Republic of Iraq

Ministry of Higher Education & Scientific Research

University of Kerbala

College of Engineering

Civil Engineering Department

Evaluation of the Operational Performance of the Karbala Wastewater Treatment Plant under Various Flow Rates Using GPS-X Model

A Thesis Submitted to the Council of the Faculty of the College of Engineering/ University of Kerbala in Partial Fulfillment of the Requirements for the Master Degree in Civil Engineering

By:

Noor Abdulhussein Khudhair Shukur

Supervisors

Prof. Dr. Basim Khalil Nile

Prof. Dr. Jabbar Hammoud Al-Baidani

March 2024 Ramadan 1445

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿يَا أَيُّهَا الَّذِينَ آمَنُوا إِذَا قِيلَ لَكُمْ تَفَسَّحُوا فِي الْمَجَالِسِ
فَافْسَحُوا يَفْسَحِ اللَّهُ لَكُمْ وَإِذَا قِيلَ انْشُزُوا فَانْشُزُوا يَرْفَعِ اللَّهُ الَّذِينَ
آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ﴾

صدق الله العلي العظيم

(المجادلة: من الآية 11)

Examination committee certification

We certify that we have read the thesis entitled " Evaluation of the Operational Performance of the Karbala Wastewater Treatment Plant under Various Flow Rates Using GPS-X Model" and as an examining committee,we examined the student " Noor Abdulhussein Khudhair Shukur" in its content and in what is connected with it and that, in our opinion, it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

Supervisor
Signature:
Name: Prof. Dr. Basim Khalil Nile
Date: / / 2024

Supervisor
Signature: Jabber
Name: Prof. Dr. Jabbar Hammoud Al- Baidani
Date: / / 2024

Member
Signature:
Name: Asst. Prof. Dr. Layla A. M.Saleh
Date:12 / 3 / 2024

Member
Signature:
Name: Asst. Prof. Dr. Maad.F.Hussian
Date: / / 2024

Chairman
Signature: Waqed H.H
Name: Prof. Dr. Waqed H. Hassan
Date: 13/ 3 / 2024

Signature:
Name: Dr. Awad Ali Sagheer
Head of the Department of Civil Engineering
Date: / / 2024

Signature:
Name: Asst. Prof. Dr. Haider Nadhom Azziz
Dean of the Engineering College
Date: 4/ 4/ 2024

Scanned with CamScanner

Supervisor Certificate

We certify that the thesis entitled "Evaluation of the Operational Performance of the Karbala Wastewater Treatment Plant under Various Flow Rates Using GPS-X Model " was written by Noor Abdulhussein Khudhair Shukur under our supervision at the Department of Civil Engineering/ Faculty of Engineering, University of Kerbala as a partial fulfilment of the requirements for the Degree of Master of Science in Civil Engineering.

Signature:
Prof. Dr. Basim Khalil Nile
Date: / /2024

Signature: Jabbar
Prof. Dr. Jabbar Hammoud Al-Baidani
Date: / /2024

Scanned with CamScanner

Undertaking

I certify that research work which is entitled " Evaluation of the Operational Performance of the Karbala Wastewater Treatment Plant under Various Flow Rates Using GPS-X Model " is my own work. The work has not been presented elsewhere for assessment. Where the material which has been used from other sources, has been properly documented.

Signature:
Noor Abdulhussein Khudhair
Shukur Date: / / 2024

Scanned with CamScanner

Dedication

I dedicate this work: For the sake of Allah Almighty The Prophet of Mercy, the Messenger of Allah, Muhammad, may Allah’s prayers and peace be upon him,and his family, and to the family of the messenger of Allah the good and pure Ahl ul- Bayt the door of mercy of Allah Almighty To tendererness..

To the grace of Allah upon me..my father, my mother They were the driving force behind my passion to learn and expand my knowledge and I will be eternally grateful to them.To my beloved husband who supported me mentally and emotionally throughout my study process .To my homeland Iraq.

Acknowledgments

All praise and glory to Almighty Allah for providing me with the health and strength to finish this work, and thanks and praise be to Allah who gave me the desire and ability to complete this step in my academic career.

I would like to take this opportunity to say warm thanks and gratitude to my supervisors, Dr. Basim Khalil Nile and Dr. Jabbar Hammoud Al-Baidani for their guidance, patience, motivation, support, and advice during all phases of the research. I am very grateful for their precious time spent and useful suggestions, which provided valuable guidance. Special thanks to the staff of karbala wastewater.

I would like to express my gratitude to my parents and my beloved husband for their unwavering and continuous support in helping me finish my researc,and I would like to express my thanks to my father in law and mother in law for their encourage and precious help throughout this thesis. Finally my thanks are to my friends for help me throughout this thesis.

Abstract

Wastewater treatment plants (WWTPs) are functional systems with a variety of treatment procedures designed to remove or minimize wastewater harm. Today, a system integrating performance assessment methodologies and modern modeling tools is employed to help determine how effectively and suitably these plants should be operated. Wastewater generation in Karbala city, Iraq, has significantly increased as a result of urbanization and population growth, necessitating the effective functioning of wastewater treatment facilities. In the present GPS-X modeling software was used to model the wastewater treatment plant using five scenarios with different flow rates scenario 1 with influent flow of 40,000 m^3/d, scenario 2 with influent flow of 60,000 m^3/d, scenario 3 with influent flow of 100,000 m^3/d , scenario 4 with influent flow of 140,000 m^3/d and scenario 5 with influent flow of 180,000 m^3/d to assess the operational effectiveness of the Karbala wastewater treatment plant (WWTP) in situations of variable flow rates.

The present study begins with a description of the Karbala WWTP's design, capacity, treatment procedures, and infrastructure. The performance of will be examined, and the treatment processes will be simulated by using the GPS-X model. By using historical data from the plant, the model is calibrated and tested to assure accuracy. The quality of the influent raw wastewater and the effluent treated wastewater have been studied throughout the year 2022 (from 1/2022 to 12/2022) in order to evaluate wastewater treatment plants. The performance efficiency of the Karbala WWTP is assessed by using the biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), ammonia-nitrogen (NH_3^+-N), orthophosphate (PO_4^{-3}), nitrate (NO_3^--N), and nitrite (NO_2^--N). Each parameter's removal efficiency from the influent and effluent wastewater is determined, and then the results are compared to Iraqi specifications. The GPS-X (v.8) software was used to create the model of the plant.

The results of the calibration of the model show that the developed model can be used for future studies because the accuracy of the model was acceptable the correlation between actual and simulated data was ranged from 0.81 to 0.92. The root mean square error RMSE results was close to zero and range from 0.011 to 0.138 , and the results of the simulation were close to the real-world concentrations of the plant. The findings of the simulation and modeling of Karbala WWTP utilizing GPS-X indicated that the facility performed well with high effectiveness according to the output parameters. The number the of primary clarifier decreased from 4 to 2 and secondary clarifier decreased from 8 to 3 when the influent flow is 40,000 m^3/d or less and the number of primary clarifiers decreased from 4 to 2 and the number of secondary clarifiers decreased from 8 to 4 when the influent flow to the treatment plant reach 60,000 m^3/d that reduce the enegy and cost of operation. The results of applying the five different scenarios showed that the values of the pollutants parameters TSS, COD, BOD_5, NO_2^--N, NO_3^--N, NH_3^+-N, and PO_4^{-3} in the effluent is remaining within acceptable limits of Iraqi standards and that the plant has high removal efficiency of pollutants with removal efficiencies ranged from 80 % to 94 % for TSS, from 83 % to 90 for COD , from 93 % to 96 % for BOD , from 86 % to 98 % for NH_3^+-N , and a the removal efficincy of PO_4^{-3} is within limit .

Table of Contents

List of figures

List of tables

List of Abbreviations

Abbreviations	Description
A2/O	Anarobic /Anoxic/Oxic reactor
APHA	American Public Health Association
ASM	Activated Sludge Model
ASP	Activated Sludge Processes
AWWA	American Water Works Association
BAF	Biological Aerated Filter
BNR	Biological Nutrient Removal
DEA	Data Envelopment Analysis
EAAS	Extended Aeration Activated Sludge
EBPR	Enhance Biological Phosphorus Removal
EPA	Environmental Protection Agency
GIS	Geographic Information System
IAWQ	International Association Water Quality
IFAS	Integrated Fixed Film Activated Sludge
KSOFM	Kohonen Self-organizing Feature Map
MBR	Membrane Bioreactor
MSW	Munisaple Solid Waste
SBR	Sequencing Batch Reactors
SCADA	Supervisory Control and Data Acquisition
STP	Sewage Treatment Plants
TDS	Total Dissolve Solids
UASB	Upflow Anaerobic Sludge Blanket
WWTP	Wastewater Treatment Plant

List of Symbols

Symbols	Description
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
F/M	Food to Microorganism
HRT	Hydraulic Retention Time
IR	Internal Recycle
MLSS	Mixed Liquor Suspended Solids
frxi	Particulate Inert Fraction of Total the COD
PO_4	Phosphate
spro	Propionate
rbCOD	Readily Biodegradable COD
frss	Readily Biodegradable Fraction of the Total COD
RAS	Return Activated Sludge
SVI	Sludge Volume Index
SRT	Solid Retention Time
SRT	Solid Retention Time
SLR	Solids Loading Rate
frsi	Soluble Inert Fraction of the Total COD
SOR	Surface Overflow Rate
SOR	Surface Overflow Rate
NH_3	Ammonia Nitrogen

Chapter One: Introduction

1.1 Bakground

The negative impacts of the changing climate, which have led to dwindling or decreasing freshwater resources, are being felt in many nations. Iraq is situated in the dry to semi-arid eastern part of the middle east. On the other hand, the demand for freshwater is anticipated to increase as a result of the growing population. This increases the already-existing pressure on water facilities. Furthermore, as a result of rapidly expanding industrial activities, water contamination has significantly increased. Several studies have indicated that the continuous discharge of wastewater into the environment worsens the issue of water scarcity by polluting freshwater resources. The gradual depletion of water resources worldwide and the significant presence of polluted water in industrial areas underscore the critical significance of wastewater treatment operations in mitigating water loss. Simultaneously, it is anticipated that the organic and hydraulic loadings on current wastewater treatment facilities will escalate due to the expansion of urban regions. Consequently, this circumstance necessitates the implementation of more effective wastewater treatment methodologies **(Zhou et al., 2014)**. Currently, the primary focus of global community development is centered around ensuring individuals have access to sufficient quantities of safe water to drink, in addition to appropriate methods for the transportation, disposal, and high-quality treatment of wastewater. Nations exhibiting elevated rates of wastewater treatment possess a greater percentage of anaerobic, anoxic, and oxic microorganisms. The A2/O (anaerobic/anoxic/oxic) technology is often selected due to its inherent stability and ease of management in daily operations **(Liao et al., 2021; Zhang et al., 2016)**.

Severe weather might bring either dry or rainy spells, and the population expansion will create new difficulties for operating a wastewater treatment facility. To prepare for these issues, the wastewater treatment process (WWTP) can be simulated under various intake circumstances. In harsh climatic circumstances, the feed stream flow rates may exceed the intended maximum values, and the compositions may fluctuate greatly **(Lahdenperä & Koiranen)**. It is crucial to employ simulation to make the most of the model's predictive skills, which may be used to quickly and effectively weed out the optimal design option and cut down on the time and expense of laboratory testing. Modeling is the process of simplification of actual representation. Time-dependent variables and parameters were used in a sequence of mathematical operations and equations to define the model **(Faris, Zwain, Hosseinzadeh, Majdi, et al., 2022)**. Recent times have seen a rise in the use of dynamic modeling and simulation in wastewater treatment. Many models are created to enhance activated sludge. Several software programs, such as SIMBA, GPS-X, AQUASIM, BioWin, STOAT, FOR, and WEST, that promote dynamic modeling of wastewater treatment facilities use these models. Tools for simulation and modeling are used to evaluate process procedures, optimize designs, and analyze costs **(Hernandez-Sancho & Sala-Garrido, 2008)**. The program GPS-X, which can model wastewater treatment processes including sequencing batch reactors (SBR), aeration biofilters, oxidation ditches, and others, has been used in multiple recent research to simulate and forecast wastewater treatment processes. BAF model, a denitrification filter, and other components are included in its contact growth model. The model also features a number of settlement models and aerobic (anaerobic) digestion models that may be constructed and simulated in response to the demands of the designer **(Abbasi et al., 2021)**.

1.2 Problem Statement

Wastewater treatment facilities hold significant environmental importance, necessitating the preservation of their efficiency to ensure that the concentrations of discharged pollutants into rivers post-treatment remain within acceptable limits.

Over the past few years, there has been a significant decline in the levels of the Rivers, which can be attributed to the construction of numerous dams in its originating country. The significance of adequately treating wastewater prior to its discharge into the river has been heightened.

The Karbala WWTP, located in Karbala province, is a recently established wastewater treatment plant that commenced operations in 2019. This plant holds significant importance due to the substantial volume of wastewater effluents that are discharged subsequent to treatment. There is a variable flow between the plants during the year and from year to year because Karbala is a holy city. Millions of visitors enter the city every year. The main justification of the present study is to understand and already know the effect of the variable flow on the operational performance of the Karbala wastewater treatment plant modeled in GPS-X by five scenarios. Each scenario illustrates a specific case of discharge.

1.3 The Aim and Objective of the Study

1.3.1 Research Aim

The main aim of the present study is to obtain and employ a simulation of the operational performance of the Karbala wastewater treatment plant using the GPS-X model by obtaining different operational scenarios that are more suitable for the different values of flow rates of the plant.

1.3.2 Research Objectives

1. Collecting data from the Karbala WWTP field laboratory over the duration of one year (2022). These collected data contain the influent and effluent wastewaters of BOD, TSS, COD, PO_4^{-3}, NH_3^+, NO_3^-, and NO_2^-.
2. Using GPS-X software to make a model of the Karbala wastewater treatment plant using five different scenarios to determine the impact of the fluctuating flow rates on the performance of the plant.
3. Evaluation the operational performance of the plant under different values of flow rates.

1.4 Layout of the Study

The chapters that make up this study are listed below.

1. **Chapter One** provided an overview of the problem of the study, aims, the methodology, and developing thesis.
2. **Chapter Two** incorporates comprehensive studies, theoretical considerations, and some earlier works related to the topic**.**
3. **Chapter Three** describes the research area, the operational evaluation of the Karbala WWTP, the field work, and the GPS-X modeling of the Karbala WWTP.

4. **Chapter Four** illustrates the findings of five scenarios examination and discussion.
5. **Chapter Five** highlights the most significant conclusions and recommendations reached once the thesis was completed.

Chapter Two: Literature Review

2.1 Wastewater

Wastewater is any water or liquid that has contaminants or pollutants in the form of solids, liquids, or gases, or their combination, in a way that would be risky to release into the environment **(Eriksson et al., 2002)**. Because water is so important to man's daily activities, "trash" is dumped into the water various substances such as biological waste (feces and urine), hair shampoo and conditioner, lipids, human hair, scraps of food, bathroom paper, washing machine powder, cloth conditioners, dirt, chemicals, detergent, cleaning products, and microorganisms (germs) have the potential to cause harm to both human health and the environment.

It is common knowledge that more water is provided for wastewater production, making its treatment necessary. In order to reduce contamination and safeguard the ecosystem, wastewater treatment is a technique and a mechanism for getting rid of most of the dangers found in wastewater. Thus, managing wastewater involves treating it in a way that preserves the environment while simultaneously guaranteeing public health, social cohesion, economic prosperity, and political stability **(Yaqoob et al., 2020).**

Water is an essential resource for the sustainable development of ecosystems and the improvement of human health. Globally, because of changes in consumption patterns, the development of cities, industrialization, and growing populations, there is a higher demand for supplies of freshwater **(Sun et al., 2016).**

The quality of wastewater can be described using physical, chemical, and biological parameters. The community's water quality, the kinds of businesses that are already there, and the services such businesses offer in terms of treatment their sewage significantly alter the characteristics of sewage **(Jasim, 2020)**. Along with additional essential elements like sulfur, phosphorus, and iron, organic compounds are primarily composed of carbon, hydrogen, oxygen, and nitrogen. Numerous wastewater inorganic indicators are important for the development and control of wastewater quality criteria with regard to organic components.

2.2 Types of Wastewaters

Wastewaters are widely categorized as follows based on the source of generation:

Domestic: It is the wastewater that the sewage system has gathered from a city or society's institutional, commercial, and residential areas. In typically, domestic wastewater is 99.9% water and contains barely 0.1% pollutants also known as municipal wastewater or sanitary wastewater **(Karia & Christian, 2013)**

Municipal Wastewater: regardless of any groundwater, surface water, or storm water that may be available, is the transported waste from households, workplaces, or contemporary enterprises. Untreated wastewater typically has high levels of natural material and a variety of harmful microorganisms, as well as additives and toxic mixtures. Because of this, it is bad for the environment and must be moved quickly and carefully away from its source before it can be moved for good **(Mallik et al., 2018).**

Industrial: Industrial wastewaters are often the waste products of large- and medium-sized businesses. The amount and quality of these wastewaters depends on the industry and within a single industry from process to process. Most manufacturing companies produce a lot of high hazardous wastewaters **(Karia & Christian, 2013)**

Infiltration/Inflow: water that both directly and indirectly enters the collection system. Extraneous water infiltration occurs when these seams, cracks, and breaks leak, allowing it to infiltrate the collecting system. Inflow is the term for stormwater that comes into the collection system through access ports (manhole covers), roof leaders, foundation and basement drains, and storm drain connections (catch basins). **(Metcalf et al., 2014)**

Agricultural Wastewater: is water that has been used for agriculture. Common contaminants include pesticides, fertilizers, and animal waste. Only point sources of agricultural wastewater, such as live breeding facilities, are significant to treatment procedures. Most of the time, polluted water in fields is not collected; instead, it goes straight into the ground or into riverbanks **(Naidoo & Olaniran, 2014).**

Storm Water: Runoff resulting from rainfall and snowmelt **(Metcalf et al., 2014)**

2.3 Concept of Wastewater Treatment

The process of treating wastewater produces an effluent that can be returned back into the water system with little to no negative environmental effects. This treated wastewater can be used for a variety of additional purposes **(Mallik et al., 2018)**. In emerging nations, water pollution has grown to be a significant environmental hazard for both public and environmental health. Mixing domestic, municipal, and industrial wastewaters together is the main factor causing water resources to become contaminated. Due to financial limitations, the state of wastewater management and treatment is terrible due to an absence of technically qualified human resources and electrical supplies. Additionally, finding affordable, straightforward, dependable, and efficient wastewater treatment systems is difficult for the scientific community and experts in managing wastewater (**Ali et al., 2017)** .

It's possible to describe water pollution in a variety of ways. Water becomes contaminated when one or more substances are discharged into it that could harm it. These substances have the capacity to affect ecosystems, people, animals, and the environment. Different types of water contamination exist **(Crini & Lichtfouse, 2019).**

2.4 Wastewater Characteristics

The environment, the social and economic status of the population, the reason the water is used, and other factors all have an impact on the properties of the wastewater **(Henze et al., 1995)**. The availability of fresh water is significantly threatened by pollution and excessive use, and these issues could lead to major disputes in the future.One of most significantly important physical characteristics of wastewater is the quantity of solids, which comprises float materials, silt, suspended material, and dissolved matter. Other physical qualities include the temperature, color, and degree of turbidity. In terms of chemical composition, it also includes both organic and inorganic materials. **(Jasim, 2020)**. Some of the signs used to detect pollution include **(Kolev Slavov, 2017)** .

2.4.1 Physical

- **Total Suspended Solids (TSS)**: This group of particles are filtered out using a 0.45-1.2 µm filter size.
- **Total Dissolve Solids (TDS)**: These are particles of a size less than 0.45 µm **(Henze et al., 1995).**

In WWTPs, suspended solids are removed physically using methods like grit removal and main sedimentation tanks, while dissolved solids, particularly organic compounds, are removed biologically using biological processes.

2.4.2 Chemical

- **Biological Oxygen Demand (BOD):** The quantity of oxygen needed to keep a waste biologically stable throughout time **(Metcalf et al., 2014).**
- **Chemical Oxygen Demand (COD)**: Is the quantity of oxygen that is consumed when organic contaminants are chemically oxidized. It is regarded as a proximate indicator of organic substance **(Pereira, 2014)**.
- **Dissolved Oxygen (DO)**: The amount of dissolved oxygen in wastewater

- **Nitrogen: NH_4-N and NO_3-N**: Serve as representatives of dissolved nitrogen **(Kolev Slavov, 2017)**.
- **Phosphorus:** Phosphorus is present in wastewater as phosphate, which is created when detergents and other chemicals are used (**Pereira, 2014)**.

2.5 Wastewater treatment processes

The most efficient purification method should be used to satisfy the decontamination requirements (as set forth by legislation) when decontamination of the water is necessary. Preliminary treatment, primary treatment, secondary treatment, tertiary treatment, and sludge treatment are the five stages of the treatment method **(Russell, 2019)**. A physical process is used for preliminary treatment; a physical method or a combination of chemical and physical methods is used for primary treatment; a mix of physical and biological processes is used for secondary treatment; a mix of physical and chemical processes is used for tertiary treatment; and a mix of physical and chemical processes is used for sludge treatment.

A physical process is used for preliminary treatment; a physical method or a combination of chemical and physical methods is used for primary treatment; a mix of physical and biological processes is used for secondary treatment; a mix of physical and chemical processes is used for tertiary treatment; and a mix of physical and chemical processes is used for sludge treatment **(Cheremisinoff, 2019).**

2.5.1 Preliminary treatment:

The initial phase of the therapy process is preliminary treatment. This process involves using screens to catch and remove large solid objects additionally to putting down gravel and sand by pumping water entering the plant via a hole where large objects fell. This phase is essential for protecting the machinery of the plant against failure, especially the pipelines and pumps. It includes subsystems like the screen and grit chamber. While removing grit and other objects that are greater in weight than organic matter is known as grit removal, screens are generally used to remove big particles such as rags, paper, plastics, and metals **(Khiewwijit et al., 2015)**. The significance of this stage in terms of preventing malfunctions in the machinery of the plant, particularly in the pipes and pumps.

2.5.2 Primary Treatment:

The second stage is the primary treatment process, which theoretically removes all inorganic solids and about 25% of the waste material is composed of organic matter. pH adjustments, chemical additions, and flow balancing may all be required for water carrying industrial effluents. The screen, the grit chamber, and the equalization basin are some of its parts. The removal of organic materials that can settle is done by the main sedimentation unit, which is also a part of the primary treatment. Typically, between 50% and 70% of the total suspended particles are removed during initial sedimentation **(Jasim, 2020)**.

2.5.3 Secondary Treatment:

The secondary treatment, which is a biological procedure, is the third stage of the treatment. The precisely constructed bioreactor receives the settled wastewater, and microorganisms like bacteria, algae, and fungi utilize the organic contents there either aerobically or anaerobically. During the biological and chemical wastewater treatment processes, the bioreactor is the device that supplies the ideal bioenvironmental circumstances for bacteria to multiply and use the dissolve organic matter as energy for themselves. As long as the microorganisms are supplied with nutrients and oxygen in the form of settled wastewater, the biological oxidation of soluble organic matter will continue.

The bacteria that together make up the basic trophic level (level of organism is determined by its place in a food chain) of the food chain inside the bioreactor are responsible for the majority of the biological process. The biological conversion of soluble organic molecules into thick bacterial biomass can substantially purify the wastewater. The treated wastewater must subsequently go through sedimentation to remove the microbiological biomass. Because bacterial cells rather than fecal particles make up the sludge in this case, secondary sedimentation differs significantly from primary sedimentation. The biological removal of organic compounds from settling wastewater is carried out by microorganisms, mainly heterotrophic bacteria but occasionally also fungus. Microorganisms can digest the organic material thanks to the biological oxidation and biosynthesis processes **(Gray, 2005).**

During secondary treatment, over 85% of the organic substances can be eliminated. However, no significant quantities of heavy metals, degradable organics, nitrogen, phosphorus, bacteria, or viruses would be eliminated. There is a chance that additional pollutants will need to be eliminated (advanced one) **(Soomaree, 2015).**

2.5.4 Tertiary Treatment:

Tertiary treatment is used to remove certain wastewater components that a secondary treatment cannot get rid of. Large volumes of phosphate, nitrogen, toxic metals, biodegradable organics, microbes, and viruses are removed during the tertiary treatment stage. Secondary effluent can be successfully filtered using both conventional sand (or other comparable medium) filters and more modern membrane materials. Helminths are eliminated by both filters and membranes, some of which have been improved. Disk filtration is the most contemporary method, which filters water using sizable cloth media disks mounted to revolving drums. At this point, the water can be disinfected using UV radiation, chlorination, and ozonation to meet the most recent international standards for agriculture and urban re-use **(Comber et al., 2019)**.

The treated wastewater can be applied to non-potable tasks like vegetable gardening and flushing toilets, as well as discharged into surface waterway outfalls. Finally, tertiary treatment, which is also referred to as the "advanced" or "final" treatment, aims to further purify wastewater by eliminating any potentially harmful elements or nutrients that may still be present after secondary treatment, as well as specifically eradicating or disinfecting pathogenic bacteria. Water that has undergone tertiary treatment is safe to drink again. In addition to the aforementioned, chlorination may be applied throughout the entire treatment process to improve the quality of wastewater. **(Machineni, 2019)**.

2.5.5 Sludge Treatment:

Sludge is a byproduct of treating wastewater. It is rich in organic molecules, pathogens, plant nutrients, and both organic and inorganic elements. Therefore, it's crucial to handle this sludge properly to lessen its influence on the environment. For sludge treatment, there are four common procedures or steps: process- Sludge Thickening, process- Sludge Digestion, Dewatering and disposal **(Martí et al., 2017)**.

2.6 Biological Treatment Systems

The conversion of soluble and particulate biodegradable elements into desirable end products is the key aim of biological treatment of residential wastewater, the transformation or get rid of nutrients like nitrogen and phosphorus, the gathering and incorporation of dissolved organic compounds into a biological floc or biofilm, and in some situations, the removal of specific trace organic components **(Metcalf et al., 2014)**. Microorganisms help biological treatment systems remove organic contaminants from wastewater by first degrading them in the wastewater. The biological treatment mostly involves the suspended growth process and the attached growth process **(Cervantes et al., 2006)**.

Activated sludge process is an application on the suspended growth process. Microorganisms in suspended growth systems tend to form flocs while growing in close proximity to the wastewater they are purifying. The aggregates, also known as flocs, are made up of many different kinds of microorganisms and are responsible for cleaning the water. Bacteria, protozoa, and metazoan are the most common and consequential of these microorganisms. Some viruses and fungi are present as well, but they likely play a small role in effluent treatment **(Horan, 2003)**.

In the suspended process, the microorganisms stay suspended in the wastewater, which is thoroughly mixed and has oxygen. The microorganisms break down the organic pollutants **(Metcalf et al., 2014),** while the attached growth procedures involve the attachment of microorganisms that convert organic material or nutrients to an inert packing material. The adhering growth, also known as a biofilm, removes organic material and nutrients from wastewater as it flows by. Rock, gravel, slag, sand, redwood, and a variety of plastics and other synthetic materials are utilized as packing materials in attached growth techniques. Attached growth mechanisms can be either aerobic or anaerobic in nature **(Metcalf et al., 2014)**.

2.7 Activated Sludge Process

The activated sludge process (also known as ASP) is the most widely used technique for wastewater treatment. Its high versatility, which enables the designer to employ it with any type of wastewater, lower price, and capacity to create a high-quality effluent that complies with the increasingly stringent effluent laws are the main reasons for this **(Arif, Sorour et al. 2018)** .The activated sludge method utilizes a dense microbial population suspended in aerobic wastewater. Bacterial growth and respiration can occur at high rates when there are plenty of nutrients and oxygen available, leading to the conversion of readily available organic matter into oxidized end-products (such as CO_2, NO_3, NO_2, SO_2, and PO_3) or the development of newly arrived microorganisms. The bioreactor, activated sludge, aeration and mixing system, sedimentation tank, and returned sludge are the five interdependent parts of the activated sludge process **(Samer, 2015)**.

