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COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

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DEPARTMENT OF WATER AND WASTEWATER TECHNOLOGY

Performance Assessment of Wastewater Treatment Plant in Ethio-leather Factory using GPS-X Wastewater Modeling and Simulation Software

By
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Addis Ababa, Ethiopia.

AFRICA CENTRE OF EXCELLENCE FOR WATER MANGEMENT

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Advisor

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A thesis submitted to the school of Research and Graduate Studies of Africa Centre of Excellence for Water Management, Addis Ababa University, in partial fulfillment of the requirements for the Degree of Master of Science in Water Management (Water and Wastewater Technology).

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Addis Ababa, Ethiopia.

Declaration

I, Kibrework Agiza Nigani, declare that the thesis comprises my work towards the MSc degree and that, to the best of my knowledge in compliance with internationally accepted practices, I have acknowledged and refereed all materials used in this work. I have undertaken the research work independently with the guidance and support of the research advisor.

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Date of submission ______________________

Signature ________________________________

This thesis has been submitted for examination with my approval as a university advisor.

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THESIS APPROVAL PAGE

APPROVED BY BOARD OF EXAMINERS

This is to certify that we the undersigned, have examined this MSc thesis entitled “Performance Assessment of Wastewater Treatment Plant in Ethio-leather Factory using GPS-X Wastewater Modeling and Simulation Software’’ and that in our opinion; it is fully adequate in scope and quality, as MSc thesis for the degree of Master of Science in Water Management (Water and Wastewater Technology).

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Symbols

%	Percent
°C	Degree Celsius
μscm^{-1}	Micro Siemens per centimeter
Cl^{-}	Chloride
Cr	Total Chromium
Cr (III)	Trivalent chromium
Hr.	Hour
L	Liter
Lt/kg	Liter per kilogram
m	Meter
m^2	Meter square
m^3	Cubic meter
m^3/day	Meter cube per day
mgl^{-1}	Milligram per liter
mm/year	Millimeter per year
S^{2-}	Sulfide
T/day	Tone per day

Abbreviations

ACSL	American Computer Science League
APHA	American Public Health Association
BOD	Biological Oxygen Demand
CETPs	Common effluent treatment plants

COD	Carbon Oxygen Demand
Cr (VI)	Hexavalent chromium
DO	Dissolved oxygen
EEPA	Ethiopian Environmental Protection Authority
ELICo	Ethio-Leather Industry Corporation
FDRE	Federal Democratic Republic of Ethiopia
FEPA	Federal Environmental Protection Act
GPS-X	Georgia-Pacific Corporation
m.a.s.l	Above mean sea level
SS	Suspended solids
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TN	Total nitrogen
TP	Total phosphorus
TSS	Total Suspended Solids
UNICEF	United Nations International Children's Emergency Fund
VSS	Volatile suspended solids
WHO	World Health Organization
WWTP	Wastewater treatment plant

Abstract

Ethio-leather industry (ELICo) is one of the most important factories in Ethiopia, located in Addis Ababa's Akaki Kality sub-city, with an annual capacity of 6600 tons. The company generates a maximum of 1200 m^3/day of wastewater effluent. Company uses raw water at a rate of 2000 m^3/day on average, equivalent to 90 m^3 of water per ton of finished leather goods. This research investigated the efficiency of the tannery wastewater treatment plant for water recycles as a substitute for groundwater. It has also evaluated the performance of the wastewater treatment plant using Hydromantis GPS-X, a commercially available wastewater treatment plant modeling and simulation software tool. For this task Physicochemical laboratory analysis, field measurement and secondary data, were used to acquire the input data for process modeling and simulation. It tested all parameters using the Water and Wastewater Standard Method from the Physico-chemical analysis of the wastewater generated from the plant. This paper understands, effluent water quality found below the standard discharge limit by Ethiopian Environment, Forest and Climate change Commission. According to physico chemical characteristics treatment plant has 93.6% of COD, 97.44% of BOD_5 and TSS of 98.8% removal efficiency this is some of conducted parameters. In this research, the GPS-X model was run after a sensitivity analysis calibration and validation phase. According to the result of the steady-state and time dynamic sensitivity analysis, the model was sensitive to changes in input and good enough to be used as a parameter prediction. This research successfully validated the developed model while meeting the assumption of the models' constant stoichiometry and kinetic coefficients for any plant influent characteristics. Model validation also shows that it is 76.11 percent accuracy in predicting plant performance and the simulation result shows a satisfactory effluent water quality parameter. Therefore, this research discovered that it can be recycle in some parts of the tannery process. The findings of the physicochemical characterization and process simulation evaluation substantiated this.

Key words: Ethio-leather, GPS-X, Performance, Simulation, Wastewater

1. INTRODUCTION

1.1. General Context

In terms of job creation and tax revenue, the leather industry sector has made a significant contribution to the nation's socioeconomic development (UNIDO 2003). At this time, there are more than 32 tanneries in Ethiopia, with a few more under construction. Livestock serves a variety of functions in the Ethiopian economy, including providing food, regulating crop productivity and generating money (Endalew and Ayalew 2016).

Ethiopia, being one of the world's developing countries, is undergoing rapid economic development as well as large-scale urbanization. Population expansion is due to both natural growth and rural-urban migration (Gebrekidan et.al 2009). Growing populations will increase water demand and the number of cost-effective water delivery options is limited (MoWIE 2017). Rapid urbanization and growth of resident number contributed to Pollution in rivers, lakes and coastal waters as defined in various ways, often characterized in terms rapid but unintended growth of industrial clusters with several factories discharging large amounts of wastewater to water body. Surface water quality deterioration due to pollution needs a significant threat to the wastewater before discharging into the natural environment (Narayan and Charles 2017). Industries frequently discharge either poorly treated or untreated wastewater openly into the environment and disturbing the local community wetland, health, livestock and vegetable farms (Firdissa et.al 2016).

Wastewater from tanning operations can cause environmental difficulties related to its suspended solids, high organic matter and chromium (UNIDO 2003). In tanning manufacturing processes Chromium (III) salts are one of the most frequently used chemicals, in case of that tannery wastewater are the most critical pollutant. Often, wastewater from tanning finds its approach to surface water, wherever poisons passed to downstream and pollute water used for cooking, irrigation, bathing and swimming. In addition, chromium pollutant in water can affect aquatic animals', cattle and people food source and Soil (Rehman 2015).

Management of tannery wastewater involves optimization of water and chemical consumption used in wastewater treatment this will indirectly main leading to reduction of both wastewater treatment plant size and energy consumption. Wastewater treatment plant is necessary to reduce this toxicity and has been a good performance to be important role in water infrastructure and sanitation (Sachidananda et.al 2016).

According to WHO and UNICEF Joint Monitoring report titled “Progress on Drinking Water and Sanitation 2018 update”, trends in global drinking water coverage in the years 1990 to 2014 indicated that the percentage of piped on premises and other improved water sources are increased from 45 to 56 and 31 to 33 respectively. Even though this achievement is encouraging, much remains to be done. More than 700 million people, which nearly half of sub-Saharan Africa. Still lack of improved drinking water sources.

The Addis Ababa city administration must implement various wastewater management options in order to boost the city's green economic development strategy and make it a clean, healthy and pleasurable place to visit. Collecting wastewater to cleanse and return to the environment is essential for public safety and health (Terefe Gemeda et al. 2020). To facilitate this, a variety of physical, chemical and biological treatment challenges are required. Pollutant removal efficiency of wastewater treatment plant is important to recycle the treated water for further purpose with permissible limit standard. Currently observed climate, demographic and water consumption changes can affect significantly wastewater treatment plant performance (Assefa and Sahu 2016).

1.2. Statement of the Problem

Leather factory is one of consumes large amount of chemicals and process water and generate a large amount of wastewater that is characterized by wide variation both in the discharge volume and in the strength of pollutants. In general, the leather industry requires around 30-40 L water per kg of skin processed. Discharging such amount of treated water without considering water recycling option it has its own economical implication. Ethio leather industry has advanced wastewater treatment plant including total chrome and sulfide removal system. Based on the laboratory analysis the wastewater discharges from this treatment plant have improved water quality characteristics such as such as biological oxygen demand (BOD_5), carbon-oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), total nitrogen (TN), total chromium (Cr), sulphide (S^{2-}), chlorides (Cl^-), Ammonia (NH_3) and Total phosphorus (TP) parameters. Computer process modeling and simulation becoming a useful tool for evaluating the efficiency and performance of wastewater treatment systems. It gives more alternatives for better understanding and evaluating wastewater treatment plant designs. For that reason, it is very important to assess the performance of treatment plant before it released effluents to Environment and simulation of its performance of treatment plant using cost effective, time saver and high control response system model. GPS-X is premium wastewater treatment plant modeling and simulation software. By using GPS-X increasingly a reality and not just a laboratory-scale project. It suggests clear advantages in terms of analyzing the performance of the treatment plant as well as better optimization and control tools, reducing the costs related with laboratory analysis. However, the efficiency of process modelling depends on a good calibration, which is generally needed to adjust the simulation results to the real behavior of the WWTP. GPS-X used to simulate and prove the process performance in regular situation and shock loading situations.

Therefore, the present study focuses to evaluate the wastewater treatment performance using commercially available wastewater treatment modeling and simulation software in order to assess if there is a possibility of recycling the treated water so that we can minimize the raw water consumption which is ground water.

1.3. Objectives

1.3.1. General Objective

The study overall goal is to predict the Ethio-leather wastewater treatment plant's pollutant removal effectiveness using process modeling and simulation in order to recycle the treated water.

1.3.2. Specific Objective

The specific research objectives are the followings:

- To characterize physico-chemical properties of input/output from ELICo wastewater treatment plant.
- To develop a simulation-working environment, simulate and validate the pollutant (BOD_5, COD, TP, NH_3, TSS, TN and Alkalinity) removal efficiency of ELICo wastewater treatment plant unit operation at different operational parameters (that is collected directly from the plant and Physico-chemical analysis) that represent the existing wastewater treatment plant using GPS-X process modeling and simulation software.
- To evaluate the performance of the ELICo wastewater treatment plant at different scenarios such as air flowrate and different chemical dosage to understand the critical parameters and suggest the appropriate water recycle application.

1.4. Research Question

1. What are the characteristics of the tannery wastewater for the selected physico-chemical parameters?

2. What is the removal efficiency of BOD_5, COD, TDS, TSS, TP, Cl^-, Cr, NH_3, S^{2-} and TN of wastewater treatment plant?

3. What is the ELICo wastewater treatment plant performance at low and high air flow rate and chemical dosage?

4. Which recycled water quality fits to blend with ground water /main source?

1.5. Significance of Study

This study shows status of the selected industrial wastewater effluent and full-scale performance of the Ethio-leather wastewater treatment plant by simulating treatment plant common effluent parameters using cost effective simulation. The finding can be used for-

- Ethio-leather factory in different parts of Ethio-leather Share Company
- For environmental scientists, Engineers and Ethiopia Environment Protection Authority
- Stakeholders working in the Environmental pollution control etc.

1.6. Limitation of the Study

Researcher period in Ethio-leather Company during study was regulated and bounded by wastewater treatment plant administration. Consequently, the circumscribed of the time was greatly limit the characteristic quantity of pollutants determined.

1.7. Outline of Work

This research is composed of five sections. The first section is the introduction part that contains introduction of the study, problem of statement, research questions, objectives, motivation, significance of the study and outline of work. In the second section, the literature reviews related to tanning, tanning process, wastewater generated from tannery and their health effect, treatment process and process modelling and simulation process, different software used to model and simulate wastewater treatment plant and why GPS-X is selected briefly discussed in this section. In the third section, the methodology that is used for doing the research is introduced. In this section, the research process, material and method used for research are discussed. In the fourth section, the results of the study are briefly presented with its corresponding discussions. Finally, in section five, the conclusion and recommendation are briefly reflected.

2. LITERATURE REVIEW

2.1. General Introduction

A fast growth of population, industrialization and an increasing trend of developments related to tannery, problems linked to the management of wastewater is becoming one of the issues in terms of assuring environmental sustainability nowadays. Tannery wastewater have a number of antagonistic effects on the water bodies (Omondi 2018).

2.2. Tanning

Tanning is the process of preparing skins and hides of animals to manufacture leather. The skins and hides are the basic material of leather. The external cover of a small animal referred to as skin whereas that of a bigger animal is known as hide (Chowdhury et al. 2015). Almost the world's entire yield of leather is manufactured from cattle hides, calfskin, goatskin, lambskin and sheepskin. Other skins and hides used contain those of the kangaroo, horse, pig, reptile, deer, walrus and seal but they expense significantly less. In leather industry, used raw materials originate largely as by-product of livestock sector and meat industry. Tanning hide converts into leather includes a process, which continuously changes protein structure of the skin manufacture it stronger and less vulnerable to decay and possibly coloring it. In the tanning, process animal skins and hides treated to eliminate hair and non-structured fats and proteins, departure a fundamental pure collagen matrix (Kadam 1990). Then hides preserved by impregnation with tanning agents. Tanning is a widespread, global industry that works with both light and heavy types of leather. Light leather mostly used for shoes and other soft products and heavy leather used for bands and belts.

2.3. Production processes in Tannery

Tanneries may process the hide/skin throughout different steps of leather production. Among the main specifications for identifying and characterizing the tannery system (Gutterres et al. 2015). Tanneries according to the stages of production categorized into four, this are: -

A) Hide and skin storage and beam house operations,

B) Tan yard operations,

C) Post-tanning operations and

D) Finishing operations.

A) Pre-tanning (beam house operations)

Cleaning and conditioning hides and skins yield the main part of the effluent weight.

Soaking: The conserved raw hides recover their usual water contents. Manure, Dirt, preservatives (sodium chloride, bactericides), blood and other are detached.

Fleshing and trimming: In this process unnecessary tissue detached and removing hair is done by chemical closure like alkaline medium of sulphide and lime. Liming and removing hair produce the effluent with maximum COD value (Kadam 1990).

Deliming and bating: the alkaline hides fleshed and removed hair neutralized through acid ammonium salts then preserved with enzymes. Corresponding to those originated in digestive system to remove the remaining hair and to reduce proteins. Through this process, pigments and hair roots are eliminated. These is the major part of the ammonium load resulted in the effluents.

Pickling - pickling rises the pH value to three acidities of the hide adding liquor of acid and salts, allowing chromium tannins to arrive the hide. Salts additional to avoid the hide from swelling. For conservation purposes 0.03-2% by weighting of fungicides and bactericides are commonly applied.

Degreasing: Ordinarily completed together with soaking, pickling or after tanning, degreasing is achieved by organic solvents or surfactants, leading to a higher COD value in the effluent (Kadam 1990).

B) Tanning (tan yard operations)

Principally, there are two possible processes:

Chrome tanning: Subsequently pickling, when little amount of pH value, chromium (III) salts added. To possess chromium, the pH slowly increased through adding of a base. The progression of chromium tanning grounded on the cross-linkage of chromium ions with free carboxyl groups in the collagen. It makes the hide impervious to bacteria and extraordinary temperature. The chromium-tanned hide covers about 2-3% by dry weight of Cr (III). Wet blue, i.e. The raw hide later the chrome tanning process, has about 40% of dry matter (Federal Environmental Protection Authority 2012).

Vegetable tanning: is usually consummate in a sequence of vats (first the rocker-section vats in which the liquor is disturbed and second the lay-away vats without distress) with growing concentrations of tanning liquor.

C) Wet finishing (post-tanning)

The wet finishing processes are occasionally accomplished in one single float. Chromium wet blue or tanned hides are often reserved the necessary properties throughout that process of more than one tanning agent integrated. Before definite drying is permit take place, the excess water removed to make the hides appropriate for splitting and shaving. Splitting and shaving done to acquire the preferred thickness of the hide. The conformation of contaminants in the wet finishing effluent is composite due to the occurrence of dyes, fat liquors and combined tanning agents, but the total amounts produced are smaller than in earlier steps and often not considered as significant (IFC 2007).

D) Finishing

The crust results afterward retentive and drying exposed to a number of ultimate operations. The determination of these processes is to make the hide laxer and to cover minor faults. The hide preserved with an organic solvent or water-based dye and varnish. Completed product has between 66 and 85% by weight of dry matter. Environmental features are mainly related to the finishing chemicals, which is also extent of effluent water (Gutterres et al. 2015).

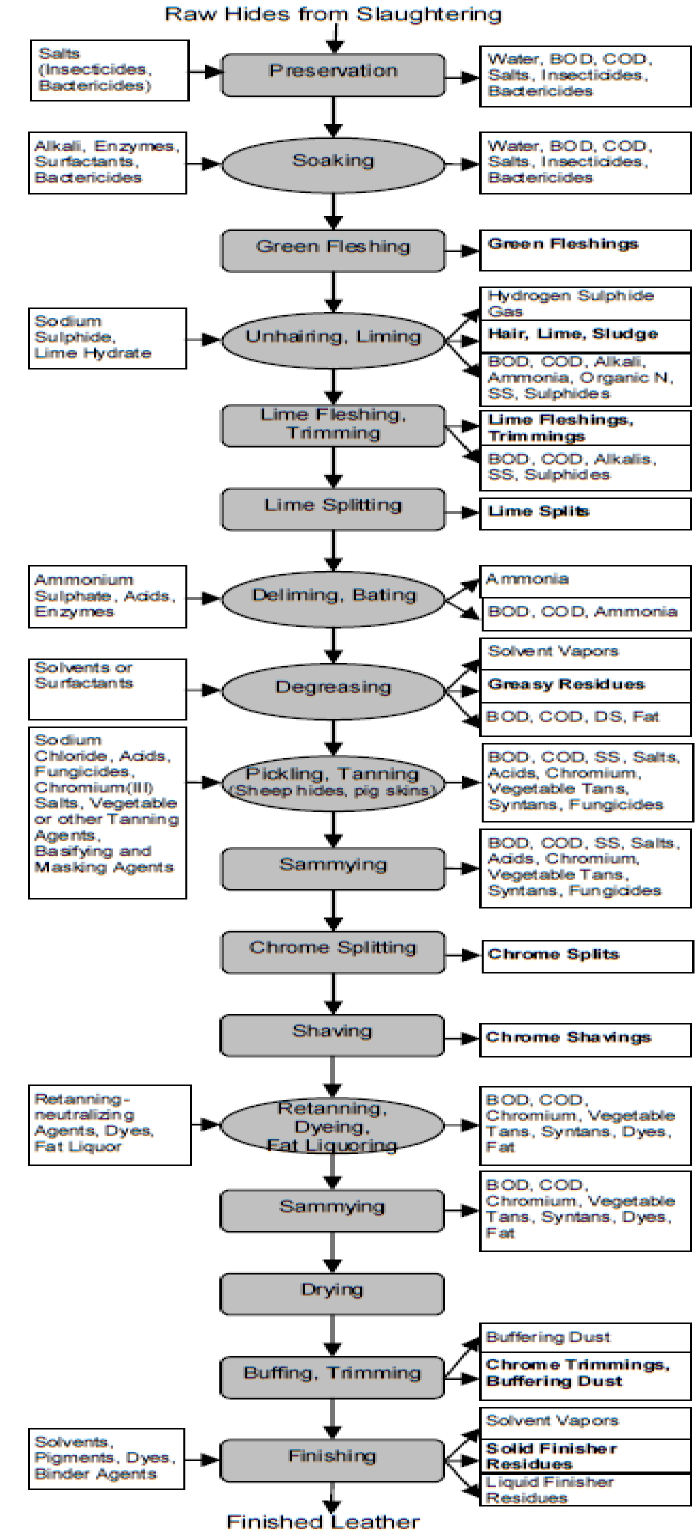


Figure 2-1 Overview steps on leather (Kadam 1990)**.**

Leather tanning Industrial activity consume large amounts of water for production of leather, with high levels of employing toxic substances, such as chrome and sulfide (Chowdhury et al. 2013). According to various aqueous steps of the process due to the treatment of hide/skins with intermittent discharges making this an industrial activity, which is used high amount of water and produces large amount of effluents that, in turn require significant investment and operating costs for their treatment to satisfy the emission standards required by environmental legislation.

The distinctive characteristics of three main classes of tannery wastewater are-

- Effluents comes from the beam-house – liming, bating /deliming, water from splitting and fleshing machines they contain Sulphide, they are chrome-free but their pH is high.
- Effluents comes from the tan yard (tanning and re-tanning, sammying) has high chromium content, acidic.
- Other general effluents and Soaking, mostly from post-tanning operations (fat liquoring, dyeing) has low chromium content (Gutterres et al. 2015).

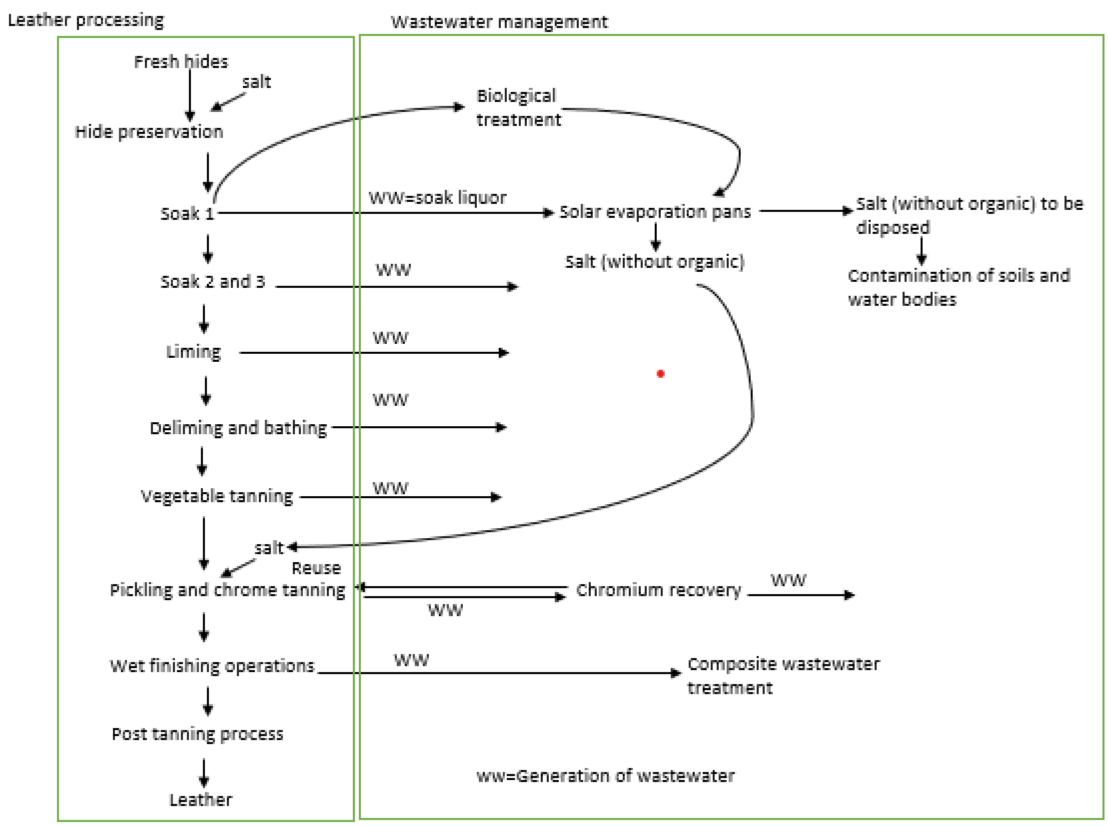


Figure 2-2 Simplified leather production chain and management.

2.3.1. Characteristics of Tannery Wastewater

Water quality parameters that can directly or indirectly influence the quality of prepared leather. Tannery wastewater characteristics vary from tannery to tannery depending on chemicals used for a specific process amount of water, type of final product produced by a tannery and size of the tannery. Tannery wastewater mainly characterized by measurements of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), Total suspended solids (TSS), total dissolved solids (TDS), chlorides, chromium and sulfide (Mocanu 2016).

Table 2-1 EEPA 2003 discharge limit value for tannery (Abate et.al 2020)

Physicochemical parameters	Discharge limit values
	EEPA
Temperature (^oC)	40
pH	6-9
TDS (mgl^{-1})	NL
TSS (mgl^{-1})	50
BOD_5 (mgl^{-1})	200
COD (mgl^{-1})	500
Chloride (mgl^{-1})	1000
Sulphide (as s^{2-}) (mgl^{-1})	1
Total nitrogen as (N) (mgl^{-1})	60
Total Chromium (Cr) (mgl^{-1})	2
Total phosphorus (TP) (mgl^{-1})	10
Ammonium NH_3 (mgl^{-1})	30

Note: -NL is no limit state

2.4. Tannery Wastewater Health Effect

Constitute in Tannery wastewater has greatly affected environment, human health, plants and animals or biotic and abiotic components with global, regional and local implications. Industrial effluent considered as the core environmental pollutants containing inorganic and organic compounds (Firdissa et al. 2016).

Wastewater from tanning operations frequently discover their way into surface water, where poisons supported downstream and pollute water used for different purposes. Chromium waste can also leak into the soil and pollute groundwater systems that offer drinking water for neighboring communities. Soil that polluted by chromium waste also stances a health danger toxic dust breathes in by both livestock and people. In addition, pollution in water can construct up in aquatic animals, which are a common basis of food (Genawi et al. 2020). Chromium commonly arises in two forms. Trivalent chromium (chromium III) is a naturally arising element that is comparatively unchanging and innocuous and may found in plants, animals and soil. Hexavalent chromium Cr(VI) is extremely more hazardous for humans and commonly created through anthropogenic causes (Bosnic et.al 2000).

