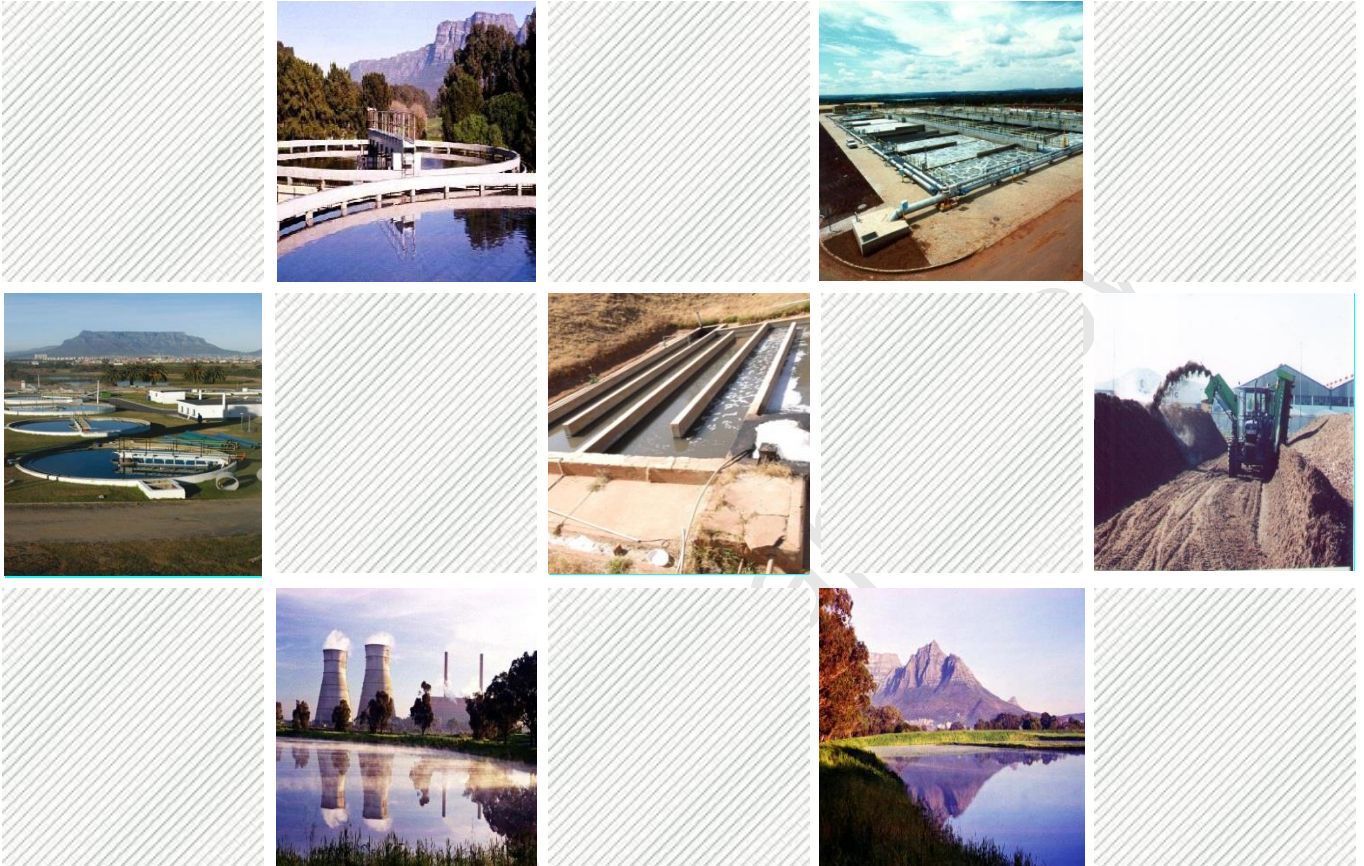




UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD



CIV5000Z

Dissertation for partial fulfilment of the requirement for the degree of Master of Science in Engineering (specialising in Water Quality Engineering)

A COMPARISON OF WASTEWATER PROCESS MODELLING TOOLS: CASE STUDY OF POTSDAM WWTW

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SUBMISSION DATE:

21 JUNE 2022

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FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING
(SPECIALISING IN WATER QUALITY ENGINEERING)

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i. LIST OF ACRONYMS AND SYMBOLS

°C	Degrees Celsius
1DFT	Idealised 1-Dimensional Flux Theory
μ_{Max}	Maximum specific growth rate of nitrifiers
ADM	Anaerobic digestion model
ADWF	Average dry weather flow
Alk	Alkalinity (as mgCaCO ₃ /L)
AS	Activated Sludge
ASM	Activated sludge model
ASM1	Activated sludge model Number 1
ASM2	Activated sludge model Number 2
BEPR	Biological Excess Phosphorous Removal
BIM	Building information modelling
Bioreactor	Biological Reactor
BNR	Biological Nutrient Removal
BPO	Biodegradable Particulate Organics (mgCOD/L or mgVSS/L)
CAD	Computer-aided design
CaCO ₃	Calcium Carbonate
CBD	Central Business District
CH ₄	Methane
CO ₂	Carbon dioxide
COD	Chemical Oxygen Demand
C _x H _y O _z NaP _b	Biomass empirical composition
DAF	Dissolved air flotation
DO	Dissolved Oxygen concentration (mgO/l)

Dp1	Denitrification Potential in the primary anoxic reactor
DSVI	Diluted sludge volume index
DWS	Department of Water and Sanitation
f_{at}	Active Fraction of active biomass with respect to total suspended solids concentration
f_{av}	Active Fraction of active biomass with respect to volatile suspended solids concentration
f_c	Carbon (C) to mass (VSS or molar mass) ratio
f_{cv}	COD to mass (VSS or molar mass) ratio
f_n	Nitrogen (N) to mass (VSS or molar mass) ratio
f_p	Phosphorous (P) to mass (VSS or molar mass) ratio
F-RBCOD	Fermentable Readily Soluble Biodegradable Organic COD
FSA	Free and Saline Ammonia
HAP	Hydroxy-apatite
HCO_3^-	Bi-carbonate
HDP	Hydroxy-dicalcium-phosphorous
ISS	Inorganic suspended (particulate) solids
IWA	International Water Association
Ml/day	Mega litres per day
MBR	Membrane Biological Reactor
MBBR	Moving Bed Biological Reactor
MLE	Modified Ludzack–Ettinger activated sludge system configuration
N	Elemental Nitrogen
ND	Nitrification-Denitrification
NDBEPR	Nitrification, Denitrification and Biological Excess Phosphorous Removal
NH_4	Ammonia
NO_2-N	Nitrite

NO ₃ -N	Nitrate
OHO	Ordinary Heterotrophic Organism
OrgN	Organic Nitrogen (mgN/ℓ)
OrgP	Organic Phosphorous (mgP/ℓ)
Ortho-P	Ortho-phosphates
OUR	Oxygen Utilisation Rate
P	Elemental Phosphorus
PAO	Polyphosphate accumulating organisms
PDWF	Peak Dry Weather Flow
PFD	Process Flow Diagram
pH	Activity of Hydrogen ions
P&ID	Process and Instrumentation Diagram
PST	Primary settling tanks
PWSSD	Plant-Wide Steady-State Design
PWWF	Peak Wet Weather Flow
RBCOD	Readily biodegradable COD
RS	Sludge Age
SBCOD	Slowly biodegradable COD
SCADA	Supervisory Control and Data Acquisition
SetS	Total Settleable solids
SOUR	Specific Oxygen Utilisation Rate
SST	Secondary settling tank
SSVI	Stirred Sludge Volume Index
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TSetS	Total Settleable Solids

TSS	Total suspended (particulate) solids
UCT	University of Cape Town
UPO	Unbiodegradable Particulate Organics (mgCOD/L or mgVSS/L)
USO	Unbiodegradable Soluble Organics (mgCOD/L)
UV	Ultra-violet
VFA	Volatile Fatty Acid
VSetS	Volatile Settleable Solids
VSS	Volatile suspended (particulate) solids
WAS	Waste activated sludge
WWTW	Wastewater treatment works

ii. ABSTRACT

A wastewater process model can either be based on a steady-state or dynamic mathematical modelling approach. The characterisation of the influent wastewater and specific wastewater parameters are critical input parameters to the mathematical model, whether for design, optimisation or to measure the expected performance of a wastewater treatment works (WWTW). A wastewater treatment process is inherently dynamic because of the changes in wastewater characteristics and flow rates, impacting the plant's process capacity and performance. Mathematical models have the capability to model such changes with ease and predict the expected performance of the plant.

This dissertation involves a theoretical modelling approach to compare steady-state and dynamic-state modelling tools on an existing full-scale WWTW, namely the Potsdam WWTW located in Cape Town (South Africa). The models adopted for this research included: i) A plant-wide steady-state model developed by the Author as part of this dissertation (Author's PWM); ii) Plant-Wide Steady-State Design (PWSSD) developed by Wu (2014); iii) BioWin 5.0 (developed by EnviroSim Associates Ltd; Barker and Dold, 1997; EnviroSim 2007); and iv) UCTPHO dynamic model (Wentzel *et al.*, 1992). The goal was to compare the output and results of the various models adopted for this research under steady-state and dynamic-state conditions where the models have been calibrated on historical field data and to examine the impact that specific wastewater characteristics have on the process capacity and the overall performance of the WWTW. To accomplish this goal, the following objectives were achieved:

1. The characterisation of the influent wastewater is critical in modelling. For a new plant (green field site), the wastewater characterisation will be based on typical norms as published in the relevant research literature. For an existing plant, the wastewater characterisation is typically based on historical sampling data. There can be challenges with historical sampling data, as data is often not measured, missing or not credible. In this case, designers are required to make assumptions to fill the gaps in the wastewater characterisation, adopting typical norms as published in the research literature and using sound process engineering judgement which was the scenario for the case study WWTW.
2. The documented design capacity of the Potsdam WWTW is 47 Ml/day (47,000 kgCOD/day) whereas the total theoretical process capacity estimated as part of this dissertation is 60.75 Ml/day (64,660 kgCOD/day), 37.5% higher than the documented process capacity.
3. The various models correlated well in terms of output results for both steady-state and dynamic-state conditions when compared across all process units for both the liquid and sludge streams, using the same input process parameters (flow rates, load patterns, wastewater characterisation, fractions and design assumptions). The steady-state models (Author's PWM and PWSSD) were almost identical in output results except for the aerobic digester. The output results of the dynamic-state models (BioWin and UCTPHO) were similar to the steady-state models but did differ for a few variables, attributed to the fact that the dynamic models use dynamic kinetic equations under constant or dynamic flow and load conditions, and this will produce different results than the less complex steady-state models which are based on constant flow and load conditions.
4. An evaluation of the impact of selected influent characteristic parameters on the system performance variables for biological nutrient (nitrogen and phosphorus) removal was performed for each of the steady-state and dynamic-state models. The parameters selected included the influent TKN (TKN/COD ratio), the maximum specific growth rate of nitrifiers (μ_{Max}) and readily biodegradable COD (RBCOD), and during the analysis, all other input parameters to the models were kept constant. The influent TKN and RBCOD are specific wastewater

characteristics that can vary during the lifetime of a WWTW having a strong impact on its N and P removal performance. μ_{Max} is also a critical wastewater parameter and at sludge ages close to the minimum sludge age for nitrification, this parameter impacts severely on the performance of biological nitrogen removal systems. It was concluded that substantial changes in the influent TKN, μ_{Max} and RBCOD will significantly impact a WWTW, specifically concerning N and P removal, therefore, impacting effluent and sludge quality. The various models followed similar trends; however, the following discrepancies were noted:

- When the TKN was increased, only the BioWin model considered the impact that the pH outside the range of 7.2 – 8.0 would have on the μ_{Max} and nitrification capacity of the bioreactor. This is a shortfall in the other models
- When the μ_{Max} was varied, the different models followed the same trend, but nitrification problems occurred at different μ_{Max} values. The BioWin model showed partial nitrification at a higher μ_{Max} threshold value than the other models, which occurred under minimum temperature conditions only
- When the RBCOD was varied, the only difference in the models is the RBCOD fraction at which complete biological phosphate removal took place. The steady-state models had the same RBCOD fraction, and the dynamic-state model (i.e., BioWin) had a higher RBCOD fraction at which complete biological phosphorous removal took place due to the fact that BioWin adopts two different maximum specific growth rates for the poly accumulating organisms (PAOs), namely a higher growth rate constant under phosphorous rich conditions which results in a higher uptake of phosphorous, and a lower growth rate constant under phosphorous limited conditions, where phosphorous uptake is limited. With a lower PAO growth in the BioWin model resulting in a lower PAO population, there is less potential for aerobic polyphosphate uptake, resulting in higher effluent Ortho-P concentrations.

A WWTW is complex with many interactions of different processes (biological, chemical and physical) and products taking the form of various phases (aqueous, gas and solid), complicated further by variations in influent characteristics, concentrations and flows. To manage these complexities, wastewater process models have been developed over the last three decades from stand-alone models for individual process units to plant-wide computational steady-state and dynamic models, which cater for a broad spectrum of wastewater engineering objectives. Steady-state models are powerful as they comprise simple and explicit algebraic equations that easily allow the estimation of design requirements and operation requirements for a WWTW with much less input information than dynamic models. They are often pre-processors to the dynamic models. In contrast, dynamic models require detailed input formation and sophisticated mathematical solvers but are more accurate in predicting effluent quality, system responses to dynamic conditions and the inhibitory effects of pH, temperature and metabolic products. The decision of selecting a steady-state or dynamic-state model is influenced by several factors, such as available information and influent data, user competency and modelling experience, size and complexity of the plant, as well as the detail and accuracy required by the designer. Wastewater process models therefore serve as a valuable tool for design, optimisation and operational and control strategies.

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1. INTRODUCTION

1.1 Background

Wastewater is the water supply of a community after it has been used in a variety of applications and which now contains constituents that render it unsuitable for most uses without treatment. Untreated wastewater contains: i) pathogenic micro-organisms that dwell in the human intestinal tract which may lead to waterborne diseases; ii) nutrients which can stimulate the growth of aquatic plants which may lead to eutrophication and loss of aquatic life; and iii) toxic compounds that potentially may be mutagenic or carcinogenic. **Wastewater Treatment** is the removal of these constituents, so the treated effluent can be returned to the environment or reused safely - so protecting the environment and public health. **Wastewater Engineering** is a branch of environmental engineering in which the basic principles of science and engineering are applied to solve the issues associated with the collection, treatment and re-use of wastewater (Tchobanoglous *et al.*, 2014; Metcalf & Eddy, 2014).

The objectives of wastewater treatment have transformed over the last century:

- Between the early 1900s and 1980s, treatment objectives focussed on the removal of solids, the treatment of biodegradable organics and the elimination of pathogenic organics. Wastewater engineering design solutions adopted to meet these treatment objectives mainly comprised of empirical design principles
- During the last two decades, the emphasis on treatment objectives has been extended to include the removal of constituents that may cause long-term health effects and environmental impacts. During this period, wastewater treatment has primarily focussed on water quality objectives and standards established by the regulatory authorities. Wastewater engineering solutions were based on more scientific and mathematical design approaches as a result of breakthrough research in the field with examples including suspended growth systems (activated sludge), biological nutrient removal systems and advancements in equipment technology. Steady-state design approaches were most commonly used, and dynamic mathematical modelling processes were developed for specific process units (e.g., bioreactor, anaerobic digester etc.)
- In recent years, there has been a mind shift to sustainable engineering design practises which focus on overall energy balance, process-related greenhouse gas emissions, carbon footprint, total chemical use, process by-products, resource recovery, operation and maintenance considerations and the fate of the constituents present in the effluent. With this mind shift, there is also a stronger focus on the assurance of effluent and by-product compliance, reduced lifecycle costing and the potential to optimise existing facilities to increase their treatment capability and capacity (e.g., upgrade of existing biological reactors to a moving bed biological reactor process; thermal hydrolysis process upstream of existing anaerobic digesters etc.). Although steady-state design approaches are still very common, with the recent shift in treatment objectives, there has been a significant shift towards plant-wide

modelling using dynamic mathematical modelling tools to cater for the broader spectrum of wastewater engineering objectives.

In wastewater engineering, specifically the process design discipline, a wastewater engineering solution can be based on either a steady-state or dynamic mathematical modelling approach using a process unit design approach (i.e., a separate modelling platform for each process unit), or a plant-wide design approach (i.e., a single modelling platform for the entire plant). The characterisation of the influent wastewater and specific wastewater parameters are critical for the design and expected performance of the plant. The design life of a wastewater treatment works (WWTW) is typically decades, and over time, the wastewater characteristics may change, impacting the plant's process capacity and performance, which may result in ineffective process control, inefficient operation and maintenance costs and poor-quality effluent and sludge. Mathematical models have the capability to model such changes with ease and predict the expected performance of the plant with regard to effluent and sludge quality.

This document presents the dissertation, “***A Comparison of Wastewater Process Modelling Tools: Case Study of Potsdam WWTW***”. The findings presented in this dissertation have been based on a theoretical modelling approach using steady-state and dynamic mathematical modelling tools on an existing full-scale WWTW, where the models have been calibrated on actual field data. The modelling approach aims to compare the output and results of the various models adopted for this research and to examine the impact that specific wastewater characteristics have on the process capacity and its influence on the overall performance of the WWTW. The wastewater characteristics to be examined under this dissertation include those wastewater characteristics considered most sensitive to impact on biological nitrogen and phosphorous removal (Ekama and Wentzel, 2008), namely:

- i. Influent Total Kjeldahl Nitrogen (TKN)
- ii. Maximum specific growth rate of nitrifiers (μ_{Max})
- iii. Readily biodegradable COD (RBCOD).

The case study WWTW is a full-scale plant, namely the Potsdam WWTW located in Cape Town (South Africa), owned and operated by the City of Cape Town. A more detailed description of the case study WWTW is provided under **Section 3**.

1.2 Objectives of Dissertation

The objectives of this dissertation are as follows:

- i. Firstly, to determine the existing theoretical process capacity of the case study WWTW based on actual (field data) influent characteristics, and predict the effluent quality characteristics using steady-state and dynamic-state modelling tools

- ii. Secondly, to compare the output and results of the various models (steady-state and dynamic-state) developed for the existing full-scale WWTW, and establish the reasons for the difference in model output and results where these occur
- iii. Thirdly, to examine the impact that specific wastewater characteristics have on the process capacity of the various process units and its influence on the overall performance of the WWTW, specifically with respect to effluent and sludge quality. The wastewater characteristics selected were those considered most critical to impact biological nitrogen and phosphorous removal
- iv. Lastly, based on the knowledge gained in this dissertation, specifically with respect to process modelling, to evaluate the design value offered by steady-state and dynamic-state modelling approaches, and provide some thoughts to further develop and enhance modelling tools from a designer's perspective.

1.3 Limitations of this Dissertation

From the outset, it is important to recognise the limitations of this dissertation. These limitations are documented below:

- The overall capacity of a WWTW is based on both the process capacity (i.e., process unit volumes, surface areas, retention times and equipment sizing required to meet the treatment objectives in terms of treated effluent and sludge quality) and the hydraulic capacity (i.e., maximum hydraulic flow the WWTW can accommodate via interconnecting pipework and channels linking process units). Throughout this dissertation, any references to capacity will imply process capacity only, and this dissertation will not consider the hydraulic capacity of the plant. The hydraulic capacity will however be documented in **Section 3** as extracted from existing technical reports
- Specific mechanical equipment (e.g., mechanical aeration system for the aerobic bioreactor and aerobic digester; capacity of recycling pumps etc.) currently installed at the Potsdam WWTW could be a limitation in terms of process capacity. For purposes of this dissertation, it has been assumed that the mechanical equipment will not be a limiting factor in terms of the overall capacity of the plant
- The existing Potsdam WWTW does not incorporate anaerobic digesters or aerobic digestion into the sludge treatment process. For purposes of this dissertation, these process units have been incorporated into the process to evaluate the impact that varying wastewater characteristics have on the sludge treatment stream, specifically anaerobic digestion
- The plant-wide steady-state and dynamic models developed for the full-scale WWTW will not consider supernatant return flows from the sludge treatment process units (i.e., thickeners; stabilisation process units and dewatering facility), which could impact the influent flow rate and influent organic load into the plant. This shortcoming is discussed in more detail under **Section 3.4**
- The PWSSD modelling tool does not incorporate a 5-stage Bardenpho module for the biological reactor (bioreactor). This is a major limitation, as the New Lane of the case study WWTW (described in Section 3.3) incorporates a 5-stage Bardenpho process. It is not possible to simulate the bioreactor

of the New Lane with one of the available activated sludge configurations (i.e., Johannesburg or UCT), as one would be comparing different process configurations. Thus, the bioreactor of the New Lane was not modelled in the PWSSD programme. This is elaborated in more detail in **Section 6.1.2**

- The historical flow data provided for the case study WWTW was limited to daily values, and for specific short periods identified by the Author, hourly data was made available. Flow data was however only provided for the influent raw wastewater, and not for the settled wastewater. However, sludge wasting rates from the PSTs were provided in the form of monthly figures, which enabled the Author to make a high-level estimate of the primary sludge underflow rates. The estimation of the primary sludge underflow rates in turn was used to calculate the settled wastewater flow rates. This assumption is discussed under **Section 4.4**
- The information made available for evaluating the case study WWTW wastewater characteristics (concentrations), the associated wastewater characterization (fractions) and diurnal load patterns were limited to grab sample data over a period of three years. Flow-weighted composite samples, non-flow-weighted composite samples over 24-hour intervals, or two-hour concentrations measured over a 24-hour day were not available. The aforementioned type of information is critical for the determination of flow-weighted averages for wastewater characteristics, characterisation of wastewater and the development of diurnal load patterns required in dynamic-state modelling. The grab sample data provided was suitable to inform the selection of the wastewater characteristics and a portion of the wastewater characterization (fractions), but not complete for the remainder of the wastewater characterisation and diurnal load patterns. As a result, several assumptions were required to inform the wastewater characterisation, namely the use of historically measured values published in the relevant research literature. To overcome the shortfall associated with the diurnal load patterns, the diurnal concentration patterns for the case study WWTW were based on the diurnal concentration patterns of the Stellenbosch WWTW which is also located in the Western Cape and has a similar catchment size with a similar nature of influent wastewater (i.e., mainly domestic with an industrial contribution from light industries). This was a major limitation, but the aforementioned assumption was required in order to develop a diurnal flow pattern for the influent and settled wastewater streams. This is elaborated in more detail in **Section 5.2.1**
- The various models adopted for this research under steady-state and dynamic-state conditions have been calibrated on historical field data, namely influent wastewater characteristics, daily flow variations; and specific process unit parameters, namely the bioreactor volume and the SST surface area. The models were however not calibrated against actual field data (i.e., effluent quality and sludge quality data) as the models developed under this research were not subject to limitations of the actual Potsdam WWTW. The limitations at the existing Potsdam WWTW include hydraulic limitations and limitations in mechanical equipment which impact the process such as the mechanical aeration system for the aerobic bioreactor and aerobic digester, and the capacity of recycling pumps. An evaluation of the impact that specific wastewater characteristics have on the process capacity (i.e., process volumes, retention times, surface areas, aeration requirements and sludge wasting volumes) and the overall performance of the WWTW (i.e., effluent quality and sludge quality) of the

various models was undertaken. The wastewater characteristics selected for this evaluation included influent Total Kjeldahl Nitrogen (TKN), the maximum specific growth rate of nitrifiers (μ_{Max}) and readily biodegradable COD (RBCOD) which is discussed under **Section 8**.

1.4 Overview of the Dissertation

The study methodology of this dissertation is summarised below:

1.4.1 Data collection

The data collection process comprised the collection of data from the City of Cape Town as required for this dissertation. The data included:

- Historical influent data
- Historical sampling data of influent, downstream of the primary settling tanks (PSTs) and effluent. The data was limited to grab samples
- Any technical reports on the WWTW
- As-built information (drawings of the existing plant)
- Operation and maintenance manuals.

1.4.2 Industry background on the application of wastewater process modelling

This section provides background on the application of wastewater process modelling in the design industry focussing on the following aspects:

- Defining steady-state and dynamic mathematical modelling approaches, and the concept of plant-wide models which leads to a discussion on the current approach in industry and the value models offer the design industry
- Available modelling software
- A discussion on shortcomings and challenges in the modelling industry from a design perspective.

1.4.3 Description of the case study WWTW

A thorough understanding of the case study WWTW is required, which entailed researching the process layout, process and control philosophy, and specific equipment which impacts the process operation and performance of the plant (e.g., aeration system and recycle pumps).

1.4.4 Analysis of flow data

An analysis of the historical influent flow data of the case study WWTW was undertaken in order to estimate the current average dry weather flow; peak factors for the peak dry weather flow and peak wet weather flow;

and diurnal dry weather flow patterns. The duration and time interval of the influent diurnal flow patterns is dependent on the capabilities of the steady-state and dynamic-state modelling tools adopted for this dissertation.

1.4.5 Wastewater characterization

An analysis of the historical sampling data received for the case study WWTW was undertaken in order to estimate the wastewater characteristics (concentrations), the associated wastewater characterization (fractions) and the diurnal load patterns. This analysis was carried out for the influent (at the head of the plant), settled wastewater (downstream of the primary settling tanks) and the effluent (at the end of the plant before discharging into the environment). The wastewater characteristics (concentrations), the wastewater characterisation and diurnal load patterns serve as input to the steady-state and dynamic-state models discussed below.

1.4.6 Development of plant-wide steady state models

Plant-wide steady-state models were developed for the case study WWTW using the following modelling software:

- A plant-wide steady-state model developed by the Author
- Plant-wide Steady-State Design (PWSSD) developed by Wu (Wu and Ekama, 2014)
- Plant-wide simulation (adopting constant flow and load conditions) using the BioWin 5.0 developed by EnviroSim Associates Ltd
- Steady-state design of the bioreactor using the UCTPHO modelling software developed by the University of Cape Town (2001) which was recently re-coded in Excel Visual Basic (De Swart and Ekama; 2016).

The models were developed using the data and parameters described under **Sections 1.4.4 and 1.4.5** above. This section of this dissertation aims to achieve the following outcomes:

- Estimate the existing process capacity (liquid and sludge streams), and theoretically determine the effluent quality and sludge characteristics of the case study WWTW
- Comparison of the steady-state models by comparing and analysing their output and results
- These models will serve as the base models for the evaluative study which is discussed in **Section 1.4.8** below.

1.4.7 Development of plant-wide dynamic-state models

Plant-wide dynamic-state models were developed for the case study WWTW using the following modelling software:

- UCTPHO was developed by the University of Cape Town (2001) which has recently been re-coded in Excel Visual Basic (De Swart and Ekama; 2016)

- BioWin developed by EnviroSim Associates Ltd.

The models were developed using the data and parameters described under **Sections 1.4.4 and 1.4.5** above. This section of this dissertation aims to achieve the following outcomes:

- Comparison of the two dynamic-state models by comparing and analysing their output and results, as well as a comparison with the output and results of the steady-state models discussed above
- These models will serve as the base models for the evaluative study which is discussed in **Section 1.4.8** below.

1.4.8 Evaluating the impact of specific wastewater parameters on system performance

This section of this dissertation entails an evaluation of the system performance, as predicted by the steady-state and dynamic-state models, when varying specific input wastewater characteristics. The output and results shall specifically focus on those parameters that influence the WWTW capacity and performance. In terms of capacity, the output variables considered include process volumes, retention times, surface areas, aeration requirements and sludge wasting volumes. In terms of performance, the output variables considered focus on effluent quality and sludge quality. The wastewater characteristics examined in the evaluative process include those parameters considered most sensitive to impact on a plant's capacity and performance, specifically with respect to nitrogen and phosphorous removal:

- i. Influent TKN
- ii. Maximum specific growth rate of nitrifiers (μ_{Max})
- iii. Readily biodegradable COD (RBCOD).

1.4.9 Discussion of findings of the Dissertation

This section provides a conclusive discussion on the findings of this dissertation, specifically covering the following:

- The importance of wastewater characterisation data in process design modelling
- A comparison of the estimated process capacity and documented design process capacity of the case study WWTW
- A comparison of the output results for the various models (steady-state and dynamic-state) developed under this dissertation for the case study WWTW
- The impact that a varying influent TKN, μ_{Max} and RBCOD has on an existing WWTW's process capacity and performance
- Lastly, based on the knowledge gained in this dissertation specifically with respect to modelling, evaluate the design value offered by steady-state and dynamic-state modelling approaches, and provide some thoughts to further develop and enhance modelling tools from a designer's perspective.

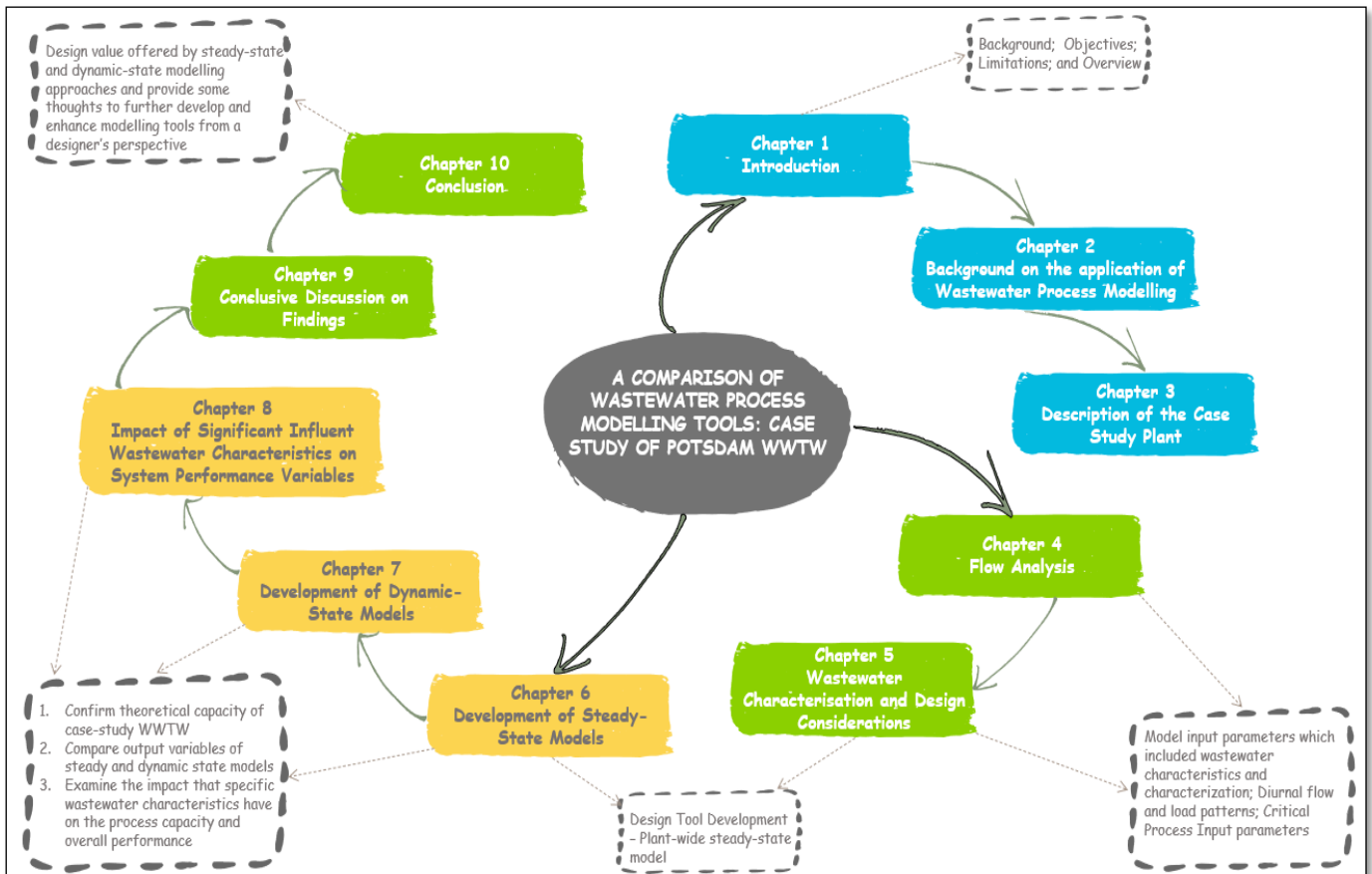
1.4.10 Conclusion

This section presents the conclusions of this dissertation.

1.4.11 Structure of Dissertation

The structure of this dissertation comprises 10 Chapters, References and Appendices. The structure of this dissertation is summarised below and further depicted in **Figure 1-1**:

1. **Chapter 1** is an introductory chapter which provides the background, the objectives, the limitations and an overview of this dissertation
2. **Chapter 2** provides background information on the application of process modelling in the wastewater engineering design industry
3. **Chapter 3** describes the case study WWTW, and provides a process description and a description of equipment which impacts the process performance of the plant
4. **Chapter 4** analyses the historical influent flow data of the case study WWTW in order to estimate the current average dry weather flow, factors for peak flows and diurnal flow patterns
5. **Chapter 5** analyses the historical sampling data of the case study WWTW in order to estimate the wastewater characteristics (concentrations), the associated wastewater characterization (fractions) and diurnal load patterns. This section also documents critical process input parameters
6. **Chapter 6** describes the modelling software adopted in this dissertation and provides a methodology for the development of the steady-state models. This chapter then presents a comparison of the steady-state models by comparing and analysing their output and results
7. **Chapter 7** provides a methodology for the development of the dynamic-state models. This chapter then presents a comparison of the two dynamic-state models by comparing and analysing their output and results, as well as a comparison to the output and results of the steady-state models
8. **Chapter 8** entails an evaluation of the system performance for nutrient removal, as predicted by the steady-state and dynamic-state models, when varying specific input wastewater characteristics
9. **Chapter 9** provides a conclusive discussion on the findings of this dissertation
10. **Chapter 10** presents the closing remarks of this dissertation.



2. BACKGROUND ON THE APPLICATION OF WASTEWATER PROCESS MODELLING

This section provides a background on the application of wastewater process modelling in the design industry, to provide insight into the following:

- Defining steady-state and dynamic mathematical modelling approaches, and the concept of plant-wide models
- A discussion on the current approach in the industry and the value models offer the design industry
- Available modelling software for the design industry
- A discussion on shortcomings and challenges in the process design modelling industry.

2.1 Types of Modelling approaches

A wastewater treatment process is a complex engineering solution due to the following:

- The process is governed by the complex interaction of biological, chemical and physical processes, with the product taking the form of various phases (aqueous, gas and solid)
- The process is inherently dynamic as a result of the following: i) The significant variations in the influent wastewater flow rate, load, composition and environmental conditions (e.g., temperature) cannot be controlled; and ii) The aforementioned variations will result in biological, chemical and environmental changes in the system, as the various processes adapt to these variations.

To manage these complexities, wastewater process models have been developed over the last 30 years to assist designers, operators and researchers. Wastewater process models are used as prognostic and diagnostic tools to design and optimise the biological, chemical and physical processes in a WWTW (Wu and Ekama, 2014). These models can be based on a steady-state or dynamic mathematical modelling approach, using a process unit design approach (i.e., a separate modelling platform for each process unit), or an integrated plant-wide design approach (i.e., a single modelling platform for the entire plant). Before any further discussion, it is important to first define the aforementioned terms as tabulated below:

TERM	DEFINITION
Mathematical model	A mathematical model is a representation of a system, which uses “mathematical concepts and language” based on “specific data and scientific principles” to describe and predict the behaviour of a system and its processes as would occur in reality.