Most of the time, a primary sedimentation comes before the activated sludge process. The aforementioned procedure primarily eliminates settleable solids, whereas the biological mechanism is optimal for the elimination of soluble, colloidal, and particulate organic substances, as well as the process of nitrification, denitrification, and phosphorus eradication **(Pereira, 2014).**

In addition to maintaining the microorganisms in suspension, the aeration system must be sufficient to provide the oxygen requirements for biomass development, endogenous respiration, and nitrification. As a result, the aeration tank's minimum dissolved oxygen (DO) level must be maintained at about 2 mg/L. The removal of phosphorus and denitrification both require anaerobic and anoxic zones in addition to the aerobic zone **(Cervantes et al., 2006)**. Particles that are suspended during the process of treatment of wastewater in aeration basins using the activated sludge method are known as mixed liquor suspended solids (MLSS), and their concentration is measured in milligrams per liter. In an aeration tank, raw wastewater and activated sludge are combined to form mixed liquor. Microbes and non-biodegradable suspended particles make up the largest portion of MLSS. The efficient and active component of the activated sludge process, MLSS, ensures that there is consistently enough viable biomass available to break down the given amount of organic pollutants **(Samer, 2015)**. This measure of how starving the bacteria are being called the Food-to-Microbe Ratio (F/M ratio) or the food-to-mass ratio. This word refers to the amount of BOD or COD applied per liter of mixed liquid.

When the F/M ratio is high (high load), there is a lot of substrates available, which causes the microorganisms to develop quickly and most of them to be purged through the sludge. In contrast, if there are more microbes present and there is available substrate (low F/M), there will be significantly less growth. Endogenous respiration, which occurs when microorganisms use oxygen to break down the stored substrate, results in less and better settling sludge production. A standard activated sludge plant's F/M ratio when extended aeration is used falls between 0.05 and 0.15 **(Wang et al., 2010)**.

According **(Gray, 2005)** all activated sludge systems have the same essential parts:

- Lagoons, tanks, or ditches can all be used as bioreactors. A bioreactor's primary quality is that its contents are suitably aerated and mixed. The aeration tank is another name for the bioreactor.
- The bioreactor's bacterial biomass, or activated sludge, mostly consists of bacteria as well as other flora and micro fauna. A flocculent suspension of these microorganisms known as "sludge" is typically composed up of between 2,000 and 5,000 mg/L of (MLSS).
- Aeration and mixing system, the raw influent and activated sludge must be aerated and mixed. Although these procedures can be carried out independently, they are often carried out using a single system of diffused air or surface aeration.
- Tank for sediment the activated sludge that is discharged from the aeration tank must be clarified or settled. Consequently, the treated wastewater and bacterial biomass are separated.
- Return of sludge the settled activated sludge from the sedimentation tank goes back into the bioreactor to keep the number of microorganisms at the right level for the treatment process to keep going.

Figure (2-1) represents a high-level scheme for the activated sludge treatment procedure:

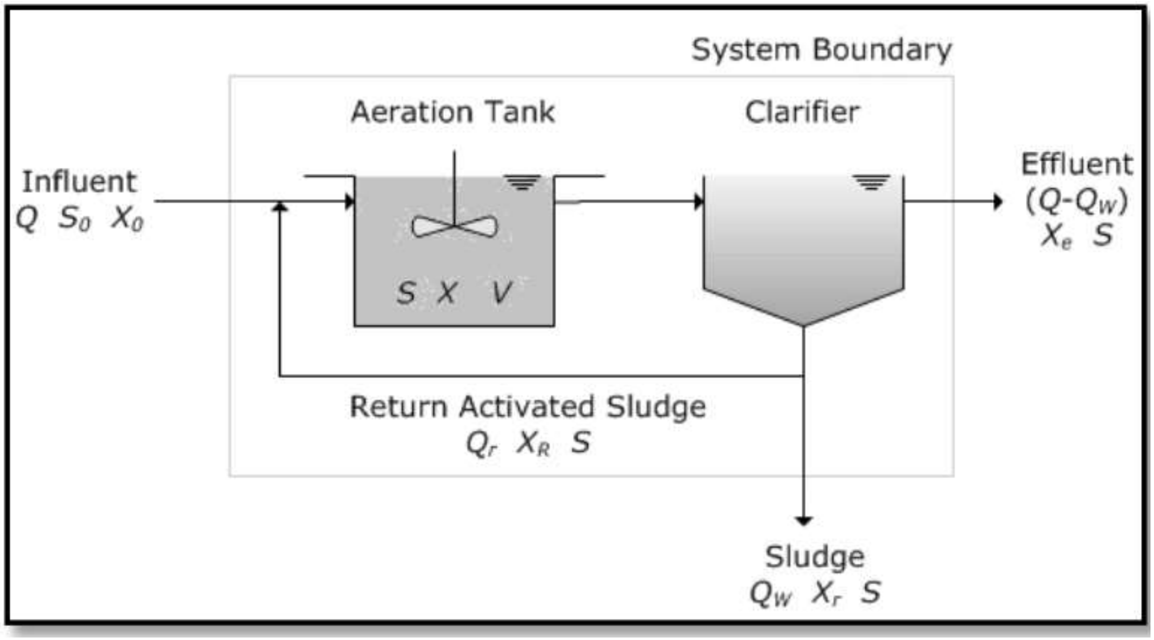


Figure 2-1 :Schematic Diagram of Activated Sludge Process. Adapted from: **(Lenntech 2019).**

Examples of activated sludge are conventional activated sludge plants, complete mix plants, sequencing batch reactors (SBRs), and the Anaerobic, Anoxic, and Oxic Activated Sludge System (A2/O) **(Mihelcic & Zimmerman, 2021).**

2.7.1 Conventional Activated Sludge Plants:

This bio treatment technology treats municipal and industrial wastewater and is the oldest bio treatment method in use. A CAS system is made to eliminate organic contaminants and the nutrients nitrogen and phosphorus to create an effluent that complies with discharge limits. However, CAS Despite their high robustness, systems cannot be considered sustainable. The high energy usage, which accounts for roughly half of the total energy consumption of 0.6 kWh per m3 of effluent, is a significant negative **(McCarty et al., 2011)**. Following the removal of suspended pollutants, wastewater is treated in a biological treatment method using the activated sludge process, which includes an aeration tank and secondary clarifier. A completely mixed or plug-low bioreactor, the aeration tank maintains a particular biomass concentration (MLSS or MLVSS) and dissolved oxygen (DO) concentration (usually 2 mg/l) to promote the biodegradation of soluble organic pollutants (BOD5 or COD).

The bottom of the aeration tank includes diffused bubble aeration pipes for biomass oxygenation and reactor mixing. Roots-type air blowers provide diffuser pipework with air. In previous installations, mechanical surface aerators have met the aeration need. Gravity-fed secondary clarifier system separates biomass from aerated mixed liquor from the aeration tank and supplies clarified, treated water to the downstream filtering system for the removal of suspended particles. RAS pumps return separated biomass to the aeration tank. Sludge handling and dewatering facilitiey waste biodegradation biomass **(Mittal, 2011)**.

The common measurements that are carried out during CAS therapy:

- **Physical Parameters**: Such as temperature, dissolved oxygen (DO), and pH have an impact on the biological processes of the biomass (and the rate of pollutant removal kinetics) as well as the chemical removal in primary and tertiary treatments. Generally speaking, based on the unique influent characteristics and removal requirements, these parameters need to be optimized. Bacteria may be inhibited or harmed by pH extremes. Lower temperature slows down the rate of removal, especially for aerobic biomass . As a result, at lower temperatures, larger activated sludge tanks are required to accomplish high organic compound removal or nitrogen removal (particularly for ammonia removal in tertiary treatment). For tertiary treatment of nitrogen, oxygen levels in aerated tanks must be verified (generally, they should be higher than 1.5–2 mg/L) **(Buttiglieri & Knepper, 2008).**

- **Hydraulic Retention Time (HRT):** Detention time, sometimes called hydraulic retention time (HRT), is the typical amount of time that incoming wastewater spends in the sedimentation tank. HRT is Calculated by dividing the tank's capacity in cubic meters by the volumetric flow rate. Obviously, the shorter the HRT and the bigger the inflow rate Q, the faster the influent wastewater reaches the exit. In order to remove the specified amount of BOD from raw wastewater, a wastewater treatment facility's hydraulic retention time must be sufficient depending on the load influent and plant layout , the HRT often between a few hours and a few days **(EPA, 2000)**.

- **Sludge Retention Time (SRT):** Is a time indicator for how long sludge stays in the water treatment system. In a CAS system, it influences both the percentage of substances adsorbed to the sludge itself as well as the total suspended solid concentration (and the sludge to be taken out of the systems). Lower SRT increases the amount of sludge that must be treated and could result in insufficient removal of organics and nutrients **(Buttiglieri & Knepper, 2008)**.

- **Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS):** Portion of the TS that was still on a filter with a certain pore size after drying at a certain temperature of about (105°C). The Whatman glass liber filter, which has a pore size of approximately 1.58 um, is the filter that is most frequently used for the measurement of TSS.VSS solids that, at temperatures of 500 + 50°C, can be volatilized and burnt off when TSS are ignited **(Metcalf et al., 2014)**.

- **BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Deamand):** BOD is a measure of how much biodegradable organic matter is present in wastewater. It is the amount of oxygen used by microbes to decompose organic materials **(Pereira, 2014)** . COD is the amount of oxygen consumed as a result of organic contaminants being chemically oxidized. It is regarded as a proximate indicator of organic matter content **(Metcalf et al., 2014).**

- **Nutrient Content:** One of the most important factors in the control and action of water pollution. Nitrogen assumes many forms and states of oxidation during the biochemical phase. It is a fundamental nutrient for microorganisms in lakes and reservoirs when the eutrophication process occurs **(Henze et al., 2008)** Nitrogen promotes the consumption of dissolved oxygen in receiving water bodies due to nitrification (ammonia is transformed to nitrite, which is then converted to nitrate). Nitrogen is a key nutrient for the microorganisms that do the biological treatment in wastewater treatment, and it encourages oxygen consumption during the nitrification phase that happens in wastewater treatment plants **(Pereira, 2014)**.

- **Pathogens and Other Aspects of Microbiology**: It is very important to verify the water's E. coli, Helminth eggs, and other pathogen content before discharging it **(Buttiglieri & Knepper, 2008).**

2.7.1.1 **A2/O Process**

Biological nitrogen removal (BNR) processes include sequencing batch reactor, the University of Cape Town system, the Bardenpho process, the Anaerobic–Anoxic–Oxic (A2/O) system, the membrane bioreactor, the BAF system, etc **(Gabaldón et al., 2007)**.The A2/O method, a single-sludge suspended growth system that comprises successive anaerobic, anoxic, and aerobic stages, is the most widely employed of these BNR procedures **(Peng et al., 2006)**. A2/O processes are widely employed in the removal of various types of wastewater contaminants, including as organic compounds, heavy metals, and nutrients (i.e., nitrogen and phosphorous species), from municipal wastewater because of their good effluent quality and affordability. **(Lim et al., 2009)**. However, depending on the initial concentration of water pollutants and the operating circumstances of the used processes, the removal rates of waste water pollutants from biological wastewater treatment procedures differed substantially **(Lu & Shim, 2015)**.

2.8 Variation in Waste Flow

Variation in waste flow affect the operation and performance of wastewater treatment plants .Wastewater flowrates change throughout the day, week, season, and year based on factors such as the composition of discharges to the collection system and the locations and rates of infiltration and outflow. Variations in wastewater flow rates due to things like weather, seasons, and industry **(Metcalf et al., 2014)**.

2.8.1 Short Time Variation:

Minimum flows are observed during the early hours of the morning when water usage is at its lowest and the base flow primarily comprises infiltration and limited amounts of sanitary wastewater. Typically, the initial peak in flowrate is observed during the late morning hours, coinciding with the arrival of wastewater generated from the maximum water consumption period in the morning, which subsequently enters the treatment facility. Typically, a secondary peak in flow rate is observed during the early evening hours, specifically between 7 and 9 p.m. In certain residential areas, the magnitude of the second peak is observed to surpass that of the morning peak. It is noteworthy that a change takes place during weekends in relation to the morning rush hour, due to individuals tending to wake up at a slightly later time.Variations in the size of the community and the length and storage capacity of the collection system are observed to have an impact on the time of occurrence and amplitude of the flowrate peaks **(Coutu et al., 2013)**.

2.8.2 Seasonal Changes:

Seasonal fluctuations are influenced by geography and community characteristics **(Zeng et al., 2022).**

2.8.3 Conservation-Related Long-Term Multiyear Variations:

The long-term flowrates monitored at wastewater treatment plants in many large cities in addition to the daily and seasonal fluctuations mentioned cities with (1) increasing population, (2) relatively constant population, and (3) falling population show three primary indicators of flowrates **(Metcalf et al., 2014)**.

2.9 Effect of Variation Flow on WWTP

Flow variation can have significant effects on the operation and performance of wastewater treatment plants (WWTPs). WWTPs are designed to treat a specific volume of wastewater within a given timeframe, and when the flow rate deviates from the design conditions, several challenges can arise.

1. **Hydraulic Overloading**: Increased flow rates can lead to hydraulic overloading in WWTPs. This occurs when the plant's capacity to handle incoming wastewater is exceeded, resulting in reduced treatment efficiency. Hydraulic overloading can cause poor mixing, inadequate solids settling, and carryover of untreated or partially treated wastewater. The increased flow may also result in hydraulic surges and overflows, causing environmental concerns **(Ghangrekar & Behera, 2014)** .
2. **Settling and Solid Separation Issues**: In wastewater treatment, settling tanks (clarifiers) are used to separate solids from the liquid phase. During high-flow periods, the increased velocity of wastewater entering the clarifiers can hinder the settling process, resulting in poor solids separation. This can lead to higher suspended solids concentrations in the effluent, increasing the risk of pollution **(Ghangrekar & Behera, 2014)**.
3. **Reduced Treatment Efficiency**: Flow variations can negatively impact the biological processes in WWTPs. Biological treatment relies on a delicate balance of microorganisms that break down organic matter. Rapid changes in flow rates can disrupt this balance, leading to decreased treatment efficiency and compromised pollutant removal. Additionally, high flow rates can shorten the hydraulic retention time, reducing the contact time between wastewater and microorganisms, and impairing the treatment process **(Smith, 2018)**.

4. **Chemical Dosing Challenges**: WWTPs often employ chemical dosing to enhance treatment processes, such as coagulation, flocculation, or pH adjustment. Flow variations can make it challenging to maintain precise chemical dosing rates. When flow rates fluctuate rapidly, the optimal dosage may not be achieved, affecting the efficiency of chemical treatments and overall treatment performance **(Arzate et al., 2019)**.
5. **Energy Consumption and Costs**: Flow variations can also impact the energy consumption and costs of operating a WWTP. During high-flow periods, additional energy may be required to pump and treat the increased volume of wastewater. Conversely, during low-flow periods, energy may be wasted due to oversized equipment or excessive aeration. These fluctuations can lead to inefficient energy usage and higher operational costs **(Colacicco & Zacchei, 2020; Smith, 2018)**.

To mitigate the effects of flow variation, WWTPs employ various strategies, such as:

a. **Flow Equalization**: Implementing flow equalization basins or tanks can help attenuate flow variations by storing excess wastewater during peak periods and releasing it during low-flow periods. This practice can smooth out flow rates and reduce the impact of hydraulic overloading **(Goel et al., 2005)**.

b. **Process Optimization**: Continuous monitoring and control systems can be utilized to optimize treatment processes in response to flow variations. By adjusting operating parameters such as aeration rates, chemical dosing, and solids handling, the treatment plant can adapt to changing flow conditions and maintain optimal performance **(Yang et al., 2014)**.

c. **Redundancy and Flexibility**: Building redundancy and flexibility into the design of a WWTP can help mitigate the impact of flow variations. This includes redundant treatment units, storage capacity, and adjustable process configurations that can accommodate fluctuations in flow rates without compromising treatment efficiency **(Kirchem et al., 2020)**.

d**. Advanced Forecasting and Planning**: Utilizing advanced flow forecasting models and real-time monitoring, WWTP operators can anticipate flow variations and plan accordingly. This proactive approach allows for better preparation, optimal resource allocation, and more effective management of flow variations **(Weissbrodt et al., 2009)**.

2.10 Performance Evaluation of Wastewater Treatment Plants:

The performance of a treatment plant depends on both good operation and maintenance practices as well as adequate design and construction. To determine if the treatment plant can handle larger hydraulic and organic loadings and to evaluate the effluent quality currently being produced, a performance evaluation of the present treatment plant is necessary. Existing treatment plant unit performance evaluation is an efficient means of gathering extra information that may be utilized to refine design processes. Process adjustments allow current facilities to manage increased hydraulic and organic loads; however, addressing increased treatment needs typically necessitates substantial expansion and/or modification of existing facilities **(Brenner, 1974)**.

Around the world, many studies have been done to figure out how well plants work by looking at different pollutants (like COD, BOD, TSS, NH3, etc.) before and after treatment and comparing the results with different criteria (**Simonich et al., 2002)** .The area of plant operation and control is one of the key factors to be taken into account while assessing an existing wastewater plant. Frequent, precise sampling, and laboratory analysis are key tools needed for proper system integration **(Kaul et al., 1993)**.Other recent causes for the poor performance of waste water treatment plants include overloading due to an increase in population and water demand and release of trade effluents . If the system is hydraulically underloaded, the effectiveness of the treatment could be severely impacted **(Kapur et al., 1999)**.

2.10.1Modeling and Simulation of Biological Treatment Systems

A model is a simple way to show what happens in real life. It is described by a set of mathematical formulas and steps, which are made up of different variables and parameters that change over time. A model makes it easier to study and analyze engineering questions in less time, saving money on the costs of lab analysis. In a WWTP, models can be used to figure out how the system reacts to different changes. This lets strategies be put in place that guarantee a better performance **(Pereira, 2014)**. The model offers a quick and economical tool to investigate and evaluate the operations of a wastewater treatment facility. By testing different operating circumstances and observing how the plant responds, the model may be used to determine the strategies that provide the plant with its greatest performance. Additionally, by offering several scenarios for the expansion of a current treatment plant or the design of alternative treatment procedures through simulation, the model can enhance and regulate operations **(Arif et al., 2020)**.

Modeling is an integral aspect of wastewater treatment system design. At the fundamental level, a design model may be purely conceptual. The engineer simplifies the complex system he is working on into a conceptual representation of its operation. Mechanistic modeling and empirical modeling are the two fundamental strategies that need to be considered. While empirical models are based on direct observation, cause-and-effect correlations between input and output variables, and extensive data records, mechanistic models are primarily concerned with understanding the behavior of system components **(Vanhooren et al., 2003)**. Although less visible than mechanistic models, empirical models are simpler to construct. Mechanical models are more complex than empirical models because they attempt to describe all processes involved in a given phenomenon and are based on a set of differential equations that include momentum, energy conservation, continuity, and biological reactions. They also offer more realistic expectations than empirical models **(Pereira, 2014)**.

Dynamic modeling which is a part of mechanical models is currently widely used in the field of wastewater treatment **(Copp et al., 2009)**. There are numerous models for ASP, including those for biological phosphorus removal, nitrification and denitrification, and the degradation of organic carbon material **(Henze et al., 2006)**. Activated sludge alterations can also be made using different models, like moving bed bioreactors and membrane bioreactors **(Mannina et al., 2011)**. All of these models are supported by numerous WWTP simulation systems, including GPS-X, SIMBA, AQUASIM, BioWin, EFOR, STOAT, and WEST. Modeling and simulation techniques have been utilized to assess process alternatives, optimize design, and assess costs **(Gernaey et al., 2004)**.

2.10.2 GPS-X Software

GPS-X is multipurpose modeling platform designed for the simulation of wastewater treatment plants. This allows for the interactive and dynamic examination of the complicated relationships between the plant's many unit processes . GPS-X is a powerful wastewater treatment plant simulation software that offers a wide range of features to facilitate the design, optimization, and operation of treatment processes. Here are some key features of GPS-X:

Process Simulation: GPS-X allows users to build comprehensive dynamic models of wastewater treatment plants, including various unit operations such as reactors, clarifiers, pumps, and filters. It accurately represents the hydraulic and biological processes, enabling engineers to assess plant performance and evaluate design alternatives **(Abbasi et al., 2021)**.

The software supports dynamic modeling: which means it can simulate the time-dependent behavior of wastewater treatment processes. This allows for the evaluation of transient conditions, startup and shutdown procedures, and dynamic process control strategies. Using a powerful graphical user interface, GPS-X enables dynamic modeling and simulation. GPS-X integrates the most latest developments in process modeling, simulation technology, graphics, and a variety of productivity tools to facilitate model construction, simulation, and result interpretation.

In terms of power and variety, no other program for modeling and simulating wastewater treatment processes rivals to GPS-X. GPS-XTM has been extensively utilized for WWTP performance analysis **(Nasr et al., 2011)**.

Kinetic and Stoichiometric Models: GPS-X provides a library of pre-built kinetic and stoichiometric models for common wastewater treatment processes, including activated sludge, anaerobic digestion, and nutrient removal. These models can be customized or extended to match specific plant configurations and operational conditions. One benefit of the GPS-X Model is the simplicity with which sensitive parameters that influence processes can be identified and manually adjusted **(Mu’azu et al., 2020)**.

Mass and Energy Balances: The software enables users to perform mass and energy balances across the treatment plant. It tracks the flow rates, concentrations, and properties of various constituents, allowing engineers to analyze nutrient removal, oxygen transfer, energy consumption, and other important parameters **(Lester et al., 2009)**.

Plant Design and Optimization: GPS-X supports the design and optimization of wastewater treatment plants. It offers tools for sizing equipment, determining optimal operating conditions, and evaluating different process configurations. This helps engineers optimize plant performance, minimize costs, and meet effluent quality targets. Utilizing such programs results in a design with a high degree of adaptability, unique biological nutrient removal arrangements that are easily adaptable to a variety of alternative treatment configurations, and operators with a high degree of adaptability to accommodate future changes in output wastewater requirements **(Mabrouki et al., 2022)**.

Real-Time Control: The software includes a real-time control module that enables the implementation and testing of advanced control strategies. It allows engineers to assess the performance of control algorithms, such as feedback, feedforward, and model predictive control, and optimize the operation of the treatment plant **(Joseph-Duran et al.).**

Scenario Analysis: GPS-X allows users to create and compare multiple scenarios to analyze the impact of design or operational changes. By adjusting parameters and configurations, engineers can assess the effects on effluent quality, energy consumption, sludge production, and other key performance indicators **(Cao et al., 2021)**.

Reporting and Visualization: The software offers comprehensive reporting and visualization capabilities. It generates detailed reports, graphs, and charts to present simulation results and performance indicators. This helps in communicating findings, making informed decisions, and sharing information with stakeholders **(Faris, Zwain, Hosseinzadeh, & Siadatmousavi, 2022)**.

Integration with Other Software: GPS-X can interface with other software applications, such as hydraulic modeling tools, laboratory data management systems, and data historians. This facilitates data exchange and integration, allowing for a more comprehensive analysis and decision-making process **(Cao et al., 2021)**

2.11 Literature Review of Previous Studies

Several previous studies related to the evaluation of the performance of WWTP , activated sludge A2/O process and GPS-X program are listed below.

2.11.1 Evaluation of the Performance of WWTP

For the preservation of environmental sustainability and human health, sanitation and wastewater treatment are crucial. The assessment of wastewater treatment facilities' (WWTPs') environmental performance has grown in popularity in recent years .

(Çinar, 2005) offered a study on an artificial neural network, a novel method for evaluating the performance of WWTP. Kohonen self-organizing feature maps were used to sort the Pelham WWPT operating data into groups so that the causes of the high TSS, BOD, and fecal coliform levels in the effluent could be found. Researchers found that using a Kohonen Self-Organizing Feature Map (KSOFM) neural network to test the performance of wastewater treatment plants is a quick and easy way to find out how different process variables are connected and how to fix operational problems in these plants.

(Azri et al., 2008) presented a study to assess the effectiveness of a wastewater treatment facility in the semi-arid Mediterranean region (Sfax city, Tunisia). Over the course of six years, the quantity and quality of data from both raw wastewaters and treated effluents were analyzed descriptively and statistically to assess the plant's performance. Poor performance was shown to be related to the quality of the raw wastewater, the growth of the population and its activities, rains, problematic grit chamber operation, and ventilation issues. Additionally, it appeared that additional elements that contributed to the industrial atmospheric input had a non-zero impact.

(Kumar & Babu, 2010) analyzed the Nesapakkam Sewage Treatment Plant's operational effectiveness. a 23 MLD average daily wastewater input at an activated sludge-based sewage treatment facility. The primary water quality indicators, including total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), and biological oxygen demand (BOD), were measured in wastewater samples that were collected at various phases of treatment units. The effectiveness of each unit at treating the pollutants was calculated. Estimates of the plant's overall performance have also been made. The outcome demonstrated that the performance was satisfactory as a whole. BOD's removal efficiency was found to be 94.56% and TSS's removal efficiency to be 93.72%. The outcomes were extremely helpful in identifying and fixing operational and maintenance issues.

(Onchoke et al., 2015) provided a study to evaluate the efficiency of the Nacogdoches in East Texas, USA, Wastewater Treatment Plant (NWWTP), a small-scale wastewater treatment facility. Using inductively coupled plasma optical emission spectrometry, the elemental concentrations of Na, Mg, Ca, Ni, Pb, Mn, Cr, Mo, and Cu, as well as Al, As, B, Ba, Ag, Cd, Fe, Hg, K, Se, Zn, Co, P, and S, were determined. Ion chromatography was used to determine the amounts of the anions (Br, NO^{-3}, NO^{-2}, $PO3^{-4}$, F, Cl, and SO_2) in the sample. The NWWTP was generally found to be 96% effective in removing metal. Anions had a removal efficiency that ranged from 33 to 100%. With the exception of phosphates, the amounts of the majority of metals and anions were discovered to be below USEPA maximum contamination levels.

(Nikmanesh et al., 2018) conducted a study on the evaluation of the aeration system's effectiveness in removing microbiological and physicochemical factors from the WWTP. The tests showed that these parameters had an average removal efficiency of 61.4% for COD, 57.7% for BOD, 84.3% for fecal coliform (FC), 84.6% for total coliform (TC), and 70.8% for TSS. The time of hydraulic retention (HRT), sludge age (c), sludge volume index (SVI), food-to-mass ratio (F/M), and mixed liquid suspended solids (MLSS) values for the tank of aeration were calculated, and they were found to be 25 hours, 5.64 days, 48.83 ml/g, 0.28 day-1, and 180 mg/l, respectively. Additionally, it was shown that the average value of pollutants in the hot months was higher than in the cold months following treatment.

(Al-Obady & Qasim, 2018) presented a study to evaluate the operational efficiency of Al-Khadraa wastewater treatment facility in Mosul, Iraq. It had a weak to medium influent strength. 0.6 BOD5/COD ratio. For dumping into rivers and valleys, the effluent quality and treatment effectiveness fell short of Iraqi standards. The removal efficiencies for BOD, COD, TSS, PO4, and NH3 were 83.15%, 79%, 69.7%, 56.15%, and 41.88%, respectively.

(Awad et al., 2019) evaluated the efficiency of the Albarrakiya trickling filter wastewater treatment facility and modeled it with the GPSX software. The findings showed that COD, TSS, and NH3 had average yearly concentrations that exceeded Iraqi quality norms at 120 mg/L, 92 mg/L, and 11 mg/L, respectively. BOD and PO4 were found to be acceptable but had critical levels of 35 mg/L and 2.8 mg/L, respectively. The outcomes of modeling and simulation using the GPS-X program demonstrated good performance in accordance with the input and output standards in both realistic and fictitious circumstances.

(Jiang et al., 2020) created a thorough efficiency evaluation system for WWTPs using data envelopment analysis (DEA), which took into account three inputs—operating cost, electricity use, and labor—three desirable outputs—chemical oxygen demand (COD) removal rate, ammonia nitrogen (NH_3-N) removal rate, and reclaimed water yield—and one unfavorable output—dry sludge yield. A cluster benchmarking-based DEA model was used to evaluate 861 WWTPs in China.

(Yazdian & Jamshidi, 2021) presented a study to investigate the performance of WWTPs during the COVID-19 pandemic and related spread preventive actions (SPAs). This assessment contrasts the performance of WWTPs in 2020 with previous information (2015–2019) and takes into account variations in the quality and amount of municipal wastewater (MW). For this reason, 23 WWTPs in the Iranian province of Isfahan were selected as the study region, and they were categorized according to their locations, biological treatment units, and capacities. The findings show that whereas COD and BOD concentrations in MW fell by 23 and 16 percent, respectively, during SPAs, the inflow of WWTPs increased on average by 20 percent. The outcome demonstrated that the secondary treatment unit's efficiency in removing pollution is consistent. Disinfection is enhanced, though, to lessen the potential hazards of reusing wastewater. Reusing treated wastewater that is released from mild WWTPs poses relatively fewer health problems.