Effluents from tanning industry are frequently adversely disturbing human life, livestock and agriculture. Which has controlled to plain ailments such as skin irritations, kidney failure, eye diseases and gastrointestinal problems. Hexavalent chromium is a hazardous human carcinogen that can source or rise the rates of certain cancers. Inhalation of chromium VI, which founds the most often amongst workers, may cause to cancer of the respiratory system. In addition, inhalation of dust polluted by chromium can be a reason to ulcerations, eye damage, irritation, asthmatic bronchitis, and swelling to the nose and throat, liver, kidney and stomach problems. Dermal contact causes a large number of skin problems, including sores, rashes and ulcers (Amshi et al. 2020). There after chromium accumulation in the body can harm a person's ability to metabolize iron, which can lead to iron deficiency.

2.5. Tannery Wastewater Treatment Processes

Water is becoming scarce and the quality of available water is weakening. Numerous steps in order to diminish the consumption and the amount of effluent discharged from the wastewater treatment plants. Wastewater treatment can contain physical, chemical or biological processes or combinations of a process dependent on the compulsory standards. Wastewater quality definite by its physical, chemical and biological characteristics (Desta et al. 2014). Wastewater before it enters a body of natural water it passes through a multi-stage process to purify and applied to the land or recycle. The goal is to decrease or eliminate organic matter, nutrients, solids, Chromium and other contaminants since each water body can only obtain certain amounts of pollutants without suffering degradation. Consequently, effluent treatment plant must follow to discharge standards limits typically spread by applicable environmental authority as permissible levels of pollutants (Balachandran and Rudramoorthy 2009).

-Physical process

Physical forces are practical to eliminate contaminants like coarse solid matter. It might be inert process, such as float to the top or sedimentation to allow suspended pollutants to settle out naturally. In general, these process used to remove or separate physically large contaminant (Arvia 2020).

-Chemical process

Different chemicals can be added to the tannery wastewater to alter the water chemistry. Chemical pretreatment may involve pH adjustment or coagulation and flocculation. The acidity or alkalinity of wastewater require to remains between 6 to 9 toward keep organisms otherwise both wastewater treatment plant and the environment can be affected the pH of wastewater (DEFRA 2018). Coagulation and flocculation are physico-chemical processes commonly used for the removal of colloidal material or color from wastewater. In wastewater treatment, coagulation indicates that step where particles destabilized by a coagulant. Large aggregates are formed due to combination of small particles, physical separation processes such as sedimentation, flotation and filtration can then more easily remove colloidal material. Flocculation also gentle agitation or slow stirring used to aggregate destabilized particles and to form rapid settling floc (Omondi 2018).

-Biological process

The biological process of wastewater treatment is grounded on the consumption of organic matter by microorganisms, which include bacterial, viruses, algae and protozoa. Therefore, knowledge of their metabolisms is necessary in order to control of the process effectively (Kobylinski and Hunter 1992).

2.6. Wastewater Treatment Options

Wastewater treatment options may classify into groups of processes according to the function they accomplish, while keeping capital and operating costs as small as possible and their complexity (Trösch 2009). This are-

- Preliminary treatment: -

This includes simple processes such as grit removal and screening to remove the gross solid contamination. Typically, in the case of common effluent treatment plants (CETPS) examining tannery clusters often found in developing countries, their role is to remove large particles, grease and grit/sand, but also to significantly decrease the content of Sulphide and chrome before the effluent is discharged into the collection system.

- **Primary treatment: -**

Frequently plain sedimentation simple settlement of the solids material in sewage can diminish the contaminating load by significant quantities.in this stage removal of settleable organic and inorganic solids by sedimentation and the removal of materials that will float (scum) by skimming (El Nadi et.al 2019). The effluent and sludge from primary sedimentation are mentioned as primary effluent and sludge.

- **Secondary treatment: -**

This used for supplementary treatment and deduction of common contaminants, in most cases, secondary treatment follows primary treatment, its goal being the removal of colloidal organic and biodegradable dissolved matter using aerobic biological treatment processes (Sanderson et al. 2019). Aerobic biological treatment is carried out by presence of oxygen. Several aerobic biological processes are different among primarily with the manner in which oxygen is supplied to the microorganisms and with the rate at which organisms metabolize the organic matter.

- **Tertiary treatment: -**

This can also use us other treatment choices usually for elimination of specific contaminants. Tertiary or advanced wastewater treatment is used to reduce residual cod load and when specific wastewater constituents are not removed by previous treatment stages. Therefore, each effluent treatment plant must obey relevant standards discharge limits to environmental authority as allowable levels of pollutants (Arvia 2020).

2.7. Description of ELICo WWTP

ELICo is one of the leather industries in Ethiopia, which produce with an annual capacity of 6600 tons it is the sole industry that processes completed goatskin and sheepskin leather. The company generates a maximum of 1200 m^3/day of wastewater effluent, which is treated in a primary and secondary tannery wastewater treatment facility before being released directly into a receiving water body. On the other hand, the company used raw water at a rate of 2000 m^3/day on average, which equates to around 90 m^3 of water per ton of finished leather (Andrea and Roberto 2015). The company has a wastewater treatment plant to eliminate the pollutants in solution and part of suspended solids thereby producing a reduced amount of sludge. A general treatment line, liming treatment line (treated before entering in to general line) and chrome line (totally it is recycled), composes the present tannery wastewater treatment plant.

In general treatment line first screening, effected through a bars screen (opening 20 mm), eliminates the coarse parts from the water, this material passing to the following phases could influence the pumps functioning. Fine screening an autocleaning screen works in automatic with the increase of the water level in the installation channel, with the aim to eliminate the screening material that can cause problems to the subsequent phases and the possible obstruction of the hydraulic lines and pumps. Then it passed through homogenization inside the homogenization tank the water is kept mixed through an air distribution line to avoid the sedimentation of the suspended solids and homogenize the water of different qualities. That is used to increase homogeneity of the influent coming from different path of the factory. below some tables are attached according to the specified design parameter there is no any calculated parameter.

Table 2-2 Information related to equalization/homogenization tank

Equalization/Homogenization tank	
Quantity (Pcs)	1
Length (m)	30
Width (m)	8
Useful height (m)	4
Total height (m)	4.25
Useful volume (m^3)	1000
Retention time (hr.)	13

The water coming from the homogenization tank pumped to the primary oxidation where is during the oxidation phase takes place the true biological depuration process where develop two main phenomena of bio-flocculation (physical-biological) for the elimination of polluting substances that cannot sediment and the bacterial metabolism (biological) for the elimination of the residual substances. To allow the realization of these phenomena it is necessary the presence of active bacterial biomass, that grows.

To facilitate the bio flocculation, it is affected the mixing of the water in the tank. The organic substance arrives in the tank together with the water, there the bacterial mass develops with the arrival of the organic substance. The oxygen is supplied through the blowers and diffusers installed on the bottom of the tank, while the temperature is maintained at 25-30°C thanks to the exothermic reaction of the biological process.

Table 2-3 Information related to primary biological oxidation tank

Primary biological oxidation tank	
Quantity (Pcs)	1
Length (m)	22
Width (m)	14
Useful height (m)	5
Total height (m)	5.5
Useful volume (m^3)	1540
Total volume (m^3)	1694
Retention time (hr.)	31

The water coming from the primary biological oxidation tank is pumped to the primary sedimentation where is affected a first separation of the liquid part from the sludge, that will sediment on the bottom of the tank. Circular tanks are generally preferred as recirculation is easier. Organic coagulant (polyelectrolyte) increases size of sludge flakes and killing bacteria. As a coagulant agent Aluminum Sulphate is mainly used, which means promoting particles collision by neutralizing charge in the purification of wastewater treatment plant (Andrea and Roberto 2015).

Table 2-4 Information related to primary sedimentation tank

Primary Sedimentation tank	
Quantity (Pcs)	1
Diameter (m)	10
Total surface (m^2)	78

Useful height(m)	2
Total height(m)	2.5
Useful volume (m^3)	166
Total volume(m^3)	207
Retention time(hr.)	3

The clarified water after the primary sedimentation will go to the secondary biological oxidation treatment stage.

Table 2-5 Information related to secondary biological oxidation tank

Secondary biological oxidation tank	
Quantity (Pcs)	1
Length (m)	21.5
Width (m)	12
Useful height (m)	4
Total height (m)	4.5
Useful volume (m^3)	1032
Total volume (m^3)	1200
Retention time (hr.)	21

From the secondary biological oxidation, the water goes to the secondary sedimentation where, with the help of the flocculant's products, the sludge is collected on the bottom of the tank to be recycled and partially sent to the treatment of filtration for its elimination.

Table 2-6 Information related to secondary sedimentation tank

Secondary Sedimentation tank	
Quantity (Pcs)	1
Diameter (m)	14
Total surface (m^2)	81
Useful height(m)	2.5
Total height(m)	4.5

Useful volume (m^3)	365
Retention time(hr.)	7

The sludge produced during the chemical treatment separates inside the sedimentation tank and wastewater constituents are not removed by previous treatment stages are removed in this stage. Therefore, each effluent treatment plant ready to discharge relevant standards limits.

Table 2-7 Information related to secondary advanced sedimentation tank

Secondary Advanced Sedimentation tank	
Quantity (Pcs)	1
Length (m)	18
Width (m)	4.5
Total surface (m^2)	81
Useful height (m)	4.35
Total height (m)	4.5
Useful volume (m^3)	246
Total volume (m^3)	258
Retention time (hr.)	4

The clarified water after this phase will reach final discharge of treated water and sludge extracted from secondary sedimentation and advanced sedimentation tank are sent to the existing mixing lime tank. After that pumped to the thickening tanks to allow their concentration and reduce the sludge volume. Surplus amount of sludge is not an appropriate condition. Accordingly, Sludge thickening is manly used to make solids thick in density and decrease the volume with removing the moisture. Condensed sludge takes small space and chemical required to stabilize the sludge coming from settling treatment units.

Finally, dewatering process is accomplished by drying beds contain a layer of sand, which is laid on a coating of gravel. Additionally, the filter press is laid over drains or perforated pipes placed on the concrete floor serving as the underdrains, which collect the filtrate draining from the beds.

If the dewatered sludge has not been stabilized, it has to be disposed of quickly and not stored for more than 2–3 days (Omondi 2018).

Table 2-8 Information related to thickening

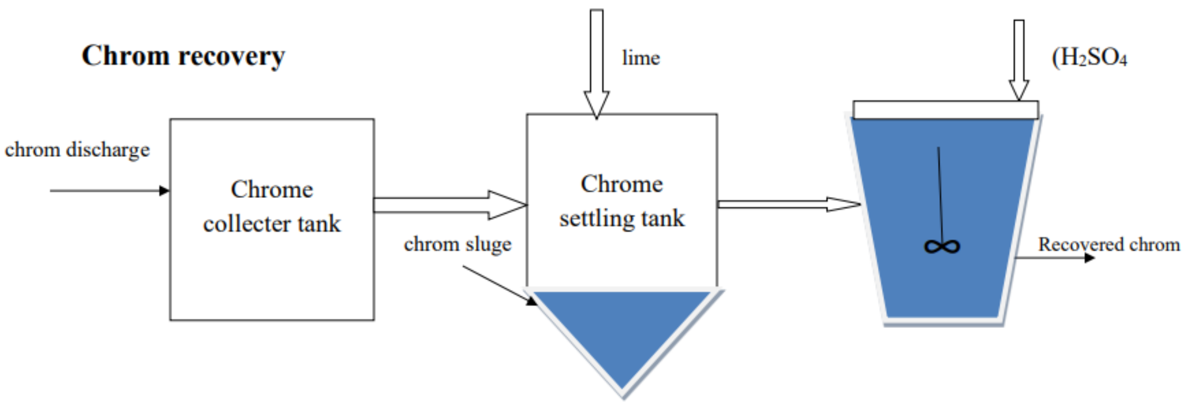
	Thickening tank
Quantity (Pcs)	1
Length (m)	7
Width (m)	3.5
Total surface (m^2)	24.5
Useful height (m)	4.4
Total height (m)	4.5
Useful volume (m^3)	75
Total volume (m^3)	77
Retention time (hr.)	24

In liming treatment line first coarse screening, effected through a bars screen at customer's charge, eliminates the coarse parts from the water, this material passing to the following phases could influence the pumps functioning. Fine screening the screen works in automatic with the increase of the water level in the installation channel, with the aim to eliminate the screening material that can cause problems to the sedimentation phase and the possible obstruction of the hydraulic lines and pumps. The water after the filtration falls into the sulphide oxidation tank the oxidation of all the dissolved sulphides (S^{2-}), present in the liming bath and following washings, takes place in this tank. Strong oxidizing atmosphere we obtain the sulphate (SO_4^{2-}). The oxygen necessary for the oxidation of the sulphide and the other substances is supplied by an aeration system. The oxygen must be supplied in excess, to allow the complete oxidation of all the sulphides and avoid further bad smells. The air diffusion system also meets the necessary agitation and prevents the sedimentation of the suspended solids. The pH value of the water is higher than 10 – 10.5.

Table 2-9 Information related to sulphide oxidation tank

Sulphide Oxidation tank	
Quantity (Pcs)	1
Length (m)	8

Width (m)	8
Useful height (m)	3.2
Total height (m)	4.5
Useful volume (m^3)	205
Total volume (m^3)	267
Retention time (hr.)	8



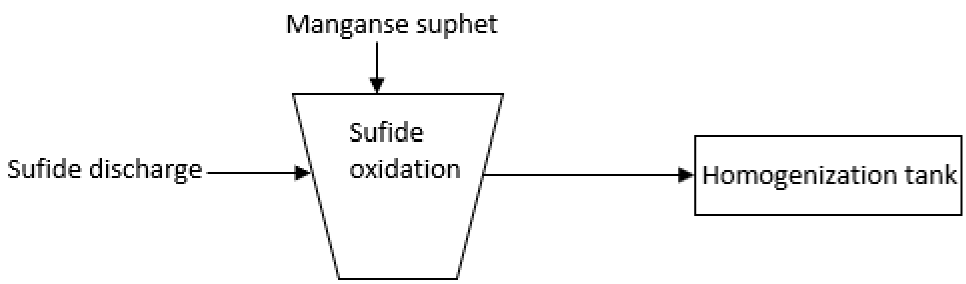


Figure 2-3 chrome and sulfide treatment process in ELICo

Below flow chart show as the general wastewater treatment line after sulfide treatment and chrome supernatant enter into homogenization tank.

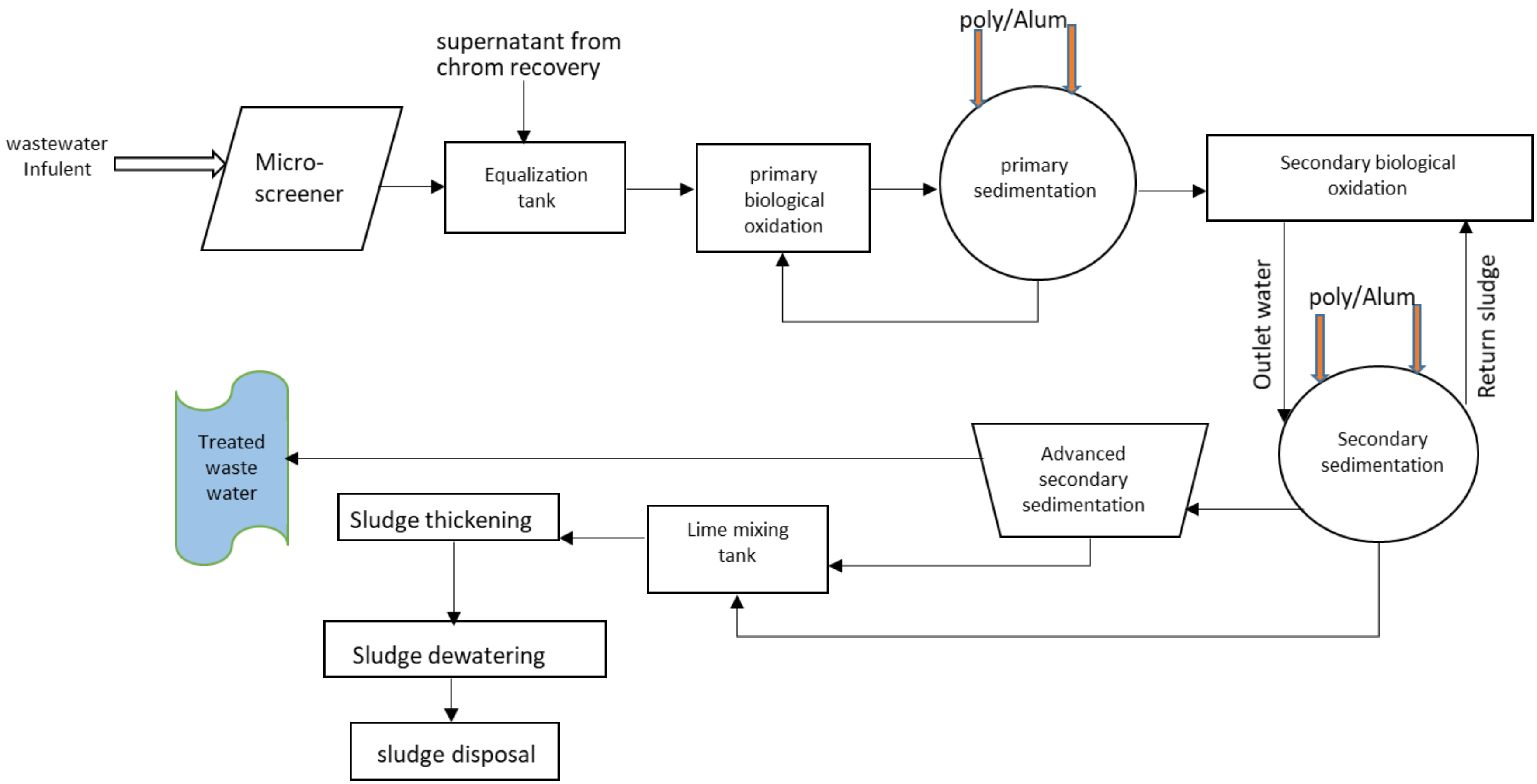


Figure 2-4 ELICo wastewater treatment plant flow diagram.

2.8. Tannery Wastewater Management

Wastewater must be properly managed to maintain a clean environment. The problems in low-income countries emanate from unplanned and rapid urbanization and population explosion. Uncontrolled growth accelerated by migration to urban centers on the one hand, lack of knowledge on the other has made planning and expansion of water systems difficult and non-existent in some cases. People live in a scattered communities is difficult to make water supply and wastewater management compared with condensed urban environment. Good management starts from the concept of combined wastewater management (Haddis et al. 2014). Wastewater management is very essential to ensure that the receiving water meet the standards for the quality of effluents.

2.8.1. Ethiopia Tannery Wastewater Management Status

Many countries in both the developed and developing world face significant problems in maintaining reliable water supplies and this is predictable to continue in future years due to that in part to the impacts of global climate change (Amanial 2016). In Ethiopia, there are regulations that sets the discharge compliance requirement for tanning industries that require tanneries to install a proper treatment plant to comply with the standards. The installation, operation and maintenance of treatment plants is a challenge for the industry.

In Ethiopia, management of liquid waste is very poor. The main threats that can be cited are unplanned and rapid urbanization without adequate infrastructure poor design and maintenance of sewer systems, inappropriate and unmaintainable technology selection low level of awareness of integrated wastewater management and poor co-ordination in monitoring, inspection, licensing and enforcement mechanisms. The current trend in industrialization gives priority for expansion of that construction of buildings without a wastewater management system but low level of attention reflects by decision makers for infrastructural development. This trend is dangerous both to human health and to the environment. Treatment systems, when present are deficient in design (Assefa and Sahu 2016).

Even large cities like Addis Ababa suffer from poor drainage and wastewater overflow from industries, institutions and residential areas. Management of tannery wastewater involves optimization of water and consumption used in wastewater treatment this will simplicity minimize the needed size of treatment plant and energy consumption. Therefore, efficiency of water consumption leads to cost reduction. Efficiency of water use improved by increased control of processing water volume.

Generally, with the growth in environmental awareness, the need to preserve natural water resources has increased. The problems of water shortage experience nowadays have led to the need to develop strategies that enhance the development stages of the technology and management of water usage. In water resource management, prioritizing activities that improve the integrated management of available resources.

2.9. Some of WWTP Modeling and Simulation Software

Models are essential to predict, describe and control the complex relations of the processes. Static models take about some assumptions in the calculations. Dynamic simulation allows definition depending on validation and understanding of certain processes in WWTP facilities (Hvala et al. 2017).

- Simulation programs for steady (static) applications are-

Aqua Designer, ARA-BER, REVIVAL EXPERT, DENICOMP, Danika/Danika plus, Denni, SASS.

- Simulation programs for unsteady (dynamic) applications are-

AQUASIM, Arasim, ASIM, DENISIM, EFOR, GPS-X, SASSPRO, SIMBA, STOAT, WEST.

Table 2-10 some of WWTP modeling and simulation software

Software's	Features
GPS-X	**Input data: -** It is user friendly due to its drag and drop interface. It allows the user to quickly enter characterization data due to the influent advisor. If influent data is entered incorrectly, a warning will be issued and provided potential problem exists. **Model build: -** It allow users too easily and quickly assemble a treatment plant model and open-code available to be edited. **Simulation: -** It is quick and easy to run simulations. Both steady state and dynamic simulations can be run. **Cost: -** It requires a site license.

	Presentation of output data: - It creates reports directly in excel format, including images, graphs, parameter settings and simulation results. Either the default or customized report format can be used for each project. **Institution: -** (Hydromantis Inc., Canada) (www.hydromantis.com).
WEST	**Input data: -** It is user friendly due to its drag and drop interface. **Model build: -** It is a powerful software and user-friendly package for dynamic modelling and simulation of wastewater treatment plants and other types of water quality related systems. It forms the basis of the secondary treatment stage of a WWTP and activated sludge process in particular. **Simulation: -** Very high simulation speed and powerful tools for model calibration. **Cost: -** No license required. **Presentation of output data: -** Customizable project documentation through inclusion of rich text notes and automated report generation**.** **Institution:-** (Hemmis, Belgium) (www.hemmis.com)
AQUASIM	**Input data: -** It is not user friendly inter the data directly into the model. It is a very slow process entering characterization data. No warnings issued so you will not know if your influent data is entered correctly or not. **Model build: -** Difficult, allows its users to define the spatial configuration of the WWTP as a set of compartments, which can be connected to each other by links. Modelling can be carried to answer any operational questions associated with WWTP but it takes more time. Its compartments are not available to be edited. **Simulation: -** It is quick and easy to run simulations. **Cost: -** No license required. **Presentation of output data: -** It can export report to excel. **Institution: -** (EAWAG, Switzerland) (www.eawag.ch).
	Input data: - Easily drag and drop unit processes to build a plant diagram.

CAPDET Works	**Model build: -** For accurate and fast preliminary design, simply and quickly building multiple treatment options to compare estimated planning level design, relative costs and costing productivity develops dramatically. **Simulation: -** It is not a process simulation tool. **Cost: -**. License is required. **Presentation of output data: -** It creates reports directly in excel format. **Institution: -** (Hydro mantis Inc. Canada) (www.hydromantis.com).
Aqua-designer	**Input data: -** It can drag and drop interface. **Model build: -** It is used for planning, design of numerous processes of a wastewater treatment plant from biology via mechanical treatment up to sludge treatment. **Simulation: -** Quickly simulate different operating units. **Cost: -** License is required. **Presentation of output data: -** Supplies wide documents prepared to be printed. **Institution: -** (bit control Gmbh, Arzfeld, Germany).
BIOWIN	**Input data: -** It ties together biological, chemical and physical process models to provide insight into the whole plant. **Model build: -** It is used to design, optimize and upgrade wastewater treatment plants of all types essentially biological model, which is complemented with other process models. **Simulation: -** Most accurate and intensively researched biological model reduces required calibration. **Cost: -** License is required. **Presentation of output data: -** It can export file to excel. **Institution: -** (EnviroSim associates ltd, Canada) (www.envirosim.com).
	Input data: - It is user friendly due to its drag and drop interface.

EFOR	**Model build: -** It can model activated sludge and has built easily to construct a varied variation of wastewater treatment plants. **Simulation: -** Simulate different operating units. **Cost: -** License is required. **Presentation of output data: -**It can export to excel. **Institution: -** (Danish hydraulic institute, Denmark) (www.efor.dk).
SIMBA	**Input data: -** It can build model easily due to drag and drop interface. **Model build: -** It can simply build sewer systems, wastewater treatment plants, sludge treatment and rivers. **Simulation: -** It is most appropriate for biological model simulation. **Cost: -** license is required. **Presentation of output data: -** It can export file to excel. **Institution: -** (institute fur automation und Kommonikation (Ifak), Germany) (www.ifaksystem.com).
STOAT	**Input data: -** Enter volumes, loads and operational data of the respective systems. **Model build: -** Users can determine in what way each unit is connected and operated, design and predict the wastewater treatment plant's performance in a specified time. **Simulation: -** Easy to run simulations. **Cost: -** License is required. **Presentation of output data: -** Simply data export to external spreadsheets. **Institution: -** (water research Centre, UK) (www.wrcplc.co.uk).
WATPRO	**Input data: -**To create model layout drag and connect unit objects then change parameters accordingly with specification. **Model build: -** It is user-friendly line allows a diagram of the wastewater treatment plant to be simply constructed within minutes.

