos y gráficas se presenta el cauce principal del Huancaro-Huatanay como una unidad (figura 1).

Análisis de DBO_5

Los resultados de las mediciones de DBO_5 en los puntos de muestreo, así como datos de análisis anteriores (para los Ríos Chocco, Huancaro y Tullumayo), se presentan en la Tabla 2.

Tabla 2. Resultados de DBO_5 en el Río Huatanay y sus afluentes

	Puntos de muestreo en el Cauce Principal	DBO_5 (mg/L)
	Río Chocco	11
	Río Huancaro	35
A	Descarga Río Chocco al Huancaro	22
	Río Tullumayo	204
B	Descarga Río Tullumayo	74
C	Santa Rosa (San Sebastián)	148
D	San Jerónimo (2 km antes de PTAR)	216
E	PTAR	74
F	200 metros después de la PTAR	61
G	1 km. Después de la PTAR	55
H	Distrito de Saylla	154
I	Confluencia Ríos Huatanay y Vilcanota	40

El Río Chocco con una concentración de 11 mg/L DBO_5 se une con el Río Huancaro que trae 35 mg/L DBO_5, resultando este último, dos kilómetros mas abajo, con una concentración de 22 mg/L DBO_5 (A).

Cuatro kilómetros aguas abajo, el Río Tullumayo con 204 mg/L DBO_5 descarga en el río Huancaro el cual trae una concentración de 147 mg/L DBO_5, dando como resultado una concentración de DBO_5 en el Río Huatanay de 74 mg/L (B).

El Rio Huatanay recibe todas las descargas del Cusco alcanzando en Santa Rosa (C) una DBO_5 de 148 mg/L y 2 kilómetros antes de la PTAR (D) alcanza el valor máximo de 216 mg/L. (Este valor es altísimo y corresponde a una dilución teórica de 1:1).

El efluente de la PTAR diluye la concentración del Río Huatanay a 55 mg/L (G). Algunos kilómetros después, el Río Huatanay recibe las descargas de Saylla, incrementando su concentración de DBO_5 a 154 mg/L. Los valores de DBO_5 del Río Huatanay decrecen después de Saylla hasta su confluencia con el Río Vilcanota.

Esta secuencia se muestra con mayores detalles en la Figura 1.

FIGURE A 1 DBO_5 BEFORE PROJECT – DIFFERENT LOCATIONS

Análisis de SST

Los resultados de las mediciones de SST de los puntos de muestreo, se muestran en la Tabla 3.

Tabla 3. Resultados de SST en el Río Huatanay y sus afluentes

	Puntos de Muestreo	SST (mg/L)
A	Descarga Río Chocco	82
B	Descarga Río Tullumayo	174
C	Santa Rosa (San Sebastián)	196
D	San Jerónimo (2 km antes de PTAR)	750
E	PTAR	106
F	200 metros después de la PTAR	150
G	1 km. Después de la PTAR	138
H	Distrito de Saylla	264
I	Confluencia Ríos Huatanay y Vilcanota	58

De la misma forma como se mencionó para la curva de DBO_5, la concentración de SST alcanza su máximo valor en la estación D, después de recibir todos los efluentes del Cusco y antes de entrar a la PTAR. La concentración de SST se incrementa nuevamente en la población de Saylla. La Figura 2 esquematiza la curva de concentraciones de SST, medidas a lo largo del río.

Figura 2. Datos de Monitoreo de Calidad de Agua del Río Huatanay – SST

FIGURE A 2 SST BEFORE PROJECT – DIFFERENT LOCATIONS

Análisis de PO_4^{-3}

Los resultados de las mediciones de PO_4^{-3} de los puntos de muestreo, se muestran en la Tabla 4. Hay que precisar que el valor medido es de ortofosfatos libres y no de fósforo total presente, que es aproximadamente, diez veces superior.

Tabla 4. Resultados de PO_4 en el Río Huatanay y sus afluentes

	Puntos de Muestreo	PO_4^{-3} (mg/L)
A	Descarga Río Chocco	0.10
B	Descarga Río Tullumayo	0.30
C	Santa Rosa (San Sebastián)	0.50
D	San Jerónimo (2 km antes de PTAR)	0.59
E	PTAR	0.20
F	200 metros después de la PTAR	0.25
G	1 km. Después de la PTAR	0.26
H	Distrito de Saylla	0.31
I	Confluencia Ríos Huatanay y Vilcanota	0.19

Al igual como se mencionó para las curvas de DBO_5 y SST, la curva de concentraciones de PO_4^{-3} alcanza su máximo valor en la estación D después de que recibe las descargas de Cusco y antes de entrar a la PTAR. La concentración de PO_4 incrementa de nuevo en la población de Saylla. La Figura 3 muestra las concentraciones de PO_4^{-3} medidas en los puntos de muestreo.

Figura 3. Datos de Monitoreo de Calidad de Agua del Río Huatanay PO_4^{-3}

FIGURE A 3 PO4 BEFORE PROJECT – DIFFERENT LOCATIONS

ANALISIS COMPARATIVO DE LOS AÑOS 2003-2004-2005

PORCENTAJE DE REMOCIÓN DE DBO5.

AÑO	Afluente	Efluente	% de remoción
2005	263.06	99.12	60.83
2004	232.28	71.88	69.05
2003	256.37	99.49	61.49
PROMEDIO	247.91	90.16	63.79

DEMANDA BIOQUÍMICA DE OXÍGENO-% DE REMOCIÓN
AFLUENTE - EFLUENTE
AÑOS 2003-2004- 2005

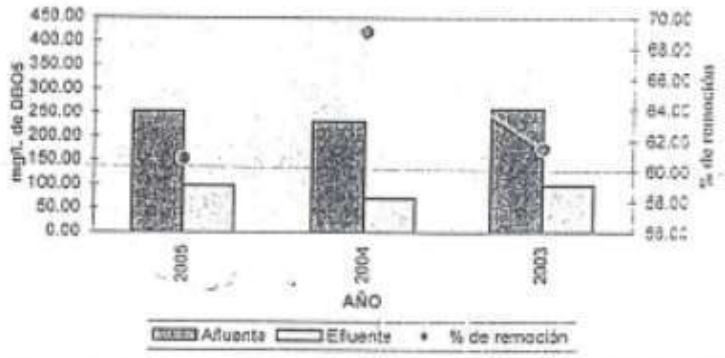


FIGURE A 4 INFLUENT AND EFFLUENT DBO5 BEFORE THE PROJECT

Appendix II

DISCHARGE REGULATIONS

ESTÁNDARES NACIONALES DE CALIDAD AMBIENTAL PARA AGUA
CATEGORÍA 1: POBLACIONAL Y RECREACIONAL

PARÁMETRO	UNIDAD	Aguas superficiales destinadas a la producción de agua potable			Aguas superficiales destinadas para recreación	
		A1	A2	A3	B1	B2
		Aguas que pueden ser potabilizadas con desinfección	Aguas que pueden ser potabilizadas con tratamiento convencional	Aguas que pueden ser potabilizadas con tratamiento avanzado	Contacto Primario	Contacto Secundario
		VALOR	VALOR	VALOR	VALOR	VALOR
FÍSICOS Y QUÍMICOS						
Aceites y grasas (MEH)	mg/L	1	1,00	1,00	Ausencia de película visible	**
Cianuro Libre	mg/L	0,005	0,022	0,022	0,022	0,022
Cianuro Wad	mg/L	0,08	0,08	0,08	0,08	**
Cloruros	mg/L	250	250	250	**	**
Color	Color verdadero escala Pt/Co	15	100	200	sin cambio normal	sin cambio normal
Conductividad	us/cm (a)	1 500	1 600	**	**	**
D.B.O.$_5$	mg/L	3	5	10	5	10
D.Q.O.	mg/L	10	20	30	30	50
Dureza	mg/L	500	**	**	**	**
Detergentes (SAAM)	mg/L	0,5	0,5	na	0,5	Ausencia de espuma persistente
Fenoles	mg/L	0,003	0,01	0,1	**	**
Fluoruros	mg/L	1	**	**	**	**
Fósforo Total	mg/L P	0,1	0,15	0,15	**	**
Materiales Flotantes		Ausencia de material flotante	**	**	Ausencia de material flotante	Ausencia de material flotante
Nitratos	mg/L N	10	10	10	10	**
Nitritos	mg/L N	1	1	1	1(5)	**
Nitrógeno amoniacal	mg/L N	1,5	2	3,7	**	**
Olor		Aceptable	**	**	Aceptable	**
Oxígeno Disuelto	mg/L	>= 6	>= 5	>= 4	>= 5	>= 4
pH	Unidad de pH	6,5 – 8,5	5,5 – 9,0	5,5 – 9,0	6-9 (2,5)	**
Sólidos Disueltos Totales	mg/L	1 000	1 000	1 500	**	**
Sulfatos	mg/L	250	**	**	**	**
Sulfuros	mg/L	0,05	**	**	0,05	**
Turbiedad	UNT (b)	5	100	**	100	**

UNT Unidad Nefelométrica Turbiedad

1 de 10

** Se entenderá que para esta subcategoría, el parámetro no es relevante, salvo casos específicos que la Autoridad competente determine.

MINISTERIO DEL AMBIENTE – SECRETARIO GENERAL – MINAM

MINISTERIO DEL AMBIENTE – VICEMINISTERIO GESTIÓN AMBIENTAL – MINAM

FIGURE A 5 STANDARD WATER CONSUMPTION QUALITY (MINAN, 2008)

de impuestos o de derechos aduaneros de ninguna clase o denominación.

Artículo 5º.- La presente Resolución Suprema será refrendada por el Presidente del Consejo de Ministros.

Regístrese, comuníquese y publíquese.

ALAN GARCÍA PÉREZ
Presidente Constitucional de la República

JAVIER VELASQUEZ QUESQUÉN
Presidente del Consejo de Ministros

469446-6

AMBIENTE

Aprueba Límites Máximos Permisibles para los efluentes de Plantas de Tratamiento de Aguas Residuales Domésticas o Municipales

DECRETO SUPREMO
Nº 003-2010-MINAM

implica necesariamente y según corresponda, la actualización de los planes originalmente aprobados al emitirse la Certificación Ambiental;

De conformidad con lo dispuesto en el numeral 8) del artículo 118º de la Constitución Política del Perú, y el numeral 3 del artículo 11º de la Ley Nº 29158, Ley Orgánica del Poder Ejecutivo;

DECRETA:

Artículo 1º.- Aprobación de Límites Máximos Permisibles (LMP) para efluentes de Plantas de Tratamiento de Agua Residuales Domésticas o Municipales (PTAR)

Aprobar los Límites Máximos Permisibles para efluentes de las Plantas de Tratamiento de Aguas Residuales Domésticas o Municipales, los que en Anexo forman parte integrante del presente Decreto Supremo y que son aplicables en el ámbito nacional.

Artículo 2°.- Definiciones

Para la aplicación del presente Decreto Supremo se utilizarán los siguientes términos:

- Planta de Tratamiento de Aguas Residuales Domésticas o Municipales (PTAR): Infraestructura y procesos que permiten la depuración de las aguas residuales Domésticas o Municipales.

LÍMITES MÁXIMOS PERMISIBLES PARA LOS EFLUENTES DE PTAR

PARÁMETRO	UNIDAD	LMP DE EFLUENTES PARA VERTIDOS A CUERPOS DE AGUAS
Aceites y grasas	mg/L	20
Coliformes Termotolerantes	NMP/100 mL	10,000
Demanda Bioquímica de Oxígeno	mg/L	100
Demanda Química de Oxígeno	mg/L	200
pH	unidad	6.5-8.5
Sólidos Totales en Suspensión	mL/L	150
Temperatura	°C	<35

469446-2

de conformidad con el Texto Único Ordenado de la Ley de Transparencia y Acceso a la Información Pública, aprobado por Decreto Supremo Nº 043-2003-PCM.

Artículo 2º.- Todos los órganos del Ministerio del Ambiente, bajo responsabilidad, deberán facilitar la información y/o documentación que les sea solicitada como consecuencia de lo dispuesto en el artículo precedente, dentro de los plazos establecidos en la normatividad vigente.

Artículo 3º.- Disponer que la presente Resolución se publique en el Diario Oficial El Peruano y en Portal de Internet del Ministerio del Ambiente.

Artículo 4º.- Notificar la presente Resolución a todos los órganos del Ministerio del Ambiente, al Órgano de Control Institucional y al responsable designado.

Regístrese, comuníquese y publíquese.

ANTONIO JOSÉ BRACK EGG
Ministro del Ambiente

469445-1

FIGURE A 6 DISCHARGE REGULATION (MINAN, 2010)

Numeral :
Página :

Consulta:

Confirmar que la única exigencia para la calidad de agua del efluente de la PTAR serán los niveles de concentración de DBO_5, 20º (Demanda bioquímica de Oxígeno) y SST (Sólidos Suspendidos Totales) de 30 mg/litro en ambos casos.

Respuesta:

Los parámetros y valores exigidos para la calidad en el agua del efluente de la PTAR, son los siguientes:

Valores Máximos Permisibles en el efluente de la PTAR San Jerónimo, Cusco

Parámetro a ser Controlados	Unidad	Valor Máximo Permisible
Demanda Bioquímica de Oxígeno	mgDBO_5/L	30
Demanda Química de Oxígeno	mgDQO/L	90
Sólidos suspendidos totales	mgSST/L	30
Aceites y Grasas	mg/L	30
Coliformes Fecales	NMP/100mL	1,000
Cloro Residual	mg/L	1.5
Nitrógeno Total	mgNT/L	30

Consulta No. 032-0132.15

Referencia(s) de las Bases

Sección : Visita Técnica a la PTAR
Numeral :
Página :

Consulta:

Solicitamos aclarar si se evaluará la eficiencia en la operación – global de la PTAR o por proceso o etapa de tratamiento- sin tener en cuenta la concentración real en el afluente a la PTAR de los distintos parámetros (DBO5, 20º, SST, SD – sólidos sedimentables-, coliformes, DQO, etcétera), permaneciendo inalterada la exigencia de los 30 mg/litro en DBO_5, 20º y SST. O por el contrario, la evaluación se realizará por la Supervisión, teniendo en cuenta la calidad del agua del afluente que llega a la PTAR.

Respuesta:

Durante el período de operación, SEDACUSCO realizará al menos 5 muestras compuestas mensuales del afluente y del efluente. El Contratista como operador responsable del funcionamiento de la PTAR, en el 80% de las muestras analizadas por SEDACUSCO, deberá cumplir con los límites de calidad mostrados la respuesta a Consulta No. 031-0131.15.