(Cecconet et al., 2022) presented performance evaluation research for a pilot-scale (2.75 m^3) UASB reactor for the treatment of urban wastewater at sub-mesophilic temperature (25 °C), below the process's ideal range, with respect to the production of biogas and the removal of organic matter. The findings demonstrate that a UASB can still perform satisfactorily despite lower methane production and COD removal efficiency than operations under ideal conditions. Although not sufficient to meet effluent discharge requirements, it may be used as a pretreatment step for carbon removal with some degree of energy recovery.

2.11.2 Performance Assessment of Activated sludge

(Moharram et al., 2017) conducted a study on domestic wastewater at the WWTP in El Berka. In this study, the anaerobic unit was replaced by a UASB reactor, and an A2/O process was used to treat household wastewater. This experiment's goal was to determine the process's viability and ideal operational parameters. The findings have demonstrated that the suggested system has a high potential to replace current traditional activated sludge systems for the treatment of municipal wastewater in sub-tropical and tropical regions. The UASB's production of biogas, reduced aeration needs, and decreased volume of sludge required for disposal might all significantly lower the cost of treating municipal wastewater. The UASB has no mechanical equipment, produces little sludge with good settling qualities, and does not require primary sedimentation or sludge thickeners.

(Rong et al., 2020) proposed a new operation mode of replenishing the mixture of fermentation liquor and tail water during the off-flow period , and the nutrient removal performance of a pilot-scale A2/O system with this operation mode was investigated in order to address the problem of sewage fluctuation and discontinuity in a rural district of China. The results of this research indicate that when the flow is interrupted, the A2/O system may replace the mixture of tail water and sludge fermentation liquor to maintain and enhance the performance of nutrient removal. This will offer fresh concepts for the future design and operation of sewage treatment facilities in rural areas.

2.12 GPS-X Modeling

(Yang et al., 2010) offered research modeling a sewage treatment system's mechanism and method. The activated sludge models ASM2D and GPS-X were used to simulate a WWTP's triple oxidation ditch process. To examine the discrepancies between the simulated results and the real results, the removal efficiency of COD, ammonia nitrogen, total nitrogen, total phosphorus, and TSS was simulated by GPS-X software using influent quality data from this WWTP from June to August 2009. The outcomes demonstrated that the simulated values might accurately represent the triple oxidation ditch process's true state. Effluent quality prediction and process optimization were suitable applications for mathematical modeling.

(Nasr et al., 2011) conducted a study using modeling and simulation of this sequencing batch reactor (SBR) system plant using a GPS-X simulator to assess the efficacy of German BIOGEST/EL-AGAMY wastewater treatment plants in Egypt. The findings demonstrated that the anoxic conditions used in the microbial denitrification process are highly recommended for removing nitrates and nitrites during the treatment of activated sludge, preventing the buildup of filamentous sludge, which is one of the major issues in the study plant, and reducing the total aeration energy used during the batch cycle.

(Wang et al., 2013) presented a study that used GPS-X modeling to look at how the UCT pilot plant affected BNR. Even during the beginning phase, the UCT pilot plant used in this study managed to attain high BNR efficiency. COD, TP, TN, NH_4^+N, and KN had average removal efficiency values of 89, 80, 65, 67, and 68%, respectively. The GPS-X modeling outcomes showed that the UCT procedure was successful in removing COD, TP, and TN.

(Pereira, 2014) created a model of Portucel's wastewater treatment plant using the GPS-X program (WWTP). In this factory, activated sludge with prolonged aeration was used. The three years' worth of collected data on this facility's influents and effluents were used to calibrate and validate the plant model created by GPS-X software. An analysis was also done on the effectiveness of adding urea to the influent prior to the start of the biological oxidation. The removal of chemical oxygen demand, which is the treatment process, is not impacted by the addition of urea, according to the results of both model simulation and testing on real samples taken from the plant. The simulation results also showed that reducing the flowrate of urea greatly lowers the nitrogen concentration of the final effluent.

(Abou-Elela et al., 2016) conducted research on the modeling and simulation of a packed bed up-flow anaerobic sludge blanket followed by a biologically aerated filter using GPS-X software. Inside both treatment units, a non-woven polyester fabric was employed as a bio-bed. The system's hydraulic and organic loading rates were 9.65 m3/m2/d and 2.64 kg BOD5/m3/day, respectively. The model was calibrated using earlier simulation and modeling, and the experimental findings were confirmed. The factors considered included packing material surface area, HLR, and OLR. According to the modeling findings, the treatment system has a lot of potential to be used as a perfect and efficient solution for high hydraulic and organic loading rates up to 19.29 m3/m2/d and 4.48 kg BOD5/m3/day. According to the model, removal efficiencies for TSS, BOD5, and COD were 98%, 88%, and 85%, respectively, when the HLR and OLR input loads to the treatment system were increased by up to 50% of their initial values.

(Moursy et al., 2018) presented a study to choose between two technologies—integrated fixed film activated sludge (IFAS) and a membrane bioreactor (MBR)—that would make the nitrogen removal process at a wastewater treatment plant work better and handle more waste. The model was calibrated using information from the Eastern Plant, an operational WWTP in Alexandria, Egypt. The model study performed by GPS-X 7 software took the activated sludge model No. 1 (ASM1). According to the results, the two systems had inadequate nitrogen removal effectiveness, which indicates that the plant has to be modified to include an anaerobic treatment unit before the aerobic zone.

(Jasim, 2020) designed Al-Hay wastewater treatment plant (WWTP) treatment units using a GPS X modeling technique to account for the population density of Al-Hay city. The total suspended solids were discovered to frequently rise as the simulation time increased. The findings also revealed a correlation between the suspended solids in mixed liquor (MLSS) and the sludge age, which is connected to the observed yield, with a value that ranged between 0.2 and 0.6 kgVSS/kg (BOD). Additionally, it was determined that the retention period and the daily production of sludge were each 27.7 days and 3339.18 kg, respectively. These findings indicate that the biological tank of the Al-Hay WWTP is operated with high efficiency.

(Cao et al., 2021) introduced an innovative way using GPS-X and response surface methodology to improve the removal of total nitrogen (TN) in WWTPs. Six crucial factors were chosen for additional adjustment after the sensitivities of 61 parameters were examined and assessed. The findings demonstrated that the denitrification rate was significantly impacted by the DO concentration that diffused into various biological compartments. SRT and TN elimination go hand in hand. Key parameter relevance and optimization orders were examined.

(Alwardy et al., 2021) presented a study to evaluate the efficacy of the oxidation ditch system in Hilla city's Al-Muamirah wastewater treatment plant in removing pollution. Samples from the plant's input wastewater and output treated water were taken in order to measure the pollutant parameters. These criteria include BOD5, COD, TSS, NH_3, PO_4, and the quantitative measurement of acidity or basicity (pH). The data was examined in Excel. The results showed that BOD5, COD, TSS, NH_3, and PO_4 had monthly elimination efficiencies of 91%, 78%, 93%, and 69%, respectively. Therefore, it is feasible to infer that the Al-Muamirah wastewater treatment plant has a sufficient level of efficacy in treating wastewater and producing water that complies with Iraqi environmental laws for water discharged to surface waters or water for other uses.

(Sakib, 2022) conducted a study to design and model a municipal wastewater treatment plant for Uttara City using GPS-X. The Sewage Treatment Plant (STP) design computation is carried out using a steady-state process. The concentration of numerous parameters, including TSS, BOD, VSS, and TN, is examined, and the removal efficiency for various pieces of equipment is computed after each unit operation. This plant's operation was planned to comply with Bangladesh's ECR 97 discharge guidelines. Distinct nations have different environmental discharge regulations. The procedure and unit activities may therefore change.

2.13 Summary of Previous Studies

1. Because of their high effluent quality and affordability, activated sludge technologies are commonly used to remove a variety of wastewater contaminants from municipal wastewater, including organic compounds, heavy metals, and nutrients (i.e., nitrogen and phosphorous species).
2. The A2/O plant's performance evaluation is based on the characteristics of the influent wastewater, the operating environment, and the maintenance schedule for each plant unit.
3. Many advancements have been made to the GPS-X program, making it popular among researchers for modeling and simulating wastewater treatment plants and applying various scenarios for estimating the plant's response in an accurate way.
4. In this study the GPS-X model is used to estimate the effect of fluctuation flow rates on the performance of Karbala treatment plant. The created model was calibrated with data of whole year of 2022, and use BOD_5, COD, TSS, NO_3, NO_2, NH_3 and PO_4 for evaluate the plant that give a good accuracy as compare with previous studies.

Chapter Three: Field and Experimental Works

3.1 Introduction

This chapter describes the methodology of modelling of Kerbala WWTP using GPS-X. Along the chapter, the following strategy was taken into account:

The first step involved depicting the WWTP in relation to the physical data of the main unit operations and the incoming effluents. Secondly, in order to assess the plant's performance and gather information for the calculation of input parameters for the modeling, it was essential to gather some historical data regarding the parameters that define the effluent throughout the whole treatment process. The third step involved the development of the layout of the plant in GPS-X, which is followed by the calibration of the model. The goal of this final phase was to fit the model to get a more accurate representation of the actual therapy procedure. Figure (3-1) represent the flow chart of this study.

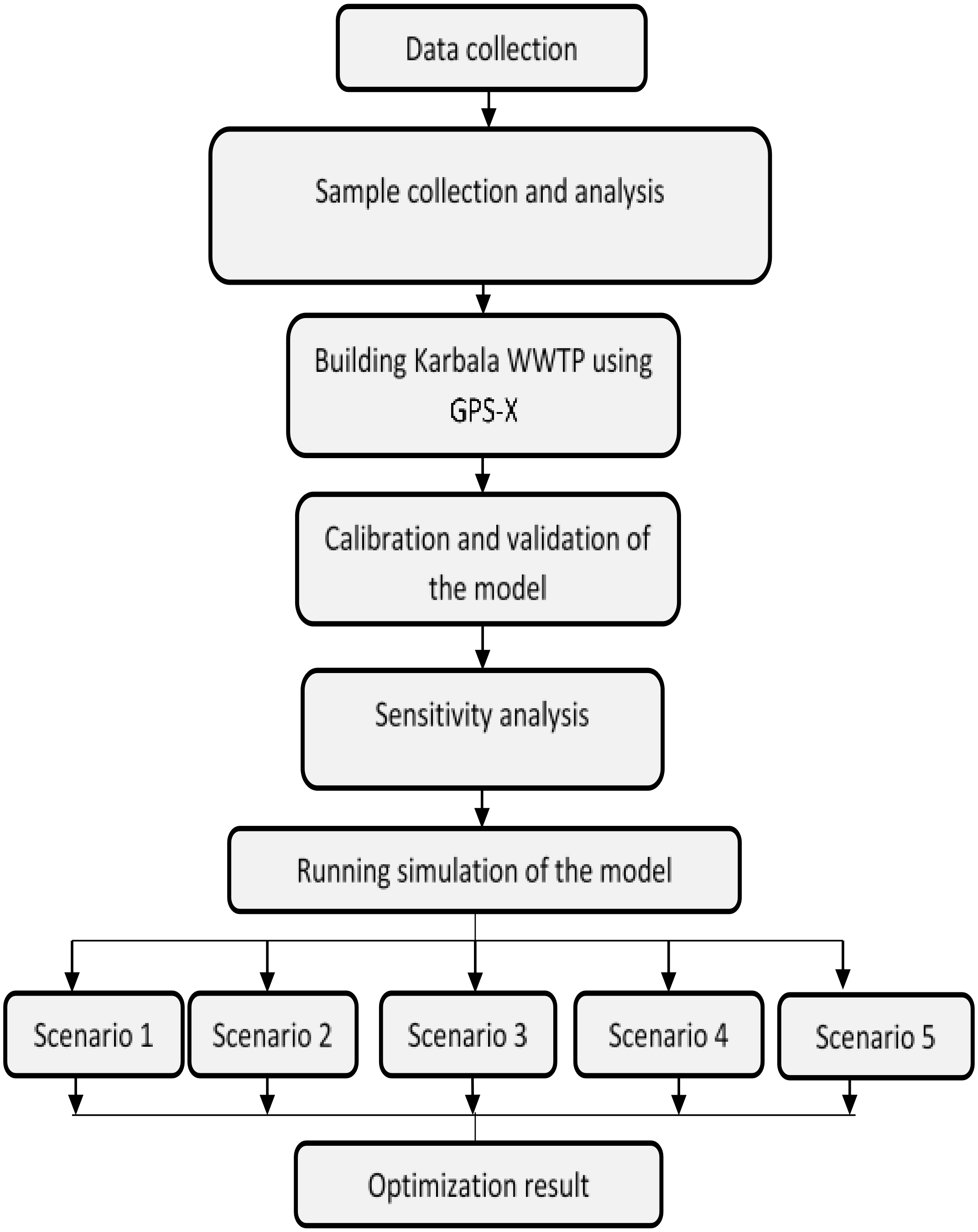


Figure 3-1: Flow Chart of the Study Methodology.

3.2 Study Area

3.2.1 Karbala Wastewater Treatment Plant

The present study was carried out in Karbala Governorate, which is a religious tourism destination for Muslims, up to 34 million visit the city annually. Karbala city has a 42.4 km^2 area and of estimated population of 1,218,732 people (2018),and this adds a high load on the water and sewage utilities. Wastewater treatment plant of Karbala is located within the geographical coordinates of 32.525590°N and 44. 074909°E **(Hammed et al., 2022)** .Figure (3-2) shows a satellite view of the Karbala WWTP.The plant serves greater than 2.5 million. Four wastewater treatment plants utilizing the conventional activated sludge system type A2/O are incorporated into the Karbala integrated Project. Each of these plants has a daily discharge capacity of one hundred thousand cubic meters. The parameters mentioned in Table (3-1) were used to design the plant.

Table 3-1: Characteristics of Sewage for the Design WWTP .

Parameter	Influent Concentration	Effluent Concentration
pH	6.8-7.5	7-7.4
COD (mg/L)	350-500	<100
BOD_5 (mg/L)	150-250	<30
TN (mg/L)	45	<10
PO_4-P (mg/L)	6	2

Figure 3-2: Satellite View of the Karbala WWTP.

3.3 Treatment Stages

Six phases of treatment in the WWTP of Karbala used which as follows:

3.3.1 The First Stage (Preliminary Treatment):

A. **Coarse Screen:** it is the first step of treatment, and it is located at the beginning of the plant. The stage is usually used to remove large object, fibers, clothes, hair and others.

B. **Fine Screen:** the solids of diameter more than 6 mm is removed in it. It safeguards machinery that might be more susceptible to solids, like membrane bioreactors, or gets rid of substances that might prevent the useful repurposing of bio solids.

C. **Grit Chamber:** A physical treatment unit that uses a physical process to remove oil and sand. Figure 3-3 shows the grit champer of Karbala WWTP.

Figure 3-3: Grit Chamber of Karbala WWTP

D. **Parshall Flume:** It is the final unit at the ending of the preliminary treatment, and it used to measure the daily flow rate and suspended solids to control the operation of the plant. As shown in figure (3-4).

Figure 3-4: Parshall Flume Unit in Karbala WWTP.

3.3.2 The Second Stage (Primary Treatment):

a. The primary sedimentation tank is the primary treatment of the plant wastewater which is carried out by four primary sedimentation tanks which are used to remove about 55% of suspended solids and about 30 % of BOD_5. Figure 3-5 shows the primary sedimentation tanks of Karbala wastewater treatment plant.

Figure 3-5: The Primary Sedimentation Tanks of Karbala WWTP .

3.3.3 The Third Stage (secondary treatment)

The secondary treatment is carried out by a process called A2/O .Figure 4-6 Shows the secondary treatment of Karbala WWTP. The secondary treatment consist of:

A. **Anaerobic Reactor**: It contains two anaerobic tanks with a volume of 8736 m^3 for both of them.

B. **Anoxic Reactor:** Two anoxic basins are including with volume of 14112 m^3

C. **Aeration Reactor:** It contains eight aeration reactor tanks with a total volume of 54054 m^3

Anaerobic reactor Anoxic reactor

Oxic reactor

Figure 3-6: Anaerobic/Anoxic/Oxic Reactors of Karbala WWTP

Secondary Sedimentation Tank: There are eight sedimentation tanks with a total surface area of 6432 m^2, as shown in figure (3-7)

Figure 3-7: Secondary Clarifier Tanks of Karbala WWTP

3.3.4 The Fourth Stage (Tertiary Treatment):

It includes chemical disinfection through the chlorination tank. The chlorine is added to the treated water in these basins as part of a chemical treatment process to kill germs and microbes. The total surface area of the chlorination tanks is 3000 m^3.

3.3.5 The Fifth Stage (Sludge Treatment):

Sludge treatment is among the most significant and difficult ones, consists of four primary elements, which are as follows:

A. **Gravity Thickener:** Two gravity thickener are including with a surface area of 400 m^2. The primary sedimentation basins collect the wastewater, thicken the suspended solids there, and then send them to the digestion basins for stabilization.

B. **Mechanical Thickener:** Three mechanical thickeners with a surface area of 60 m^2. Wastewater from the secondary sedimentation basins is sent into the mechanical thickening, where it is thickened by the addition of chemicals like polymer before being sent to the digestion tanks for treatment and size reduction.

C. **Anaerobic Digester:** Four anaerobic digesters is included in these reactors. The sludge is decreased in size and fixed. The methane gas that generated is used in electricity production.

D. **Drying Beds:** It is the last unit of sludge treatment facilities. The drying beds include 60 cells with a total surface area of 50,000 m^2 then the sludge is spread over sunlight and wind. As shown in figure 3-8.

Figure 3-8: Drying Bed in Karbala WWTP

3.3.6 SCADA System

Providing on-site or remote supervisory control and monitoring of diverse physical processes is one of the main purposes of a Supervisory Control and Data Acquisition (SCADA) system. The SCADA system, which enables technicians and facility staff to monitor and manage the facility's equipment locally or remotely using a computer control system, is used to operate the plant. For a SCADA system to run safely and securely, Karbala WWTP employs a varied spectrum of specialists from various backgrounds. moreover, a SCADA system consists of numerous interconnected technical and non-technical sub-elements; therefore, in for carrying out an exhaustive and rigorous risk management plan, it is crucial to capture the interconnections between these sub-elements. Figure (3-9) depicts the Karbala WWTP's SCADA system.

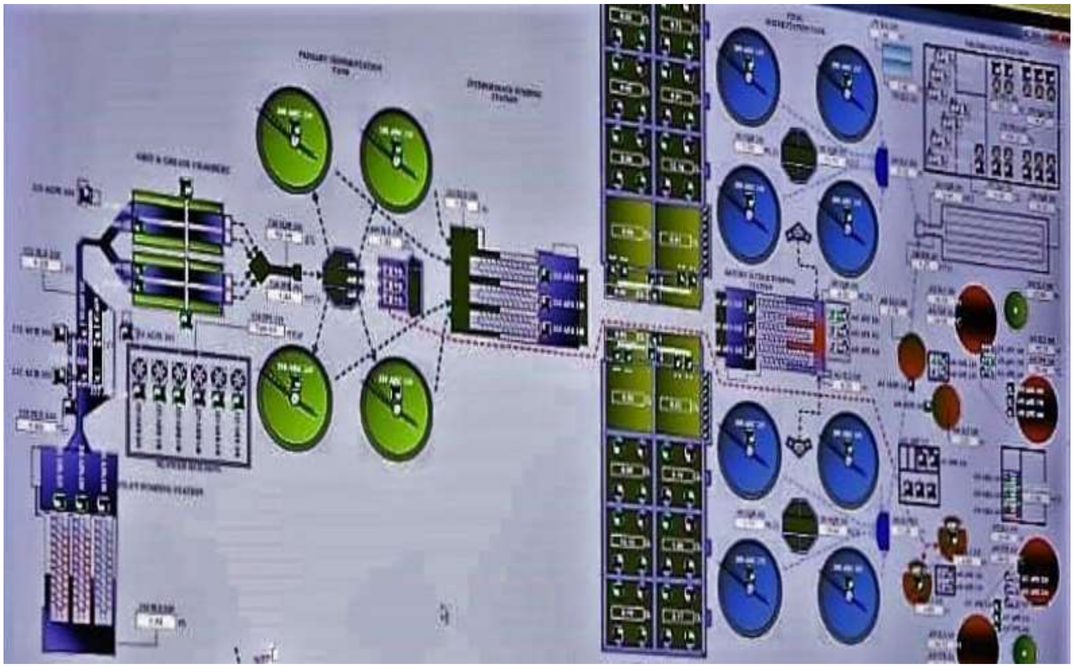


Figure 3-9: SCADA System of Karbala WWTP**(sewage, 2022)**

3.4 Evaluation of Existing plant

In order to evaluate Karbala wastewater treatment plant, this chapter includes the laboratory tests before and after treatment to determine the quantities of each parameter like (BOD_5,COD,TSS…..etc). The laboratory tests were performed of these samples, each test includes the collection of samples from both the entering point (IN) and the exiting point (OUT), and analysis at both sites

3.4.1 Collection of Samples

This study comprised field experimental activities to evaluate the effectiveness of the plant by collecting samples of wastewater before and after treatment for a period of 12 month in order to ascertain the effectiveness of the Karbala WWTP. The concentrations of each parameter were then determined for these samples using laboratory testing, and the test findings were then examined and discussed.

- **Total Suspended Solid (TSS):** This test is conducted by filtering a certain amount of water through filter paper and leave it for the next day then transfer the filter paper to the electric oven drying it at 105° C until the weight is stable, and determining the amount of suspended solid per liter. The
- **Biochemical Oxygen Demand (BOD):** The amount of oxygen used by the bacteria during a five-day experiment to investigate the organic carbon materials in the water at a temperature of 20 °C while giving them the nutrients they need and a pH-regulating solution. An electrical instrument (hach BOD Tracker) is utilized for this testing. The BOD test is executed according to the following procedure.
    1. Take a portion of the sample and put it in the device vial. Next, add the anti-nitrification to the vial.
    2. Two potassium hydroxide pills are inserted inside the vial together with the magnetic rack (bar), plastic cover (seal cup), and magnetic rack.
    3. The vials are put into the device in figure (3-11). and are kept at a temperature of 20 ° C.

Figure 3-10: The BOD Incubator

From the first day to the fifth, the device continues to record the BOD value. The device also shows a chart of the BOD values over a five-day period that were recorded.

- **Chemical Oxygen Demand (COD):** The amount of oxygen required to analyze or oxidize organic carbon molecules when utilizing a potent oxidizing agent like potassium chromate anode is measured by the chemical oxygen demand, or COD. These are the COD measurements:
  1. Carefully insert the sample into the tube, then whirl the cell to lift the bottom sediment.
  2. 3.0 ml of the collected material should be pipetted gently into a reaction cell, sealed with a screw cap, and thoroughly mixed.

3. In the thermoreactor, heat the reaction cell for a period of two hours at 148 °C.
4. Take the cell out of the thermoreactor and set it in a rack for test tubes to cool.
5. After approximately 10 minutes, swirl the cell.
6. Replace the cell in the rack for complete cooling to the room temperature.
7. Set the cell compartment. Align the cell's mark with the photometer's

- **pH Value:** Raw water pH must be measured to ensure it falls within the safe range for biological treatment. (6.5 – 8.5). Even if the pH is not in this range, any change in this value reduces bacterial activity and treatment effectiveness, meaning that industrial drainage is present in the water entering the station. This drainage needs to be identified and kept off the wastewater network. The pH value is set using an electrometric method or pH meter, and a portable pH meter like the one in figure (3-12) is used to measure PH.

Figure 3-11: A pH Measuring Device

- **Orthophosphate $PO4^{-3}$:**

1. Check the PH of the sample, specified range pH 0-10. If required, add dilute sulfuric acid drop by drop to adjust the pH.
2. Pipette 5 ml of the sample into a test tube.
3. Add 1.2 ml of PO4-1 with piette and mix
4. Transfer the solution into a corresponding cell.
5. Select method with AutoSelector.
6. Place the cell into the cell compartment

total phosphorus = sum of orthophosphate, polyphosphate, and organophosphate

- **Nitrite NO_2^{-1}:** Nitrite is one of the intermediate ions that are formed during the treatment process, as it is formed as an intermediate product of oxidation of ammonia in the water, the presence of bacteria and oxygen, and then the nitrite is transformed into nitrate. Nitrite is measured in a color manner by the spectrophotometer as follows:

1. 5 mm is withdrawn from the sample and added to the nitrite test tube and shake the tube well until the precipitate dissolves and a pink color is formed in the case of nitrite in the sample and left for 20 minutes to complete the reaction
2. After the time expires, the blank is prepared by adding 5 mm to a new tube to test for nitrite, and the device is reset and the sample reads. The tubes are transferred to the spectrophotometer, the device beeps, and the sample is read.

3.5 Determination of the Treatment Efficiency

The plant's efficiency is determined by calculating the percentage of the average concentration of pollutants in the incoming and outgoing streams. The measurement of each pollutant is determined by its unique physical, chemical, and biological processes within the reactor. The efficiency of the reactor is then evaluated using equation.

$$\boldsymbol{Removal\ Efficiency} = \frac{\boldsymbol{Cin-Ceff}}{\boldsymbol{Cin}} \times \mathbf{100}\% \text{.......................} \quad \text{3-1}$$

% = Removal efficiency;

C_{in} = Concentration of pollutant in the influent (mg/L).

C_{eff} = Concentration of pollutant in the effluent (mg/L).

3.6 Governing Equations

The following equations have been used to find physical and operational data:

3.6.1 Organic Loading Rate (OLR)

The amount of organic material applied over a surface area each day, such as kg of COD or BOD_5 per day per m^3, is known as the organic loading rate (OLR). To determine organic loading, convert BOD_5 in mg/l to kg/m^3 .

$$\boldsymbol{Organic\ Loading\ Rate}\ \left(\boldsymbol{kg}\,\frac{\boldsymbol{BOD5}}{\boldsymbol{m3}}.\boldsymbol{day}\right) = \frac{(\boldsymbol{BOD5in.x\ Q})}{(\boldsymbol{V})} \text{..........} \text{3-2}$$

3.6.2 Hydraulic Retention Time (HRT)

The amount of time influent sewage spends on average in the aeration tank is known as the detention time or hydraulic retention time. Tank volume (in m^3) divided by flow rate is used to compute it. The wastewater influent will undoubtedly arrive at the outlet more quickly the greater the inflow rate Q, and as a result, the residence time or hydraulic retention time will be shorter. HRT must be long enough when building a wastewater treatment facility to remove the necessary amount of BOD from untreated wastewater. The HRT of a typical activated sludge system ranges from 5 to 14 hours. Primary settling tanks—tanks used in flocculent settling treatment—have hydraulic residence periods of 1.5 to 2.5 hours. Longer residence hours shouldn't result in septic conditions; therefore, design considerations should take low-flow periods into account. Potential smells, solubilization, and loading to downstream processes increase in septic conditions.

$$\boldsymbol{HRT = \frac{V}{Q}} \quad \text{……… 3-3}$$

Where HRT = The typical amount of time that the influent sewage spends in aeration tank in hours.

V = the volume of the tank (m^3)

Q = influent sewage flow rate (m^3/ h)

3.6.3 Solid Loading Rate (SLR)

The secondary clarifier's mass loading rate of mixed liquid suspended solids (MLSS), measured in kilograms per square meter (kg/m^2).h

SLR (kg MLSS/m^2. h) =MLSS x (Q+RAS) / (area of the secondary clarifier) 3-4

3.6.4 Hydraulic Loading Rate (HLR)

One of the most crucial elements in the design of sedimentation basins is the hydraulic load, which is described as the flow divided by the surface area of the basin and is measured in m^3/mines the rate at which well-aerated activated sludge solids concentrate or thicken during the settling or clarifying process.

SVI= V x 1000/ MLSS……………. 3-5

S.V.I (ml/gm): (settled sludge amount in milliliters after 30 min in a one-liter cylinder or beaker divided by MLSS concentration in mg/l) multiplied by 1,000 mg/gm.

V (mL/L): Volume of settled sludge after 30 min.

MLSS (mg/L): mixed-liquor suspended solids

3.6.5 Food to Microorganism (F/M) Ratio

The amount of BOD or COD applied per volume of mixed liquor is known as the F/M ratio.

$$F/M = \frac{\textit{total applied substrate rate}}{\textit{total microbial biomass}} = \frac{QS_{\circ}}{\theta X} \ldots\ldots\ldots. 3\text{-}6$$

Where F/M = food to biomass ratio

Q = Flow of Incoming Wastewater, m^3 /d

$S_{\circ}$ = The concentration of influent BOD or bsCOD , in g/m

V =the volume of the aeration tank , m^3

X = The concentration of mixed liquor biomass in the aeration tank is measured in (g/m^3).