	Simulation: - Perfectly simulates plant operation**.** **Cost: -** License is required. **Presentation of output data: -** Summary and process output in the tables. **Institution: -** (Hydromantis Inc. Canada) (www.hydromantis.com).
SIMU WORKS	**Input data: -** Drag and build the model then add specific operational parameters. **Model build: -** It is an industry first a flight simulator for water and wastewater treatment plants. **Simulation: -** Exactly simulates the performance of a specific plant. **Cost: -** License is required. **Presentation of output data: -** Export the output tables to excel. **Institution: -** (Hydromantis Inc. Canada) (www.hydromantis.com).
TOXCHEM	**Input data: -** It drag and drop process makes configuration so much easier. **Model build: -** It is user-friendly software for estimating and reporting air emissions and contaminant fate during wastewater collection and treatment. **Simulation: -** Simply run simulations. **Cost: -** License is required. **Presentation of output data: -** Export to spreadsheets. **Institution: -** (Hydromantis Inc. Canada) (www.hydromantis.com).

2.10. Why GPS-X Software is selected

GPS-X is supplied with over 50 preconfigured layouts, covering most of the unit processes found in wastewater treatment plants. GPS-X uses over 20 process objects in its models. GPS-X was the commercially primary released dynamic wastewater treatment plant simulator. It offers a user-friendly, customizable, robust, high-speed platform with calibrated models and the most comprehensive set of unit processes. It includes optimizer, advanced controllers, scenario manager, statistical analysis, leading edge influent advisor and sensitivity analysis tools (Omondi 2018).

process models can be considered as valuable tools to complement the established wastewater treatment plant design procedures. Benefits are gained by simulating the operation under precise wastewater characterization, dynamic operating conditions as well as change kinetic and stoichiometric parameters to a particular wastewater treatment plant operation. GPS-X models can be developed and adjusted to the plant data. GPS-X program significantly facilitates selecting optimal parameters for the design and operation purposes. It allows calculating the removal efficiency with concern to any wastewater pollution indicator. It can virtually cover the entire unit processes found in a wastewater treatment plan GPS X modelling has been an important part of carrying out the simulation and testing the design. In the analysis, consideration was accomplished and some critical parameters that affect the performance of the treatment plant were predicated. Using GPS-X increasingly a reality and not just a laboratory-scale project. It suggests clear advantages in terms of analyzing the performance of the treatment plant as well as better optimization and control tools, reducing the costs related with laboratory analysis. However, the efficiency of process modelling depends on a good calibration, which is generally needed to adjust the simulation results to the real behavior of the WWTP. GPS-X used to simulate and prove the process performance in regular situation and shock loading situations. The improvement in WWTP design, analyses and optimization using GPS-X are following:

- Compare various design or operating strategies
- Verify existing plant capacity
- Assess potential flow increases or regulatory changes
- Identify cost saving strategies (energy usage, reduction)
- Support regulatory decision (Pereira 2014).

Furthermore, the performance of treatment plant evaluated at a different operational scenario such as pollution load, influent flowrate and residential time to understand the critical parameters. Predicting wastewater treatment plant efficiency throughout extreme influent variations can be made by using modeling and simulation tools.

2.11. Wastewater Treatment Plant Simulation's process

Process models support us to imagine a system as it is or as we want it to be and provide us a template that led, us in constructing a system also document the decisions we have made. Computer starts to calculates the results of those conditions on the process model and outputs results is simulation in a format that is either human or machine-readable depend upon the implementation. Though modelling of a WWTP is a very hard task due to the non-linear characteristics of the physical, biological and chemical processes involved, a better control and operation of a WWTP can be achieved by developing healthy models for forecasting the plant performance based on the past observation (Sewnet 2012). Therefore, it is very important to assess the performance of treatment plant before it released effluents to environment and simulation of its the performance of treatment plant using cost effectively, time saver and high control response system model (Mu'azu et al. 2020).

Wastewater treatment plants are very complex hydro-technical facilities. Calculation and design of WWTP including knowledge of hydraulics, technology, chemistry, biology, physics, math and structure. Wastewater treatment processes are naturally dynamic because of the large variations in the concentration, influent wastewater flow rate and composition (Banks et al. 2012). In conducting process modeling a wastewater treatment system's to increasing capacity, process engineers first visit the existing plant to gather information and data. They define the extent of model calibration and sensitivity analysis recommended each model calibrated to minimize observable discrepancies between field data and model predictions.

The simulation will be performed based on operational parameters collected from the plant and from physico-chemical analysis. Simulation is technical processes in software it is model-based illustration of physical, chemical, biological and other unit operations (Drewnowski 2019). Collecting of necessary data for modeling is maybe the most challenging task. To evaluate existing WWTPs, long-term (several years) dynamic influent data are compulsory. In absenteeism of these data, influent data reassembled using existing making assumptions and measurements on the influent properties (Ge 2018). Gathering WWTP data including plant documentations of influent and effluent wastewater characteristics for more than a year wastewater flow. After data collection, desktop studies will begin to assess the stand processes and accommodations based on the historical data (Kurtz and Kurtz 2009). Field and laboratory tests for diverse processes are supportive to evaluate the performance of the WWTP facilities (El-sheikh 2011).

2.11.1. Development of WWTP Model in GPS-X

Initially, when developing a simulation for a WWTP, the modeler should decide the purpose and scope of the simulation. The model complexity the data required and the level of model calibration depend on the purpose and scope of the model. A key rule of modelling is that a model should be as simple as possible and only as complex as needed (Connell 2015). It is important to note that a model does not need to exactly represent the subject system in order to answer relevant questions. Model calibration is one of the main process bottlenecks to modelling.

Influent Advisor is one of Main components of GPS-X software it is an Excel-based tool that enables users to achieve influent characteristics most consistent with the available data. In many cases, detailed influent data may not be available and experienced modeler allows detailed characteristics of the influent wastewater to be estimated using only basic influent characteristics. In addition, GPS-X objects are also important components, which model various physical components of a WWTP (e.g., Influent processes, primary settlers and secondary treatment processes). Some of the following user inputs can define each object:

- Hydraulic configuration (e.g., Influent and effluent flow rates)
- Physical attributes (e.g., Physical dimensions of units)
- Operational attributes (e.g., The actions performed by the object, stoichiometry and kinetics)
- Display variables (definition of the variables associated with an object that can be displayed to the user)
- Stream labels (these allow identification of flows into and out of objects).

A user can use a combination of various objects to model their processes and define how each object interacts with other objects (this is known as the model layout). GPS-X translates the layout into a high-level computer language (ACSL) and generates an executable program. GPS-X achieves this using a specialized translator, which converts the layout into dynamic model equations. Once the executable code is generated, a fully featured interactive simulation control window enables simulations to be conducted.

A model can be in run in steady state or dynamic mode. In steady state modelling, the process variables do not vary with respect to time. In dynamic modelling the process variables vary with respect to time until the process is stabilized, assuming the system is not disturbed by external factors.

2.11.2. Model Description

A generic modelling development approach, which included the three main steps to model development and calibration are discussed below.

Step 1: Data Collection

The collection of data for model development can often be a costly and expensive undertaking. The quality of the data used to calibrate the model will have a direct impact on the reliability of the predictions made when using the final calibrated model. Influent characterization is one of the dominant factors and involves translating data available from the WWTP. In existing treatment, plant gather available information on flow patterns and wastewater characteristics. Historical plant records can provide enough information to make a calibration of a simulator, although the accuracy of the calibration can depend on the quantity, quality and nature of the data available (Pijáková and Derco 2013).

Step 2: Sensitivity Analysis and Model Calibration

The most relevant parameters to be estimated during calibration are determined by completing a sensitivity analysis as this identifies the parameters to be adjusted during calibration. Model calibration, also known as parameter estimation. Process of adjusting model parameters is identify differences between observed and simulated results are minimized (Connell 2015) . Sensitivity analysis and model calibration are one of the most important components. The choice of calibration approach depends on heavily complexity on the WWTP being modelled.

- **Objective of Sensitivity Analysis**

Sensitivity analysis is used to identify the parameters to be adjusted during calibration. The influence of parameters on model calibration can vary due to the WWTP's operating conditions and influent composition. By examining the sensitivity of the model parameters, an indication is given as to which parameters require adjusting to fit modelled and measured data.

Sensitivity analysis is used to determine the sensitivity of the simulations model has output variables (dependent variables) to changes in its parameters (independent variables). This helps to identify the parameters that have the greatest impact on the model. The sensitivity analysis is set up after the model has been built (Abbasi et al. 2021).

- **Objective of Model Calibration**

Calibration is the process in which model parameters are adjusted until the model predictions match selected sets of data from the actual WWTP. The objective is to minimize the error between the measured datasets and the model predictions. It is not necessary to achieve a perfect match between modelled and measured data, since the model is a simplified representation of the plant and often ignores some of the inputs and processes occurring at the actual plant. The exact matching of modelled and measured data is not necessary as while it might reduce the total error for one particular dataset, it can reduce the model's predictive power and increase model error for other datasets (Solutions et al. 1985).

Step 3: Simulation, Model Validation and Verification

Once the model is calibrated, the modeler is ready to run numerous model simulations. In the first simulation, the model behavior is validated. Model validation involves checking that the model responses generated during the model analysis agree with that obtained from the true process. Model verification consists of comparing the simulation results to an independent set of data.

2.12. Benefit and Impact of process Modelling and Simulation

2.12.1. Benefits of process Modeling and Simulation

Process Modeling and simulation can assist understanding a systems behavior without really testing the system in the real world (Bis et al. 2008). Besides, simulation can be used to sequence persons using a virtual environment that would otherwise be expensive or difficult to produce. According to practitioners, modeling, simulation and analysis is one of the most frequently used operations research techniques (Carson 2005). When used thoughtfully, modeling simulation and analysis makes it possible to-

- Get results quickly
- Handles difficulty with relative ease

- Inexpensive than building or modifying the real system
- Risk-free see the consequences before implementation
- Easier than process testing on existing systems
- Develop well-designed and robust systems and reduce system development time
- Employ a systems approach to problem solving.

2.12.2. Impacts on Designing and Upgrading Wastewater Treatment Plants

Complete WWTP design is a complex problem for numerous reasons, the following being the most remaining:

- Deficient of Reliable information on the characteristics of the wastewater to be treated is common.
- Unclear objective, Invalid model and Erroneous assumptions
- Simulation model too simple or too complex
- Various interrelated physicochemical and biological processes involve in Wastewater treatment but there is Undocumented assumptions
- Bugs in the simulation program
- Using standard statistical formulas that assumed as individuality in simulation output analysis
- Poor budget and communication and schedule planning
- Poor between the workers involved in the simulation study
- Simulation can be a time consuming and complex exercise from modeling through output analysis that requires the contribution of resident experts and decision makers in the whole process (Maria 1997).

2.13. Recycle Opportunities in Tannery Wastewater

In tanneries, the phases of hide preparation (cleaning and conditioning treatment for tanning), as well as the fixation and transport of tanning and adjusting substances into collagen structure are all passed in aqueous media. Furthermost of the steps in these processes are passed with fresh water, which is used as a vehicle for the dispersion of chemical goods and the abstraction of diverse materials from the hide (Guterres et al. 2015). The leather industry transforms rawhide into an impervious material via a process that consumes great quantities of water and chemical reagents, subsequently generating a great extent of effluent (Paridash et al. 2019). Wastewater reuse mechanism is a powerful tool to prevent fresh water and to mitigate climate change. The possibilities for the recycling and recycle of water at each stage of leather tanning. Leather industry needs around 30-40 L water per kg of skin processed, the washing and 57% in the steps of tanning and retanning consume 35%. Recycle of wastewater from the retanning stage after its filtration through leather wastes from the shaving process. Leathers found with this water recycle presented similar characteristics of those retanned with fresh water. Wastewater recycle mechanism is a powerful tool to prevent fresh water and to mitigate climate change(Kadam 1990).

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3. MATERIAL AND METHODS

3.1. Study Area

The research was carried out in the Ethio-leather industry (ELICo), which is located at 8° 57' 6" N 38° 45' 46" E in Addis Ababa's Akaki Kality sub-city. With an annual capacity of 6600 tons, it is the sole industry that processes completed goatskin and sheepskin leather. The company generates a maximum of 1200 m^3/day of wastewater effluent, which is treated in a primary and secondary tannery wastewater treatment facility before being released directly into a receiving water body. Primary aeration/biological oxidation tank, homogenization tank, primary sedimentation, secondary aeration/secondary biological oxidation tank, secondary sedimentation tank, advanced secondary sedimentation tank and sludge thickening unit operations make up the treatment plan. On the other hand, the company used raw water at a rate of 2000 m^3/day on average, which equates to around 90 m^3 of water per ton of finished leather goods.

3.2. Research Design

The experimental analysis and process modeling and simulation stages were separated into two parts of the study. Primary and secondary data collection were utilized to acquire the essential input data for process modeling and simulation. Primary data was derived from direct wastewater quality information obtained through sampling and physico-chemical laboratory analysis. A personal site visit, review of factory treatment plant design and technical document, factory personnel consultation, operational document and published materials such as journal articles were also used to understand the overall treatment plant setup and unit operation arrangement, as well as to find the operational input parameters. Other important documents, such as past laboratory analyses, particular previous research in this plant, standard and guidelines, were also taken into account. Volume, equipment size (surface area, diameter and height), incoming wastewater and process air flowrate, chemical dose and equipment efficiency were all considered.

3.3. Methodology for Wastewater Sampling and Analysis

3.3.1. Sampling Techniques

When analyzing wastewater, the manner in which samples are obtained, as well as the laboratory methods and practices used, have a significant impact on the quality of the results. To obtain samples that would be representative of the actual wastewater quality throughout wastewater treatment operation, Closed reflux (colorimetric) method, Temperature meter (glass thermometer), pH meter, inductively coupled plasma optical emission spectrometry, Argentometric Methods, Methylene Blue Method and HACH LANGE standard analytical procedures were used. Because tannery wastewater is often not homogeneous because of different treatment operation are held on different treatment plant unit, a composite of grab samples was used, consisting of three equal-volume samples taken from the top, middle and bottom of the wastewater-receiving tank. Finally, the collected samples were combined to ensure that a representative sample was obtained.

3.3.2. Sample Preservation and Transportation

The materials, which were used during conducting of field analysis, are pH meter, temperature meter (glass thermometer) and plastic bottles for collecting the tannery wastewater samples labeled by kind and location then stored at 4°C in iceboxes before being delivered to the designated laboratories for examination within 2 to 4 hours of sampling. All parameters were tested using the Water and Wastewater Standard Method (APHA, 2017). All sample analyses were performed in duplicate on homogeneous samples. Table 3.1 provides an overview of the analytical procedures used.

Table 3-1 List of Analytical methods

S/N	Parameter	Analytical methodology
1.	Chemical Oxygen Demand (COD)	Closed reflux (colorimetric) method using COD digester DR6000 UV-VIS Spectrophotometer
2.	Temperature	Temperature meter (glass thermometer)
3.	pH	pH meter
4.	Total Suspended Solids (TSS)	HACH (photometric Method DR/2400)
5.	Total Nitrogen (TN)	Persulfate digestion
6.	Total chromium (Cr)	Inductively coupled plasma optical emission spectrometry (ICP-OES)
7.	Chloride (Cl^-)	Argentometric Methods

8.	Sulfide (S^{2-})	Methylene Blue Method
9.	Biological Oxygen Demand (BOD_5)	Winkler Modified method
10.	Total Dissolved Solids (TDS)	Measurement of specific conductivity meter
11.	Total phosphorus (TP)	HACH LANGE (LCK 349)
12.	Ammonium NH_3	APHA2320 -NH_3

3.4. Removal Efficiency

The final effluent results were also compared with Tannery wastewater standard limit values for discharges according to Ethiopia provisional pollution control waste guidelines. The removal efficiency of the selected wastewater quality parameters was calculated using the following formula.

Removal Efficiency (%) = $\left[\frac{\mathrm{Ci}-\mathrm{Cf}}{\mathrm{Ci}}\right] * 100$ (Anon 2020).

Ci- is the initial concentration of waste materials

Cf-is the final concentration of waste materials

3.5. Process Modeling and Simulation

The chosen wastewater treatment facility (ELICo WWTP) was simulated in this study utilizing GPS-X wastewater treatment plant simulation software created by Hydromantis Co. of Canada. It is marketed as the world's premier wastewater treatment plant simulation platform, as well as the most advanced tool on the market for mathematical modeling, control, optimization and management of wastewater treatment facilities. To facilitate static and dynamic modeling and simulation, the GPS-X employs an advanced graphical user interface. GPS-X also provides an easy-to-use, robust, flexible, high-speed platform with calibrated models and the most comprehensive suite of unit processes. It has cutting-edge tools such as Influent Advisor, Advanced Controllers, Optimizer, Sensitivity Analysis, Scenario Manager and Statistical Analysis.

In GPS-X, model library is a collection of wastewater process models that use a standard set of wastewater components or state variables. The basic variables that are continually integrated across time are referred to as state variables. The composite variables are those that are derived from (or made up of) the state variables. Nine libraries are available in GPS-X for different wastewater and process water modeling are:

• Comprehensive – Carbon, Nitrogen, Phosphorus, pH (MANTIS2LIB)

• Selenium and Sulfur (MANTIS2SLIB)

• Carbon Footprint – Carbon, Nitrogen, Phosphorus, pH (MANTIS3LIB)

• Process Water Treatment Library (PROCWATERLIB)

• Petrochemical Wastewater LIBRARY (MANTISIWLIB)

• Carbon – Nitrogen (CNLIB)

• Carbon – Nitrogen – Industrial Pollutant (CNIPLIB)

• Carbon – Nitrogen – Phosphorus (CNPLIB)

• Carbon – Nitrogen – Phosphorus – Industrial Pollutant (CNPIPLIB)

Before proceeding to the physical characterization of each unit process it was necessary to select the library that better suited the entire WWTP plant. A library is a collection of wastewater treatment components to which are inherent certain state variables. GPS-X has nine libraries, each one of them having default values and expressions for the calculation of state variables. Since there was an interest in modelling carbon, nitrogen and phosphorus then, the Comprehensive-Carbon, Nitrogen, Phosphorus, pH (MANTIS2LIB) library was chosen for this study. It is the most commonly observed biological, physical, and chemical processes in wastewater treatment plants was developed and implemented in GPS-X. The key features of the MANTIS2 model are:

• Carbon, Nitrogen, and Phosphorus removal with integrated anaerobic digestion processes.

• Mass balance for COD, C, N, P, Ca, Mg, K and charge

• 48 state variables (21 soluble + 27 particulate)

• 56 processes

• Methanol degradation process with methylotroph biomass

• Anaerobic digestion processes with gas phase modelling for N_2, CO_2, H_2 and CH_4

• pH and alkalinity estimation in both liquid and solid train

The flowchart below (Figure 3.1) depicts the basic process model development and simulation workflow of GPS-X.

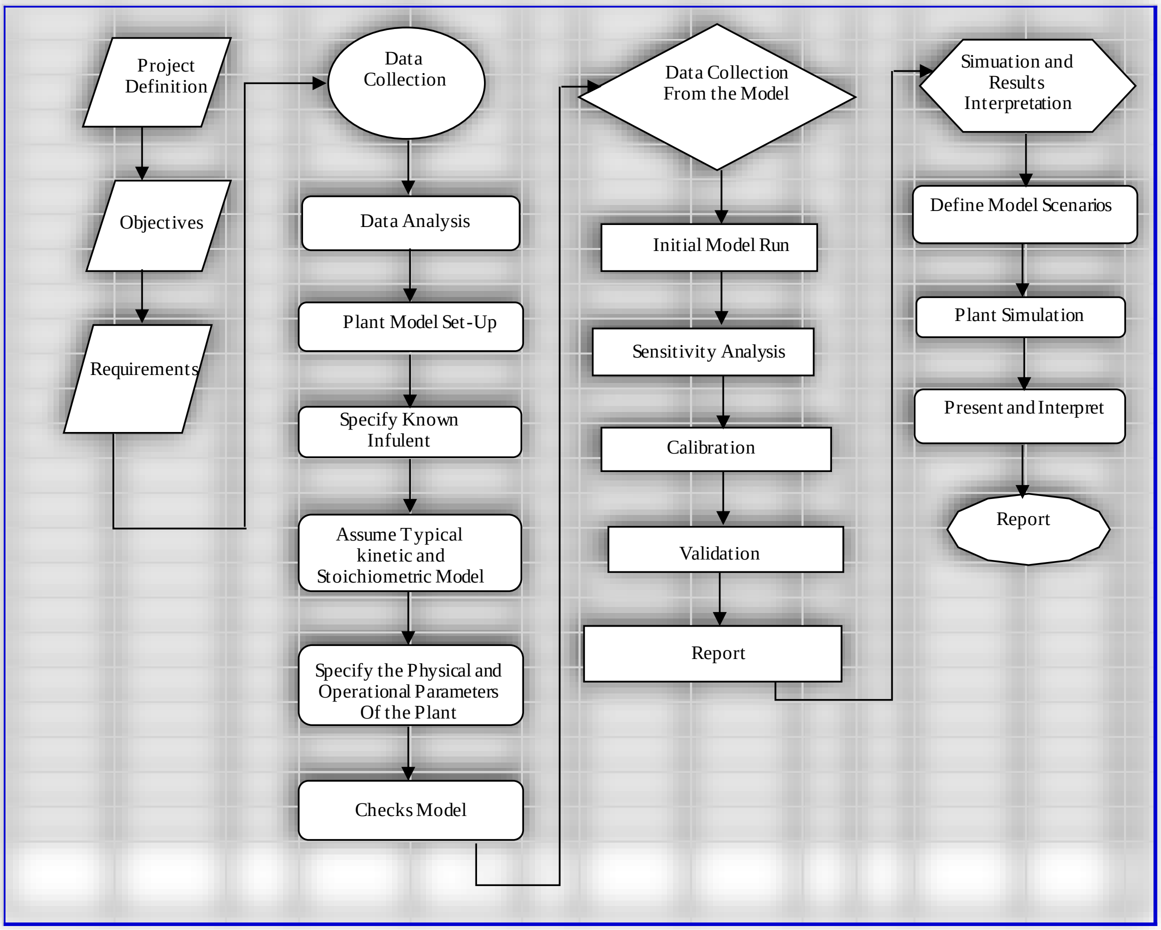


Figure 3-1 Model development and simulation workflow of GPS-X

3.5.1. Components of the model

Model components are separated into two categories: state variables and composite variables. The first are referred to as the basic variables since they are in charge of system characterization (GPS-X's dynamic model of differential equations) and are continually integrated throughout time. Composite variables, on the other hand, are derived from the matrix product of state variables and stoichiometric constants. The characteristics that characterize a WWTP model are state and composite variables and they provide an overview of how the WWTP is acting at any given time.

When GPS-X creates a layout model, it first calculates the corresponding composite variables by establishing a material balance for each state variable in the unit process.

Both of these variables can be classified into two types of matter soluble matter (S components) and particulate matter (X components). Soluble components are carried with the water during the treatment process and may have an ionic charge, whereas particulate components (electrically neutral) are connected with the activated sludge and can thus be concentrated through sedimentation/thickening.

State variables

In GPS-X, a group of state variables are calculated for each connection point in the plant layout. These state variables are the fundamental components that are acted upon by the processes in the models in each library. These particular state variable components are not always easily measurable or interpretable in practical applications. Therefore, a series of composite variables are calculated from the state variables.