Consulta No. 033-0133.15

29

FIGURE A 7 DESIGN PARAMETERS OF THE WWTP, CUSCO-PERU (2012)

Appendix III

TECHNICAL DRAWINGS OF STRUCTURES

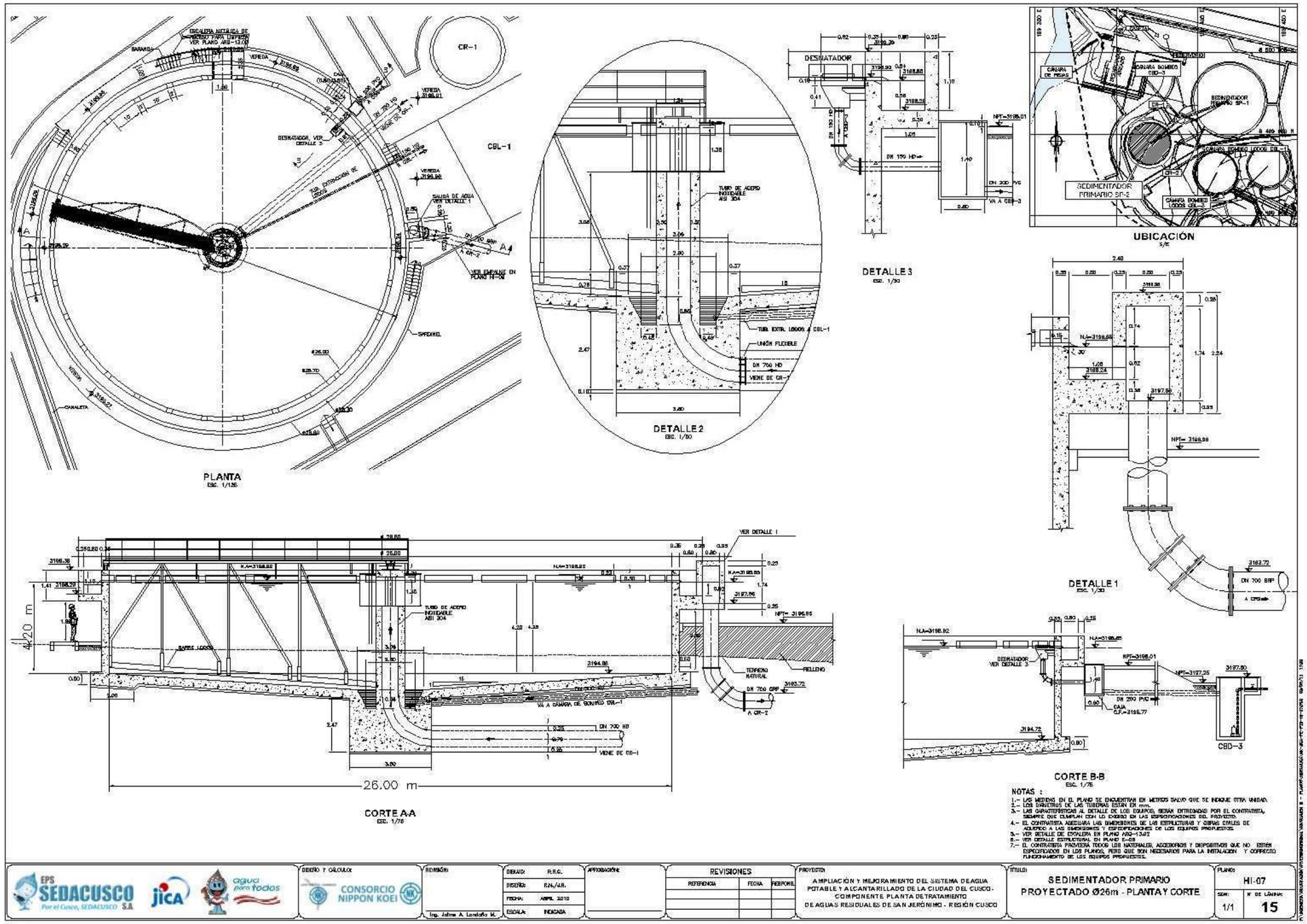


FIGURE A 8 PRIMARY SETTER D = 26 M, H = 4.2 M

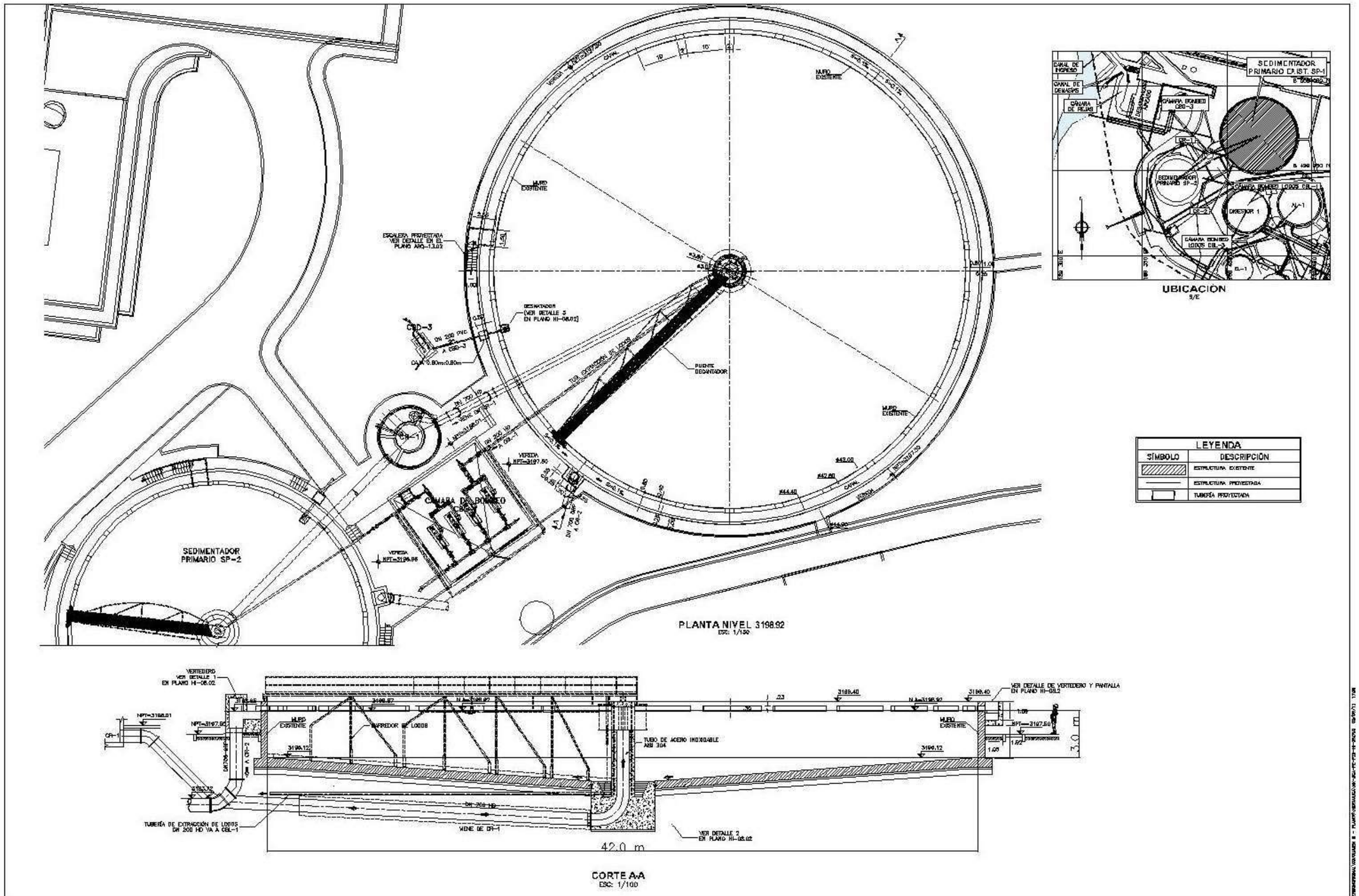


FIGURE A 9 PRIMARY SETTER D = 42 M, H = 3 M

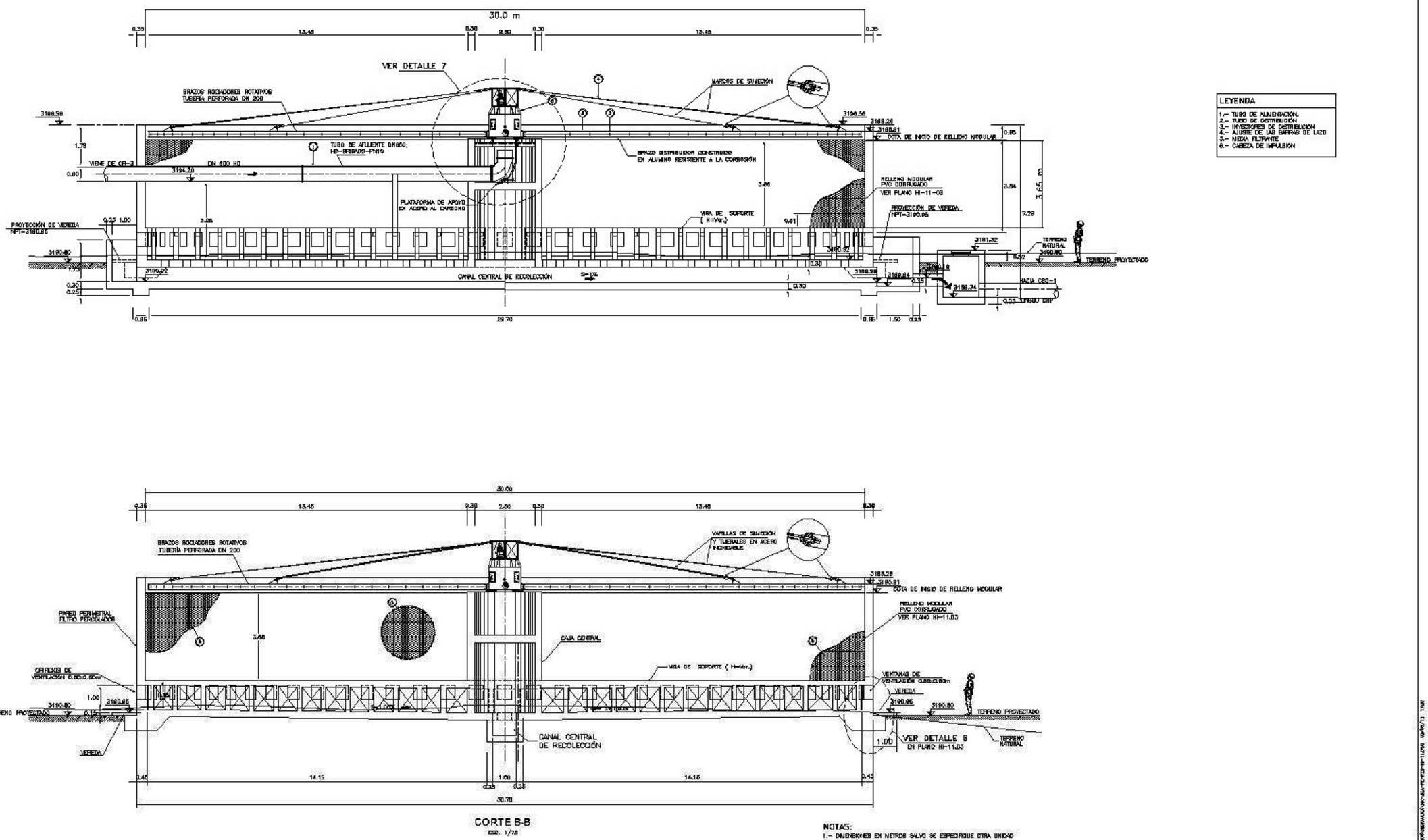
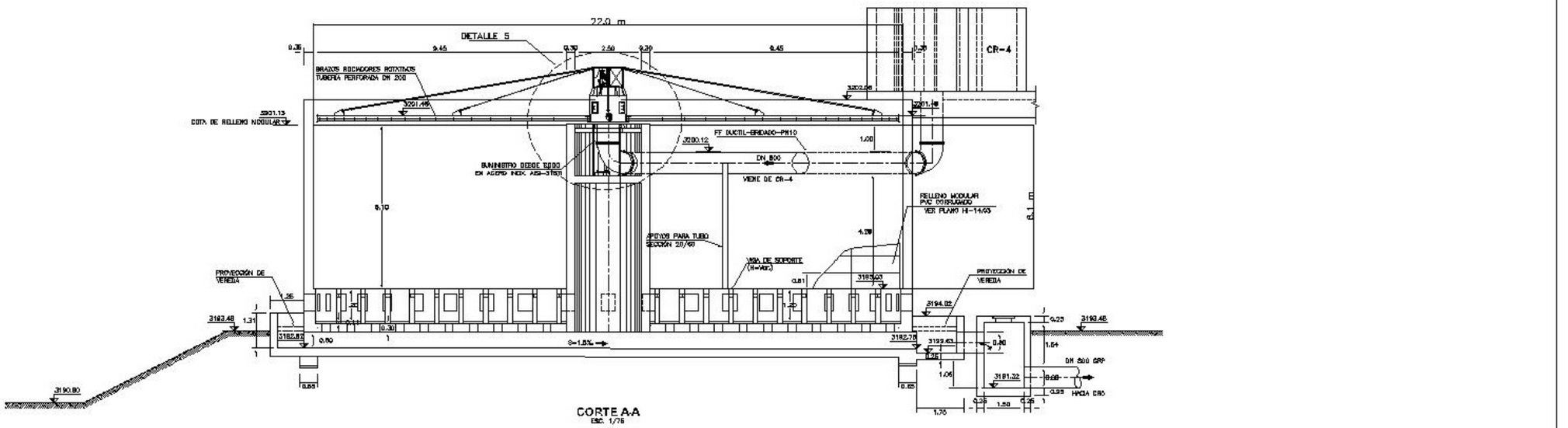
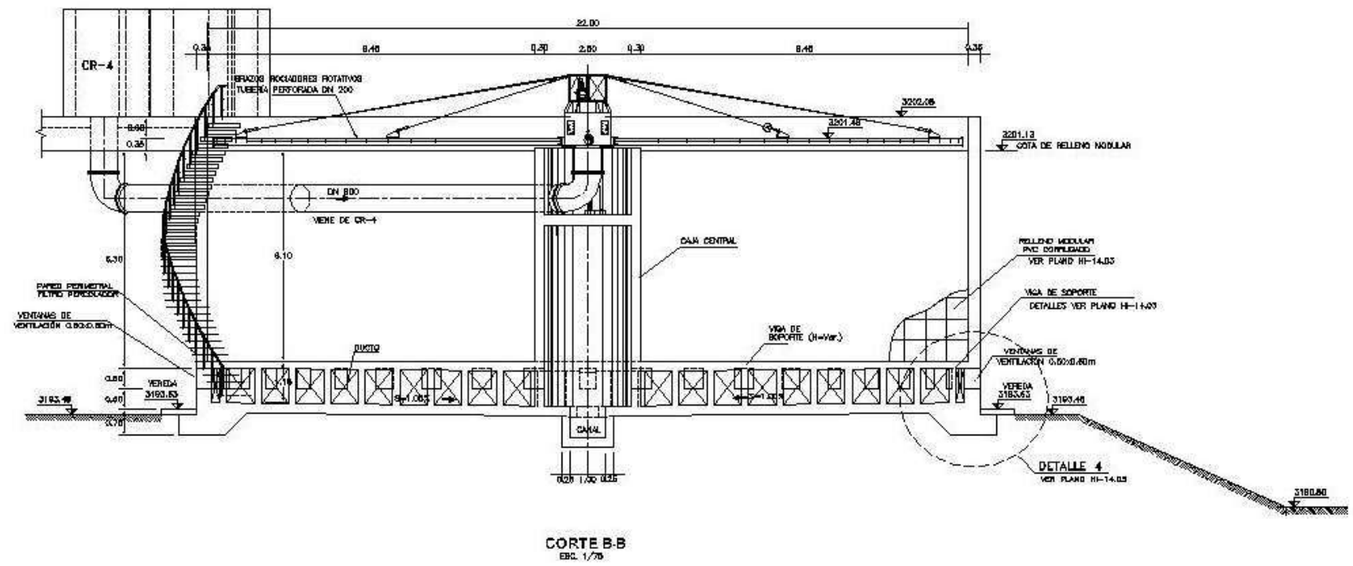


FIGURE A 10 PRIMARY TRICKLING FILTER D = 30 M, H = 3.66 M





NOTAS:

1.– DIMENSIONES EN METROS SALVO SE ESPECIFIQUE OTRA UNIDAD
2.– LOS DIÁMETROS DE LAS TUBERÍAS ESTAN EN mm.
3.– VER PLANTA EN PLANO HI–14.1
4.– VER SECCIÓNES Y DETALLES EN PLANO HI–14.3
5.– LAS CARACTERISTICAS AL DETALLE DE LOS EQUIPOS, SERÁN ENTREGADOS POR EL CONTRATISTA SIEMPRE QUE CUMPLAN CON LO EXIGIDO EN LAS ESPECIFICACIONES DEL PROYECTO.
6.– EL CONTRATISTA ADECUARÁ LAS DIMENSIONES DE LAS ESTRUCTURAS Y OBRAS CIVILES DE ACUERDO A LAS DIMENSIONES Y ESPECIFICACIONES DE LOS EQUIPOS PROPUESTOS.
7.– VER DETALLE ESTRUCTURAL EN PLANO E–19
8.– VER INSTALACIONES ELÉCTRICAS EN PLANO IE–12
9.– EL CONTRATISTA PROVEERA TODOS LOS MATERIALES, ACCESORIOS Y DISPOSITIVOS QUE NO ESTEN ESPECIFICADOS EN LOS PLANOS, PERO QUE SON NECESARIOS PARA LA INSTALACION Y CORRECTO FUNCIONAMIENTO DE LOS EQUIPOS PROPUESTOS.