θ =HRT of aeration tank, V/Q, d

For a deeper understanding of how transitory loads affect a system, consider using the F/M ratio. The substrate utilization rate increases with the particular BOD loading rate (g BOD/g VSS-d), and the reactor will have a larger substrate concentration as a result.

3.6.6 Flow Rate Measurements

The mainstream, side stream, returned activated sludge, internal recycling, and discarded activated sludge are the five crucial flows of the Karbala wastewatrer treatment facility. The quantity and quality of wastewater entering the plant affects each of these flows. The proper operation of the plant is ensured by regulating these fluxes. The three equations below are used to determine IR, RAS, and WAS.

- **Waste Activated Sludge (WAS)**

To maintain balance in the biomass to food provided (sewage or wastewater) ratio and a specific range for the F:M ratio, this amount of solid (known as Waste Activated Sludge WAS) is removed from the treatment process. It can be calculated using the equation below:

$$\boldsymbol{Q_w = \frac{VX}{SRT\ X_R}} \quad \text{……….} \ 3\text{-}7$$

Where:

$Q_w =$ underflow rate

V = aeration tank volume

X = Mixed Liquor Suspended Solids in aeration tank

SRT = retention time of solids, d

X_R = MLSS in bottom sedimentation basin

- **Return Activated Sludge (RAS)**

Return Activated Sludge (RAS) is used to treat wastewater by keeping an acceptable population of microorganisms in the aeration tank and preventing their loss. Microbes expand and reproduce as they break down their substrate. It can be calculated using the equation below:

$$\text{RAS} = \frac{\boldsymbol{X}}{\boldsymbol{X_R} - \boldsymbol{X}} \text{ ………. 3-8}$$

Where:

X =MLSS in aeration tank

X_R = MLSS in bottom sedimentation basin.

- **Internal recycle IR**

$$\boldsymbol{IR = \frac{NO_x}{N_{NO3-N}} - (1 + R_{RS})} \text{…………….. 3-9}$$

Where, IR= Internal recycle, m^3/d

$$NO_X = TKN - NH4\text{-}N \text{ effluent} - 0.12P_x/Q \text{ ……….. 3-10}$$

P_x= biomass as VSS wasted, g/d

R_{RS} = ratio of return N_{NO3-N} = NO3-N concentration in the effluent or internal recycle from aeration basin, mg/L or g/m3.

n sludge flows to influent flow, dimensionless.

3.7 Modelling of Karbala WWTP Using GPS-X Model

Modelling the plant by GPS-X is described in the following steps

1. Open GPS-X by double click on the model icon. The interface of the program that is shown figure (3-13) will appear

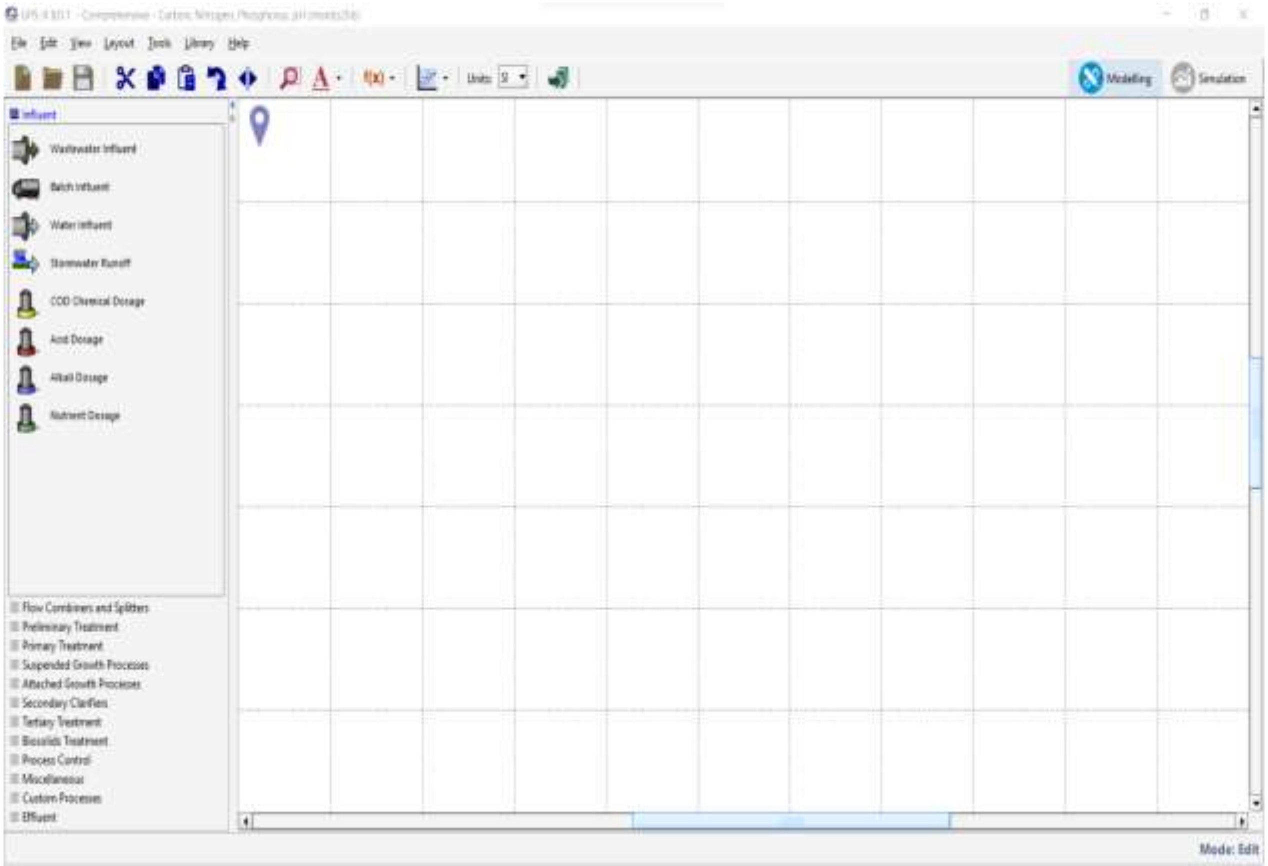


Figure 3-12: GPS-X Program Interface at the Beginning.

2. The library of (Comprehensive - Carbon, Nitrogen, Phosphorus, pH (mantis3lib)) was selected from the libraries list, as illustrated in (3-14). The best library that fit the entire WWTP plant should be chosen. A collection of wastewater treatment parts is called a library, and these parts all have inherent state variables. Six libraries make up GPS-X, and each one has equations for computing state variables as well as default values. The interest in modeling carbon, nitrogen, phosphorus, and pH at the time led to the selection of the Carbon Footprint Carbon, Nitrogen, Phosphorus, pH (mantis3lib) library for this work.(Pereira, 2014) .

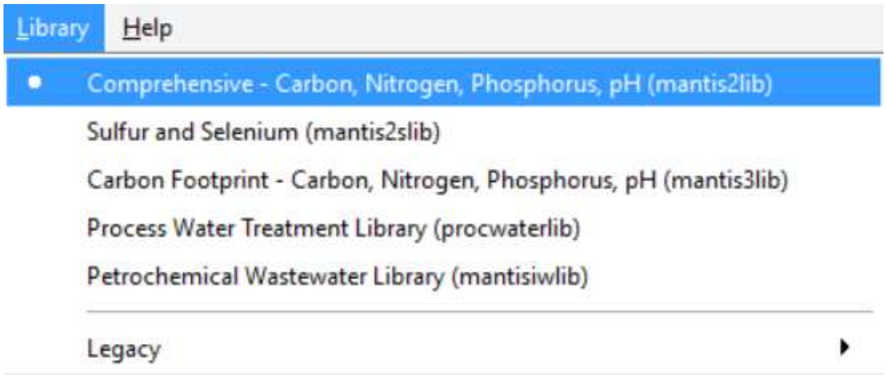


Figure 3-13: Libraries Menu

3. To ensure that the drawing model accurately represented the actual plant, each component section of the plant was picked out and moved to the drawing board from the process table to the left of the window as follows:

A. Choosing the first object in the WWTP model ,the wastewater influent.

B. picking the grit chamber icon from the preliminary treatment group.

C. From primary group selecting primary clarifier.

D. Then reflecting the activated sludge A2/O process by choosing two Anoxic CSTR and completely mixed tank one after the other from suspended growth processes.

E. From secondary clarifier selecting the circular secondary clarifier.

F. Picking chemical disinfection from the Tertiary treatment group.

G. Selecting waste water outfall from effluent group.

H. For representation the sludge treatment processes choosing thickener, two dewatering (represent belt thickener and drying bed), and an aerobic digestion.

I. Picking sludge disposal from effluent group.

The modeling of this stages is shown in figure (3-15).

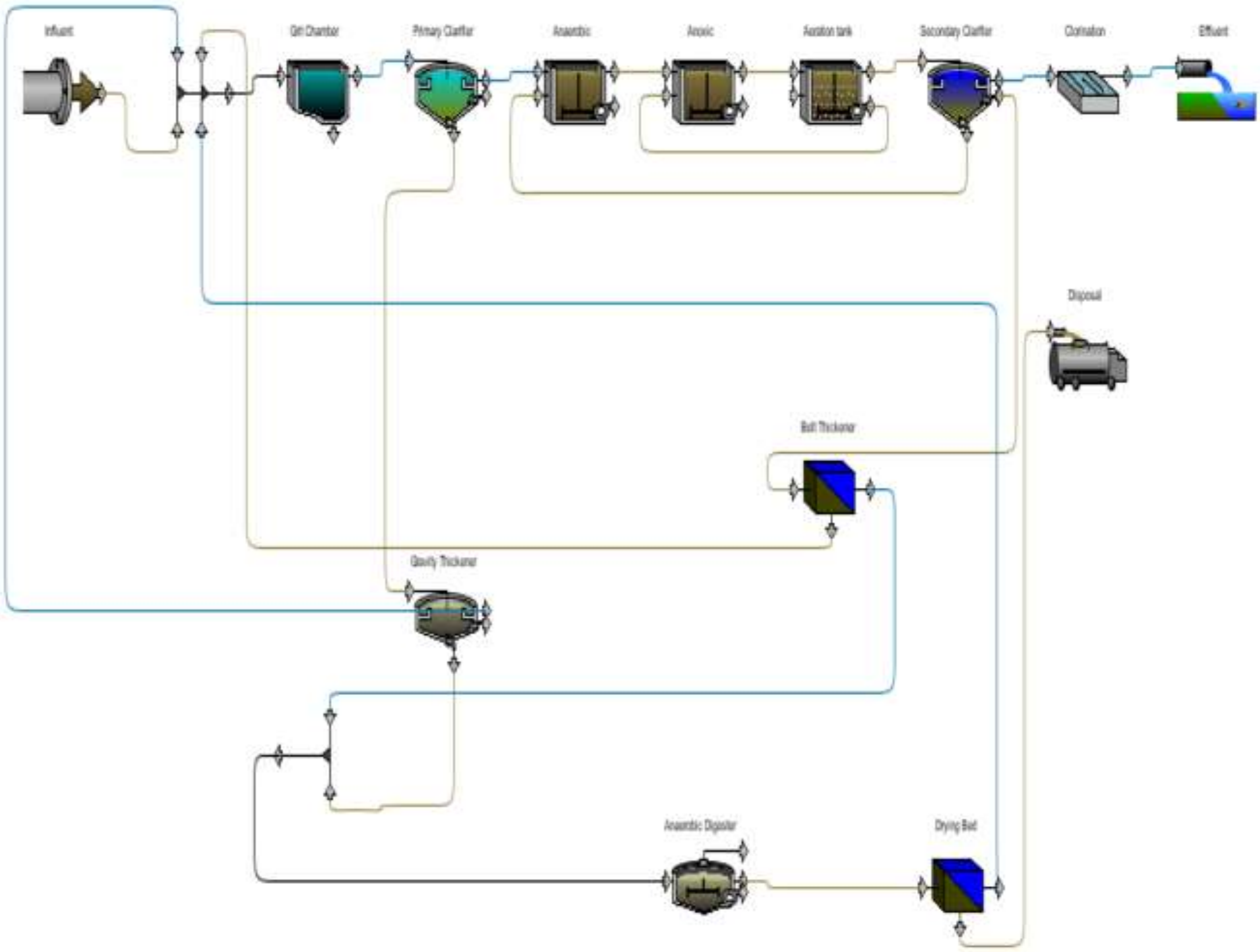
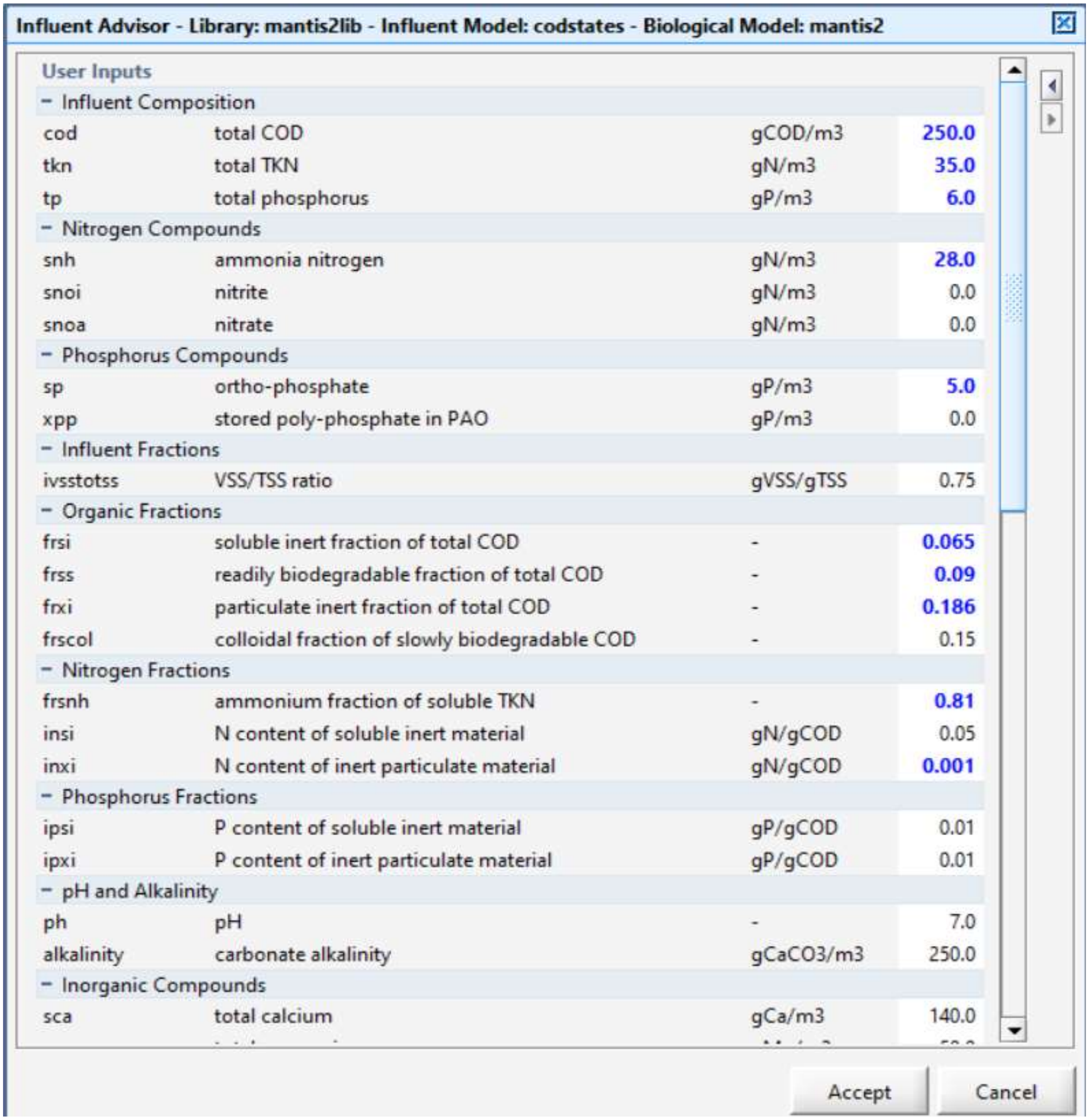


Figure 3-14: Layout of the Plant in GPS-X.

3.7.1 Input Influent Wastewater Characteristics

The model allows adding the entering wastewater characteristics by right-clicking on the influent icon and choosing influent characterization from composition, as shown in figure (3-16)



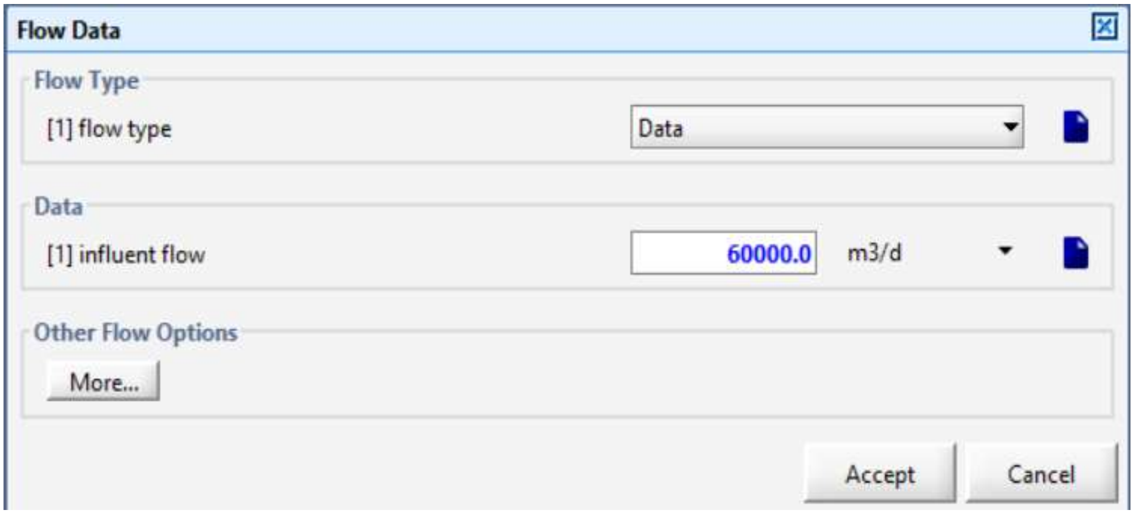
Influent Advisor - Library: mantis2lib - Influent Model: codstates - Biological Model: mantis2

User Inputs

− Influent Composition			
cod	total COD	gCOD/m3	**250.0**
tkn	total TKN	gN/m3	**35.0**
tp	total phosphorus	gP/m3	**6.0**
− Nitrogen Compounds			
snh	ammonia nitrogen	gN/m3	**28.0**
snoi	nitrite	gN/m3	0.0
snoa	nitrate	gN/m3	0.0
− Phosphorus Compounds			
sp	ortho-phosphate	gP/m3	**5.0**
xpp	stored poly-phosphate in PAO	gP/m3	0.0
− Influent Fractions			
ivsstotss	VSS/TSS ratio	gVSS/gTSS	0.75
− Organic Fractions			
frsi	soluble inert fraction of total COD	-	**0.065**
frss	readily biodegradable fraction of total COD	-	**0.09**
frxi	particulate inert fraction of total COD	-	**0.186**
frscol	colloidal fraction of slowly biodegradable COD	-	0.15
− Nitrogen Fractions			
frsnh	ammonium fraction of soluble TKN	-	**0.81**
insi	N content of soluble inert material	gN/gCOD	0.05
inxi	N content of inert particulate material	gN/gCOD	**0.001**
− Phosphorus Fractions			
ipsi	P content of soluble inert material	gP/gCOD	0.01
ipxi	P content of inert particulate material	gP/gCOD	0.01
− pH and Alkalinity			
ph	pH	-	7.0
alkalinity	carbonate alkalinity	gCaCO3/m3	250.0
− Inorganic Compounds			
sca	total calcium	gCa/m3	140.0

Figure 3-15: Influent Wastewater Characteristics Menu.

The flow is also entered in flow data as shown in figure (3-17).



[1] flow type: Data

[1] influent flow: 60000.0 m3/d

Figure 3-16: Flow Data

The physical and operational aspects of plant units vary depending on the scenario, while others stay the same. The values of the variables entered in the model are displayed in Tables (3-2).

Table 3-2: Physical and Operational Data Used within GPS-X Simulation.

Units	**Variables**	**Input values**
Influent wastewater	Influent Flow	Varied According scenario
	TSS	140 mg/L
	BOD	115 mg/L
	COD	250 mg/L
	TP	6 mg/L
	Ammonia Nitrogen	28 mg/L
	Ortho-Phosphate	5 mg/L
	VSS/TSS Ratio	0.75
Grit chamber	Grit Production per Flow	20 mg/L

Primary clarifier	Clarifier Type	Sloping Bottom
	Surface Area	3216 m^2
	Center Water Depth	4.5 m
	Sidewall Water Depth	3.5 m
	Underflow Rate	Varied According Scenario
Anaerobic tank	Volume	8736 m^3
	The Depth of the Tank	6 m
Anoxic tank	volume	14112 m^3
	The Depth of the Tank	6 m
Aeration tank	volume	54054 m^3
	The Depth of the Tank	6 m
	Aeration Method	Mechanical (surface aeration)
	DO set Point	3.5 mg/L
	Pumping Flow	Varied according scenario
Secondary clarifier	Clarifier Type	Sloping bottom
	Bottom Feed Point	4.3 m
	Surface Area	6432 m^2

	Sidewall Water Depth	5.5 m
	Center Water Depth	6.5 m
	Under Flow Rate	Varied according scenario
	Pumped Flow	Varied according scenario
Chlorination	Volume	3655 m^3
	Chlorine Dosage	6 mg/L

3.8 Calibration and Validation of the Model

Calibration is a crucial process that involves the adjustment of model parameters to achieve a desirable level of agreement between the model predictions and selected datasets obtained from the actual WWTP. The goal is to reduce the discrepancy between the measured datasets and the model predictions. Attaining an exact correspondence between the modelled and measured data is not imperative, as the model is a simplified depiction of the plant and frequently disregards certain inputs and processes transpiring at the factual plant. Achieving an exact match between modelled and measured data is not imperative. While it may decrease the overall error for a specific dataset, it has the potential to diminish the predictive capability of the model and elevate the model error for other datasets. Examining the plant's effluent in 2022, when the performance of the plant was run in accordance with actual criteria, was crucial to achieving the goal of calibration. Statistical Analysis

When assessing the correspondence between the modeled and measured data, it is imperative to consider all pertinent variables **(Melcer et al., 2003).** It is advisable to achieve a reasonable fit for the majority of the measured variables, rather than striving for a perfect fit to a single selected component concentration at the expense of poor fits to others.. Using the root mean square error (RMSE) and correlation coefficieit(R),

this discrepancy is statistically analyzed after model calibration, validation, and obtaining very close results between the model's output and reality.

similarity between the model and reality.

3.8.1 Statistical Analysis

When assessing the correspondence between the modeled and measured data, it is imperative to consider all pertinent variables **(Melcer et al., 2003).** It is advisable to achieve a reasonable fit for the majority of the measured variables, rather than striving for a perfect fit to a single selected component concentration at the expense of poor fits to others.. Using the root mean square error (RMSE) and correlation coefficieit(R),

this discrepancy is statistically analyzed after model calibration, validation, and obtaining very close results between the model's output and reality.

$$r = \frac{n(\sum XY)-(\sum X)(\sum Y)}{\sqrt{[n\sum(X^2)-(\sum X)^2][n\sum(Y^2)-(\sum Y)^2]}} \text{.........3-15}$$

- r : the correlation coefficient between X and Y.
- n : the number of pairs in the data.
- $\sum XY$: the sum of the products of the corresponding values of X and Y.
- $\sum X$ and $\sum Y$: the sums of X and Y values respectively.

- $\sum(X^2)$ and $\sum(Y^2)$: the sums of the squares of X and Y values respectively.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(yi - \hat{y}i)^2} \text{……….3-16}$$

- $RMSE$: the Root Mean Square Error.
- n : the number of observations or data points.
- yi : the actual observed values.
- $\hat{y}i$: the predicted values from the model or estimator.
- $\sum_{i=1}^{n}$: the sum over all observations or data points.

3.9 Sensitivity Analysis in GPS-X

Once the calibration of the model was completed, the identification of sensitive parameters that positively or negatively impact the plant's performance was achieved. The objective is to identify the parameters that have the greatest impact on station performance by monitoring simulation outputs while manipulating their values. Operational factors may have an impact on the sensitivity of the station's work **(Cao et al., 2021)**.

The primary aim of conducting sensitivity analysis in GPS-X is to evaluate the degree of responsiveness of the output variables (dependent variables) of the simulation model to variations in its parameters (independent variables). This facilitates the identification of the parameters that exert the most significant influence on the model. The setup of sensitivity analysis takes place subsequent to the construction of the model. The process of setting up a sensitivity analysis in GPS-X involves three main steps.

- The first step is to define the model parameters that will be used as independent variables.

- Step 2 by inputting the minimum, maximum, and increment values for the independent variable. Additionally, specify the control window where the analysis control will be displayed.
- Step 3 by transitioning to a simulation model, activating the preferred analysis mode, and initiating the simulation.

Upon completion of these steps, the GPS-X software will commence the calculation of steady state values. Upon discovering a solution for the present value of the independent variable, the output windows will display these points. Following this, the independent variable will be incremented, and the solution procedure will commence once more **(O’Connell, 2015)**.

Chapter Four: Results and Discussion

4.1 Introduction

This chapter contains the results of the model calibration and result and disscution for the data obtained from scenarios .

4.2 Modeling of Karbala WWTP Using GPS-X Program

The Karbala WWTP was modeled using GPS-X with utilizing five different scenarios. In chapter three, it was discussed the modeling procedures, which covered things like model construction within the framework of the program, the entry of physical and operational data, and model calibration and validation.

4.2.1 Model Calibration

In order to evaluate the effectiveness of the model, it is recommended to perform calibration procedures utilizing real data, as outlined in chapter three. The model was verified using effluent chemical organic demand (COD) effluent total suspended solids (TSS), biological oxygen demand (BOD), Ortho-phosphate, ammonia nitrogen, nitrite and nitrate as indicators that is, the model can be adopted for result of most polutants.

The model was calibrated with a data of average monthly pollutant concentration of a whole year of 2022 as shown in tables (4-1) and (4-2). Several critical parameters that influenced the alteration of outcomes were adjusted characterizing the influent wastewater is seen to be the most important phase in the modeling process, and it required rigorous investigation. The laboratory data pertains to the influent and effluent data for an influent flow of 60,000 m^3/d. This represents the second scenario, which involves adjustments to achieve minimal differences among the simulated and observed levels of the pollutants in the effluent wastewater.

Table 4-1:Actual and Simulated Data of TSS,COD,BOD and PO4^{-3} at 2022.

month	TSS		COD		BOD		PO_4^{-3}	
	actual	simulated	actual	simulated	actual	simulated	actual	simulated
January	11	11.62	23	24.5	4	4.14	3	3.6
February	12	12.90	24	24.6	6	6.81	3	4.3
March	9	8.50	20	19.7	3	3.9	4	6.9
April	13	13.70	24	24.8	4	4.9	4	6.8
May	8	9.10	22	25	6	6.85	3	4.1
June	8	9.35	23	24.5	3	3.56	2.5	4.0
July	9	8.32	24	23.2	4	3.8	4	3.2
August	11	11.90	26	27.3	7	6.96	1.5	1.0
September	13	14.20	26	28.5	7	7.9	1.5	0.8
October	11	9.93	23	22.1	4	3.6	3	2.4
November	9	9.27	23	24.5	5	5.5	4	5.7
December	10	10.57	22	22.9	4	6.5	3	5.2

Table 4-2: Actual and Simulated Data of Nitratr ,Nitrite,and Amonia nitrogen at 2022

month	NO_3^-		NH_3^+		NO_2^-	
	actual	simulated	actual	simulated	actual	simulated
January	16	15.82	1.6	1.4	0.2	0.214
February	16	15.43	1.3	1.2	0.3	0.323
March	15	13.50	0.9	0.71	0.4	0.45
April	17	18.50	0.95	0.71	0.3	0.37
May	18	17.50	0.6	1.1	0.2	0.22
June	18	16.90	0.3	0.48	0.2	0.35
July	19	17.73	0.3	0.5	0.3	0.35
August	14	13.10	1.5	2.1	0.2	0.24
September	13	12.01	2.3	3.2	0.2	0.23
October	15	14.30	0.9	0.76	0.3	0.33
November	15	13.93	0.8	0.97	0.2	0.245
December	14	15.70	0.9	0.84	0.2	0.32

The model was used for influent characterization is - carbon, nitrogen, phosphorus, and pH, (mantis3lib), library. In this regard, the GPS -X already contains the default settings for the COD fractions; however, these default values have been modified to ensure better model calibration. Soluble inert fraction of the total cod, readily biodegradable fraction of the total COD, and particulate inert fraction of total the COD. In Table (4-3), the major influent raw wastewater portions are mentioned.