Table 3-2 Cryptic name and Formulas that is used to calculate composite variables

Cryptic name	Description	Units
so	Dissolved oxygen	$gO2/m^3$
scat	Other cation	eq/m^3
sana	Other anion	eq/m^3
sclo	Chloride	gCl/m^3
snh	Ammonia nitrogen	$gNH_4\text{-}N/m^3$
stssul	Sulfide sulfur	$gH_2S\text{-}S/m^3$
ss	Readily degradable soluble substrate	$gCOD/m^3$
scol	Colloidal substrate	$gCOD/m^3$
xs	Slowly biodegradable substrate	$gCOD/m^3$
si	Soluble inert material	$gCOD/m^3$
xi	Particulate inert material	$gCOD/m^3$
xu	Unbiodegradable cell products	$gCOD/m^3$
snd	Soluble biodegradable organic nitrogen	gN/m^3
xns	Particulate biodegradable organic nitrogen	gN/m^3
xps	Particulate biodegradable organic phosphorus	gP/m^3
xbh	Heterotrophic biomass	$gCOD/m^3$
xbai	Ammonia oxidizer biomass	$gCOD/m^3$
xbaa	Nitrite oxidizer biomass	$gCOD/m^3$

Composite variables

Cryptic name	Description	Units
totdissol	total dissolved solids	mg/L
x	total suspended solids	g/m^3
vss	volatile suspended solids	g/m^3
xiss	total inorganic suspended solids	g/m^3
ivt	VSS/TSS ratio	gVSS/gTSS
scod	soluble COD	$gCOD/m^3$
cod	total COD	$gCOD/m^3$
sbod	soluble $cBOD_5$	gO_2/m^3
bod	total $cBOD_5$	gO_2/m^3
sbodu	filtered ultimate carbonaceous BOD	gO_2/m^3
xbodu	particulate ultimate carbonaceous BOD	gO_2/m^3
bodu	total ultimate carbonaceous BOD	gO_2/m^3
substsbod	soluble substrate $cBOD_5$	gO_2/m^3
substxbod	particulate substrate $cBOD_5$	gO_2/m^3
substbod	total substrate $cBOD_5$	gO_2/m^3
sninert	soluble inert nitrogen	gN/m^3
stkn	filtered TKN	gN/m^3
xninert	particulate inert nitrogen	gN/m^3
xtkn	particulate TKN	gN/m^3
tkn	total TKN	gN/m^3
tn	total nitrogen	gN/m^3
tnplusgas	total nitrogen including dinitrogen gas	gN/m^3
stp	total soluble phosphorus	gP/m^3
xtop	particulate organic phosphorus	gP/m^3
xtip	particulate inorganic phosphorus	gP/m^3
xtp	total particulate phosphorus	gP/m^3
tp	total phosphorus	gP/m^3
stoc	soluble organic carbon	gC/m^3
xtoc	particulate organic carbon	gC/m^3
toc	total organic carbon	gC/m^3
xtic	particulate inorganic carbon	gC/m^3
tic	total inorganic carbon	gC/m^3
totc	total carbon	gC/m^3
ph	estimated pH	
econductivity	conductivity	S/m
turbidity	turbidity	NTU

Cryptic name	Formula
x	x = vss+xiss
vss	vss = x*ivt
xiss	xiss = x-vss
ivt	ivt = vss/x

scod	scod = ss+scol+si
cod	xcod = xbh+xbai+xbaa+xs+xu+xi
	cod = scod+xcod
sbod	sbod = fssbodtosscod*(ss+scol)
	sbod = fssbodtosscod*(ss+scol)
bod	xbod = bod-sbod
	xbod = fpsbodtopscod*xs+fbbodtobcod*(xbh+xbai+xbaa)
	bod = sbod+xbod
sbodu	sbodu = (ss+scol) *(1.0-yhglobal*fuu)
xbodu	xbodu = xs*(1.0-yhglobal*fuu) +(xbh+xbai+xbaa) *(1.0-fuu)
bodu	bodu = sbodu+xbodu
substsbod	substsbod = sbod
substxbod	substxbod = fpsbodtopscod*xs
substbod	substbod = sbod+substxbod
sninert	sninert = insi*si
stkn	stkn = tn-xtkn-snoi-snoa
	stkn = snh+snd+insi*si
xninert	xninert = inxi*xi
xtkn	xtkn = inxbh*xbh+inxbai*xbai+inxi*xi+inxu*Xu+
	xns+inxmgnh4po4*xmgnh4po4
tkn	tkn = stkn+xtkn
tn	snox = snoa+snoi
	tn = tkn+snox
stp	stp = sp+ipsi*si
	stp = sp+ipsi*si
xtop	xtop = tp-stp-xtip
	xtop = ipxbh*xbh+ipxbai*xbai+ipxbaa*xbaa+ipxi*xi+ipxu*xu+xps
xtip	xtip = ipxalpo4*xalpo4+ipxfepo4*xfepo4+ipxcapo4*xcapo4+
	ipxmghpo4*xmghpo4+ipxmgnh4po4*xmgnh4po4
xtp	xtp = xtop+xtip
tp	tp = xtp+stp
stoc	stoc = icscol*scol+icss*ss+icsi*si
xtoc	xtoc = toc-stoc
	xtoc = icxbh*xbh+icxbai*xbai+icxbaa*xbaa+icxi*xi+icxu*xu+icxs*xs
toc	toc = stoc+xtoc
xtic	xtic = icxcaco3*xcaco3+icxmgco3*xmgco3
tic	tic = stic+xtic
totc	totc = toc+tic
ph	ph = ph
econductivity	tempk = temp+273.15
turbidity	turbidity = ktssturb*x+kcolloidturb*scol

The way that the composite variables are calculated from state variables changes from library to library and to a great degree from model to model. Composite variables are calculated from state variables with the use of stoichiometric constants. These constants describe the relationships between various states and composites and depend on the type of composite calculations used.

Table 3-3 Stoichiometry parameters used in estimation of composite variables

Stoichiometry Parameter	Default Value	Description
yhglobal	0.666	Heterotrophic biomass yield
fuu	0.206	Fraction of unbiodegradable residue in biomass
fssbodtosscod	0.717	BOD_5 to COD ratio of soluble substrate
fpsbodtopscod	0.58	BOD_5 to COD ratio of particulate substrate
fbbodtobcod	0.566	BOD_5 to COD ratio of biomass
icodtovssxbt	1.674	xCOD/VSS ratio of PHA

A complete description of the state variables in MANTIS2 model is located in the Comprehensive Model Library (MANTIS2LIB). The soluble states in the model can be classified into four categories: Soluble inert organic, Soluble biodegradable organics, Soluble inorganic ions and Dissolved gases.

Composite Variables MANTIS2 uses a well-defined stoichiometry for each state variable to estimate the composite variables. The state variables and their relationships to the composite variables are shown in the Composite Variables in MANTIS2LIB, GPS-X Composite Variable Calculations.

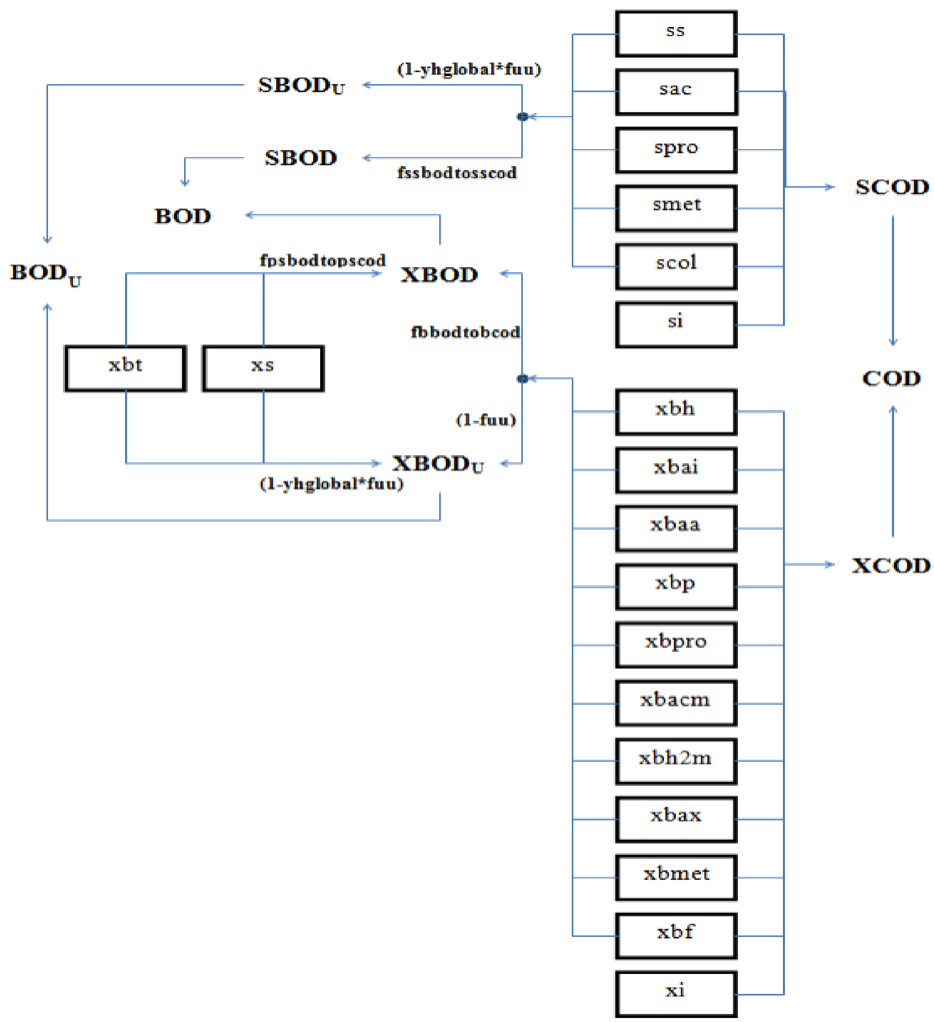


Figure 3-2 MANTIS2LIB – Calculation Procedure for Composite Variables COD, BOD.

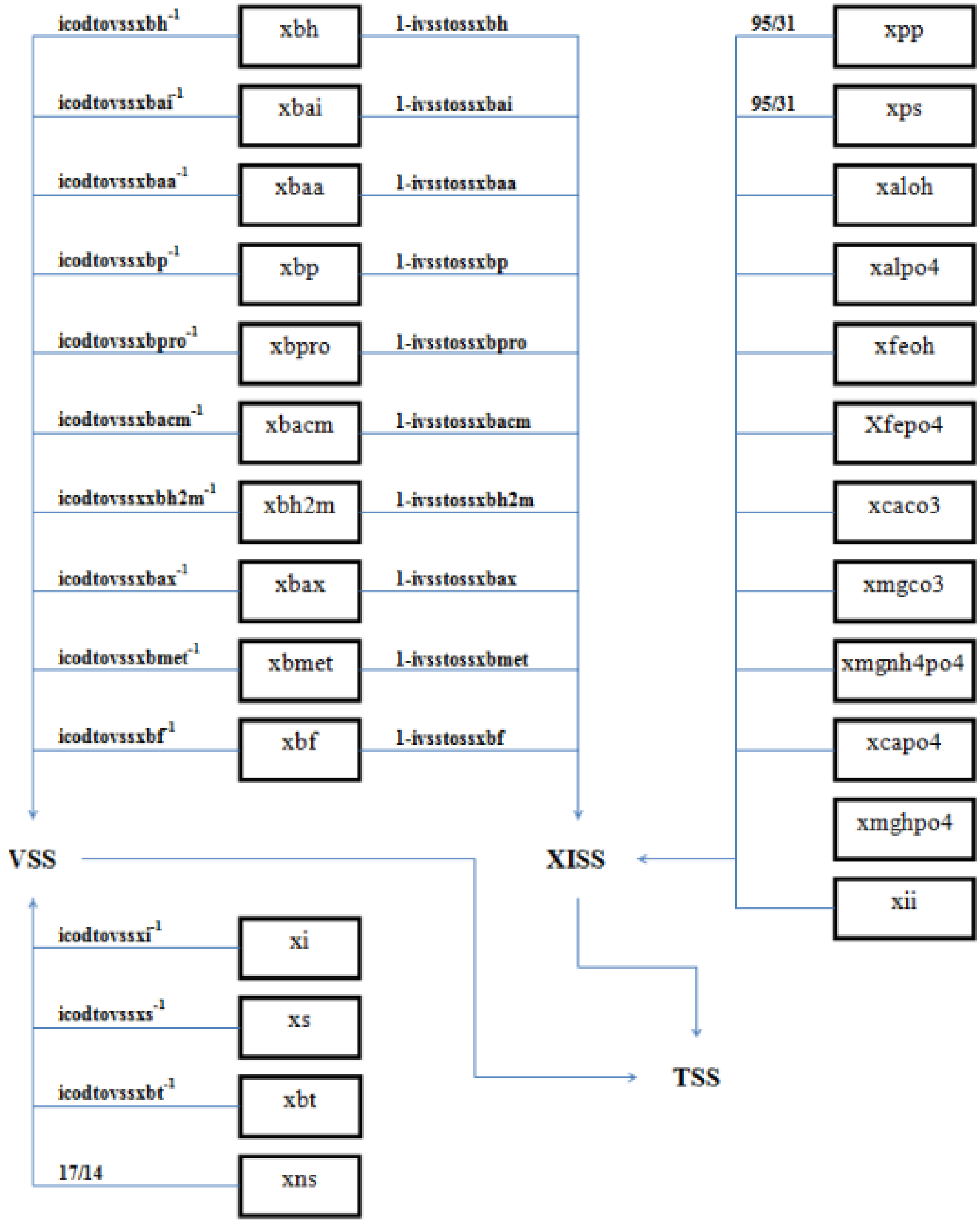


Figure 3-3 MANTIS2LIB - Calculation Procedure for Composite Variables TSS.

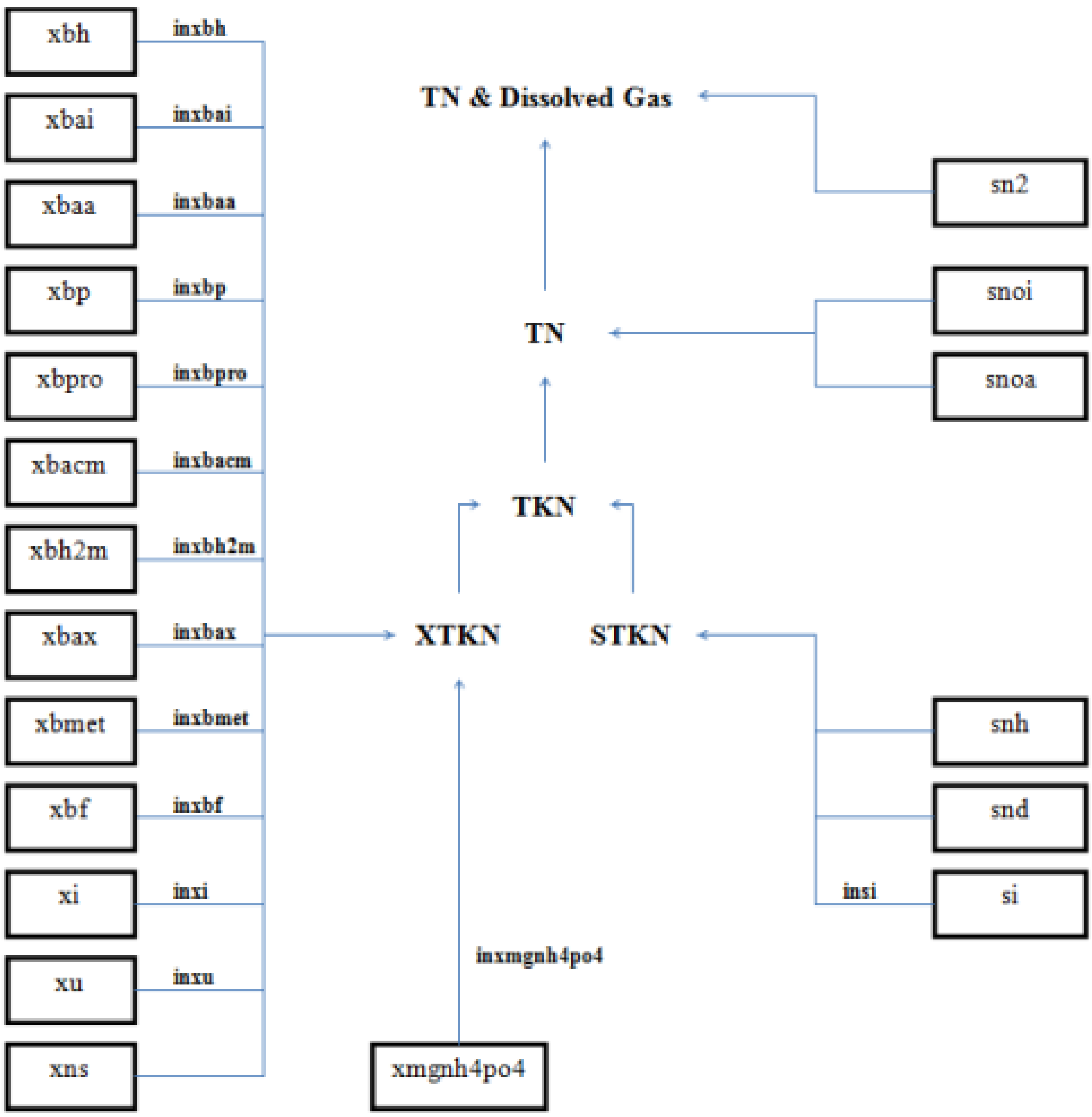


Figure 3-4 MANTIS2LIB - Calculation Procedure for Composite Variables TN.

3.5.2. Model development

Model Description

All of the models mentioned in this thesis were developed using a generic modeling development approach that included the five basic elements of-

(i) Project design,

(ii) Data gathering,

(iii) Plant model set-up,

(iv) Data collection from the model and

(v) Simulation and results interpretation. The following are the steps taken in the modeling study:

Determination of influent wastewater characteristics:

Ethio-leather tannery Wastewater Treatment Plant provided the wastewater characteristics. Based on material balances, Hydromantis has created a Microsoft Excel-based utility tool called ‘Influent Advisor,' which can assist customers in improving influent wastewater characterization. The single most significant part of a simulated system is the mathematical description of the influent wastewater that is fed into the plant model. The plant model's ability to forecast the dynamic behavior of the plant will be hampered if the influent characterization is not taken into account.

Treatment plant layout build-up:

To begin, a plant flowsheet must be established using the graphical interface by choosing unit processes and linking their flow lines. The code for the dynamic computer model is generated automatically depending on the arrangement. In GPS-X, a layout contains information about the physical information being modeled. The model(s) being used, physical dimensions of the units and connectivity between unit operations.

Data input:

After constructing the plant layout, the input data must be entered by configuring input controls in GPS-X. Dynamic input data (measured) collected from the treatment plant can be used in this manner. As well as physical and operational data.

Sensitivity analysis:

The model parameters that function as independent variables must first be stated. Sensitivity analysis should be performed on these parameters. During sensitivity testing, the lowest, maximum and increment value for an independent variable must be entered. Following the sensitivity testing, GPS-X displays an output graph that displays the parameter values vs the specified output parameter. The amount of change in output that results from a unit change in input is referred to as sensitivity. For example, how much does increasing the chemical dose or the air flowrate enhance the effluent? Manually performing sensitivity analysis by entering numbers and recording the findings might be time consuming. The GPS-X sensitivity analyzer is a built-in tool that runs several simulations, automatically adjusts input, collects all output and graphs the results (output vs. input). In general, make it simple to see the links between plant loading/operation and performance. The GPS-X sensitivity analyzer can perform a variety of analyses.

1. **Steady State:** Change one variable and receive a steady state solution for every stop along the way from a low value to a high value, where we get a complete steady state solution for each one of those.

2. **Phase Dynamic:** This is essentially the same process, except that after steady state, we conduct dynamic simulation and collect the data from the end of the dynamic simulation. As a result, if we have something where we want to change one variable but do not want to get a steady state solution, or we want to see what happens after a few days or weeks. The analyzer feature will make the input change for us solve for steady state, run a dynamic simulation to the end where we specify collected that data point and make the change do it again.

3. **Time Dynamics:** It is a dynamic simulation, but in this case, we want to be able to plot multiple runs on the same graph.

4. **Monte Carlo Analysis:** It is a probabilistic approach to sensitivity analysis in which we provide a number of input parameters and their distribution and then use the Monte Carlo feature to perform steady-state or dynamic analysis (Connell 2015).

Parameter optimization:

The sensitive parameters should be optimized following sensitivity analysis. Because model parameters might differ widely from one treatment facility to the next, parameter optimization is a critical step. As a result, a model that has been fitted to real-world plant data will be more valuable for forecasting plant behavior. All optimization issues in GPS-X are formulated as data fitting problems. The user enters the data into a file, selects an objective function, the parameters of interest and the model response variables to be fitted. The parameters that have been chosen are tweaked until the objective function is minimized. GPS-X offers dynamic parameter estimation, which is intended for estimating time-varying parameters.

Validation:

At the end of the modeling study, the improved parameters should be confirmed using multiple kinds of data. For the most part, it is assumed that the model predictions will be close to the actual values. Biological treatment plants, for example, may exhibit varying behavior depending on the season. A successful model should clearly be able to predict the required parameters pretty well throughout the year. Calibration for a piece of data should thus be checked using multiple sets of data (Connell 2015).

Model Assumptions

Assumptions are adopted for the development of the model in this study are as follows: -

- Constant influent flowrate was assumed
- Effluent flowrate was calculated using entered data
- All unit operates at a constant temperature
- The model's coefficients are assumed to be constants for any influent characteristics
- Different value used as their GPS-X default value (attached in appendix E) which means except the laboratory, historical, physical and some operational data's.

3.6. GPS-X Modeling Approach

In reality, the user defines influent and alter these unknown factors based on the model behavior and how it connects to what has been observed or measured at the plant. Each wastewater is unique, and each will necessitate some adjusting of these factors in order to obtain a characterization that results in model behavior that is congruent with your plant's activity.

One of a system's core properties is its ability to be controlled and observed. Its interactions with its surroundings are divided into two types:

i. Environment-generated variables that influence the system's behavior (called inputs).
ii. Variables determined by the system, which influence the behavior of the environment (called outputs).

In this study simulation in the GPS-X environment using the following steps

1. Gather the bare minimum of real-world WWTP data required for GPS-X modeling.

2. Representing the current WWTP in terms of influent and physical data from the unit operations

3. Model item selection in the GPS-X environment via the creation of the WWTP layout representation

4. Determination of the quality characteristics of WWTP influent wastewater (inserting the required measured values)

5. Using the GPS-X influent advisor, adjust and set influent fractionation of the solid and organic content and nitrogen components (not simple to measure influent components) to an acceptable state and Composite variables mass

6. Running the model and calibration via adjusting kinetic, stoichiometric and other relevant parameters to fit the model to obtain the best matching between model output and the actual plant effluent quality data

7. Validate the calibrated model using a different set of WWTP wastewater quality data

8. Running simulations under different scenarios to analyze the effect of relevant operational parameters of the plant capacity and performance in terms of final effluent quality.

4. RESULT AND DISCUSSION

4.1. Performance Evaluation of ELICo WWTP

The raw wastewater is entering the treatment system from the inlet which is called Influent whereas the treated wastewater (effluent) which is discharged to the receiving water system. In order to assess the performance of the treatment plant, the amount of substance removed from the system can be determined by calculating the percentage removed from the raw water to end up as effluent concentration. Three sample were grabbed from each sampling points for analysis of the parameters listed below. The average or mean value is used for input for the software.

After the samples are analyzed for Physico-chemical parameters following the procedures mentioned in the methodology section, results are generated as an average data of the wastewater characteristics from the influent and effluent unit of the treatment plant.

Table 4-1 Physico-chemical characterization results and efficiency of ELICo WWTP

S/N	Parameter	Unit	Influent	Effluent	Efficiency (%)	EEPA
1.	Chemical Oxygen Demand (COD)	mg/l	1900	121	93.6	500
2.	Temperature	^{0}C	26	29	-	40
3.	pH	-	8.3	7.3	-	6-9
4.	Total Suspended Solids (TSS)	mg/l	939	11	98.8	50
5.	Total Nitrogen (TN)	mg/l	220	147	33.18	60
6.	Total chromium (Cr)	mg/l	2	1.9	5	2
7.	Chloride (Cl^-)	mg/l	1100	1041	5.36	1000
8.	Sulfide ($S^{2-)}$	mg/l	2	2	0	1
9.	Biological Oxygen Demand (BOD_5)	mg/l	980	25	97.44	200
10.	Total Dissolved Solids (TDS)	mg/l	2226	965	56.65	NL
11	Total phosphorus (TP)	mg/l	5.8	3.9	48.7	10
12	Ammonia (NH_3)	mg/l	32	46	-	30

Solid in a moving body of water tends to settle out at a various point or be carried longer distances, depending on their size and the rate of the flow. Suspended matter can affect the amount of light entering water and therefore restrict the amount of photosynthesis that can occur and therefore the growth of plants. Small particles settling out in large amount on the bottom of a water body can prevent some organisms from living there as well as preventing green plants from photosynthesizing (Omondi 2018). The efficiency of the treatment plant in terms of TSS reduction was found to be 98.8%, which is quite impressive. If the TSS concentration is not controlled it affects disposed environment, so wastewater treatment plant has a good ability to treat.

As shown in the table 4.1, the treatment capacity of the ELICo wastewater treatment plant to reduce the chemical oxygen is nearly 93.6% of the COD is removed from the system at the outlet. The number of COD remaining at this point was 121mg/l, which is It has a good Performance evaluation of ELICo-WWTP is below from EEPA guideline limits.

The BOD_5 removal efficiency from the existing treatment plant system was around 97.44%. The amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period is referred as BOD_5. The continued disposal of biodegradable organic waste into the water system leads to increased consumption of dissolved oxygen thus affecting the aquatic life. High BOD_5 indicates that there could be low oxygen available for living organisms in the wastewater. The high BOD_5 may deplete dissolved oxygen, causing death of aerobic organisms and increase anaerobic properties of water (Jody and Dons, 2000). ELICo-WWTP has 97.44% removal efficiency which is good performance and below from EEPA guideline limits.

Temperature and pH are another very important quality of the wastewater for better treatment process in the treatment plant as well as after disposal of the effluent. Optimum level of these parameters protects the aquatic environment. pH value of waste water has no health implication but many chemical reactions are controlled by pH. Biological activities and some chemical treatment processes are usually restricted by pH. The surface discharge guideline limit of pH value ranges from 6 to 9, as either high or low pH will be harmful to man, aquatic animals and it affects biological activity of the river if discharged untreated. The optimum temperature of the effluent should be less than $40^{o}C$ based on the EEPA standard. When the temperature is not in the optimum range, it affects different part of the system.

Nitrogen is an essential element for treatment plants and is often the limiting nutrient in water environment. Total Nitrogen is a measure of all forms of nitrogen (organic and inorganic) which can present in industrial wastewater on the other had TKN includes other nitrogen compounds except nitrate and nitrites (Terefe Gemeda et al. 2020). As shown the plant has 33.8% removal efficiency it is low performance in reduction of organic and inorganic nitrogen.