EPS SEDACUSCO S.A. Por el Cusco, SEDACUSCO S.A. | JICA | agua para todos | CONSORCIO NIPPON KOEI

DISEÑO Y CÁLCULO:
DIBUJO: R.R.G. / E.A.M.
DISEÑO: R.H. / A.R.
FECHA: ABRIL 2010
ESCALA: INDICADA

REVISIÓN: Ing. Jaime A. Landaeta M.

APROBACIÓN:

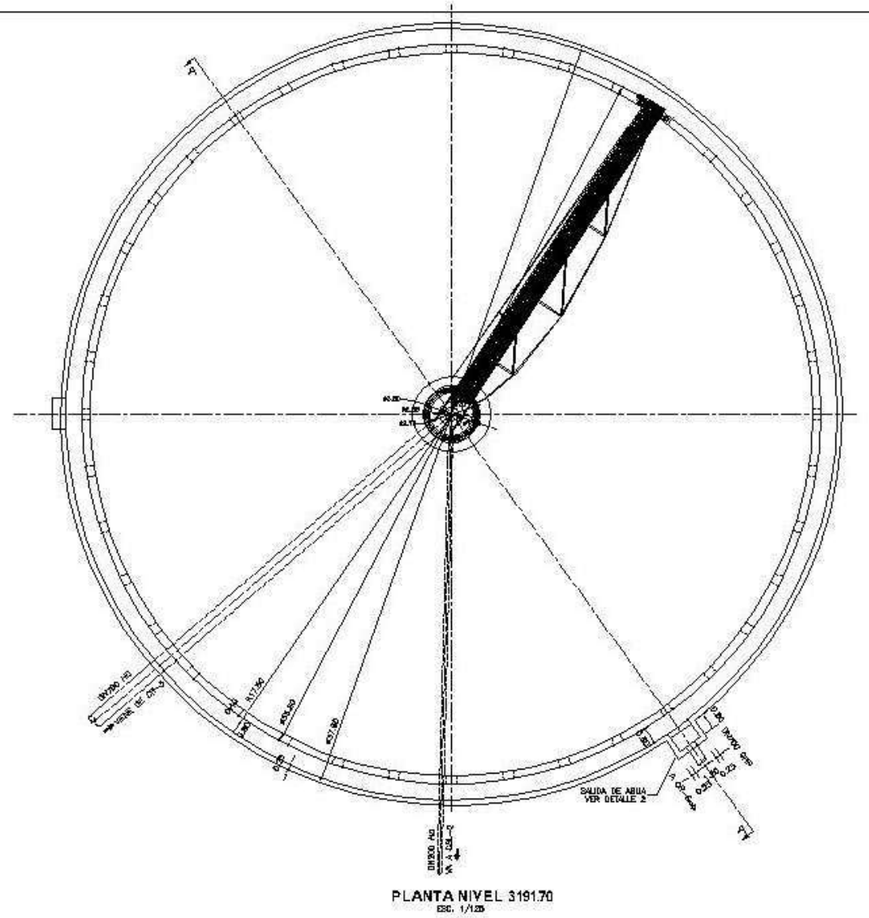
REVISIONES		
REFERENCIA	FECHA	RESPONS.

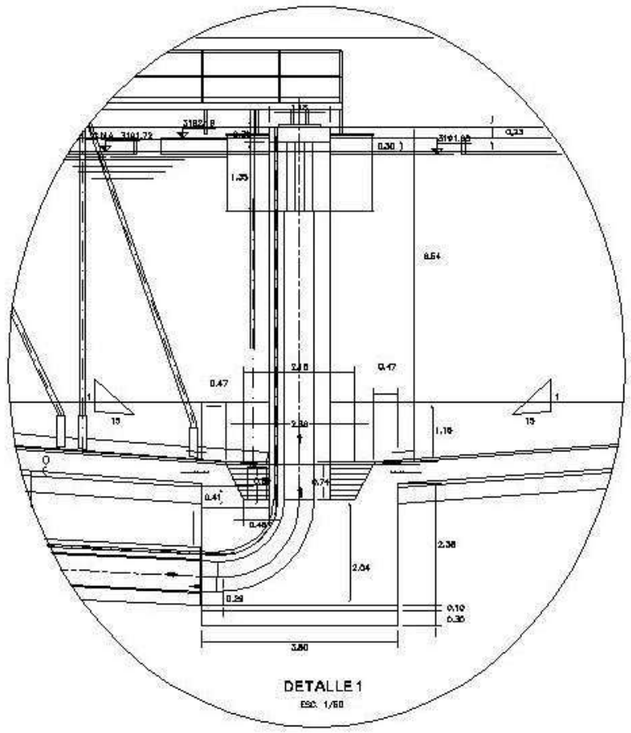
PROYECTO: AMPLIACIÓN Y MEJORAMIENTO DEL SISTEMA DE AGUA POTABLE Y ALCANTARILLADO DE LA CIUDAD DEL CUSCO - COMPONENTE PLANTA DE TRATAMIENTO DE AGUAS RESIDUALES DE SAN JERÓNIMO - REGIÓN CUSCO

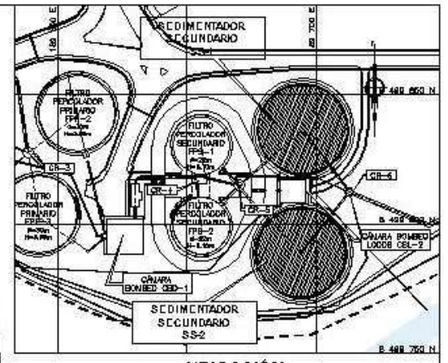
TITULO: FILTRO PERCOLADOR SECUNDARIO PROYECTADO Ø 22 m CORTES

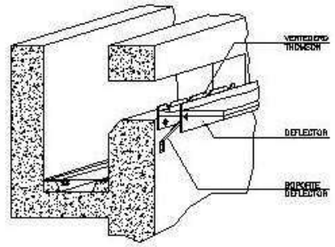
PLANO: HI-14.02
HOJA: 2/3
N° DE LÁMINA: 29

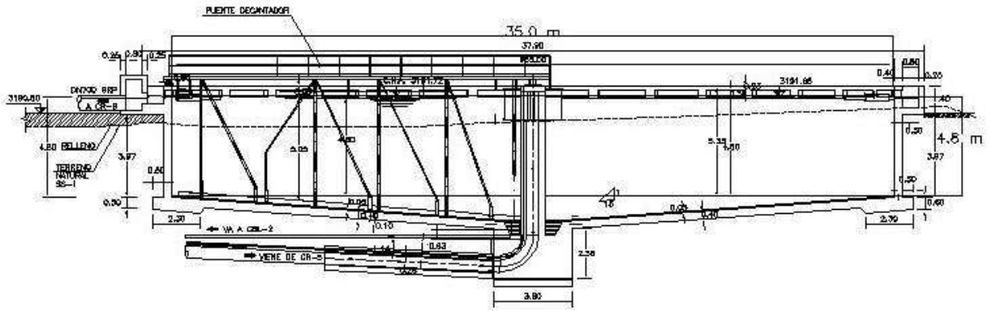
FIGURE A 11 SECONDARY TRICKLING FILTER D = 22 M, H = 6.1 M

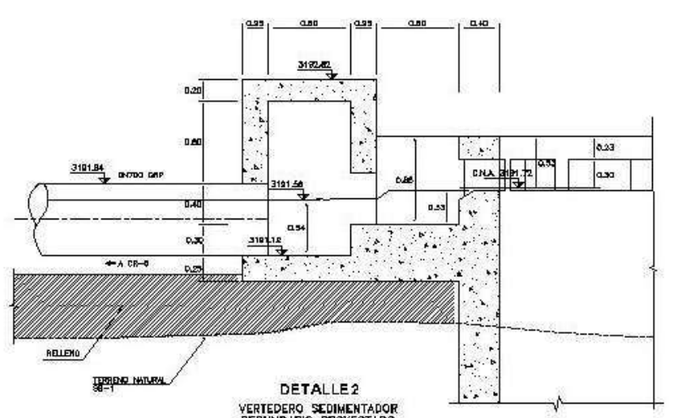












NOTAS :

1.- LAS MEDIDAS EN EL PLANO SE ENCUENTRAN EN METROS SALVO QUE SE INDIQUE OTRA UNIDAD.
2.- LOS DIAMETROS DE LAS TUBERIAS ESTAN EN mm.
3.- LAS CARACTERISTICAS AL DETALLE DE LOS EQUIPOS, SERÁN ENTREGADOS POR EL CONTRATISTA, SIEMPRE QUE CUMPLAN CON LO EXIGIDO EN LAS ESPECIFICACIONES DEL PROYECTO.
4.- EL CONTRATISTA ABECUARÁ LAS DIMENSIONES DE LAS ESTRUCTURAS Y OBRAS CIVILES DE ACUERDO A LAS DIMENSIONES Y ESPECIFICACIONES DE LOS EQUIPOS PROPUESTOS.
5.- VER DETALLE ESTRUCTURAL EN PLANO E-20.
6.- VER INSTALACIONES ELÉCTRICAS EN PLANO IE-13.
7.- EL CONTRATISTA PROVEERÁ TODOS LOS MATERIALES, ACCESORIOS Y DISPOSITIVOS QUE NO ESTÉN ESPECIFICADOS EN LOS PLANOS, PERO QUE SON NECESARIOS PARA LA INSTALACIÓN Y CORRECTO FUNCIONAMIENTO DE LOS EQUIPOS PROPUESTOS.

EPS SEDACUSCO S.A. Por el Cusco, SEDACUSCO S.A. | JICA | agua para todos

DISEÑO Y CÁLCULOS: CONSORCIO NIPPON KOEI

REVISIÓN: Ing. Jaime A. Londoño M.

DIBUJO:	R.R.G. / E.A.M.
DISEÑO:	R.N./J.R.
FECHA:	ABRIL 2010
ESCALA:	INDICADA

APROBACIÓN:

REVISIONES

REFERENCIA	FECHA	RESPONS.

PROYECTO: AMPLIACIÓN Y MEJORAMIENTO DEL SISTEMA DE AGUA POTABLE Y ALCANTARILLADO DE LA CIUDAD DEL CUSCO - COMPONENTE PLANTA DE TRATAMIENTO DE AGUAS RESIDUALES DE SAN JERÓNIMO - REGIÓN CUSCO

TITULO: SEDIMENTADOR SECUNDARIO Ø 35 m
PLANTA, CORTE

PLANO: HI-16
SEM: 1/1
N° DE LÁMINA: 32

FIGURE A 12 SECONDARY CLARIFIER D = 35 M, H = 4.8 M

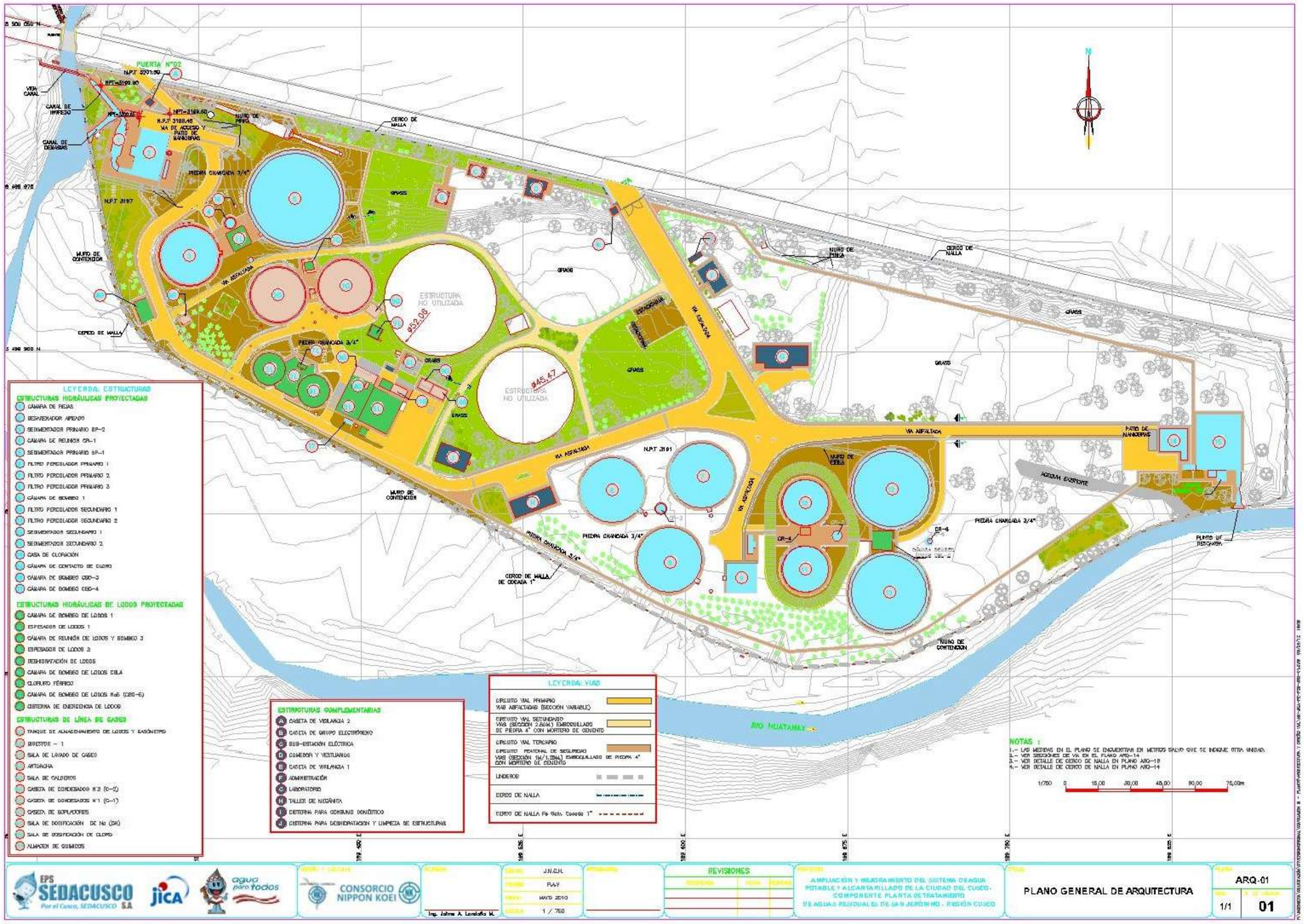


FIGURE A 13 LAYOUT OF THE WASTEWATER TREATMENT PLANT

Appendix IV

A. RAW DATA OF WWTP PROVIDED BY SEDACUSCO

1. Aceites y Grasas: Oil and Grease
2. Coliformes Fecales: Faecal coliforms
3. Demanda Bioquímica de Oxígeno: Biochemical Oxygen Demand (BOD_5)
4. Demanda Química de Oxígeno: Chemical Oxygen Demand (COD)
5. Solidos Suspendidos Totales: Total Suspended Solids
6. NTK: TOTAL KJELDAHL NITROGEN

EPS SEDACUSCO S.A.

DATOS – PLANTA DE TRATAMIENTO DE AGUAS RESIDUALES
SAN JERONIMO - CUSCO

Cuestionario:

1.- Caudal Promedio Diario

El caudal promedio diario de recepción de aguas residuales en la PTAR San Jerónimo de la ciudad del Cusco, durante el año 2018 registra un promedio de 495.20 litros/seg. desde el mes de abril a la fecha el caudal de recepción de aguas residuales del influente se ha incrementado, por los trabajos de interconexión de aguas residuales a los colectores de la EPS SEDACUSCO S.A. destacan los de la zona de Alto Cusco, y de la zona sur del distrito de San Sebastián

AÑO 2018		INFLUENTE					
		Afluente	V ingreso m3	Caudal máximo L/s	Caudal Mínimo L/s	NTU	pH
1	ENERO	455.02	1,167,604.75	728.46	198.77	182.19	7.15
2	FEBRERO	450.91	1,055,429.55	710.73	197.09	195.11	7.34
3	MARZO	372.22	970,814.01	692.71	168.55	155.48	8.12
4	ABRIL	574.41	1,474,522.44	797.94	273.46	140.08	8.25
5	MAYO	535.73	1,426,613.23	745.28	259.09	155.79	8.29
6	JUNIO	542.42	1,387,693.57	749.10	267.71	175.50	7.28
7	JULIO	535.73	1,426,613.23	780.26	236.19	156.35	7.56
TOTAL		**495.20**	**8,909,290.78**	**743.50**	**228.69**	**165.79**	**7.71**

Información:
Centro SCADA
PTAR S-J

2.- Horas Pico y Máximo Caudal

Los máximos caudales que se registran en Horas pico diario en la Planta se produce entre las 09:00 horas hasta las 16:00 horas, registrándose durante el presente año un caudal promedio máximo de 743.50 litros/seg , esto se debe a que la mayor parte de las actividades de la población hacen uso de agua potable y sus vertimientos en horas de la mañana y parte de la tarde, a esas horas llegan en mayores volúmenes a la planta y en horas de la noche y al amanecer entre las 11:00 y 03:00 horas en las que la mayor parte de la población duerme hay poco uso de agua potable y los caudales son mínimos, llegando a un caudal mínimo promedio durante el presente año de 228.69 litros/seg. (como se observa en el cuadro anterior).