TERM	DEFINITION
Empirical mathematical model	An empirical model is based on the recognition of parameters that seem to be essential to describe the behavioural pattern of interest and linking these by empirical relationships established by observation. The mechanisms and/or processes operating in the system are not known or are ignored (Van Loosdrecht <i>et al.</i> , 2008; Henze <i>et al.</i> , 2008).
Mechanistic mathematical model	A mechanistic model is based on some conceptualization of the biological/physical mechanisms operating in the system, i.e., is based on a conceptual idea (or model). The complexity of this mechanistic model will depend on the degree of understanding of the biological and chemical processes occurring in the system (Van Loosdrecht <i>et al.</i> , 2008; Henze <i>et al.</i> , 2008).
Steady-state mathematical model	<u>General definition:</u> A steady-state model is used to mathematically express and model the behaviour of a system and its processes at a specific time in a state of equilibrium. <u>Definition in the field of wastewater engineering:</u> In a steady-state model, the model is simulated with a constant organic load (combination of flow and wastewater concentrations) and is governed by specific rates (i.e., slowest kinetic rates) in terms of system design and operating parameters, linking the slowest rates to system performance.
Dynamic mathematical model	<u>General definition:</u> A dynamic model is used to mathematically express and model the behaviour of a system and its processes over time where all relevant variables are considered. <u>Definition in the field of wastewater engineering:</u> In a dynamic-state model, the model is simulated with a varying organic load (combination of flow and wastewater concentrations) and is governed by a variety of rates and parameters which requires computational support to simulate.
Plant-wide model	A plant-wide model is a library of models (mathematical and physical), integrated into a single platform to express and model the behaviour of a complete system, where all relevant variables and models are interlinked with outputs of one unit becoming inputs to the next. This approach can be incorporated into a steady-state or dynamic-state design.

Table 2-1 : List of key modelling definitions

As discussed in **Section 1.1** above, the objectives of wastewater treatment have transformed over the last century. During this period, the approach in wastewater process design has also transformed significantly as follows:

- Up until the 1980s, the process design mainly comprised of empirical design approaches which adopted a black box approach
- Between the early 1980s and the last decade, wastewater process design has been based on more scientific and mathematical design approaches as a result of breakthrough research in the field. These

design approaches lead to the development of steady-state models and dynamic mathematical models catering for specific process units (e.g., bioreactor, anaerobic digester etc.). The development of the activated sludge models (e.g., ASM1 by Henze *et al* (1987); ASM2 by Henze *et al* (1995); and ASM2D by Henze *et al* (1999) etc.) has been the most significant contribution to the field of modelling biological processes for municipal wastewater (Makinia, 2010).

In recent years, with the mind shift towards sustainable engineering design practises which focusses on stringent quality compliance, plant optimisation, minimising environmental impacts and the use of bi-products (effluent re-use; energy recovery; and nutrient recovery etc.), there has been a significant change in the field of wastewater process design. Although steady-state design approaches are still very common, there has been a significant shift toward plant-wide modelling using dynamic mathematical modelling tools which cater for the broader spectrum of wastewater engineering objectives and allow for more efficient design practises. This has opened the market for commercial wastewater treatment simulation software, further discussed in **Section 2.2** below.

More recently, WWTW modelling appears to be entering the next generation, where plant-wide modelling tools are being developed with the capacity to interface with a supervisory control and data acquisition (SCADA) system, therefore allowing real-time input for monitoring and control strategies. In the modern age, models are now required to cater for design, optimisation, scenario development, predict, simulate, monitor and control of the WWTW, and a dynamic model that adopts a plant-wide approach provides a powerful tool to achieve these requirements. Models are further required to ensure efficiency in design (save time and money); reduce design risk and inaccuracies; the capability to simulate a spectrum of available process configurations and technologies (established and emerging); and further function to assist designers with costing and reporting.

Steady-state models are powerful in the sense that they comprise simple, explicit, algebraic equations that allow high-level answers to be found easily and quickly, but with much less input information (Ekama, 2009). These models are usually simple and quick to estimate design requirements (i.e., volumes, areas, aeration requirements etc.) and operation requirements (e.g., wasting rates) of a WWTW. In contrast, dynamic models require detailed input information and sophisticated mathematical solvers (Wu and Ekama, 2014), but are more accurate in predicting effluent quality, system responses to dynamic conditions and the inhibitory effects of pH, temperature and metabolic products.

There is the notion that dynamic models are more suited to the optimisation of an existing WWTW, than the design of a new WWTW. This reasoning is supported by the extensive input requirements of dynamic models, especially as input information may not always be available. While this notion has merit, there is no reason why a new WWTW cannot be designed using a dynamic modelling approach, provided the model is updated as more credible input becomes available. However, based on the current commercial modelling simulators available, it is best practise to first simulate a steady-state design, where the output of the steady-state design will serve as input to the dynamic model which can then be used to refine and optimise the design. With this design procedure, it can be seen that steady-state models are pre-processors to the dynamic models, and that they complement the dynamic models as they generate the starting conditions required to initiate the

dynamic simulation (Ekama, 2009). Steady-state models are therefore powerful pre-processors for dynamic models as they can generate the overall WWTW scheme, main system defining parameters, and major sources of plant data error, which should be known before dynamic models are used (Ekama, 2009).

The option of selecting a steady-state modelling approach versus a dynamic modelling approach is dependent on several factors:

- Available data: Where data is limited, steady-state models are preferred as they typically require less user input and are therefore based on fewer assumptions. Where data is extensive and sufficient to meet the requirements of a dynamic model, then a dynamic model should be considered
- Time: Steady-state models using available tools are quick to build, model, optimise and validate. Dynamic models typically require more time for a similar type of scope.
- Project design stage: During the early stage of a project (feasibility and concept design), steady-state models are preferred due to their simplicity and speed, and that data may be limited during this early stage of the project. However, when a project enters the latter stages of the design process (preliminary and detailed design), more information is available, and the design requires a higher level of accuracy, and as such, a dynamic model is preferred
- Size and complexity of the plant: A simple works can be defined as a small-scale plant, or a plant with a few process units. For a simple works, steady-state models are preferred. A complex works can be defined as a large plant (comprising numerous lanes as per the case study WWTW), or a plant with numerous process units. For a complex works, dynamic models adopting an integrated plant-wide approach are preferred.

Wastewater process models can serve as a valuable tool for design, optimisation and operational and control strategies. The selection of a steady-state versus dynamic modelling approach will be dependent on the factors discussed above, as well as the detail and accuracy required by the designer.

2.2 Available Modelling Software

Wastewater process models fall within the following modelling platform categories:

- Spreadsheets. (e.g., Microsoft Excel) and hand calculations: These can be used effectively for steady-state models but are prone to human error. This approach is commonly used by designers
- Low-level programmes (e.g., C++, Fortran, Visual Basic etc.): These can be used for steady-state and dynamic models, but the development process is time-consuming. This approach is typically adopted for stand-alone models (i.e., single process design unit such as a bioreactor) developed in the research field
- Simulation tools (e.g., BioWin, GPS-X, SIMBA, West, SUMO etc.): A wastewater treatment simulator can be described as software that allows the modeller to simulate a wastewater treatment plant configuration. Some of the available software allows an open model structure, that allows users a

degree of freedom for amending modelling processes and parameters or developing user-specified process units.

The user interface of wastewater process models has a large impact on the success of the software, specifically those offered in the commercial market. As such, commercial software is continuously being upgraded to ensure the interface is user-friendly, the programme is efficient in terms of simulation runs and the programme is up to date with the latest research and technologies. In the design industry, the following commercial wastewater simulation software currently makes up the majority of the market share:

MODELLING SOFTWARE	DEVELOPER	APPLICATIONS
BioWin www.envirosim.com	EnviroSim Associates Ltd; Canada	Design; optimisation; and operational and control strategies. Regularly updated with the latest research and technologies
EFOR www.dhisoftware.com/efor	Wise-RTD; Denmark	Design; and optimisation
GPS-X www.hydromantis.com	Hydromantis; Canada	Design; optimisation; and operational and control strategies. One of the first commercial simulators
SIMBA (SIMulation programms für die Biologische Abwasserreinigung) www.inctrl.ca/software/simba/	InCTRL Solutions; Germany	Design; optimisation; and operational and control strategies
STOAT (Sewage Treatment Optimization and Analysis over Time) www.wrcplc.co.uk/ps-stoat	WRc; United Kingdom	Design; and optimisation
WEST (Worldwide Engine for Simulation, Training and Automation) www.mikepoweredbydhi.com/products/west	Danish Hydraulic Institute (DHI); Denmark	Design; optimisation; operational and control strategies; online monitoring and troubleshooting of treatment plant operations; and Integration with SCADA systems

MODELLING SOFTWARE	DEVELOPER	APPLICATIONS
SUMO https://dynamita.com/	Dynamita; France	Design; optimisation; operational and control strategies; cost and energy calculator; and open source simulator.

Table 2-2 : List of commercial wastewater simulation packages

The above commercial wastewater simulators are based on physical, chemical and biological (e.g., Activated sludge model (ASM) Nos 1, 2, 2d and 3; Anaerobic digestion model (ADM) No 1 etc.) models. BioWin and WEST® are currently the most commonly used software platforms in the South African market.

2.3 Shortcomings and Challenges

As discussed in **Section 2.1**, a wastewater treatment process is a complex one due to the complex interactions of different processes and variations in influent parameters. To manage these complexities, wastewater process models have been developed over the last 30 years to assist designers. These models have evolved from stand-alone models for individual process units to an integrated plant-wide modelling approach (Jones and Takács, 2004; Grau *et al.*, 2007). The modelling field is now entering the next generation, where plant-wide modelling tools are being developed with the capacity to interface with a SCADA system, therefore allowing real-time input for monitoring and control strategies (i.e., digital twins; IWA, 2021a; Johnson *et al.*, 2021). Despite these advances, there are still shortcomings and challenges in the wastewater modelling environment as follows:

- Lack of data:
 - In the South African modelling environment, actual plant data (flows, sampling and laboratory analysis data etc.) is always lacking due to poor monitoring practises. In the majority of cases, especially where an existing plant is being evaluated, the user is required to make educated and calculated estimates of the wastewater influent parameters
 - In a greenfield design, there is no data, so safety factors need to be incorporated into the modelling design, which could result in a plant that is over-designed. This may lead to an inefficient design which results in higher capital and lifecycle costs.
- Modelling simulators:
 - Several different commercial modelling simulators are available in the market, and many plant owners use a specific model. In the South African environment, BioWin and West appear to be the most commonly adopted by local authorities and water utilities. As a result, designers in the South African market need to be proficient with both tools

- Design approaches and processes differ between the different simulation software, and in most cases, these models can be viewed as black box approaches as they are closed source and very little is known about the biological, chemical and physical processes underlying the model
- Most modelling simulators require an independent steady-state design to be performed initially to estimate design requirements (i.e., volumes, surface areas, aeration requirements etc.), and these would typically serve as input parameters to the modelling simulator. Even though most modelling simulators incorporate a steady-state design model, the aforementioned design requirements are also input parameters to the modelling simulator's steady-state design, hence the need for an independent steady-state design.
- Lack of validation of commercial modelling simulators:
 - Limited independent research has been done on the validation of commercial modelling simulators, especially those incorporating a plant-wide approach. Any validation can be outdated quickly, as commercial simulators are updated regularly to incorporate the latest research.

Despite the shortcomings and challenges discussed above, the significant advancement in wastewater process models in recent years, especially commercial wastewater simulation software has provided designers, operators and researchers with a powerful design tool to aid in the process design of a WWTW. These tools are fast evolving to manage prolific data inputs, improve process design modelling efficiency and the capacity to interface with a SCADA system of an actual WWTW for monitoring and control strategies.

3. DESCRIPTION OF THE CASE STUDY PLANT

This chapter provides background on the case study WWTW, a process description of the liquid and sludge streams, and a description of the critical mechanical equipment which impacts the operation and process performance of the plant and is most relevant to this dissertation.

3.1 History of Potsdam WWTW

The City of Cape Town operates 26 wastewater treatment facilities, two oxidation ponds, three marine wastewater disposal outfalls, one trickling filter system, four rotating biological contactor systems and sixteen activated sludge plants with a total treatment capacity of approximately 750 Mℓ/day. The Potsdam WWTW is the fifth largest of the City's plants with a design average dry weather flow (ADWF) capacity of 47 Mℓ/day. The plant was originally commissioned in 1957 and receives most of its wastewater from a rapidly developing area along the western seaboard, north of the Cape Town central business district. The composition of the wastewater received at the Potsdam WWTW is mainly domestic with an industrial contribution from light industries in the catchment area. A summary of the major upgrades to the plant over the last 20 years is documented below:

- In 1997, the plant was upgraded to a treatment capacity of 32 Mℓ/day in terms of ADWF, which comprised an existing 15 Mℓ/day biological trickling filter lane and a new 17 Mℓ/day biological nutrient removal (BNR) lane
- In 2008, the plant was upgraded and extended to a treatment capacity of 47 Mℓ/day in terms of ADWF, which comprised the existing 17 Mℓ/day BNR lane and a new 30 Mℓ/day BNR lane. The old 15 Mℓ/day biological trickling filter lane was decommissioned during this upgrade.

3.2 Description of Catchment Area

A locality map of the Potsdam WWTW is included in **Figure 3-1** below. The Potsdam WWTW receives most of its wastewater from a rapidly developing area along the western seaboard, which includes the Milnerton area, Table View area, development towards Koeberg interchange, Sandrif, Century City as well as parts of Parow. Flow arrives at the inlet works from four bulk sewer pump stations, namely the Table View East pump station, Koeberg Road pump station, De Noon pump station and Lupin Crescent pump station. In addition, a small flow gravitates to the plant from the Bothasig area.

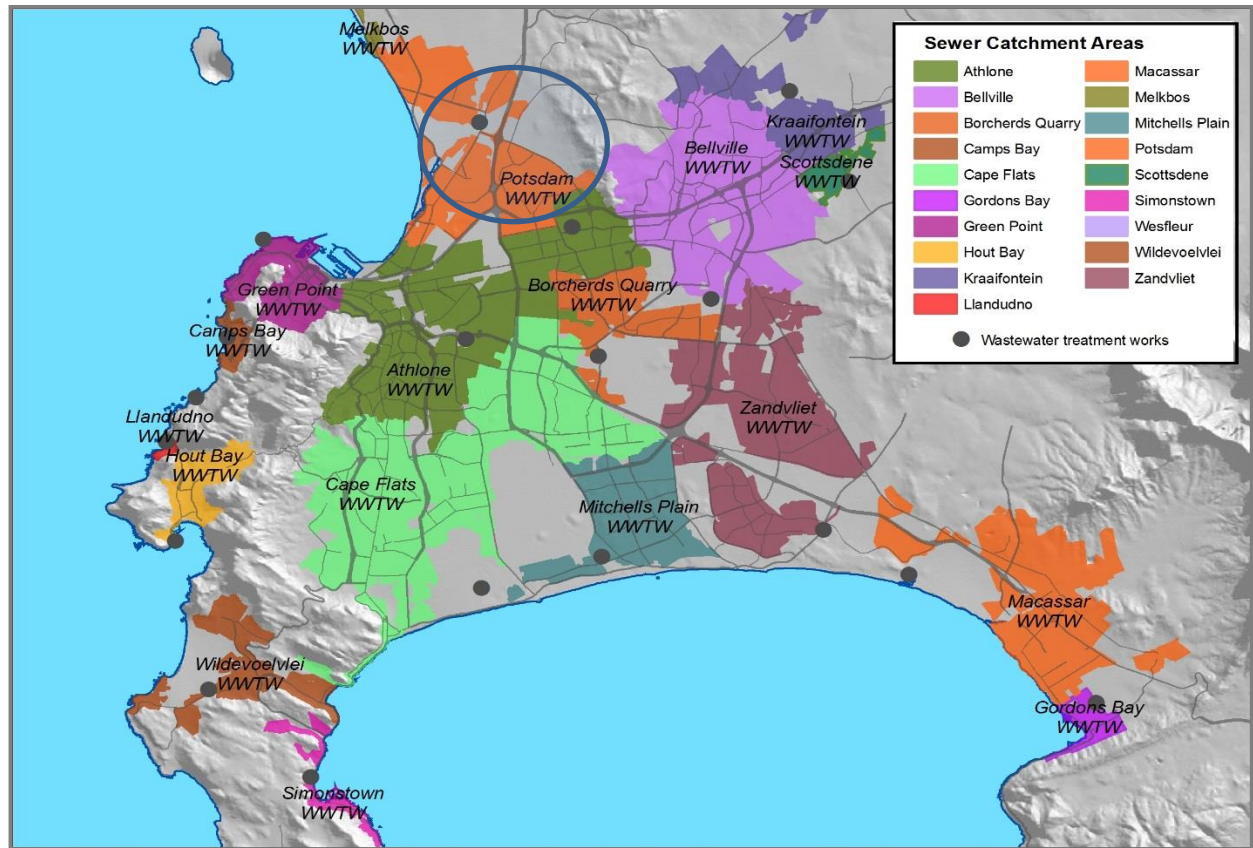


Figure 3-1 : A locality map of the Potsdam WWTW

The WWTW is located along the Koeberg main road located near the Table View residential area and in close proximity to the Rietvlei protected natural environment. The treated effluent from the plant is released into a channel that bypasses the Rietvlei protected natural environment and routes the treated effluent to join the Diep River between the developments of Sunset Beach and Royal Ascot. The Water Use License for the plant, issued by the Department of Water and Sanitation (DWS) prescribes effluent treatment standards which must comply with the General Authorisation in terms of Section 39 of the National Water Act (Act No. 36 of 1998). The effluent released from the Potsdam WWTW into the downstream environment must comply with the general limit, with the exception of the phosphorous, which must comply with the special limit (ortho-phosphates as phosphorous to be less than 1mg/l).

The remainder of the treated effluent (approximately 11 Ml/day in summer) is re-used for irrigation and industrial purposes, where treated effluent from the plant is pumped to a treated effluent storage reservoir feeding users in the Table View area. A separate pump station distributes treated effluent to the Century City area. A summary of the large treated effluent users who have existing agreements with the City of Cape Town is documented below:

- Century City (summer and winter)
- Farmers in the Durbanville area (summer and winter)
- Milnerton Golf course (summer only)
- Theo Marais Sports Fields (summer only)

- SAPPI (industrial) (summer and winter)
- Milnerton High School (summer only)
- Milnerton Primary School (summer only)
- Unitas Parl (summer only)
- Woodbridge Primary (summer only)
- Table View Irrigation (summer only)
- Caltex (summer and winter).

3.3 Process Description of Liquid Stream

The Potsdam WWTW comprises a combined inlet works and two liquid stream lanes referred to as the Old Lane and New Lane as follows:

- **Combined Inlet Works:** The influent flow enters a combined inlet works which then feeds the Old Lane and New Lane
- **Old Lane:** This lane was constructed in 1997 and has a design capacity of 17 M³/d ADWF at a 1,000 mg/l Chemical Oxygen Demand (COD). This lane comprises two primary setting tanks (PSTs), a lift pump station to the bioreactor, a biological nutrient removal bioreactor (University of Cape Town (UCT) process) system with internal recycle pump stations (referred to as UCT bioreactor), six secondary settling tanks (SSTs), sludge return (s) recycle pump station, and centralised disinfection facilities for the Old Lane and New Lane which comprises a series of maturation ponds and ultraviolet (UV) disinfection (open channel system). The hydraulic capacity of this lane for all flow conduits and process units is 2.7 x ADWF, with the exception of the disinfection facility which is designed for 2.8 x ADWF
- **New Lane:** This lane was commissioned in 2008 and has a design capacity of 30 M³/d ADWF at a 1,000 mg/l COD. This lane comprises a raw sewage lift pump station (downstream of inlet works), three PSTs, a biological nutrient removal bioreactor (5-stage Bardenpho process) system with internal recycle pump stations (referred to as Bardenpho bioreactor), six SSTs, s-recycle pump station and the centralised disinfection facilities described above. The hydraulic capacity of this lane for all flow conduits and process units is 3.5 x ADWF, with the exception of the disinfection facility which is designed for 2.8 x ADWF.

This dissertation will only evaluate the process units which impact the process capacity, effluent quality and sludge quality (i.e., process units specific to the liquid stream will include the PSTs, bioreactor and associated recycle pump stations, SSTs, s-recycle pump station and sludge waste pump stations).

3.3.1 Combined Inlet Works

All flow received from the bulk sewer pump stations and bulk sewer outfall passes through the combined inlet works which comprise coarse mechanical front raked screens, fine rotating drum screens, grit removal and flow measurement. The coarse mechanical front raked screens are installed at the old inlet works structure,

and the balance of the aforementioned equipment is installed at the new inlet works structure. The screened sewage then collects at a two-way splitter, splitting flow proportionally to the following liquid stream lanes:

- The two PSTs dedicated to the Old Lane (17 Mℓ/d in terms of ADWF) as illustrated in **Figure 3-2**
- The lift pump station is dedicated to the New Lane (30 Mℓ/d in terms of ADWF) is illustrated in **Figure 3-3**.

3.3.2 Old Lane

A detailed summary of the process configuration of the Old Lane is summarised below and also graphically illustrated in **Figure 3-2**:

- Primary settling tanks (PSTs): From the two-way splitter downstream of the combined inlet works, approximately 17 Mℓ/d in terms of ADWF is distributed to the two PSTs (circular, sloping bottom type) of the Old Lane. The following process streams exit the PSTs:
 - The settled sewage from the PSTs collects at the common sump of a settled sewage pump station
 - The primary sludge gravitates to a primary sludge holding tank, from where it is pumped to the sludge treatment facilities which is discussed under **Section 3.4**
- Settled sewage pump station: The settled sewage is lifted to the UCT bioreactor via a lifting pump station (comprising four pumps, three duty and one standby) to a two-way bioreactor flow splitter. Each pump has a maximum duty flow of 174 ℓ/s (15 Mℓ/d)
- Biological reactor system: From the two-way bioreactor flow splitter, the flow is distributed equally between two identical bioreactor lanes. After exiting the two UCT bioreactor lanes, the flow collects at the sump of an SST six-way splitter. The bioreactor system comprises a UCT treatment process which is a nitrification, denitrification and biological excess phosphorus removal (NDBEPR) activated sludge system. The UCT process further incorporates the following:
 - An anaerobic zone, anoxic zone and aerobic zone allow for biological nutrient removal
 - Mechanical mixers (platform mounted fixed speed mixers) are equipped in the unaerated zones
 - The aerobic zone comprises platform mounted fixed speed surface aerators
 - Dedicated a-recycle pumps per lane (two sets of axial flow pumps, one duty and one standby per pump station) returns flow from the aerobic zone to the anoxic zone
 - Dedicated r-recycle pumps per lane (two axial flow pumps, one duty and one standby per pump station) returns flow from the anoxic zone to the anaerobic zone
 - The sludge age in the system is hydraulically controlled by wasting from the aerobic zone of the UCT bioreactor. The waste activated sludge (WAS) gravitates to the sludge treatment facilities which is discussed under **Section 3.4**
 - The UCT process caters for higher biological phosphorous removal when compared to other Nitrification, Denitrification and Biological Excess Phosphorous Removal systems (NDBEPR) by minimising nitrate recycled to the anaerobic zone. This is achieved by recycling mixed

liquor from the anoxic zone to the anaerobic zone which has a very low nitrate concentration, thus limiting nitrate to the anaerobic zone and making more readily biodegradable COD (RBCOD) available for the poly accumulating organisms (PAOs) in the anaerobic zone, thereby enhancing phosphorous removal. The relationship between RBCOD and PAOs is discussed in more detail in **Section 8.4.1**. Complete denitrification is not possible in a UCT process because it lacks a post-aerobic and anoxic reactor. However, the anoxic reactor in a UCT process generally has a high denitrification rate, and can generally provide a high percentage of nitrogen removal (approximately 80%) (Wu and Ekama, 2014)

- Secondary setting tanks (SSTs): From the six-way SST flow splitter, the flow is distributed proportionally between six SSTs (circular, sloping bottom type). The following process streams exit the SSTs:
 - The effluent from the SSTs collects at a collection chamber from where it gravitates to a series of maturation ponds
 - The sludge underflow is recycled from the SSTs via the s-recycle (RAS) pump station to the anaerobic zone of the UCT bioreactors
 - The s-recycle pump station comprises 3 immersible pumps, 2 duty pumps required to meet the average and peak dry weather flow scenarios, and 3 duty pumps required to meet the peak wet weather flow scenario
- Maturation ponds: The effluent from the Old Lane discharges into a maturation pond before being discharged into the ultraviolet (UV) disinfection facility
- Ultra-Violet (UV) disinfection facility: The flow together with the effluent from the New Lane passes through an open channel (two channels) UV disinfection facility before being discharged into a holding pond
- Holding Pond: From the holding pond, the treated effluent is distributed as follows:
 - A nominal amount (approximately 5 Mℓ/day) is recycled for on-site use, namely process water for the various process units (mechanical screens and belt presses at dewatering building), on-site wash-water and irrigation
 - Approximately 11 Mℓ/day (summer) is re-used for off-site irrigation and industrial purposes as discussed in **Section 3.2**
 - The balance of the treated effluent is released into the Diep River.

A schematic process flow diagram of the Old Lane's liquid stream is depicted in Figure 3-2 (see overleaf):

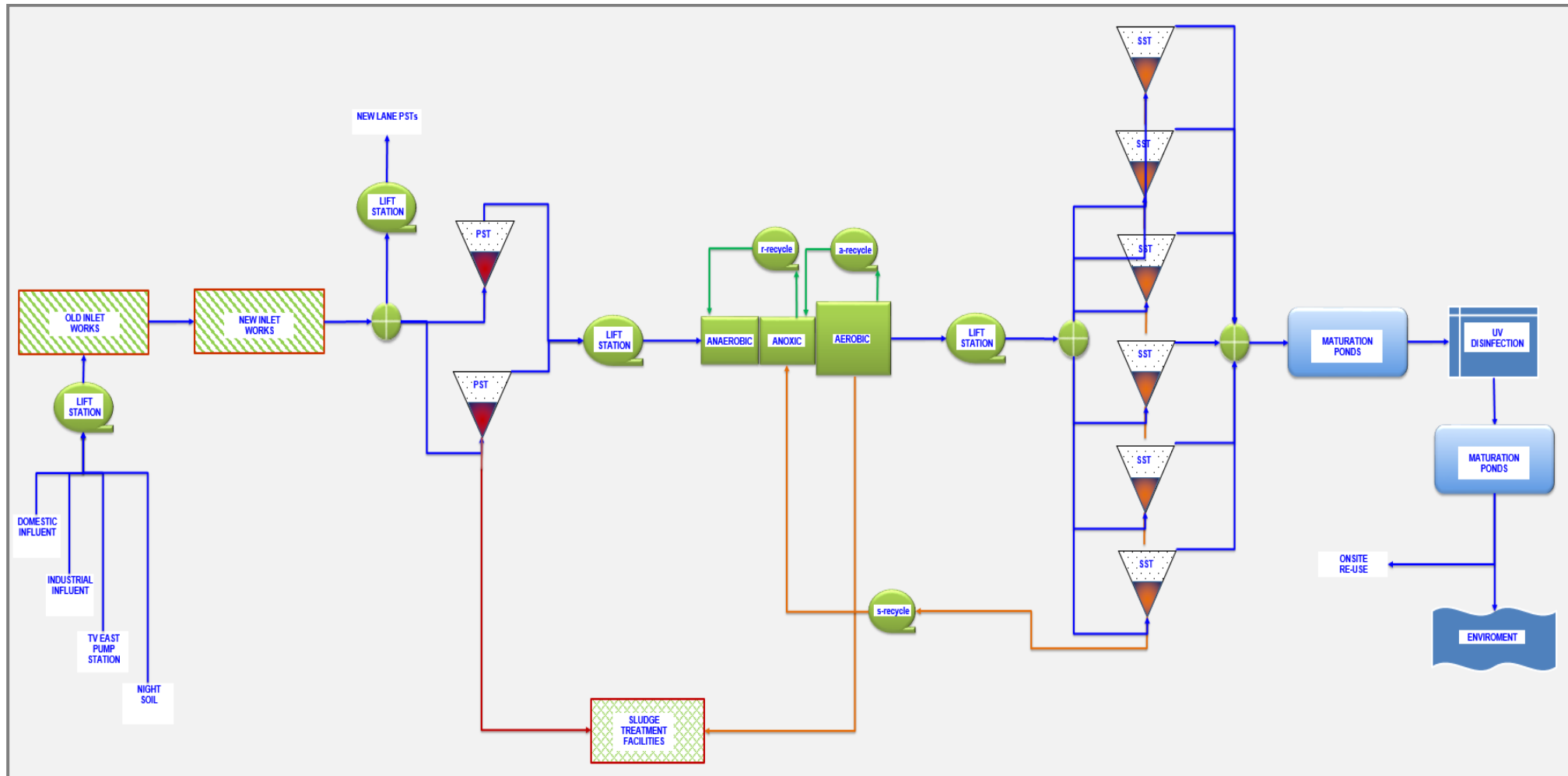


Figure 3-2 : Schematic process flow diagram of Old Lane (liquid stream)

A summary of the key process units and their features (i.e., volume, surface areas and mechanical specifications) which impact the process operation and performance of the plant is summarised in Table 3-1 below:

PROCESS UNIT		PROCESS PARAMETER
Primary Settling Tanks		Number of PSTs = 2 Diameter of PST = 25 m Surface area per PST = 491 m²
Biological Reactor (UCT process)	Anaerobic Zone	Total volume for both UCT bioreactors = 1 640 m ³
	Anoxic Zone	Total volume for both UCT bioreactors = 1 100 m ³
	Aerobic Zone	Total volume for both UCT bioreactors = 7 100 m³ The aeration system comprises platform-mounted surface aerators. Total Installed Aeration Power = 390 kW for both bioreactors, comprising 2 x 75 kW and 1 x 45 kW (per bioreactor lane)
	a-recycle Pumps	Duty flow per pump = 394 l/s comprising a set of one duty and one standby pump per reactor lane a-recycle ratio: 4 : 1
	r-recycle Pumps	Duty flow per pump = 197 l/s comprising a set of one duty and one standby pump per reactor lane r-recycle ratio: 1 : 1
Secondary Settling Tanks		Number of SSTs = 6 Diameter of SST = 25 m Surface area per SST = 491 m² Side water depth: 3.575 m

PROCESS UNIT	PROCESS PARAMETER
	Sloping bottom type (1:6) Sludge Collection: Sludge withdrawal pipe gravitating to RAS pump station sump. The sludge withdrawal rate is controlled via a telescopic valve
s-recycle pumps (RAS pump station)	Average duty flow scenario = 295 l/s comprising two duty and one standby (1.5 x ADWF) Peak duty flow scenario = 443 l/s comprising three duty and no standby (2.25 x ADWF)

Table 3-1 : Summary of process units (Old Lane)

3.3.3 New Lane

A detailed summary of the process configuration of the New Lane is summarised below and graphically illustrated in **Figure 3-3**:

- Lift pump station: From the two-way splitter downstream of the combined inlet works, approximately 30 Ml/d in terms of ADWF is distributed to the Lift pump station of the New Lane. From the lift pump station (comprising three pumps, two duty and one standby), the screened sewage is lifted to a three-way PST flow splitter
- PSTs: From the three-way PST flow splitter, the flow is distributed proportionally between three PSTs (circular, sloping bottom type). The following process streams exit the PSTs:
 - The settled sewage from the PSTs collects at the common sump of a two-way bioreactor splitter
 - The primary sludge gravitates to a primary sludge holding tank, from where it is pumped to the sludge treatment facilities, which is discussed further under **Section 3.4**
- Biological reactor system: From the two-way bioreactor flow splitter, the flow is distributed equally between two identical Bardenpho bioreactor lanes. After exiting the two bioreactor lanes, the flow collects at the sump of an SST six-way splitter. The bioreactor system comprises a 5-stage Bardenpho process configuration, which is also a NDBEPR activated sludge system. The 5-stage Bardenpho process further incorporates the following:
 - An anaerobic zone, primary anoxic zone, aerobic zone, secondary anoxic zone and re-aeration zone which allows for biological nutrient removal
 - Mechanical mixers (platform-mounted fixed speed mixers) are equipped in the unaerated zones

- The aerobic zone comprises platform-mounted fixed speed surface aerators. Each aerator has an associated DO probe, and the speed of each aerator is controlled by its associated DO probe so that a selectable residual DO is maintained
- The re-aeration zone comprises one platform mounted fixed speed aerator per Bardenpho bioreactor lane
- An a-recycle pump station (two axial flow pumps, one duty and one standby) can return flow from the aerobic zone to either the anoxic or anaerobic zone
- The sludge age in the system is hydraulically controlled by wasting from the re-aeration zone of the Bardenpho bioreactor. The WAS gravitates to the sludge treatment facilities which is discussed further under **Section 3.4**
- The 5-stage Bardenpho process caters for high nitrogen removal by introducing a secondary anoxic zone downstream of the aerobic zone, thereby allowing for denitrification of any nitrate exiting the aerobic zone. The 5-stage Bardenpho process has the ability for complete denitrification, but where the influent TKN/COD ratio is greater than 0.10 mgN/mgCOD, this is not possible, resulting in elevated nitrate concentrations in the effluent and the underflow recycle from the SSTs to the anaerobic zone (Ekama and Wentzel., 2008). The latter negatively impacts phosphorous removal which is discussed in more detail in **Section 8.4.1**. The re-aeration zone is used to strip residual nitrogen gas from solution and to raise the dissolved oxygen (DO) concentration to minimise phosphorous release in the SSTs
- SSTs: From the six-way SST flow splitter, the flow is distributed proportionally between six SSTs (circular, sloping bottom type). The following process streams exit the SSTs:
 - The effluent from the SSTs collects at a collection chamber from where it gravitates to a series of maturation ponds
 - The sludge underflow is recycled from the SSTs via the s-recycle (RAS) pump station to the anaerobic zone of the Bardenpho bioreactor
 - The s-recycle pump station comprises three immersible pumps, 2 duty pumps required to meet the average and peak dry weather flow scenarios, and 3 duty pumps required to meet the peak wet weather flow scenario
- Maturation Ponds: The effluent from the New Lane circulates through a series of four maturation ponds, before being discharged into the UV disinfection facility
- UV Disinfection Facility: The flow together with the flow from the Old Lane passes through an open channel (two channels) UV disinfection facility before being discharged into a holding pond
- Holding Pond: From the holding pond, the treated effluent is distributed for various uses as discussed in **Section 3.3.2** above.