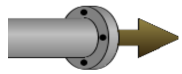
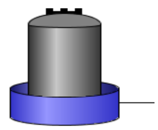
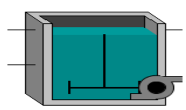
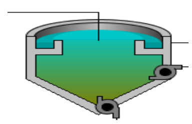
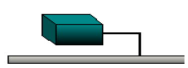
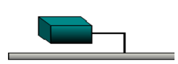
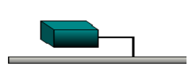
The concentration of ammonia at the outlet of the factory was 46mg/l this value is far from the 30 mg/L maximum permissible national limit. As shown above, the ammonia concentration is higher this can be due to introduction of nitrogen compounds. The excess release of ammonia can be toxic to some forms of aquatic life. Other aquatic organisms, such as algae, may be limited in their growth until a nutrient such as ammonia or nitrate leads to an incident of explosive growth (Amanial 2016).

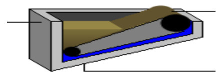
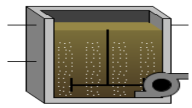
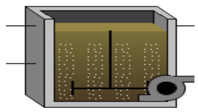
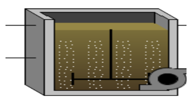
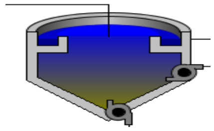
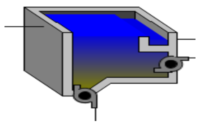
Sulfide and chromium are recycled/treated before entering in to the general line which is shown in the above figure 2.3 according to that general line is used more for biological process as we can see from the result it passes the EEPA guideline. Generally, the results showed comparable quality standard but TDS and Chloride has high value which is expected as the tannery has no technology in place to remove the chloride level.

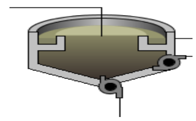
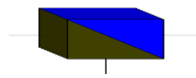
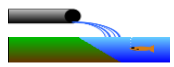
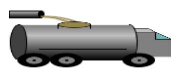
4.2. GPS-X symbol and their physical data as collected from the factory

Direct laboratory investigation yielded the following physical properties (Table 4.1). As shown in the table, wastewater has strong characteristics in most parameters and discharging such, wastewater into the environment has a major impact on both the environment and human health. On the other hand, the effluent water quality showed better water quality, indicating that the water may be recycled after further treatment or improved the performance of the existing WWTP operational condition.

Table 4-2 List of major unit operations, corresponding GPS-X symbol and their physical data as collected from the factory

Unit operations	GPS-X Symbol	Required Physical and operational parameters
Wastewater Influent		Flow: 1200 m^3/day
Alkali Dosage		Chemical: $Ca(OH)_2$ Purity: 0.1 % Concentration: 1000mg/L
Equalization Tank		Volume: 1000 m^3 Height: 4 m Entering Airflow: 500 m^3/h
Circular Primary Clarifier		Surface Area: 78 m^2 Depth: 2.5 m Pumped Flow: 10 m^3/day
In-line Chemical Dosage for Circular Primary Clarifier		Chemical: $Al_2(SO_4)_3.18H_2O$ Purity:17% Dose: 420 kg/day
In-line Chemical Dosage for Circular Secondary Clarifier		Chemical: $Al_2(SO_4)_3.18H_2O$ Purity:17% Dose: 240 kg/day
In-line Chemical Dosage for Lime Mixing Tank		Chemical: $FeCl_3$ Purity: 40% Dose: 60 kg/day

Unit operations	GPS-X Symbol	Required Physical and operational parameters
Belt Micro screen/Micros screener		Fraction of influent flow: 0.05 Efficiency 60%
First Completely-Mixed Tank/1st biological oxidation		Volume: 1694 m^3 Tank depth: 5.5 m Entering airflow: 1000 m^3/h
Second Completely-Mixed Tank/2nd biological oxidation		Volume: 1200 m^3 Tank depth: 4.5 m Entering airflow: 1800 m^3/h
Lime Mixing Tank		Volume: 100 m^3 Depth: 4.0 m
Circular Secondary Clarifier		Surface area:81m^2 Depth: 4.5 m Pumping flow: 60 m^3/h Underflow solid: 565.6 mg/l
Rectangular Secondary Clarifier/Advanced		Surface area: 81m^2 Depth: 4.5 m Pumping flow: 60 m^3/h Removal Efficiency: 565.6 mg/l

Unit operations	**GPS-X Symbol**	**Required Physical and operational parameters**
Sludge Thickener		Surface area: 25 m^2 Depth: 4.4 m Pumping flow: 55 m^3/day Removal Efficiency: 90%
Sludge Dewatering		Pumping flow: 55 m^3/day Removal Efficiency: 95%
Wastewater Outfall/Effluent		Parameter not required
Sludge Disposal		Parameter not required

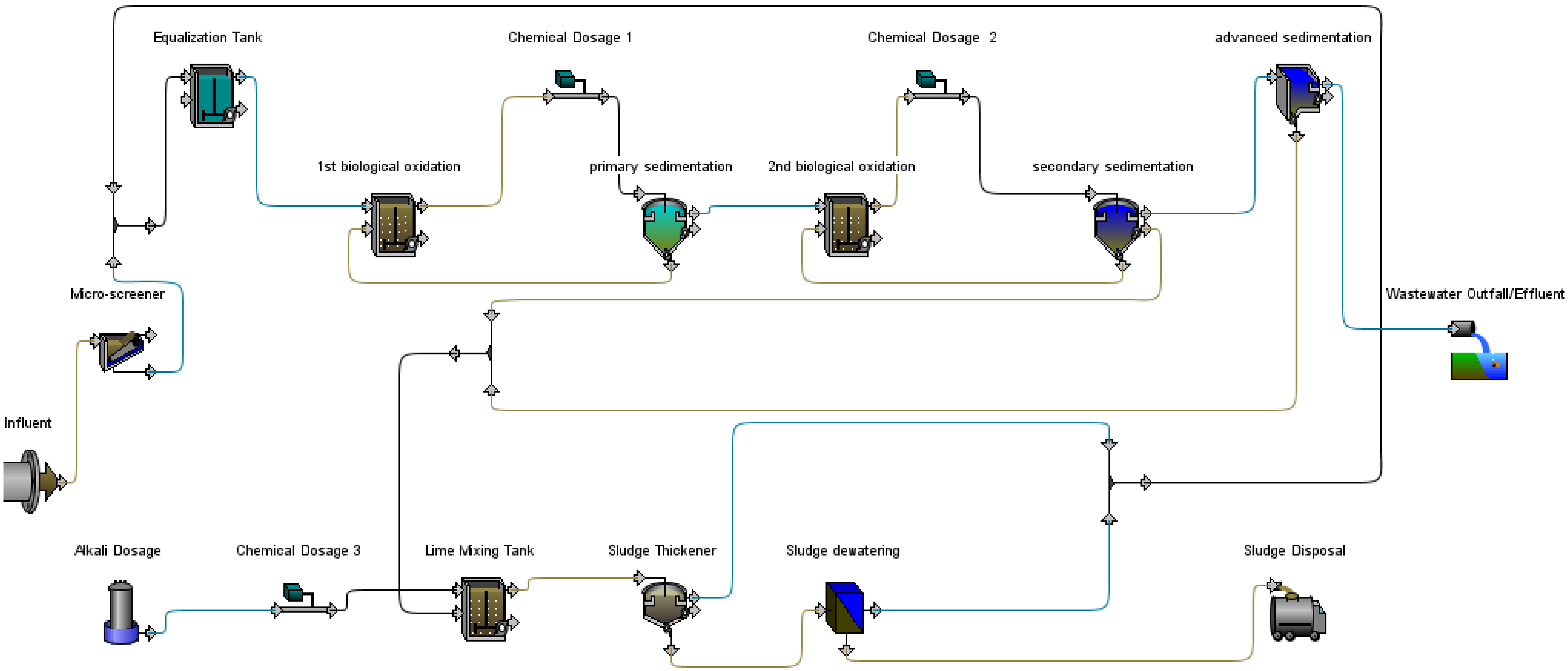


Figure 4-1 Process Flow Diagram of Ethio-leather industry (ELICo) WWTP

4.3. Simulation Results of Mass Balance data on wastewater outfall/effluent section

Table 4.3 displays the steady-state simulation results of modeled wastewater treatment with the given input and operational information from Tables 4.1 and 4.2. For this particular simulation result, all inputs including influent flow were considered constant. However, before using this data for further research and evaluation, the correctness of the results was assessed using sensitivity analysis and parameter adjustment. Following table 4.2 and 4.3, these analyses were carried out in accordance with the GPS-X simulator software's instructions.

Table 4-3 Simulated result

Parameters	Wastewater Outfall/Effluent	
Flow	m^3/d	1139
TSS	mg/L	8.698
VSS	mg/L	6.468
cBOD5	mg/L	5.441
COD	mg/L	105.1
Ammonia NH_3	mgN/L	32.69
Nitrite N	mgN/L	109.1
Nitrate N	mgN/L	$1.104e^{-05}$
TKN	mgN/L	38.53
TN	mgN/L	147.7
Soluble PO_4^-P	mgP/L	2.529
TP	mgP/L	3.653
Total Alkalinity	$mgCaCO_3/L$	400.6
pH	-	7.0
DO	mgO_2/L	8.777

4.4. Sensitivity analysis

The GPS-X sensitivity analyzer is a built-in tool that runs several simulations, automatically adjusts input, collects all output and graphs the results (output vs. input). In general, make it simple to see the links between plant loading/operation and performance. The GPS-X sensitivity analyzer can perform a variety of analyses Steady State, Phase Dynamic, Time Dynamics and Monte Carlo Analysis which is explained in methodology.

The first three types of analysis are known as step analyses, in which the output is examined in a specific input range with a predetermined step value. The fourth one, on the other hand, might be either steady state or dynamic.

It was performed steady state and dynamic sensitivity analyses in this study by altering one of the inputs, such as air flowrate to the first biological oxidation tank. Furthermore, it was assumed sinusoidal flow and concentration load type rather than constant flow type in order to comprehend the change in output. The input parameters for the sensitivity analysis are shown in Table 4.4 COD, BOD_5, TSS and TN were chosen as output variables.

Table 4-4 Input parameters for Sensitivity analysis

Parameter	Condition	Input Range
Influent flow	Sinusoidal flow type	600 – 1200 m^3/day
Influent composition	Sinusoidal load type	-
Air flow to first oxidation tank	Step Change (50)	500 – 1000 m^3/h
Alum dose In-line Chemical Dosage for Circular primary Clarifier	Step Change (50)	200 – 420 kg/day
Alum dose In-line Chemical Dosage for Circular Secondary Clarifier	Step Change (50)	100 – 240 kg/day

Figures 4.2 and 4.3 indicate that the output variable changes with respect to the step change on the inputs, in this case air flow to the first oxidation tank, for both steady state and time dynamic analysis. These results revealed that the modeled treatment plant is sensitive to changes in input and is good enough to be used as a parameter prediction.

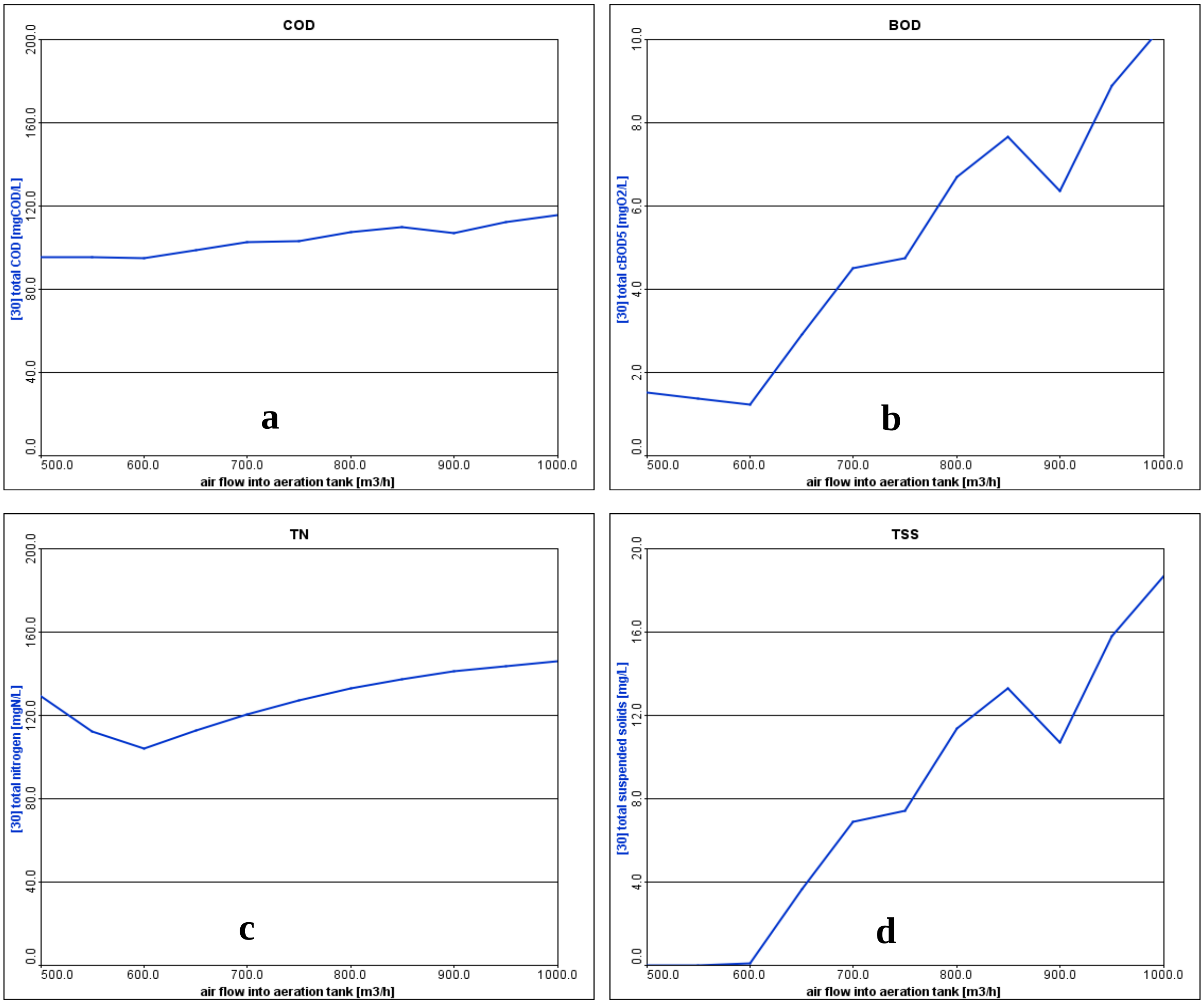


Figure 4-2 Steady State Sensitivity Analysis result on the selected output parameters

a) COD, b) $cBOD_5$, c) TN and d) TSS as a function of airflow into aeration tank/1st oxidation tank

The process has been at a steady-state prior to the start of the simulation (t=0). After starting, the changes made to model inputs or parameters cause some dynamic behavior to occur. This is the case mentioned above, where the steady-state solver has been used first to calculate the steady-state. After doing so, the state variables are given these steady-state values at the starting time (t=0). A preliminary steady-state analysis may be sufficient to make useful predictions about the behavior of the plant.

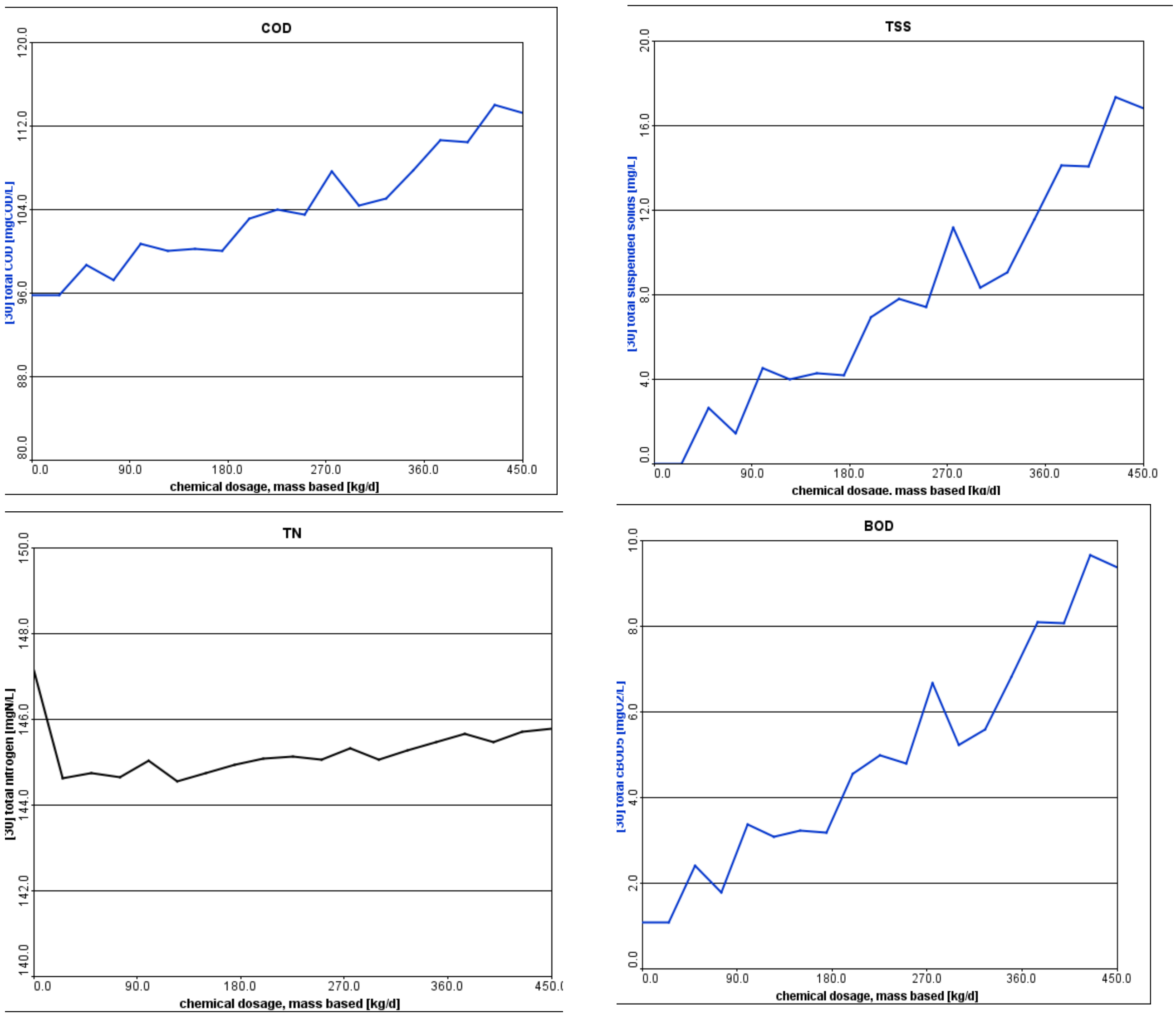


Figure 4-3 Steady State Sensitivity Analysis result on the selected output parameters

COD, $cBOD_5$, TN and TSS as a function of Chemical Dose to the first sedimentation tank

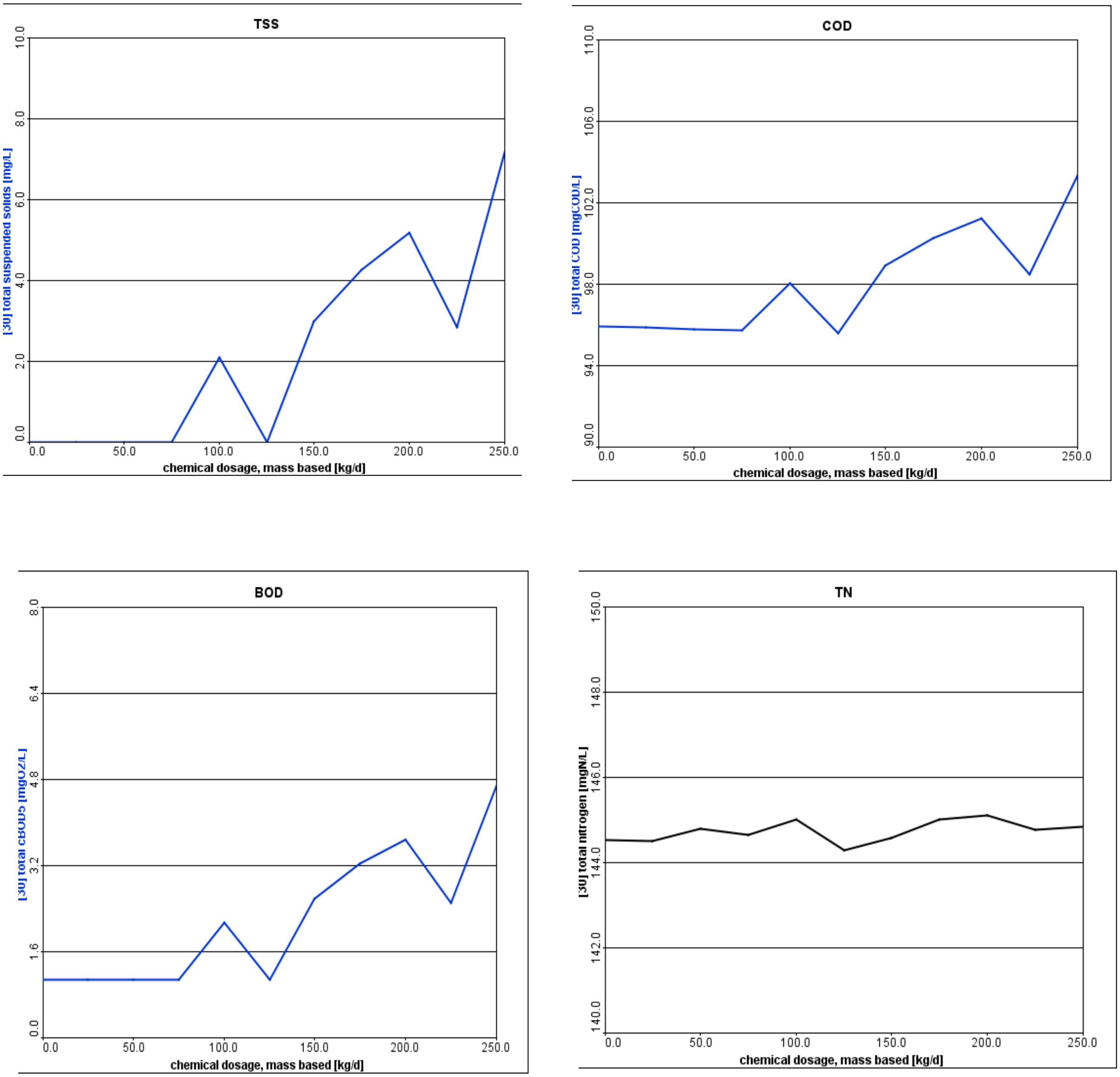


Figure 4-4 Steady State Sensitivity Analysis result on the selected output parameters

COD, $cBOD_5$, TN and TSS as a function of Chemical Dose to the secondary sedimentation tank

Coagulant Dosage in many plants, changing water characteristics require the operator to adjust coagulant dosages at intervals to achieve optimal coagulation. Coagulant aids increase density of slow-settling flocs and help improve floc formation in the process of waste water.

In operations, it is useful to know the ultimate or steady-state response of the plant, such as the effects of moving to a different operating point. A preliminary steady-state analysis may be sufficient to make useful predictions about the behavior of the plant.