3.- Tipo de influente tratado (domestico, industrial, agro, camales etc.)

FIGURE A 14 INFLUENT PARAMETERS (PART 1)

La planta de tratamiento de aguas residuales de San Jerónimo trata, aguas residuales Municipales, constituidas por aguas residuales domésticas, aguas comerciales, aguas industriales, aguas de infiltraciones y aguas pluviales.

La red de alcantarillado de la ciudad del Cusco especialmente la del centro histórico y del casco monumental, en su mayor parte son mixtas es decir recolectan aguas residuales y también aguas pluviales, en temporada de lluvias.

4.- Datos del Ingreso (P, N, DBO5, DQO, Sólidos Suspendidos, etc)

Las aguas residuales que ingresan a la planta para su tratamiento de acuerdo a su características y grado de contaminación están tipificadas como aguas de Concentración Alta, la DBOs, DQO, Solidos Totales en suspensión, nitrógeno total, etc.

Parámetro	Unidad	MES					
		Enero del 2018	Febrero del 2018	Marzo del 2018	Abril del 2018	Mayo del 2018	Junio del 2018
Aceites y Grasas	mg/L	139.5	186.25	73.8	94	104.8	127.33
Coliformes Termotolerantes	NMP/100ml	1.30E+07	5.40E+07	7.00E+05	2.70E+06	2.20E+07	2.30E+07
Demanda Bioquímica de Oxígeno	mg/L	456.6	309.42	294.36	361.9	403.29	360.25
Demanda Química de Oxígeno	mg/L	836.87	606.01	547.2	783.67	753.32	761.13
pH		6.97	7.35	7.66	7.65	7.78	7.93
Sólidos Totales en Suspensión	mg/L	331.67	291.25	221.5	286.25	408.33	349
Temperatura	°C	19.4	20.6	20.2	18.9	18.4	18.5
NTK	m/L	47.0	47.5	47.5	42.5	35.2	34.5

Fuente: Laboratorio Acreditado

5.- Cantidad de biosólidos generados. Tratamiento post deshidratación(para disposición , venta o uso).

La cantidad de biosólidos producidos en la planta durante el año 2018, fue de 6,040.80 m3 con un promedio de producción mensual de 861.9 m3, sólidos totalmente digeridos que salen fuera de la planta después del proceso de centrifugación, con una concentración promedio en peso de 30% seco y 70% de humedad que pueden servir para venta o materia prima para compostaje de fertilizantes orgánicos.

FIGURE A 15 INFLUENT PARAMETERS (PART 2)

GENERACIÓN DE BIOSOLIDOS 2018

AÑO 2018		Lodos extraídos	Biosólidos Producidos
		m3/mes	m3/mes
1	ENERO	7,800.28	953.40
2	FEBRERO	7,331.31	1,031.50
3	MARZO	5,280.69	659.10
4	ABRIL	7,061.16	631.10
5	MAYO	7,659.59	831.70
6	JUNIO	8,465.22	953.30
7	JULIO	8,200.78	980.70
TOTAL		51,799.03	6,040.80

6.- Cantidad de biogás generado. Reuso del gas para algún proceso en planta, generación de energía o quemado.

GENERACIÓN DE BIOGAS 2018

AÑO 2018		ANTORCHA	CALDERO	TOTAL GAS PRODUCIDO
		Nm3/mes	Nm3/mes	Nm3/mes
1	ENERO	89,768.25	17,063.00	106,831.25
2	FEBRERO	66,096.75	15,332.50	81,429.25
3	MARZO	69,159.75	15,310.88	84,470.63
4	ABRIL	90,275.00	14,959.44	105,234.44
5	MAYO	85,400.50	16,789.50	102,190.00
6	JUNIO	81,149.75	17,760.88	98,910.63
7	JULIO	92,841.50	17,611.81	110,453.31
TOTAL		574,691.50	114,828.00	689,519.50

La producción de Biogás durante el año 2018 fue de 680,519 Nm3, registrando una producción promedio mensual de 98,502.8 Nm3, del total de biogás producido en la planta sólo se utiliza el 16.6% de biogás, durante el año 2018 el caldero que sirve para atemperar los lodos para mantener las temperaturas adecuadas dentro del digestor utilizado en el proceso de estabilización de los lodos, utilizo un total de 114,828 Nm3 con un promedio mensual de 16,404 Nm3 por mes.

En vez de continuar incinerando el resto de biogás que no es aprovechado en la planta que llega a 574,691.50 Nm3 durante este período con un promedio mensual de 82,098.8 Nm3, serviría para ser utilizado como combustible en equipos de cogeneración de electricidad, lo que permitiría un ahorro en la Empresa en los altos costos de suministro de energía eléctrica.

FIGURE A 16 BIOSOLIDS AND BIOGAS PARAMETERS (PART 3)

8.- Datos del Efluente (P, N, DBO5, DQO, Sólidos Suspendidos, etc)

AÑO 2018		EFLUENTE			
		Efluente L/s	V Salida m3	NTU	Cloro Residual
1	ENERO	391.35	1,048,179.19	20.59	0.11
2	FEBRERO	395.69	957,246.60	17.25	0.12
3	MARZO	359.69	963,380.71	12.33	0.11
4	ABRIL	553.85	1,435,571.24	36.62	0.10
5	MAYO	506.73	1,357,218.64	31.59	0.12
6	JUNIO	505.99	1,311,536.15	32.41	0.13
7	JULIO	512.02	1,371,402.43	35.91	0.14
TOTAL		**460.76**	**8,444,534.96**	**26.67**	**0.12**

Los caudales de aguas residuales producidos en la PTAR alcanzan un promedio de 460.76 litros/seg, habiendo producido 8'444,534.96 M3 durante el período, los resultados de los análisis de las aguas producidas, todas se encuentran dentro de los LMPs exigidos por DS 003-2010-MINAM.

Parámetro	Unidad	MES					
		Enero del 2018	Febrero del 2018	Marzo del 2018	Abril del 2018	Mayo del 2018	Junio del 2018
Aceites y Grasas	mg/L	4	4.71	4	4	4	4
Coliformes Termotolerantes	NMP/100ml	4.5	11	4.5	79	17	34
Demanda Bioquímica de Oxígeno	mg/L	30.54	31.39	19.82	23.44	20.7	22.55
Demanda Química de Oxígeno	mg/L	60.92	67.66	38.4	45.71	41.85	45.34
pH		7.32	7.76	6.5	7.73	6.74	7.96
Sólidos Totales en Suspensión	mg/L	28	47	16	21	33.5	28
Temperatura	°C	19.1	20.6	20.1	20.5	18.8	18.4
NTK	mg/L	39.5	40.5	31.5	33	27.8	29.5

Fuente: Laboratorio Acreditado

FIGURE A 17 EFFLUENT PARAMETERS (PART 4)

1. Afluente: Influent
2. Efluente Desarenador Aireado: Grit Chamber Effluent
3. Sedimentador Primario: primary settler
4. Cámara de Ingreso A Biofiltros: Tank before Biofilters.
5. Filtro Percolador Primario (FPP): Primary Trickling Filter (PTF)
6. Cámara de reunión de FPP: Mixer tank for FPP flow.
7. Filtro Percolador Secundario (FPS): Secundary Trickling Filter (STF)
8. Sedimentador Secundario: Secondary Clarifier.
9. Cámara de contacto de cloro: Chlorine Mixing Tank.
10. Efluente: Effluent.

EPS SEDACUSCO S.A.

INFORME DE CALIDAD

Solidos Suspendidos Totales mg/L

ESTACION	PUNTO DE MUESTREO	Enero del 2018	Febrero del 2018	Marzo del 2018	Abril del 2018	Mayo del 2018	Junio del 2018	Julio del 2018	Agosto del 2018	Setiembre del 2018	Octubre del 2018	Noviembre del 2018	Diciembre del 2018	Enero del 2019	Febrero del 2019	Marzo del 2019
1	Afluente	350.00	507.50	350.00	447.50	562.50	437.50	410.00	540.00	620.00	395.00	384.00	460.00	505.00	314.00	377.50
2	Efluente desarenador	357.50	612.50	450.00	467.50	430.00	452.50	497.50	450.00	572.50	795.00	460.50	445.00	467.50	495.00	450.00
3	Sedimentador primario 1	102.00	140.00	96.00	156.00	150.00	123.00	166.50	178.00	165.00	193.00	119.00	133.00	119.00	114.00	113.00
4	Sedimentador Primario 2	104.00	140.00	77.00	148.00	135.00	135.00	203.00	171.00	140.00	169.00	97.00	127.00	142.00	152.00	76.50
5	Cámara de Ingreso a Biofiltros CR-3	131.00	164.00	93.00	166.00	195.00	155.00	180.00	216.00	184.00	200.00	117.00	160.00	179.00	241.00	168.00
6	Filtro Percolador Primario 1	172.00	117.00	87.50	186.00	228.00	283.00	105.00	139.00	627.50	141.00	119.00	99.00	144.00	146.00	130.00
7	Filtro Percolador Primario 2	117.00	122.00	88.00	113.00	156.00	277.50	124.00	132.00	128.00	112.00	70.00	90.00	96.00	149.00	75.00
8	Filtro Percolador Primario 3	139.00	126.00	75.00	144.00	262.50	286.50	110.00	186.00	111.00	117.00	70.00	88.00	146.00	122.00	98.00
9	Cámara de reunión de Filtros Percoladores Primarios CR-7	177.00	130.00	84.50	155.00	214.00	254.00	113.00	178.00	120.00	142.00	87.00	81.00	117.00	163.00	85.00
10	Filtro Percolador Secunadrio 1	207.50	113.00	83.00	106.00	118.00	319.50	190.00	225.00	68.00	53.00	55.00	74.00	70.00	82.00	52.00
11	Filtro Percolador Secunadrio 2	213.00	112.00	91.00	126.00	158.00	360.00	153.00	174.00	103.00	152.00	76.00	48.00	97.00	78.00	57.00
12	Cámara de reunión de Filtros Percoladores Secundarios CR-5	128.00	113.00	79.00	128.00	151.00	310.50	109.00	176.00	86.00	97.00	75.00	55.00	98.00	82.50	47.50
13	Sedimentador Secundario 1	42.50	34.00	23.00	52.00	62.00	126.00	22.00	43.00	42.00	32.00	20.00	34.50	35.00	42.00	29.00
14	Sedimentador Secundario 2	44.00	37.00	25.00	46.00	59.00	68.00	24.50	47.00	45.50	29.00	27.00	27.00	39.50	28.00	30.00
15	Cámara de contacto de Cloro	42.00	31.00	22.00	49.00	50.00	70.00	25.00	69.00	48.00	31.50	27.50	34.00	45.00	47.00	33.00
16	Efluente	44.00	35.00	22.00	44.00	44.00	64.00	23.00	71.00	44.00	33.50	24.00	32.25	42.00	23.07	28.50

FIGURE A 18 TOTAL SUSPENDED SOLIDS

Oxigeno Disuelto (mg/L)-PTAR SAN JERÓNIMO																
ESTACION	PUNTO DE MUESTREO	Enero del 2018	Febrero del 2018	Marzo del 2018	Abril del 2018	Mayo del 2018	Junio del 2018	Julio del 2018	Agosto del 2018	Setiembre del 2018	Octubre del 2018	Noviembre del 2018	Diciembre del 2018	Enero del 2019	Febrero del 2019	Marzo del 2019
1	Afluente	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	CR-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Sedimentador primario 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Sedimentador Primario 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Cámara de Ingreso a Biofiltros CR-3	0.00	0.00	0.35	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.30
6	Filtro Percolador Primario 1	1.15	3.75	3.45	2.85	1.84	3.00	1.40	1.35	1.10	0.65	2.80	2.25	1.55	2.90	2.65
7	Filtro Percolador Primario 2	3.55	3.55	4.50	2.40	1.25	2.95	0.65	0.75	0.55	0.40	2.70	2.20	1.15	2.90	2.05
8	Filtro Percolador Primario 3	3.00	3.80	4.75	2.60	1.29	2.55	0.70	1.05	0.95	0.40	2.80	2.40	1.35	2.80	2.65
9	Cámara de reunión de Filtros Percoladores Primarios CR-7	3.40	3.90	4.40	2.65	1.57	2.30	0.80	1.00	1.05	0.70	2.85	2.50	1.50	2.60	3.45
10	Filtro Percolador Secundario 1	3.50	3.95	4.80	3.60	2.91	3.25	2.80	3.70	3.90	4.10	4.10	4.20	4.30	4.35	4.85
11	Filtro Percolador Secundario 2	3.30	3.85	4.90	3.45	2.49	3.40	2.25	4.00	3.90	3.40	3.60	4.40	4.20	4.70	4.75
12	Cámara de reunión de Filtros Percoladores Secundarios CR-5	3.65	4.00	5.10	3.40	2.32	3.55	2.75	3.85	4.25	4.00	3.75	4.10	4.70	4.35	3.35
13	Sedimentador Secundario 1	3.10	3.50	3.55	2.60	2.24	3.25	1.90	1.10	2.60	2.55	2.50	2.20	2.50	1.95	2.90
14	Sedimentador Secundario 2	3.15	3.60	3.70	3.00	3.20	3.00	2.20	1.50	2.70	2.75	2.85	2.45	2.55	2.40	3.95
15	Cámara de contacto de Cloro	5.10	4.90	5.30	3.85	3.09	4.55	4.25	5.05	4.50	4.55	4.40	4.55	5.55	4.70	4.95
16	Efluente	5.40	5.50	5.80	4.87	5.06	5.47	4.20	5.75	4.58	4.40	4.85	5.50	6.00	5.70	5.60

FIGURE A 19 OXYGEN DEMAND

DBO - Total mg/L																
ESTACION	PUNTO DE MUESTREO	Enero del 2018	Febrero del 2018	Marzo del 2018	Abril del 2018	Mayo del 2018	Junio del 2018	Julio del 2018	Agosto del 2018	Setiembre del 2018	Octubre del 2018	Noviembre del 2018	Diciembre del 2018	Enero del 2019	Febrero del 2019	Marzo del 2019
1	Afluente	365.10	400.45	337.13	388.28	494.90	456.10	329.73	415.85	461.43	389.20	428.00	483.85	450.20	350.83	358.00
2	Efluente desarenador	380.20	460.45	298.10	416.00	441.95	445.15	323.43	425.05	419.10	654.40	390.70	538.40	455.80	307.20	368.00
3	Sedimentador primario 1	219.78	302.00	145.50	256.45	264.28	237.05	250.80	266.50	231.23	318.08	209.15	263.53	256.85	162.75	164.50
4	Sedimentador Primario 2	201.25	244.63	137.33	269.90	265.15	261.05	272.10	288.70	241.60	277.00	179.55	277.40	284.90	217.10	161.00
5	Cámara de Ingreso a Biofiltros CR-3	205.85	185.10	130.70	228.25	237.70	295.65	275.20	255.10	293.15	303.73	218.78	288.53	290.00	266.88	194.50
13	Sedimentador Secundario 1	38.85	36.15	20.28	44.65	34.60	34.68	36.10	56.08	33.45	23.40	27.75	65.00	46.90	42.30	31.50
14	Sedimentador Secundario 2	35.75	36.83	25.15	40.50	34.15	19.23	31.80	51.55	31.30	30.05	29.90	47.60	43.25	29.05	57.25
15	Cámara de contacto de Cloro	34.05	35.40	23.50	24.20	25.30	27.55	32.80	54.80	27.75	31.65	22.65	44.85	34.90	34.15	29.60
16	Efluente	35.20	32.20	23.35	18.80	19.85	22.83	30.50	32.38	25.45	29.45	24.60	29.35	24.50	27.23	20.00