Table 4-3: The Influent Stoichiometry Composition.

Influent Stoichiometry Composition			
Parameter	Symbol	Default value	Calibrated value
soluble inert fraction of the total cod	frsi	0.05 (raw) 0.08 (primary)	0.065
Readily biodegradable fraction of the total COD	frss	0.2 (raw) 0.32 (primary)	0.09
Particulate inert fraction of total the COD	frxi	0.13 (raw) 0.12 (primary)	0.168

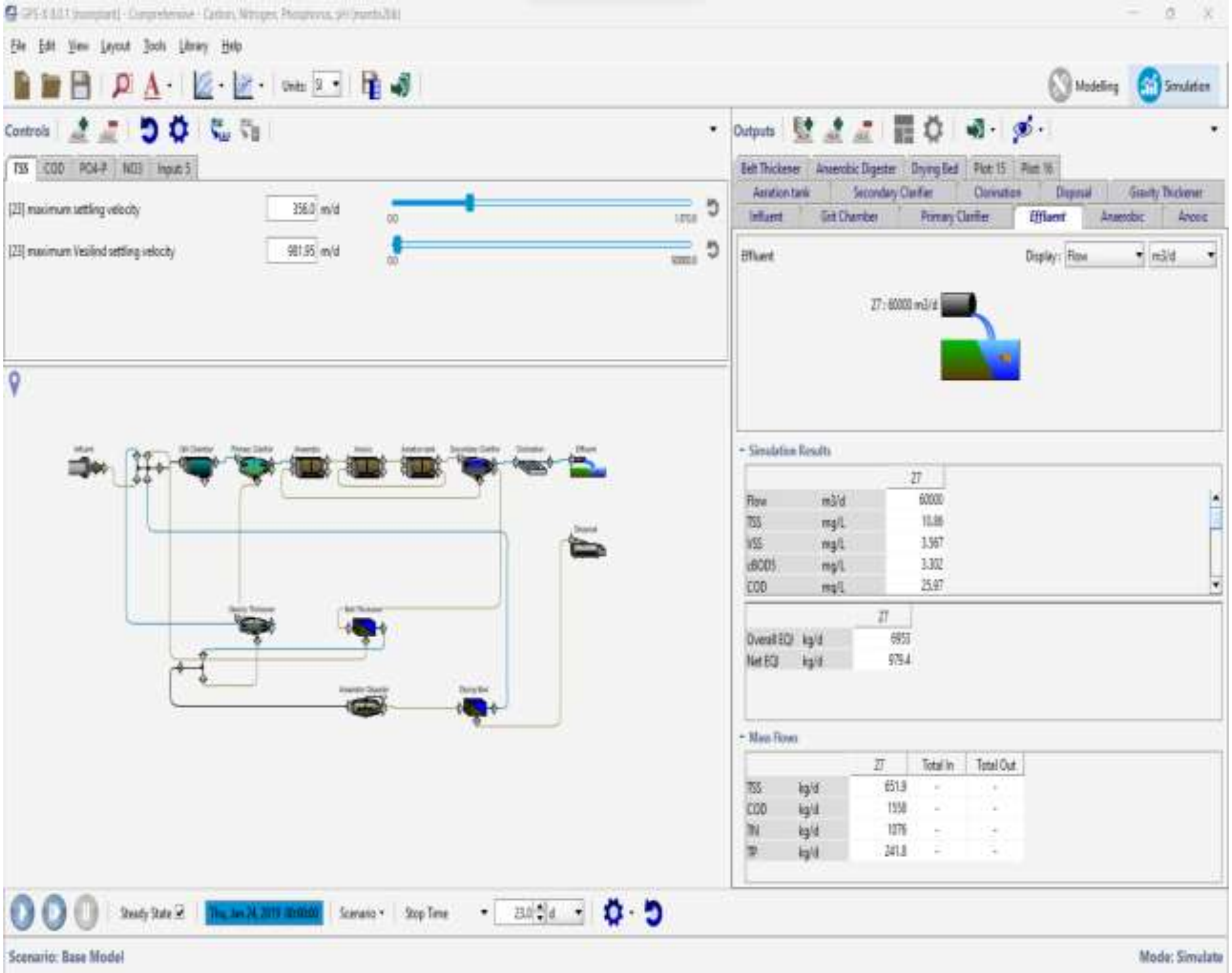
The TSS readings were found to be more than 30 mg/L in this instance, which was far away from the result of the actual influent flow of 60000 m3/d. As a result, the GPS-X Model's sensitive parameters with regard to the secondary sedimentation basin were changed. Some delicate parameters have been adjusted, including the maximum vesilind settling velocity, which has gone from 410 m/d to 981.95 m/d, maximum settling velocity has been adjusted from 274 m/d to 356 m/d, and the feeding point from the bottom, which has been changed from the default 1 m to the real 4.3 m. Along with other operational characteristics of a different dimension, these three parameters were the most sensitive.

The COD reading found higher than the result of the plant settling correction factor for xii and settling correction factor for xbai were adjusted from there default values 1and 1 to 0.07 and 0.26. actate fraction of total COD was changed from default value 0 to 0.102 to adjust the value of PO_4^{-3} which its reading was 5 after the calibration the reading was 3.122. The default nitrate values were shown to be substantially lower than the actual quantities, but the adjustment resulted in fitting the projected nitrate concentration with reality after modifying some sensitive parameters on the kinetics of ammonia and nitrates, including (Ammonium fraction of soluble TKN) and (Aerobic heterotrophic yield on soluble substrate). The effluent stoichiometry composition is shown in table (4-4).

Table 4-4: The Effluent Stoichiometry Composition

Effluent Stoichiometry Composition		
Calibrated fraction	Default	Calibrated
Maximum settling velocity	274	365
Maximum vesilind settling velocity	410	981.95
settling correction factor for xii	1	0.07
settling correction factor for xbai	1	0.26
acetate fraction of total COD	0	0.102
Aerobic heterotrophic yield on soluble substrate	0.6666	0.36963

Figure (4-1) shows the technique to handle the calibration process, which was accurate and heighly efficient based on the results that obtained from the model, which were close to the effluent of the plant .After calibration, the model is ready to apply the scenarios.



[23] maximum settling velocity 356.0 m/d

[23] maximum Vesilind settling velocity 981.95 m/d

Simulation Results

		27
Flow	m3/d	60000
TSS	mg/L	10.86
VSS	mg/L	3.567
cBOD5	mg/L	3.302
COD	mg/L	25.97

		27
Overall EQI	kg/d	6953
Net EQI	kg/d	979.4

Mass Flows

		27	Total In	Total Out
TSS	kg/d	651.9	-	-
COD	kg/d	1558	-	-
TN	kg/d	1076	-	-
TP	kg/d	241.8	-	-

Figure 4-1: Calibration Process.

4.2.2 Statistical Analysis

The next task after calibration of the model for a whole year of 2022 is examined the calibration by using statistical analysis. Figure (4-2) shows the actual and simulated of each concentration of pollutants the slight rise and fall in the result that shown in figure (4-2) is normal and whithen the allowable limit. The statistical equations that used to examine the calibration process are correlation coefficient (R) and root mean square error (RMSE).

The correlation coefficient for each parameter of actual and simulated data was above 0.8 and that means that there is positive linear relationship, that as one variable increases, the other variable also increases proportionally. The Root Mean Square Error (RMSE) for each parameter was close to zero and that means that the model has more accurate predictions and matches the data well. Higher levels, on the other hand, imply greater mistake and fewer accurate forecasts. Table (4-5) shows the correlaltion and the root mean square error for each parameter between actual and simulated values for average monthly data of a period of 12 months during 2022.

Table 4-5: The Values of R and RMSE of the Calibration Process

Parameter	R-value	RMSE
TSS	0.92	0.011
BOD	0.87	0.082
COD	0.85	0.021
NH_3^+-N	0.89	0.022
NO_2^--N	0.83	0.027
NO_3^--N	0.86	0.138
PO_4^{-3}	0.81	0.011

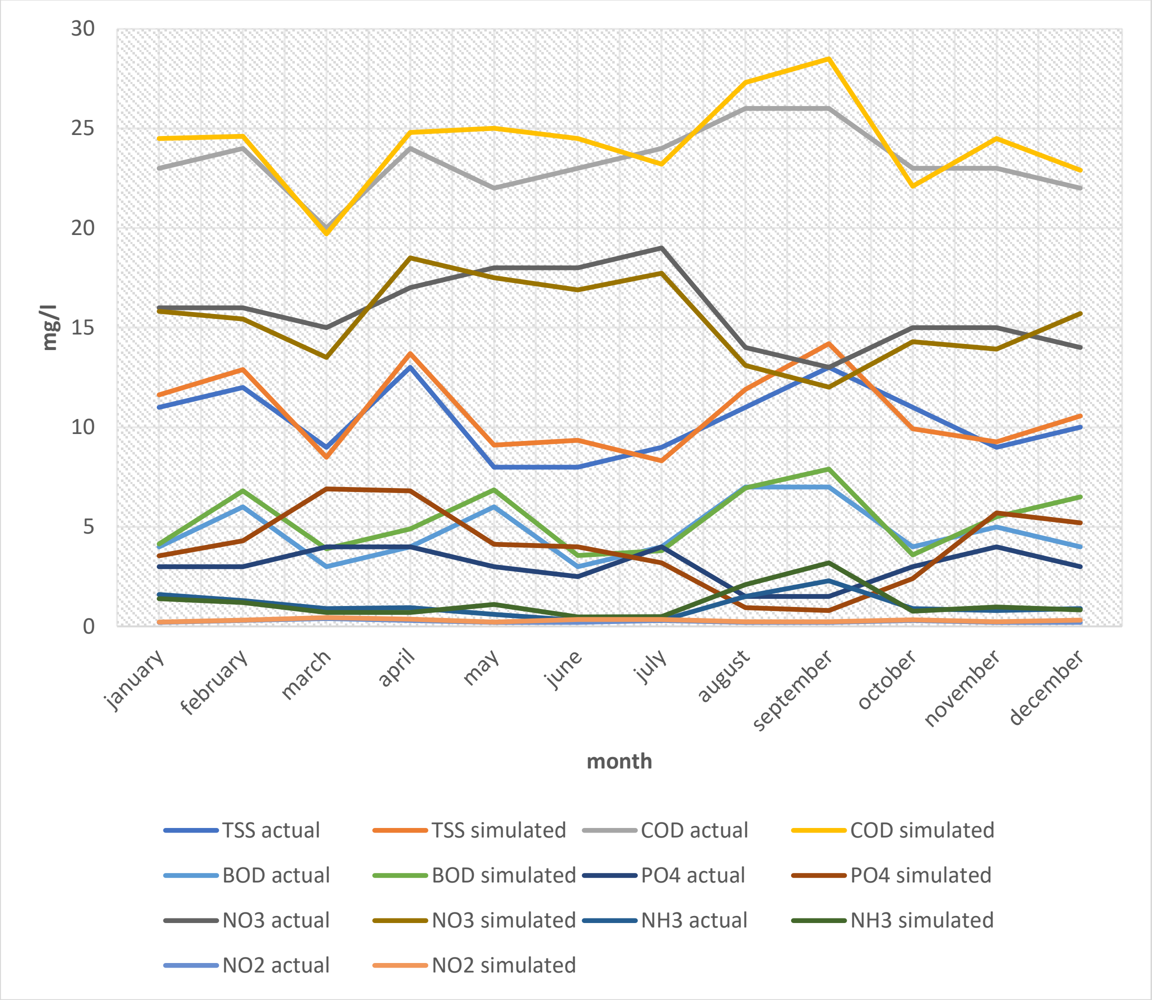


Figure 4-2: The Calibration of the Actual and the Simulated Values.

4.2.3 Sensitivity Analysis

A basic sensitivity analysis was conducted as part of this study to determine the potential impact of variable flows on the output variables (BOD, COD, TSS, PO_4^{-3}, NH_3^+-N, NO_3^--N and NO_2^--N of effluent). This analysis is beneficial as it primarily enhances model prediction and lowers the number of model parameters that need to be calibrated as EPA recommendations **(EPA, 2000)** .

Figures (4-3 and 4-4) demonstrate how the influent discharge has an impact on the plant's production. The hydraulic as well as organic loads on the plant's reactors rise with rising in discharge, which has a detrimental impact on the treatment procedures and raises BOD, COD, and TSS concentrations in the effluent wastewater that has been treated. However, even if the expenditures of the Karbala wastewater treatment plants reached to 180,000 m^3/d which it is the peak flow of the plant, the concentrations of BOD, COD, and TSS did not go over the Iraqi standards. If the mass balance could be quickly adjusted depending on the quantity and quality realities, it could be possible to lower the concentrations of contaminants in the treated wastewater. The effectiveness of removing phosphate was shown to improve with increasing discharge. The presence of acetate during rbCOD fermentation is necessary for phosphorus elimination. Detention periods of 0.25 to 1.0 h are adequate for rbCOD fermentation **(Metcalf et al., 2014)**.

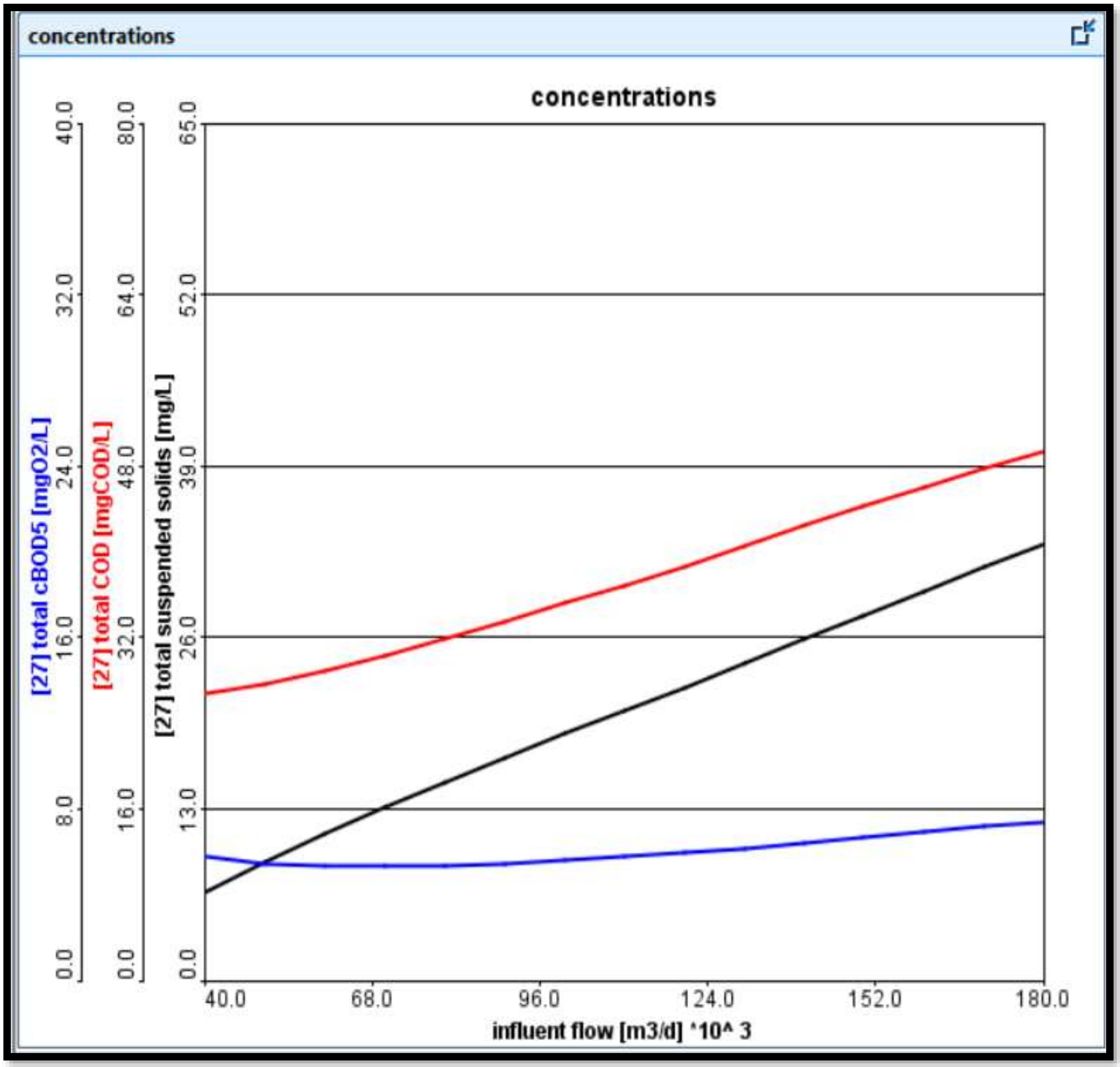


Figure 4-3:Effect of Flowrate on Effluent COD, BOD and TSS Concentrations.

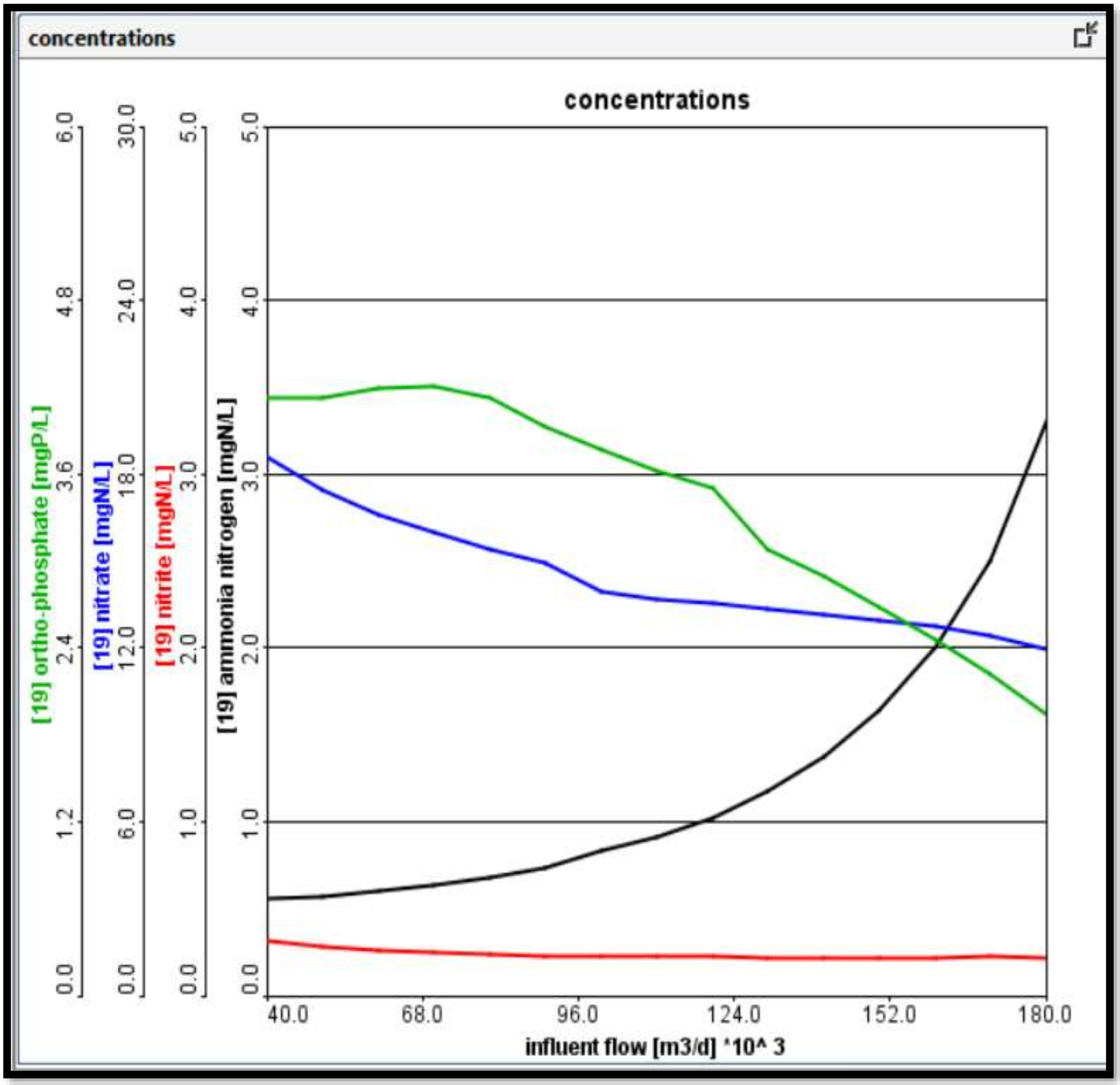


Figure 4-4: Effect of Flowrate on Effluent Concentrations of Ortho-Phosphate, Ammonia nitrogen, Nitrite and Nitrate.

Figures (4-5 and 4-6) demonstrates how RAS has affected the amount of contaminants in the treated wastewater. When the RAS ratio was between 20 and 100%, a very small influence was seen in the concentrations of COD, BOD, and TSS. In order to reduce energy loss and raise MLSS concentrations in the aeration tank, it is therefore better to utilize the lowest percentage of RAS. Sludge return has an impact on phosphate levels because it may include levels of dissolved oxygen and nitrates that interfere with phosphate removal efficiency **(Chen et al., 2015).** Due to an increase in SLR in the secondary sedimentation basin, the concentrations of TSS marginally increase as RAS increases. As the proportion of RAS increases, the concentrations of COD and BOD in the treated water decrease.

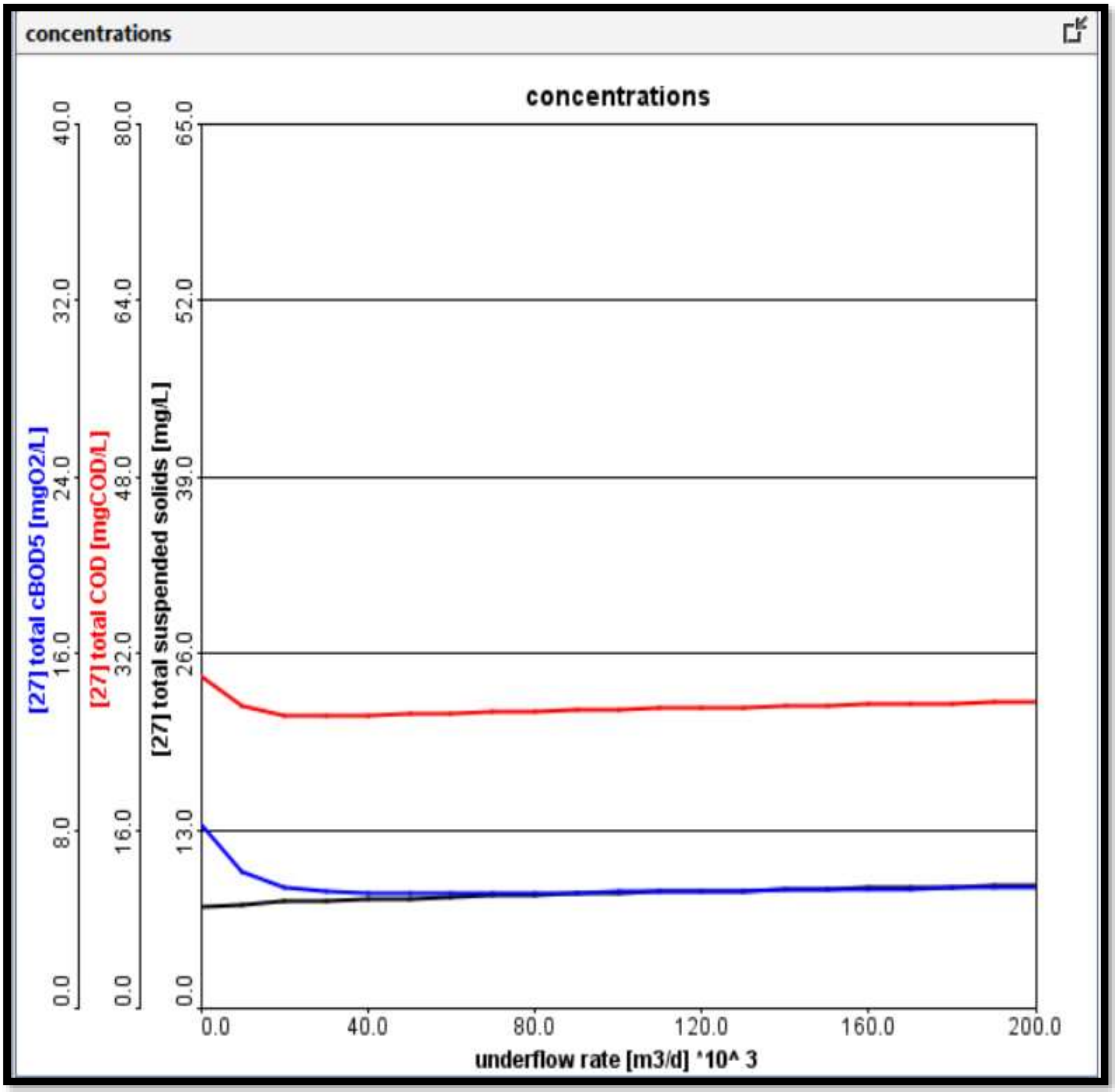


Figure 4-5:Effect of RAS on Effluent COD, BOD and TSS Concentrations.

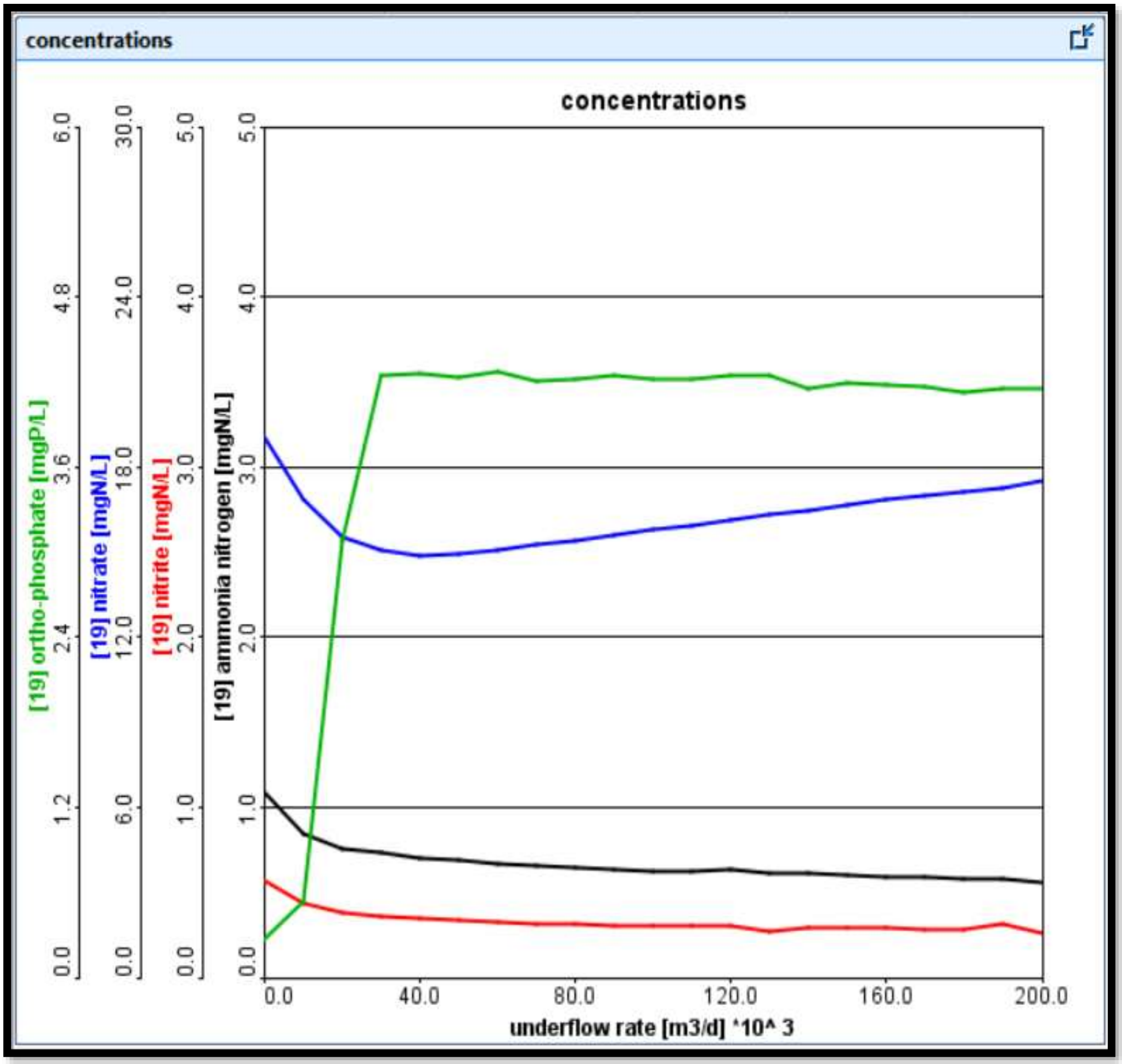


Figure 4-6: Effect of RAS on Effluent Concentrations of Ortho-Phosphate, Ammonia nitrogen, Nitrite and Nitrate.