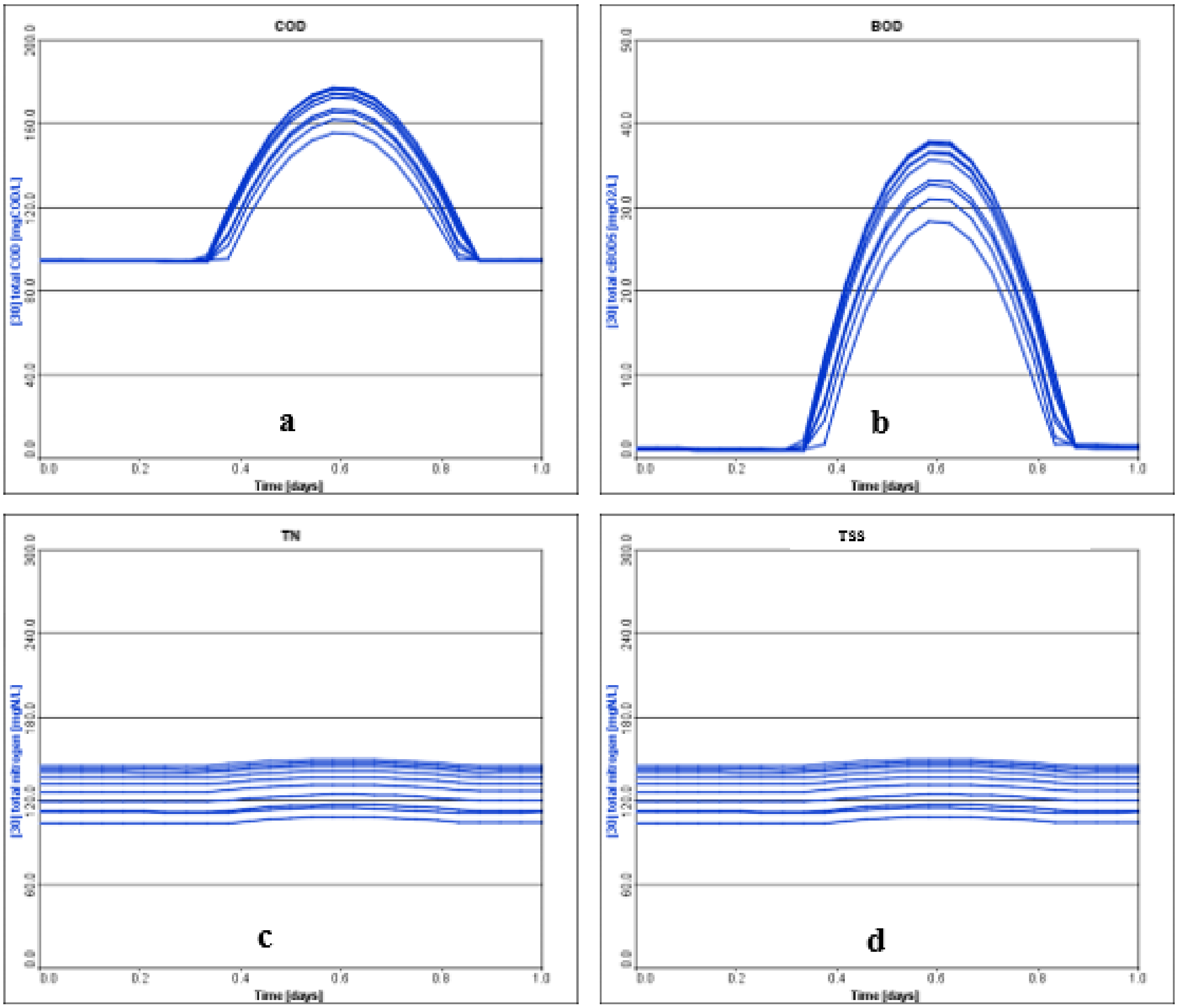


Figure 4-5 Time Dynamic Sensitivity Analysis result on the selected output parameters

a) COD, b) $cBOD_5$, c) TN and d) TSS as a function of airflow into aeration tank/1st oxidation tank

The state variables at any time after the start are influenced by changes to model inputs or parameters resulting in the dynamic behavior is observe. In operations, it is useful to know the ultimate or steady-state response of the plant, such as the effects of moving to a different operating point. The results demonstrate how the model responds to different values of the rate starting from specific values of the model state variables, including the Air flow rate. In this case, it may be necessary to either extend the simulation or to perform a number of re-runs to observe the ultimate, periodic steady-state for the system. In this case the simulation starts at a different Air flow rate value for each run. Here the steady-state solver is used to determine steady-state values for each value of the independent variable, set the initial conditions equal to these values and then started a dynamic simulation. The model is assumed to have been operating in a steady state. At time=0 the value of the independent variable changes to that specified in the sensitivity analysis and a dynamic simulation is conducted until the specified stop time.

4.5. Parameter Optimization

One of the most critical parts of any modeling endeavor is model calibration. It is the process of modifying model parameters to minimize the disparity between the observed and simulated results. GPS-X's built-in parameter estimator tools are used in this investigation. The target variable (COD) and the manipulated variables (airflow to the first and second oxidation tanks, alum dose to the primary and secondary sedimentation) were chosen accordingly.

In order to compare the simulated output by altering the selected input variables, factory's real wastewater parameter, COD, was chosen (Figure 4.6). As shown in the table 4.5, the optimum value was modified to the new value, resulting in a minimal output result between the simulated and observed results. Figure 4.6 also shows the reserved and simulated results.

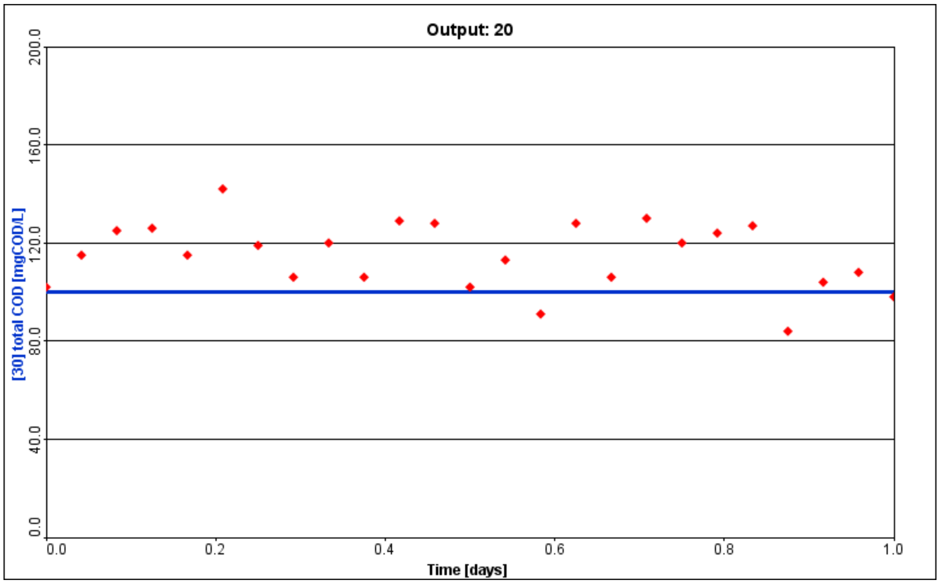


Figure 4-6 Model predicted and measured effluent COD concentration vs. Time.

Table 4-5 Manipulated and adjusted parameters

Manipulated Parameter	Input Range	Optimum/adjusted result
Air flow to first oxidation tank	500 – 1000 m^3/h	1000 m^3/h
Air flow to second oxidation tank	1000 – 1800 m^3/h	1800 m^3/h
Alum (17%) Dose In-line Chemical Dosage for Circular primary Clarifier	200 – 420 kg/day	200 kg/day
Alum (17%) Dose In-line Chemical Dosage for Circular Secondary Clarifier	100 – 240 kg/day	240 kg/day

Table 4.4 illustrates the plant output values at the adjusted parameter as a result of parameter calibration. When compared to the plant simulation data prior to calibration (Table 4.5), no significant difference is observed. This could be because the plant simulation model has already reached its maximum performance depending on the parameters provided. This parameter compares the plant outlet results from simulation to the raw ground water quality that the factory primarily used as process water. As shown in Table 4.5, the results for discharges to water according to Ethiopian standard requirements for specific industrial sectors, except total nitrogen,

are lower than the prescribed limit values (Table 4.7). Furthermore, with the exception of certain considerable variations in some metrics such as TDS, Ammonia N and Alkalinity, the effluent water quality is quite similar to the raw ground water but it's not exceeded the standard limit that the plant can uses as process water. To bring the effluent water quality closer to that of raw ground water, the plant performance was investigated under various scenarios, including an examination of the effects of main WWTP inputs such as air flow and coagulant chemical inputs.

Table 4-6 Simulation result before and after calibration

Parameter		Wastewater Outfall/Effluent	
	Unit	Before calibration	After calibration
Flow	m^3/d	1139	1139
TSS	mg/L	3.723	6.741
VSS	mg/L	2.772	4.997
$cBOD_5$	mg/L	2.944	4.445
COD	mg/L	99.54	102.7
Ammonia NH_3	mgN/L	35.27	32.83
Nitrite N	mgN/L	103.1	108.7
Nitrate N	mgN/L	$1.012e^{-05}$	$1.099e^{-05}$
TKN	mgN/L	40.76	38.53
TN	mgN/L	143.8	147.2
Soluble PO_4-P	mgP/L	2.665	2.349
TP	mgP/L	3.682	3.431
Total Alkalinity	$mgCaCO_3/L$	381.0	398.8
pH	-	7.0	7.3
DO	mgO_2/L	8.411	8.781

4.6. Model validation

The model's accuracy is also validated using measured values from the plant and anticipated values from simulation. The observed values are the measured target variable values provided in the. The predicted values are the target variable values calculated by the model that correspond to the observed values (they are calculated at the same points in time).

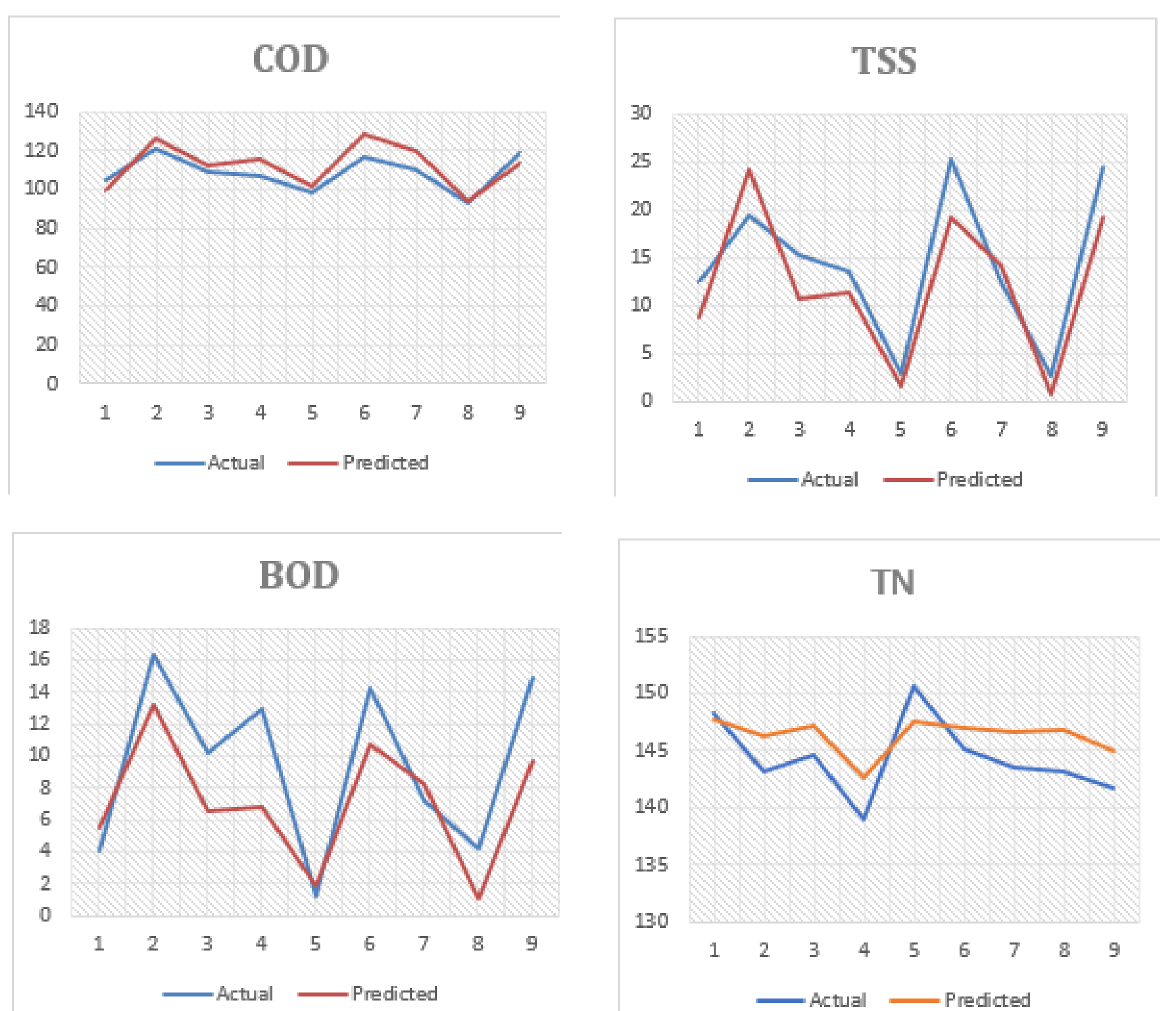


Figure 4-7 Actual and predicted values

In below figure the predicted values are plotted against the measured values. A 45-degree line is also placed on this graph to see the deviation of data points from this line. Assuming a perfect fit, the plotted data points will plot on the 45-degree line. Visual inspection of this plot can highlight the model biases and other systematic errors in the model.

Figure 4.8 shows a visualization of the actual vs. projected value with the regression coefficient of determination. The regression coefficient of determination was also discovered to be approximately 76.11 percent, which is a reasonable accepted value, and there is predicted uncertainty and parameter variances because various assumptions and direct plant data are employed as input for this simulation job. This model can also be used to forecast parameters for any scenario.

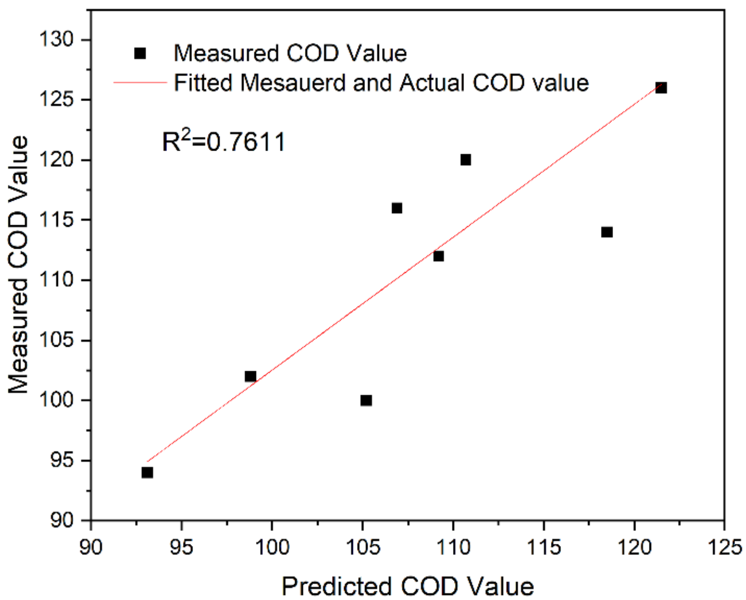


Figure 4-8 Validation plot for measured vs Actual COD Value

Table 4-7 Comparison of selected water quality parameters between ground water, plant effluent and wastewater discharge limit

Parameter	Ground water	Plant Effluent	Limit Values for Discharges to Water[1]
COD (mg/L)	75.8	102.7	500
BOD_5 (mg/L)	56.3	4.445	200
TSS (mg/L)	77	6.741	50
TDS (mg/L)	1338	2954	---
pH	6.8	7.0	6-9

TN (mg/L)	1.276	147.2	60
TP (mg/L)	0.32	3.431	10
Total Alkalinity (mg/L)	79.4	398.8	---
Ammonia NH_3	0.089	32.83	30
DO (mg/L)	3.9	8.781	---

[1] Ethiopian standard requirement for leather finishing industry

-- No limit states

4.7. Scenarios Analysis

Scenario refers to the process of creating many cases that are adjustments to the base model layout in order to understand the change in the process output. The current study includes five scenarios based on the assumption of increasing effluent quality on certain parameters such as COD, Ammonia NH_3, TN, TP and Alkalinity in order to bring it very close to ground water quality. Scenario analysis cases are selected according to cost effective methods according to the company stated treatment process which can be changed without building new treatment pant unit.

First Scenario: This scenario is designed to evaluate if adjusting airflow as basic plant inputs, such as airflow to the first biological oxidation and airflow to the second biological oxidation, improves effluent quality. Study range specified according to design parameter of existing treatment plant units and adjusted according to collected historical data. Aeration provides oxygen to bacteria for treating and stabilizing the wastewater. Oxygen is needed by the bacteria to allow biodegradation to occur. The supplied oxygen is utilized by bacteria in the wastewater to break down the organic matter containing carbon to form carbon dioxide and water (Sandberg 2016) . The following parameter range was chosen for this case study: (Table 4.8).

Table 4-8 Selected manipulated parameter for first scenario

Parameter	Study Range	Adjusted Value
Air flow to 1st biological oxidation	0-1,000 m^3/h	580.20 m^3/h
air flow to 2nd biological oxidation	0-2,000 m^3/h	1994.56 m^3/h

Second Scenario: Adjust coagulant chemical (alum) as basic plant inputs, such as the amount of alum added before the Circular Primary Clarifier and Circular Secondary Clarifier, can improve the present plant in this case. Alum (aluminum sulfate) is a nontoxic liquid that is commonly used in water treatment plants. Alum functions as an excellent primary coagulant readily dissolves water. Through charge neutralization and flocculation in raw water, alum removes Turbidity. But it is effective at certain pH (Chowdhury et al. 2013). The following parameter range was chosen for this case study: (Table 4.9)

Table 4-9 Selected manipulated parameter for second scenario

Parameter	Study Range	Adjusted Value
Alum (17%) Dose In-line Chemical Dosage for Circular primary Clarifier	0-500 kg/day	200 kg/day
Alum (17%) Dose In-line Chemical Dosage for Circular Secondary Clarifier	0-500 kg/day	240 kg/day

Third Scenario: This scenario was likewise constructed with the notion that increasing the amount of airflow rate and alum at the same time can improve the effluent discharge quality.

Table 4-10 Selected manipulated parameter for third scenario

Parameter	Study Range	Adjusted Value
Air flow to 1st biological oxidation	0-1000 m^3/h	575.76 m^3/h
Air flow to 2nd biological oxidation	0-1800 m^3/h	1706.53 m^3/h

Alum (17%) Dose In-line Chemical Dosage for Circular primary Clarifier	0-500 kg/day	211.71 kg/day
Alum (17%) Dose In-line Chemical Dosage for Circular Secondary Clarifier	0-500 kg/day	224.70 kg/day

Fourth Scenario: This scenario is similarly based on the idea that increasing both the amount of airflow rate and PAC at the same time can improve the effluent discharge quality. It provides high coagulation efficiency and it has the widest pH and temperature application ranges compared to other wastewater treatment chemicals.it requires lower alkalinity consumption as well as its lower dose requirement and PACs are more soluble and have a higher pH of minimum solubility than alum (Chowdhury et al. 2013). In this case, however, Poly aluminum chloride (PAC) coagulant was utilized.

Table 4-11 Selected manipulated parameter for fourth scenario

Parameter	Study Range	Adjusted Value
Air flow to 1st biological oxidation	0-1000 m^3/h	580.50 kg/day
Air flow to 2nd biological oxidation	0-2000 m^3/h	1967.08 kg/day
PAC (0%) Dose In-line Chemical Dosage for Circular primary Clarifier	0-1000 kg/day	93.07 kg/day
PAC (40%) Dose In-line Chemical Dosage for Circular Secondary Clarifier	0-1000 kg/day	0.03 kg/day

Fifth Scenario: This scenario is similarly based on the idea that increasing both the amount of airflow rate and $FeCl_2$ at the same time can improve the effluent discharge quality. Ferric chloride is the most common iron salt used to achieve coagulation used for to remove impurities in wastewater treatment. Ferric chloride is also one of the few water treatment chemicals that can sequester odors (Chowdhury et al. 2013). In this case, however, Ferric Chloride ($FeCl_2$) coagulant was utilized.

Table 4-12 Selected manipulated parameter for fifth scenario

Parameter	Study Range	Adjusted Value
Air flow to 1st biological oxidation	0-1000 m^3/h	368.51 m^3/h
Air flow to 2nd biological oxidation	0-1800 m^3/h	785.01 m^3/h
Ferric chloride (20%) Dose In-line Chemical Dosage for Circular primary Clarifier	0-1000 kg/day	191.84 kg/day
Ferric chloride (20%) Dose In-line Chemical Dosage for Circular Secondary Clarifier	0-1000 kg/day	999.77 kg/day

Table 4-13 Wastewater quality parameters at different scenarios

Parameter	Unit	Result before scenario analysis	Result from First Scenario	Result from Second Scenario	Result from third Scenario	Result from Forth Scenario	Result from Fifth Scenario
Flow	m^3/d	1139	1139	1139	1139	1139	1139
TSS	mg/L	6.741	3.026	4.567	4.985	5.622	4.123
VSS	mg/L	4.997	2.315	3.012	4.456	4.110	3.561
$cBOD_5$	mg/L	4.445	1.244	1.239	1.26	1.219	1.242
COD	mg/L	102.7	95.47	95.46	95.5	94.64	94.02
Ammonia NH_3	mgN/L	32.83	37.88	37.47	39.12	38.92	37.71
Nitrite N	mgN/L	108.7	10.85	11.03	10.32	10.52	11.03
Nitrate N	mgN/L	$1.099e^{-05}$	$6.048e^{-06}$	$6.408e^{-06}$	$5.739e^{-06}$	$5.896e^{-06}$	$6.018e^{-06}$
TKN	mgN/L	38.53	93.09	92.68	94.33	94.09	92.84
TN	mgN/L	147.2	103.9	103.7	104.6	104.6	103.9
Soluble PO_4-P	mgP/L	2.349	2.656	2.661	2.681	1.708	2.078
TP	mgP/L	3.431	3.593	3.598	3.618	2.637	3.001
Total Alkalinity	$mgCaCO_3/L$	398.8	51.74	45.93	50.98	50.07	53.62
pH	-	7.31	7.22	7.0	7.4	7.45	7.3
DO	mgO_2/L	8.781	9.127	9.998	8.979	9.125	8.896

As demonstrated in the table 4.13, there was no significant reduction in total COD in the effluent for all scenarios, although there was a substantial reduction in total nitrogen and total alkalinity. Based on this finding, one can conclude that, at the existing plant facility, modifying the amount of airflow rate and coagulant chemical dose, as well as coagulant type, did not result in a substantial improvement in effluent quality as expected in terms of COD but other parameters improve significantly. This could be because to the presence of non-biodegradable chemicals in tannery wastewater. Non-biodegradable chemicals are typically recalcitrant in nature, necessitating a more complicated tertiary process to eliminate. In addition, the facility can incorporate biological nitrification and denitrification processes.

Biological (activated sludge) treatment is the most widely utilized nitrogen removal technology in wastewater treatment plants (WWTPs). In biological treatment, nitrogen is removed in two steps: nitrification and denitrification. Nitrifies, such as ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB), convert total ammonia (free and un-ionized ammonia) to nitrate during this process. Denitrification occurs in an anoxic environment when denitrifies convert nitrate and nitrite to nitrogen gas.

Though the water quality cannot be improved further with the current facilities, we can recycle the effluent as process water to partially or completely replace raw ground water. In addition, the tannery wastewater contains additional contaminants such as chloride and sulphide (Table 4.1). It is distinguished by a high concentration of chloride, which is extremely difficult to remove using typical wastewater treatment procedures. As a result, the impact of this contaminant on the quality of leather products should be thoroughly researched. If other types of unit operations, such as nitrification and denitrification process, are included in the current facility, the economic benefit of recycling water should be weighed against the investment required to establish the other facility.

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

This research investigated the efficiency of the tannery wastewater treatment plant for water recycles as a substitute for groundwater. The performance of the wastewater treatment plant was evaluated using Hydromantis GPS-X, a commercially available wastewater treatment plant modeling and simulation software tool. This paper used Primary data (physicochemical laboratory analysis) and secondary data (site visit, factory treatment plant design, technical document, factory personnel consultation, operational document and published materials such as journal articles) to acquire the input data for process modeling and simulation for this task. From the Physico-chemical analysis of the wastewater generated from the treatment plant the paper understands, it has strong characteristics and effluent water quality was found below the standard discharge limit by Ethiopian Environment, Forest and Climate change Commission. Furthermore, when compared to the physicochemical properties of groundwater, the wastewater treatment plant effluent was remarkably similar to certain of the parameters. As a result, in this study, various options looked to improve plant performance. First, it creates a process flow diagram using GPS-X software and then feeds it to the relevant primary and secondary data. Then the model run after a sensitivity analysis, calibration and validation phase. According to the results of the steady-state and time dynamic sensitivity analyses, the model is very sensitive to changes in input and is good enough to be used as a parameter prediction. It is successfully validated the developed model while meeting the assumption of the models' constant stoichiometry and kinetic coefficients for any treatment plant influent characteristics. It employed the developed model to treat plant performance to recycle the treated water. Model calibration was also carried out to reduce the difference between the observed and simulated outcomes. The model validation also shows that it is 76.11 percent accurate in predicting plant performance and the simulation result shows a satisfactory effluent water quality parameter. Some of the value indices as COD, TN, TP, Ammonia as NH_3 and total alkalinity, were far from the value of groundwater characteristics. As a result, this paper tried five scenarios to get these parameters closer to groundwater quality. In all situations, there was no significant reduction in total COD in the effluent, although there was a considerable reduction in total nitrogen and total alkalinity. Therefore, because of the water's excellent quality, this research discovered that it can be recycled in some parts of the tannery process as a replacement for raw water. However, it is necessary to evaluate the effect of recycling treated water on the quality of finished leather.

This research showed the possibility of recycling the final treated wastewater from ELICo tannery for recycling at various stages of leather processing. It can be used for soaking and liming processes. The Physico-chemical characterization evaluation results supported this.

5.2. RECOMMENDATION

Based on results of the study, ELICo tannery wastewater treatment plant are not fully meet standard discharge limits of Ethiopian Environmental Protection Authority (EEPA, 2003) and has no effective response to control process of the plant. Therefore, to make the plant more effective control response and meet standard discharge limits (EEPA, 2003) the following recommendation were drawn: -

- The treatment plant lacks skillful professionals for operation and maintenance and operating conditions, which differ from designed values. Proper operation and maintenance activities will improve better performance of the system.
- The factory has a water quality laboratory for checking the effluent quality occasionally. However, pH is the only characterized parameter in the tannery and the other parameters conducted outside. There should be a well-equipped laboratory to be carried out and assess the quality of effluent. The factory may take some technological and technical measure.
- Using more detailed reordered data in factories gives us the more accurate result for that reason, factories must seriously record their data. We can even use this simulation result for another factory. It helps them predict their wastewater treatment plant performance.