FIGURE A 20 BOD_5

B. RAW DATA OF WWTP PROVIDED BY LABORATORY (APPROVED BY SEDACUSCO)

1. Control De Calidad – Linea De Liquidos: Quality Control – Liquid Phase

Parámetro	Enero del 2017	Febrero del 2017	Marzo del 2017	Abril del 2017	Mayo del 2017	Junio del 2017	Julio del 2017	Agosto del 2017	Setiembre del 2017	Octubre del 2017	Noviembre del 2017	Diciembre del 2017	Enero del 2018	Febrero del 2018	Marzo del 2018	Abril del 2018	Mayo del 2018
Demanda Bioquímica de Oxígeno Afluente PTAR	369.46	496.17	329.29	398.33	367.53	357.6	372.5	455.94	402.3	351.64	372.5	330.78	456.6	309.42	294.36	364.9	403.29
Demanda Bioquímica de Oxígeno Efluente PTAR	22.8	47.98	19.3	20.07	17.58	11.92	19.37	22.55	30.75	28.31	29.7	70.86	30.54	31.39	19.82	23.44	20.7
LMP-DSO 003-2010-MINAM - Efluente	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Valor de Diseño PTAR	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30

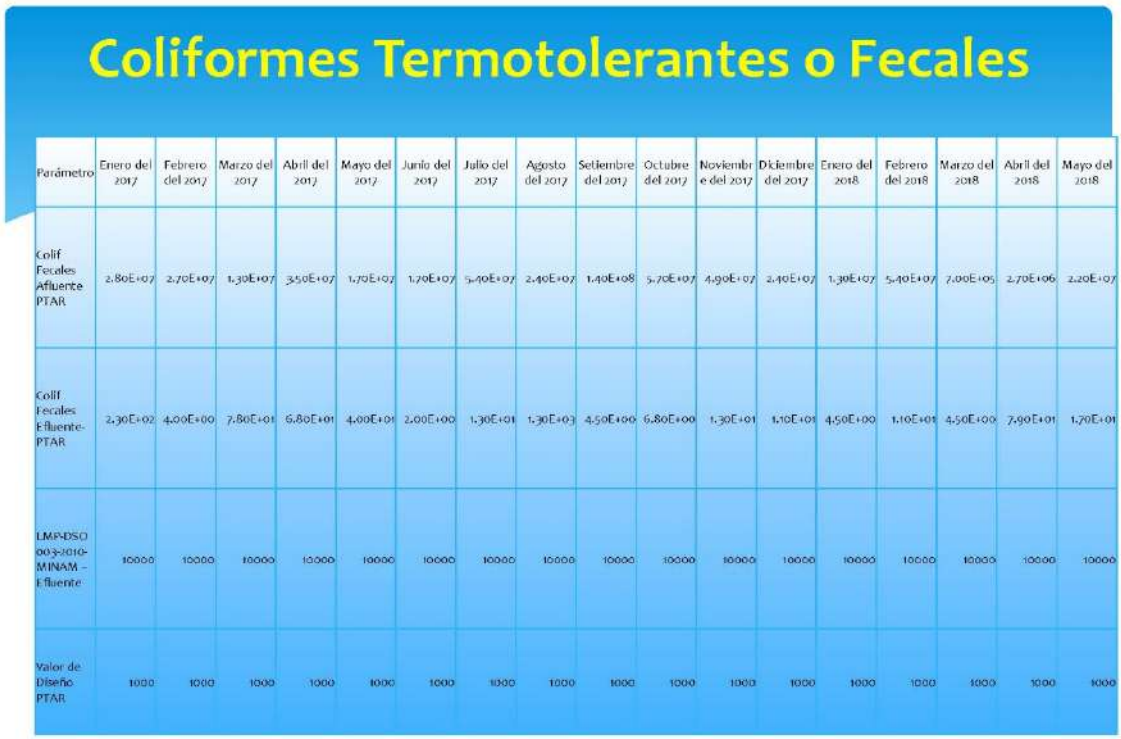
FIGURE A 21 BIOCHEMICAL OXYGEN DEMAND (BOD_5)

Parámetro	Enero del 2017	Febrero del 2017	Marzo del 2017	Abril del 2017	Mayo del 2017	Junio del 2017	Julio del 2017	Agosto del 2017	Setiembre del 2017	Octubre del 2017	Nov del 2017	Dic del 2017	Enero del 2018	Febrero del 2018	Marzo del 2018	Abril del 2018	Mayo del 2018
Demanda Química de Oxigeno Afluente PTAR	816.3	1022.3	674.7	768	734.69	728.74	754.84	903.49	811.27	702.04	640	771.08	836.87	606.01	547.2	783.67	753.32
Demanda Química de Oxigeno Efluente PTAR	51.61	97.36	57.83	44.8	42.45	35.63	48.39	46	54.73	58.78	60.8	44.98	60.92	67.66	38.4	45.71	41.85
LMP-DSO 003-2010-MINAM - Efluente	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Valor de Diseño PTAR	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90

FIGURE A 22 CHEMICAL OXYGEN DEMAND (COD)

Parámetro	Enero del 2017	Febrero del 2017	Marzo del 2017	Abril del 2017	Mayo del 2017	Junio del 2017	Julio del 2017	Agosto del 2017	Set del 2017	Octubre del 2017	Nov del 2017	Diciembre del 2017	Enero del 2018	Febrero del 2018	Marzo del 2018	Abril del 2018	Mayo del 2018
Sólidos Suspendidos Totales Afluente PTAR	377.5	239	281	340	452	552.5	427.5	456	437.5	325	295	358.33	331.67	291.25	221.5	286.25	408.33
Sólidos Suspendidos Totales Efluente PTAR	36	31.72	20.5	16	21	13.5	4	6	22	24	27.33	26.43	28	47	16	21	33.5
LMP-DSO 003-2010-MINAM - Efluente	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Valor de Diseño PTAR	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30

FIGURE A 23 TOTAL SUSPENDED SOLIDS



Coliformes Termotolerantes o Fecales

Parámetro	Enero del 2017	Febrero del 2017	Marzo del 2017	Abril del 2017	Mayo del 2017	Junio del 2017	Julio del 2017	Agosto del 2017	Setiembre del 2017	Octubre del 2017	Noviembre del 2017	Diciembre del 2017	Enero del 2018	Febrero del 2018	Marzo del 2018	Abril del 2018	Mayo del 2018
Colif Fecales Afluente PTAR	2.80E+07	2.70E+07	1.30E+07	3.50E+07	1.70E+07	1.70E+07	5.40E+07	2.40E+07	1.40E+08	5.70E+07	4.90E+07	2.40E+07	1.30E+07	5.40E+07	7.00E+05	2.70E+06	2.20E+07
Colif Fecales Efluente-PTAR	2.30E+02	4.00E+00	7.80E+01	6.80E+01	4.00E+01	2.00E+00	1.30E+01	1.30E+03	4.50E+00	6.80E+00	1.30E+01	1.10E+01	4.50E+00	1.10E+01	4.50E+00	7.90E+01	1.70E+01
LMP-DSO 003-2010-MINAM - Efluente	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Valor de Diseño PTAR	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

FIGURE A 24 FAECAL COLIFORMS

Aceites y Grasas

Parámetro	Enero del 2017	Febrero del 2017	Marzo del 2017	Abril del 2017	Mayo del 2017	Junio del 2017	Julio del 2017	Agosto del 2017	Setiembre del 2017	Octubre del 2017	Noviembre del 2017	Diciembre del 2017	Enero del 2018	Febrero del 2018	Marzo del 2018	Abril del 2018	Mayo del 2018
Aceites y Grasas Afluente PTAR	94	65.2	100	44.4	48.91	240	92.4	99.75	100.5	76.2	45	71	139.5	186.25	73.8	94	104.8
Aceites y Grasas Efluente PTAR	4	4	4	4	4	4	4	4	4	4	4	4	4	4.71	4	4	4
LMP-DSO 003-2010-MINAM - Efluente	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20

FIGURE A 25 OIL AND GREASE

C. STATISTICS OF PARAMETERS OF THE WWTP

		Average influent		Effluent	
	Sample	[L/s]	[m^3/d]	[L/s]	[m^3/d]
Jan-17	1	455.02	39313.73	391.35	33812.64
Feb-17	2	450.91	38958.62	395.69	34187.62
Mar-17	3	372.22	32159.81	359.69	31077.22
Apr-17	4	574.41	49629.02	553.85	47852.64
May-17	5	535.73	46287.07	506.73	43781.47
Jun-17	6	542.42	46865.09	505.99	43717.54

Average Influent [m3/d]

Mean	42202.22
Standard Error	2666.46
Median	42800.4
Standard Deviation	6531.46
Minimum	32159.81
Maximum	49629.02
Sum	253213.34
Count	6
Confidence Level(95.0%)	6854.351

Effluent [m3/d]

Mean	39071.52
Standard Error	2806.51
Median	38952.6
Standard Deviation	6874.51
Minimum	31077.22
Maximum	47852.64
Sum	234429.12
Count	6
Confidence Level(95.0%)	7214.355

		Influent	Effluent
	Sample	TKN [mg/L]	TKN [mg/L]
Jan-17	1	47	39.5
Feb-17	2	47.5	40.5
Mar-17	3	47.5	31.5
Apr-17	4	42.5	33
May-17	5	35.17	27.8
Jun-17	6	34.5	29.5

Influent TKN [mg/L]

Mean	42.36
Standard Error	2.50
Median	44.75
Standard Deviation	6.13
Minimum	34.5
Maximum	47.5
Sum	254.17
Count	6
Confidence Level(95.0%)	6.433

Effluent TKN [mg/L]

Mean	33.63
Standard Error	2.142
Median	32.25
Standard Deviation	5.25
Minimum	27.8
Maximum	40.5
Sum	201.8
Count	6
Confidence Level(95.0%)	5.506

		Influent	Effluent
	Sample	BOD_5 [mg/L]	BOD_5 [mg/L]
Jan-17	1	369.46	22.8
Feb-17	2	496.17	47.98
Mar-17	3	329.29	19.3
Apr-17	4	398.33	20.07
May-17	5	367.53	17.58
Jun-17	6	357.6	11.92
Jul-17	7	372.5	19.37
Aug-17	8	455.94	22.55
Sep-17	9	402.3	30.75
Oct-17	10	351.64	28.31
Nov-17	11	372.5	29.2
Dec-17	12	330.78	20.86
Jan-18	13	365.1	35.2
Feb-18	14	400.45	32.2
Mar-18	15	337.13	23.35
Apr-18	16	388.28	18.8
May-18	17	494.9	19.85
Jun-18	18	456.1	22.83
Jul-18	19	329.73	30.5
Aug-18	20	415.85	32.38
Sep-18	21	461.43	25.45
Oct-18	22	389.2	29.45
Nov-18	23	428	24.6
Dec-18	24	483.85	29.35

Influent BOD_5 [mg/L]	
Mean	398.09
Standard Error	10.77
Median	388.74
Standard Deviation	52.784
Minimum	329.29
Maximum	496.17
Sum	9554.06
Count	24
Confidence Level(95.0%)	22.289

Effluent BOD_5 [mg/L]	
Mean	25.61
Standard Error	1.52
Median	23.98
Standard Deviation	7.447
Minimum	11.92
Maximum	47.98
Sum	614.65
Count	24
Confidence Level(95.0%)	3.145

		Influent	Effluent
	Sample	TSS [mg/L]	TSS [mg/L]
Jan-17	1	372.5	36
Feb-17	2	239	31.72
Mar-17	3	281	20.5
Apr-17	4	340	16
May-17	5	452	21
Jun-17	6	552.5	13.5
Jul-17	7	427.5	4
Aug-17	8	456	6
Sep-17	9	437.5	22
Oct-17	10	325	24
Nov-17	11	295	27.33
Dec-17	12	358.33	26.43
Jan-18	13	350	44
Feb-18	14	507.5	35
Mar-18	15	350	22
Apr-18	16	447.5	44
May-18	17	562.5	44
Jun-18	18	437.5	64
Jul-18	19	410	23
Aug-18	20	540	71
Sep-18	21	620	44
Oct-18	22	395	33.5
Nov-18	23	384	24
Dec-18	24	460	32.25

Influent TSS [mg/L]	
Mean	416.68
Standard Error	19.32
Median	418.75
Standard Deviation	94.642
Minimum	239
Maximum	620
Sum	10000.33
Count	24
Confidence Level(95.0%)	39.964

Effluent TSS [mg/L]	
Mean	30.38
Standard Error	3.26
Median	26.880
Standard Deviation	15.961
Minimum	4
Maximum	71
Sum	729.23
Count	24
Confidence Level(95.0%)	6.740