A schematic process flow diagram of the New Lane's liquid stream is depicted below (see overleaf):

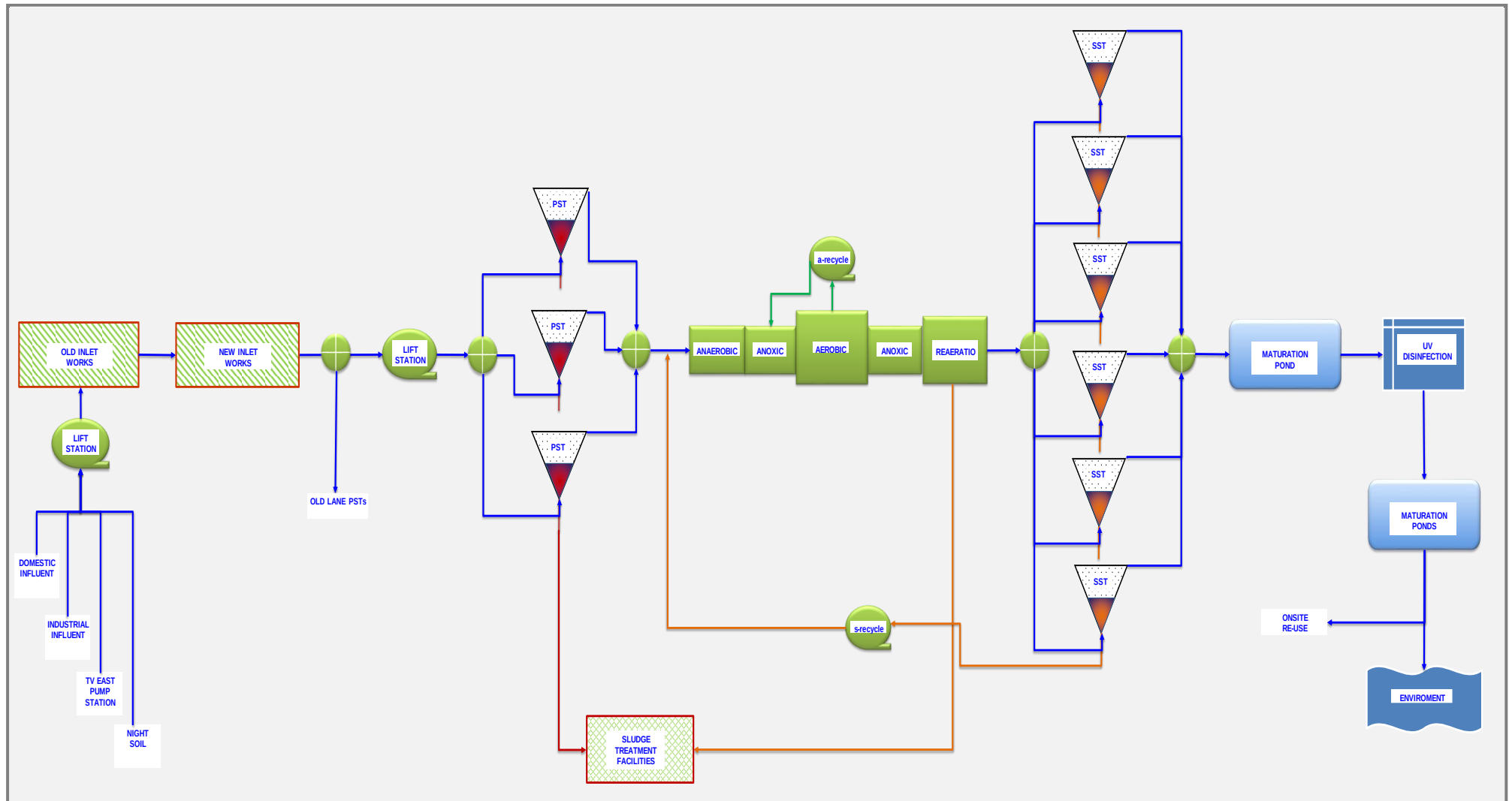


Figure 3-3 : Schematic process flow diagram of New Lane (liquid stream)

A summary of the key process units and their features (volume, surface areas and mechanical specifications) which impact the process operation and performance of the plant is summarised in the table below:

PROCESS UNIT		PROCESS PARAMETER
Primary Settling Tanks		Number of PSTs = 3 Diameter of PST = 33 m Surface area per PST = 855m²
Biological Reactor (5-stage Bardenpho process)	Anaerobic Zone	Total volume for both Bardenpho bioreactors = 5 400 m ³
	Primary Anoxic Zone	Total volume for both Bardenpho bioreactors = 7 150 m ³
	Aerobic Zone	Total volume for both Bardenpho bioreactors = 16 800 m³ Aeration system comprises platform mounted surface aerators. Total Installed Aeration Power = 1100 kW for both bioreactors, comprising 2 x 110 kW and 3 x 110 kW (per bioreactor lane)
	Secondary Anoxic Zone	Total volume for both Bardenpho bioreactors = 5 100 m ³
	Re-aeration Zone	Total volume for both Bardenpho bioreactors = 1 850 m³ The aeration system comprises platform-mounted surface aerators. Total Installed Aeration Power = 90 kW for both bioreactors, comprising 1 x 45 kW (per bioreactor lane)
	a-recycle Pumps	Duty flow per pump = 694 l/s comprising a set of one duty and one standby pump per reactor lane a-recycle ratio: 4 : 1
Secondary Settling Tanks		Number of SSTs = 6 Diameter of SST = 35 m Surface area per SST = 962 m² Side water depth: 3.5 m

PROCESS UNIT	PROCESS PARAMETER
	Sloping bottom type (1:6) Sludge Collection: Sludge withdrawal pipe gravitating to RAS pump station sump. The sludge withdrawal rate is controlled via a telescopic valve
s-recycle pumps (RAS pump station)	Average duty flow scenario = 521 l/s comprising two duty and one standby (1.5 x ADWF) Peak duty flow scenario = 694 l/s comprising three duty and no standby (2 x ADWF)

Table 3-2 : Summary of process units (New Lane)

3.4 Process Description of Sludge Stream

The Potsdam WWTW comprises a sludge handling and dewatering facility, treating sludge received from the two liquid stream lanes, namely the Old Lane and New Lane. The sludge handling and dewatering facility comprise two treatment lanes:

- **Primary sludge lane:** The primary sludge from the underflow of the PSTs for both the Old Lane and New Lane gravitates to two holding tanks. From the holding tanks, the sludge is pumped onto the mechanical filter belt presses installed at the dewatering building. The dewatered sludge is then pumped into a dedicated sludge silo. The dewatered sludge in the sludge silo is collected, then transported and disposed of at the Vissershok landfill site. The primary sludge is not stabilised. The supernatant from the primary sludge dewatering facility is relayed back to the combined Inlet Works which is discussed in more detail under **Section 3.4.1** below
- **Waste activated sludge (WAS) lane:** The WAS sludge from the bioreactors of the two lanes is pumped to three dissolved air flotation tanks (DAF units), where the sludge is thickened. The thickened sludge is then pumped to two aerobic digesters where the sludge is stabilised⁵. The digested sludge is then pumped to a holding tank, which eventually feeds onto mechanical filter belt presses installed at the dewatering building. The dewatered sludge is then pumped into a dedicated sludge silo. The

⁵ Following discussion with the plant's operational personnel in April 2016, the City of Cape Town currently bypasses the aerobic digesters, and the thickened sludge from the DAF units is pumped directly to a holding tank upstream of the dewatering facility. The proposed reason for bypassing the aerobic digester is that aerobically digested sludge generated on-site achieves a lower solids concentration after dewatering, which increases disposal costs to the Vissershok landfill site.

dewatered sludge in the sludge silo is collected, then transported and disposed of at the Vissershok landfill site. The supernatant from the WAS dewatering facility is relayed back to the UCT bioreactor of the Old Lane which is described in more detail under **Section 3.4.2** below.

3.4.1 Primary Sludge Lane

A detailed summary of the process configuration for the primary sludge lane is summarised below and graphically illustrated in **Figure 3-4** below:

- Primary sludge holding tank and pump station: The primary sludge from the underflow of the PSTs of both the Old Lane and New Lane gravitates to two holding tanks. Wasting from the PSTs is controlled such that the solids concentration of the primary sludge is 3.5% or more, which is controlled by the sludge withdrawal rate via a flow meter and sludge density meter. An emergency overflow links the smaller tank to the larger tank, specifically for storage during an emergency. A sludge pump station then relays the sludge from the holding tanks to two mechanical filter belt presses located at the dewatering facility. The sludge pump station comprises two variable speed progressing cavity pumps (duty and standby configuration) each with a duty flow of approximately 13.9 l/s (1.2 Ml/day)
- Dewatering Facility:
 - Mechanical filter belt presses: The primary sludge received at the dewatering facility is dosed with polymer and then dewatered on mechanical filter belt presses, and the dewatered sludge is then pumped into a sludge silo
 - Sludge Silo: A dedicated sludge silo temporally stores the dewatered sludge
 - Supernatant: All supernatant from the primary sludge dewatering facility gravitates to the Table View East pump station, where it is pumped to the inlet works. Primary sludge typically has a low nitrogen and phosphorous content. As a result, returning the supernatant back to the liquid stream (head of works) should not have a major impact on the liquid stream treatment process as the supernatant will have a low nitrogen and phosphorous content
- Disposal: The dewatered sludge in the sludge silo is collected almost daily, transported and disposed of at the Vissershok landfill site.

A schematic process flow diagram of the sludge stream (primary sludge lane and WAS lane) is depicted below (see overleaf):

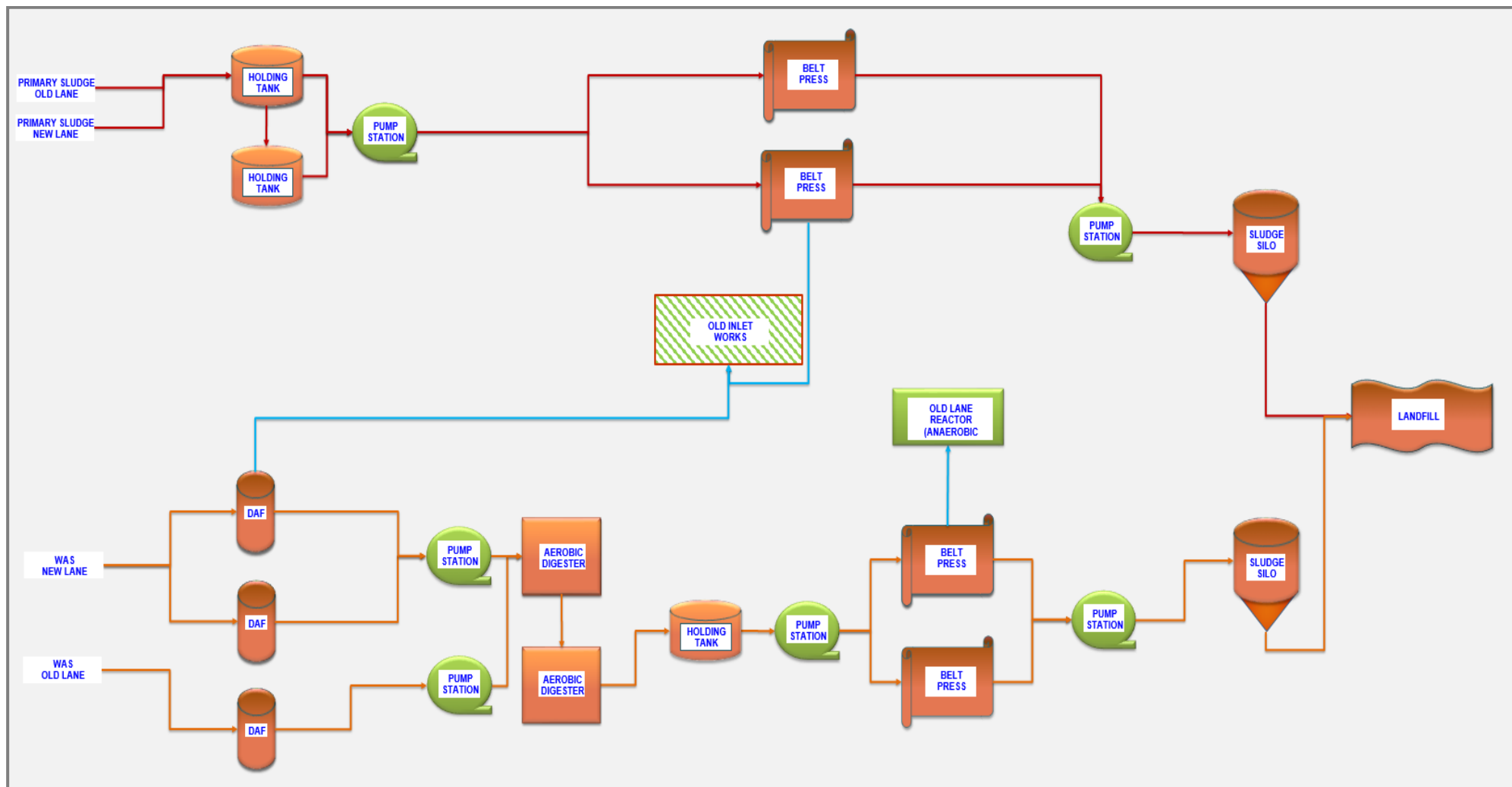


Figure 3-4 : Schematic process flow diagram of sludge stream

A summary of the key process units and their features (volume, surface areas, loading rates and mechanical specifications) which impact the process operation and performance of the plant's sludge facilities are summarised in the table below:

PROCESS UNIT	PROCESS PARAMETER
Mechanical filter belt presses (Primary sludge)	Number = 2 Hydraulic loading rate = 40 m³/hr per unit Solids loading rate = 1100 kgTSS/hr per unit

Table 3-3 : Summary of process units (primary sludge stream)

The existing plant does not incorporate an anaerobic digestion process for the primary sludge. This dissertation will however assume the presence of anaerobic digesters in order to evaluate: i) How the various modelling software adopted for this dissertation models the anaerobic digestion process; ii) The impact that varying wastewater characteristics have on the sludge treatment stream, specifically if anaerobic digesters are present. As previously discussed, primary sludge typically has a low nitrogen and phosphorous content. When anaerobically digesting primary sludge, the nitrogen and phosphorous concentrations in the supernatant generated from the anaerobic digester will be higher than from the belt press, but low enough, if returned to the influent stream to not significantly increase the nitrogen and phosphorous concentrations in the final effluent (Ekama, 2017).

This dissertation will only evaluate the process units which will impact the process capacity and sludge quality. In terms of primary sludge processing, this will be limited to the anaerobic digesters.

3.4.2 Waste Activated Sludge Lane

A summary of the process configuration for the WAS lane is summarised below and graphically illustrated in **Figure 3-4** above:

- WAS pump stations:
 - The WAS sludge from the UCT bioreactor of the Old Lane gravitates to the sump of the Old WAS pump station. The Old WAS pump station then pumps the sludge to one of the three DAF units. The Old WAS pump station comprises two variable speed submersible pumps, one duty pump and one standby pump
 - The WAS sludge from the Bardenpho bioreactor of the New Lane gravitates to the sump of the New WAS pump station. The New WAS pump station then pumps the sludge to the remaining two DAF units. The New WAS pump station comprises two sets of variable speed submersible pumps, one duty and one standby pump per set. This pump station is configured such that the pumps can also pump to the DAF unit dedicated to the Old Lane

- DAF Units: The three DAF units thicken the WAS from both lanes and operate such that two DAF units (commissioned in 2008) are dedicated to the New Lane and the third DAF unit is dedicated to the Old Lane. The thickened sludge then gravitates to two thickened sludge pump stations (dedicated to each DAF set), from where it is then pumped to the aerobic digesters. Details on the thickened sludge pump stations and the DAF supernatant are noted below:
 - Old Lane: The thickened (float) WAS is pumped by two progressing cavity pumps (1 duty and 1 standby)
 - New Lane: The thickened (float) WAS is pumped by two progressing cavity pumps (1 duty and 1 standby)
 - The underflow (supernatant) from the DAF units gravitates to the Table View East pump station, from where it is pumped to the inlet works
- Aerobic digester: The two aerobic digesters aerobically digest and stabilise the sludge. The current set-up on site allows for the digesters to operate in parallel (single digestion system), or to operate in series as a dual digestion system. When comparing a single digestion system (two digesters in parallel) to a dual digestion system (two digesters in series), the fraction of VSS removed and the total digester oxygen demand will be the same for the two systems. However, the series digestion system will have a shorter digester retention time, and thus a smaller total required aerobic digester volume. For this reason, this dissertation has assumed that the two digesters will be operated in series as a two-aerobic digestion system. The aerobic digestion process operates purely as an aerobic digester, and not as an anoxic-aerobic digester (i.e., aerators are not switched off during current on-site operation). The digesters should ensure almost complete nitrification, but the nitrate generated cannot be denitrified to recover the alkalinity loss and reduce the oxygen demand. As a result, the digested sludge will have nitrate present. The digested sludge then gravitates to a digested sludge pump station, from where it is pumped to a holding tank at the dewatering facility. The digested sludge pump station comprises two progressive cavity fixed speed pumps (duty and standby arrangement)
- Dewatering Facility:
 - From the holding tank (effective volume of approximately 1100 m³) at the dewatering facilities, the digested sludge is pumped onto the filter belt presses. This pump set comprises three variable speed progressing cavity pumps each with a capacity of 25 m³/hr, comprising two duty and one standby, with a duty pump dedicated to each belt press
 - Mechanical filter belt presses: The thickened and digested sludge received at the belt presses is dosed with polymer and then dewatered on the mechanical filter belt presses, and the dewatered sludge is then pumped into a sludge silo
 - Sludge Silo: A dedicated sludge silo temporally stores the dewatered sludge
 - Supernatant: All supernatant from the WAS belt presses is returned to the anaerobic zone of the old reactor system under gravity. WAS typically has a high nitrogen and phosphorous content, especially NDBEPR WAS. The two lanes of the case study WWTW both comprise a NDBEPR process. During the upstream aerobic digestion process, the organically bound nitrogen and phosphorous bound up in organism mass are released which increases the ammonia and ortho-phosphates (OP) concentrations in the bulk liquid. If nitrifiers are present

in the aerobic digester, this ammonia may be oxidised to nitrate (i.e., via aerobic nitrification; Henze *et al.*, 2008). As the aerobic digester is only an aerobic process (i.e., aerators are not switched off to allow denitrification), the nitrate generated cannot be denitrified, so nitrate will be present in the WAS and the supernatant from the belt presses. With regards to phosphorous, when the NDBEPR WAS is aerobically digested, high bulk liquid concentrations of Ortho-P will occur from the release of the internally stored poly-phosphate (PP) in the PAO component of the sludge mass due to endogenous mass loss of the organism group (Vogts *et al.*, 2014). The concentration of organically bound nitrogen and phosphorous released to the bulk liquid as ammonia and Ortho-P is equal to the nitrogen and phosphorous content of the volatile suspended solids (VSS) concentration removed (i.e., via the aerobic degradation process). As a result, the supernatant from the dewatering process will have a high phosphorous concentration which will increase the phosphorous load to the bioreactor of the liquid stream. This may result in elevated phosphorous levels in the final effluent

- Disposal: The dewatered sludge in the sludge silo is collected almost daily, transported and disposed of at the Vissershok landfill site.

A schematic process flow diagram of the sludge stream (primary sludge lane and WAS lane) is depicted in **Figure 3-4** above.

A summary of the key process units and their features (volume, surface areas, loading rates and mechanical specifications) which impact the process operation and performance of the plant's sludge facilities are summarised in the table below:

PROCESS UNIT	PROCESS PARAMETER
Dissolved Air Flotation Units	Old Lane: Shape: Circular ; Number = 1 ; Diameter of DAF = 7.5 m ; Surface Area per DAF = 44.2 m² Minimum Float Concentration = 3% New Lane: Shape: Circular ; Number = 2 ; Diameter of DAF = 8.25 m ; Surface Area per DAF = 53.4 m² Minimum Float Concentration = 3%
Aerobic Digester	Dual digestion system (two digesters in series)

PROCESS UNIT	PROCESS PARAMETER
	Shape: Circular with a diameter of 28 m and water depth of 3.8 m; Number = 2 Total Volume Aerobic Digester No. 1 = 2340 m³ Total Volume Aerobic Digester No. 2 = 2340 m³ The aeration system comprises platform mounted surface aerators. Total Installed Aeration Power = 290 kW, comprising 1 x 90 kW and 1 x 55 kW per aerobic digester
Mechanical filter belt presses (WAS)	Number = 4 Hydraulic loading rate = 25 m³/hr Solids loading rate = 375 kgTSS/hr

Table 3-4 : Summary of process units (WAS Stream)

This dissertation will only evaluate the process units which will impact the process capacity and sludge quality. In terms of WAS, this will be limited to the DAF units and aerobic digesters.

3.5 Future Upgrades and Extensions

At the beginning of 2017, the City of Cape Town commenced planning the upgrade of the Potsdam WWTW which will be undergoing a 53 Ml/day extension which will result in a total treatment capacity of 100 Ml/day (ADWF). This upgrade project is currently underway with construction anticipated to commence in late 2022.

3.6 Closing Remarks on Process Configuration of Case Study WWTW

The liquid stream of the case study WWTW is an effective process for meeting the effluent quality standards. The following general comments are noted:

- For a plant of this scale, the incorporation of PSTs into the process is ideal as this reduces the aeration and volume requirements in the bioreactor to between 30% and 40%, depending on the organic content that is captured in the PSTs. This results in a significant saving in electrical costs, as energy requirements for the aeration process typically account for between 40% and 60% of the annual running cost of a WWTW in South Africa, primarily due to the high cost of electrical power

- The existing Water Use License imposes a strict effluent quality standard, especially for phosphorous. This requirement will most likely become stricter in future as the regulatory authority (Department of Water and Sanitation) is imposing stricter requirements on WWTW, specifically those discharging into sensitive water environments as is the case for the Potsdam WWTW. The Old Lane comprises a UCT process which enhances the biological removal of phosphorous. The New Lane incorporates a 5-stage Bardenpho process which is not typically incorporated at WWTWs requiring a strict phosphorous limit as this process favours nitrogen removal. The reason for selecting this process configuration is unknown, and this process is not considered ideal where stringent effluent phosphorous levels are imposed unless methanol addition to the secondary anoxic reactor is contemplated to ensure a zero nitrate return to the anaerobic reactor (and effluent).

The sludge stream of the case study WWTW is an effective process where the WAS is stabilised and thickened, and the primary sludge is thickened but is not stabilised. The primary sludge is currently disposed of at the Vissershok hazardous landfill site while the WAS is disposed of via land application for agricultural purposes. The following general comments are noted:

- The primary sludge is not stabilised, and as a result, is required to be disposed of at a hazardous landfill site at a significant cost. In future, the City of Cape Town may have to consider the incorporation of anaerobic digestion for primary sludge stabilisation as this will present a cheaper disposal option (e.g., land application etc.) when compared to the current disposal option. The anaerobic digestion process has a further advantage of the potential production of energy from the biogas generated from the anaerobic digestion process. The N and P content of anaerobically digested primary sludge dewatering supernatant may be low enough to be returned to the influent without adversely affecting effluent N and P concentrations
- The aerobic digestion of WAS is suitable for the current plant, as this is a simple process for stabilisation of concentrated WAS (which is usually rich in nitrogen and phosphorous) from a NDBEPR system (Vogts *et al.*, 2014). However, the following concerns are noted:
 - The aerobic digestion process operates purely as an aerobic digester, and not as an anoxic-aerobic digester. Aerobic digestion will allow for complete nitrification, and as the nitrate generated cannot be denitrified, one loses the advantage of the recovery of alkalinity loss and also the reduction in oxygen demand which occurs in an anoxic-aerobic digester. The City of Cape Town should investigate operating this process unit as an anoxic-aerobic digester, by using an intermittent aeration cycle (i.e., 3 hours on and 3 hours off). This process will ensure almost complete nitrification and denitrification, allowing for low ammonia and nitrate concentrations in the supernatant
 - Aerobic digestion of WAS consumes significant energy which is a concern due to the high cost of electricity and the above-inflation increases in electricity prices in South Africa. Globally, there is a focus on conserving energy with energy efficiency in the wastewater treatment field becoming increasingly important. In future, the City of Cape Town should investigate alternative options for the stabilisation of WAS. An option may include the anaerobic digestion (e.g., mesophilic, thermophilic and thermal hydrolysis etc.) of a mixture of

primary sludge and WAS which is becoming a popular solution. This option has disadvantages specifically around the anaerobic digestion of WAS due to the slow hydrolysis rate of the WAS biodegradable organics, and the high nitrogen and phosphorous content of the dewatering supernatant which cannot be returned to the influent without significantly increasing effluent N and P concentrations from the NDBEPR system (Ekama, 2017). As a result, the dewatering supernatant from an anaerobic digestion process treating primary sludge and WAS will require side-line N and P removal technologies before returning to the influent stream. Alternatively, to avoid a high N and P containing dewatering supernatant, lime can be dosed to an anoxic-aerobic digester (Vogts *et al.*, 2014), but then energy is consumed rather than recovered as in the case of the anaerobic digestion system. Both options have merit, and the selection of either will be dependent on the main driver of the WWTW, which could be energy conservation which will promote anaerobic digestion, or a high-standard effluent quality which will favour the anoxic-aerobic digester system.

4. FLOW ANALYSIS

An analysis of the historical flow data for the case study WWTW was undertaken in order to estimate the current average dry weather flow; peak factors for the peak dry weather flow and peak wet weather flow; and influent and settled diurnal (24-hour) dry weather flow patterns. The aforementioned flows are defined as follows (Tchobanoglous *et al.*, 2014; Metcalf & Eddy, 2014):

- Average dry weather flow (ADWF): The average daily flow during the dry weather period, where daily records of more than 0.25 mm rainfall are omitted from the average
- Peak day dry weather flow (PDWF): The maximum daily flow occurring during the dry weather period, where daily records of more than 0.25 mm rainfall are omitted
- Peak hourly dry weather flow: This is defined as the peak (maximum) hourly flowrate experienced during peak day dry weather flow (PDWF)
- Peak day wet weather flow (PWWF): The maximum daily flow occurring during the wet weather period
- Peak hourly wet weather flow: This is defined as the peak (maximum) hourly flowrate experienced during peak day wet weather flow (PWWF).

4.1 Available Data

When evaluating an existing plant's historic flow data in terms of average flows, peak flows and diurnal dry weather flow patterns, the ideal data required for a comprehensive flow analysis includes:

- An extended history (at least three years or longer) of flow data in at least hourly intervals, or shorter intervals if available. This data should cover the following:
 - Flow data at the head of the works which will assist in categorising the influent flows
 - Flow data downstream of the PSTs which will assist in categorising the settled flows; alternatively, flow data of the primary sludge wasted from the PSTs can be used to calculate and categorise the settled flows
 - Flow data of the final effluent which can be used to verify the influent flows and wasting rates
- Daily rainfall data recorded from on-site (or nearby) rain gauges which will assist in the determination of the dry and wet weather periods.

The City of Cape Town provided historical influent flow data for the period 01 January 2013 to 31 December 2015 which comprised the following:

- Accumulated daily flow data (single recording taken each day at 12pm) recorded on a data logger at the Inlet Works flow meter from which the Author could determine the annual average daily flow and average day dry weather flow (ADWF). This analysis is discussed in **Section 4.2** below
- Hourly flow data was not readily available, and from the accumulated daily flow data discussed above, the Author identified periods during which peak day dry weather flow (PDWF) and peak day wet weather flow (PWWF) conditions occurred. For the PDWF scenario, the Author selected a maximum

PDWF flow scenario for each year (three data periods), namely 2013, 2014 and 2015. For each period, a week of flow data was made available in hourly steps. Similarly, for the PWWF scenario, the Author selected a maximum PWWF scenario for each year (three data periods), for which a week of flow data was made available in hourly steps. This hourly data was extracted from the plant's SCADA system and made available to the Author. This data was then used to abstract the peak factors for PDWF and PWWF conditions which are discussed in more detail in **Section 4.3** below. The aforementioned data was also used to determine the diurnal dry weather flow patterns (hourly steps) which are discussed in more detail in **Section 4.4** below

- Daily rainfall data recorded from on-site rain gauges were captured manually by the operational staff. This data was used in the selection of the PDWF and PWWF periods discussed in **Sections 4.2** and **4.3** below.

Historical flow data was not made available for the settled wastewater streams, namely, flow records downstream of the PSTs for both the Old Lane and New Lane. The City of Cape Town provided monthly sludge volumes wasted from the PSTs for both the Old Lane and New Lane for the year 2015, which enabled the Author to estimate the primary sludge underflow rates for the year 2015. This data was recorded on data loggers at flow meters installed on the primary sludge waste pipelines. The analysis of this data is discussed in **Section 4.5** below. The estimation of the primary sludge underflow rates in turn was used to calculate the settled wastewater flows which are presented in **Section 4.4** below.

The historical flow data made available for evaluating the influent and primary sludge flows were considered suitable to determine the average flows, peak flows and diurnal flow patterns (influent and settled streams) which are presented below.

4.2 Average Inflows

The average daily influent flow was extracted from the accumulated daily flow data recorded at the inlet works flow meter, by subtracting the reading on a specific day from the previous day's reading. The average daily influent flow for the period 01 January 2013 to 31 December 2015 is illustrated in the hydrograph below:

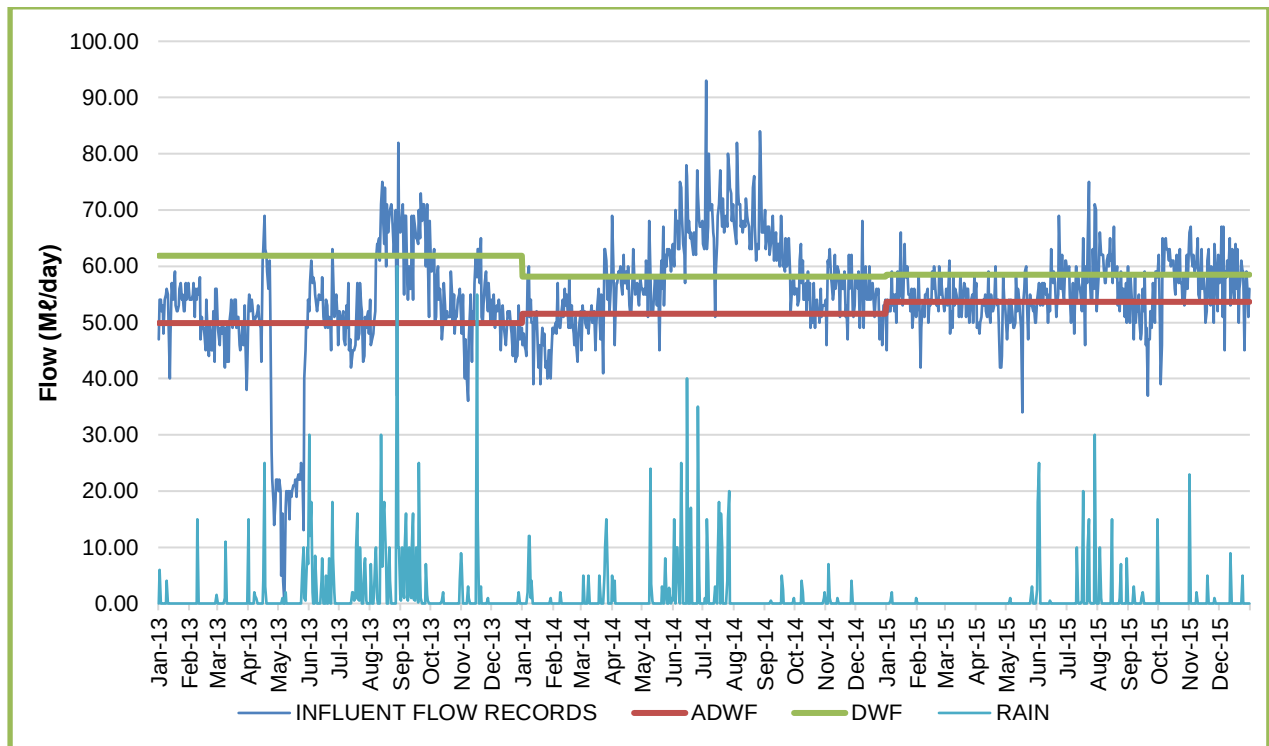


Figure 4-1 : Average Daily Influent flow hydrograph for the period January 2013 to December 2015

From the hydrograph above, there was an anomaly in the flow record for the period 24 April 2013 to 26 May 2013 where the average daily flow was approximately 18 Ml/day. This is an error in the flow meter readings. In order not to skew the analysis, all average daily flows less than 30 Ml/day were treated as outliers and removed from the data set. This omission only accounted for a total of 33 data records being removed from the three-year data set. The daily flow records for the period stipulated above were then analysed to determine the following:

- Average annual daily flow: Average daily flow during the period January to December for each year where “daily flows of less than 30 Ml/day” were omitted from the data set
- Average summer daily flow: Average daily flow during the dry period January to April for each year where “daily flows of less than 30 Ml/day” were omitted from the data set
- Average day dry weather flow (ADWF): Average daily flow during the dry period January to April for each year where “daily flows of less than 30 Ml/day and days with more than 0.25 mm rainfall” were omitted from the data set
- Peak day dry weather flow (PDWF): Maximum daily flow during the dry period January to April for each year where “days with more than 0.25 mm rainfall were omitted from the data set”
- Peak day wet weather flow (PDWF): Maximum daily flow during the period May to December for each year specifically where a significant rainfall event was recorded on the on-site (or nearby) rain gauge.

The daily flow scenarios described above are tabulated below:

Year	Annual Average Daily Flow (Mℓ/day)	Average Summer Daily Flow (Mℓ/day)	ADWF (Mℓ/day)	PDWF (Mℓ/day)	PWWF (Mℓ/day)
2013	53.88	51.89	51.29	62.00	82.00
2014	58.11	51.58	51.09	68.00	93.00
2015	55.51	53.66	53.66	66.00	75.00

Table 4-1 : Average flows, ADWF, PDWF and PWWF for the period January 2013 to December 2015

From the table above, the following is observed:

- The average summer daily flow is slightly higher than the ADWF, as this data is inclusive of days with more than 0.25 mm rainfall
- It can be seen that the ADWF received at the plant for the years 2013 to 2015 is more than the plant's documented ADWF design capacity of 47 Mℓ/day.

4.3 Peak Inflows

4.3.1 Peak dry weather flow

The PDWF is defined above as “the maximum daily flow occurring during the dry weather period, where daily records of more than 0.25 mm rainfall are omitted”. This maximum daily flow represents the maximum average flow over 24 hours. From **Table 4-1** above, the PDWF factor (PDWF divided by ADWF) is 1.21, 1.33 and 1.23 for the years 2013, 2014 and 2015 respectively.

The above values for the PDWF factor are considered on the low end, and as a result, the peak hourly dry weather flow was evaluated. The maximum peak week dry weather flow was extracted from the average daily influent flows presented in **Figure 4-1** above, and over the three-year data record, this occurred between the period of 15 January 2015 to 21 January 2015. For this period, a week of flow data, as recorded at the inlet works, was made available in hourly steps which were tabulated and analysed. This data was then transposed onto a daily flow hydrograph illustrating the daily flow variation (over a 24-hour period) for the weekly average, weekday average and weekend day average, which is presented in **Figure 4-3** (see page 42). From **Figure 4-3**, the weekday average had the highest peak flow occurring around 11 am, which was approximately 3,416.4 m³/hr (81.994 Mℓ/day). This represents the peak hourly dry weather flow, and using the 2015 ADWF, results in a peak hourly dry weather flow factor of 1.53.