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APPENDICES

APPENDIX A

Pictures of some major components of the actual wastewater treatment plant

Primary sedimentation

Secondary sedimentation

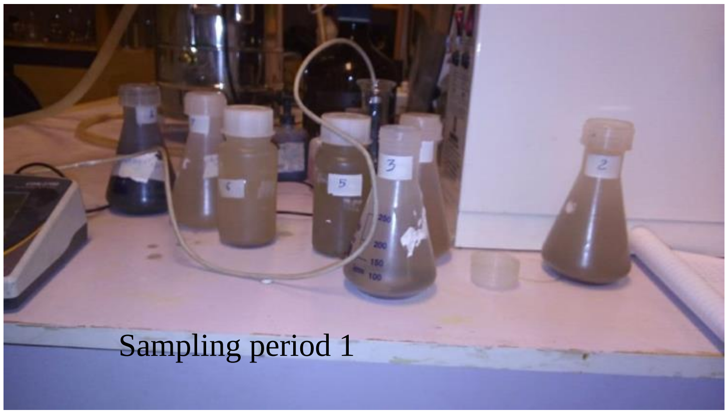
Primary aeration

Chemical storage tank

Secondary aeration

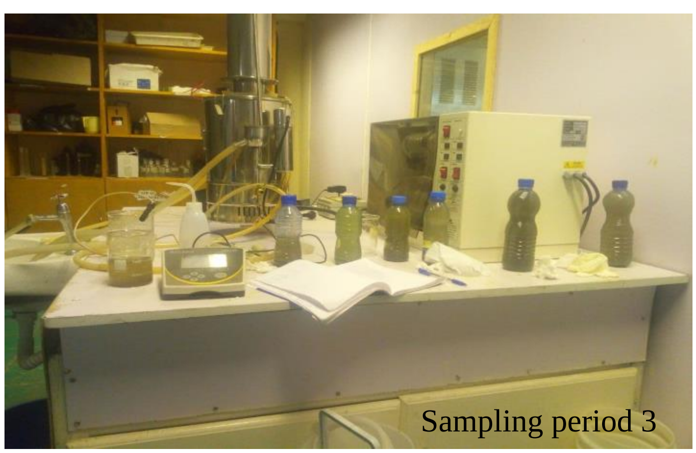
APPENDIX B

Collected sample during assessment period



Sampling period 1

Sampling period 2



Sampling period 3

APPENDIX C

Mean and standard deviation assessment results obtained during three sampling period

Parameters	Sample code					
	T-04	T-03	T-06	T-05	T-07	T-08
COD (mg/l)	370.56±65.8	304.44±136.59	249.72±60.81	202.22±41.9	294.72±62.04	337.78±58.58
BOD (mg/l)	230±99.52	203.06±139.18	155.67±43.92	158.14±32.96	169±58.2	236.51±81.75
Chloride(mg/l)	2363.81±1370.74	2025.53±1299.27	1749.82±1533.93	1735.83±1432.69	1732.43±2333.09	1492.24±1500.74
TN (mg/l)	55.58±9.87	45.67±20.49	37.46±9.12	30.33±6.29	44.21±9.31	50.67±8.79
Chromium(mg/l)	1.00±0.50	1.21±0.79	1.00±0.63	0.98±0.36	1.00±0.46	0.98±0.35
Sulfide(mg/l)	2.33±1.02	2.03±1.04	1.93±1.08	1.98±0.81	2.05±0.46	2.08±6.93
TDS (mg/L)	893±328	8.54±3.37	937.24±363.61	934.14±339.68	961.87±380.47	999.08±418.48
TSS (mg/L)	416.11±89.76	247.78±65.89	303.33±74.63	223.33±38.68	380±82.66	304.44±72.67
PH	6.68±0.01	6.28±0.16	6.71±0.07	6.4±0.02	6.62±0.13	6.49±0.26
Temp(^{0}c)	20.76±1.55	20.68±1.24	21±2.31	21.36±2.09	20.63±2.6	21.81±3.38

T-04 Equalization tank, T-03 Primary biological oxidation tank, T-06 Secondary biological oxidation tank, T-05 Primary sedimentation tank, T-07 Secondary sedimentation tank, T-08 Advance secondary sedimentation tank

Historical laboratory data

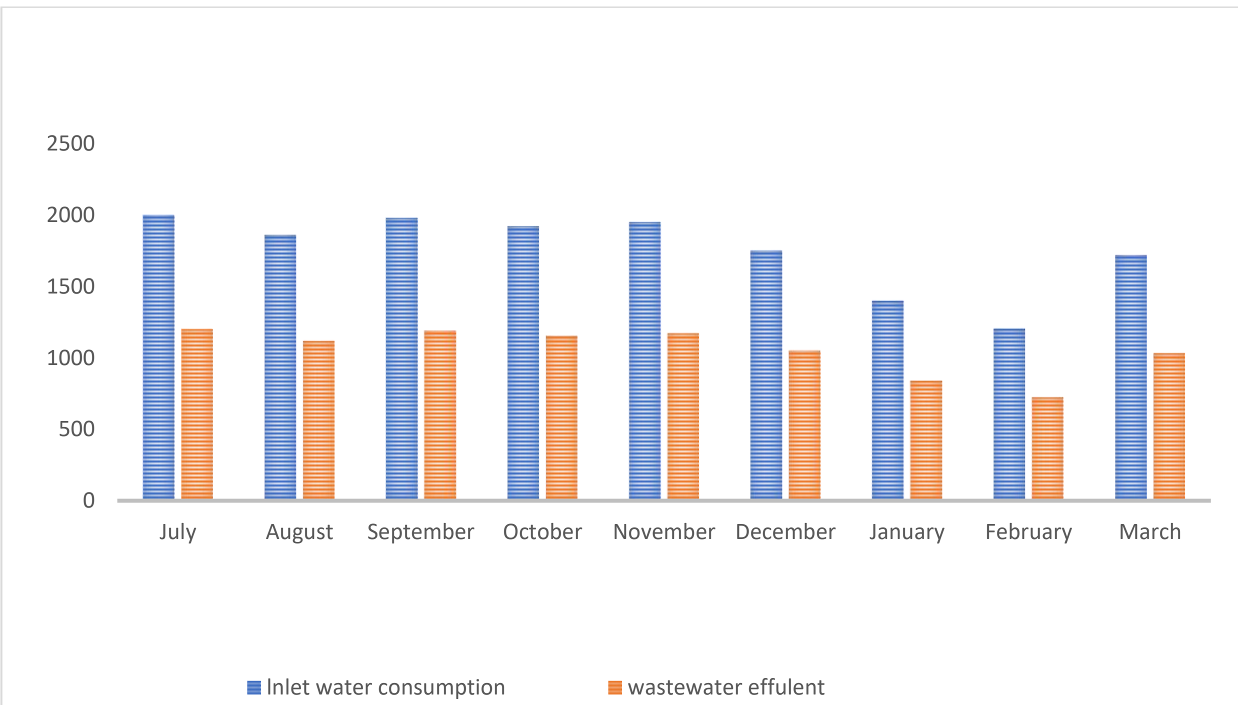
Inlet

Months	COD (mg/l)	BOD (mg/l)	Chloride (mg/l)	TN (mg/l)	Total Cr (mg/l)	Sulfide (mg/l)	TDS (mg/L)	TSS (mg/L)	pH	Temp (^{0}c)
July	1900	980	1100	220	2	2	2226	939	8.3	26
August	267.5	174.77	4764.48	143.09	1.48	2.08	1186	326	6.66	23.6
September	1205	360.66	4963	144.6	0.36	1.9	1651	201	6.42	23.7
October	300.5	202.4	6451.9	139.02	0.28	2.39	1194	292	6.58	23.3
November	1301	483.6	7940.8	150.69	0.38	2.02	1421	224	6.45	25.6
December	766	410.4	3937.31	145.23	0.49	2.6	1226	533.33	6.58	21.93
January	444.67	276	4036.57	143.56	1.24	2.05	1159	499.33	6.69	21.33
February	365.33	243.67	4830.64	143.23	1.39	2.15	1105.23	297.33	6.41	20.4
March	299.67	186.8	4499.79	141.62	1.25	1.8	1186.67	364	6.67	20.2

Out let

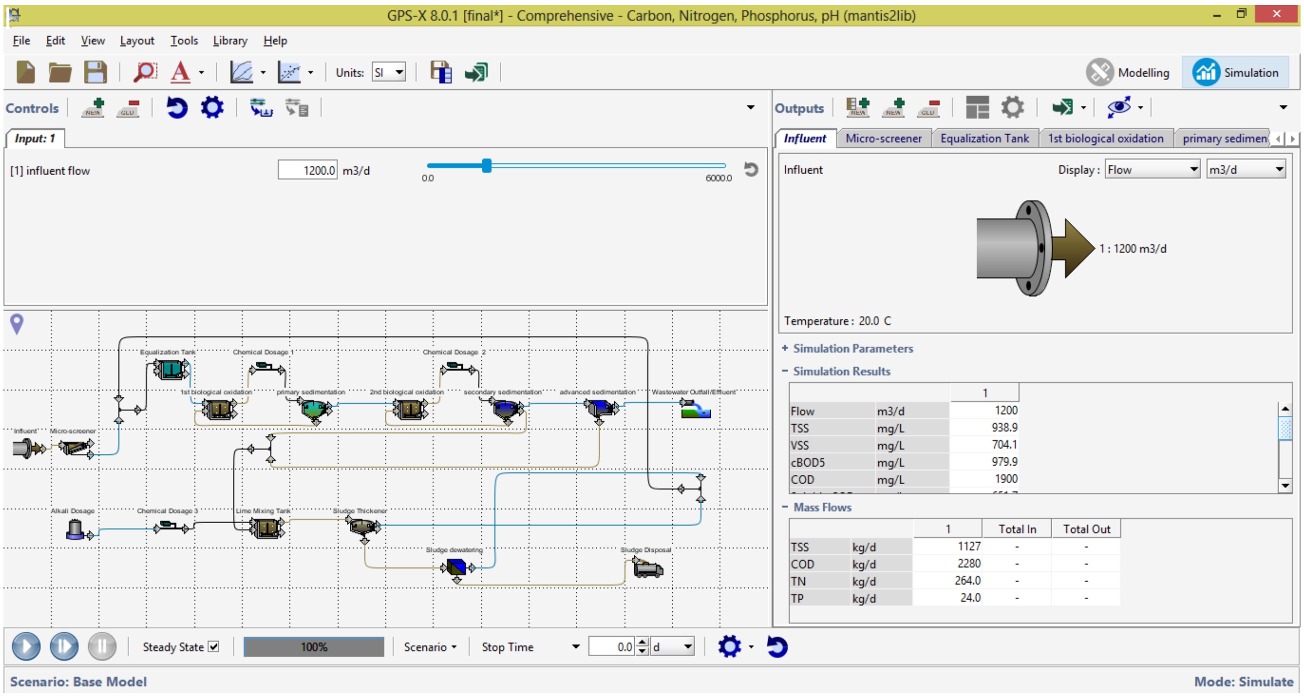
Months	COD (mg/l)	BOD (mg/l)	Chloride (mg/l)	TN (mg/l)	Total Cr (mg/l)	Sulfide (mg/l)	TDS (mg/L)	TSS (mg/L)	pH	Temp (^{0}c)
July	121	25	1041	147	1.9	2	965	11	7.3	29
August	121.5	16.3	1786.68	40.13	1.42	2.1	1150.33	19.36	6.67	19
September	109.2	10.25	2183.7	30.75	0.35	1.9	1140.67	15.22	6.1	19.6
October	106.9	12.9	1985.2	45.08	0.28	2.4	1187.67	13.54	6.79	19.2
November	98.8	1.2	2481.5	45.15	0.3	2	1246	2.91	6.4	19.7
December	116.9	14.23	2084.48	114.9	0.48	2.6	985.87	25.3	6.77	18.1
January	110.7	7.22	1345.24	66.7	1.23	2.05	1078.67	12.36	6.77	19.1
February	93.11	4.2	1466.7	54.8	1.35	2.15	1043.67	2.59	6.62	22.67
March	118.5	14.96	1268.18	44.95	1.23	1.8	1144	24.36	6.67	21.93

Water consumption and wastewater generation historical data

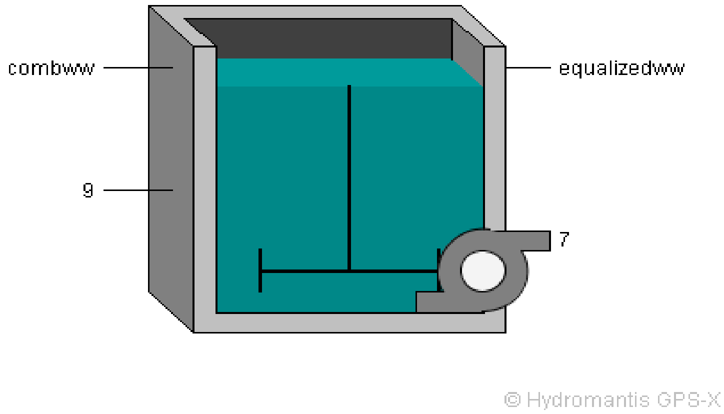


APPENDIX D

GPS-X software out puts of some major units in wastewater treatment plant



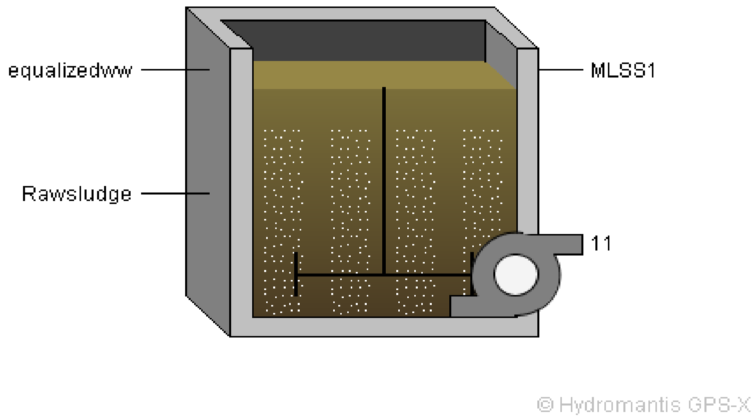
Equalization tank



Simulation Results

Parameters	Units	combww	equalizedww	7
Flow	m^3/d	2579	2579	0.0
TSS	mg/L	284.5	284.6	284.6
VSS	mg/L	229.9	229.9	229.9
$cBOD_5$	mg/L	386.6	386.6	386.6
COD	mg/L	754.3	754.4	754.4
Ammonia N	mgN/L	83.93	83.92	83.92
TKN	mgN/L	103.1	103.1	103.1
Soluble PO_4-P	mgP/L	5.548	5.547	5.547
TP	mgP/L	10.33	10.33	10.33
Total Alkalinity	$mgCaCO_3/L$	1591	361.6	361.6
pH	-	7.0	7.0	7.0

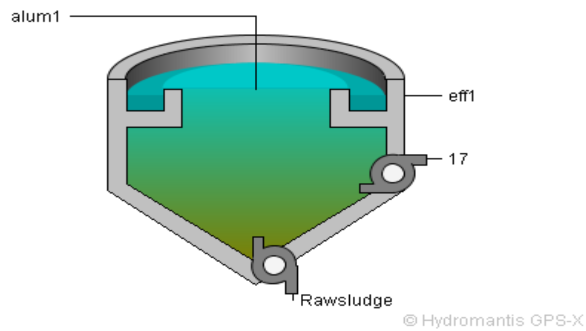
1st biological oxidation



Simulation Results

Parameters	Units	equalizedww	Internal	MLSS1
MLSS	mg/L	284.6	722.7	722.7
MLVSS	mg/L	229.9	554.3	554.3
Soluble COD	mg/L	352.5	103.4	103.4
Ammonia N	mgN/L	83.92	48.33	48.33
Nitrite N	mgN/L	76.6	92.96	92.96
Nitrate N	mgN/L	$1.694e^{-05}$	$2.343e^{-06}$	$2.343e^{-06}$
Soluble PO_4-P	mgP/L	5.547	2.746	2.746
TP	mgP/L	10.33	18.27	18.27
Total Alkalinity	$mgCaCO_3/L$	361.6	376.3	376.3
pH	-	7.0	7.0	7.0
HRT	h	-	14.42	-
DO	mgO_2/L	-	2.736	-

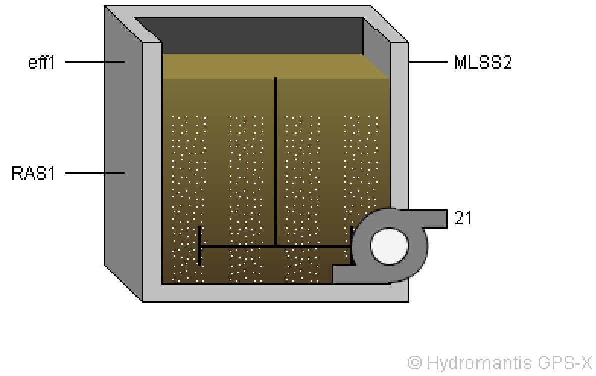
Primary sedimentation



Simulation Results

Parameters	Units	alum1	eff1	Raw sludge
Flow	m^3/d	2819	2579	240.0
TSS	mg/L	725.8	333.9	4938
VSS	mg/L	554.5	255.0	3772
$cBOD_5$	mg/L	401.0	188.0	2690
COD	mg/L	954.8	494.9	5897
TKN	mgN/L	106.1	77.84	409.3
Soluble PO_4-P	mgP/L	2.649	2.649	2.649
TP	mgP/L	18.27	10.34	103.5
Total Alkalinity	$mgCaCO_3/L$	376.2	376.2	376.2
pH	-	7.0	7.0	7.0
DO	mgO_2/L	2.736	2.736	0.0

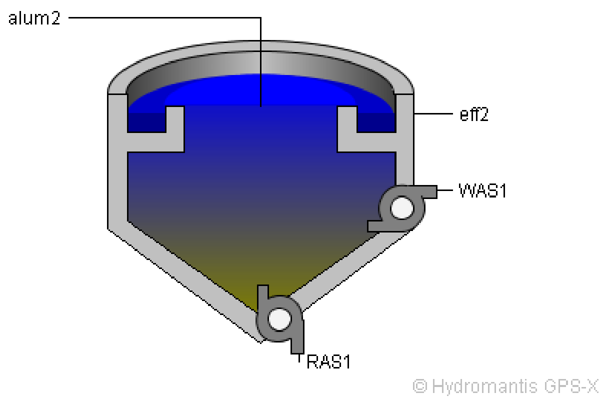
2^{nd} biological oxidation



Simulation Results

Parameters	Units	eff1	Internal	MLSS2
MLSS	mg/L	333.9	404.9	404.9
MLVSS	mg/L	255.0	303.1	303.1
Soluble COD	mg/L	103.1	95.43	95.43
Ammonia N	mgN/L	48.33	32.69	32.69
Nitrite N	mgN/L	92.96	109.1	109.1
Nitrate N	mgN/L	$2.343e^{-06}$	$1.104e^{-05}$	$1.104e^{-05}$
Soluble PO_4-P	mgP/L	2.649	2.793	2.793
TP	mgP/L	10.34	12.24	12.24
Total Alkalinity	$mgCaCO_3/L$	376.2	400.7	400.7
pH	-	7.0	7.0	7.0
HRT	h	-	7.166	-
DO	mgO_2/L	-	8.777	-

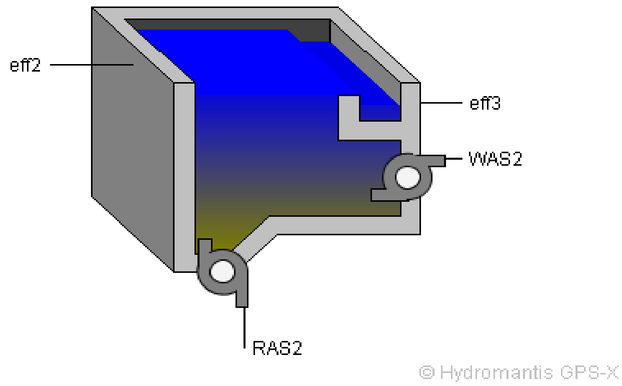
Secondary sedimentation



Simulation Results

		alum2	eff2	RAS1
Flow	m^3/d	4019	2579	1440
TSS	mg/L	407.8	319.6	565.6
VSS	mg/L	303.2	237.7	420.6
$cBOD_5$	mg/L	206.1	161.8	285.4
COD	mg/L	557.9	457.9	736.9
Ammonia N	mgN/L	32.69	32.69	32.69
Nitrite N	mgN/L	109.1	109.1	109.1
Nitrate N	mgN/L	$1.104e^{-05}$	$1.104e^{-05}$	$1.104e^{-05}$
TKN	mgN/L	67.62	61.2	79.13
TN	mgN/L	176.7	170.3	188.2
Soluble PO_4-P	mgP/L	2.529	2.529	2.529
TP	mgP/L	12.24	10.35	15.64
Total Alkalinity	$mgCaCO_3/L$	400.6	400.6	400.6
pH	-	7.0	7.0	7.0
DO	mgO_2/L	8.777	8.777	0.0

Advanced secondary sedimentation



Simulation Results

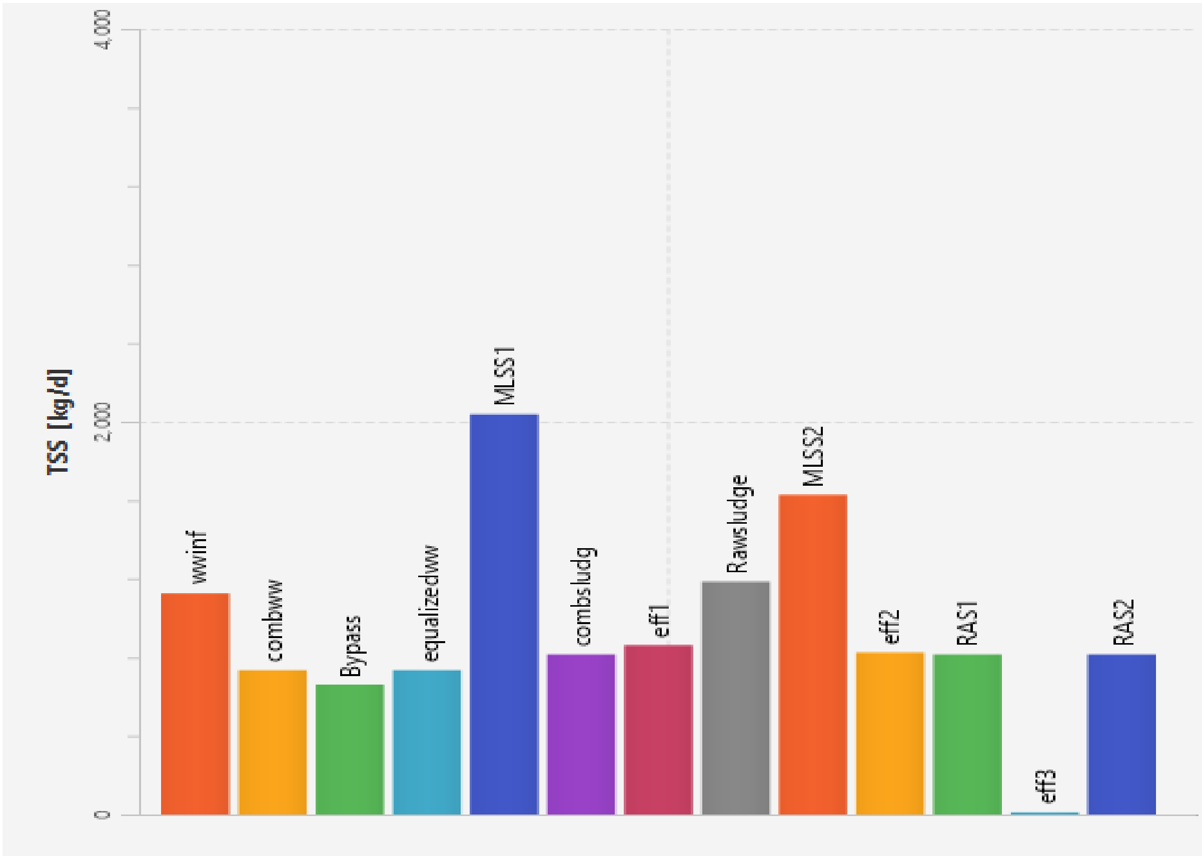
Parameters	Units	eff2	eff3	RAS2
Flow	m^3/d	2579	1139	1440
TSS	mg/L	319.6	8.698	565.6
VSS	mg/L	237.7	6.468	420.6
$cBOD_5$	mg/L	161.8	5.441	285.4
COD	mg/L	457.9	105.1	736.9
Ammonia N	mgN/L	32.69	32.69	32.69
Nitrite N	mgN/L	109.1	109.1	109.1
Nitrate N	mgN/L	$1.104e^{-05}$	$1.104e^{-05}$	$1.104e^{-05}$
TKN	mgN/L	61.2	38.53	79.13
TN	mgN/L	170.3	147.7	188.2
Soluble PO_4-P	mgP/L	2.529	2.529	2.529
TP	mgP/L	10.35	3.653	15.64
Total Alkalinity	$mgCaCO_3/L$	400.6	400.6	400.6
pH	-	7.0	7.0	7.0
DO	mgO_2/L	8.777	8.777	0.0