To lower the levels of MLSS in the aeration tank and guarantee that the pollutants are effectively treated, the extra sludge must be removed. In addition to altering the organic substrate, the removal of sludge from the system influences the removal of nitrogen while enhancing the phosphate removal operation. Due to reduction in biomass concentrations, which aid in the breakdown of organic matter and nutrients, a rise in WAS causes the concentrations of COD and BOD in the treated wastewater to slightly increase.as shown in figures (4-7 and 4-8).

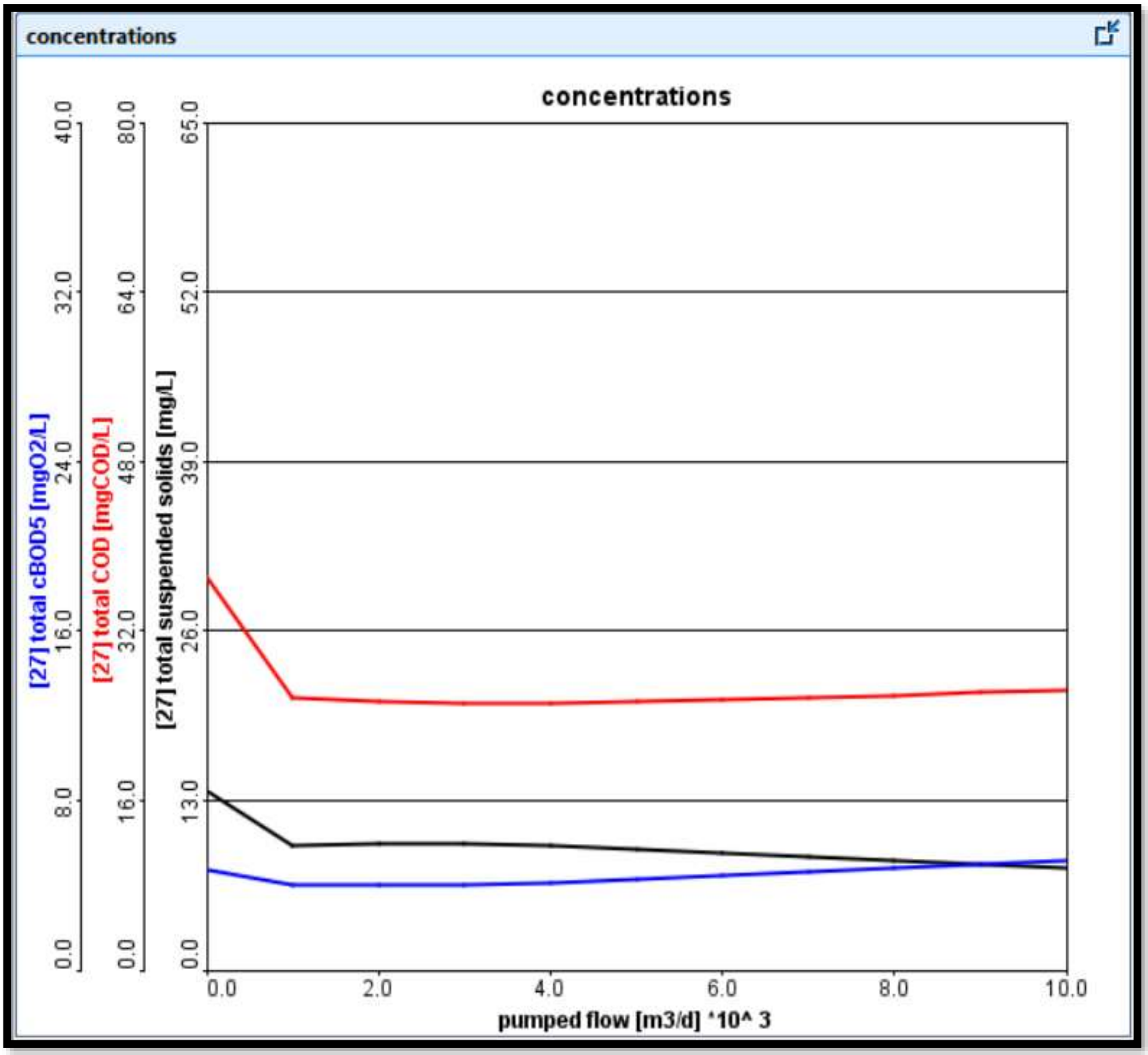


Figure 4-7: Effect of WAS on Effluent COD, BOD and TSS Concentrations.

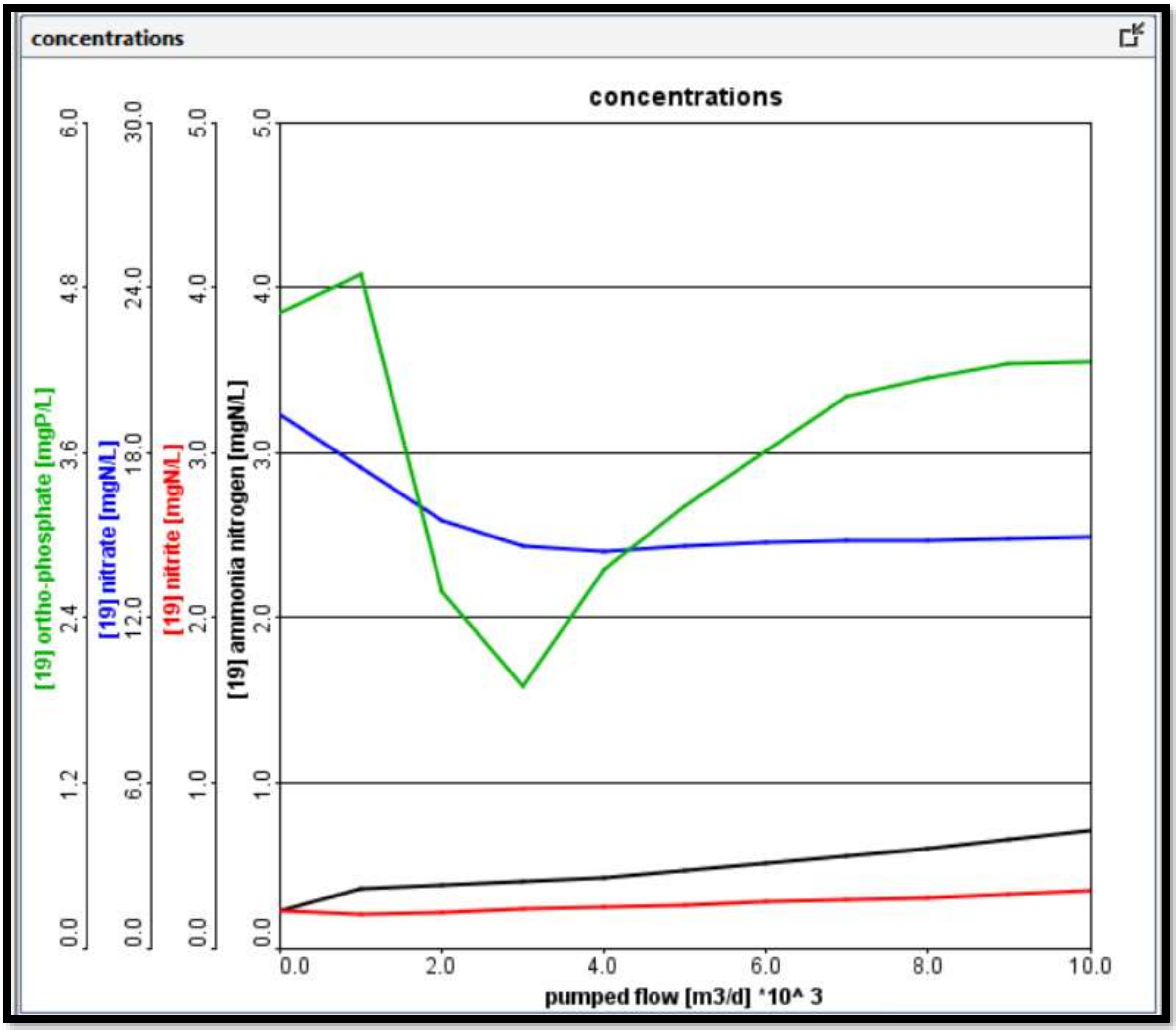


Figure 4-8: Effect of WAS on Effluent Concentrations of Ortho-Phosphate, Ammonia nitrogen, Nitrite and Nitrate

4.3 Processes Regulation of Karbala Wastewater Treatment Plant under Variable Flow

Based on the amount and type of sewage enter the wastewater treatment facility, one of the most crucial processes that must be under control is the mass balance. By running the plant at its most efficient and economical level while maintaining compliance with international standards, modifying the mass balance has a favorable impact. Five scenarios with five different influent flow rates were adopted to calulate the mass balance of the Kerbala WWTP plant as shown in table (4-6). The following steps show the measurment of the mass balance of scenario 1 with influent flow of 40,000 m^3/d :

1. Calculate the mass loadings in the primary clarifier influent. For each scenario

The changes in volume and solids through screening and grit chamber units are relatively small. Both processes may be ignored in mass balance analysis.

- For scenario 1 (with influent flow of 40,000 m^3/d)

Mass of BOD5, $W_{BOD5,1} = S_0Q = 115\ g/m^3 \times 40{,}000\ m^3/d \times 10^{-3}\ kg/g = 4600\ kg/d$

Mass of TSS, $W_{TSS,1} = TSS_0Q = 140 g/m^3 \times 40{,}000\ m^3/d \times 10^{-3}\ kg/g = 5600\ kg/d$

2. Calculate the primary sludge characteristics for each scenario.

Based on the information obtained from the management of the plant, it was observed that the efficiency of the primary sedimentation basin was 55% of TSS removal and 35% BOD5 removal. Also the solids content in the primary sludge ps,2 = 4% and specific gravity Ss,2 = 1.01 (Qasim & Zhu, 2017).

- Scenario 1 (with influent flow of 40,000 m^3/d)

Mass of BOD5, $W_{BOD5,2} = 0.35 \times W_{BOD5,1} = 0.35 \times 4600\ kg/d = 1610\ kg/d$

Mass of TSS, $W_{TSS,2} = 0.55 \times W_{TSS,1} = 0.55 \times 5600\ kg/d = 3080\ kg/d$

$$sludge\ flowrate\ from\ primary\ clarifier = \frac{100\% \ \times \ W_{TSS,2}}{P_{s2} \ \times S_{s2} \times \rho_w}$$

$$= \frac{100\% \times 3080\ kg/d}{4\% \times 1.01 \times 1000\ kg/m3} \cong 76\ m^3/d$$

The flow of primary effluent= flowrate- sludge flowrate from the primary clarifier

=40000-76=39924 m^3/d

3. Calculate WAS flowrate for each scenario
    - Scenario 1 (with influent flow of 40,000 m^3/d)

$$WAS\ flowrate = \frac{54054\ m^3 \ \ \times \ \ \ 3800\ mg/L}{14\ d \times 11000\ mg/L} = 1334\ m^3/d$$

4. Calculate RAS flowrate:
    - Scenario 1 (with influent flow of 40,000 m^3/d)

$$RAS\ flowrate = \frac{39924\ m^3 \ \ /d \times \ 3800\ mg/L}{11000 \frac{mg}{L} - 3800\ mg/L} \cong 21000\ m^3/d$$

5. Calculate belt thickener flowrate for each scenario: To calculate this discharge, Solids content in thickened sludge is 6% and Solids capture rate of 94% is taken into account.
    - Scenario 1 (with influent flow of 40,000 m^3/d)

$$\text{Belt thickener flowrate} = \frac{\frac{13340\ kg}{d} \times 94\%}{\frac{1000 kg}{m3} \times 6\%} = 209\ m^3/d$$

6. Calculate HLR for each scenario:
    - For primary clarifier
    - Scenario 1 (with influent flow of 40,000 m^3/d)

$$HLR = \frac{Q}{A} = \frac{39924\ m^3/d}{3216\ m^2} = 12.4\ m3/m2.d$$

Through the results obtained through the above equation, it was noted that HLR is for scenario 1,2 and 3 lower than the required determinant in the Metcalf, which is 40 m^3/m^2. d. Therefore, it requires the removal of some units from the operation to obtain m close to the required determinants. Therefore, we extract the number of primary sedimentation basins that must be entered by working according to 40 m^3/m^2. d based on the equation below:

- Scenario 1 (with influent flow of 40,000 m^3/d)

$$A = \frac{Q}{HLR} = \frac{39924\ m^3/d}{40m3/m2.d} = 998.1\ m\text{^}2$$

It was observed that the ratio of the second area to the first for scenario 1 reached almost 0.3, which is 0.3 the number of basins, since the number of operating basins is 4, it is necessary to reduce their number to become 2 at present while the ratio of the second scenario reached about 0.5 which mean half of the number of basins, and the ratio of the third scenario is 0.7 that mean need to operate all the basins.

- For secondary clarifier
- Scenario 1 (with influent flow of 40,000 m^3/d)

$$HLR = \frac{Q}{A} = \frac{39924\ m^3/d}{6432\ m^2} = 6.2\ m3/m2.d$$

HLR was observed at a level lower than the required specification in Metcalf at scenario 1,2,3 and 4, so it requires removing some basins from service to be closer to the value of HLR, which is 22 m3/m2. d. To calculate the number of tanks required to operate in the Karbala WWTP as such:

- Scenario 1 (with influent flow of 40,000 m^3/d)

$$A = \frac{Q}{HLR} = \frac{39924\ m\text{^}3/d}{22m3/m2.d} = 1814\ m2$$

The second area ratio was observed to the first at 0.3 for scenario 1, so it requires operating three of the tanks. while the number of operating basins is currently 8. For second scenario the ratio was 0.45 which mean 4 basins is required. the ratio for scenario 3 reaches 0.7 so 6 basins is required, and for scenario 4 the ratio was 0.98 which mean 8 basins is required .

Table 4-6: Mass balance of Karbala WWTP

parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Influent flow m^3/d	40000	60000	100000	140000	180000
Sludge flowrate m^3/d	76	114	191	267	343
WAS m^3/d	1334	1577	2027	2413	2574
RAS m^3/d	21000	32000	60000	78000	90000
Belt thickener flowrate m^3/d	209	247	318	378	403
Primary clarifier HLR m^3/m^2.d	12.4	18.7	31	43	55.86
No. of primary clarifier tanks	2	2	4	4	4
Secondary clarifier HLR m^3/m^2.d	6.2	9.3	15.5	21.7	27

No. of secondary clarifier tanks	3	4	6	8	8

4.4 The Efficiency of Kerbala WWTP According Applied Scenarios

To achieve the objective of the study to evaluate the operational performance of Kerbala WWTP under variable flow rates five scenarios with five different flow rates were applied as follows:

4.4.1 Scenario 1

The first scenario represents the response of the plant when the influent flow to the wastewater treatment plant is minimum flow of Karbala WWTP which is 40,000 m^3/d. The input parameters' characteristics in the first scenario are presented in the table 4-7 shown below.

Table 4-7:Variables Data of Scenario 1

Units	Input Parameter	Values m^3/d
Influent	Influent flow	40000
Primary Clarifier	Under Flow Rate	100
Aeration Tank	Internal Recycle (IR)	120000
Secondary Clarifier	Under Flow Rate (RAS)	21000
	Pumped Flow (WAS)	1334

In this scenario the number of primary sedimentation basins was decreased from 4 to 2, which resulted in a reduction in energy consumption of 50% as well as maintenance and operating expenses. The number of secondary sedimentation basins reduced from 8 to 3 that help reduce the energy consumption and maintanance cost about 38% .RAS and WAS was redused from 36000 m^3/d and 3500 m^3/d to 21000m^3/d and 1334 m^3/d that help to reduse cost and energy.The result of this scenario was obtained from the simulation process after calibration and validation of the model. the observed values of BOD, COD, TSS, NH_3, NO_3, NO_2 and Ortho-phosphate are shown in table 4-8.

Table 4-8: Effluent Concentration of Scenario 1

Output Parameter	Observed Value From the Model	Efficiency %	Iraqi Specifications
TSS mg/l	7.918	94 %	60
COD mg/l	24.36	90 %	100
BOD5 mg/l	3.807	96 %	40
Nitrate mg/l	17.19	-	50
Nirite mg/l	0.2123	-	-
Ammonia nitrogen mg/l	0.3291	98 %	10
Ortho-phosphate mg/l	3.089	withen limit	3

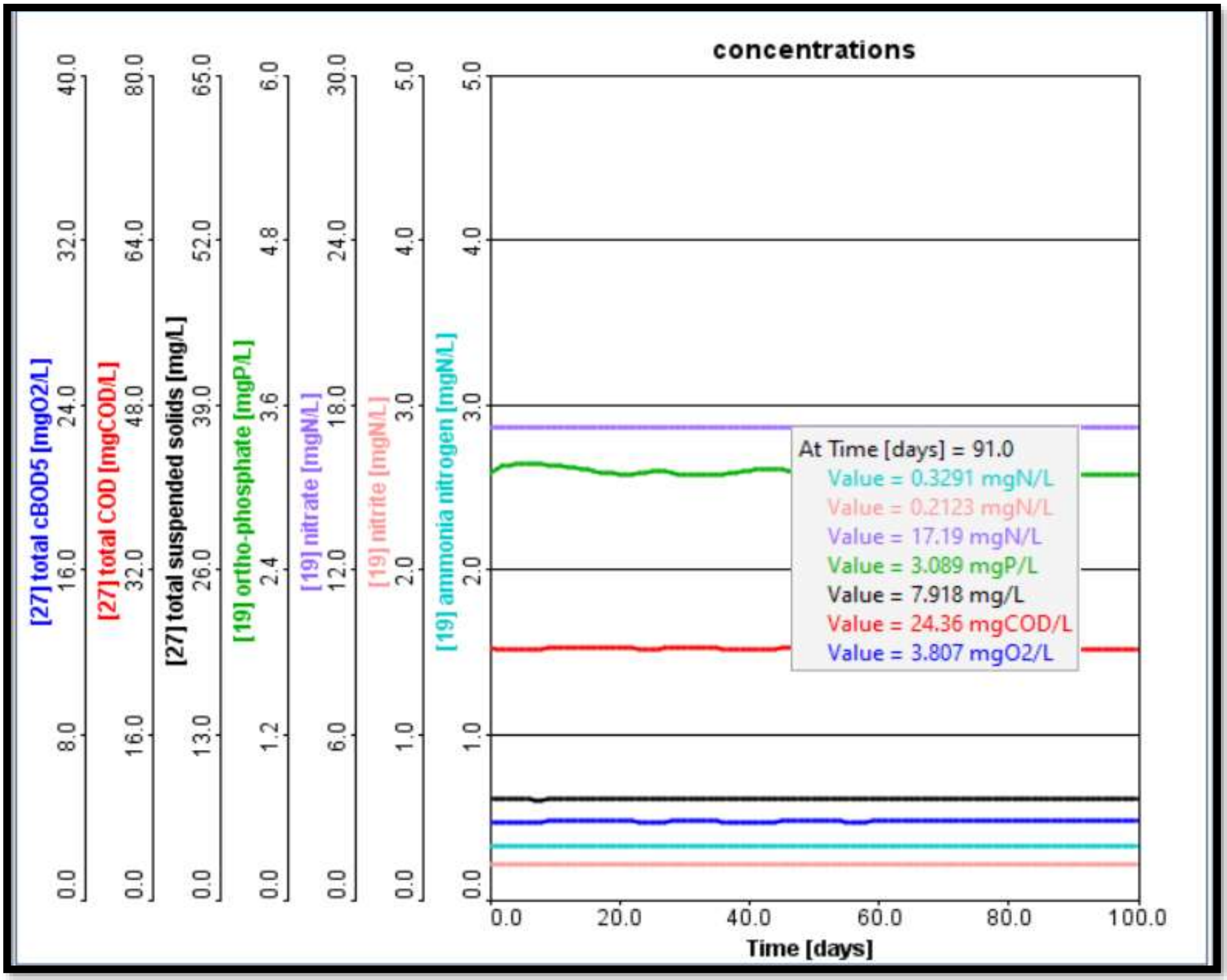


Figure 4-9: The Simulation Result of Scenario 1 for a Period of 100 Days.

4.4.2 Scenario 2

This case depicts Karbala WWTP on a typical day of operations. This scenario's input data is consistent with those used in the calibration procedure because they were collected in 2022 over the same time frame (identical wastewater parameters and operational conditions). Table 4-9 shows the parameter of the second scenario.

Table 4-9:Variables Data of Scenario 2

Units	Input Parameter	Values m^3/d
Influent	Influent Flow	60000
Primary Clarifier	Under Flow Rate	130
Aeration Tank	Internal Recycle (IR)	180000
Secondary Clarifier	Under Flow Rate (RAS)	32000
	Pumped Flow (WAS)	1577

The influent flow of the plant is almost steady during the year so this scenario used to calibrate the model. The simulated and observed values of the pollutant parameter which used the scenario of influent flow rate of 60,000 m^3/d which represents the reality of the Karbala wastewater plant during one year of operation.the number of primary and secondary clarifiers was reduced to half and that reduce 50 % of the enegy and cost of operation. The WAS redused about 55% that increase the SRT contributed to reducing the excess output of the sludge to the sludge treatment line . WAS reduction reduced upper flow belt thickening. Polymer prices decrease when upper flow belt thickener discharge is lowered. The values of concentrations of each parameter are displayed in actual and simulated form in table 4-10.

Table 4-10:Effluent Concentration of Scenario 2

Output Parameter	Actual Values	Observed Value from the Model	Efficiency %	Iraqi Specifications
TSS mg/l	11	11.53	91 %	60
COD mg/l	23	26.97	89 %	100
BOD5 mg/l	4	4.155	96 %	40

Nitrate mg/l	16	15.84	-	50
Nirite mg/l	0.2	0.2153	-	-
Ammonia nitrogen mg/l	0.5	0.41	98 %	10
Orthophosphate mg/l	3	3.168	withen limit	3

Figure 4-10 demonstrates the plant's behavior in the second scenario, which is the actual scenario that depicts the plant's actuality throughout the 100 days of operation during which the actual samples were collected and examined. This answer was collected following the run phase, during the steady-state phase. All the pollutants were under the Iraqi specifications as shown in table 4-10 .

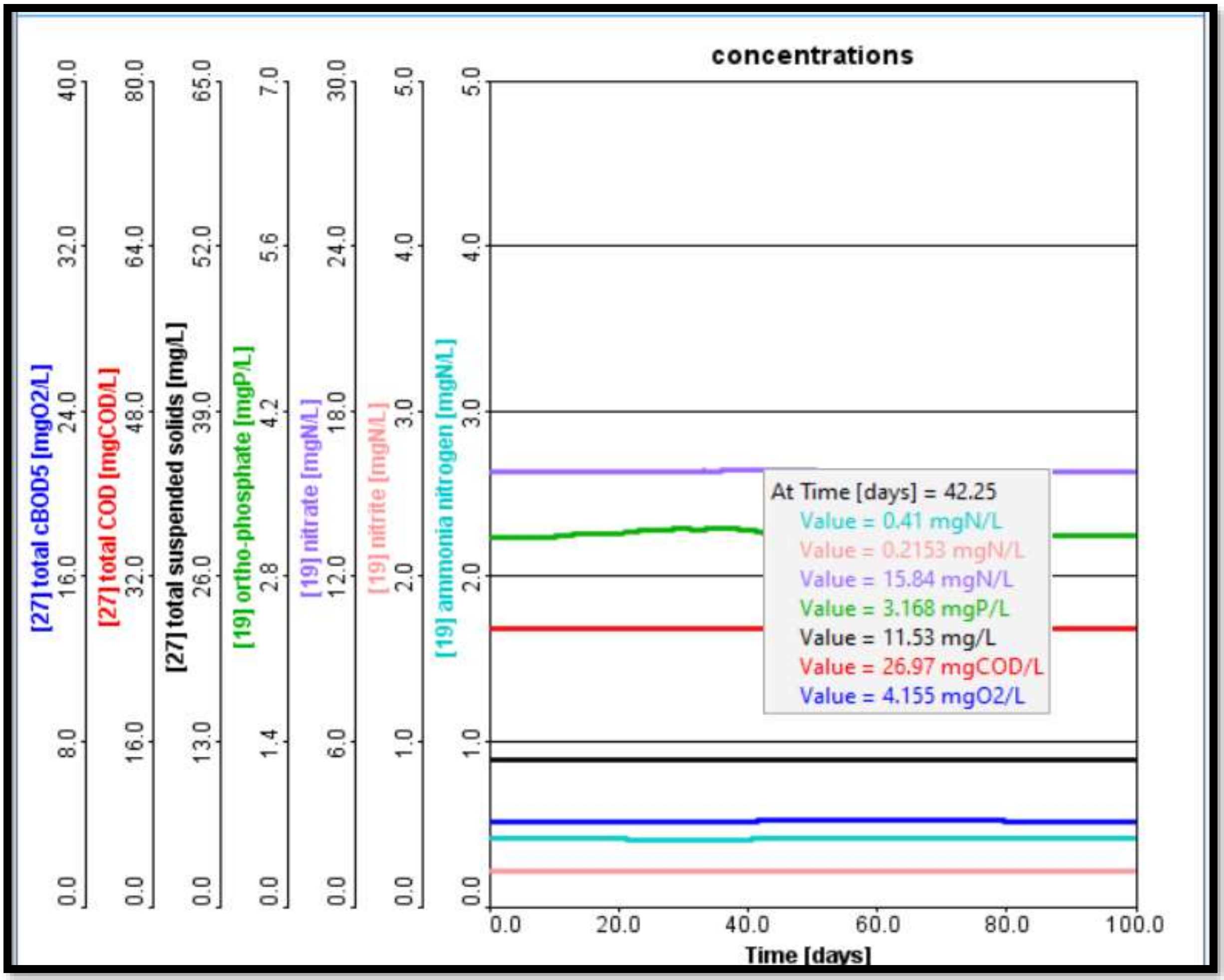


Figure 4-10: The Simulation Result of Scenario 2 for a Period of 100 Days.

4.4.3 Scenario 3

This scenario represents the response of Karbala waste water treatment plant to the design flow. The values of the effluent concentration was taken from the simulation of the model under flow rate of 100,000 m^3/d for aperiod of 100 days as shown in figure 4-11. The operational parameter of the plant are shown in table 4-11.

Table 4-11:Variables Data of Scenario 3

Units	Input parameter	Values m^3/d
Influent	Influent flow	100000
Primary Clarifier	Under Flow Rate	230
Aeration Tank	Internal Recycle (IR)	300000
Secondary Clarifier	Under Flow Rate (RAS)	60000
	Pumped Flow (WAS)	2027

In this scenario number of secondary clarifier was redused from 8 to 6 that reduse the energy and maintanance cost. The predictive values of the effluent concentration and the efficiency of the plant are shown in table 4-12.

Table 4-12: Effluent Concentration of Scenario 4.