The PDWF factors for the years 2013, 2014 and 2015 and the peak hourly dry weather flow factor of 1.53 discussed above are considered on the low end for a municipal WWTW of this size, and these values were compared to empirical methods typically used for estimating the PDWF factor where flow data is lacking. The empirical methods adopted for the comparison included Mutschmann & Stimmelmayer (2007) and Harmon (1918) which uses population as a basis for estimating PDWF factors. These are tabulated below:

Parameter	Unit	2013	2014	2015
Unit Sewerage yield per person ⁷	l/psn/day	200	200	200
Influent Flowrate (ADWF)	Ml/d	51.29	51.09	53.66
Population Equivalent	persons	256450	255471	268291
Peak Dry Weather Flow Factor				
Mutschmann & Stimmelmayer (2007) ⁸		1.51	1.51	1.50
Harmon (1918) ⁹		1.70	1.70	1.69

Table 4-2 : Peak dry weather flow factors estimated using empirical methods

The PDWF factors estimated from the flow data records are much lower than that calculated from the above empirical methods. The peak hourly dry weather flow factor of 1.53 for the period 15 January 2015 to 21 January 2015 ties up with the Mutschmann & Stimmelmayer (2007) method but is lower than the Harmon (1918) method. It was decided to assume a conservative PDWF factor of 1.75 for all steady-state process design simulations carried out under this dissertation, which is slightly higher than the value calculated from the Harmon (1918) method. The reason for selecting a higher value than that estimated from the flow data records and the empirical methods was to ensure an intentional factor of safety with respect to the modelling presented in **Sections 6** and **7**. The PDWF has a minimum impact on the process unit sizing, but does impact the mechanical equipment sizing, specifically the mechanical aeration system for the aerobic zone of the bioreactor and the recycle ratio of the RAS pump station under dry weather flow conditions. The PDWF factor is not considered critical for this dissertation, as this dissertation specifically focusses on the process unit sizing and not the mechanical equipment sizing which is discussed in more detail in **Section 6.2.4**.

As previously discussed, the maximum peak week dry weather flow was extracted from the average daily flows presented in **Figure 4-1** above and over the three-year data period, which occurred between the period of 15 January 2015 to 21 January 2015. This flow data was used to simulate all ADWF dynamic process design simulations carried out under this dissertation and is discussed further in **Section 4.4** below.

4.3.2 Peak wet weather flow

The PWWF is defined above as the “maximum daily flow occurring during the wet weather period”. This maximum daily flow represents the maximum average flow over 24 hours. From **Table 4-1** above, the PWWF factor (PWWF divided by ADWF) is 1.60, 1.82 and 1.40 for the years 2013, 2014 and 2015 respectively.

⁷ Daily sewage production flow per person as documented in the Red Book (CSIR, 2000) for medium income range catchment areas with a minor contribution allowance from commercial and industry

⁸ Mutschmann & Stimmelmayer equation: PDWF factor = $6.003 \times \text{Population}^{(-0.1109)}$

⁹ Harmon equation (1918): PDWF factor = $1+14/[4+\text{SQRT}(\text{Population}/1000)]$

The above values for the PWWF factor are considered on the low end, and as a result, the peak hourly wet weather flow was evaluated. The maximum peak week wet weather flow was extracted from the average daily flows presented in **Figure 4-1** above, and over the three-year data record, this occurred between the period of 25 July 2014 to 31 July 2014. For this period, a week of flow data as recorded at the inlet works was made available in hourly steps which were tabulated and analysed. This data was then transposed onto a daily flow hydrograph illustrating the daily flow variation (over a 24-hour period) for the weekly average, weekday average and weekend day average as presented in **Figure 4-2** below. From **Figure 4-2**, the weekend average had the highest peak flow occurring at 11 am, which was approximately 4212 m³/hr (101.088 Ml/day). This represents the peak hourly wet weather flow, and using the 2014 ADWF, this results in a peak hourly wet weather flow factor of 1.98.

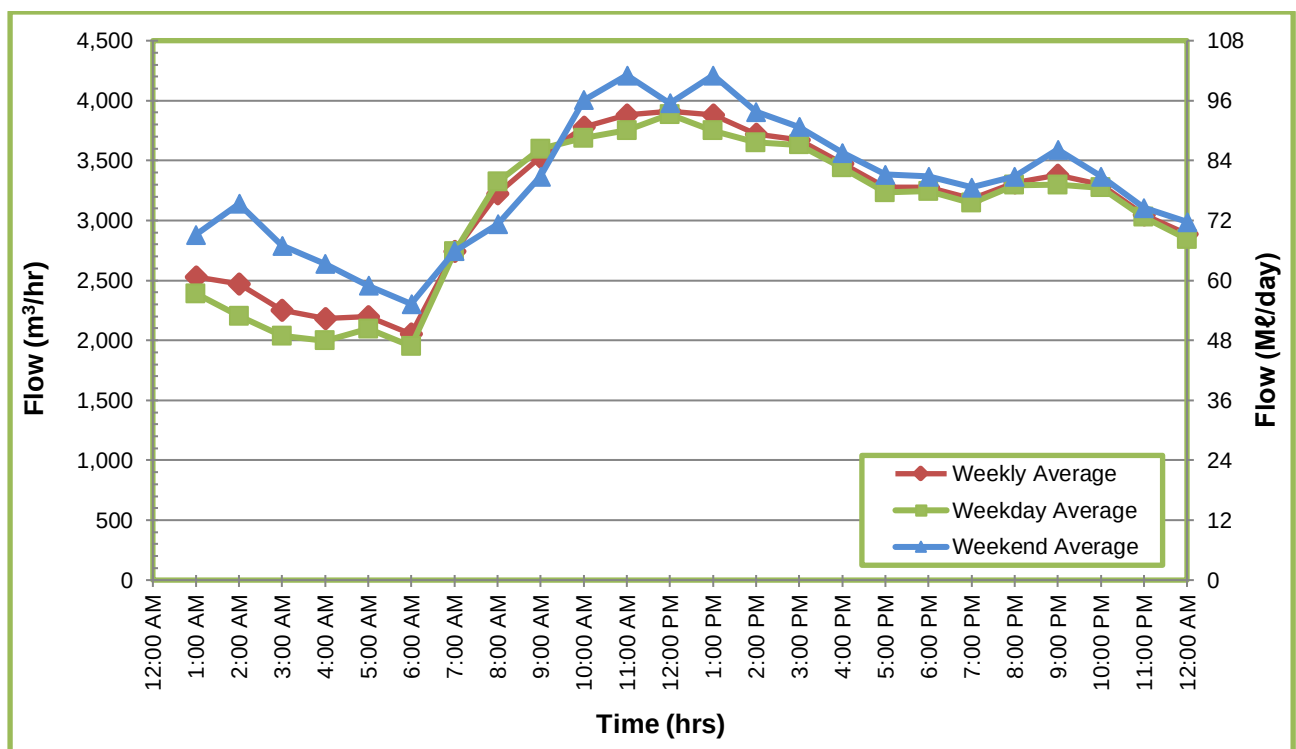


Figure 4-2 : Maximum peak week wet weather flow (25 July 2014 to 31 July 2014)

The PWWF factors for the years 2013, 2014 and 2015 and the peak hourly wet weather flow factor of 1.98 discussed above are considered on the low end for a municipal WWTW located in the Cape Town area. South African design guidelines typically state that this factor varies between 200% and 300% of the ADWF. The PWWF factor is dependent on the following aspects:

- The age of the sewer reticulation network, the older the network, the higher the infiltration rate of groundwater into the sewer network
- Interconnections between the sewer and stormwater system typically occur in older settlements
- The maximum hydraulic design capacity of incoming sewers.

The PWWF factor extracted from the historical inflow data (i.e., hourly data) is considered too low, and as a result, it was decided to use a conservative PWWF factor of 250% of the ADWF for all steady-state process

design simulations carried out under this dissertation. Unlike the PDWF discussed in **Section 4.3.1** above, the PWWF does impact the process unit sizing, specifically the SST surface area and the mechanical equipment sizing, specifically the recycle ratio of the RAS pump station under wet weather flow conditions. The PWWF factor is not considered critical for this dissertation, as this dissertation specifically focusses on the biological process unit sizing and not the physical process unit sizing and mechanical equipment sizing.

4.4 Diurnal Flow Patterns

As discussed in **Section 4.3.1**, hourly flow data was not readily available, and the influent maximum peak week dry weather flow was extracted from the average influent daily flows presented in **Figure 4-1** above, which occurred between 15 January 2015 and 21 January 2015. For this period, a week of flow data as recorded at the inlet works was made available in hourly steps which were tabulated and analysed. This data was then transposed onto a daily flow hydrograph illustrating the daily flow variation (over a 24-hour period) for the weekly average, weekday average and weekend day average shown in Figure 4-3 below.

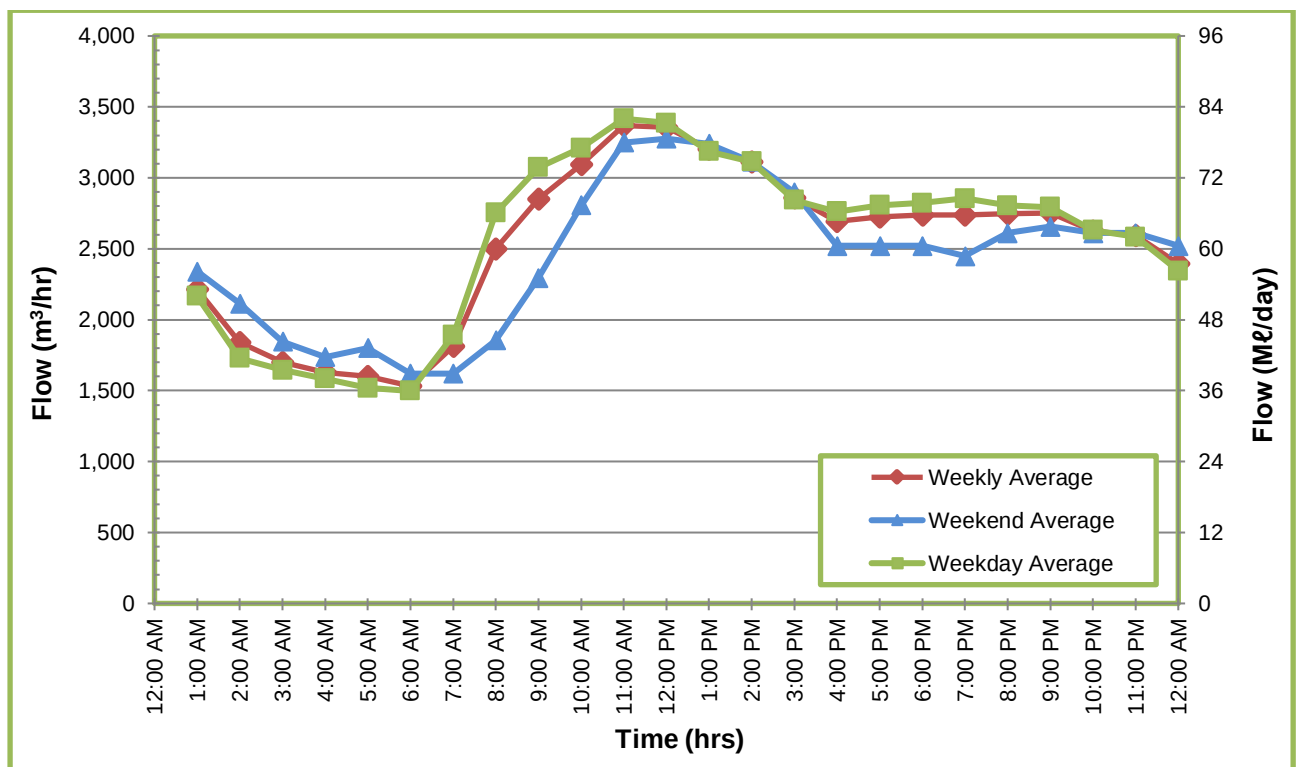


Figure 4-3 : Influent flow variation over a 24 hour period – Raw wastewater

From Figure 4-3 above, it can be seen that the weekday average has the highest peak flow. As a result, the weekday average was used to simulate a 24-hour diurnal dry weather flow pattern which was adopted for all dynamic process design simulations carried out under this dissertation. The weekday average was selected as this would present the worst-case scenario in terms of hydraulic and organic load on the plant. The weekday average is also graphically illustrated in the figures below for the Old Lane (average dry weather flow of raw

wastewater is 718.75 m³/hr /or/ 17.250 Mℓ/day) and the New Lane (average dry weather flow of raw wastewater is 1,812.50 m³/hr /or/ 43.500 Mℓ/day).

As previously discussed, historical flow data was not made available for the settled wastewater streams. However, the PST underflow rate recorded on site is 0.60% of the ADWF making the settled wastewater flows 0.60% lower than the raw wastewater flows (see **Section 4.5** below). For purposes of this dissertation, a constant PST underflow rate of 0.775% of ADWF over the 24-hour day was used as a basis for all process design simulations carried out under this dissertation. A 0.775% primary sludge underflow rate will result in a primary sludge TSS concentration of 4.0% (i.e., 40,000 mgTSS/ℓ) which is acceptable for the hydraulic flow under gravity for primary sludge. For practical purposes from an operational perspective, the PST underflow design rate is usually selected as a value between 0.5% and 2.0% of the ADWF. This results in a primary sludge TSS concentration of between 1.0% and 4.0% for typical municipal wastewater which is acceptable for the hydraulic flow under gravity for primary sludge. Figures 4-4 and 4-5 below illustrate the influent (raw) and settled wastewater flows for both the Old Lane and New Lane respectively, assuming a constant PST underflow rate of 0.775% of ADWF.

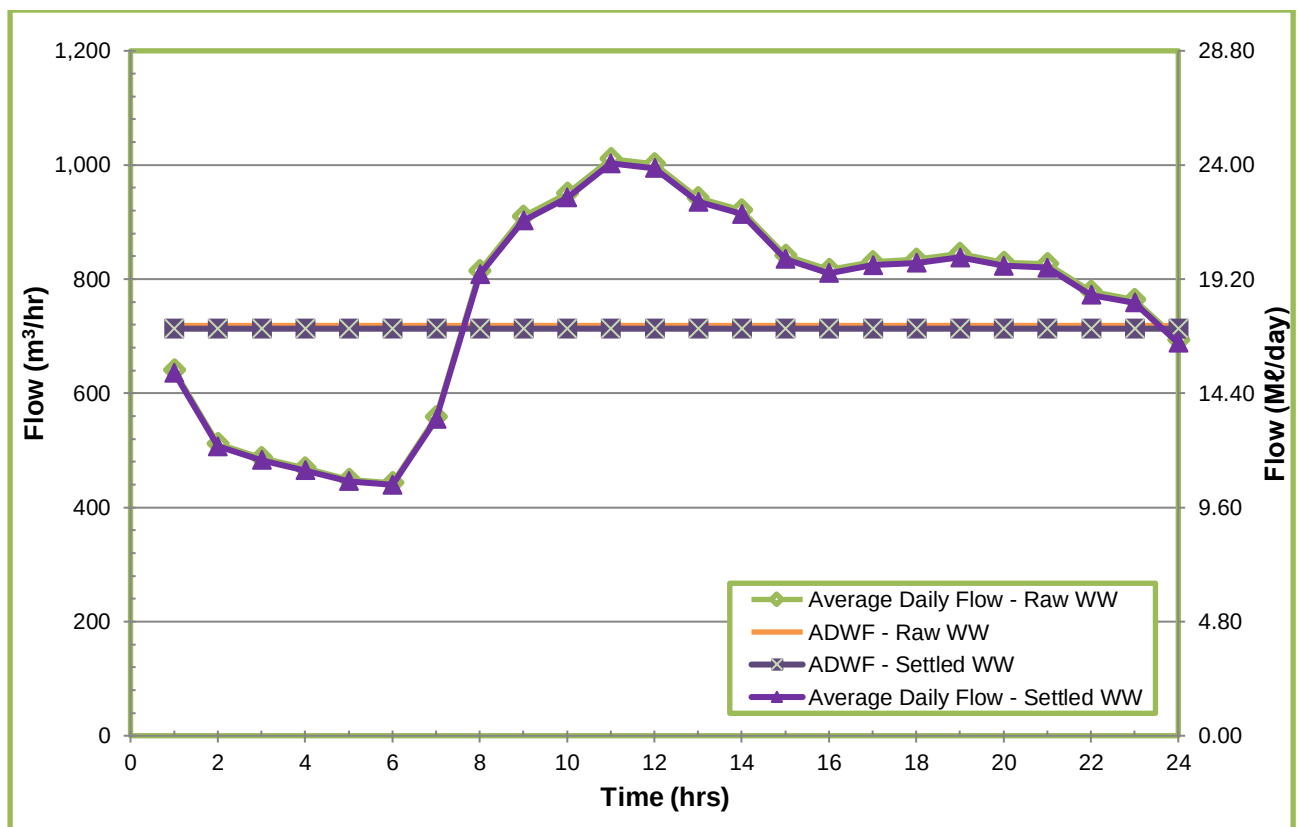


Figure 4-4 : Old Lane: Plant flow variation over a 24-hour period (raw and settled wastewater)

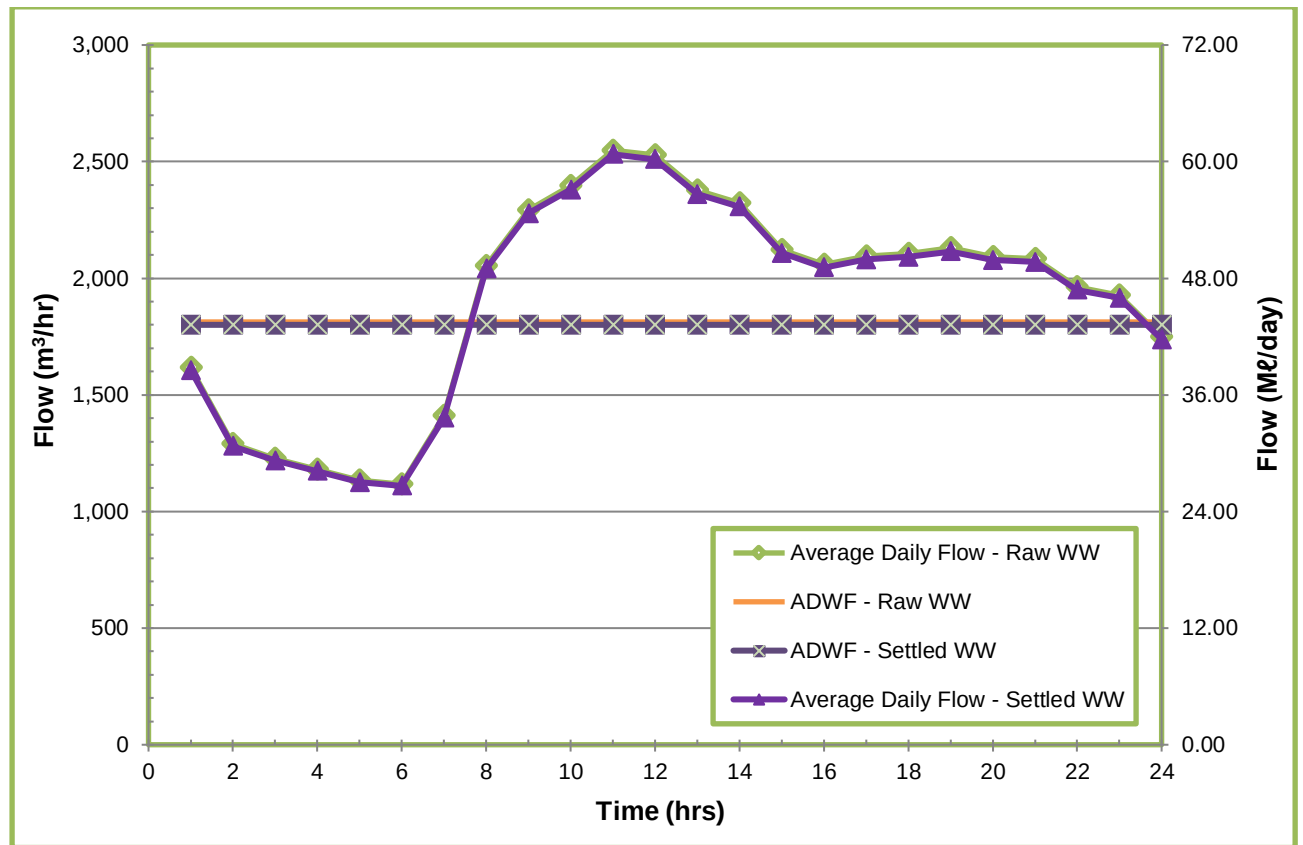


Figure 4-5 : New Lane – Plant flow variation over a 24-hour period (raw and settled wastewater)

4.5 Primary Sludge flows

As discussed in **Section 4.1** above, data was provided for the monthly sludge volumes wasted from the PSTs for both the Old Lane and New Lane for the year 2015. These monthly values were averaged to a daily value, and the annual average daily sludge volumes wasted from the PSTs for both the Old lane and New lane were estimated as summarised below:

Year	Average Daily Flow (M ³ /day)	Sludge wasted from Old Lane (m ³ /day)	Sludge wasted from new Lane (m ³ /day)	Average Daily Total Sludge wasted (m ³ /day)	PST Underflow (% of Average Daily Flow)
2015	55.51 ¹¹	94.84	237.42	332.26	0.60%

Table 4-3 : Annual average daily sludge volumes wasted from PSTs (2015)

The annual average daily primary sludge underflow rate as a percentage of the annual average daily flow amounts to 0.60% for 2015, and the monthly average varied between 0.39% and 0.84%. This concludes that the existing plant is operated to produce a low primary sludge flow rate but at a high concentration in terms of total solids. For purposes of this dissertation, a constant PST underflow rate of 0.775% of ADWF over the 24-hour day was used as a basis for all process design simulations.

4.6 Closing Remarks on Available Flow Data

The historical flow data provided was limited to average daily values for the influent flow, and for specific short periods identified by the Author, hourly flow data was made available. Flow data was only available for the influent raw wastewater, and not for the settled wastewater. However, sludge wasting rates from the PSTs were provided in the form of monthly figures, which enabled the Author to make a high-level estimate of the primary sludge underflow rates. The estimated primary sludge underflow rates in turn were used to calculate the settled wastewater flow rates. The hourly flow data received was used to determine the PDWF and PWWF factors which were considered on the lower end for the case study WWTW, considering its size and location. As a result, empirical approaches were used to determine a PDWF factor, and a more conservative factor was used for the PWWF factor. The hourly flow data was also used to determine the diurnal dry weather flow patterns (hourly steps) which would be adopted for the dynamic process design simulations. In conclusion, the Author was able to confirm the average dry weather flow; estimate peak factors for the peak dry weather flow and peak wet weather flow; and confirm influent and settled diurnal (24 hour) flow patterns which would be adopted for the development of the steady-state and dynamic-state models discussed in **Sections 6 and 7** respectively.

Suitable online monitoring at the case study WWTW is lacking, and it is recommended that the City of Cape Town improve online monitoring of the influent wastewater (raw and settled wastewater streams) by measuring influent flow in short time intervals, ensuring that all important flow streams (including sludge streams) are measured, and that all data is stored on a suitable management information system that is easily accessible.

¹¹ This average excludes daily flows of less than 30 M³/day.

5. WASTEWATER CHARACTERISATION AND DESIGN CONSIDERATIONS

Wastewater characterisation is an important component in the process design of a WWTW, as this determines the organic load on a plant which influences the design and size of the process units. For a new plant (green field site), the wastewater characterisation will be based on typical norms as published in the relevant research literature. For an existing plant, the characterisation is typically based on historical sampling data of the wastewater characteristics. In the design industry, the wastewater characterisation can be a complex task for an existing plant mainly due to the following factors:

- Historical sampling data is typically limited because data is collected more for compliance purposes than for WWTW optimisation and control, and there are cases where available data may not be credible
- In some cases, sampling data may be available, but the flow and time at which the grab sample was collected is not recorded, making it difficult to interpret the data
- Important wastewater parameters (e.g., unbiodegradable particulate COD and the readily biodegradable COD) are typically not measured (i.e., sampled and tested) and so need to be estimated.

When presented with the above limitations, designers are required to make calculated assumptions to fill the gaps in the wastewater characterisation, adopting typical norms as published in the relevant research literature and using sound process engineering judgement.

Historical sampling data received for the case study WWTW was analysed in order to estimate the wastewater characteristics (concentrations), the associated wastewater characterization (fractions) and diurnal load patterns. This section will summarise the data analysis, discuss the selection of wastewater characteristics and diurnal load patterns, and present process unit design considerations which will serve as input to the development of the steady-state and dynamic-state models.

5.1 Available Data

When evaluating an existing plant's wastewater characteristics (flows and concentrations) and the associated wastewater characterization (fractions), the ideal information typically required to undertake an informed evaluation will include:

- An extended history (i.e., at least three years or longer) of grab sample data taken daily or at least every alternative day covering all the key wastewater characteristics where the flow and time at which the sample was collected are also recorded. Key wastewater characteristics should include the total COD, Total Kjeldahl Nitrogen (TKN – filtered and unfiltered), Ammonia, Nitrate/Nitrite, total phosphates (Total-P – filtered and unfiltered), ortho-phosphates (Ortho-P), total suspended

(particulate) solids (TSS), volatile suspended (particulate) solids (VSS), total settleable solids (TSetS), pH and alkalinity. This data should include the influent (raw), settled wastewater (if applicable) and the treated effluent (filtered and unfiltered). The aforementioned can give an idea of the trend of the wastewater characteristics over the data record period, determine the current value of each wastewater characteristic (influent, settled and effluent) and assist with the calculation of the characterisation of certain wastewater concentrations. The longer the record of such data, the more reliable the data is in terms of statistical analysis and the easier to select realistic wastewater characteristics.

- Recent results of flow-weighted composite samples, non-flow-weighted composite samples over 24-hour intervals, or two-hour concentrations measured over a specific period (preferably a week). This data should cover the key wastewater characteristics discussed above, as well as other characteristics such as the volatile fatty acids, soluble COD (floc filtered COD and/or glass fibre filtered COD) and soluble TKN (glass fibre filtered TKN). Ideally, this data should include the influent (raw), settled wastewater (if applicable) and the treated effluent. Due to the significant costs of such tests, in industry, these tests are typically limited to the influent (raw) and settled wastewater. Such tests should be carried out for at least a week, to give an indication of the weekday loading versus a weekend day loading and should be carried out during the dry weather flow period. The aforementioned data can guide the selection (or verification of the grab sample data) of the wastewater characteristics, the characterisation of the wastewater and the selection of the diurnal load patterns (dry weather flow).

The City of Cape Town provided historical sampling data for the period January 2012 to March 2016 which measured the following:

- Total suspended (particulate) solids (TSS), volatile suspended (particulate) solids (VSS) and Total settleable solids (TSetS)
- Total COD (S_{ti})
- Total Kjeldahl Nitrogen (N_{ti}), Ammonia (NH_4) and Nitrate/Nitrite (NO_3-N/NO_2-N)
- Total phosphorous (P_{ti}) and Ortho-phosphates (Ortho-P)
- pH and alkalinity
- Solids concentration and pH of the primary sludge withdrawn from the PSTs.

The data typically comprised three to four grab samples per month collected at the following locations:

- The inlet works
- Downstream of the PSTs of the Old Lane
- Downstream of the PSTs of the New Lane
- The final effluent stream downstream of the disinfection units
- Primary sludge stream exiting the PSTs of the Old Lane and New Lane, where the parameters sampled and analysed were limited to solids concentration and pH.

The above data was collected and measured by the City of Cape Town's Scientific Services Department. There were significant limitations on the above grab sample data as follows:

- There were no flow readings recorded with the grab samples
- The time at which the grab samples were collected was not documented. After consultation with the City of Cape Town, it was noted that grab samples are typically taken in the morning period, between 10 am and 12 pm. From **Figure 4-3** (see **Section 4.4**) above, it can be seen that the peak flow is observed between 11 am and 1 pm on a weekday and a weekend day. In most cases, the peak load occurs with the peak flow. As a result, it can be assumed that only a portion of the grab samples is representative of the peak load.

Flow-weighted composite samples or non-flow-weighted composite samples over 24-hour intervals were not available. Also, two-hourly concentrations measured over a 24-hour day were not available. The aforementioned type of information is critical for the determination of flow-weighted averages for wastewater characteristics, characterisation of wastewater and the selection of diurnal load patterns required in dynamic-state modelling.

The historical information made available for evaluating the case study plant's wastewater characteristics (concentrations) and the associated wastewater characterization (fractions) was not ideal. The grab sample data was the only credible information available for this dissertation, and as such, could only be used for determining the wastewater characteristics (concentrations) and some of the associated wastewater characterization (fractions). The balance of the wastewater fractions required for the characterisation needed to be assumed based on typical norms as published in the relevant research literature. The wastewater characteristics and diurnal load patterns (dry weather flow) of the case study plant were determined as follows:

- **Section 5.2:** The grab sample data was firstly analysed statistically to determine the wastewater characteristics for the influent wastewater, the settled wastewater and effluent wastewater. The wastewater characteristics not measured as part of the grab sample data were assumed based on relevant research literature applicable to municipal wastewater conditions. This section also discusses the selection of the diurnal load patterns (dry weather flow)
- **Section 5.3:** Some of the wastewater fractions were then derived from the influent, settled and effluent wastewater characteristics determined from the grab sample data in **Section 5.2** above. These derived fractions were compared to typical values documented in the relevant research literature. Those fractions that could not be derived from the grab sample data were then assumed and based on relevant research literature. The aforementioned fractions were then adopted for the wastewater characterisation which was carried out on the raw influent stream, and the settled wastewater streams for both the Old Lane and New Lane
- **Section 5.4:** The grab sample data for the primary sludge was limited to the underflow solids concentration which was analysed statistically. There was no other data available for the primary sludge characterisation. However, based on the characterisation of the raw and settled wastewaters carried out under **Section 5.3**, the primary sludge could be characterised based on the flux difference between the raw wastewater and the settled wastewater.

5.2 Wastewater Characteristics

5.2.1 Influent wastewater characteristics

The influent (raw) wastewater characteristics have been derived from a three-year data record of 209 grab samples collected at the Inlet Works. As the process design is affected by variations in wastewater characteristics, the wastewater characteristics need to be analysed carefully from existing records. This analysis is discussed below.

5.2.1.1 Statistical analysis of influent wastewater characteristics

The grab sample data was firstly analysed for outliers. The three-year data record did not comprise significant anomalies, but there were specific wastewater characteristics that contained outliers. These outliers were omitted from the data set (described below in bullet 1). The data was then analysed statistically per wastewater characteristic to confirm if the data were normally distributed. The distribution of the data was evaluated via two methods. The first method comprised projecting the data on a probability curve (described below in bullet 2) to confirm if the data were normally distributed. The second method assessed the data's normality, by evaluating the skewness of the data via a histogram and bell curve (described below in bullet 2) and evaluating the coefficients of skewness and kurtosis (described below in bullets 11 and 12). If a data record is normally distributed and not skewed significantly, then standard statistical measures (e.g., mean, standard deviation, coefficient of variation etc.) can be applied to evaluate the data. The results of the statistical analysis are summarised in **Table 5-1** below. A brief description of the statistical measures (parameters) presented in **Table 5-1** is described below:

- Row 1: Outliers removed: Outliers omitted from the wastewater characteristics data were as follows:
 - COD where values of less than 300 mgCOD/ℓ, or values of more than 1750 mgCOD/ℓ were deemed outliers
 - Ortho-P where values of more than 25 mgP/ℓ were deemed outliers
 - TSS where values of less than 100 mgTSS/ℓ, or values of more than 1000 mgTSS/ℓ were deemed outliers
- Row 2: Data normally distributed: The distribution (variability) of concentrations was analysed by graphically projecting the data for each concentration on a probability curve. Two probability curves were considered, first an arithmetical probability curve and secondly a logarithmic probability curve. If the variation in the concentration is not proportional to the magnitude of the concentration then the concentrations may be arithmetically normally distributed, but if the variation in the concentration is proportional to the magnitude of the concentration, then the concentrations may be geometrically or log normally distributed. The data for each concentration was firstly plotted on an arithmetical probability curve, and if the data can be fitted with a straight line, then the data can be assumed to be normally distributed. Where a straight line could not be fitted on an arithmetical probability curve, this is an indication of the skewness of the data. If this was the case, the data was then plotted on a logarithmic probability curve, and if the data can be fitted with a straight line, then the data is log-normally distributed. The concentrations presented in **Table 5-1** below were analysed using the

aforementioned technique. **Figure 5-1 (a-f)** presents the probability curves for the COD, TKN and Total-P concentrations only

- **Row 3: No. of Samples (excl. Outliers):** Number of grab samples per wastewater characteristic where outliers have been excluded
- **Row 4: Mean Value:** The average value of the sample range is determined by the “sum of the sample values divided by the number of samples (excl. outliers)”
- **Row 5: Minimum Value:** The minimum value of the sample range (excl. outliers)
- **Row 6: Maximum Value:** The maximum value of the sample range (excl. outliers)
- **Row 7: Median:** The series of sample data was arranged in order of increasing value, and the median of the series is defined as the middlemost sample, or the arithmetic mean of the two middlemost samples
- **Row 8: Mode:** The sample value with the greatest frequency in the series is known as the mode. If a continuous graph of the frequency distribution is drawn as per the histogram and bell curve in **Figure 5-1**, the mode is the value of the high point of the curve. In a symmetrical (normally distributed) set of observations, the mean, median, and mode will be the same value
- **Row 9: Standard Deviation:** A statistical measure expressing how much the samples of a series differ from the mean value of the series – 68% of values fall within +/- 1 of the standard deviation
- **Row 10: Coefficient of variation:** A statistical measure of the dispersion of sample points in a series around the mean (standard deviation divided by the mean)
- **Row 11: Coefficient of Skewness:** When a frequency distribution is asymmetrical, it is usually defined as being a skewed distribution. The coefficient of skewness is a measure of deviation or distance from the symmetry of distribution, having a value close to zero when the distribution curve is symmetrical (normal distribution of data) and tends to be positive when the distribution is skewed to the right, and negative when skewed to the left. The skewness of the data can also be graphically illustrated in a histogram and bell curve as shown in **Figure 5-1** below. A coefficient of skewness value of zero is unrealistic for field data, and the following guideline by Bulmer (1979) is proposed for assessing the coefficient of skewness:
 - If the coefficient of skewness is between -0.5 and +0.5, the distribution is approximately symmetrical
 - If the coefficient of skewness is between -1.0 and -0.5, or between +0.5 and +1.0, the distribution is moderately skewed
 - If the coefficient of skewness is less than -1.0, or greater than +1.0, the distribution is highly skewed
- **Row 12: Coefficient of Kurtosis:** The coefficient of kurtosis measures the degree of curvature or flatness of a distribution. For a normal distribution, the coefficient of kurtosis will have a value of 3, where a peaked curve will have a value greater than 3, and a flatter curve will have a value less than 3. The degree of curvature or flatness of distribution can also be graphically illustrated in a Histogram and Bell curve as shown in **Figure 5-1**.