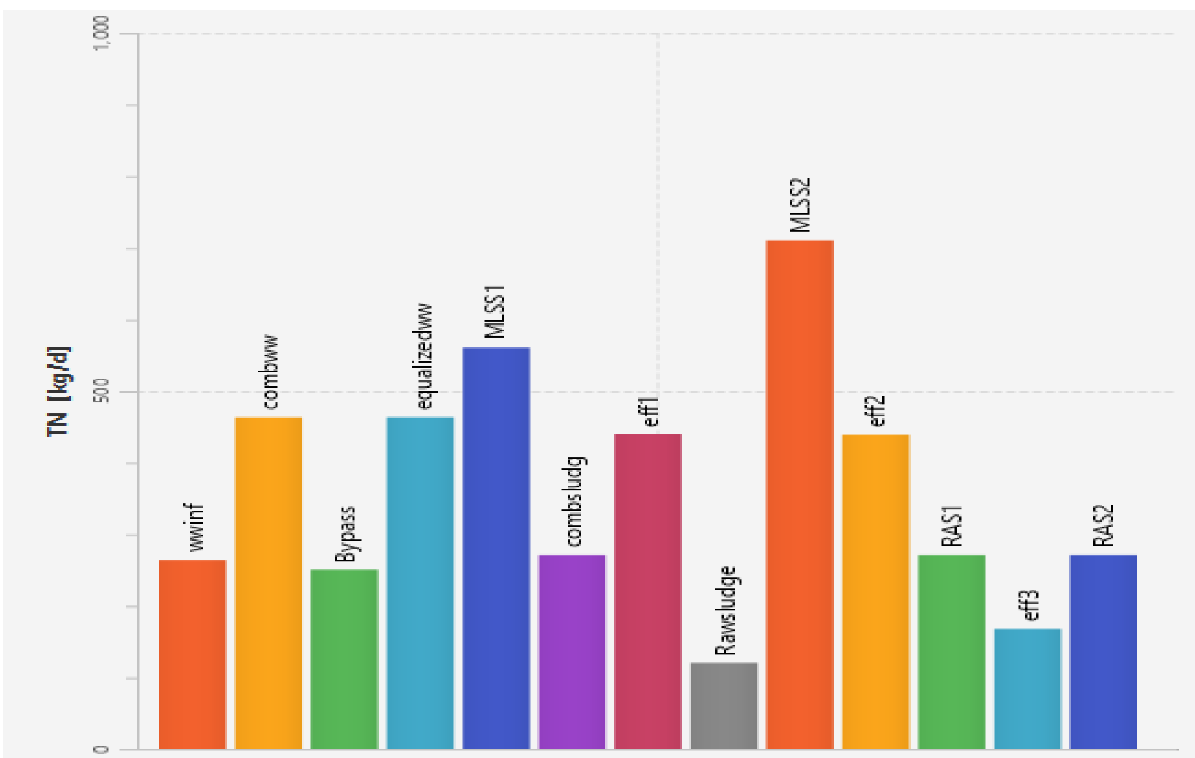
		wwinf	combww	Bypass	equalizedww	MLSS1	combsludg	eff1	Raw sludge
Flow	m^3/d	1200	2579	1194	2579	2819	1440	2579	240.0
TSS	mg/L	938.9	284.5	553.5	284.6	722.7	565.6	333.9	4938
	kg/d	1127	733.8	660.9	733.9	2037	814.5	861.0	1185
cBOD5	mgO_2/L	979.9	386.6	805.7	386.6	401.0	285.2	188.0	2690
	kg/d	1176	997.1	962.0	997.1	1131	410.7	484.8	645.7
COD	mgCOD/L	1900	754.3	1451	754.4	954.8	736.8	494.9	5897
	kg/d	2280	1945	1733	1946	2692	1061	1276	1415
Ammonia Nitrogen	mgN/L	179.0	83.93	179.0	83.92	48.33	32.73	48.33	48.33
	kg/d	214.8	216.4	213.7	216.4	136.3	47.13	124.7	11.6
TN	mgN/L	220.0	179.6	210.0	179.7	199.0	188.2	170.8	502.3
	kg/d	264.0	463.2	250.7	463.4	561.0	271.1	440.5	120.5
TP	mgP/L	20.0	10.33	15.94	10.33	18.27	15.65	10.34	103.5
	kg/d	24.0	26.65	19.04	26.65	51.51	22.53	26.68	24.84
Dissolved Oxygen	mgO_2/L	2.0	5.91	2.0	9.824	2.736	0.0	2.736	0.0
	kg/d	2.4	15.24	2.388	25.34	7.714	0.0	7.057	0.0
pH	-	8.3	7.0	7.0	7.0	7.0	7.0	7.0	7.0

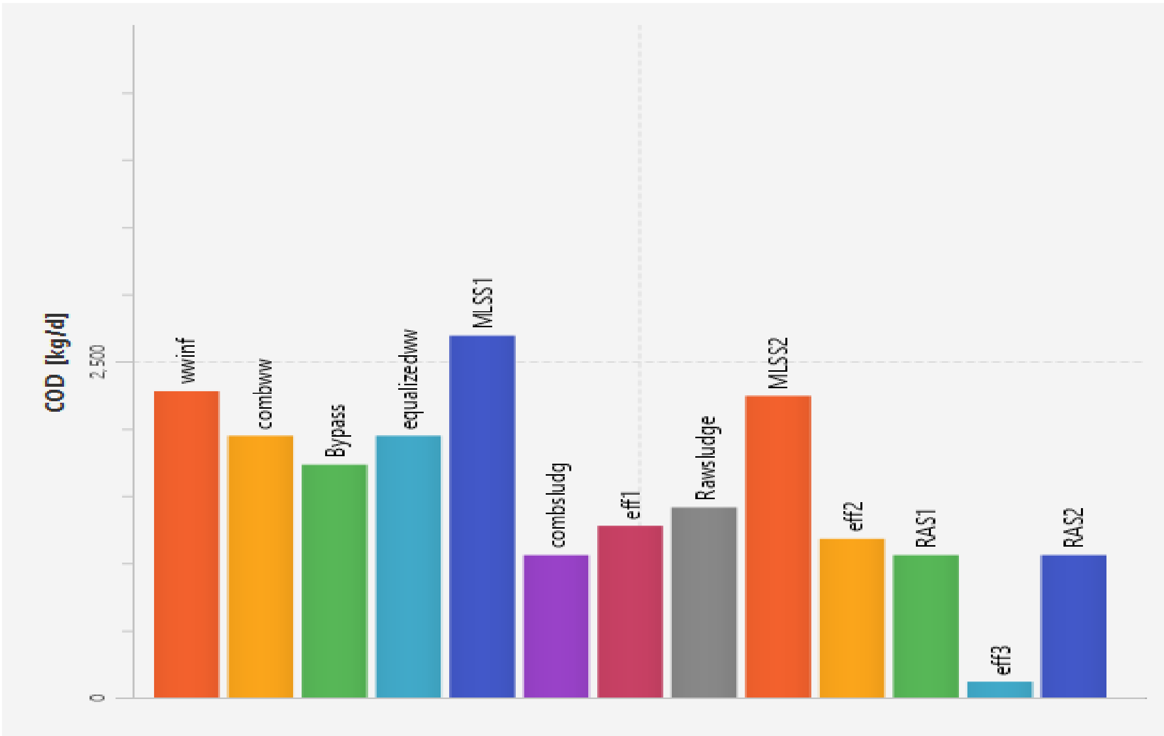
Continued

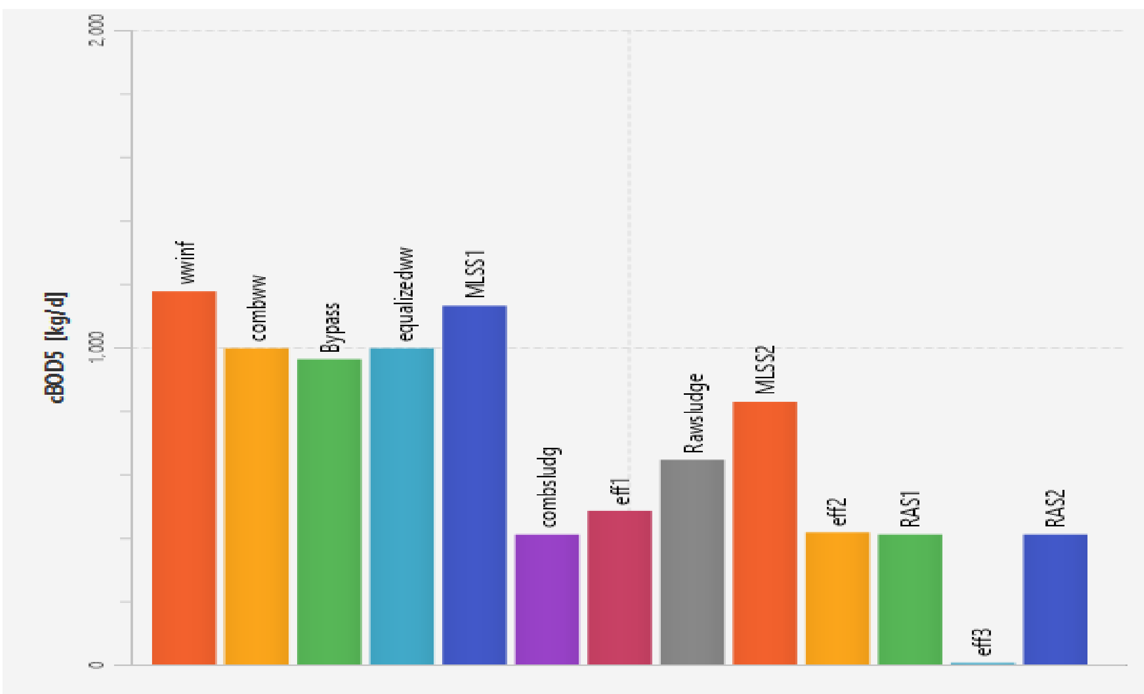
		MLSS2	eff2	RAS1	eff3	RAS2
Flow	m^3/d	4019	2579	1440	1139	1440
TSS	mg/L	404.9	319.6	565.6	8.698	565.6
	kg/d	1627	824.4	814.5	9.907	814.5
cBOD5	mgO_2/L	206.1	161.8	285.4	5.441	285.4
	kg/d	828.1	417.2	411.0	6.198	411.0
COD	mgCOD/L	557.9	457.9	736.9	105.1	736.9
	kg/d	2242	1181	1061	119.7	1061
Ammonia Nitrogen	mgN/L	32.69	32.69	32.69	32.69	32.69
	kg/d	131.4	84.3	47.07	37.23	47.07
TN	mgN/L	176.7	170.3	188.2	147.7	188.2

	kg/d	710.3	439.3	271.1	168.2	271.1
TP	mgP/L	12.24	10.35	15.64	3.653	15.64
	kg/d	49.21	26.69	22.53	4.161	22.53
Dissolved Oxygen	mgO_2/L	8.777	8.777	0.0	8.777	0.0
	kg/d	35.28	22.64	0.0	9.997	0.0
pH	-	7.0	7.0	7.0	7.0	7.0

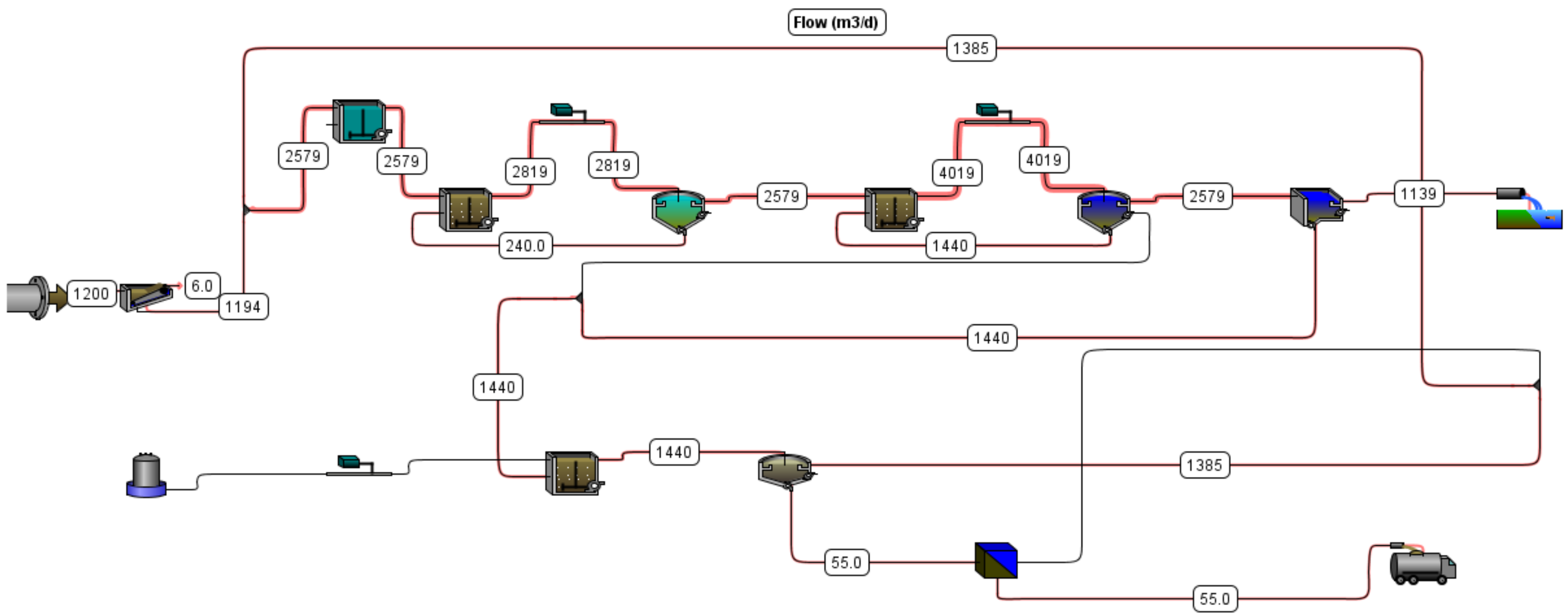

TSS [kg/d]
0
2,000
4,000
wwinf
combww
Bypass
equalizedww
MLSS1
combsludg
eff1
Rawsludge
MLSS2
eff2
RAS1
eff3
RAS2

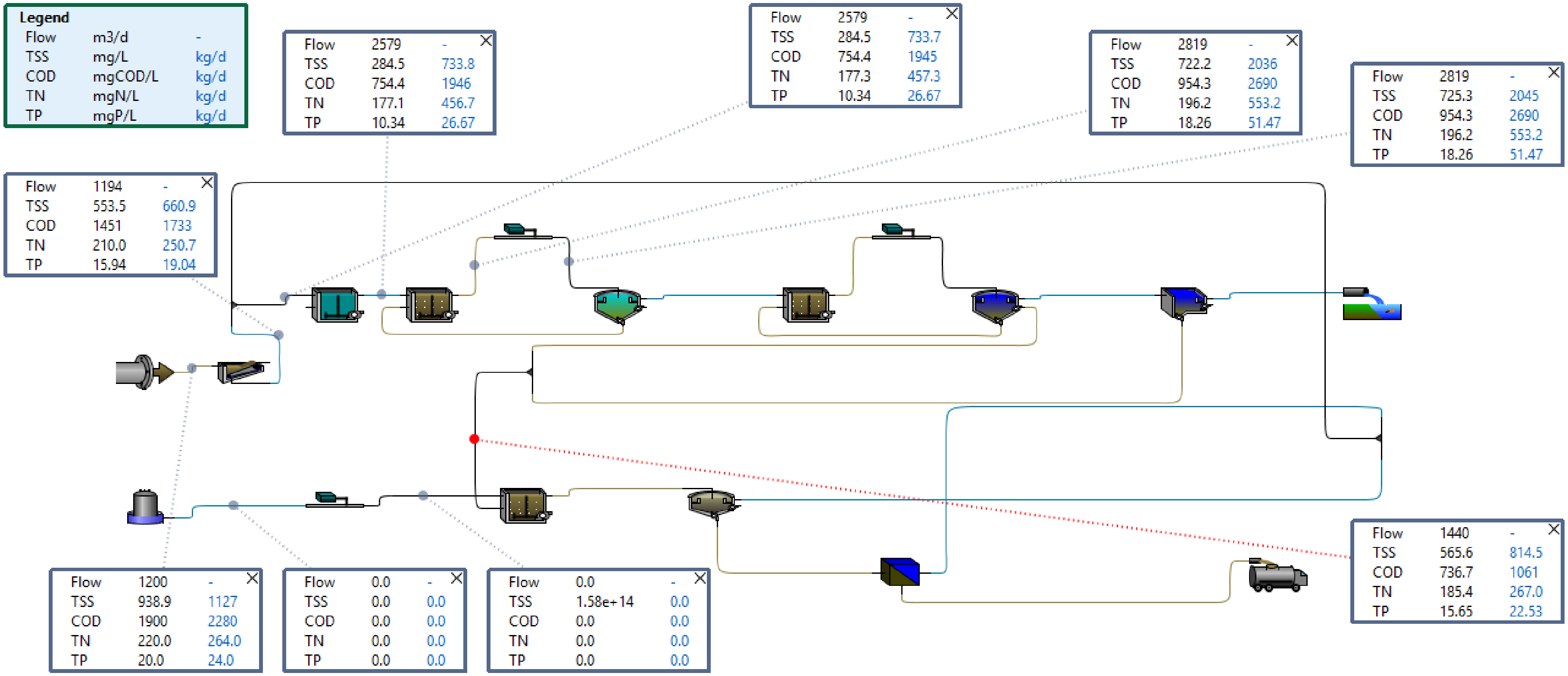

TN [kg/d]
0
500
1,000
wwinf
combww
Bypass
equalizedww
MLSS1
combsludg
eff1
Rawsludge
MLSS2
eff2
RAS1
eff3
RAS2


COD [kg/d]
2,500
0
wwinf
combww
Bypass
equalizedww
MLSS1
combsludg
eff1
Rawsludge
MLSS2
eff2
RAS1
eff3
RAS2


cBOD5 [kg/d]
2,000
1,000
0
wwinf
combww
Bypass
equalizedww
MLSS1
combsludg
eff1
Rawsludge
MLSS2
eff2
RAS1
eff3
RAS2

Sankey diagram




Legend
Flow m3/d -
TSS mg/L kg/d
COD mgCOD/L kg/d
TN mgN/L kg/d
TP mgP/L kg/d
Flow 2579 -
TSS 284.5 733.8
COD 754.4 1946
TN 177.1 456.7
TP 10.34 26.67
Flow 2579 -
TSS 284.5 733.7
COD 754.4 1945
TN 177.3 457.3
TP 10.34 26.67
Flow 2819 -
TSS 722.2 2036
COD 954.3 2690
TN 196.2 553.2
TP 18.26 51.47
Flow 2819 -
TSS 725.3 2045
COD 954.3 2690
TN 196.2 553.2
TP 18.26 51.47
Flow 1194 -
TSS 553.5 660.9
COD 1451 1733
TN 210.0 250.7
TP 15.94 19.04
Flow 1440 -
TSS 565.6 814.5
COD 736.7 1061
TN 185.4 267.0
TP 15.65 22.53
Flow 1200 -
TSS 938.9 1127
COD 1900 2280
TN 220.0 264.0
TP 20.0 24.0
Flow 0.0 -
TSS 0.0 0.0
COD 0.0 0.0
TN 0.0 0.0
TP 0.0 0.0
Flow 0.0 -
TSS 1.58e+14 0.0
COD 0.0 0.0
TN 0.0 0.0
TP 0.0 0.0

APPENDIX E

Summary of Changes from the Default

Influent

Variable	**Unit**	**Default**	**Value**
total COD	$gCOD/m^3$	430.0	1900.0
total TKN	gN/ m^3	40.0	220.0
total phosphorus	gP/ m^3	10.0	20.0
ammonia nitrogen	gN/ m^3	25.0	179.0
pH	-	7.0	8.3
carbonate alkalinity	$gCaCO_3/ m^3$	250.0	3500.0
other cation	eq/ m^3	3.0	1000.0
other anion	eq/ m^3	12.0	26.0
dissolved oxygen	gO_2/ m^3	0.0	2.0
influent flow	m^3/d	2000.0	1200.0

Alkali Dosage

Variable	**Unit**	**Default**	**Value**
chemical		NaOH	$Ca (OH)_2$
density of $Ca (OH)_2$ solution	mg/L	1000000	1000.0
Feed Setup		Constant Flow	Dose-Based
chemical dose	kg/m^3	0.0	0.0041

Equalization Tank

Variable	**Unit**	**Default**	**Value**
air flow into aeration tank	m^3/h	0.0	2000.0

Chemical Dosage 3

Variable	Unit	Default	Value
chemical type		aluminum sulfate-$Al_2(SO_4)_3.18H_2O$	ferric chloride-$FeCl_3$
chemical dosage, mass based	kg/d	0.0	200.005
chemical dosage, mass based	kg/d	0.0	60.0

1st biological oxidation

Variable	Unit	Default	Value
maximum volume	m^3	1000.0	1694.0
tank depth	m	4.0	5.5
specify oxygen transfer by...		Using a DO Controller	Entering Airflow
air flow into aeration tank	m^3/h	316.667	1000.0

Chemical Dosage 1

Variable	Unit	Default	Value
percent hydrated aluminum sulfate	%	50.0	17.0
chemical dosage, mass based	kg/d	0.0	200.0
percent as Al_2O_3	%	10.0	20.0
chemical dosage, mass based	kg/d	0.0	400.0
chemical dosage, mass based	kg/d	0.0	200.0

Lime Mixing Tank

Variable	Unit	Default	Value
air flow into aeration tank	m^3/d	7600.0	1799.7

Primary sedimentation

Variable	**Unit**	**Default**	**Value**
surface area	m^2	100.0	78.0
depth	m	3.0	2.5
specify solids removal		set removal efficiency (concentration)	use solids removal efficiency model
pumped flow	m^3/h	0.416667	10.0
underflow solids	mg/L	20000.0	400.0

Sludge Thickener

Variable	**Unit**	**Default**	**Value**
surface area	m^2	100.0	25.0
depth	m	3.0	4.4
pumped flow	m^3/d	6.0	55.0

2nd biological oxidation

Variable	**Unit**	**Default**	**Value**
maximum volume	m^3	1000.0	1200.0
tank depth	m	4.0	4.5
specify oxygen transfer by...		Using a DO Controller	Entering Airflow
air flow into aeration tank	m^3/h	316.667	1800.0

Chemical Dosage 2

Variable	Unit	Default	Value
percent hydrated aluminum sulfate	%	50.0	17.0
chemical dosage, mass based	kg/d	0.0	240.0
percent as Al_2O_3	%	10.0	20.0
chemical dosage, mass based	kg/d	0.0	400.0
chemical dosage, mass based	kg/d	0.0	200.0

Sludge dewatering

Variable	Unit	Default	Value
pumped flow	m^3/d	1.5	55.0

Secondary sedimentation

Variable	Unit	Default	Value
surface area	m^2	100.0	81.0
depth	m	3.0	4.5
specify solids removal by setting		removal efficiency (conc.) and underflow	underflow and solids
pumped flow	m^3/h	83.3333	60.0
underflow solids	mg/L	5000.0	565.6
removal efficiency (concentration basis)	-	0.995	0.97

Advanced sedimentation

Variable	Unit	Default	Value
surface area	m^2	100.0	81.0
depth	m	3.0	4.5
specify solids removal by setting...		removal efficiency (conc.) and underflow	underflow and solids
pumped flow	m^3/h	83.3333	60.0
underflow solids	mg/L	5000.0	565.6
removal efficiency (concentration basis)	-	0.995	0.97

APPENDIX F

Modelling Aeration Systems with GPS-X rate equations for hydrolysis (Pereira 2014)

Process:	**Rate equation:**
Aerobic Hydrolysis	$K_H \times \frac{S_O}{K_{O_2} + S_O} \times \frac{\frac{X_S}{X_{BH}}}{K_X + \frac{X_S}{X_{BH}}} \times X_{BH}$
Anoxic Hydrolysis	$K_H \times \eta_{NO_3} \times \frac{K_{O_2}}{K_{O_2} + S_O} \times \frac{S_{NO}}{K_{NO_3} + S_{NO}} \times \frac{\frac{X_S}{X_{BH}}}{K_X + \frac{X_S}{X_{BH}}} \times X_{BH}$
Anaerobic Hydrolysis	$K_H \times \eta_{fe} \times \frac{K_{O_2}}{K_{O_2} + S_O} \times \frac{K_{NO_3}}{K_{NO_3} + S_{NO}} \times \frac{\frac{X_S}{X_{BH}}}{K_X + \frac{X_S}{X_{BH}}} \times X_{BH}$

Label: K_H – Hydrolysis rate constant (d^{-1}); K_{O2} – Saturation/inhibition coefficient for oxygen (g $O_2.m^{-3}$); K_X – Saturation/inhibition coefficient for particulate COD (g X_S. g^{-1} X_H); K_{NO3} – Saturation/inhibition coefficient for nitrate (g $N.m^{-3}$); η_{NO3} – Anoxic hydrolysis reduction factor; η_{fe} – Anaerobic hydrolysis reduction factor.