Output Parameter	Observed Value from the Model	Efficiency%	Iraqi Specifications
TSS mg/l	17.23	87 %	60
COD mg/l	31.22	87 %	100
BOD5 mg/l	5.434	95 %	40
Nitrate mg/l	16.02	-	50
Nirite mg/l	1.443	-	-
Ammonia nitrogen mg/l	0.7273	97 %	10
Orthophosphate mg/l	1.443	67 %	3

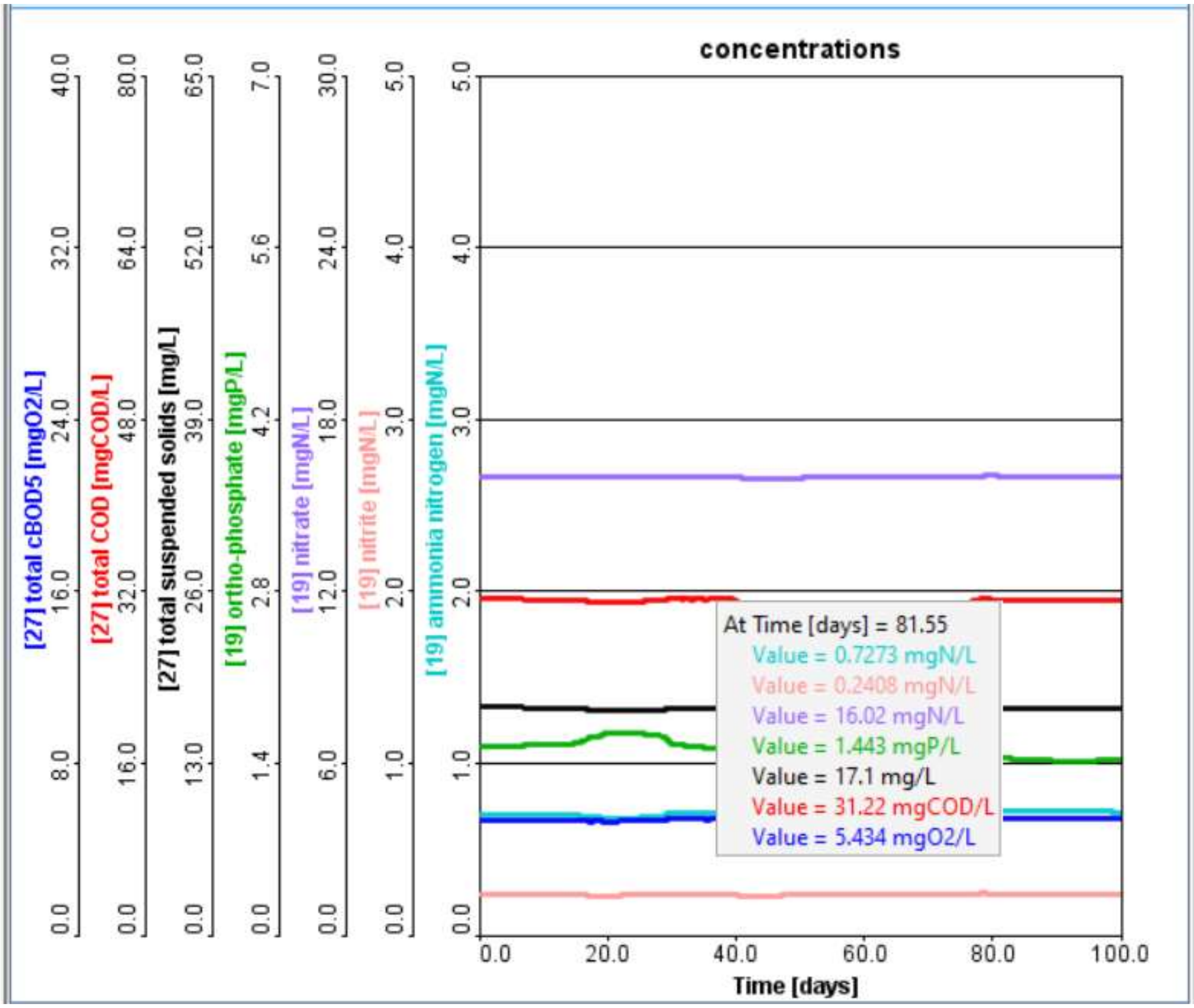


Figure 4-11:The Simulation of Result of Scenario 3 for a Period of 100 Days.

4.4.4 Scenario 4

This scenario represents the performance of Karbala wastewater treatment plant when the influent flow to the plant is 140,000 m^3/d which is above the design flow of the plant. The operational parameter of the plant change as shown in table 4-13 .

Table 4-13:Variables Data of Scenario 4

Units	Input Parameter	Values m^3/d
Influent	Influent Flow	140000
Primary Clarifier	Under Flow Rate	350
Aeration Tank	Internal Recycle (IR)	420000
Secondary Clarifier	Under Flow Rate (RAS)	78000
	Pumped Flow (WAS)	2413

The values of the effluent concentrations are obtained from the simulation of the model as shown in figure 4-12. In addition to the simulation results, table 4-14 shows the efficiency of pollutant removal and with comparison with the Iraqi standards.

Table 4-14: Effluent Concentration of Scenario 4

Output Parameter	Observed Value from the Model	Efficiency %	Iraqi Specifications
TSS mg/l	21.92	84 %	60
COD mg/l	35.65	85 %	100
BOD5 mg/l	6.748	94 %	40
Nitrate mg/l	15.95	-	50
Nirite mg/l	0.2582	-	-
Ammonia nitrogen mg/l	1.491	94 %	10
Ortho-phosphate mg/l	0.8426	81 %	3

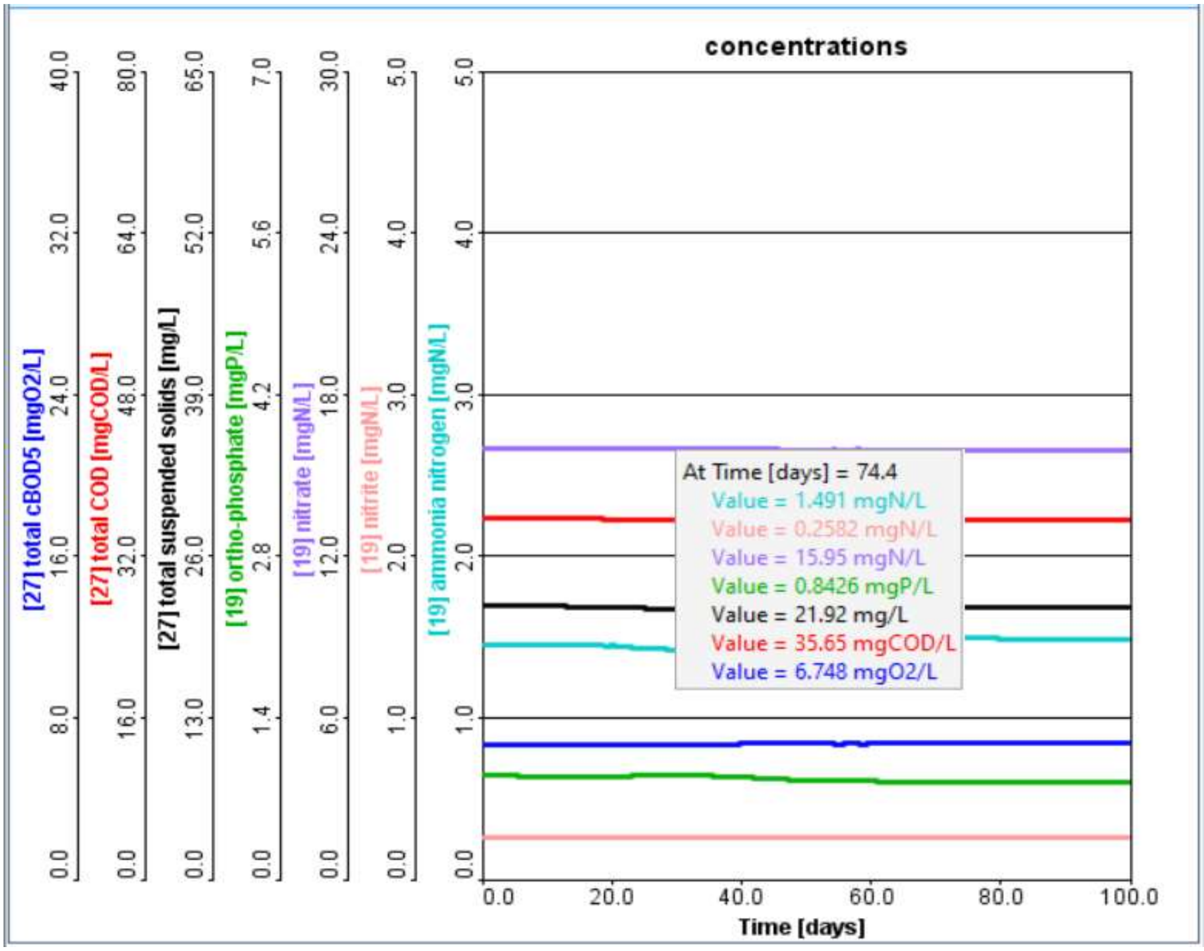


Figure 4-12: The Simulation of Results of Scenario 4 For a Period of 100 Days.

4.4.5 Scenario 5

This scenario represents the response of Karbala wastewater treatment plant when the influent flow to the plant reach to a value of 180000 m^3/d which is above the peak flow of Karbala wastewater treatment plant which was of 175000 m^3/d. table 4-15 shows the parameter of the scenario.

Table 4-15:Variables Data of Scenario 5

Units	Input Parameter	Values m^3/d
Influent	Influent Flow	180000
Primary Clarifier	Under Flow Rate	420
Aeration Tank	Internal Recycle (IR)	520000
Secondary Clarifier	Under Flow Rate (RAS)	90000
	Pumped Flow (WAS)	2474

The result of the simulation for a period of 100 days are shown in figure 4-13. The efficiency of the plant with the effluent pollutants concentrations are presented in table 4-16 below .

Table 4-16:Effluent Concentration of Scenario 5

Output Parameter	Observed Value From the Model	Efficiency%	Iraqi Specifications
TSS mg/l	27.25	80 %	60
COD mg/l	40.86	83 %	100
BOD5 mg/l	7.829	93 %	40
Nitrate mg/l	14.16	-	50
Nirite mg/l	0.2692	-	-
Ammonia Nitrogen mg/l	3.835	86 %	10
Ortho-Phosphate mg/l	0.6231	86 %	3

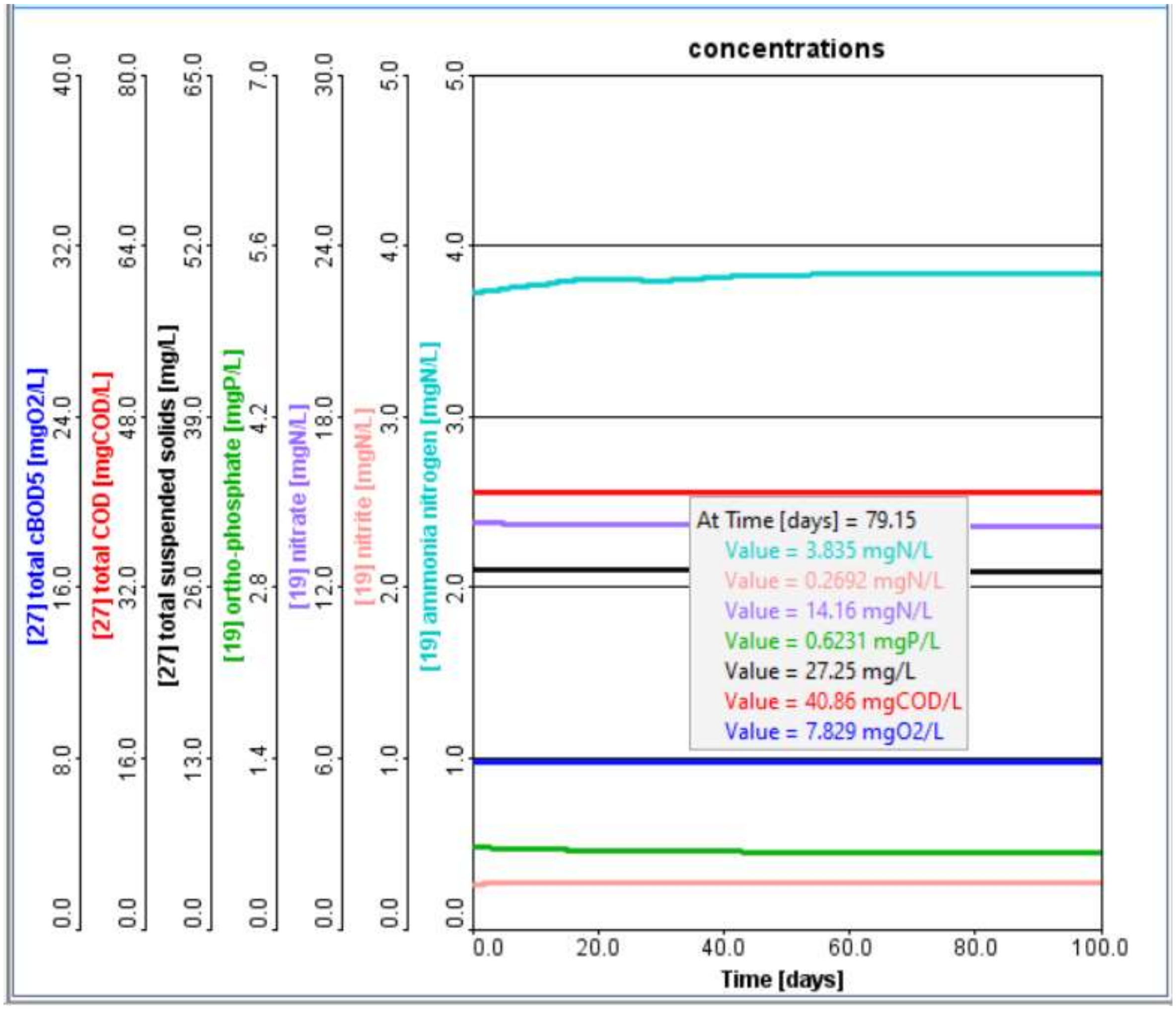
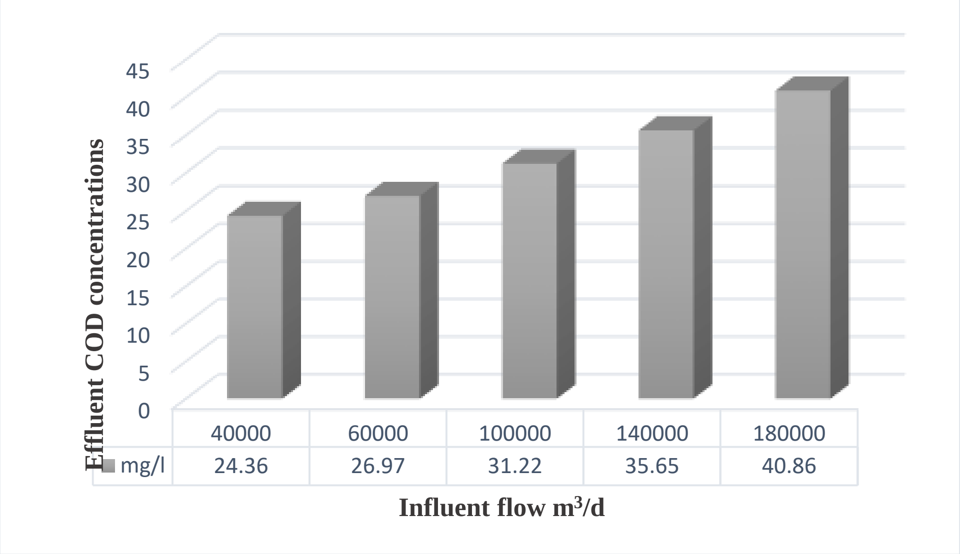


Figure 4-13: The Simulation of Results of Scenario 5 For a Period of 100 Days.

4.5 Evaluation of Karbala wastewater treatment plant performance under variable flows

From the previously mentioned applied scenarios, it can be shown that the removal efficiency of the organic matter (COD and BOD) for each scenario's investigated flows was over 90%, indicating that the organic matter was removed in a highly efficient methods, and thus can be attributed to sufficient supply of dissolved concentrations presented and t sufficient mixing inside the reactor, which caused these compounds to decompose and transform into fixed substances, microorganisms, particularly heterotrophic bacteria, helped to eliminate organic matter **(Bankston et al., 2020)**. When the flow increases, COD and BOD readings slightly increase; this slightly increasement because of shorter period of retention time The amount of time wastewater is allowed to remain in the treatment system is known as the retention time. Shorter retention times occur when the influent flow is increased because the wastewater is treated more quickly. As a result, the microorganisms in charge of breaking down organic waste have less time to work, which raises the COD and BOD levels in the effluent as indicated in the figures 4-14 and 4-15 below.



	40000	60000	100000	140000	180000
▨ mg/l	24.36	26.97	31.22	35.65	40.86

Figure 4-14: The Variation of The Effluent Concentrations of COD With Varios Flow Rates.

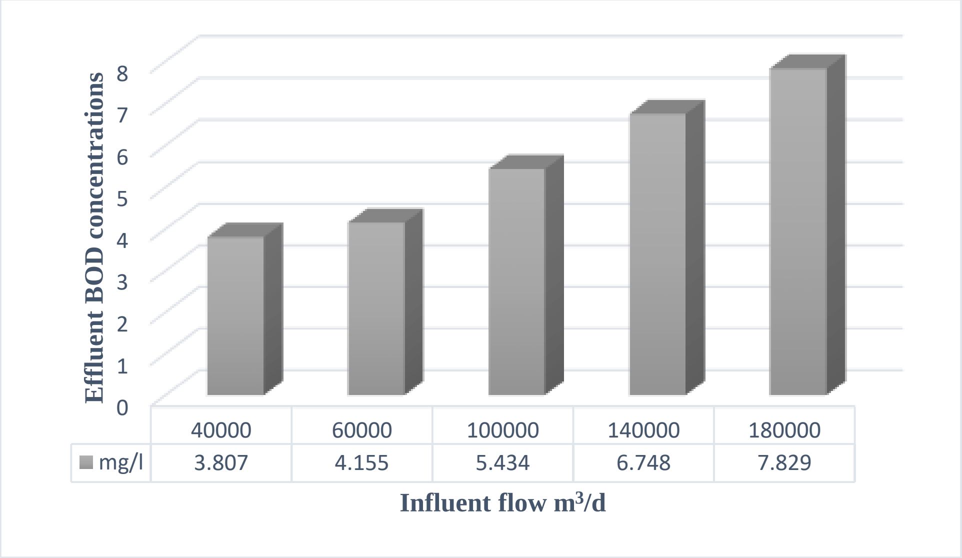


Figure 4-15: The Variation of the Effluent Concentrations of BOD With Various Flow Rates.

The effluent concentration of TSS was insignificant increase with increasing of influent flow because when the influent flow increased, the flow rate through the settling tanks can reduce the settling efficiency. As a result, a higher amount of suspended solids may carry over into the effluent, leading to an increasing in TSS values also shorter retention time reduced contact time between the wastewater and the treatment processes can hinder the settling of suspended solids, causing higher TSS levels in the effluent. The secondary sedimentation basins performed well in the removal of suspended solids (TSS) for all scenarios, obtaining a removal rate of more than 90%.

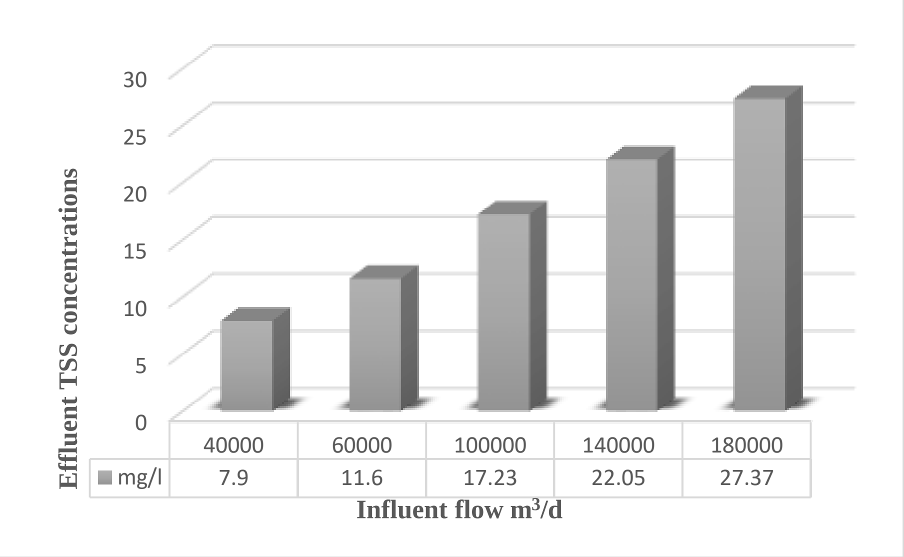


Figure 4-16: The Variation of the Effluent Concentrations of TSS with Various Flow Rates.

The NH_3^+-N values change for each scenario as shown in figure 4-17 .The value of NH_3^+-N reached to 3.835 when the flow is 180000 m^3/d that because the HRT decreases due to the increased flow rate. With less time available for treatment, the nitrification process, which converts ammonium (NH_3^+-N) to nitrate (NO_3^--N), incomplete. As a result, higher levels of ammonium can be observed in the effluent. Another reason of slightly increasing the concentration of NH_3^+-N is that when when the influent flow increases, the contact time between the wastewater and the air or airation mechanisms reduced. This can limit the stripping of ammonia, leading to insignificant rise in NH_3^+-N concentrations in the effluent.as the effluent concentration of ammonia nitrogen slightly increase with increasing flow the removal efficiency decrease where it is 98% when the flow is with a minimum value, and then it is insignificantly decreased to reach 86 % when the flow is 180000 m^3/d, The nitrification process was observed to be functioning effectively at the Karbala wastewater treatment plant, with ammonia being oxidized by over 95% for minimum and actual flow.

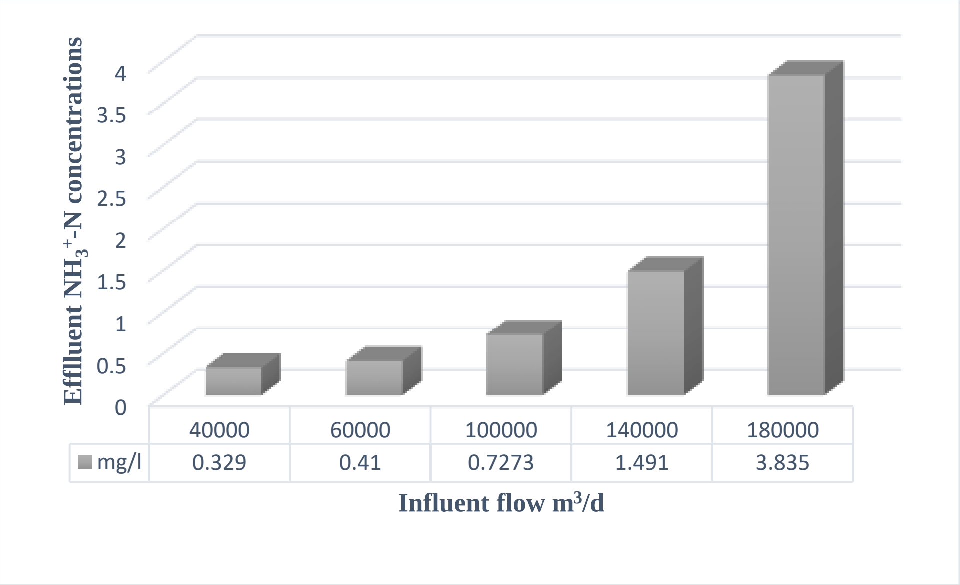


Figure 4-17: The Variation Effluent Concentrations of NH_3^+-N with Different Values of Flow Rates.

The primary source of nutrition for phosphorous bacteria is rbCOD. Additionally, it serves as a source of nourishment and functions as an electron donor in the process of nitrate reduction. The removal efficiency of phosphorous of Karbala wastewater treatment plant is concedered whithen limit .An increase in rbCOD concentration correlates with improved efficiency in phosphate removal, as well as enhanced nitrification and denitrification processes.

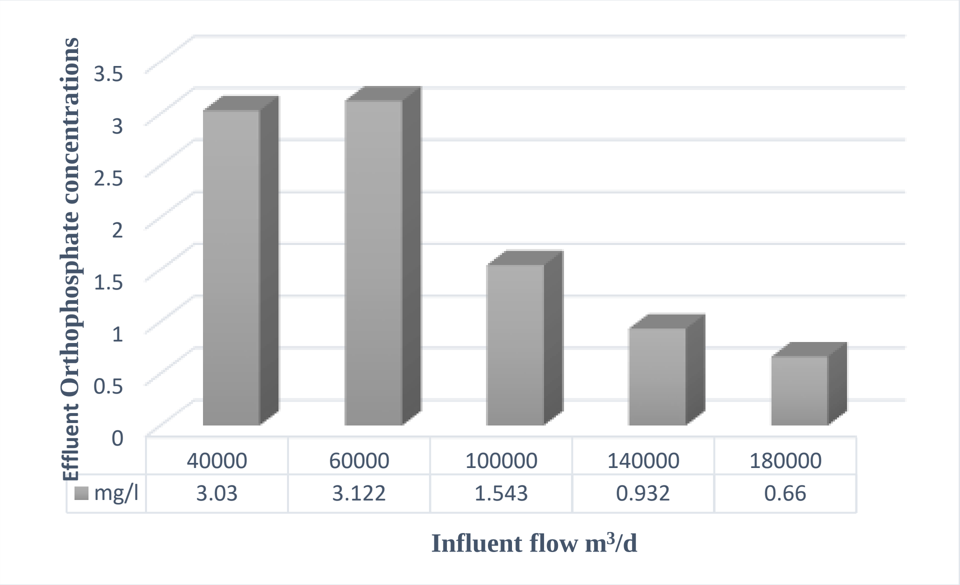


Figure 4-18:The Variation of the Effluent Concentrations of Orthophosphate with Different Values of Flow Rates.Different Values of Flow Rates.

When the discharge increases, it is seen that nitrates and nitrite are only very slightly influenced.

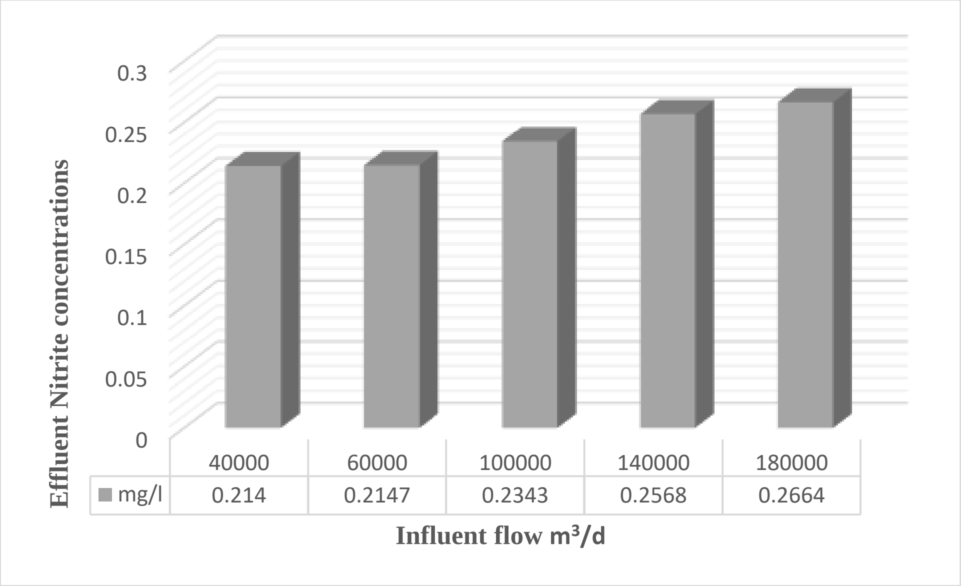


Figure 4-19:The Variation of the Effluent Concentrations of Nitrite with Different Values of Flow Rates.

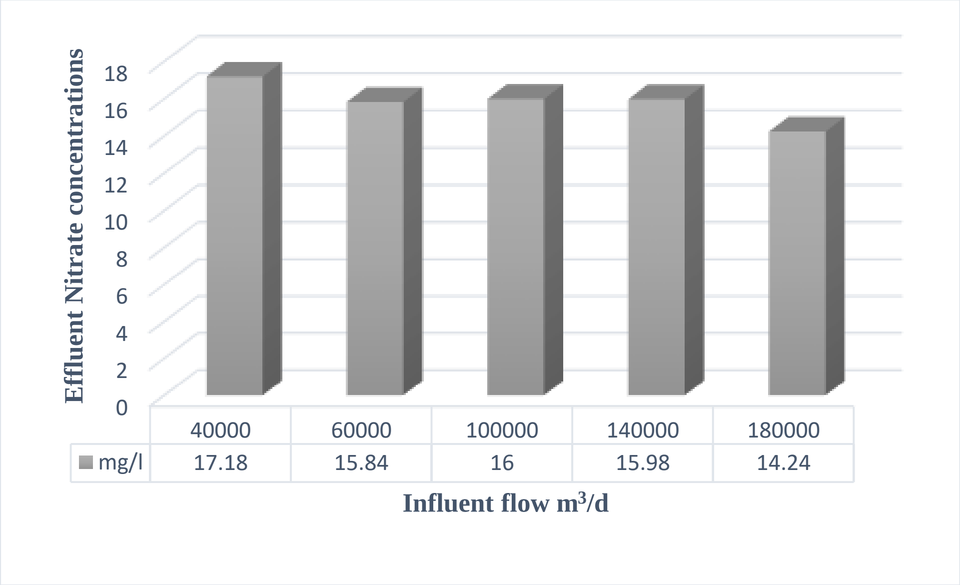


Figure 4-20: The Variation of the Effluent Concentrations of Nitrate with Different Values of Flow Rates.