Appendix V

A. OUTPUT DATA

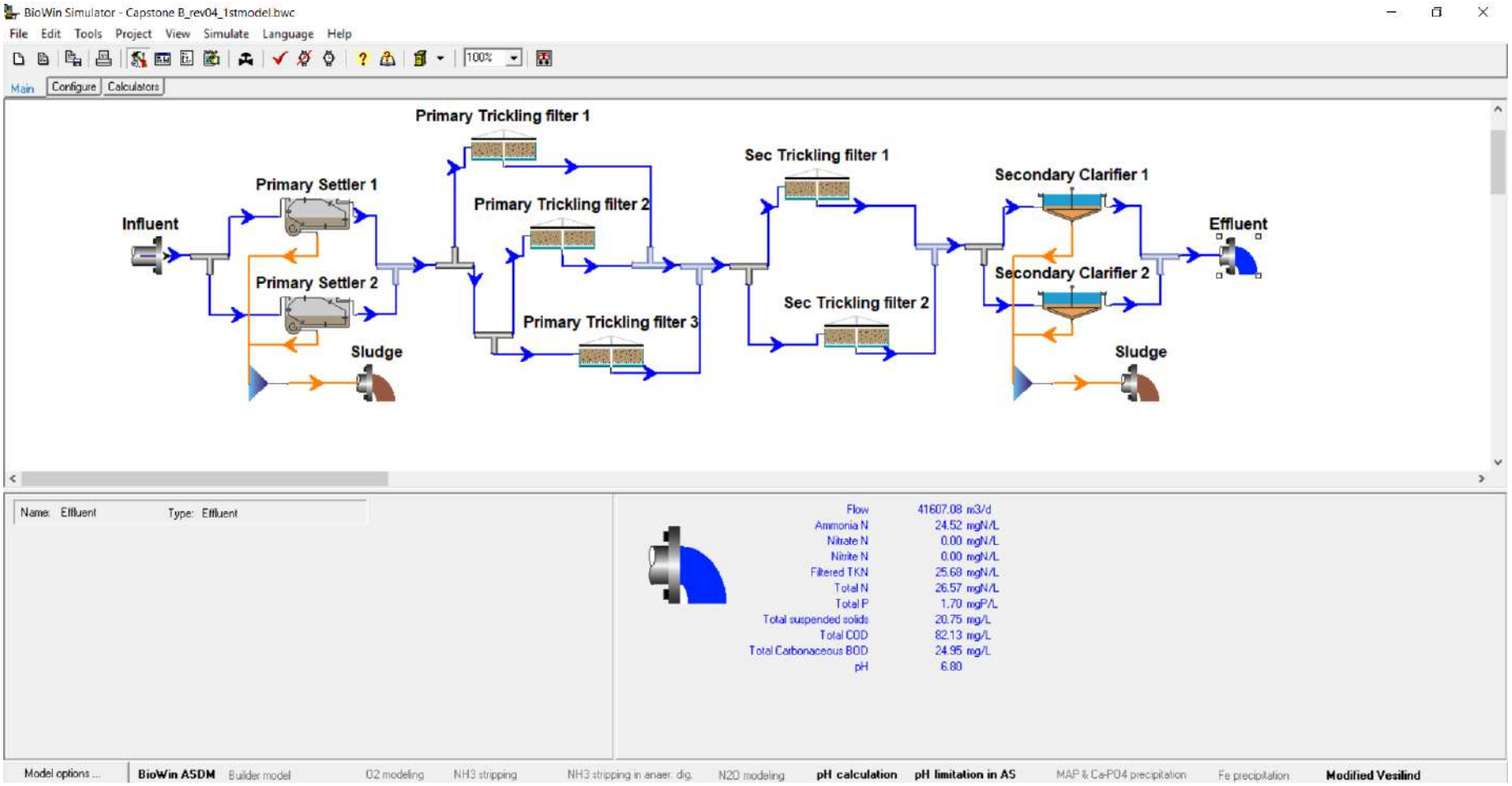


FIGURE A 26 EFFLUENT RESULT OF THE FIRST MODEL OF THE EXISTING WWTP

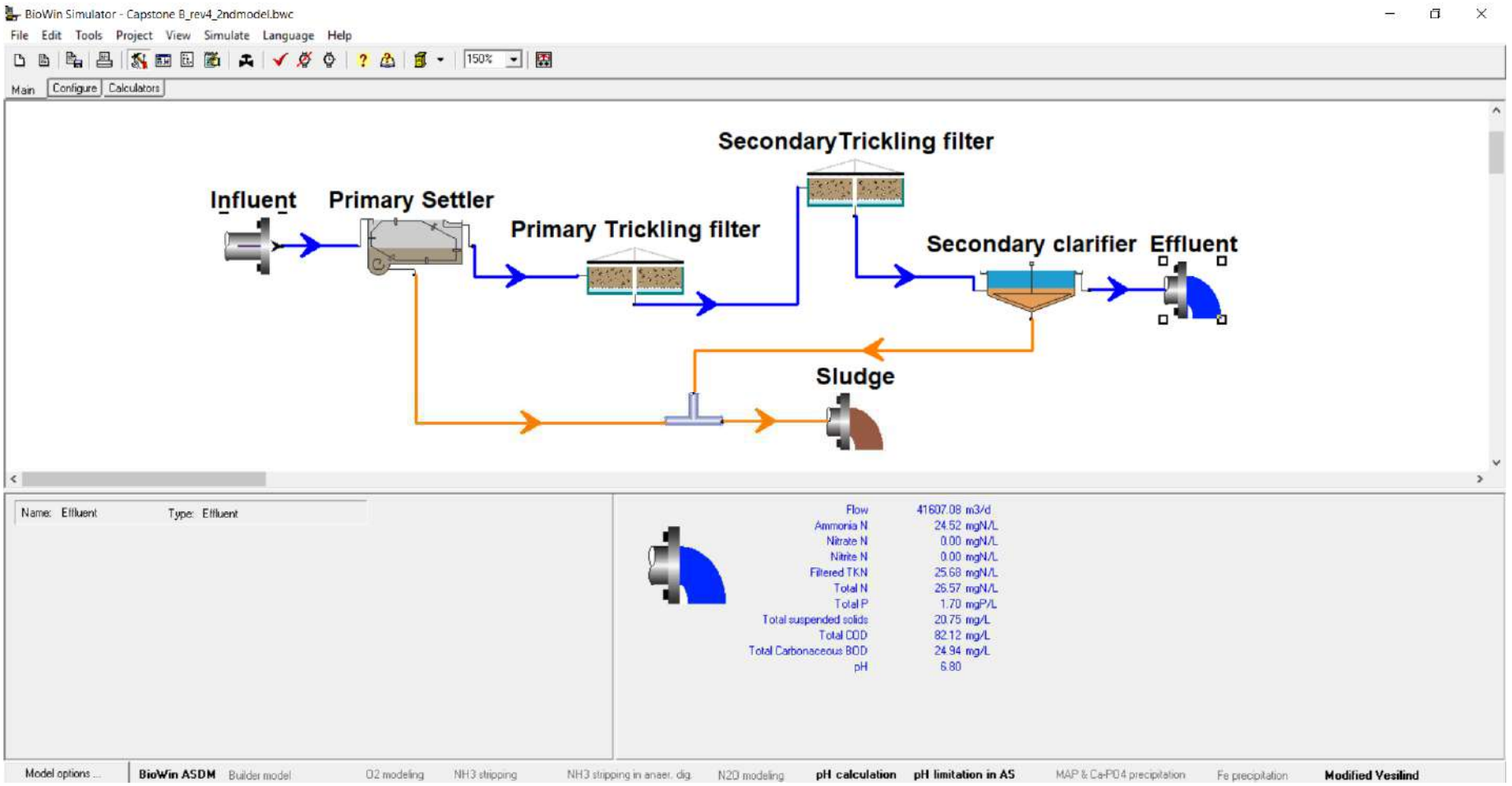


FIGURE A 27 EFFLUENT RESULT OF THE SECOND MODEL (CONSOLIDATED) OF THE EXISTING WWTP

B. RESULTS

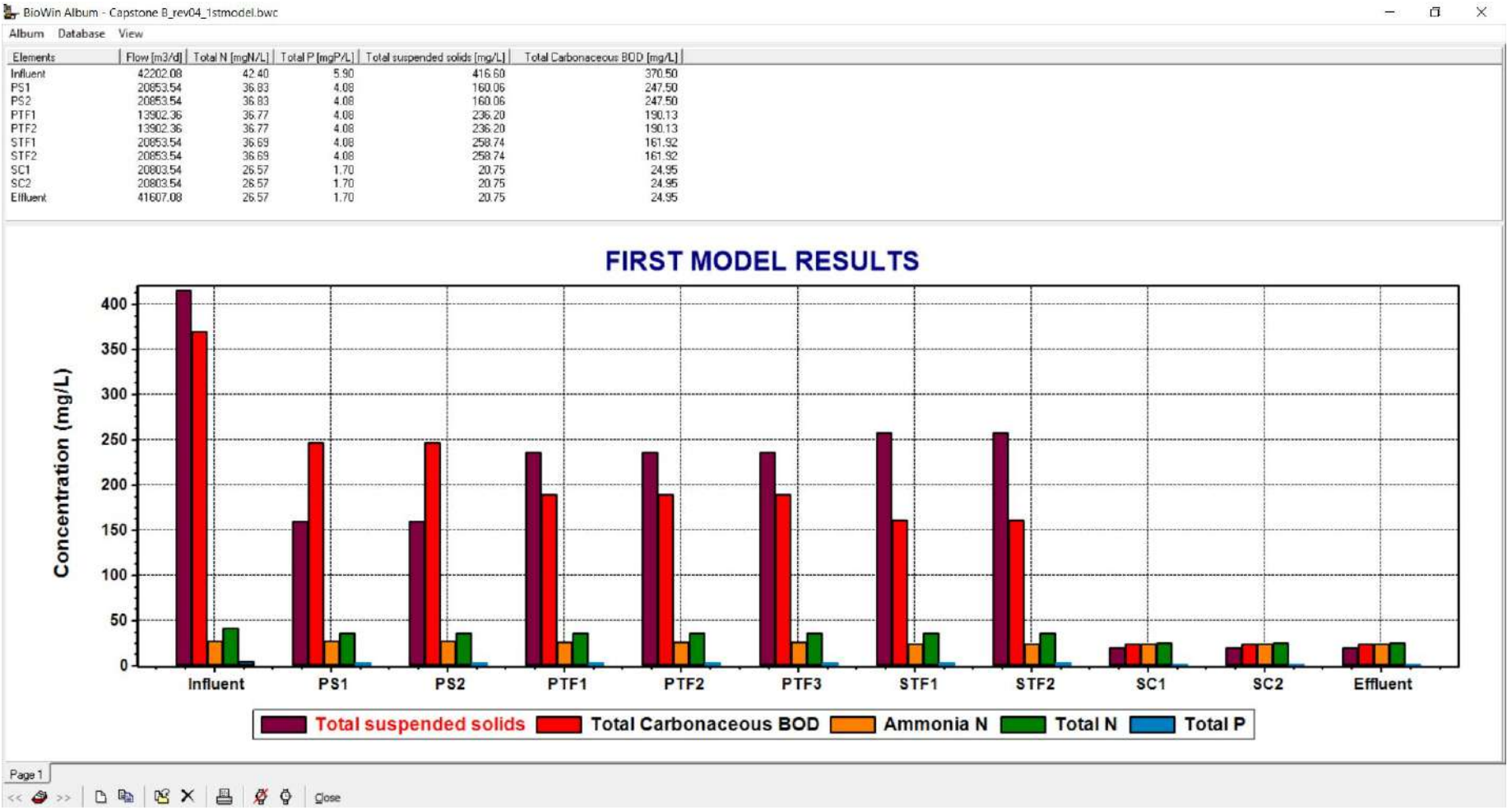


FIGURE A 28 FIRST MODEL ALBUM

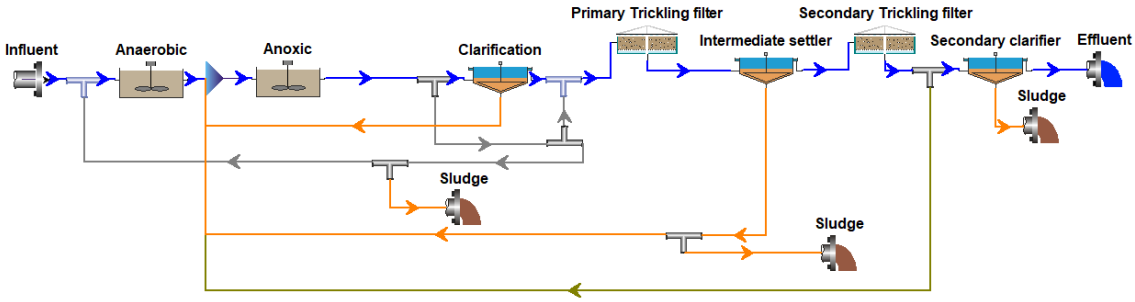
Appendix VI

A. SENSITIVITY ANALYSIS – CONSOLIDATED MODEL

		Increasing/Decreasing	Flow [m^3/d]	Flow [L/s]	HRT [vol/flow= h]	Ammonia [mg/L]	TKN mg/L	Total N	Total P mg/L	TSS mg/L	Total COD mg/L	Total BOD mg/L
001	Influent	BASE SCENAR	42202.08	488.45	3.92		42.4		5.9	416.6	753.65	370.5
	Effluent		41607.08	481.56		24.52	25.68	26.57	1.7	20.75	82.12	24.94
2	Influent	5%	44312.184	512.87			42.4		5.9	416.6	753.65	370.5
	Effluent	+5 Flow	41717.2	482.84	3.74	24.74	25.91	26.78	1.83	20.68	85.69	27.49
						1%	1%	1%	7%	0%		9%
3	Influent	10%	46422.288	537.30	3.57		42.4		5.9	416.6	753.65	370.5
	Effluent	+10 Flow	45827.3	530.41		24.96	26.14	26.99	1.91	20.59	89.63	30.32
						2%	2%	2%	11%	-1%		18%
4	Influent	15%	48532.392	561.72	3.41		42.4		5.9	416.6	753.65	370.5
	Effluent	+15 Flow	47937.4	554.83		25.17	26.37	27.2	1.97	20.47	93.92	33.4
						3%	3%	2%	14%	-1%		25%
5	Influent	20%	50642.496	586.14	3.27		42.4		5.9	416.6	753.65	370.5
	Effluent	+20 Flow	50047.5	579.25		25.38	26.6	27.41	2.02	20.34	98.49	36.7
						3%	3%	3%	16%	-2%		32%
6	Influent	60.90%	69292.8	802.00	2.39		42.4		5.9	416.6	753.65	370.5
	Effluent	+60.9 Flow	68697.8	795.11		26.82	28.24	28.92	2.28	18.99	137.53	64.83
						9%	9%	8%	25%	-9%		62%
7	Influent	-5%	40091.976	464.03	4.13		42.4		5.9	416.6	753.65	370.5
	Effluent	-5 Flow	39496.976	457.14		24.3	25.45	26.35	1.55	20.79	78.91	22.66
						-1%	-1%	-1%	-10%	0%		-10%
8	Influent	-10%	37981.872	439.61	4.31		42.4		5.9	416.6	753.65	370.5
	Effluent	-10 Flow	37386.872	432.72		24.07	25.22	26.14	1.4	20.79	76.09	20.79
						-2%	-2%	-2%	-21%	0%		-20%
9	Influent	-5%	42202.08	488.45	3.92		42.4		5.9	416.6	715.55	351.7
	Effluent	-5 BOD	41607.08	481.56		24.81	25.95	26.85	1.6	19.86	75.62	22
						1%	1%	1%	-6%	-4%		-13%
10	Influent	-10%	42202.08	488.45	3.92		42.4		5.9	416.6	677.45	333.04
	Effluent	-10 BOD	41607.08	481.56		25.08	26.27	27.11	1.56	18.99	69.72	19.48
						2%	2%	2%	-9%	-9%		-28%
11	Influent	5%	42202.08	488.45			42.4		5.9	416.6	791.5	389.1
	Effluent	+5 BOD	41607.08	481.56	3.92	24.27	25.42	26.32	1.78	21.6	89.16	28.29
						-1%	-1%	-1%	4%	4%		12%
12	Influent	10%	42202.08	488.45	3.92		42.4		5.9	416.6	828.98	407.52
	Effluent	+10 BOD	41607.08	481.56		24.05	25.19	26.1	1.8	22.42	96.88	32.15
						-2%	-2%	-2%	6%	7%		22%
13	Influent	15%	42202.08	488.45	3.92		42.4		5.9	416.6	867.7	426.56
	Effluent	+15 BOD	41607.08	481.56		23.86	24.99	25.92	1.81	23.22	105.88	36.89
						-3%	-3%	-3%	6%	11%		32%
14	Influent	20%	42202.08	488.45	3.92		42.4		5.9	416.6	905.1	444.95
	Effluent	+20 BOD	41607.08	481.56		23.71	24.84	25.77	1.82	23.94	115.62	42.23
						-3%	-3%	-3%	7%	13%		41%
15	Influent	5%	42202.08	488.45	3.92		42.4		6.20	416.6	753.65	370.5
	Effluent	+5 P	41607.08	481.56		24.52	25.68	26.57	1.86	20.75	82.12	24.94
									9%			
16	Influent	10%	42202.08	488.45	3.92		42.4		6.49	416.6	753.65	370.5
	Effluent	+10 P	41607.08	481.56		24.52	25.68	26.57	2.02	20.75	82.11	24.93
									16%			
17	Influent	20%	42202.08	488.45	3.92		42.4		7.08	416.6	753.65	370.5
	Effluent	+20 P	41607.08	481.56		24.52	25.68	26.57	2.33	20.76	82.09	24.92
									27%			
18	Influent	-5%	42202.08	488.45	3.92		42.4		5.61	416.6	753.65	370.5
	Effluent	-5 P	41607.08	481.56		24.52	25.68	26.57	1.55	20.75	82.14	24.95
									-10%			
19	Influent	-10%	42202.08	488.45	3.92		42.4		5.31	416.6	753.65	370.5
	Effluent	-10 P	41607.08	481.56		24.52	25.69	26.57	1.39	20.74	82.15	24.96
									-22%			
20	Influent	-20%	42202.08	488.45	3.92		42.4		4.72	416.6	753.65	370.5
	Effluent	-20 P	41607.08	481.56		24.52	25.69	26.57	1.09	20.73	82.19	24.99
									-56%			

		Increasing/Decreasing	Flow [m^3/d]	Flow [L/s]	HRT [vol/flow= h]	Ammonia [mg/L]	TKN mg/L	Total N	Total P mg/L	TSS mg/L	Total COD mg/L	Total BOD mg/L
001	Influent	BASE SCENAR	42202.08	488.45	3.92		42.4		5.9	416.6	753.65	370.5
	Effluent		41607.08	481.56		24.52	25.68	26.57	1.7	20.75	82.12	24.94
21	Influent	5%	42202.08	488.45	3.92		44.52		5.90	416.6	753.65	370.5
	Effluent	+5 TKN	41607.08	481.56		26.28	27.49	28.39	1.7	20.75	82.12	24.94
						7%	7%	6%				
22	Influent	10%	42202.08	488.45	3.92		46.64		5.90	416.6	753.65	370.5
	Effluent	+10 TKN	41607.08	481.56		28.03	29.3	30.2	1.7	20.75	82.11	24.94
						13%	12%	12%				
23	Influent	20%	42202.08	488.45	3.92		50.88		5.90	416.6	753.65	370.5
	Effluent	+20 TKN	41607.08	481.56		31.55	32.92	33.84	1.7	20.75	82.11	24.93
						22%	22%	21%				
24	Influent	-5%	42202.08	488.45	3.92		40.28		5.90	416.6	753.65	370.5
	Effluent	-5 TKN	41607.08	481.56		22.77	23.88	24.75	1.7	20.75	82.13	24.95
						-8%	-8%	-7%				
25	Influent	-10%	42202.08	488.45	3.92		38.16		5.90	416.6	753.65	370.5
	Effluent	-10 TKN	41607.08	481.56		21.01	22.07	22.93	1.7	20.75	82.14	24.95
						-17%	-16%	-16%				
26	Influent	-20%	42202.08	488.45	3.92		33.92		5.90	416.6	753.65	370.5
	Effluent	-20 TKN	41607.08	481.56		17.5	18.45	19.3	1.7	20.75	82.15	24.96
						-40%	-39%	-38%				