Row No.	Statistical Parameter	Total COD mgCOD/ℓ	TKN mgN/ℓ	Ammonia mgN/ℓ	Total Phosphorous mgP/ℓ	Ortho-phosphates mgP/ℓ	TSS mgTSS/ℓ	VSS mgVSS/ℓ
1	Outliers removed	Yes	No Outliers	No Outliers	No Outliers	Yes	Yes	No Outliers
2	Data Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed
3	No. of Samples (excl. Outliers)	205	71	209	70	208	205	42
4	Mean Value	937	76	50	9.8	6.0	396	325
5	Minimum Value	514	44	25	5.8	1.0	216	180
6	Maximum Value	1403	115	87	15.7	10.5	725	473
7	Median	931	73	47	10.1	5.7	387	320
8	Mode	919	66	42	10.8	5.1	370	310
9	Standard Deviation	160	14	12	2.0	1.7	92	73
10	Coefficient of variation	0.17	0.19	0.24	0.21	0.29	0.23	0.22
11	Coefficient of Skewness	0.19 (Approx. symmetrical)	0.34 (Approx. symmetrical)	0.76 (Moderate. skewed)	0.39 (Approx. symmetrical)	0.05 (Symmetrical)	0.67 (Moderate. skewed)	0.11 (Approx. symmetrical)
12	Coefficient of Kurtosis	3.37 (Peaked curve)	3.02 (Peaked curve)	3.27 (Peaked curve)	3.30 (Peaked curve)	3.15 (Peaked curve)	3.86 (Peaked curve)	2.70 (Flat curve)

Table 5-1 : Influent wastewater characteristics - Summary of statistical analysis

The following conclusions can be drawn from the statistical analysis presented in **Table 5-1** above and **Figure 5-1** below:

- From the probability curves in **Figure 5-1** for the COD, TKN and Total-P, this specific data could be fitted with a straight line (normal distribution line) on an arithmetical probability curve. As a result, this data can be described as normally distributed. Although not shown in **Figure 5-1**, arithmetical probability curves were also developed for the remaining wastewater characteristics shown in **Table 5-1** which also fitted with a straight line, indicating that this data is also normally distributed
- The normality of the data was also checked by assessing the skewness and degree of curvature of the data. The following was found:
 - The grab sample data was approximately symmetrical as represented by the coefficient of skewness, except for the ammonia and TSS which were moderately skewed
 - The degree of curvature of the data distribution was mostly peaked as represented by the coefficient of kurtosis, except for the VSS which was flatter
 - The symmetry and degree of curvature described above were also confirmed via a histogram and bell curve as shown in **Figure 5-1** for the COD, TKN and Total-P. Although not shown in **Figure 5-1**, histogram and bell curves were also developed for the remaining wastewater

characteristics shown in **Table 5-1** which also confirmed the findings of the coefficients of skewness and kurtosis as presented in **Table 5-1**.

From the above statistical analysis, it can be concluded that the grab sample data is normally distributed. As a result, standard statistical measures can be used to describe the data, or aid in the selection of design values.

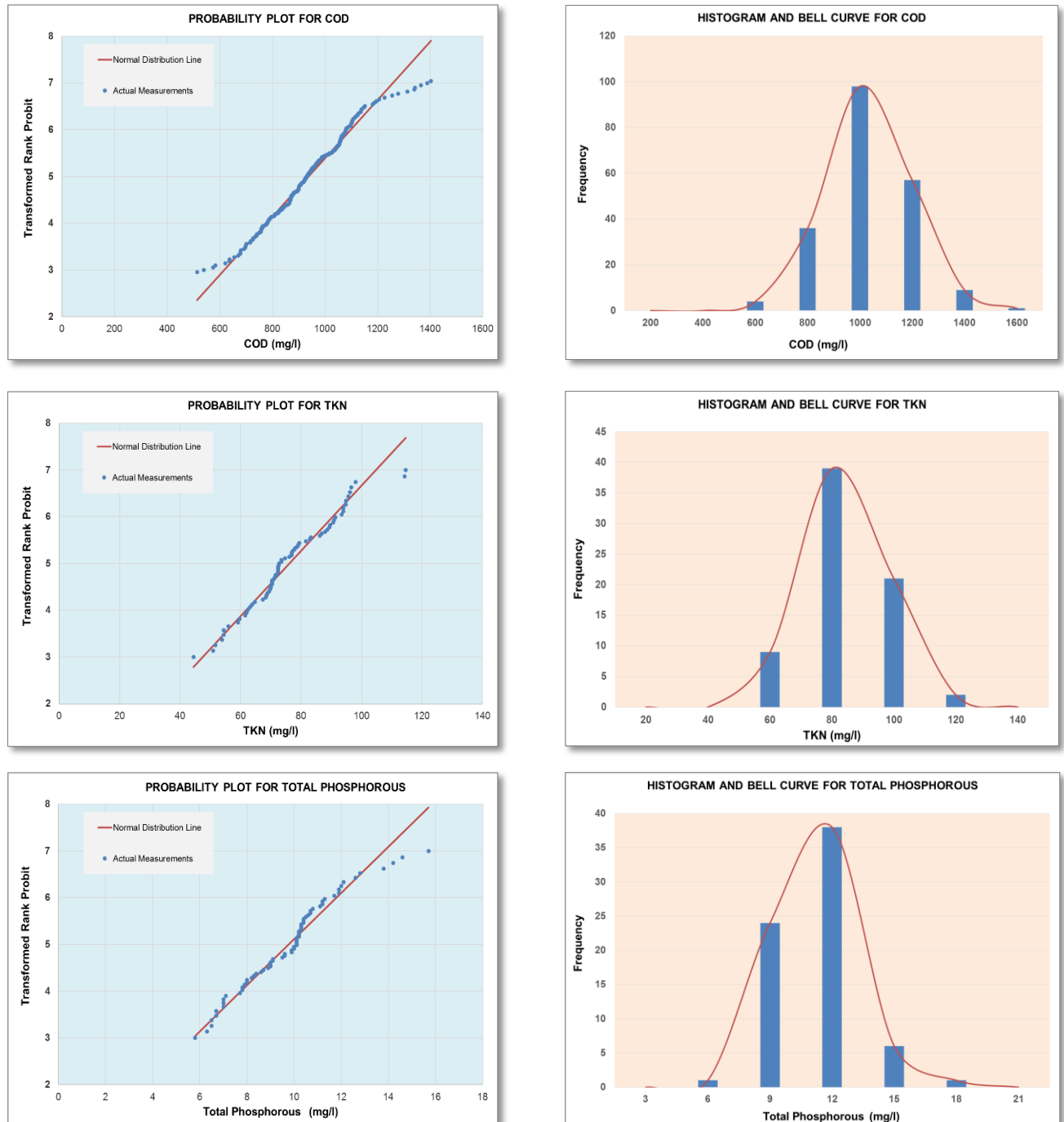


Figure 5-1: Influent wastewater characteristics - Probability curve and Histogram & Bell curve

5.2.1.2 Selected influent wastewater characteristics

The statistical analysis discussed above has confirmed that the grab sample data is normally distributed, and as a result, standard statistical measures can be used. The mean statistical measure was used to guide the selection of design values for the influent (raw) wastewater characteristics as tabulated in **Table 5-2** below. The following is noted:

- Column 3 in the table below presents the data range (minimum and maximum value) over the data record period (excl. outliers)
- Column 4 in the table below presents the mean concentration per parameter over the data record period, also presented in **Table 5-1** above
- Column 7 presents the typical concentration range for “raw municipal wastewater with a minor industrial contribution” which has been based on relevant research literature applicable to municipal wastewater conditions¹⁴
- Column 5 presents the selected design value used in the steady-state analysis presented in **Section 6** of this dissertation, while Column 6 presents the percentile value of the selected design value in relation to the data range. The following is noted:
 - The COD, TKN, ammonia, total P, ortho-P, TSS and VSS is based on the 75thile of the data series and falls within the acceptable range measured for municipal wastewater. As discussed in **Section 5.1** above, only some of the sample data is representative of the peak load. Also, the grab sample data accounts for an entire three years’ data, where a portion of the data is representative of the wet season, where concentrations maybe diluted due to infiltration. As a result, it was decided to scale these parameters to be more representative of the dry weather load by selecting the 75thile of the data series. If one had selected the mean flow-weighted concentration (for example COD) for a specific mean ADWF, the influent flux (kgCOD/day) will be higher for 50% of the time, and lower for the remaining 50% of the time which means there could be several consecutive days where the influent COD flux is higher than the design flux, and this is a concern where these number of consecutive days is higher than the sludge age of the system. The advantage of selecting the higher percentile flux avoids the likelihood of too many consecutive days where the influent COD flux is higher than the design flux and ensures that the number of these consecutive days is lower than the sludge age of the system. For these reasons, it is good practise to select a percentile flux greater than 50%, like the 75thile proposed above, so the plant is designed to cater for a higher flux
 - The inorganic suspended (particulate) solids (ISS) did not form part of the grab sample data, and were calculated from the difference between the TSS and VSS
 - The three-year average for the total settleable solids (TSetS) is an anomaly and is higher than the three-year average for Total suspended (particulate) solids (TSS), which is not possible. This is an error in the sampling measurements and the TSetS historical sampling data has not been considered any further under this dissertation. However, the influent TSS was measured and included in **Table 5-2** below, and the settled TSS for both the Old Lane and New Lane was also measured and summarised in **Table 5-3** further below. As a result, the

Author was able to calculate the influent TSetS from the difference between the influent and settled wastewater flows by performing mass balance checks over the PSTs. This calculation estimates the total settleable solids (TSetS) to be 310 mgSS/ℓ for the Old Lane and 270 mgSS/ℓ for the New Lane. These figures fall within the acceptable range measured for raw municipal wastewater

- The pH and alkalinity are based on the mean value and fall within the acceptable range measured for raw municipal wastewater.

Row No. / Column No	Parameter	Abbrev.	Data Range	Mean for Data Range	Selected Design Value	Percentile Value of Selected Design Value	Typical Municipal ¹³	Unit
1	2	3	4	5	6	7	8	
1	Total COD	S _{ti}	514 – 1403	937	1060	75 th ile	500 - 1200	mgCOD/ℓ
2	Total Kjeldahl Nitrogen (TKN)	N _{ti}	44 -115	76	85	75 th ile	35 - 120	mgN/ℓ
3	Ammonia	N _{ai}	25 – 87	50	55	75 th ile	21 - 96	mgN/ℓ
4	Nitrate/Nitrite (NO ₃ ⁻ -N/NO ₂ ⁻ -N)	NO _{xi}	0	0	0	n/avail.	0.00	mgN/ℓ
5	Total Phosphorous	P _{ti}	5.8 – 15.7	9.8	11	75 th ile	8 - 22	mgP/ℓ
6	Ortho-phosphates	P _{ai}	1.0 – 10.5	6.0	8	75 th ile	5.6 – 19.8	mgP/ℓ
7	Total suspended (particulate) solids	TSS	216 – 725	396	450	75 th ile	270 – 700	mgTSS/ℓ
8	Volatile suspended (particulate) solids	VSS	180 – 473	325	380	75 th ile	260 – 64	mgVSS/ℓ
9	Inorganic Suspended Solids (Inert SS)	ISS	n/appl.	n/appl.	70	n/avail.	10 - 60	mgISS/ℓ
10	Total Settleable solids	TSetS	26.3 – 2104	516	310 (Old) 270 (New)	n/avail.	150 – 550	mgSS/ℓ
11	pH	pH	5.0 – 8.0	7.2	7.2	50 th ile	6.8 – 7.8	
12	Alkalinity	Alk	77 - 555	344	350	50 th ile	200 – 400	mg/ℓ as CaCO ₃

Table 5-2 : Influent wastewater characteristics - Summary of selected design values

The selected design value for the influent wastewater characteristics presented in **Table 5-2** above fall within the range of typical municipal wastewater characteristics. As discussed in **Section 5.1** above, flow-weighted composite samples, non-flow-weighted composite samples over 24-hour intervals, or two-hour concentrations measured over a 24-hour day were not available. As a result, the selected design influent wastewater characteristics could not be validated with a flow-weighted average. In terms of validation of the selected

¹³ Henze, M.C.M. & Comeau, Y. 2008a. Chapter 3: Wastewater Characterisation. In Biological Wastewater Treatment: Principles, Modelling and Design. 1st ed. M. Henze, M.C.M. van Loosdrecht, G.A. Ekama, & D. Brdjanovic, Eds. IWA Publishing. Table 3.6. 35.

design influent wastewater characteristics, a comparison with typical municipal wastewater characteristics as published in relevant research literature applicable to municipal wastewater conditions was undertaken as presented in **Table 5-2** above, which is considered acceptable.

Flow-weighted composite samples, non-flow-weighted composite samples over 24-hour intervals, or two-hour concentrations measured over a 24-hour day are critical for the development of diurnal load patterns (dry weather flow) required in dynamic-state modelling. As this was not available, the actual diurnal load pattern for the influent and settled wastewater was not available. To overcome this, the diurnal load patterns for the influent and settled wastewater were assumed based on the following assumptions:

- The diurnal flow patterns presented in **Section 4.4** for the Old Lane (**Figure 4-4**) and New Lane (**Figure 4-5**) were used as hourly flow data in the diurnal load patterns
- The diurnal concentration patterns (hourly concentration per wastewater parameter) for the Potsdam WWTW were based on the diurnal concentration patterns (in hourly intervals) of the Stellenbosch WWTW which is also located in the Western Cape and has a similar catchment size. The Stellenbosch WWTW receives flow in the order of 30 Ml/day, and has a similar nature of wastewater composition and similar wastewater characteristics to the Potsdam WWTW as presented in **Table 5-2** above. The Stellenbosch WWTW diurnal concentration was changed by a specific factor for each wastewater concentration (COD, TKN, total-P, ortho-P, TSS and VSS), such that the flow-weighted average using Simpson's rule (product of diurnal flow rates presented in **Section 4.4** and the changed diurnal concentrations) for each wastewater characteristic were equal to the selected wastewater characteristic design value for each stream as presented in the following tables:
 - Influent (raw) wastewater stream (**Table 5-2**)
 - Settled wastewater streams for both the Old Lane and New Lane (**Table 5-3**).

The aforementioned resulted in an assumed diurnal concentration pattern for the COD, TKN, TP, TSS, VSS and ISS concentrations which is graphically represented in **Annexure A** for both the raw and settled (Old Lane and New Lane) wastewater streams.

Due to the limited information, several calculated assumptions were required to inform the influent wastewater characteristics and diurnal load patterns. However as these values fell within the range expected for typical municipal wastewater, the Author was satisfied that the proposed influent wastewater characteristics and proposed influent diurnal load pattern be adopted as input to the development of the steady-state and dynamic-state models discussed in **Sections 6** and **7**.

5.2.2 Settled wastewater characteristics

The settled wastewater characteristics have been derived from a three-year data record of 187 and 184 grab samples collected for the Old Lane and New Lane respectively. The analysis of the settled wastewater characteristics followed the same approach as the influent (raw) wastewater discussed in **Section 5.2.1** above. The data was firstly analysed for outliers as follows:

- The grab sample data comprised anomalies, namely some records where the COD, TKN, ammonia, Total-P and ortho-P were not recorded or analysed¹⁴. The data did contain outliers which were omitted from the data set. Outliers omitted from the wastewater characteristics data for the Old Lane were as follows:
 - COD where values of more than 1750 mgCOD/ℓ were deemed outliers
 - TKN where values of more than 150 mgN/ℓ were deemed outliers
 - TSS where values of more than 1000 mgTSS/ℓ were deemed outliers.
- The grab sample data of the New Lane comprised anomalies, namely some records where the COD, TKN, ammonia, Total-P, ortho-P and TSS were not recorded or analysed¹⁵. The data did contain outliers which were omitted from the data set. Outliers omitted from the wastewater characteristics data for the New Lane were as follows:
 - COD where values of more than 1750 mgCOD/ℓ were deemed outliers
 - TKN where values of more than 150 mgN/ℓ were deemed outliers
 - Ammonia where values of more than 100 mgN/ℓ were deemed outliers
 - Ortho-P where values of more than 25 mgP/ℓ were deemed outliers
 - TSS where values of more than 1000 mgTSS/ℓ were deemed outliers.

The data was then analysed statistically per wastewater characteristic to confirm if the data were normally distributed; and lastly the normality of the data was checked by assessing the skewness and degree of curvature. The Author has not discussed the aforementioned analysis and the findings of the statistical analysis further. The reader is referred to **Section 5.2.1** above for details on the statistical analysis process and **Annexure B** for the findings of the statistical analysis for the Old Lane and New Lane respectively. From the statistical analysis for the Old Lane and New Lane presented in **Annexure B**, it can be concluded that the grab sample data is normally distributed. As a result, standard statistical measures can be used to describe the data, or aid in the selection of design values. The selection of the settled wastewater characteristics for the Old Lane and New Lane are discussed together in **Section 5.2.2.1** below.

5.2.2.1 Selected settled wastewater characteristics for the Old Lane and New Lane

The statistical analysis discussed above confirmed that the grab sample data for both the Old Lane and New Lane is normally distributed, and as a result, standard statistical measures can be used. The mean statistical measure was used to guide the selection of design values for the settled wastewater characteristics as tabulated in **Table 5-3** below. The following is noted for **Table 5-3**:

- Columns 1 and 6 present the data range (minimum and maximum value) over the data record period (excl. outliers) for the Old Lane and New Lane respectively

¹⁴ In this case, the fields were left blank, and this omission did not skew the data analysis.

¹⁵ In this case, the fields were left blank, and this omission did not skew the data analysis.

- Columns 2 and 7 present the mean concentration per parameter over the data record period, also presented in and above
- Column 11 presents the typical concentration range for “settled municipal wastewater with a minor industrial contribution” which has been based on industry-accepted standards¹⁸
- Column 3 presents the selected design value of the Old Lane used in the steady-state analysis presented in **Section 6** of this dissertation, while Column 4 presents the percentile value of the selected design value of the Old Lane in relation to the data range. The following is noted:
 - The COD, TKN, total P, TSS, pH and alkalinity are based on the 75thile of the data series and fall within the acceptable range measured for municipal settled municipal wastewater. As for the raw wastewater discussed in **Section 5.1**, only some of the sample data is representative of the peak load. Also, the grab sample data accounts for an entire three years, where a portion of the data is representative of the wet season, where concentrations could be diluted due to infiltration. As a result, it was decided to scale these parameters to be more representative of the dry weather load by selecting the 75thile of the data series. If one had selected the mean flow-weighted concentration (for example COD) for a specific mean ADWF, the influent flux (kgCOD/day) will be higher for 50% of the time, and lower for the remaining 50% of the time which means there could be several consecutive days where the influent COD flux is higher than the design flux, and this is a concern where these number of consecutive days is higher than the sludge age of the system. The advantage of selecting the higher percentile flux avoids the likelihood of too many consecutive days where the influent COD flux is higher than the design flux and ensures that the number of these consecutive days is lower than the sludge age of the system. For these reasons, it is good practise to select a percentile flux greater than 50%, like the 75thile proposed above, so the plant is designed to cater for a higher flux. This same assumption was adopted for the influent wastewater stream as discussed in **Section 5.2.1.2**
 - The mean values for the ammonia and ortho-P in the settled wastewater are lower than the influent values, implying that a percentage of ammonia and ortho-P is removed in the PSTs. These concentrations are dissolved constituents, and for an ideal PST, these dissolved constituents are not removed in the PST. As a result, the sample data for the ammonia and ortho-P is not reliable. As a result, it was assumed that ammonia and ortho-P will not be removed in the PSTs (i.e., influent ammonia and ortho-P equal the corresponding settled values), and the selected ammonia and ortho-P settled values is equivalent to the 90thile of

¹⁸ WERF. 2003. Methods for wastewater characterisation in activated sludge modelling. Water Environment Research Foundation Report. 99-WWF-3.

Henze, M.C.M. & Comeau, Y. 2008a. Chapter 3: Wastewater Characterisation. In Biological Wastewater Treatment: Principles, Modelling and Design. 1st ed. M. Henze, M.C.M. van Loosdrecht, G.A. Ekama, & D. Brdjanovic, Eds. IWA Publishing. 33–52.

- the data series which falls within the acceptable range measured for municipal settled municipal wastewater
- The VSS did not form part of the grab sample data. The VSS was assumed to be 120 mg/l, based on a similar PST capture rate percentage as the TSS described above
 - The total settleable solids did not form part of the grab sample data. The total settleable solids were assumed to be completely removed in the PSTs, implying a 100% capture rate of total settleable solids
 - The ISS did not form part of the grab sample data, and was calculated from the difference between the TSS and assumed VSS
- Column 8 presents the selected design value of the New Lane used in the steady-state analysis presented in **Section 6** of this dissertation, while Column 9 presents the percentile value of the selected design value in relation to the data range. The following is noted:
 - The COD, TKN, total P, TSS, pH and alkalinity are based on the 75thile of the data series and fall within the acceptable range measured for municipal settled municipal wastewater. This is based on the same assumption which was adopted for the settled wastewater of the Old Lane as discussed above
 - The mean values for the ammonia and ortho-P in the settled wastewater are lower than the influent values, implying that a percentage of ammonia and ortho-P is removed in the PSTs. As discussed above for the Old Lane, these concentrations are dissolved constituents, and for an ideal PST, these dissolved constituents are not removed in the PST. As a result, the sample data for the ammonia and ortho-P is not reliable. As a result, it was assumed that ammonia and ortho-P will not be removed in the PSTs (i.e., influent ammonia and ortho-P equal the corresponding settled values), and the selected ammonia and ortho-P settled values is equivalent to the 90thile of the data series which falls within the acceptable range measured for municipal settled wastewater
 - The VSS and total settleable solids did not form part of the grab sample data. The VSS was assumed to be 140 mg/l, based on a similar PST capture rate percentage as the TSS. The total settleable solids were assumed to be completely removed in the PSTs as assumed for the Old Lane, implying a 100% capture rate of total settleable solids
 - The ISS did not form part of the grab sample data, and was calculated from the difference between the TSS and assumed VSS
 - Columns 6 and 10 present the percentage concentration removal (capture rate) in the PSTs for the Old Lane and New Lane respectively, which is attributed to the removal of a significant portion of the particulate component from the influent wastewater, removed via the primary sludge underflow. The following is also noted:
 - Historically measured values (Metcalf & Eddy, 2014) on the organics removal percentages (i.e. capture rates) in a PST can vary between 25% to 45% for COD, 15% to 35% for TKN and 10% to 25% for total-P. From **Table 5-3** below, it can be seen that the estimated capture rates in the PSTs for the case study WWTW fall within the range of historically measured values.

The selected design values for the settled wastewater characteristics presented in **Table 5-3** below fall within the range of typical municipal wastewater characteristics. In the Author's experience, such values would be expected for a plant like the Potsdam WWTW. However, one would have expected the mean values of the concentrations (settled wastewater) presented in **Table 5-3** for the Old Lane and New Lane to be the same. Although the mean values differ per concentration parameter, the difference is not significant, with each set of mean values per concentration parameter within 95% of each other, except for the TSS and VSS, where the TSS value of the New Lane is 20% lower than the Old Lane, and the VSS value of the New Lane is 15% lower than the Old Lane. The differences in the TSS and VSS could be attributed to the PST sizing and design. In the absence of data, one would typically have selected similar concentration values for the Old Lane and New Lane.

As previously discussed in **Section 5.1**, flow-weighted composite samples, non-flow-weighted composite samples over 24-hour intervals, or two-hour concentrations measured over a 24-hour day were not available. As a result, the selected design settled wastewater characteristics could not be verified with a flow-weighted average, and the diurnal load pattern for the settled wastewater was not available. In terms of verification of the selected design settled wastewater characteristics, a comparison with typical municipal wastewater characteristics as published in relevant research literature applicable to municipal wastewater conditions was undertaken as presented in **Table 5-3** below. To overcome the shortfall of the diurnal load patterns, the diurnal load pattern for the settled wastewater needed to be assumed for both the Old Lane and New Lane, which is discussed earlier in **Section 5.2.1.2** above. The assumed diurnal load patterns for COD, TKN, TP, TSS, VSS and ISS are graphically represented in **Annexure A** for both the raw and settled (Old Lane and New Lane) wastewater streams.

As previously discussed, there was a lack of sampling data for the settled wastewater which resulted in several calculated assumptions required to inform the settled wastewater characteristics and diurnal load patterns. As the selected design values fell within the range expected for typical municipal wastewater, the Author was satisfied that the proposed settled wastewater characteristics and proposed settled diurnal load patterns be adopted as input to the development of the steady-state and dynamic-state models discussed in **Sections 6** and **7**.

Parameter /	Abbreviation	Old Lane						New Lane				Typical Municipal ²⁰	Unit
		Data Range	Mean for Data Range	Selected Design Value	Percentile Value of Selected Design Value	% removal in PSTs	Data Range	Mean for Data Range	Selected Design Value	Percentile Value of Selected Design Value	% removal in PSTs		
Column No.		1	2	3	4	5	6	7	8	9	10	11	12
Total COD	S _{ti}	268 – 901	547	620	75 th ile	42%	332 – 992	582	660	75 th ile	38%	350 – 750	mgCOD/l
Total Kjeldahl Nitrogen	N _{ti}	36 – 73	51	68	75 th ile	20%	42 – 86	54	68	75 th ile	20%	30 – 110	mgN/l
Ammonia	N _{ai}	24 – 60	38	55	n/appl.	0%	20 – 57	39	55	n/appl.	0%	21 – 99	mgN/l
Nitrate/Nitrite (NO ₃ -N/NO ₂ -N)	NO _{xi}	0	0	0	n/avail	0%	0	0	0	n/avail	0%	0.00	mgN/l
Total Phosphorous	P _{ti}	4.4 – 11.4	7.2	9.0	75 th ile	18%	5.1 – 14.3	7.7	9.0	75 th ile	18%	6 – 22	mgP/l
Ortho-phosphates	P _{ai}	2.8 – 9.7	5.8	8.0	90 th ile	0%	2.2 – 10.9	5.9	8.0	90 th ile	0%	4.5 – 20.9	mgP/l
TSS	X _O	36 – 236	95	140	75 th ile	69%	44 – 338	120	180	75 th ile	60%	150 – 375	mgTSS/l
VSS	X _{VSS}	n/avail.	n/avail.	120	n/avail.	68%	n/avail.	n/avail.	140	n/avail.	63%	145 – 355	mgVSS/l
Inorganic Suspended Solids (Inert SS)	X _{ISS}	n/avail.	n/avail.	20	n/avail.	73%	n/avail.	n/avail.	40	n/avail.	43%	5 – 20	mgISS/l
Total settleable solids	SetS	n/avail.	n/avail.	0	n/avail.	100%	n/avail.	n/avail.	0	n/avail.	100%	0 – 75	mgTSS/l
pH	pH	5.5 – 7.3	6.9	7.2	75 th ile	0%	5.2 – 8.2	6.9	7.2	75 th ile	0%	6.8 – 7.8	
Alkalinity	Alk	173 – 435	329	350	75 th ile	0%	151 – 429	328	350	75 th ile	0%	200 – 400	mg/l as CaCO ₃

Table 5-3: Settled wastewater characteristics – Summary of selected design values

²⁰ WERF. 2003. Methods for wastewater characterisation in activated sludge modelling. Water Environment Research Foundation Report. 99-WWF-3.

Henze, M.C.M. & Comeau, Y. 2008a. Chapter 3: Wastewater Characterisation. In Biological Wastewater Treatment: Principles, Modelling and Design. 1st ed. IWA Publishing. 33–52.

5.2.3 Effluent characteristics

The availability of effluent quality data can be used to assist in the characterisation of the raw and settled wastewater, specifically in determining the unbiodegradable soluble components, provided the biodegradable (soluble and particulate) and unbiodegradable particulate components are completely removed in the upstream treatment process.

The effluent characteristics have been derived from a three-year data record of 218 grab samples. The analysis of the effluent characteristics followed the same approach as the influent (raw) wastewater discussed in **Section 5.2.1** above. The data was firstly analysed for outliers which did not comprise any significant anomalies, but there were specific effluent characteristics that did contain outliers. These outliers were omitted from the data set. Outliers omitted from the effluent characteristics data were as follows:

- COD where values of more than 100 mgCOD/l were deemed outliers
- TKN where values of more than 12 mgN/l were deemed outliers
- Ammonia where values of more than 10 mgN/l were deemed outliers
- Total-P where values of more than 10 mgP/l were deemed outliers
- Ortho-P where values of more than 10 mgP/l were deemed outliers
- TSS where values of more than 100 mgTSS/l were deemed outliers.

The data was then analysed statistically per wastewater characteristic to confirm if the data were normally distributed; and lastly the normality of the data was also checked by assessing the skewness and degree of curvature. The Author has not discussed the aforementioned analysis and the findings of the statistical analysis further. The reader is referred to **Section 5.2.1** above for details on the statistical analysis process and **Annexure B** for the findings of the statistical analysis for the effluent wastewater characteristics. From the statistical analysis presented in **Annexure B**, it can be concluded that the grab sample data is normally distributed. As a result, standard statistical measures can be used to describe the data, or aid in the selection of design values. The section below discusses the selection of the design effluent characteristics.

5.2.3.1 Selected effluent wastewater characteristics

The statistical analysis confirmed that the grab sample data is normally distributed, and as a result, standard statistical measures can be used. The mean statistical measure was used to guide the selection of design values for the effluent characteristics as tabulated in **Table 5-4** below. The following is noted:

- Column 3 in the table below presents the data range (minimum and maximum value) over the data record period (excl. outliers)
- Column 4 in the table below presents the mean concentration per parameter over the data record period, also presented above
- Column 5 in the table below presents the selected design concentration per parameter which has been kept the same as the mean value

- Column 6 presents the effluent discharge standards stipulated in the Water Use License for the Potsdam WWTW.

Parameter /	Abbrev.	Data Range	Mean for Data Range	Selected Design Value	Effluent Standards ²¹	Unit
Column No.	2	3	4	5	6	7
Total COD	S _{ti}	26 – 67	44	44	75	mgCOD/ℓ
Total Kjeldahl Nitrogen (TKN)	N _{ti}	0.5 – 10.1	4.5	4.5	Not stipulated	mgN/ℓ
Ammonia	N _{ai}	0.4 – 9.3	1.2	1.2	6	mgN/ℓ
Nitrate/Nitrite (NO ₃ -N/NO ₂ -N)	NO _{xi}	0.1 – 7.2	1.5	1.5	5	mgN/ℓ
Total Phosphorous	P _{ti}	0.1 – 3.6	1.3	1.3	Not stipulated	mgP/ℓ
Ortho-phosphates	P _{ai}	0.1 – 3.6	1.0	1.0	1	mgP/ℓ
TSS	X _o	1.0 – 29.0	7.3	7.3	25	mgTSS/ℓ
pH	pH	6.9 – 8.0	7.61	7.61	5.5 – 9.5	
Alkalinity	Alk	66 – 268	161	161	Not stipulated	mg/ℓ as CaCO ₃

Table 5-4 : Effluent wastewater characteristics – Summary of selected design values

The mean values for the effluent characteristics are low and generally below the effluent standard, except for the ortho-P. The effluent standard for phosphorous is very strict, and practically, it is very difficult to achieve an ortho-P of less than 1mg/l with a biological process only. Typically, chemical enhanced phosphorous removal systems are implemented on plants where a strict phosphorous limit is imposed. From the table above, it can be concluded that the plant is treating the wastewater to the required standard. As a result, it can be assumed that the process is completely removing the biodegradable (soluble and particulate) and unbiodegradable particulate components, leaving only the unbiodegradable soluble component in the effluent. On these grounds, it can be assumed that the mean values tabulated in **Table 5-4** above represent the unbiodegradable soluble component which can be used in the characterisation of the wastewater. The aforementioned is further discussed in **Section 5.3.1** below.

²¹ The Water Use License for the Potsdam WWTW issued by the Department of Water and Sanitation prescribes effluent treatment standards which must comply with the General Authorisation in terms of Section 39 of the National Water Act (Act No. 36 of 1998). The effluent released from the Potsdam WWTW into the downstream environment needs to comply with the general limit, with the exception of the phosphorous, which must comply with the special limit (ortho-phosphates as phosphorous to be less than 1mg/ℓ).

5.3 Wastewater Characterisation

The wastewater characterisation is one of the most critical steps in the design of a WWTW. The wastewater is typically categorised for the influent (raw), settled and primary sludge (if applicable) streams, and typically into the COD, TKN, total-P and total organic carbon (TOC) concentrations. Each wastewater concentration is then divided into two groups, biodegradable and unbiodegradable. Each group is then further subdivided into a soluble and particulate component. The particulate component of the biodegradable (BPO) and unbiodegradable (UPO) groups is made up of a settleable component and a non-settleable component respectively, of which the settleable component will typically be captured (removed) in the PST. Thus, the settled wastewater will mainly comprise non-settleable particulates, while the primary sludge will comprise mainly settleable particulates. There is very limited research (historically measured values) to quantify the split between the settleable and non-settleable particulates for both the BPO and UPO groups, but it has been observed that the UPO settle out in greater proportion (65-85%) in a PST than the BPO (30-45%) (Wentzel *et al.*, 2006; Ikumi *et al.*, 2014). Although quantifying the composition of the settleable and non-settleable particulates is complex, it is based on mass balance modelling of the PST and is required for the design of the bioreactor and anaerobic digester because the PST splits the organic load between the activated sludge reactor and the anaerobic digester. This is discussed further under **Section 5.3.3** below. The following is further applicable to the characterisation of the following concentrations:

- **COD:** The soluble biodegradable component of the COD is commonly termed readily biodegradable COD (RBCOD) and is further subdivided into volatile fatty acids (VFA) and fermentable biodegradable COD (F-RBCOD) (Wentzel *et al.*, 1999). This division is critical in biological excess phosphorous removal (BEPR) systems making the RBCOD one of the most critical wastewater characteristics. The BPO is termed slowly biodegradable COD (SBCOD) (Wentzel *et al.*, 1999). The extent of denitrification is dependent on the number of electron donors available, namely RBCOD and slowly biodegradable organics (SBCOD) where RBCOD is the preferred substrate in N only removal systems, and RBCOD and SBCOD are both used in N and P combined removal systems. This specific aspect is discussed in more detail in **Section 8.4.1**
- **TKN:** The TKN is firstly divided into two groups, free and saline ammonia and organic nitrogen, where the organic nitrogen is further characterised into the same four groups as the organics (i.e., COD), namely biodegradable and unbiodegradable components, each with a soluble and a particulate portion. This ratio can impact significantly on the performance of a WWTW with respect to N removal, specifically with respect to the breakdown of organic N to free and saline ammonia. This specific aspect is discussed in more detail in **Section 8.2.1**
- **Total-P:** Similar to the TKN, the total-P is firstly divided into two groups, ortho-P and organic phosphates (OrgP), where the OrgP is further characterised into the same four groups as the organics (i.e., COD), namely biodegradable and unbiodegradable components, each with a soluble and a particulate portion as discussed above.