Chapter Five: Conclusions and Recommendations

5.1 Cnclusions

The conclusion of the present studycan be summarized as follows:

1. The GPS-X program was successfully used in the present study to model the largest WWTP in Karbala city, Iraq. The removal efficiency of Karbala wastewater treatment plant model is acceptable and close to the removal efficiency of Karbala WWTP which it is above 80 % for most pollutant, and the removal efficiency of the plant is acceptable even if the influent flow reach 180000 m^3/d which is above the peak flow of the plant.
2. The model was calibrated and validated with an average monthly data of year of 2022 with an influent flow of 60000 m^3/d, and the result after calibration and validation was close to the effluent of the wastewater treatment plant.
3. The result of the scenario 2 which has influent flow rate of 60000 m^3/d was well agree with the simulation of the remaining scenarios with influent flow rates of (40000 m^3/d,100000m^3/d,140000 m^3/d and 180000m^3/d)
4. RAS has less effect on The plant's output.

5.2 Recommendations of Karbala Treatment plant

1. It is suggested to use the model of the plant for future studies because the model's accuracy was acceptable and the result of the simulation was close to real parameters concentration of the plant.
2. It is suggested to decrease the number of primary clarifier to 2 and secondary clarifier to 3 when the influent flow is 40,000 m^3/d or less and use 2 primary clarifiers and 4 secondary clarifiers when the influent flow to the treatment plant reach 60,000 m^3/d in summer or in dry days of the year.
3. It is suggested to operate all the primary and secondary clarifier when the influent flow reach 180,000 m3/d in winter and in the time of millions visits of the city.
4. It is suggested to monitor the operation of the wastewater treatment plant and enter the data of the plant into the model when influent flow rates vary, and rainwater enter the wastewater treatment plant.

5.3 Recomondation of future study

1. Utilizing the GPS-X program for the purpose of conducting future study with new factors, such as a variation in temperature, in order to evaluate and model the operation of the wastewater treatment plant in Karbala city.
2. The modeling of Karbala WWTP also, can be done with using of several models such as ASM3, TUDP, and Mantis2, might also be interesting as a future development.

3. It is necessary to conduct a future study to analyze the cost of optimal operation of the plant based on the model results which showed the possibility of reducing energy and chemicals used.

References

Abbasi, N., Ahmadi, M., & Naseri, M. (2021). Quality and cost analysis of a wastewater treatment plant using GPS-X and CapdetWorks simulation programs. *Journal of Environmental Management*, *284*, 111993.

Abou-Elela, S., Hamdy, O., & El Monayeri, O. (2016). Modeling and simulation of hybrid anaerobic/aerobic wastewater treatment system. *International journal of environmental science and technology, 13*, 1289-1298.

Al-Obady, O. M. K., & Qasim, A. F. (2018). Performance Evaluation of Al-Khadraa'Wastewater Treatment Plant, Mosul-Iraq. *Tikrit Journal of Pure Science*, *23*(7), 42-46.

Ali, I., Khan, Z., Peng, C., Naz, I., Sultan, M., Ali, M., Mahmood, M., & Niaz, Y. (2017). Identification and elucidation of the designing and operational issues of trickling filter systems for wastewater treatment. *Polish Journal of Environmental Studies*, *26*(6).

Alwardy, A., Alquzweeni, S. S., & Al-Saadi, R. J. (2021). Modelling and Simulation of Al-muamirah Wastewater Treatment Plant by GPS-X Software. *Kerbala Journal for Engineering Science*, *1*(2), 113-130.

Arif, A. U. A., Sorour, M. T., & Aly, S. A. (2020). Cost analysis of activated sludge and membrane bioreactor WWTPs using CapdetWorks simulation program: Case study of Tikrit WWTP (middle Iraq). *Alexandria Engineering Journal,*
.4667-4659 ,(6)59

Arzate, S., Pfister, S., Oberschelp, C., & Sánchez-Pérez, J. A. (2019). Environmental impacts of an advanced oxidation process as tertiary treatment in a wastewater treatment plant. *Science of the Total Environment*, *694*, 133572.

Awad, A., Jafar, R., & Ali, K. (2019). Modeling Banias Refinery Treatment Plant using the GPS-X. *Tishreen University Journal-Engineering Sciences Series*, *41*(6).

Azri, C., Abida, H., & Medhioub, K. (2008). Performance evaluation of the wastewater treatment plant of Sfax City (Tunisia): Influence of intrinsic and extrinsic factors. *Asian Journal of Water, Environment and Pollution*, *5*(3), 35-47.

Bankston, E., Wang, Q., & Higgins, B. T. (2020). Algae support populations of heterotrophic, nitrifying, and phosphate-accumulating bacteria in the treatment of poultry litter anaerobic digestate. *Chemical Engineering Journal*, *398*, 125550.

Brenner, R. C. (1974). *Process Design Manual for Upgrading Existing Wastewater Treatment Plants* (Vol. 2). US Environmental Protection Agency.

Buttiglieri, G., & Knepper, T. (2008). Removal of emerging contaminants in wastewater treatment: conventional activated sludge treatment. *Emerging*

Contaminants from Industrial and Municipal Waste: Removal Technologies, 1-35.

Cao, J., Yang, E. ,Xu, C., Zhang, T., Xu, R., Fu, B., Feng, Q., Fang, F., & Luo, J. (2021). Model-based strategy for nitrogen removal enhancement in full-scale wastewater treatment plants by GPS-X integrated with response surface methodology. *Science of the Total Environment*, *769*, 144851.

Cecconet, D., Callegari, A., & Capodaglio, A. G. (2022). UASB performance and perspectives in urban wastewater treatment at sub-mesophilic operating temperature. *Water*, *14*(1), 115.

Cervantes, F. J., Pavlostathis, S. G., & van Haandel, A. (2006). *Advanced biological treatment processes for industrial wastewaters*. IWA publishing.

Chen, Y., Li, B., Ye, L., & Peng, Y. (2015). The combined effects of COD/N ratio and nitrate recycling ratio on nitrogen and phosphorus removal in anaerobic/anoxic/aerobic (A2/O)-biological aerated filter (BAF) systems. *Biochemical engineering journal*, *93*, 235-242. https://doi.org/https://doi.org/10.1016/j.bej.2014.10.005

Cheremisinoff, P. N. (2019). *Handbook of water and wastewater treatment technology*. Routledge.

Çinar, Ö. (2005). New tool for evaluation of performance of wastewater treatment plant: artificial neural network. *Process Biochemistry*, *40*(9), 2980-2984.

Colacicco, A., & Zacchei, E. (2020). Optimization of energy consumptions of oxidation tanks in urban wastewater treatment plants with solar photovoltaic systems. *Journal of Environmental Management*, *276*, 111353.

Comber, S., Gardner, M., Sörme, P., & Ellor, B. (2019). The removal of pharmaceuticals during wastewater treatment: can it be predicted accurately? *Science of the Total Environment*, *676*, 222-230.

Copp, J., Johnson, B., Shaw, A., Burbano, M., Narayanan, B., Frank, K., Kinnear, D., Melcer, H., & Brischke, K. (2009). A balancing act: the consulting engineers' pragmatic view of process modelling. *Water Science and Technology*, *59*(4), 763-769.

Coutu, S., Wyrsch, V., Wynn, H. K., Rossi, L., & Barry, D. A. (2013). Temporal dynamics of antibiotics in wastewater treatment plant influent. *Science of the Total Environment*, *458*, 20-26.

Crini, G., & Lichtfouse, E. (2019). Advantages and disadvantages of techniques used for wastewater treatment. *Environmental Chemistry Letters*, *17*(1), 145-155.

EPA. (2000). *Environmental Protection Agency (EPA). Wastewater Technology Fact Sheet: Oxidation Ditches. US EPA, Washington, DC, USA, (2000)*.

Eriksson, E., Auffarth, K., Henze, M., & Ledin, A. (2002). Characteristics of grey wastewater. *Urban water*, *4*(1), 85-104.

Faris, A. M., Zwain, H. M., Hosseinzadeh, M., Majdi, H. S., & Siadatmousavi, S. M. (2022). Start-up and operation of novel EN-MBBR system for sidestreams treatment and sensitivity analysis modeling using GPS-X simulation. *Alexandria Engineering Journal*, *61*(12), 10805-10818.

Faris, A. M., Zwain, H. M., Hosseinzadeh, M., & Siadatmousavi, S. M. (202 .(2 Modeling of novel processes for eliminating sidestreams impacts on full-scale sewage treatment plant using GPS-X7. *Scientific Reports*, *12*(1), 2986.

Gabaldón, C., Izquierdo, M., Martínez-Soria, V., Marzal, P., Penya-Roja, J.-M., & Alvarez-Hornos, F. J .(2007) .Biological nitrate removal from wastewater of a metal-finishing industry. *Journal of hazardous materials*, *148*(1-2), 485-490.

Gernaey, K. V., Van Loosdrecht, M. C., Henze, M., Lind, M., & Jørgensen, S. B. (2004). Activated sludge wastewater treatment plant modelling and simulation: state of the art. *Environmental Modelling & Software*, *19*(9), 763-783.

Ghangrekar, M., & Behera, M. (2014). Suspended growth treatment processes.

Goel, R. K., Flora, J. R., & Chen, J. P. (2005). Flow equalization and neutralization. *Physicochemical treatment processes*, 21-45.

Gray. (2005). *Water Technology: An Introduction for Environmental Scientists and Engineers (2nd Edition), Elsevier Science & Technology Books*.

Hammed, A. N., Nile, B. K., & Al-Baidani, J. H. (.(2022Improving the Performance of the Karbala Wastewater Treatment Plant by Using GPS-X Model. 2022 International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT),

Henze, M., Gujer, W., Mino, T., Matsuo, T., Wentzel, M., & Marais, G. (1995). Wastewater and biomass characterization for the activated sludge model no. 2: biological phosphorus removal. *Water Science and Technology*, *31*(2), 13-23.

Henze, M., Gujer, W., Mino, T., & Van Loosedrecht, M. (2006). Activated sludge models ASM1, ASM2, ASM2d and ASM3.

Henze, M., van Loosdrecht, M. C., Ekama, G. A., & Brdjanovic, D. (2008). *Biological wastewater treatment*. IWA publishing.

Hernandez-Sancho, F., & Sala-Garrido, R. (2008). Cost modelling in waste water treatment processes: an empirical analysis for Spain. Dangerous pollutants (xenobiotics) in urban water cycle,

Horan, N. (2003). 21 - Suspended growth processes. In D. Mara & N. Horan (Eds.), *Handbook of Water and Wastewater Microbiology* (pp. 351-360). Academic Press. https://doi.org/https://doi.org/10.1016/B978-012470100-7/50022-4

Jasim, N. A. (2020). The design for wastewater treatment plant (WWTP) with GPS X modelling. *Cogent Engineering*, *7*(1), 1723782.

Jiang, H., Hua, M., Zhang, J., Cheng, P., Ye, Z., Huang, M., & Jin, Q. (2020). Sustainability efficiency assessment of wastewater treatment plants in China: A data envelopment analysis based on cluster benchmarking. *Journal of Cleaner Production*, *244*, 118729.

Joseph-Duran, B., Muñoz, E., Meseguer, J., Maruejouls, T., Ly, D. K., & Cembrano, G. Integrated Sewer Network and WWTP Real-Time Control.

Kapur, A., Kansal, A., Prasad, R., & Gupta, S. (1999). Performance evaluation of sewage treatment plant aha sludge bio-methanation. *Indian Journal of Environmental Protection*, *19* .100-96 ,

Karia, G., & Christian, R. (2013). *Wastewater treatment: Concepts and design approach*. PHI Learning Pvt. Ltd.

Kaul, S., Mukherjee, P., Sihorwala, T., Kulkarni, H., & Nandy, T. (1993). Performance evaluation of full scale wastewater treatment facility for finished leather industry. *Journal of Environmental Science & Health Part A*, *28*(6), 1277-1286.

Khiewwijit, R., Temmink, H., Rijnaarts, H., & Keesman, K. J. (2015). Energy and nutrient recovery for municipal wastewater treatment: how to design a feasible plant layout? *Environmental Modelling & Software*, *68*, 156-165.

Kirchem, D., Lynch, M. A., Bertsch, V., & Casey, E. (2020). Modelling demand response with process models and energy systems models: Potential applications for wastewater treatment within the energy-water nexus. *Applied Energy*, *260*, 114321.

Kolev Slavov, A. (2017). General characteristics and treatment possibilities of dairy wastewater–a review. *Food technology and biotechnology*, *55*(1), 14-28.

Kumar, S., & Babu, M. J. R. (2010). Performance evaluation of wastewater treatment plant. *International Journal of Engineering Science and Technology*, *Vol. 2(12)*,.

Lahdenperä, E., & Koiranen, T. E ects of Variable Feeds in Wastewater Plants by Means of Process Simulation.

Lester, J., Soares, A., San Martin, D., Harper, P., Jefferson, B., Brigg, J., Wood, E., & Cartmell, E. (2009). A novel approach to the anaerobic treatment of municipal wastewater in temperate climates through primary sludge fortification. *Environmental technology*, *30*(10 .994-985 ,(

Liao, Z., Chen, Z., Xu, A., Gao, Q., Song, K., Liu, J., & Hu, H.-Y. (2021). Wastewater treatment and reuse situations and influential factors in major Asian countries. *Journal of Environmental Management*, *282*, 111976.

Lim, E.-T., Jeong, G.-T ,.Bhang, S.-H., Park, S.-H., & Park, D.-H. (2009). Evaluation of pilot-scale modified A2O processes for the removal of nitrogen compounds from sewage. *Bioresource technology*, *100*(24), 6149-6154.

Lu, Q., & Shim, H. (2015). Comparison of chloride effect between A2O and SBR processes treating domestic wastewater. *Desalination and Water Treatment*, *53*(9), 2549-2554.

Mabrouki, J., Benbouzid, M., Dhiba, D., & El Hajjaji, S. (2022). Simulation of wastewater treatment processes with Bioreactor Membrane Reactor (MBR) treatment versus conventional the adsorbent layer-based filtration system (LAFS). *International Journal of Environmental Analytical Chemistry*, *102*(19), 7458-7468.

Machineni, L. (2019). Review on biological wastewater treatment and resources recovery: attached and suspended growth systems. *Water Science and Technology*, *80*(11), 2013-2026.

Mallik, A., Arefin, M. A., & Shahadat, M. M. Z. (2018). Design and feasibility analysis of a low-cost water treatment plant for rural regions of Bangladesh. *AIMS Agriculture and Food*, *3*(3), 181-204.

Mannina, G., Di Trapani, D., Viviani, G., & Ødegaard, H. (2011). Modelling and dynamic simulation of hybrid moving bed biofilm reactors: model concepts and application to a pilot plant. *Biochemical engineering journal*,-23 ,(2-1)56 .36

Martí, N., Barat, R., Seco, A., Pastor, L., & Bouzas, A. (2017). Sludge management modeling to enhance P-recovery as struvite in wastewater treatment plants. *Journal of Environmental Management*, *196*, 340-346.

McCarty, P. L., Bae, J., & Kim, J. (2011). Domestic wastewater treatment as a net energy producer–can this be achieved? In: ACS Publications.

Melcer, H., Dold, P., Jones, R., Bye, C., Takacs, I., Stensel, H., Wilson, A., Sun, P., & Bury, S. (2003). Methods for Wastewater Characterization in Activated Sludge Modelling. *Narrative*, *1*, 12.

Metcalf, Eddy, Abu-Orf, M., Bowden, G., Burton, F. L., Pfrang, W., Stensel, H. D., Tchobanoglous, G., Tsuchihashi, R., & AECOM. (2014). *Wastewater engineering: treatment and resource recovery*. McGraw Hill Education.

Mihelcic, J. R., & Zimmerman, J. B. (2021). *Environmental engineering: Fundamentals, sustainability, design*. John wiley & sons.

Mittal, A. (2011). Biological wastewater treatment. *Water Today*, *1*, 32-44.

Moharram, M., Abdelhalim, H., & Rozaik, E. (2017). Performance appraisal of the A2/O process in domestic wastewater treatment replacing the anaerobic unit with UASB. *HBRC journal*, *13*(1), 98-105.

Moursy, A., Sorour, M. T., Moustafa, M., Elbarqi, W., Fayd, M., & Elreedy, A. (2018). Simulation analysis of capacity and performance improvement in wastewater treatment plants: Case study of Alexandria eastern plant. AIP Conference Proceedings, Mu’azu, N. D., Alagha, O., & Anil, I. (2020). Systematic modeling of municipal wastewater activated sludge process and treatment plant capacity analysis using GPS-X. *Sustainability*, *12*(19), 8182.

Naidoo, S., & Olaniran, A. O. (2014). Treated wastewater effluent as a source of microbial pollution of surface water resources. *International journal of environmental research and public health*, *11*(1), 249-270.

Nasr, M. S., Moustafa, M. A., Seif, H. A., & El Kobrosy, G. (2011). Modelling and simulation of German BIOGEST/EL-AGAMY wastewater treatment plants–Egypt using GPS-X simulator. *Alexandria Engineering Journal*, *50*(4), 351-357.

Nikmanesh, M. S., Eslami, H., Momtaz, S. M., Biabani, R., Mohammadi, A., Shiravand, B., & Zarei Mahmoudabadi, T. (2018). Performance evaluation of the extended aeration activated sludge system in the removal of physicochemical and microbial parameters of municipal wastewater: a case study of nowshahr wastewater treatment plant. *Journal of Environmental Health and Sustainable Development*, *3*(2), 509-517.

O’Connell, N. J. (2015). *Modelling a batch biofilm passive aeration process using an activated sludge process and a biofilm process* National University of Ireland].

Onchoke, K. K., Janusa, M. A., & Sasu, S. A. (2015). Evaluation of the performance of a rural municipal wastewater treatment plant in Nacogdoches, East Texas (USA). *Chemistry and Ecology*, *31*(6), 567-582.

Peng, Y.-Z., Wang, X.-L., & Li, B.-K. (2006). Anoxic biological phosphorus uptake and the effect of excessive aeration on biological phosphorus removal in the A2O process. *Desalination*, *189*(1-3), 155-164.

Pereira, S. F. (2014). *Modelling of a wastewater treatment plant using GPS-X* Faculdade de Ciências e Tecnologia].

Qasim, S. R., & Zhu, G. (2017). *Wastewater treatment and reuse, theory and design examples, volume 1: Principles and basic treatment*. CRC Press.

Rong, Y., Shao, J.-B., Yu, Y.-C., Shi, X., & Jin, P.-K. (2020). Characteristics of Nutrient Removal in a Pilot-scale A 2/O with Mixture of Sludge Fermentation Liquor and Tail Water as External Carbon Source. *Huan Jing ke Xue= Huanjing Kexue*, *41*(11), 5089-50 .96

Russell, D. L. (2019). *Practical wastewater treatment*. John Wiley & Sons.

Sakib, F. S. (2022). Designing and Modeling of a Municipal Wastewater Treatment Plant With GPS-X.

Samer, M. (2015). Biological and chemical wastewater treatment processes. *Wastewater treatment engineering*, *150*, 212.

Simonich, S. L., Federle, T. W., Eckhoff, W. S., Rottiers, A., Webb, S., Sabaliunas, D., & De Wolf, W. (2002). Removal of fragrance materials during US and

European wastewater treatment. *Environmental science & technology*, *36*(13), 2839-2847.

Smith, J., Johnson, A., Brown, R. (2018). Variable Flow Considerations for Wastewater Treatment Plants. *Water Environment Federation Technical Exhibition and Conference (WEFTEC)*.

Soomaree, K. (2015). Detail design of wastewater treatment plant. *University of Mauritius*.

Sun, Y., Chen, Z., Wu, G., Wu, Q., Zhang, F., Niu, Z., & Hu, H.-Y. (2016). Characteristics of water quality of municipal wastewater treatment plants in China: implications for resources utilization and management. *Journal of Cleaner Production*, *131*, 1-9.

Vanhooren, H., Meirlaen, J., Amerlinck, Y., Claeys, F., Vangheluwe, H., & Vanrolleghem, P. A. (2003). WEST: modelling biological wastewater treatment. *Journal of Hydroinformatics*, *5*(1), 27-50.

Wang, L. K., Shammas, N. K., & Hung, Y.-T. (2010). *Advanced Biological Treatment Processes: Volume 9* (Vol. 9). Springer Science & Business Media.

Wang, Z., Liu, B., & Wan, F. (2013). Evaluation of biological removal efficiency in an UCT process treating municipal wastewater during start-up stage. *Journal of environmental biology*, *34*(2 suppl), 459.

Weissbrodt, D., Kovalova, L., Ort, C., Pazhepurackel, V., Moser, R., Hollender, J., Siegrist, H., & McArdell, C. S. (2009). Mass flows of X-ray contrast media and cytostatics in hospital wastewater. *Environmental science & technology*, *43*(13), 4810-4817.

Yang, L., Salcedo-Diaz, R., & Grossmann, I. E. (2014). Water network optimization with wastewater regeneration models. *Industrial & Engineering Chemistry Research*, *53*(45) .17695-17680 ,

Yang, Y., Zhang, J., Liu, L., Hu, Y., & Xu, Z. (2010). Simulation of Triple Oxidation Ditch Wastewater Treatment Process. AIP Conference Proceedings,

Yaqoob, A. A., Parveen, T., Umar, K., & Mohamad Ibrahim, M. N. (2020). Role of nanomaterials in the treatment of wastewater: A review. *Water*, *12*(2), 495.

Yazdian, H., & Jamshidi, S. (2021). Performance evaluation of wastewater treatment plants under the sewage variations imposed by COVID-19 spread prevention actions. *Journal of Environmental Health Science and Engineering*, *19*, 1613-1621.

Zeng, Y., Chang, F., Wen, X., Duan, L., Zhang, Y., Liu, Q., & Zhang, H. (2022). Seasonal Variation in the Water Quality and Eutrophication of Lake Xingyun in Southwestern China. *Water*, *14*(22), 3677.

Zhang ,Q., Yang, W., Ngo, H., Guo, W., Jin, P., Dzakpasu, M., Yang, S., Wang, Q., Wang, X., & Ao, D. (2016). Current status of urban wastewater treatment plants in China. *Environment international*, *92*, 11-22.

Zhou, Y., Khu, S.-T., Xi, B., Su, J., Hao, F., Wu, J., & Huo, S. (2014). Status and challenges of water pollution problems in China: learning from the European experience. *Environmental earth sciences*, *72*, 1243-1254.

الخلاصة

محطات معالجة مياه الصرف الصحي (WWTPs) هي أنظمة وظيفية مع مجموعة متنوعة من إجراءات المعالجة المصممة لإزالة أو تقليل أضرار مياه الصرف الصحي. واليوم، يتم استخدام نظام يدمج منهجيات تقييم الأداء وأدوات النمذجة الحديثة للمساعدة في تحديد مدى فعالية وملاءمة تشغيل هذه المحطات. لقد زاد توليد المياه العادمة في مدينة كربلاء بالعراق بشكل كبير نتيجة للتوسع الحضري والنمو السكاني، مما استلزم التشغيل الفعال لمرافق معالجة المياه العادمة. في برنامج النمذجة GPS-X الحالي، تم استخدام نموذج محطة معالجة مياه الصرف الصحي باستخدام خمسة سيناريوهات بمعدلات تدفق مختلفة، السيناريو 1 مع تدفق داخل للمحطة قدره 40.000 م^3/ي، السيناريو 2 مع تدفق داخل للمحطة قدره 60.000 م^3/ي ، السيناريو 3 مع تدفق داخل للمحطة 100,000 م^3/ي ، السيناريو 4 مع تدفق داخل للمحطة 140,000 م^3/ي والسيناريو 5 مع تدفق داخل للمحطة 180,000 م^3/ي لتقييم الفعالية التشغيلية لمحطة معالجة مياه الصرف الصحي في كربلاء (WWTP) في حالات معدلات التدفق المتغيرة.

تبدأ الدراسة الحالية بوصف تصميم محطة معالجة مياه الصرف الصحي في كربلاء، وقدراتها، وإجراءات معالجتها، وبنيتها التحتية. سيتم فحص الأداء ومحاكاة عمليات المعالجة باستخدام نموذج GPS-X وباستخدام البيانات التاريخية من المصنع، تتم معايرة النموذج واختباره لضمان الدقة. تمت دراسة جودة مياه الصرف الصحي الخام المتدفقة ومياه الصرف الصحي المعالجة طوال عام 2022 (من 2022/1 إلى 2022/12) وذلك لتقييم محطات معالجة مياه الصرف الصحي. يتم تقييم كفاءة أداء محطة معالجة مياه الصرف الصحي في كربلاء باستخدام الطلب على الأكسجين البيولوجي (BOD_5)، والطلب على الأكسجين الكيميائي (COD)، وإجمالي المواد الصلبة العالقة (TSS)، والأمونيا والنيتروجين ($NH3^+$-N)، والأورثوفوسفات ($PO4^{-3}$)، والنترات. ($NO3^-$)، والنتريت ($NO2^-$)يتم تحديد كفاءة إزالة كل معلمة من المياه العادمة والصرف الصحي ومن ثم مقارنة النتائج بالمواصفات العراقية. تم استخدام برنامج GPS-X (v.8) لإنشاء نموذج المحطة.

أظهرت نتائج معايرة النموذج أنه يمكن استخدام النموذج الخاص بالمحطة في الدراسات المستقبلية لأن دقة النموذج كانت مقبولة وتراوحت علاقة الارتباط بين البيانات الفعلية والمحاكاة من 0.81 إلى 0.92. كانت نتائج جذر متوسط مربع الخطأ RMSE قريبة من الصفر وتتراوح من 0.011 إلى 0.138، وكانت نتائج المحاكاة قريبة من التركيزات الحقيقية للمحطة. أشارت نتائج المحاكاة والنمذجة لمحطة معالجة مياه الصرف الصحي في كربلاء باستخدام GPS-X إلى أن أداء المنشأة كان جيدًا وبفعالية عالية وفقًا لمعايير الإخراج. انخفض عدد المصفيات الأولية من 4 إلى 2 والمصفيات الثانوية من 8 إلى 3 عندما يكون التدفق الداخل

40.000 م^{3}/ي أو أقل وانخفض عدد المصفيات الأولية من 4 إلى 2 وانخفض عدد المصفيات الثانوية من 8 إلى 4 عندما يصل تدفق المياه إلى محطة المعالجة إلى 60,000 م^{3}/ي مما يقلل من الطاقة وتكلفة التشغيل.

أظهرت نتائج تطبيق السيناريوهات الخمسة المختلفة أن قيم عوامل الملوثات TSS و COD و BOD5 و $NO2^{-}$-N و NO3--N و $NH3^{+}$-N و $PO4^{-3}$ في النفايات السائلة تبقى ضمن الحدود المقبولة للمواصفات العراقية. وأن المصنع يتمتع بكفاءة عالية في إزالة الملوثات حيث تراوحت كفاءة الإزالة من 80% إلى 94% للمواد الصلبة العالقة، ومن 83% إلى 90 بالنسبة للأكسجين الكيميائي، ومن 93% إلى 96% بالنسبة للـ BOD، ومن 86% إلى 98% بالنسبة إلى NH3+- N، وكفاءة إزالة $PO4^{-3}$ ضمن الحد.

جمهورية العراق

وزارة التعليم العالي و البحث العلمي

جامعة كربلاء

كلية الهندسة

قسم الهندسة المدنية

تقييم الأداء التشغيلي لمحطة معالجة مياه الصرف الصحي في كربلاء تحت معدلات جريان مختلفة باستخدام نموذج GPS-x

رسالة مقدمة الى مجلس كلية الهندسة / جامعة كربلاء وهي جزء من متطلبات نيل درجة الماجستير في علوم الهندسة المدنية

المؤلف:

نور عبد الحسين خضير شكر

باشراف :

أ.د. باسم خليل نايل

أ.د. جبار حمود البيضاني

رمضان - 1445 آذار - 2024