B. AnoxAn – NO AEROBIC REACTOR SB = 0 - 50 % ANA = 3026.9 m^3, TOTAL ANOXIC = 3832.8 m^3; PTF-STF DO 3mg/L



		Increasing/Decreasing	SB	Flow [m3/d]	Flow [L/s]	HRT [vol/flow= h]	Ammonia [mg/L]	Nitrate [mg/L]	Nitrite [mg/L]	TKN mg/L	Total N	Total P mg/L	TSS mg/L	Total COD mg/L	Total BOD mg/L
001	Influent	BASE SCENARIO		42202.08	488.45	3.92	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent	DO TF = 3mg/L		41607.08	481.56		24.52	-	--	25.68	26.57	1.7	20.75	82.12	24.94
2	Influent	NO AEROBIC REACTOR SB = 0 % ANA = 3026.9 M3, ANOXIC = 3832.8 M3 PTF-STF DO3mg/L	0.00	42202.08	488.45	1.72	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		84899.16	41607.08	481.56	2.18	24.89	0	0.07	26	26.12	1.45	0.93	48.93	6.47
							1%			1%	-2%	-17%	-2131%		-285%
3	Influent	NO AEROBIC REACTOR SB = 5 % ANA = 3026.9 M3, ANOXIC = 3832.8 M3 PTF-STF DO3mg/L	2110.10	42202.08	488.45	1.72	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		87009.26	41607.08	481.56	2.18	25.29	0	0.01	26.43	26.58	1.45	3.85	56.13	10.83
							3%			3%	0%	-17%	-439%		-130%
4	Influent	NO AEROBIC REACTOR SB = 10 % ANA = 3026.9 M3, ANOXIC = 3832.8 M3 PTF-STF DO3mg/L	4220.21	42202.08	488.45	1.72	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		89119.37	41607.08	481.56	2.18	25.38	0	0	26.52	26.74	1.47	6.3	60.17	12.91
							3%			3%	1%	-16%	-229%		-93%
5	Influent	NO AEROBIC REACTOR SB = 20 % ANA = 3026.9 M3, ANOXIC = 3832.8 M3 PTF-STF DO3mg/L	8440.42	42202.08	488.45	1.72	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		93339.58	41607.08	481.56	2.18	25.21	0	0	26.35	26.7	1.5	10.19	65.41	15.39
							3%			3%	0%	-13%	-104%		-62%
6	Influent	NO AEROBIC REACTOR SB = 30 % ANA = 3026.9 M3, ANOXIC = 3832.8 M3 PTF-STF DO3mg/L	12660.62	42202.08	488.45	1.72	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		97559.78	41607.08	481.56	2.18	25.05	0	0	26.19	26.63	1.54	13.15	69.2	17.14
							2%			2%	0%	-10%	-58%		-46%
6	Influent	NO AEROBIC REACTOR SB = 40 % ANA = 3026.9 M3, ANOXIC = 3832.8 M3 PTF-STF DO3mg/L	16880.83	42202.08	488.45	1.72	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		101779.99	41607.08	481.56	2.18	25.16	0	0	26.29	26.81	1.57	15.39	72.93	18.98
							3%			2%	1%	-8%	-35%		-31%
7	Influent	NO AEROBIC REACTOR SB = 50 % ANA = 3026.9 M3, ANOXIC = 3832.8 M3 PTF-STF DO3mg/L	21101.04	42202.08	488.45	1.72	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		106000.20	41607.08	481.56	2.18	25.06	0	0	26.19	26.77	1.59	17.25	75.27	20.05
							2%			2%	1%	-7%	-20%		-24%

C. AnoxAn –SB = 0 - 50 %, ANA = 3026.9 m^3, ANOXIC = variable, AEROBIC = (34.1%-75.0%) OF TOTAL ANOXIC (3832.8 m^3); PTF-STF DO 3mg/L

- **SB = 25 %, ANA = 3026.9 m^3, ANOXIC and AEROBIC = variables**

		Increasing/Decreasing	SB	Flow [m3/d]	Flow [L/s]	HRT [vol/flow= h]	Ammonia [mg/L]	Nitrate [mg/L]	Nitrite [mg/L]	TKN mg/L	Total N	Total P mg/L	TSS mg/L	Total COD mg/L	Total BOD mg/L
001	Influent	BASE SCENARIO		42202.08	488.45	3.92	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent	DO TF = 3mg/L		41607.08	481.56		24.52	-	--	25.68	26.57	1.7	20.75	82.12	24.94
2	Influent	SB = 25 % ANA = 3026.9 M3, ANOXIC = 2525.84 M3 AEROBIC = 1307 M3 (34.1%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	1.72	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 1.44 0.74	NO SOLUTION FOUND								
3	Influent	SB = 25 % ANA = 3026.9 M3, ANOXIC = 2414.7 M3 AEROBIC = 1418.2 M3 (37%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	1.72	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 1.37 0.81	NO SOLUTION FOUND								
4	Influent	SB = 25 % ANA = 3026.9 M3, ANOXIC = 2357.2 M3 AEROBIC = 1475.6 M3 (38.5%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	1.72	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 1.34 0.84	NO SOLUTION FOUND								
4	Influent	SB = 25 % ANA = 3026.9 M3, ANOXIC = 2299.7 M3 AEROBIC = 1533.1 M3 (40%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 1.31 0.87	NO SOLUTION FOUND								
5	Influent	SB = 25 % ANA = 3026.9 M3, ANOXIC = 2334.2 M3 AEROBIC = 1498.6 M3 (39.1%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 1.33 0.85	8.36 -193%	1.9	0.18	9.75 -163%	12.34 -115%	0.22 -673%	9.28 -124%	49.86	4.23 -490%
6	Influent	ADDITIONAL SIMULATION SB = 25 % ANA = 3026.9 M3, ANOXIC = 2223 M3 AEROBIC = 1609.8 M3 (42%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 1.31 0.87	7.88 -211%	2.03	0.18	9.28 -177%	11.99 -122%	0.2 -750%	9.18 -126%	49.74	4.09 -510%
7	Influent	SB = 25 % ANA = 3026.9 M3, ANOXIC = 2142.6 M3 AEROBIC = 1690.3 M3 (44.1%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 1.22 0.96	7.54 -225%	2.12	0.18	8.94 -187%	11.74 -126%	0.19 -795%	9.12 -128%	49.66	4 -524%
6	Influent	SB = 25 % ANA = 3026.9 M3, ANOXIC = 1978.9 M3 AEROBIC = 1854.0 M3 (48.37%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 1.13 1.05	6.87 -257%	2.3	0.17	8.27 -211%	11.23 -137%	0.19 -795%	9.02 -130%	49.53	3.85 -548%
7	Influent	SB = 25 % ANA = 3026.9 M3, ANOXIC = 1782.3 M3 AEROBIC = 2050.6 M3 (53.5%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 1.01 1.17	6.08 -303%	2.5	0.17	7.48 -243%	10.63 -150%	0.19 -795%	8.91 -133%	49.4	3.71 -572%
8	Influent	SB = 25 % ANA = 3026.9 M3, ANOXIC = 1533.1 M3 AEROBIC = 2299.7 M3 (60%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 0.87 1.31	5.11 -380%	2.75	0.15	6.52 -294%	9.9 -168%	0.2 -750%	8.8 -136%	49.26	3.56 -601%
9	Influent	SB = 25 % ANA = 3026.9 M3, ANOXIC = 958.2 M3 AEROBIC = 2874.6 M3 (75%) DO 2 mg/L AND PTF-STF DO3mg/L	10550.52	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		95449.68	41607.08	481.56	2.18 0.54 1.63	3.29 -645%	3.22	0.12	4.7 -446%	8.52 -212%	0.24 -608%	8.58 -142%	48.97	3.29 -658%

- **SB = 30 %, ANA = 3026.9 m^3, ANOXIC and AEROBIC = variables**

		Increasing/Decreasing	SB	Flow [m3/d]	Flow [L/s]	HRT [vol/flow= h]	Ammonia [mg/L]	Nitrate [mg/L]	Nitrite [mg/L]	TKN mg/L	Total N	Total P mg/L	TSS mg/L	Total COD mg/L	Total BOD mg/L
001	Influent	BASE SCENARIO		42202.08	488.45	3.92	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent	DO TF = 3mg/L		41607.08	481.56		24.52	-	--	25.68	26.57	1.7	20.75	82.12	24.94
10	Influent	SB = 30 % ANA = 3026.9 M3, ANOXIC = 2357.2 M3 AEROBIC = 1475.6 M3 (38.5%) DO 2 mg/L AND PTF-STF DO3mg/L	12660.62	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		97559.78	41607.08	481.56	2.18 1.34 0.84	8.69 -182%	1.77	0.18	10.08 -155%	12.59 -111%	0.29 -486%	10.53 -97%	51.05	4.8 -420%
11	Influent	SB = 30 % ANA = 3026.9 M3, ANOXIC = 2334.2 M3 AEROBIC = 1498.6 M3 (39.1%) DO 2 mg/L AND PTF-STF DO3mg/L	12660.62	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		97559.78	41607.08	481.56	2.18 1.33 0.85	NO SOLUTION FOUND								
12	Influent	SB = 30 % ANA = 3026.9 M3, ANOXIC = 2299.7 M3 AEROBIC = 1533.1 M3 (40%) DO 2 mg/L AND PTF-STF DO3mg/L	12660.62	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		97559.78	41607.08	481.56	2.18 1.31 0.87	NO SOLUTION FOUND								
13	Influent	ADDITIONAL SIMULATION SB = 30 % ANA = 3026.9 M3, ANOXIC = 2223 M3 AEROBIC = 1609.8 M3 (42%) DO 2 mg/L AND PTF-STF DO3mg/L	12660.62	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		97559.78	41607.08	481.56	2.18 1.31 0.87	8.1 -203%	1.93	0.18	9.5 -170%	12.17 -118%	0.22 -673%	10.38 -100%	50.88	4.6 -442%
14	Influent	SB = 30 % ANA = 3026.9 M3, ANOXIC = 2142.6 M3 AEROBIC = 1690.3 M3 (44.1%) DO 2 mg/L AND PTF-STF DO3mg/L	12660.62	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		97559.78	41607.08	481.56	2.18 1.22 0.96	7.78 -215%	2.02	0.18	9.17 -180%	11.93 -123%	0.21 -710%	10.31 -101%	50.79	4.5 -454%
15	Influent	SB = 30 % ANA = 3026.9 M3, ANOXIC = 1978.9 M3 AEROBIC = 1854.0 M3 (48.37%) DO 2 mg/L AND PTF-STF DO3mg/L	12660.62	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		97559.78	41607.08	481.56	2.18 1.13 1.05	7.13 -244%	2.19	0.17	8.53 -201%	11.45 -132%	0.2 -750%	10.19 -104%	50.61	4.33 -476%
16	Influent	SB = 30 % ANA = 3026.9 M3, ANOXIC = 1782.3 M3 AEROBIC = 2050.6 M3 (53.5%) DO 2 mg/L AND PTF-STF DO3mg/L	12660.62	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		97559.78	41607.08	481.56	2.18 1.01 1.17	6.37 -285%	2.4	0.17	7.76 -231%	10.87 -144%	0.2 -750%	10.07 -106%	50.45	4.17 -498%
17	Influent	SB = 30 % ANA = 3026.9 M3, ANOXIC = 1533.1 M3 AEROBIC = 2299.7 M3 (60%) DO 2 mg/L AND PTF-STF DO3mg/L	12660.62	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		97559.78	41607.08	481.56	2.18 0.87 1.31	5.42 -352%	2.64	0.16	6.82 -277%	10.15 -162%	0.2 -750%	9.94 -109%	50.27	4 -524%
18	Influent	SB = 30 % ANA = 3026.9 M3, ANOXIC = 958.2 M3 AEROBIC = 2874.6 M3 (75%) DO 2 mg/L AND PTF-STF DO3mg/L	12660.62	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		97559.78	41607.08	481.56	2.18 0.54 1.63	3.58 -585%	3.11	0.13	4.97 -417%	8.74 -204%	0.24 -608%	9.7 -114%	49.93	3.7 -574%

- **SB = 35 %, ANA = 3026.9 m^3, ANOXIC and AEROBIC = variables**

		Increasing/Decreasing	SB	Flow [m3/d]	Flow [L/s]	HRT [vol/flow= h]	Ammonia [mg/L]	Nitrate [mg/L]	Nitrite [mg/L]	TKN mg/L	Total N	Total P mg/L	TSS mg/L	Total COD mg/L	Total BOD mg/L
001	Influent	BASE SCENARIO		42202.08	488.45	3.92	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent	DO TF = 3mg/L		41607.08	481.56		24.52	-	--	25.68	26.57	1.7	20.75	82.12	24.94
19	Influent	SB = 35 % ANA = 3026.9 M3, ANOXIC = 2357.2 M3 AEROBIC = 1475.6 M3 (38.5%) DO 2 mg/L AND PTF-STF DO3mg/L	14770.73	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		99669.89	41607.08	481.56	2.18 1.34 0.84	NO SOLUTION FOUND								
20	Influent	SB = 35 % ANA = 3026.9 M3, ANOXIC = 2334.2 M3 AEROBIC = 1498.6 M3 (39.1%) DO 2 mg/L AND PTF-STF DO3mg/L	14770.73	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		99669.89	41607.08	481.56	2.18 1.33 0.85	NO SOLUTION FOUND								
21	Influent	SB = 35 % ANA = 3026.9 M3, ANOXIC = 2299.7 M3 AEROBIC = 1533.1 M3 (40%) DO 2 mg/L AND PTF-STF DO3mg/L	14770.73	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		99669.89	41607.08	481.56	2.18 1.31 0.87	NO SOLUTION FOUND								
22	Influent	ADDITIONAL SIMULATION SB = 35 % ANA = 3026.9 M3, ANOXIC = 2223 M3 AEROBIC = 1609.8 M3 (42%) DO 2 mg/L AND PTF-STF DO3mg/L	14770.73	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		99669.89	41607.08	481.56	2.18 1.31	8.31 -195%	1.84	0.18	9.69 -165%	12.33 -115%	0.25 -580%	11.48 -81%	51.94	5.08 -391%

						0.87										
23	Influent	SB = 35 % ANA = 3026.9 M3, ANOXIC = 2142.6 M3 AEROBIC = 1690.3 M3 (44.1%) DO 2 mg/L AND PTF-STF DO3mg/L	14770.73	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		99669.89	41607.08	481.56	2.18 1.22 0.96	7.99 -207%	1.93	0.18	9.37 -174%	12.1 -120%	0.23 -639%	11.4 -82%	51.82	4.97 -402%
24	Influent	SB = 35 % ANA = 3026.9 M3, ANOXIC = 1978.9 M3 AEROBIC = 1854.0 M3 (48.37%) DO 2 mg/L AND PTF-STF DO3mg/L	14770.73	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		99669.89	41607.08	481.56	2.18 1.13 1.05	7.37 -233%	2.1	0.17	8.75 -193%	11.64 -128%	0.21 -710%	11.26 -84%	51.62	4.78 -422%
25	Influent	SB = 35 % ANA = 3026.9 M3, ANOXIC = 1782.3 M3 AEROBIC = 2050.6 M3 (53.5%) DO 2 mg/L AND PTF-STF DO3mg/L	14562.48	41607.08	481.56	2.18	-	-	-	9.4	-	0.2	11.4	51.82	5.0
	Effluent		98271.64	41607.08	481.56	2.21 1.03 1.18	6.63 -270%	2.3	0.17	8.01 -221%	11.08 -140%	0.21 -710%	11.12 -87%	51.42	4.6 -442%
26	Influent	SB = 35 % ANA = 3026.9 M3, ANOXIC = 1533.1 M3 AEROBIC = 2299.7 M3 (60%) DO 2 mg/L AND PTF-STF DO3mg/L	14770.73	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		99669.89	41607.08	481.56	2.18 0.87 1.31	5.71 -329%	2.53	0.16	7.09 -262%	10.39 -156%	0.21 -710%	10.98 -89%	51.21	4.41 -466%
27	Influent	SB = 35 % ANA = 3026.9 M3, ANOXIC = 958.2 M3 AEROBIC = 2874.6 M3 (75%) DO 2 mg/L AND PTF-STF DO3mg/L	14770.73	42202.08	488.45	idem	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent		99669.89	41607.08	481.56	2.18 0.54 1.63	6.53 -275%	2.08	0.16	7.8 -229%	10.65 -149%	1.45 -17%	10.93 -90%	51.34	4.06 -514%