Each of the seven organic groups, namely unbiodegradable soluble organics (USO), fermentable biodegradable soluble organics (FBSO), VFA, BPO (settleable and non-settleable) and UPO (settleable and

non-settleable) have their composition expressed as $C_x H_y O_z N_a P_b$ where the x , y , z , a and b values of the BPO settleable and non-settleable are the same, and the UPO settleable and non-settleable are the same. The x , y , z , a , and b values are related to the COD/VSS (f_{cv}), TOC/VSS (f_c), N/VSS (f_n) and P/VSS (f_p) mass ratios and are determined by mass balance considerations over the PST and the concentration measurements of the raw wastewater entering the PST, and the settled wastewater and primary sludge exiting the PST.

The section below will discuss the characterisation of the influent (raw) and settled wastewater, while the characterisation of the primary sludge is discussed under **Section 5.4**. The following approach has been adopted for the characterisation of the influent (raw) and settled wastewater:

- Firstly, specific wastewater fractions can be derived from the historic sampling data as presented for the influent characteristics (**Table 5-2**), settled characteristics (**Table 5-3**) and effluent characteristics (**Table 5-4**). This analysis is discussed in **Section 5.3.1** below
- Secondly, the wastewater fractions derived from the sampling data discussed above are limited. Those fractions that could not be derived from the historic sampling data needed to be assumed based on available literature (historically measured values). These assumptions are discussed in **Section 5.3.2** below
- Lastly, the wastewater characterisation for both the Old Lane and New Lane is presented in **Section 5.3.3** below.

5.3.1 Wastewater fractions derived from sampling data

As discussed in **Section 5.2.3** above, the effluent quality data can be used to assist in the partial characterisation of the raw and settled wastewater, specifically in determining the unbiodegradable soluble components (USO). This assumption is valid provided the biodegradable (soluble and particulate) and unbiodegradable particulate components are completely removed in the upstream treatment process which was concluded at the end of **Section 5.2.3** for the case study WWTW. As a result, the following wastewater fractions have been derived from the influent characteristics (**Table 5-2**), settled characteristics (**Table 5-3**) and effluent characteristics (**Table 5-4**) which are summarised in **Table 5-5** below:

- Fraction of total COD that is unbiodegradable and soluble ($f_{s'us}$): For the influent (raw) wastewater, this fraction is calculated from the effluent COD as a ratio of the total influent COD, where the effluent COD is completely unbiodegradable and soluble. The same procedure is adopted for the settled wastewater value, except the total influent COD is substituted with the total settled COD
- Fraction of TKN that is free and saline ammonia ($f_{N'a}$): For the influent (raw) wastewater, this fraction is calculated from the influent ammonia as a ratio of the influent TKN. The same procedure is adopted for the settled wastewater value, except the influent values are substituted with the settled values
- Fraction of TKN that is unbiodegradable and soluble ($f_{N'ous}$): For the influent (raw) wastewater, this fraction is calculated from the effluent TKN (unbiodegradable and soluble component only) as a ratio of the total influent TKN. The effluent TKN (unbiodegradable and soluble component only) is calculated as the difference between the effluent TKN and the sum of the effluent ammonia and effluent nitrate.

The same procedure is adopted for the settled wastewater value, except the influent TKN is substituted with the settled TKN

- Fraction of total-P that is ortho-P ($f_{P's}$): For the influent (raw) wastewater, this fraction is calculated from the influent ortho-P as a ratio of the influent total-P. The same procedure is adopted for the settled wastewater value, except the influent values are substituted with the settled values
- Fraction of total-P that is organic unbiodegradable soluble ($f_{P'ous}$): For the influent (raw) wastewater, this fraction is calculated from the effluent total-P (unbiodegradable and soluble component only) as a ratio of the influent total-P. The same procedure is adopted for the settled wastewater value, except the influent total-P is substituted with the settled total-P.

Parameter	Abbrev.	Selected Design Value (Raw)	Typical Raw ²²	Selected Design Value (Settled – Old Lane)	Selected Design Value (Settled – New Lane)	Typical Settled ²¹	Unit
COD							
Fraction of COD that is unbiodegradable and soluble	$f_{s'us}$	0.042	0.04 – 0.10	0.071	0.067	0.05 – 0.20	mgCOD/mgCOD
Nitrogen (N)							
Fraction of TKN that is free and saline ammonia	f_{Na}	0.647	0.60 – 0.80	0.809	0.809	0.70 – 0.90	mgN/mgN
Fraction of TKN that is unbiodegradable and soluble	$f_{N'ous}$	0.021	0.00 – 0.04	0.026	0.026	0.00 – 0.05	mgN/mgN
Phosphorous (P)							
Fraction of total-P that is ortho-phosphate	$f_{P's}$	0.727	0.70 – 0.90	0.889	0.891	0.75 – 0.95	mgP/mgP
Fraction of total-P that is organic unbiodegradable soluble	$f_{P'ous}$	0.027	0.00 – 0.03	0.033	0.033	0.00 – 0.04	mgP/mgP

Table 5-5 : Wastewater fractions derived from sampling data

The table above presents the selected design value of the above-mentioned wastewater fractions for the raw and settled wastewater and compares these fractions to historically measured values (columns labelled “Typical”). The selected design value for the above wastewater fractions falls within the range of typical municipal wastewater fractions¹⁸, and as such, the Author was satisfied that these be adopted as input for the characterisation of the wastewater discussed in **Section 5.3.3** below.

5.3.2 Wastewater fractions assumed based on relevant research literature

As discussed in **Section 5.1** above, the wastewater parameters sampled and tested for the Potsdam WWTW are limited, and as a result there are several critical wastewater parameters (fractions) that had to be assumed

²² Henze, M.C.M. & Comeau, Y. 2008a. Chapter 3: Wastewater Characterisation. In Biological Wastewater Treatment: Principles, Modelling and Design. 1st ed. M. Henze, M.C.M. van Loosdrecht, G.A. Ekama, & D. Brdjanovic, Eds. IWA Publishing. 33–52.

based on available literature (Henze *et al.*, 2008). These fractions have been assumed to be the same for both the Old Lane and New Lane and are summarised below:

Parameter	Abbreviation	Selected Design Value (Raw)	Typical Raw	Selected Design Value (Settled)	Typical Settled	Unit
COD						
Fraction of readily biodegradable COD that is VFA	f_{ac}	0.200	0.100 – 0.400	0.200	0.100 – 0.400	mgCOD/mgCOD
Fraction of total COD that is readily biodegradable	$f_{s'bs}$	0.175 ^{old Lane} & 0.187 ^{New Lane}	0.080 – 0.250	0.300	0.100 – 0.350	mgCOD/mgCOD
Fraction of total COD that is particulate unbiodegradable	$f_{s'up}$	0.120	0.070 – 0.200	0.050	0.000 – 0.100	mgCOD/mgCOD
Nitrogen						
N content of the particulate unbiodegradable COD	$f_{Sup'N}$	0.068	0.060 – 0.080	0.068	0.060 – 0.080	mgN/mgCOD
Fraction of biodegradable organic TKN that is particulate	f_{nox}	0.785	0.700 – 0.850	0.625	0.550 – 0.700	mgN/mgN
Phosphorous						
P content of the particulate unbiodegradable COD	f_{upP}	0.013	0.010 – 0.020	0.110	0.010 – 0.020	mgP/mgCOD
Fraction of the biodegradable organic influent TP which is particulate	f_{XPB}	0.700	0.600 – 0.750	0.500	0.500 – 0.650	mgP/mgP

Table 5-6 : Wastewater fractions assumed based on available literature

Of the above fractions, the “fraction of total COD that is particulate unbiodegradable ($f_{s'up}$)” and the “fraction of total COD that is readily biodegradable ($f_{s'bs}$)” are important wastewater characteristics, and these are rarely measured for municipal WWTWs. As discussed above, the RBCOD is critical for the design of a biological nutrient removal system specifically with respect to the amount of phosphorous and nitrate which can be removed biologically. The unbiodegradable particulate COD is critical for the design of the PST as it was found that PSTs remove greater proportions of UPO than BPO (Ekama, 2006).

The following assumptions have also been adopted for the characterization of the wastewater:

- The mass ratios for the unbiodegradable particulate organics (UPO) were assumed to have the same composition and mass ratios as activated sludge biomass as commonly done:
 - COD/VSS ratio (f_{cv}) = 1.481
 - TKN/VSS ratio (f_n) = 0.100
 - TP/VSS ratio (f_p) = 0.025
- Settleable and non-settleable particulates (BPO and UPO) have been assumed to have the same mass ratios.

5.3.3 Wastewater Characterisation for the Old Lane and New Lane

In summary, the following information was used for purposes of the wastewater characterisation:

- The wastewater characteristics as presented in **Section 5.2**
- The wastewater fractions that were derived from the sampling data as presented in **Section 5.3.1** above
- The wastewater fractions that were assumed as presented in **Section 5.3.2** above.

Based on a mass balance of the COD, TOC, TKN, TP, TSS and VSS over the PST, the wastewater characterisation was carried out for the biodegradable (particulate and soluble) and unbiodegradable (particulate and soluble) portions of the COD, TKN, TP and total organic carbon (TOC) concentrations. This was further undertaken for the raw and settled wastewater for both the Old Lane and New Lane respectively and is represented in block diagram formats and a table summarising concentrations and associated fluxes, included in **Annexure C**. Block diagram formats of the COD, TKN and TP are shown in the figures below for the following streams:

- Influent (raw) wastewater – **Figure 5-5**
- Settled wastewater streams (Old Lane and New Lane) – **Figure 5-7** and **Figure 5-6**
- Primary sludge (Old Lane and New Lane combined) – **Figure 5-8**.

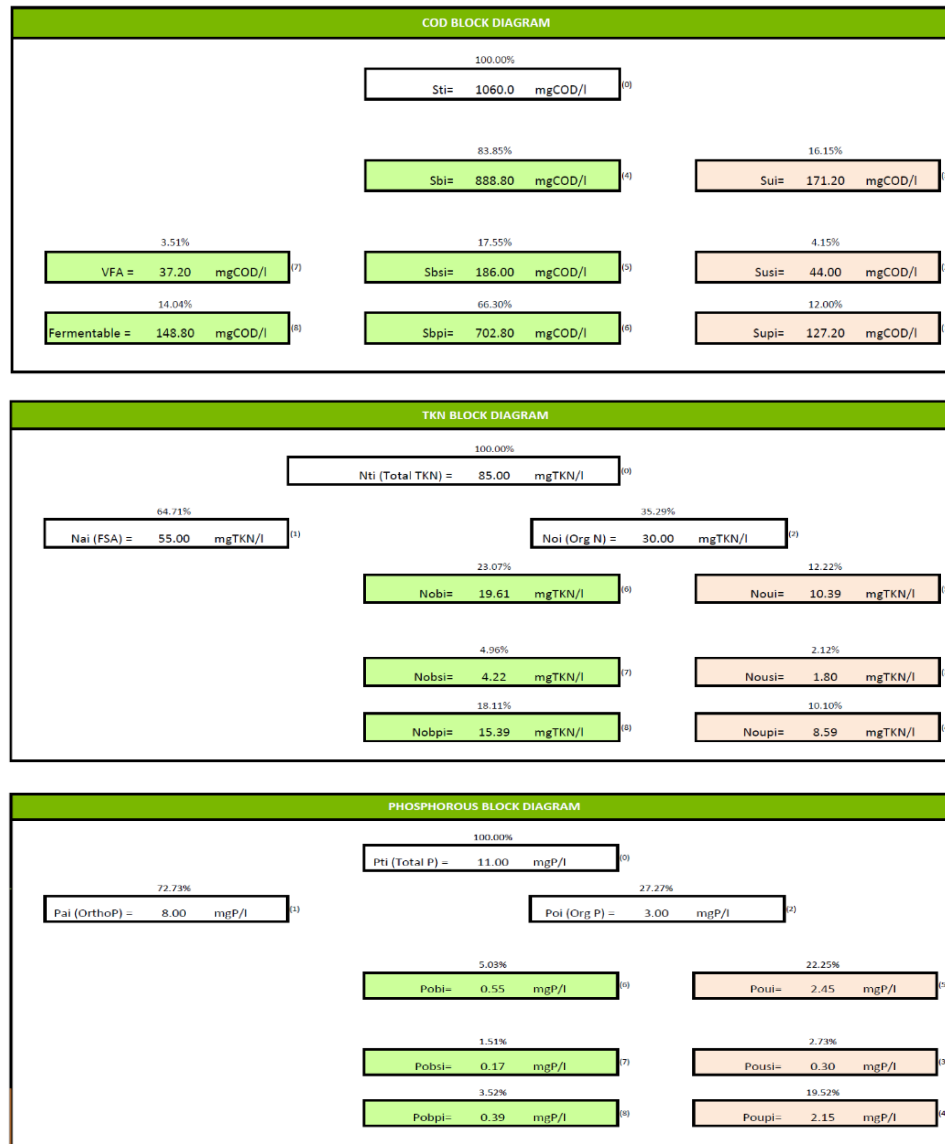


Figure 5-5: Block Diagram – Influent Wastewater

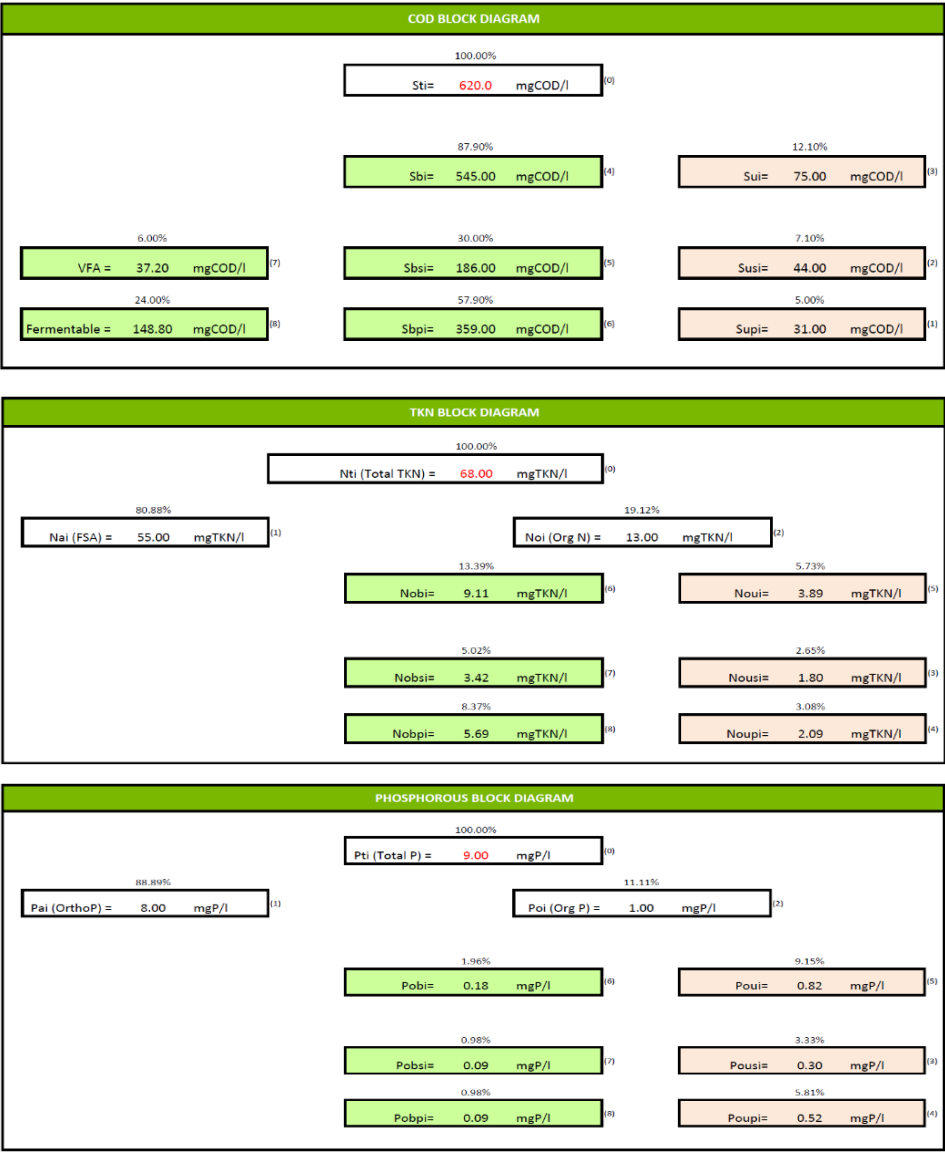


Figure 5-7: Block Diagram – Settled Wastewater (Old Lane)

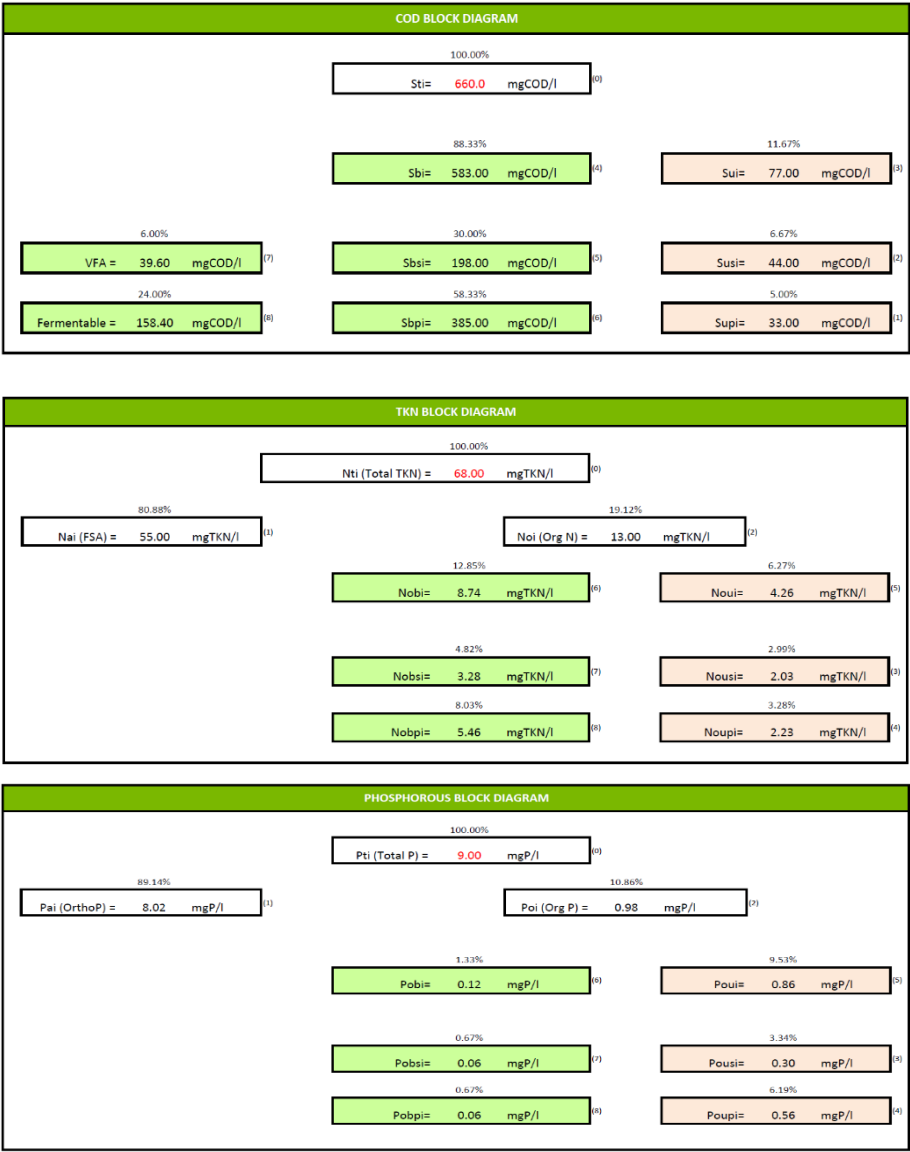


Figure 5-6: Block Diagram – Settled Wastewater (New Lane)

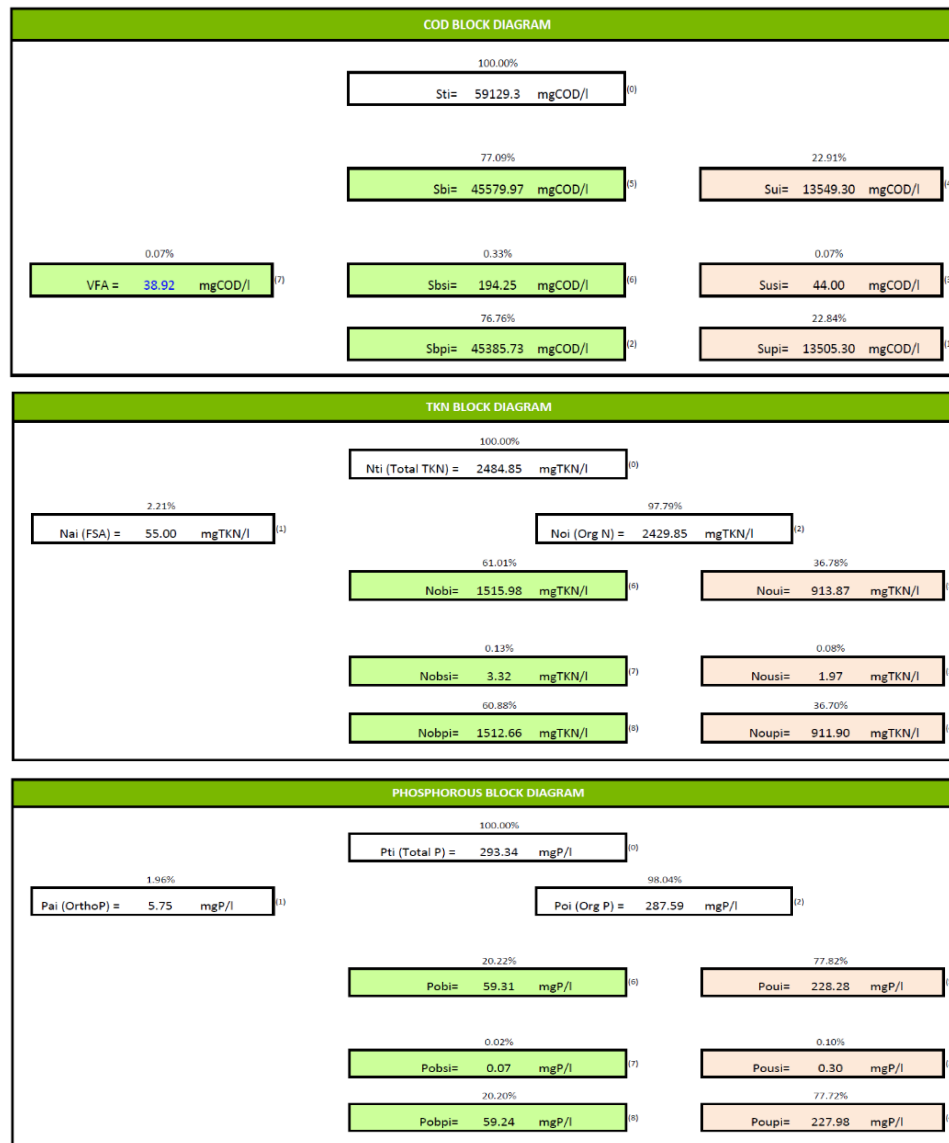


Figure 5-8: Block Diagram – Primary Sludge (Old and New Lanes combined)

As previously discussed, the UPO and the BPO both comprise settleable and non-settleable particulates which are required for the PST and bioreactor design. The UPO is of more significance, as this influences the bioreactor in terms of volume, oxygen demand and sludge production. The higher the UPO (non-settleable component) in the settled wastewater, the larger the reactor volume and sludge production, and the lower the oxygen demand. For the wastewater characterisation, the settleable and non-settleable particulates of the same group have the same mass ratios, but the mass ratios of the UPO and BPO are different. The mass ratios of the UPO have been assumed to have the same composition and mass ratios as activated sludge biomass (Henze *et al.*, 2008). There is very limited research (historically measured values) to quantify the split between the settleable and non-settleable particulates for both the BPO and UPO groups, but it has been observed that the UPO settle out in greater proportion (65-85%) in a PST than the BPO (30-45%) (Wentzel *et al.*, 2006; Ikumi *et al.*, 2014). From the wastewater characterisation block diagrams presented in **Annexure C** and shown in the figures above, the percentage of UPO and BPO that settle in the PSTs was calculated and presented in **Table 5-7** below. From **Table 5-7**, it can be seen that the values calculated from the wastewater characterisation align well with the values observed by Wentzel (2006), with the exception of the BPO for the TKN and total-P which is higher than those predicted by Wentzel.

Parameter	UPO removed in PSTs (Settleable particulates)		BPO removed in PSTs (Settleable particulates)	
	Old Lane	New Lane	Old Lane	New Lane
Total COD	76%	74%	49%	44%
Total Kjeldahl Nitrogen	76%	74%	63%	65%
Total-P	76%	74%	77%	85%

Table 5-7 : Percentage of UPO and BPO that settle in the PSTs

The mass ratios, namely the COD/VSS ratio (f_{cv}), TKN/VSS ratio (f_n) and TP/VSS ratio (f_p) were also calculated for both the raw and settled wastewater flows from the wastewater characterisation block diagrams presented in **Annexure C** and **Figure 5-5**, **Figure 5-7** and **Figure 5-6**. The mass ratios were calculated for the following five organic groups:

- Dissolved organics: Volatile fatty acids (VFA), fermentable biodegradable soluble organics (FBSO) and unbiodegradable soluble organics (USO)
- Particulate organics: Biodegradable particulate organics (BPO) and unbiodegradable particulate organics (UPO) with the settleable and non-settleable having the same composition (i.e., same mass ratios).

The calculated mass ratios were then checked against historically measured values (Wentzel *et al.*, 2006, Ekama *et al.*, 2009 and Ikumi *et al.*, 2014) to verify the wastewater characterisation. This comparison of the

calculated mass ratios versus historically measured values is presented in the following tables, where significant variations are shown in red font:

- Old Lane: **Table 5-8, Table 5-9 and Table 5-10**
- New Lane: **Table 5-11, Table 5-12 and Table 5-13.**

From the tables below, it can be seen that for both the Old Lane and New Lane, the calculated mass ratios align well with the historically measured values except for the calculated influent COD/VSS ratio of the BPO for both the Old Lane and New Lane (indicated in red font). The calculated influent COD/VSS mass ratio of the BPO is much higher than the historically measured value for both the Old Lane and New Lane, and is attributed to the low values measured for the influent TSS and VSS. For purposes of the development of the steady-state and dynamic-state models presented in **Sections 6 and 7**, it was decided to adopt the historically measured influent COD/VSS ratio of the BPO for both the Old Lane and New Lane. If a COD/VSS ratio of 1.550 gCOD/gVSS was selected, one is effectively increasing the VSS concentration of the influent without changing the influent COD concentration. As the models for the activated sludge system and anaerobic digester are COD based, effectively increasing the influent VSS does not affect the sizing, capacity and performance of the aforementioned process units. Apart from the aforementioned COD/VSS mass ratio, the remaining calculated mass ratios compare well with historically measured values and these have been adopted for design purposes as presented in **Sections 6 and 7**. As a result, the Author is satisfied that the proposed wastewater characterisation for the influent and settled streams be adopted for the development of the steady-state and dynamic-state models discussed in **Sections 6 and 7**.

Parameter	Abbr.	USO (influent)		VFA (influent)		FBSO (influent)		Unit
		Calculated	Typical Municipal	Calculated	Typical Municipal	Calculated	Typical Municipal	
COD/VSS Ratio	f_{cv}	1.493	1.500	1.000	1.067	1.420	1.450	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content)	f_n	0.061	0.035	0.000	0.000	0.040	0.051	mgN/mgVSS
TP/VSS Ratio (Phosphorous Content)	f_p	0.010	0.000	0.000	0.000	0.002	0.000	mgP/mgVSS

Table 5-8 : Old Lane - Mass ratios of dissolved organics (influent - raw)

Parameter	Abbreviation	BPO (influent)		UPO (influent)		Unit
		Calculated	Typical Municipal	Calculated	Typical Municipal	
COD/VSS Ratio	f_{cv}	2.390	1.550	1.481	1.481	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content)	f_n	0.052	0.040	0.100	0.100	mgN/mgVSS
TP/VSS Ratio (Phosphorous Content)	f_p	0.001	0.006	0.025	0.025	mgP/mgVSS

Table 5-9 : Old Lane - Mass ratios of particulate organics (influent - raw)

Parameter	Abbr.	USO (settled)		VFA (settled)		FBSO (settled)		Unit
		Calculated	Typical Municipal	Calculated	Typical Municipal	Calculated	Typical Municipal	
COD/VSS Ratio	f_{cv}	1.493	1.500	1.000	1.067	1.420	1.450	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content)	f_n	0.061	0.035	0.000	0.000	0.033	0.051	mgN/mgVSS
TP/VSS Ratio (Phosphorous Content)	f_p	0.000	0.000	0.000	0.000	0.001	0.000	mgP/mgVSS

Table 5-10 : Old Lane - Mass ratios of dissolved organics (settled)

Parameter	Abbr.	USO (influent)		VFA (influent)		FBSO (influent)		Unit
		Calculated	Typical Municipal	Calculated	Typical Municipal	Calculated	Typical Municipal	
COD/VSS Ratio	f_{cv}	1.493	1.500	1.000	1.067	1.420	1.450	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content)	f_n	0.058	0.035	0.000	0.000	0.038	0.051	mgN/mgVSS
TP/VSS Ratio (Phosphorous Content)	f_p	0.010	0.000	0.000	0.000	0.001	0.000	mgP/mgVSS

Table 5-11 : New Lane - Mass ratios of dissolved organics (influent - raw)

Parameter	Abbreviation	BPO (influent)		UPO (influent)		Unit
		Calculated	Typical Municipal	Calculated	Typical Municipal	
COD/VSS Ratio	f_{cv}	2.349	1.550	1.481	1.481	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content)	f_n	0.053	0.040	0.100	0.100	mgN/mgVSS
TP/VSS Ratio (Phosphorous Content)	f_p	0.001	0.006	0.025	0.025	mgP/mgVSS

Table 5-12 : New Lane - Mass ratios of particulate organics (influent - raw)

Parameter	Abbr.	USO (settled)		VFA (settled)		FBSO (settled)		Unit
		Calculated	Typical Municipal	Calculated	Typical Municipal	Calculated	Typical Municipal	
COD/VSS Ratio	f_{cv}	1.493	1.500	1.000	1.067	1.420	1.450	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content)	f_n	0.069	0.035	0.000	0.000	0.029	0.051	mgN/mgVSS
TP/VSS Ratio (Phosphorous Content)	f_p	0.000	0.000	0.000	0.000	0.001	0.000	mgP/mgVSS

Table 5-13 : New Lane - Mass ratios of dissolved organics (settled)

5.4 Primary Sludge Characterisation

5.4.1 Measured characteristics

The primary sludge parameters measured and analysed by the City of Cape Town were limited to the solids concentration and pH. These characteristics have been derived from a three-year data record of 80 and 180 grab samples for the Old Lane and New Lane respectively. The data record comprised minor anomalies but was not considered critical to skew the data analysis. The analysis of the primary sludge data followed the same approach as the influent (raw) wastewater discussed in **Section 5.2.1** above. The data was firstly analysed for outliers; the data was then analysed statistically to confirm if the data were normally distributed; and lastly the normality of the data was also checked by assessing the skewness and degree of curvature. From the statistical analysis, it was found that the data were normally distributed, and as a result, standard statistical measures can be used to describe the data, or aid in the selection of design values. The data was used to extract the average value per parameter as tabulated in **Table 5-14** below. The following is noted:

- Columns 2 and 5 in the table below present the data range (minimum and maximum value) over the data record period (excl. outliers)
- Columns 3 and 6 in the table below present the average value per parameter (excl. outliers) over the data record period for the Old Lane and New Lane respectively
- Columns 4 and 7 present the selected design value of the Old Lane and New Lane respectively used in the steady-state and dynamic-state analysis. The following is noted:
 - The solids concentration average was approximately 4.29% in 2013, 4.52% in 2014 and 3.84% in 2015. This validates the conclusion in **Section 4.5**, confirming that the PSTs are operated to produce a high concentration of primary sludge by wasting a low primary sludge volume
 - The pH of the primary sludge is low and for purposes of the anaerobic digestion modelling, specifically for the dynamic modelling, it was assumed that the pH of the digester would be increased chemically to above 7.00 (i.e., pH was modelled as 7.00).

Parameter	Old Lane			New Lane			Unit
	Data Range	Average for Data Range	Selected Design Value	Data Range	Average for Data Range	Selected Design Value	
Column No.	2	3	4	5	6	7	8
Solids Concentration	0.35 – 8.08	4.11	4.00	0.52 – 11.00	4.11	4.00	%
pH	4.00 – 7.75	4.81	7.00	4.20 – 7.60	5.05	7.00	

Table 5-14: Measured Primary Sludge characteristics

5.4.2 Primary sludge characterisation

The characterisation of the primary sludge is important for the anaerobic digestion modelling as the unbiodegradable soluble organics exit with the effluent, the unbiodegradable particulate organics pass through

unchanged and the biodegradable organics are digested to form biomass, methane gas (CH_4), free and saline ammonia (FSA), carbon dioxide (CO_2), H_2CO_3 as alkalinity and ortho-phosphates. The characterisation of the primary sludge was carried out for the biodegradable (particulate and soluble) and unbiodegradable (particulate and soluble) portions of the COD, TKN, TP and TOC concentrations, in a similar fashion to the raw and settled wastewater discussed above. The characterisation of the primary sludge was derived from the wastewater characterisation of the raw and settled wastewater streams by a mass balance of the difference, namely by subtracting the flux of the raw wastewater from the settled wastewater, and then determining the associated concentration of the various portions (biodegradable: particulate and soluble; and unbiodegradable: particulate and soluble) based on the assumed primary sludge underflow rate of 0.775% of ADWF as previously discussed in **Section 4.5**. This was calculated per wastewater characteristic (COD, TKN, TP and TOC). The characterisation of the primary sludge is presented in block diagram formats and a table summarising concentrations and associated fluxes in the same format as the raw and settled wastewaters. This information is included in **Annexure D** and shown in **Figure 5-8** above.

The mass ratios, namely the COD/VSS ratio (f_{cv}), TKN/VSS ratio (f_n) and TP/VSS ratio (f_p) were also calculated for the primary sludge from the wastewater characterisation block diagrams presented in **Figure 5-8** above and **Annexure D**. The mass ratios calculated for the five organic groups of the primary sludge is also tabulated in **Annexure D** and **Table 5-15**, **Table 5-16**, **Table 5-17** and **Table 5-18** below. The calculated mass ratios were then checked against historically measured values (Wentzel *et al.*, 2006 and Ekama, 2009) to verify the wastewater characterisation of the primary sludge. This comparison of the calculated mass ratios versus historically measured values is presented in the tables below.

From the tables below, it can be seen that for both the Old Lane and New Lane, the calculated mass ratios align well with the historically measured values. As a result, the Author is satisfied that the proposed characterisation of the primary sludge is adopted for the development of the steady-state and dynamic-state models discussed in **Sections 6** and **7**.

Parameter	Abbr.	USO		VFA		FBSO		Unit
		Calculated	Typical Municipal	Calculated	Typical Municipal	Calculated	Typical Municipal	
COD/VSS Ratio	f_{cv}	1.493	1.420	1.000	1.067	1.420	1.420	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content)	f_n	0.061	0.049	0.000	0.000	0.033	0.002	mgN/mgVSS
TP/VSS Ratio (Phosphorous Content)	f_p	0.010	0.000	0.000	0.000	0.001	0.000	mgP/mgVSS

Table 5-15 : Old Lane – Mass ratios of dissolved organics (Primary Sludge)

Parameter	Abbreviation	BPO		UPO		Unit
		Calculated	Typical Municipal	Calculated	Typical Municipal	
COD/VSS Ratio	f_{cv}	1.782	1.720	1.481	1.481	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content)	f_n	0.054	0.022	0.100	0.100	mgN/mgVSS
TP/VSS Ratio (Phosphorous Content)	f_p	0.002	0.006	0.025	0.025	mgP/mgVSS

Table 5-16 : Old Lane – Mass ratios of particulate organics (Primary Sludge)

Parameter	Abbr.	USO		VFA		FBSO		Unit
		Calculated	Typical Municipal	Calculated	Typical Municipal	Calculated	Typical Municipal	
COD/VSS Ratio	f_{cv}	1.493	1.420	1.000	1.067	1.420	1.420	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content)	f_n	0.069	0.049	0.000	0.000	0.029	0.002	mgN/mgVSS
TP/VSS Ratio (Phosphorous Content)	f_p	0.010	0.000	0.000	0.000	0.001	0.000	mgP/mgVSS

Table 5-17 : New Lane – Mass ratios of dissolved organics (Primary Sludge)

Parameter	Abbreviation	BPO		UPO		Unit
		Calculated	Typical Municipal	Calculated	Typical Municipal	
COD/VSS Ratio	f_{cv}	1.753	1.720	1.481	1.481	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content)	f_n	0.061	0.022	0.100	0.100	mgN/mgVSS
TP/VSS Ratio (Phosphorous Content)	f_p	0.002	0.006	0.025	0.025	mgP/mgVSS

Table 5-18 : New Lane – Mass ratios of particulate organics (Primary Sludge)

5.5 Process Design Parameters

The following process design parameters are common for all steady-state and dynamic-state simulations presented in **Sections 6 and 7**:

5.5.1 Site characteristics

Site characteristics include the on-site conditions required for the process design summarised as follows:

- Minimum liquid temperature = 16 °C
- Maximum liquid temperature = 24 °C
- Site Altitude = 20 m.

5.5.2 Stoichiometric and kinetic constants for the activated sludge system

The Stoichiometric and Kinetic Constants were sub-divided into the following categories and summarised in **Annexure E**:

- Heterotroph organisms
- Nitrifiers (Autotrophs)
- Denitrification rates
- Poly-phosphate accumulating organisms
- Primary Sludge.

The stoichiometric and kinetic constants were based on historical measured values for municipal wastewater as extracted from the “Henze *et al.*, 2008; Principle, modelling and design of biological wastewater treatment”.

5.6 Process Unit Design Assumptions

The following process unit design assumptions are common for all steady-state and dynamic-state simulations presented in **Sections 6 and 7**:

5.6.1 Primary settling tanks

The surface area of the PSTs is designed to satisfy the following design criteria:

- Overflow rate at average dry weather flow must not exceed 1.2 m/hr
- Overflow rate at peak dry weather flow must not exceed 2.4 m/hr
- The primary sludge wasting rate is controlled to achieve a 4% solids concentration.

5.6.2 Aeration parameters

Design parameters required for calculating the actual power requirements for mechanical aeration (surface aerators) are summarised in **Annexure F**.

5.6.3 Secondary settling tanks

The following design assumptions are applicable for the SST design:

- The SSTs were designed using the flux theory, and using a flux rating (correction factor for 1 Dimensional Flux Theory) of 0.80 to account for non-idealities experienced in the SSTs (Ekama *et al.*, 1997 and Ekama and Marais, 2004)
- The sludge settleability of the raw wastewater is 120 ml/gTSS in terms of the diluted sludge volume index (DSVI).

5.6.4 DAF unit

The design basis of the DAF unit is for the purposes of thickening based on the solids loading rate and the depth of the float above water level. Key design considerations are summarised below (Bratby and Marais, 1976):

- The optimum air solids ratio (a_s) calculated is 0.007 which is considered very low and will further give rise to a deep float. For this reason, an a_s of 0.02 has been selected
- The settling velocity of an average activated sludge particle is 36 m/day (where $a_s = 0$)
- The actual down-flow rate (v_L) must be less than the limiting down-flow rate, where the actual v_L is further inclusive of a safety factor of 25% applied to the total flow through flotation unit (Q_T)
- The actual discharge per unit length of the weir must be less than the maximum allowed discharge per unit length of the weir, where the maximum allowed discharge per unit length of the weir is $6.8v_L$. The actual discharge per unit length of the weir also determines the number of DAF units required
- The depth of the clarification zone has been assumed to be 2.496m
- The diameter of the pipe entering the inlet is based on a minimum velocity of 25 m/min
- The diameter of the inlet feed well is based on a minimum upward velocity of 1.5 m/min to maintain a reasonable swirl. Velocities greater than the aforementioned value may give rise to disturbance of the accumulated float layer at the top
- The area of the saturator is based on a maximum surface loading rate of $1700 \text{ m}^3/(\text{m}^2\text{day})$
- According to Bratby (Bratby *et al.*, 2008), WAS can typically be thickened to 4-6% TSS concentration in a DAF unit. However, based on Metcalf and Eddy (Metcalf & Eddy, 2014), DAF units are capable of thickening WAS to 3-5% without chemicals and 4-6% with chemicals. Actual on-site operations at the Potsdam WWTW achieve a 3.5% TSS concentration, and no chemicals are used. The DAF unit for thickening of the WAS shall be designed for a maximum TSS concentration of 3.5% which is in line with the thickened concentration achieved with actual on-site operations.

5.6.5 Aerobic digester

One of the outputs of the aerobic digester is the active fraction of the sludge which gives an indication of the “stability” of the sludge (i.e., the remaining biodegradable organics in the sludge mass). The higher the active fraction, the greater the proportion of biodegradable organics in the sludge mass and the greater the utilizable energy content of the sludge mass. For an activated sludge to be stable, the remaining utilizable organics in it should be low so that it will not generate odours through further biological activity. Typical design criteria for the active fraction of WAS are summarised below from the following guidelines:

- US Environmental Protection Agency (1999) & Metcalf and Eddy, 5th Edition: The active fraction is related to the specific oxygen utilization rate (SOUR in gO/kgVSS.hr). In terms of the aforementioned sludge guidelines, a stable sludge has a $\text{SOUR} < 1.5 \text{ gO}/(\text{kgVSS.hr})$, which implies that the f_{av} should be less than 0.1 for a stable sludge
- Guidelines for the utilisation and disposal of wastewater sludge, Department of Water Affairs and Water Research Commission (2009): Reduction in vector attraction can be demonstrated if the SOUR of the sludge that is used or disposed of, determined at 20°C, is equal to or less than 2 milligrams of oxygen per hour per gram of total sludge (dry-weight basis). The aforementioned is equivalent to 2.0 gO/(kgVSS.h) SOUR and is based on the fact that if the sludge consumes very little oxygen, its value as a food source for micro-organisms is very low and therefore micro-organisms are unlikely to be attracted to it.

The anoxic-aerobic digester will be designed to stabilise the WAS to the following conditions for the steady-state and dynamic-state models:

- The Specific Oxygen Utilisation Rate (SOUR) (including nitrification) is 2.0 gO/(kgVSS.hr).

5.6.6 Anaerobic digester

The existing Potsdam WWTW does not incorporate anaerobic digesters in the sludge treatment process. For purposes of this dissertation, these process units have been incorporated into the process to evaluate the impact that varying wastewater characteristics have on the sludge treatment stream, specifically anaerobic digestion. The following design assumptions have been adopted for the hypothetical anaerobic digester with the model of Sötemann (Sötemann *et al.*, 2005):

- The process of anaerobic digestion is a mesophilic process based on a retention time of 12 days and a digester temperature of 35 °C.
- It was assumed that the pH of the digester would be maintained at a value of 7.00 via chemical addition
- Stoichiometric and Kinetic Constants are summarised in **Annexure E**.

5.7 Closing Remarks on Wastewater Characterisation Data

The wastewater characterisation is one of the most important steps in the process design of a WWTW, as this determines the organic load on the plant, which in turn influences the process design. For an existing plant

like the case study WWTW, the establishment of the wastewater characterisation is dependent on historical sampling data of the wastewater characteristics. The information made available for evaluating the case study plant's wastewater characteristics (concentrations), the associated wastewater characterization (fractions) and diurnal load patterns were limited to grab sample data over a period of three years, comprising an average of four samples per month. Flow-weighted composite samples, non-flow-weighted composite samples over 24-hour intervals, or two-hour concentrations measured over a 24-hour day were not available. The aforementioned type of information is critical for the determination of flow-weighted averages for wastewater characteristics, characterisation of wastewater and the development of diurnal load patterns required in dynamic-state modelling. As the time of day that the grab sample was taken was not recorded, the grab sample data provided was suitable to inform the selection of the wastewater characteristics and a portion of the wastewater characterization (fractions), but not a complete set for determining wastewater characteristics and diurnal load patterns. As a result, several calculated assumptions were required to inform the wastewater characterisation and diurnal load patterns, based on relevant research literature applicable to municipal wastewater conditions.

In terms of the wastewater characteristics, the grab sample data was found to be normally distributed for influent and settled wastewater and treated effluent. As such, normal statistical methods could be applied for the evaluation of the data, where the mean statistical measure guided the selection of wastewater characteristics for the aforementioned liquid streams of the WWTW. In terms of verification of the selected design values, the selected wastewater characteristics were compared to historically measured values as published in relevant research literature applicable to municipal wastewater conditions. As the selected design values fell within the range expected for typical municipal wastewater, the Author was satisfied that the proposed wastewater characteristics be adopted as input to the development of the steady-state and dynamic-state models discussed in **Sections 6 and 7**.

As mentioned above, flow-weighted composite samples, non-flow-weighted composite samples over 24-hour intervals, or two-hour concentrations measured over a 24-hour day were not available for the development of diurnal load patterns required in dynamic-state modelling. To overcome this shortfall, the diurnal load patterns for the influent and settled wastewater streams were assumed using the following information: i) Diurnal flow patterns (hourly) presented in **Section 4.4** for the Old Lane and New Lane; and ii) Diurnal concentration patterns (hourly concentration per wastewater parameter) for the case study WWTW was based on the diurnal concentration patterns (in hourly intervals) of the Stellenbosch WWTW which is also located in the Western Cape and has a similar catchment size with a similar nature of influent wastewater. However, the Stellenbosch WWTW diurnal concentration patterns were changed by a specific factor for each wastewater concentration (COD, TKN, total-P, ortho-P, TSS and VSS), such that the flow-weighted average using Simpson's rule for each wastewater characteristic was equal to the selected wastewater characteristic design value for each stream. The aforementioned assumptions were necessary to develop a diurnal flow pattern for the influent and settled wastewater streams.

The wastewater characterisation for both the influent and settled wastewater was developed using the following information and assumptions: i) Specific wastewater fractions were derived from the influent

characteristics, settled characteristics and effluent characteristics as presented in **Section 5.3.1** above; ii) The mass ratios for the unbiodegradable particulate organics (UPO) were assumed to have the same composition and mass ratios as activated sludge biomass as commonly done; and iii) The remaining wastewater fractions were assumed based on historically measured values as published in relevant research literature applicable to the municipal wastewater conditions which are presented in **Section 5.3.2** above. To verify the wastewater characterisation, the mass ratios, namely the COD/VSS ratio (f_{cv}), TKN/VSS ratio (f_n) and TP/VSS ratio (f_p) were calculated by performing a mass balance over the PST for both the raw and settled wastewater, and primary sludge flows from the wastewater characterisation block diagrams, and the calculated mass ratios were then checked against historically measured values (Wentzel *et al.*, 2006 and Ekama, 2009). The calculated mass ratios aligned well with the historically measured values except for the calculated influent COD/VSS ratio of the BPO for the raw and settled wastewater streams. It was found that this calculated mass ratio for the BPO is higher than the historically measured values attributed to the low measured TSS and VSS in the influent and settled wastewater. For purposes of the development of the steady-state and dynamic-state models, it was decided to adopt the historically measured influent COD/VSS ratio of the BPO for both the Old Lane and New Lane.

By following a mass balance over the PST approach, the characterisation of the primary sludge was done simultaneously with the raw and settled wastewater discussed above. The characterisation of the primary sludge was derived from the wastewater characterisation of the raw and settled wastewater streams, namely by subtracting the flux of the raw wastewater from the settled wastewater, and then determining the associated concentration of the various portions (biodegradable: particulate and soluble; and unbiodegradable: particulate and soluble) based on the assumed primary sludge underflow rate of 0.775% of ADWF. The mass ratios of the primary sludge were also calculated and were compared to historically measured values (Wentzel *et al.*, 2006 and Ekama, 2009). The calculated mass ratios align well with the historically measured values.

In conclusion, the information made available for evaluating the case study plant's wastewater characteristics (concentrations), the associated wastewater characterization (fractions) and diurnal flow patterns were not ideal. The grab sample data was the only credible information available for this dissertation, and as such, could only be used for determining the wastewater characteristics (concentrations) and some of the associated wastewater characterization (fractions). The balance of the wastewater fractions required for completion of the characterisation needed to be assumed based on relevant research literature for municipal wastewater. The values selected for the wastewater characteristics and wastewater fractions were verified, and the proposed wastewater characteristics, characterisation and diurnal load patterns were adopted as input to the development of the steady-state and dynamic-state models discussed in **Sections 6** and **7**.

For best practise process control and operation, it is recommended that the City of Cape Town consider the following sampling and testing procedures:

- The frequency of grab sample data be extended to daily or at least every alternative day covering all the key wastewater characteristics where the flow and time at which the sample is collected is also recorded in a data retrieval system from which it is easily accessible. The parameters currently being

tested are adequate, namely the COD, TKN, ammonia, Nitrate/Nitrite, Total-P, Ortho-P, TSS, VSS, settleable solids, pH and alkalinity

- As a minimum, during the dry season and wet season, a detailed sampling analysis is undertaken to comprise either a flow-weighted composite samples, non-flow-weighted composite samples over 24-hour intervals, or two-hour concentrations measured over a 24-hour day which should cover the parameters listed above, as well as other characteristics such as the volatile fatty acids, soluble COD (floc filtered COD and glass fibre filtered COD) and soluble TKN (glass fibre filtered TKN).

The contribution of such sampling and testing data will realise in the generation of reliable information that can be used by operators of the plant to improve process control and operation; evaluate the plant's reliability level based on the design process capacity; and understand the performance of the biological treatment plant based on influent parameters. Most importantly, this information will be critical for any process capacity checks, or the design of future extensions to the plant.

6. DEVELOPMENT OF STEADY-STATE MODELS

The case study WWTW was analysed using four steady-state models developed in the following modelling platforms:

- A plant-wide steady-state model developed by the Author, via integration and tailoring of the unit operation steady state model mass balanced equations from literature (Marais and Ekama, 1976; Wentzel *et al.*, 1990; Sötemann *et al.*, 2005; Ekama *et al.*, 1997; Henze *et al.*, 2008) to suit the virtual replication of the full-scale WWTW. This model is referred to in this dissertation as the “Author’s Plant Wide model (PWM)”
- Plant-Wide Steady-State Design (PWSSD) tool of Wu (Wu *et al.*, 2014) referred to in this dissertation as “PWSSD”
- Plant-wide simulation (adopting constant flow and load conditions) using BioWin 5.0 developed by EnviroSim Associates Ltd, referred to in this dissertation as “BioWin”
- UCTPHO dynamic model (adopting constant flow and load conditions) (Wentzel., *et al.*, 1992; De Swardt 2016) referred to in this dissertation as “UCTPHO”.

This chapter will discuss the development of the abovementioned models for the case study WWTW as follows:

- Provide a description of the modelling platforms which is discussed in **Section 6.1** below
- Document considerations for the steady-state modelling towards estimating the process capacity of the case study WWTW, which is documented in **Section 6.2**
- Simulation of the case study WWTW and comparison of the steady-state models in terms of output and results are discussed in **Section 6.3**
- **Section 6.4** presents the findings of the steady-state models for the case study WWTW.

6.1 Description of Models

This section provides an overview of the four modelling platforms adopted for this dissertation as follows:

- The Author’s PWM is discussed in **Section 6.1.1**
- The PWSSD is discussed in **Section 6.1.2**
- The BioWin modelling software is discussed in **Section 6.1.3**
- The UCTPHO model is discussed in **Section 6.1.4**.

As an introduction, **Table 6-1** below provides an overview of the modelling capabilities of the abovementioned modelling platforms in terms of design features offered, and the types of process units that can be simulated in each modelling platform:

Design Module	Steady-State Models		Simulation Models	
	Author's PWM	PWSSD	BioWin	UCTPHO
Design features				
Steady-state modelling	✓	✓	✓	✓
Dynamic-state modelling	No	No	✓	✓
Wastewater characterisation	✓	✓	✓	✓
Optimisation capabilities	No	✓	No	No
Automated capacity estimation	No	✓	No	No
Process Units - Liquid Treatment				
Balancing Tank	✓	✓	✓	No
PSTs	✓	✓	✓	No
Trickling Filter	✓	No	✓	No
Bioreactor: Modified Ludzack–Ettinger (MLE) system	✓	✓	✓	No ²⁶
Bioreactor: 3-Stage Bardenpho system	✓	No	✓	No ²⁴
Bioreactor: UCT system	✓	✓	✓	✓
Bioreactor: 5-Stage Bardenpho system	✓	No	✓	✓
Bioreactor: Johannesburg system	✓	✓	✓	✓
Media Bioreactor	No	No	✓	No
Sequential Batch Reactor (SBR)	No	No	✓	No
Chemical Phosphorous precipitation	✓	No	✓	No
Aeration: Surface Aerators	✓	✓	✓	No
Aeration: Fine Bubble Diffused Aeration	✓	No	✓	No
Membrane Separation	✓	No	✓	No
SSTs	✓	✓	✓	No
Disinfection (Chlorine and ultraviolet)	✓	No	No	No
Process Units - Sludge Treatment				
DAF for WAS thickening	✓	✓	✓	No
Gravity Thickener	✓	✓	✓	No
Aerobic Digester	✓	✓	✓	No
Anaerobic Digester	✓	✓	✓	No
Thermal Hydrolysis Unit	No	No	✓	No
Dewatering Unit	✓	No	✓	No

Table 6-1 : Comparison of design features and process unit modules offered by modelling software

From the table above, BioWin is the most comprehensive in terms of process unit modules offered, which would be expected for a commercial wastewater treatment simulation software. UCTPHO (Wentzel *et al.*,

²⁶ UCTPHO is exclusively for nitrification, denitrification and biological excess phosphorous removal (NDBEPR) systems. UCTOLD is exclusively for nitrification and denitrification (N&D) systems.

1992) is limited to the bioreactor only and was developed with the purpose of modelling a NDBEPR bioreactor system under diurnal (dynamic-state) conditions. The sections below will present more detail on the four modelling platforms.

6.1.1 Author's PWM

The user interface of the Author's PWM was developed in Microsoft Excel comprising of various modules/sheets (see **Figure 6-1** below) which are interlinked, with outputs of one module becoming inputs to the next. In summary, the process design philosophy of this tool comprises the input of loads (flow and wastewater concentrations) and design parameters which simulates a wastewater characterisation. Process unit modules which replicate the candidate plant are then selected, and the simulated wastewater characterisation and input design parameters then inform the sizing of the selected process units.

The design sequence for the Author's PWM is a step-by-step approach for each module/sheet as summarised below:

- Flow and Load Module: In this module, the user inputs load data (flows and wastewater characteristics) specific to the plant. The model allows for hourly input, where the hourly flow, concentrations and loads are averaged to a daily value, and these averages then serve as input to the downstream design modules. This is the first design step when using the Author's PWM.
- Design Parameters/Assumptions Module: The second step is entering design parameters and assumptions which are plant specific. These include site characteristics, wastewater fractions, stoichiometric and kinetic constants and aeration design parameters (surface and fine bubble systems). These parameters then serve as input to the wastewater characterisation module and process unit modules.
- Wastewater characterisation Module: This module simulates the wastewater characterisation and mass ratio calculation for the raw and settled wastewater, and primary sludge components which are presented in a block diagram format as presented in **Annexures C** and **D**. In this module, the user can verify the wastewater characterisation and calculated mass ratios against historically measured values, where the historically measured values are presented in a table adjacent to the calculated values.
- Process Unit Modules: The fourth step in the calculation sequence is the selection of the process unit modules required to replicate the plant. After the selection of the process unit modules, the user is required to enter design assumptions/parameters relevant to the selected process unit modules. The process unit modules offered by the Author's PWM are presented in **Table 6-1** above, and further discussed below. Each process unit model then presents the design procedure and associated calculations, and output variables. The output is relevant to process design information and includes process unit sizing, quantification and quality of effluent and sludge characteristics exiting the specific process unit and design specifications for mechanical equipment (i.e., aeration requirements, recycle pump rates etc.).
- The various modules include guidance notes to assist the user, and basic mass balance verification checks.

1.1_Flow & Loading Data	1.2_WW Design Parameters	1.3_WW Charact	2.1_PSTs	2.3_Anaerobic Digester	4.3 5-Stage Bardenpho_Reactor	4.5_Reactor SST Optimisation	4.6_SST Design	5.1_DAF
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Figure 6-1 : Snippet of certain modules in Author's PWM (depicting the New Lane)

The process unit modules discussed above and as presented in **Table 6-1** for the Author's PWM comprise biological and non-biological (chemical and physical) processes. The process unit modules used in this dissertation to replicate the case study WWTW are summarised below:

- PSTs: Design procedure is an empirical approach (Metcalf and Eddy, 2014)
- Anaerobic Digester: Based on the steady-state anaerobic digestion model by Sötemann (Sötemann *et al.*, 2006)
- Bioreactor (UCT process and 5-stage Bardenpho activated sludge system configuration): Based on the steady-state design procedures presented in the literature (Marais and Ekama, 1976; Wentzel *et al.*, 1990; Henze *et al.*, 2008).
- SSTs: The SSTs were based on the idealised 1-Dimensional Flux Theory (1DFT; Ekama *et al.*, 1997)
- DAF Thickener: Design procedure by Bratby and Marais (Bratby *et al.*, 1976)
- Aerobic Digestion of WAS: Based on the steady-state model developed by Ekama (Ekama *et al.*, 2006) and has been modified by the Author to include recent research on the endogenous respiration rates of the polyphosphate accumulating organisms (PAOs) by Vogts (Vogts *et al.*, 2015).

The Author's PWM includes additional process units which were not used in this dissertation. These are summarised below:

- Balancing Tank (flow and load balancing)
- Bioreactor: Modified Ludzack–Ettinger activated sludge system configuration often referred to as MLE; 4-Stage Bardenpho activated sludge system configuration; and Johannesburg activated sludge system configuration
- Gravity thickener for both primary sludge and WAS
- Dewatering equipment (linear screen, screw press, belt filter press and centrifuge) for primary sludge, WAS and a combination of the aforementioned
- Disinfection: Gas chlorination and ultra-violet technology.

As previously mentioned, the output variables of the Author's PWM are process design requirements such as process volumes, surface areas, aeration requirements and recycle ratios. In the case of most commercial modelling simulators, these process design requirements would typically serve as input parameters to the modelling simulator, requiring an independent steady-state design to be undertaken upfront in order to estimate the aforementioned. The Author's PWM can be adopted for this independent steady-state design. The Author's PWM has limitations, namely:

- The model is limited to a steady-state simulation only
- The model tracks changes in alkalinity in specific process unit modules (reactor configurations, aerobic digester and anaerobic digester), and uses this as an indicator of potential pH instability problems.

The model does not calculate changes in pH, but rather assumes the pH remains constant and is in a region that does not impact the biological activity. It is difficult to model pH because the underlying components and reactions are fast and complex. The calculation of the pH must consider the concentrations of strong acids and bases, the dissociation states of the weak acid/base, carbonate and phosphorous systems, chemical precipitation reactions, and potential stripping of components involved in the acid-base systems such as ammonia and carbon dioxide. All of these processes can be described using a kinetic approach (Musvoto *et al.*, 2000), but the rates of many of the reactions involved are four to twenty orders of magnitude larger than typical biological rates. The aforementioned makes the calculation and modelling of pH too complex to incorporate into the Author's steady-state model

- The model in its current form, does not lend itself to easily model the supernatant return flows from the sludge treatment process units (i.e., thickeners; stabilisation process units and dewatering facility), which could impact the influent flow rate and influent organic load into the plant. However, the impact of supernatant return flows can be included in the model, where supernatant return flows can be added to the input load data (flow, concentration and load) in the "Flow and Load Module". However, for purposes of this dissertation, supernatant return flows were not considered for any of the steady-state and dynamic-state models, as previously discussed in **Section 3**
- The cells in the model which contain explicit formulas (i.e., calculations) and non-user input are not protected. This could be useful for the intuitive identification of significant parameters for process performance variables but also has the disadvantage of potentially being edited and overwritten by the user, resulting in modelling errors.

The Author's PWM incorporates all the process unit modules required to replicate the case study WWTW. The case study WWTW has been simulated in two models (i.e., two spreadsheets) using the Author's PWM:

- Model One: A dedicated model (i.e., spreadsheet) for the liquid stream of the Old Lane which modelled the PSTs, UCT bioreactor and SSTs only.
- Model Two: A dedicated model (i.e., spreadsheet) for the liquid stream of the New Lane (modelled the PSTs, Bardenpho bioreactor and SSTs); and the Combined Sludge Lane where the following was modelled:
 - Primary sludge treatment lane which modelled the anaerobic digester by combining³² the underflow from the PSTs of the Old Lane and New Lane
 - WAS treatment lane which modelled the DAF unit and aerobic digester by combining³¹ the flow wasted from the bioreactors of the Old Lane and New Lane.

³² Primary Sludge: The total combined primary sludge was calculated in terms of flow, concentration and flux. The flows were calculated by summing the underflow rates from the Old Lane and New Lane. The concentrations were calculated from the "sum of the flux" of the primary sludge for both the Old Lane and New Lane, and the aforementioned flux was divided by the "sum of the flows" to get the respective combined concentration. A similar approach was adopted for the WAS.

6.1.2 Plant-Wide Steady-State Design

Plant-Wide Steady-State Design (PWSSD) is a plant-wide steady-state model developed by Wu (2014), and is a design tool offered free of charge in the market. The user interface was developed in Microsoft Excel and Visual Basic comprising various modules which are interlinked limiting user input. The program integrates various steady-state models with a guided user-friendly interface, which creates a platform for step-by-step assisted interaction and exploration of the steady-state models. The programme is protected, and non-user input cannot be overwritten thus limiting potential modelling errors.

In summary, the process design philosophy of this tool comprises the input of loads (flow and wastewater concentrations) and design parameters which simulates a wastewater characterisation profile. Process unit modules which replicate the candidate plant are then selected, and the simulated wastewater characterisation and input design parameters then inform the steady-state design. The programme comprises three main modules:

1. Wastewater characterisation: The first component is the wastewater characterisation module that serves as a pre-processor for all the steady-state models. This module comprises four main methods to determine the wastewater characterisation, and the selected method is dependent on the quality and quantity of influent data. The four methods include direct input of influent data; diurnal flow data; characterisation tree or preloaded profiles which are used to generate a wastewater profile which serves as input to the steady-state design.
2. Plant-wide steady-state design: With a wastewater profile generated from the wastewater characterisation module, the PWSSD module can be used to complete the steady-state design. This module comprises a collection of integrated steady state models as presented in **Table 6-1**, where the activated sludge reactor is intricately linked to the upstream (e.g., PST) and downstream (e.g., SST) units. The output variables of the various steady-state models are the relevant process design information and include process unit sizing, quantification and quality of effluent and sludge characteristics exiting the specific process unit and design specifications for mechanical equipment (i.e., aeration requirements, recycle pump rates etc.).
3. Capacity estimation: This component is a tool that can be used to determine the maximum influent ADWF for the activated sludge reactor and SST configuration; or on the existing aeration system. This tool can also be used to determine the optimum reactor concentration based on the COD wastewater profile and activated sludge reactor and SST configuration. The capacity estimation module works in unison with the Wastewater characterisation and PWSSD modules, where the steady-state models contained in the PWSSD module are processed in reverse, and the wastewater profile created in this module can be used to find the maximum ADWF capacity of the WWTW. This tool is very useful and is not currently available in the other three modelling platforms considered in this dissertation.

The process unit modules as presented in **Table 6-1** for the PWSSD model comprise biological and non-biological (chemical and physical) processes. The process unit modules used in this dissertation to replicate the case study WWTW are summarised below:

- PSTs
- Anaerobic Digester
- UCT Bioreactor: UCT process activated sludge system configuration (only used for the Old Lane which comprises a UCT process and not used to model the New Lane which comprises a 5-stage Bardenpho process)
- SSTs
- Thickener which was used to replicate the DAF unit for thickening of the WAS
- Aerobic Digestion of WAS.

In addition, the PWSSD tool includes additional process units which were not used in this dissertation. These are summarised below:

- Balancing Tank (balancing)
- Bardenpho Bioreactor: MLE and Johannesburg activated sludge system configuration
- Gravity thickener for both primary sludge and WAS
- Additional analysis and optimisation tools such as: i) A hypothetical cost and system modularisation tool; ii) A Capacity Estimation tool to determine the maximum influent average dry weather flow (ADWF) capacity, and graphical summaries the system specifications and plant-wide COD, N, P, C and total oxygen demand mass balances.

The steady-state models for the various process units incorporated into the PWSSD platform are based on the same design principles as the Author's PWM discussed in **Section 6.1.1** above. A visual snapshot of the PWSSD platform is shown below:

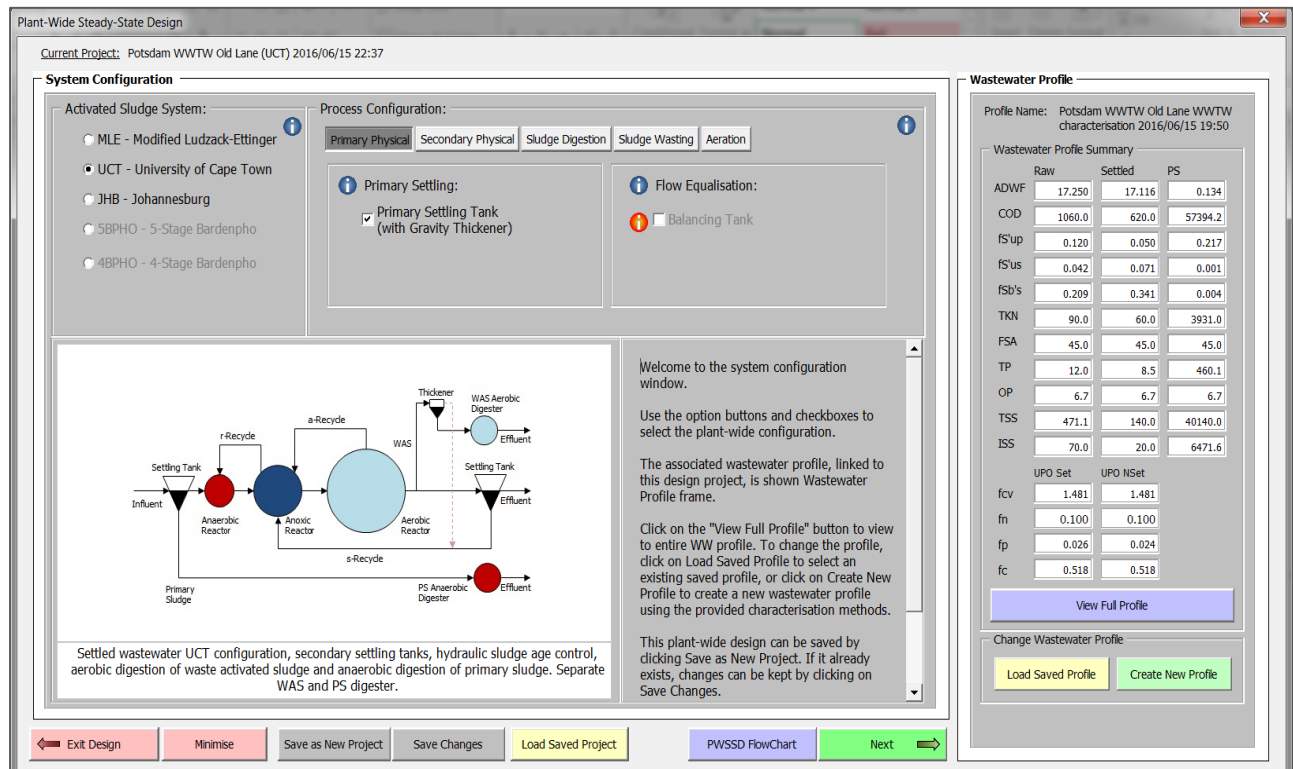


Figure 6-2 : Snapshot of PWSSD plant-wide model for Case Study WWTW (Old Lane UCT system)

The output variables of the PWSSD model are process design requirements such as process volumes, surface areas, aeration requirements and recycle ratios. These process design outputs typically serve as input parameters to the dynamic modelling simulators which require an independent steady-state design to be undertaken upfront to initiate a simulation. As with the Author's PWM, the PWSSD model can be used for this independent steady-state estimation of WWTW process unit sizes.

The PWSSD model has limitations, namely:

- The model is limited to a steady-state simulation only. However, recently, de Swart (2016) translated UCTOLD and UCTPHO to an Excel Visual Basic format for integration with the PWSSD model (Wu, 2014)
- As with the Author's PWM, the PWSSD model tracks changes in alkalinity in specific process unit modules (reactor configurations, aerobic digester and anaerobic digester), and uses this as an indicator of potential pH instability problems. The model does not calculate changes in pH, but rather assumes the pH remains constant and is in a region that does not impact the biological activity
- PWSSD caters for the most commonly used activated sludge configurations, namely MLE, Johannesburg and UCT. The programme does not yet cater for the 4-stage and 5-stage Bardenpho activated sludge configurations. This is a major limitation for this study as the New Lane of the case study WWTW incorporates a 5-stage Bardenpho process. It is not possible to simulate the Bardenpho bioreactor of the New Lane with one of the available activated sludge configurations (i.e., Johannesburg or UCT), as one would be comparing different process configurations. As a result, the Bardenpho bioreactor of the New Lane was not modelled with the PWSSD programme

- As with the Author's PWM, the PWSSD model in its current form, does not consider the effect of the supernatant return flows from the sludge treatment process units (i.e., thickeners; stabilisation process units and dewatering facility), which could impact on the nutrient load into the plant. However, the impact of supernatant return flows can be included in the model, where supernatant return flows can be manually added to the input load data (flow, concentration and load) in the "wastewater characterisation module"
- Apart from the activated sludge configurations, PWSSD does not incorporate all process unit modules compared with BioWin, and most notably does not model the DAF Unit which is incorporated into the combined sludge lane of the case study WWTW. However, the PWSSD does incorporate a thickener, which was used to replicate the DAF unit for thickening of the WAS. Also, PWSSD does not include a fine bubble aeration system for the bioreactor, which is becoming the preferred aeration system at most WWTW in South Africa due to its process advantages and energy efficiency
- During aerobic digestion of WAS, Mebrahtu (2007) assumed that during the endogenous respiration of the PAOs, the stored polyphosphate is released at the same rate as their endogenous respiration rate, and subsequently, mineral precipitation of the released P, Mg, and Ca occurs (Mebrahtu, 2007). This can be taken into account in the stoichiometric equations. Vogts & Ekama (2015) showed experimentally that polyphosphate is released 2.5 times faster than the PAO endogenous respiration rate so that after a 20-day aerobic digestion period, virtually all the polyphosphate was released but only about half the PAO biomass was digested. The latest version of the PWSSD model as adopted in this dissertation keeps the stoichiometry simple and assumes the cell-mass P (OrgP of the PAO and OHO) and polyphosphate release are at the same rate as their endogenous respiration rates and does not include mineral precipitation from this polyphosphate release in the stoichiometry. While of course not accurate, to some extent, releasing polyphosphate at the PAO endogenous respiration rate compensates for mineral precipitation (Wu and Ekama, 2014).