D. SB = RAS = 30 % ANA = 3026.9 m3, ANOXIC = 2142.6 m3, AEROBIC = 1690.3 m3 (44.1%) $DO_{AEROBICREACTOR}$ = VARIABLE, DOPTF-STF 3mg/L

		Increasing/Decreasing	SB	Flow [m3/d]	Flow [L/s]	HRT [vol/flow= h]	Ammonia [mg/L]	Nitrate [mg/L]	Nitrite [mg/L]	TKN mg/L	Total N	Total P mg/L	TSS mg/L	Total COD mg/L	Total BOD mg/L
001	Influent	BASE SCENARIO		42202.08	488.45	3.92	-	-	-	42.4	-	5.9	416.6	753.65	370.5
	Effluent	DO TF = 3mg/L		41607.08	481.56		24.52	-	--	25.68	26.57	1.7	20.75	82.12	24.94
		SB = RAS = 30 % ANA = 3026.9 M3, ANOXIC = 2142.6 M3 AEROBIC = 1690.3 M3 (44.1%) PTF-STF DO3mg/L													
2	Effluent	DO AEROBIC REACTOR = 0.01 mg/L	12482.12	41607.08	481.56		25.02 2%	0	0	26.15 2%	26.6 0%	1.22 -39%	12.97 -60%	69.2 -19%	16.58 -50%
3	Effluent	DO AEROBIC REACTOR = 0.05 mg/L		41607.08	481.56		23.04 -6%	0.03	0.08	24.19 -6%	24.74 -7%	1.57 -8%	12.72 -63%	65.71 -25%	13.96 -79%
4	Effluent	DO AEROBIC REACTOR = 0.1 mg/L		41607.08	481.56		18.68 -31%	0.29	0.13	19.93 -29%	20.86 -27%	1.64 -4%	12.18 -70%	57.12 -44%	9.1 -174%
5	Effluent	DO AEROBIC REACTOR = 0.15 mg/L		41607.08	481.56		14.91 -64%	0.72	0.17	16.27 -58%	17.7 -50%	0.94 -81%	11.47 -81%	53.94 -52%	6.81 -266%
6	Effluent	DO AEROBIC REACTOR = 0.20 mg/L		41607.08	481.56		NO SOLUTION FOUND								
7	Effluent	DO AEROBIC REACTOR = 0.50 mg/L		41607.08	481.56		NO SOLUTION FOUND								
8	Effluent	DO AEROBIC REACTOR = .75 mg/L		41607.08	481.56		8.76 -180%	1.66	0.19	10.15 -153%	12.57 -111%	0.22 -673%	10.41 -99%	51.16 -61%	4.71 -430%
9	Effluent	DO AEROBIC REACTOR = 1 mg/L		41607.08	481.56		8.3 -195%	1.77	0.19	9.69 -165%	12.22 -117%	0.21 -710%	10.37 -100%	50.99 -61%	4.62 -440%
10	Effluent	DO AEROBIC REACTOR = 1.50 mg/L		41607.08	481.56		7.92 -210%	1.93	0.18	9.31 -176%	11.99 -122%	0.21 -710%	10.34 -101%	50.85 -61%	4.54 -449%
11	Effluent	DO AEROBIC REACTOR = 1.75 mg/L		41607.08	481.56		7.83 -213%	1.98	0.18	9.23 -178%	11.95 -122%	0.21 -710%	10.32 -101%	50.81 -62%	4.52 -452%
12	Effluent	DO AEROBIC REACTOR = 2 mg/L		41607.08	481.56		7.78 -215%	2.02	0.18	9.17 -180%	11.93 -123%	0.21 -710%	10.31 -101%	50.79 -62%	4.5 -454%

E. SENSITIVITY ANALISYS FOR (B = RAS = 30 % ANA = 3026.9 m3, ANOXIC = 2142.6 m3, AEROBIC = 1690.3 m3 (44.1%) $DO_{AEROBICREACTOR}$ = 1.75 mg/L, DOPTF-STF 3mg/L)

		Increasing/Decreasing	Flow [m3/d]	Flow [L/s]	Ammonia [mg/L] 1%	Nitrate [mg/L] 1%	Nitrite [mg/L] 1%	TKN mg/L 1%	Total N 1%	Total P mg/L 1%	TSS mg/L 5	Total BOD mg/L
001	Influent	BASE SCENAR	42202.08	488.45				42.4		5.9	416.6	370.5
	Effluent		41607.08	481.56	7.83	1.98	0.18	9.23	11.95	0.21	10.32	4.52
2	Influent	5%	44312	512.87				42.4		5.9	416.6	370.5
	Effluent	+5 Flow	43817	507.14	8.28	1.94	0.18	9.67	12.37	0.21	10.62	4.65
					5%	-2%	0%	5%	3%	0%	3%	3%
3	Influent	10%	46422	537.30				42.4		5.9	416.6	370.5
	Effluent	+10 Flow	45927	531.57	8.69	1.9	0.18	10.08	12.76	0.22	10.9	4.78
					10%	-4%	0%	8%	6%	5%	5%	5%
4	Influent	11%	46844	542.18				42.4		5.9	416.6	370.5
	Effluent	+11 Flow	46349	536.45	8.77	1.89	0.18	10.16	12.83	0.22	10.95	4.8
					11%	-5%	0%	9%	7%	5%	6%	6%
5	Influent	12.5%	47477	549.51				42.4		5.9	416.6	370.5
	Effluent	+12.5 Flow	46982	543.78	8.89	1.88	0.18	10.28	12.94	0.22	11.04	4.84
					12%	-5%	0%	10%	8%	5%	7%	7%
6	Influent	15%	48532	561.72				42.4		5.9	416.6	370.5
	Effluent	+15 Flow	48037	555.99	NO SOLUTION FOUND							
7	Influent	20%	50642	586.14				42.4		5.9	416.6	370.5
	Effluent	+20 Flow	50147	580.41	NO SOLUTION FOUND							
8	Influent	60.90%	69293	802.00				42.4		5.9	416.6	370.5
	Effluent	+60.9 Flow	68798	796.27	NO SOLUTION FOUND							
9	Influent	-5%	40092	464.03				42.4		5.9	416.6	370.5
	Effluent	-5 Flow	39497	457.14	7.37	2.02	0.18	8.76	11.5	0.2	10.02	4.38
					-6%	2%	0%	-5%	-4%	-5%	-3%	-3%
10	Influent	-10%	37982	439.61				42.4		5.9	416.6	370.5
	Effluent	-10 Flow	37387	432.72	6.87	2.05	0.17	8.27	11.03	0.2	9.7	4.24
					-14%	3%	-6%	-12%	-8%	-5%	-6%	-7%
11	Influent	-20%	33762	390.76				42.4		5.9	416.6	370.5
	Effluent	-20 Flow	33167	383.87	5.84	2.1	0.17	7.24	10	0.19	9.01	3.94
					-34%	6%	-6%	-27%	-20%	-11%	-15%	-15%
12	Influent	-50%	21101	244.23				42.4		5.9	416.6	370.5
	Effluent	-50 Flow	20506	237.34	2.82	1.95	0.13	4.24	6.67	0.17	6.51	2.91
					-178%	-2%	-38%	-118%	-79%	-24%	-59%	-55%
13	Influent	-34%	42202.08	488.45				42.4		5.9	416.6	245.8
	Effluent	-34 BOD	41607.08	481.56	10.91	3.13	0.25	12.31	16.05	0.41	7.84	3.11
					28%	37%	28%	25%	26%	49%	-32%	-45%
14	Influent	-49%	42202.08	488.45				42.4		5.9	416.6	189.3
	Effluent	-49 BOD	41607.08	481.56	10.4	4.86	0.28	11.75	17.18	2.41	6.4	2.36
					25%	59%	36%	21%	30%	91%	-61%	-92%
15	Influent	5%	42202.08	488.45				42.4		5.9	416.6	389.1
	Effluent	+5 BOD	41607.08	481.56	7.33	1.81	0.17	8.71	11.29	0.23	10.69	4.7
					-7%	-9%	-6%	-6%	-6%	9%	3%	4%
16	Influent	10%	42202.08	488.45				42.4		5.9	416.6	407.52
	Effluent	+10 BOD	41607.08	481.56	6.86	1.65	0.16	8.24	10.68	0.26	11.04	4.87
					-14%	-20%	-13%	-12%	-12%	19%	7%	7%
17	Influent	15%	42202.08	488.45				42.4		5.9	416.6	426.56
	Effluent	+15 BOD	41607.08	481.56	6.42	1.48	0.16	7.79	10.08	0.31	11.4	5.06
					-22%	-34%	-13%	-18%	-19%	32%	9%	11%
18	Influent	20%	42202.08	488.45				42.4		5.9	416.6	444.95
	Effluent	+20 BOD	41607.08	481.56	6	1.33	0.15	7.37	9.54	0.38	11.75	5.23
					-31%	-49%	-20%	-25%	-25%	45%	12%	14%
19	Influent	5%	42202.08	488.45				42.4		6.20	416.6	370.5
	Effluent	+5 P	41607.08	481.56	7.59	2.07	0.18	8.99	11.8	0.2	10.33	4.53
					-3%	4%	0%	-3%	-1%	-5%	0%	0%
20	Influent	10%	42202.08	488.45				42.4		6.49	416.6	370.5
	Effluent	+10 P	41607.08	481.56	7.95	2.04	0.18	9.36	12.13	0.2	10.34	4.54
					2%	3%	0%	1%	1%	-5%	0%	0%
21	Influent	20%	42202.08	488.45				42.4		7.08	416.6	370.5
	Effluent	+20 P	41607.08	481.56	8.04	2.09	0.18	9.47	12.3	0.21	10.35	4.55
					3%	5%	0%	3%	3%	0%	0%	1%
22	Influent	-5%	42202.08	488.45				42.4		5.61	416.6	370.5
	Effluent	-5 P	41607.08	481.56	7.8	1.95	0.18	9.19	11.88	0.23	10.31	4.51
					0%	-2%	0%	0%	-1%	9%	0%	0%
23	Influent	-10%	42202.08	488.45				42.4		5.31	416.6	370.5
	Effluent	-10 P	41607.08	481.56	7.8	1.92	0.18	9.17	11.83	0.27	10.3	4.5
					0%	-3%	0%	-1%	-1%	22%	0%	0%
24	Influent	-20%	42202.08	488.45				42.4		4.72	416.6	370.5
	Effluent	-20 P	41607.08	481.56	7.88	1.83	0.18	9.23	11.81	0.44	10.24	4.48
					1%	-8%	0%	0%	-1%	52%	-1%	-1%

		Increasing/Decreasing	Flow [m3/d]	Flow [L/s]	Ammonia [mg/L] 1%	Nitrate [mg/L] 1%	Nitrite [mg/L] 1%	TKN mg/L 1%	Total N 1%	Total P mg/L 1%	TSS mg/L 5	Total BOD mg/L
001	Influent	BASE SCENAR	42202.08	488.45				42.4		5.9	416.6	370.5
	Effluent		41607.08	481.56	7.83	1.98	0.18	9.23	11.95	0.21	10.32	4.52
25	Influent	5%	42202.08	488.45				44.52		5.90	416.6	370.5
	Effluent	+5 TKN	41607.08	481.56	8.85	2.18	0.19	10.29	13.22	0.21	10.33	4.52
					12%	9%	5%	10%	10%	0%	0%	0%
26	Influent	10%	42202.08	488.45				46.64		5.90	416.6	370.5
	Effluent	+10 TKN	41607.08	481.56	11.43	2.02	0.2	12.84	15.62	0.2	10.39	4.47
					31%	2%	10%	28%	23%	-5%	1%	-1%
27	Influent	20%	42202.08	488.45				50.88		5.90	416.6	370.5
	Effluent	+20 TKN	41607.08	481.56	13.94	2.37	0.21	15.5	18.65	0.21	10.33	4.52
					44%	16%	14%	40%	36%	0%	0%	0%
28	Influent	-5%	42202.08	488.45				40.28		5.90	416.6	370.5
	Effluent	-5 TKN	41607.08	481.56	6.63	1.82	0.17	7.98	10.54	0.21	10.32	4.52
					-18%	-9%	-6%	-16%	-13%	0%	0%	0%
29	Influent	-10%	42202.08	488.45				38.16		5.90	416.6	370.5
	Effluent	-10 TKN	41607.08	481.56	5.59	1.64	0.16	6.89	9.25	0.21	10.32	4.52
					-40%	-21%	-13%	-34%	-29%	0%	0%	0%
30	Influent	-20%	42202.08	488.45				33.92		5.90	416.6	370.5
	Effluent	-20 TKN	41607.08	481.56	3.86	1.2	0.14	5.08	6.98	0.21	10.31	4.51
					-103%	-65%	-29%	-82%	-71%	0%	0%	0%

F. RESULT TABLES (B = RAS = 30 % ANA = 3026.9 m3, ANOXIC = 2142.6 m3, AEROBIC = 1690.3 m3 (44.1%) $DO_{AEROBICREACTOR}$ = 1.75 mg/L, DOPTF-STF 3mg/L)

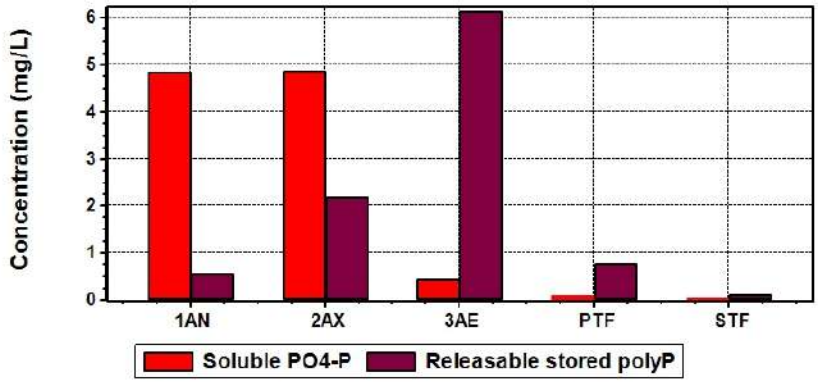


FIGURE A 29 PROCESS OF PHOSPHORUS REMOVAL

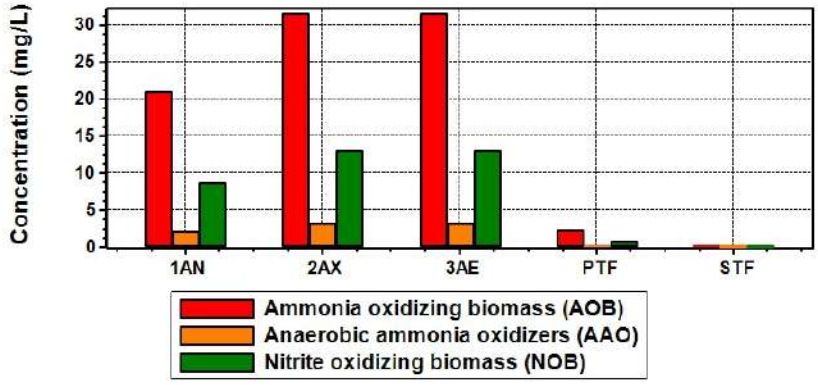


FIGURE A 30 TYPES OF BIOMASS IN REACTORS