The University of Cape Town (Department of Civil Engineering) plans to address some of the above limitations in an update of the PWSSD software, specifically the incorporation of additional activated sludge configurations (4-stage and 5-stage Bardenpho systems), DAF for WAS thickening, membrane solid-liquid separation and fine bubble aeration system for the bioreactor.

The PWSSD model incorporates most of the process unit modules required to replicate the case study WWTW, except the Bardenpho bioreactor (5-stage Bardenpho system) for the New Lane. The case study WWTW has been simulated in three models (i.e., three spreadsheets) using PWSSD:

- Model One: A dedicated model (i.e., spreadsheet) for the liquid stream of the Old Lane UCT system which modelled the PSTs, UCT bioreactor and SSTs only
- Model Two: A dedicated model (i.e., spreadsheet) for the liquid stream of the New Lane which modelled the PSTs and SSTs only. The reactor was not modelled as discussed above. To model the SST, the model was manipulated by incorporating a dummy reactor (Johannesburg system) to generate a flow, concentration and load onto the SSTs

- Model Three: A dedicated model (i.e., spreadsheet) for the Combined Sludge Lane where the following was modelled:
 - Primary sludge treatment lane which modelled the anaerobic digester by combining³⁵ the underflow from the PSTs of the Old Lane and New Lane
 - WAS treatment lane which modelled the DAF unit (i.e., modelled as a thickener in PWSSD) and aerobic digester by combining³² the flow wasted from the bioreactors of the Old Lane and New Lane (dummy reactor). To quantify and characterise the WAS from the New Lane, the reactor of the New Lane was a dummy model using a Johannesburg process configuration which resulted in different sludge characteristics than would have been generated in a 5-stage Bardenpho system.

6.1.3 BioWin

BioWin is a commercial simulation tool for biological wastewater treatment plant design, analysis and training, and can simulate both steady-state and dynamic-state conditions. BioWin originated from models developed by the University of Cape Town (UCTOLD and UCTPHO) and the International Water Association (IWA) and is commercially available from EnviroSim & Associates situated in Canada. The software has evolved over the years and caters for almost every type of process unit with the most recent additions including models for a Thermal Hydrolysis reactor and moving bed bioreactor (MBBR). The software is continuously being updated to ensure the interface is user-friendly, the programme is efficient in terms of simulation runs and the programme is up to date with the latest research and technologies. This makes it one of the most commonly used process simulation tools in the industry. In addition to the biological processes that take place in wastewater treatment, the model incorporates other unit operations such as grit removal, primary sedimentation, secondary sedimentation and chemical precipitation among others, and can merge both activated sludge and anaerobic biological processes in a plant-wide set-up. BioWin is a dynamic simulator and has been used under constant flow and load conditions to mimic steady-state conditions for this section of the dissertation. A graphical illustration of the plant-wide model set-up in BioWin to replicate the case study WWTW (single plant-wide model which incorporates the liquid streams of the Old Lane and New Lane, and Combined Sludge Lane) is shown below:

³⁵ Primary Sludge: The total combined primary sludge was calculated in terms of flow, concentration and flux. The flows were calculated by summing the underflow rates from the Old Lane and New Lane. The concentrations were calculated from the “sum of the flux” of the primary sludge for both the Old Lane and New Lane, and the aforementioned flux was divided by the “sum of the flows” to get the respective combined concentration. A similar approach was adopted for the WAS.

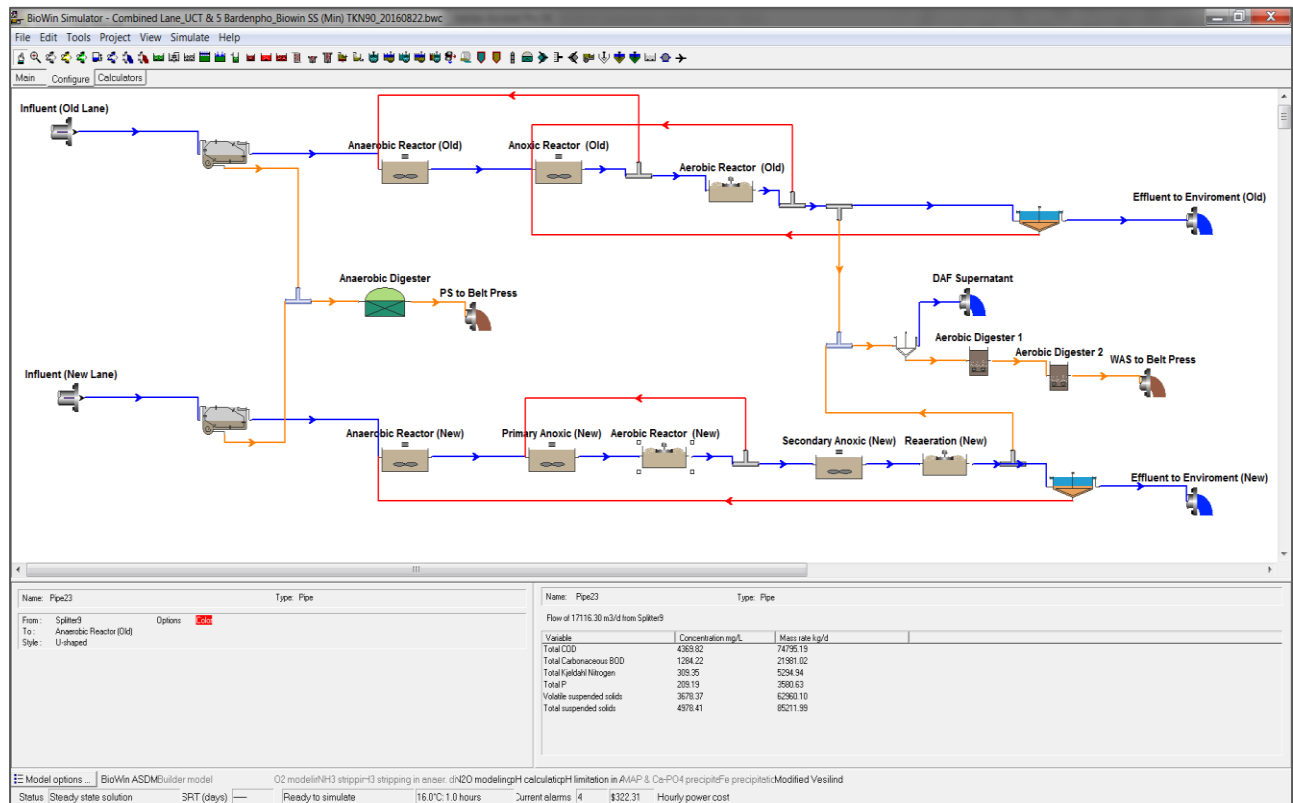


Figure 6-3 : Snapshot of BioWin plant-wide model for Case Study WWTW

One of the major differences between BioWin and the other models considered in this dissertation is that BioWin includes denitrification by the PAO population whereas the other models do not. The PAOs in BioWin can therefore uptake P in both the aerobic and anoxic zones as per Barker and Dold (1997), while in UCTPHO, the PAOs do not uptake P in the anoxic zone (Wentzel *et al.*, 1992 and De Haas *et al.*, 2001). The Author's PWM and PWSSD model uses the same explicit steady state model equations as UCTPHO, where the PAOs only uptake P in the aerobic zone.

BioWin offers the following advantages:

- The software can simulate both a steady-state and dynamic-state conditions
- The interface is user-friendly, and the programme is efficient in terms of simulation runs for both the steady-state and dynamic-state simulations
- The programme is up to date with the latest research and technologies. From **Table 6-1** above, it can be seen that BioWin can model the majority of process units, including a trickling filter, media bioreactor, sequential batch reactor, membrane separation (MBR reactor)
- The software can easily model the impact of supernatant return flows from the sludge treatment process units (i.e., thickeners; stabilisation process units and dewatering facility), and does not require manipulation of the influent flows, concentrations and loads as would be the case with the other models considered in this dissertation
- pH is an important factor in simulating the performance of biological wastewater treatment processes, including activated sludge and anaerobic digestion. The pH impacts the species distribution of the

weak acid systems (carbonate, ammonia, phosphorous, acetate, propionate, etc.) present in the process. This in turn dictates the rate of many of the biological and physical chemical processes occurring in these systems. For example, pH can affect: i) the biological activity when outside an optimal pH range; ii) chemical precipitation reactions when metal salts such as alum or ferric chloride are added for chemical P removal; iii) spontaneous precipitation of magnesium and calcium phosphorous (struvite, hydroxy-dicalcium-phosphorous (HDP) and hydroxy-apatite (HAP)); and iv) stripping of ammonia at high pH. As previously discussed in **Sections 6.1.1** and **6.1.2** above, it is difficult to model pH because the underlying components and reactions are so fast and complex. The approach to date in activated sludge models has been to track alkalinity changes and use that as a pseudo indicator of potential pH instability problems. This approach assumes that the pH remains approximately constant and is in a region where it does not impact biological activity. A disadvantage of using alkalinity is that it offers no means for modelling physico-chemical reactions such as precipitation. In systems with high volatile fatty acid concentrations such as acid fermenters and digesters, or in systems where significant gas transfer may occur, the predicted alkalinity may not be a good indicator of steady pH conditions. As a result, the calculation of the pH must consider the concentrations of strong acids and bases, the dissociation states of the weak acid/base, carbonate and phosphorous systems, chemical precipitation reactions, and potential stripping of components involved in the acid-base systems such as ammonia and carbon dioxide. These processes can be described using a kinetic approach (Musvoto *et al.*, 2000), but the rates of many of the reactions involved are four to twenty orders of magnitude larger than typical biological rates. As a result, calculation of the pH using a kinetic-based model will significantly increase the simulation time or use lower than realistic rates to ameliorate this problem. BioWin uses a mixed kinetic/equilibrium based approach to minimize the negative impact on simulation speed. This approach is applicable across the range of biological treatment process models (i.e., activated sludge and anaerobic digestion, etc.) offered in the BioWin platform

- The BioWin tool can also model chemical phosphorous precipitation. The chemical precipitation model in BioWin describes insoluble metal salt formation that occurs in wastewater treatment plants under various environmental conditions. The objective of this model is to improve the prediction of soluble phosphorous residuals and provide accurate chemical sludge production estimates. Phosphorus plays an active part in both biological and chemical processes in wastewater. Phosphorus is an important part of the weak acid-base system, it is a nutrient, a component of energy-storage compounds for various microorganisms and it readily forms insoluble precipitates with magnesium, calcium, as well as iron and aluminium ions if those are added to the wastewater. All these processes should be considered for accurate effluent phosphorus predictions. The chemical precipitation model in BioWin contains the following functional modules, namely chemical phosphorus precipitation by alum or ferric; and struvite and calcium phosphorous precipitation
- As discussed above, BioWin can model the precipitation of various calcium, magnesium, aluminium and iron complexes (struvite, HDP and HAP etc.). Magnesium (Mg) and calcium are present in most wastewaters and can spontaneously form precipitates. From the large number of phosphorous and carbonate precipitates that can be formed under typical conditions, particularly under higher than

neutral pH, the most important ones affecting soluble phosphorus levels are struvite and hydroxy-dicalcium-phosphorous (HDP). Struvite typically forms in digesters, due to the high concentration of magnesium, ammonium and phosphorous ions present from the biological excess phosphorous removal (BEPR) WAS. These compounds are transported to the digester in the PAO biomass and are released. BioWin (in the anaerobic module) describes Mg, N, and P release. The resulting struvite precipitation can occur particularly in pipes and on overflow weirs, where degassing of CO₂ raises the pH. The model is described in detail in Musvoto *et al* (2000). HDP (and many other types of calcium phosphorous) can precipitate in the bioreactor due to pH changes occurring in the anaerobic and aerobic zones. Accurate prediction of phosphorous levels in biological phosphorous processes may require simulating the HDP precipitation. BioWin models one more calcium phosphorous precipitate, namely hydroxy-apatite (HAP) which is considered a sink for calcium that does not dissolve. The model is described in Maurer (Maurer *et al.*, 1999). The above-mentioned precipitation processes included in the BioWin model are formulated with kinetic equations according to the aforementioned papers by Musvoto (2000) and Maurer (1999).

- BioWin also incorporates gas transfer for stripping and dissolution of gasses, namely for O₂, CO₂, N₂, NH₃, N₂O, H₂ and CH₄ gases
- BioWin incorporates a module for operating costs for simulation scenarios, and specifically tracks energy consumption, chemicals, consumables and sludge disposal.

BioWin has a number of advantages, but also has limitations as follows:

- Some of the models can be viewed as a black box approach, as very little is known about the biological, chemical and physical processes underlying the model. This is the case for the media bioreactor and the thermal hydrolysis unit
- As with most commercial modelling simulators, BioWin requires an independent steady-state design to be performed initially to estimate process unit sizes (i.e., volumes, surface areas, aeration requirements, recycle rates etc.), and these would typically serve as input parameters to the modelling simulator. Even though BioWin incorporates a steady-state design model, the aforementioned design requirements (i.e., volumes, surface areas, aeration requirements, recycle rates etc.) are also input parameters to the modelling simulator's steady-state design, hence the need for a preliminary independent steady-state design (Ekama, 2009).

BioWin incorporates all process unit modules required to replicate the case study WWTW, and the case study WWTW has been simulated in a single BioWin model to represent the entire plant (Old Lane, New Lane and Combined Sludge Lane) as illustrated in **Figure 6-3** above.

6.1.4 UCTPHO

The University of Cape Town has produced two dynamic models, one model called UCTOLD which includes a N removal biological process only, and the other is UCTPHO, which includes both N and P removal biological processes. The increased implementation of biological excess phosphorous removal (BEPR) during the last three decades created a need to extend UCTOLD to include BEPR. Recognizing the need for a kinetic model

describing biological nutrient removal systems, the research group at the University of Cape Town set about extending the UCTOLD model to include BEPR which resulted in UCTPHO in 1992 (Wentzel *et al.*, 1992). It is noted that UCTOLD is exclusively for nitrification and denitrification systems, and UCTPHO is exclusively for nitrification, denitrification and biological excess phosphorous removal (NDBEPR) systems, and the two systems cannot be interchanged as the kinetics of denitrification differ in the two systems (Clayton *et al.*, 1991; Wentzel and Ekama, 1999).

UCTPHO can simulate both a steady-state and dynamic-state simulation but is limited to the modelling of the bioreactor only. UCTPHO is written in the old Pascal (TurboPascal 3.1) language. UCTPHO is available at no cost to the academic industry, and the private and public sectors, and can be used to model and predict the performance of activated sludge systems in a WWTW. At the time of its development (1992), UCTPHO was advanced and one of the more reliable simulation software at the time. As this was free-ware, it was very popular amongst users in the private and public sectors. However, the UCTPHO platform has limitations, mainly as the software has become outdated. The limitations include:

- The TurboPascal 3.1 coding can only be run on a 32-bit processor (or lower), and as a result, UCTPHO can only be operated from a computer meeting these specifications. In the last two decades, there has been a significant advancement in computer hardware and software operating systems. As a result, the UCTPHO software became outdated as the TurboPascal 3.1 coding could only be run on modern-day computers which incorporate a 64-bit processor using the DosBox application (De Swardt, 2016). As a result, UCTPHO is used less by process engineers in the industry. To address this limitation, de Swart (2016) has translated UCTOLD and UCTPHO to an Excel Visual Basic format for future integration with the PWSSD model (Wu, 2014). UCTPHO was incorporated into this dissertation, and the programme was run in a DOS launch application, which presented numerous challenges associated with launching the programme. Also, run times for the programme using the DOS application were long, approximately 45 minutes for the steady-state simulation and 2 to 4 hours for the dynamic-state simulation
- UCTPHO only caters for the bioreactor, and specifically for a NDBEPR activated sludge system. As a result, the software is not able to model a plant-wide system, and cannot simulate a nitrification and denitrification system (e.g., MLE and 4-stage Bardenpho)
- As the model does not incorporate PSTs, when modelling a bioreactor in UCTPHO which incorporates PSTs upstream, assumptions need to be made on the settled wastewater characteristics entering the bioreactor
- As with the Author's PWM and PWSSD, the UCTPHO model tracks changes in alkalinity in the bioreactor and the user is required to use this information as an indicator of potential pH instability problems. The model does not calculate changes in pH, but rather assumes the pH remains constant and is in a region that does not impact the biological activity
- As with the Author's PWM and PWSSD, UCTPHO in its current form, does not lend itself to easily model the supernatant return flows from the sludge treatment process units (i.e., thickeners; stabilisation process units and dewatering facility), which could impact on the influent flow rate and influent organic load into the bioreactor. However, the impact of supernatant return flows can be

included in the model, where supernatant return flows can be added to the input load data (flow, concentration and load).

UCTPHO is a dynamic simulator and has been used under constant flow and load conditions to mimic steady-state conditions for this section of the dissertation. The case study WWTW has been simulated in two UCTPHO models to represent the bioreactors only of the case study WWTW as follows:

- Model One: A dedicated model for the Old Lane UCT bioreactor only
- Model Two: A dedicated model for the New Lane Bardenpho bioreactor only.

6.1.5 Summary

The table below summarises the formulation of the case study WWTW in the Author's PWM, PWSSD, BioWin and UCTPHO by summarising the number of models required to replicate the case study WWTW (Old Lane, New Lane and Combined Sludge Lane); which process units have been modelled (✓); and which process units could not be modelled. Note that while BioWin and UCTPHO are dynamic simulators, they are both used under constant flow and load conditions to mimic steady-state conditions for this section of the dissertation:

Process Model	Author's PWM	PWSSD	BioWin	UCTPHO
No. of models developed to replicate entire case study WWTW	2	3	1	2
Liquid Stream: Old Lane UCT system				
PSTs	✓	✓	✓	Not modelled
Bioreactor: UCT system	✓	✓	✓	✓
SSTs	✓	✓	✓	Not modelled
Liquid Stream: New Lane 5-stage Bardenpho System				
PSTs	✓	✓	✓	Not modelled
Bioreactor: 5-Stage Bardenpho system	✓	Not modelled	✓	✓
SSTs	✓	✓	✓	Not modelled
Sludge Treatment				
DAF unit	✓	✓ ³⁹	✓	Not modelled
Aerobic Digester	✓	✓	✓	Not modelled

³⁹ A Thickener which was used to replicate the DAF unit for thickening of the WAS.

Process Model	Author's PWM	PWSSD	BioWin	UCTPHO
Anaerobic Digester	✓	✓	✓	Not modelled

Table 6-2 : Summary of Process Units modelled in this Dissertation

6.2 General considerations for use of the four WWTW models

Sections 6.2.1 to 6.2.6 below present considerations which are generic to the use of the four WWTW models presented in this Chapter. As previously discussed in **Section 4.2**, the 2015 ADWF entering the Potsdam WWTW is 53.66 Ml/day. This value was the current (2015) flow entering the WWTW and is not necessarily the maximum ADWF the Potsdam WWTW can accommodate in terms of its design process capacity. One of the outcomes of this section is to estimate the process capacity of the case study WWTW, which requires an estimation of the maximum ADWF capacity of the Old Lane and New Lane for the case study WWTW. This section will theoretically estimate the maximum ADWF capacity of the Old Lane and New Lane, and the approach adopted for this estimation is discussed in **Section 6.2.1** below. **Section 6.2.2** will discuss the design value adopted for the maximum specific growth rate of nitrifiers, and **Section 6.2.3** will discuss the sludge wasting procedure. The overall approach for use of the WWTW models is then summarised in **Section 6.2.4** below. **Section 6.2.5** will discuss the balanced sludge age for the Old Lane, while **Section 6.2.6** will discuss the minimum influent TKN/COD ratio at which the system can theoretically achieve complete denitrification.

6.2.1 Capacity Estimation

The case study WWTW is an existing plant, and as a result, the process volume of the bioreactors and the SST surface area for both the Old Lane and New Lane are fixed. For purposes of this dissertation, it has been assumed that the aeration system will not be a limiting factor in terms of the overall capacity of the plant (i.e., aeration capacity will not be fixed to match the actual on-site capacity). The difference between the actual on-site aeration capacity and the output aeration capacity of the steady-state and dynamic-state models is discussed under **Section 9.2**. When modelling an existing plant, the reactor concentration and sludge age are interrelated and dependent on the influent load (flow and concentrations), where the selection of either will influence the value of the other. In terms of the influent load, the wastewater characteristics and characterisation were confirmed in **Section 5**, and are assumed to be fixed. The maximum ADWF that the plant can treat is unknown and needs to be estimated, where the limiting factor is the physical characteristics (i.e., volume, surface area, depth etc.) of the process units as previously mentioned. To estimate the maximum ADWF, the sludge age and reactor concentration were calculated as discussed below.

The selection of sludge age (R_s) is one of the key design decisions taken in the activated sludge process, as this determines the mass of sludge in the reactor, reactor volume and oxygen requirements, and also influences the sludge in terms of sludge production and the degree of sludge stabilisation required. The minimum sludge age is governed by the nitrification process, while long sludge ages impact the percentage of phosphorous removal in a BEPR system. The sludge age is an input parameter, required to determine the

maximum ADWF of the reactor and SST configuration for both the Old Lane and New Lane. The sludge age was selected to best match the actual on-site operational sludge ages as follows:

- Old Lane: The Old Lane of the case study WWTW is operated on-site at a 14-day sludge age. A design sludge age of 14 days was selected for the purposes of steady-state and dynamic-state modelling which matches the actual operation sludge age
- New Lane: The New Lane of the case study WWTW is operated on-site at an 18-day sludge age. A design sludge age of 18 days was selected for the purposes of steady-state and dynamic-state modelling which matches the actual operation sludge age.

Following the selection of the sludge age, both the PWSSD model and the Author's PWM were simulated to estimate the maximum ADWF for the Old Lane and New Lane respectively as follows:

- PWSSD model – Old Lane:
 - The Capacity Estimation module was simulated to estimate the maximum ADWF for the activated sludge reactor and SST configuration of the Old Lane, where the reactor concentration of the aerobic reactor was inputted as the end condition to estimate the maximum ADWF. The sludge age was based on the value assumed (user input) above, namely 14 days. Various simulations were carried out, where the end condition reactor concentration for the aerobic reactor was varied between the range of 4000 mgTSS/l and 5500 mgTSS/l. The reactor concentration that yielded the highest ADWF flow was then selected
- PWSSD model – New Lane:
 - This simulation could not be carried out for the New Lane as the PWSSD tool does not cater for the 5-stage Bardenpho activated sludge configuration
- Author's PWM – Old Lane:
 - The sludge age was based on the value assumed above, namely 14 days
 - The reactor concentration of the aerobic reactor was selected to match the reactor concentration estimated for the PWSSD model described above which yielded the highest ADWF flow.
 - A goal seek solver (a function in MS Excel) was then run in the bioreactor steady-state model, where the reactor volume was set to be equivalent to the existing reactor volume by adjusting the ADWF. The maximum ADWF estimated from the Author's PWM was then compared to the value estimated from the PWSSD capacity estimation module, and if these values were similar, this confirmed that the bioreactor steady-state models (UCT process configuration) of the two modelling platforms were similar and correlated with each other. If the values were not similar, then this meant that the bioreactor steady-state models of the two modelling platforms were not the same, and this would most likely imply an error in the Author's PWM.
 - At the calculated ADWF and input reactor concentration, the SST steady-state model of the Author's PWM was evaluated to confirm if the SST surface area estimated in the Author's PWM was equivalent to the SST model of the PWSSD platform. If this was the same, then

this confirmed that the SST steady-state models of the two modelling platforms were similar and correlated with each other. If the values were not similar, this meant that the SST steady-state models of the two modelling platforms were not the same, and this would most likely imply an error in the Author's PWM.

▪ Author's PWM – New Lane:

- The sludge age was based on the value assumed above, namely 18 days
- A solver was formulated to estimate the maximum ADWF for the activated sludge reactor and SST configuration of the New Lane, where the reactor concentration of the aerobic reactor was inputted as the end condition to estimate the maximum ADWF based on the existing reactor volume and SST surface area. Various simulations were carried out, where the end condition reactor concentration for the aerobic reactor was varied between the range of 4000 mgTSS/l and 5500 mgTSS/l. The reactor concentration that yielded the highest ADWF was then selected
- As a check, the selected reactor concentration and calculated ADWF from the Author's PWM was then inputted into the steady-state SST model of the PWSSD platform, and the SST surface area was calculated to confirm if the SST surface area estimated in the Author's PWM was equivalent to the SST model of the PWSSD platform. If this was the case, then this confirmed that the SST steady-state models of the two modelling platforms were similar. If the values were not similar, then this meant that the SST steady-state models of the two modelling platforms were not the same, and this would most likely imply an error in the Author's PWM.

The results of the above simulations are presented in **Section 6.2.4** below.

6.2.2 Maximum specific growth rate of nitrifiers (μ_{Max})

The maximum specific growth rate of nitrifiers (μ_{Max}) is a critical wastewater parameter in the design of activated sludge systems, specifically for BNR systems because of its impact on the design (sizing) and performance of biological N removal systems. This is because this parameter directly influences the minimum sludge age to ensure nitrification occurs. The influence that the μ_{Max} has on a BNR plant is discussed in more detail in **Section 8.3.1**. This section will briefly discuss the selected design value of μ_{Max} which was adopted for purposes of the steady-state and dynamic-state modelling presented in **this Section** and **Section 7**.

For municipal wastewater, μ_{Max} typically varies between 0.30 and 0.75 per day (temperature of 20 °C) and is dependent on the nature of the wastewater and can also vary depending on the environmental conditions of the wastewater (i.e., pH, temperature and industrial component of the wastewater in terms of metals, elements and organics). For the case study WWTW, μ_{Max} has not been determined experimentally. As a result, μ_{Max} was assumed as an input value of 0.450 /day which is more on the conservative side when compared to historically measured values as documented above. As this wastewater parameter is critical in the design of a BNR system, the μ_{Max} was selected as one of the parameters to be evaluated in **Section 8.3**, where this parameter was increased and decreased in specific increments to determine its impact on the WWTW in terms of process capacity and performance.

6.2.3 Sludge harvesting

Hydraulic control of sludge age is currently incorporated on both lanes of the case study WWTW where WAS is abstracted directly from the bioreactors. This principle was maintained for the steady-state and dynamic-state models. Sludge wasting via the reactor (hydraulic control) has the following advantages over wasting sludge from the SST underflow (Ekama, 2010):

- Reactor concentration does not change much in response to diurnal influent flow.
- System failure is visible via “solids failure”, namely sludge passing over the SST weirs.
- Hydraulic control of sludge age is best for situations where operator skills are low.

6.2.4 Approach for setting up the steady-state models

The setup of the four steady-state models was the same using the following step-wise approach:

1. The models were firstly structured to replicate the configuration of the case study WWTW as presented in **Table 6-2** above.
2. All models were then inputted with the same wastewater characteristics and fractions, process design assumptions and process unit assumptions as discussed in **Section 5**.
3. All models were inputted with the same flow scenarios (i.e., factors for PDWF and PWWF, and primary sludge underflow rate) as discussed in **Section 4**
4. The bioreactor of the models was then inputted with the selected sludge ages for the Old Lane and New Lane as discussed in **Section 6.2.1** above
5. The Author's PWM and PWSSD models were then simulated as discussed in **Section 6.2.1** above to estimate the maximum ADWF of the plant. The physical characteristics (i.e., volume, surface area, depth, etc.) of the process units were fixed for all steady-state simulations and were based on those previously documented in **Sections 3.3** and **3.4**. For both the Old Lane and New Lane, it was found that the process volume of the bioreactor and SST surface area were the limiting factor. The following was estimated:
 - Old Lane: The maximum ADWF of the influent is 17.25 Ml/day at a sludge age of 14 days and a reactor concentration of 5000 mgTSS/l. This was confirmed by simulating both the PWSSD tool (capacity estimation module) and the Author's PWM as discussed in **Section 6.2.1** above which both yielded the same ADWF of 17.25 Ml/day. As the ADWF value calculated for both models is the same, this confirmed that the bioreactor steady-state models (UCT process configuration) of the two modelling platforms were correct.
 - New Lane: The maximum ADWF of the influent is 43.5 Ml/day at a sludge age of 18 days and a reactor concentration of 4500 mgTSS/l. This was confirmed by simulating the Author's PWM as discussed in **Section 6.2.1** above. As a check, the selected reactor concentration and calculated ADWF from the Author's PWM were then inputted into the steady-state SST model of the PWSSD platform, and the SST surface area was calculated. The SST surface area calculated in the PWSSD platform was equivalent to the SST surface area estimated in the Author's PWM, and this implies that the two SST steady-state models are correct

- The above calculated ADWF for the Old Lane and New Lane is the maximum ADWF that each lane can accommodate based on the existing process unit sizes and estimated wastewater characterisation presented in **Section 5**. These ADWF values were then used to run the four steady-state models presented in this section, and the dynamic-state models presented in **Section 7**
- 6. This dissertation did not consider the hydraulic capacity of interconnecting pipework and channels between process units of the plant, which could be the limiting constraint in terms of the overall capacity of the plant
- 7. This dissertation also assumes that the mechanical equipment is not a limiting factor in terms of the overall capacity of the plant. In the analysis presented further in this Section, it was found that the following mechanical equipment will limit the process capacity with respect to meeting the effluent quality discharge standards:
 - Mechanical aeration system for the aerobic bioreactor and aerobic digester for both the Old Lane and New Lane
 - Recycle pumps (i.e., RAS, a-recycle and r-recycle)
- 8. Specific process parameters (i.e., sludge age, underflow concentration of PSTs etc.) inputted into the models were based on current operations on-site as discussed below:
 - As discussed in **Section 6.2.1**, the sludge age used in the models for both lanes was based on actual on-site operational sludge ages
 - The underflow concentration of the PSTs in the models was fixed to 4% TSS as discussed in **Section 4**. The case study plant was operated in the past such that the underflow concentration was 4.29% TSS in 2013, 4.52% TSS in 2014 and 3.84% TSS in 2015.

The above design considerations are generic to the development of the four steady-state models presented in this Section and the dynamic-state models discussed in **Section 7**.

6.2.5 Balanced Sludge Age for the Old Lane (UCT process configuration)

The balanced Modified Ludzack–Ettinger (MLE) sludge age (SRT) system as proposed by van Haandel *et al* (1982) and defined by Henze *et al* (2008) is a system designed at such a sludge age that the a-recycle rate loads the anoxic reactor exactly to its denitrification potential with the optimum a-recycle ratio (a_{opt}) fixed at a maximum practical limit (e.g., $a_{prac} = 4:1$). This results in the most economical activated sludge reactor design because the sludge age and effluent nitrate concentration are the lowest and therefore the reactor volume is the smallest (Ekama, 2021). The design procedure proposed by Henze *et al* (2008) involves determining a specific sludge age (referred to as the balanced sludge age) which sets the optimum a recycle rate (a_{opt}) at the maximum practical a-recycle ratio (a_{prac}). This balanced sludge age is determined by calculating the resultant influent TKN concentration for a range of sludge ages for which $a_{opt} = a_{prac} = 4$, and the balanced sludge age is the sludge age where the calculated influent TKN concentration matches the actual wastewater TKN concentration. The step-by-step procedure (Ekama, 2016) is described below:

- The maximum design unaerated sludge mass fraction (f_{xm}) is calculated for various sludge ages (typically between 1 and 40 days)

- f_{xm} is calculated above, and where $f_{xm} < f_{xmin}$, f_{xm} is set equal to f_{xmin} (also referred to as f_{x1})
- Knowing f_{x1} and the wastewater characteristics, the denitrification potential of the anoxic reactor is calculated
- The a-recycle ratio is then set such that $a_{opt} = a_{prac} = \text{say } 4:1$
- The mass of volatile settleable solids in the reactor (MX_v), nitrification capacity (N_c), effluent ammonia concentration (N_{ae}), effluent TKN concentration (N_{te}) and TKN of sludge wastage (N_s) is then calculated.
- The calculated influent TKN (N_{ti}) is then calculated as the sum of $N_{te} + N_s + N_c$.
- The above calculation is repeated for different sludge ages and the sludge age at which the “calculated influent TKN concentration” matches the “actual influent TKN concentration” is the balanced sludge age. This can also be shown graphically as illustrated in **Figure 6-4** below, where the “calculated N_{ti} ” and the “actual N_{ti} ” versus sludge age are plotted on a graph, and the intersection of “calculated N_{ti} ” and “actual N_{ti} ” gives the balanced sludge age.

As for the balanced MLE sludge age system set out by Ekama (2016), the same approach can be adopted to determine the balanced sludge age for the UCT process configuration of the Old Lane, referred to below as the balanced UCT system. The only difference in the design procedure is that the denitrification potential for the balanced UCT system is based on the denitrification kinetics for NDBEPR systems (Clayton *et al.*, 1992; Ekama and Wentzel, 1999) and the anaerobic mass fraction is subtracted from the maximum unaerated sludge mass fraction to give the anoxic sludge mass fraction. This approach was adopted to estimate the balanced sludge age of the Old Lane, which was estimated to be 7.8 days as depicted in **Figure 6-4** below. However, for purposes of this dissertation as discussed in **Section 6.2.1**, a sludge age of 14 days was selected for all steady-state and dynamic-state simulations. The following differences are noted between the 7.8-day balanced sludge age system and the selected 14-day sludge age system:

- The mass of total solids, volatile settleable solids and inorganic matter in the reactor of the balanced UCT system is 35%, 33% and 41% lower (respectively) than the 14-day sludge age system.
- The reactor volume and hydraulic retention time in the reactor of the balanced UCT system is 31% lower than the 14-day sludge age system.
- The sludge mass fractions of the balanced UCT system and 14-day sludge age system are presented in the table below where the anaerobic mass fractions are the same as these are assumed by the user in the models, the anoxic mass fraction of the balanced UCT system is 34% higher than the 14-day sludge age system and the aerobic mass fraction of the balanced UCT system is 9% lower than the 14-day sludge age system.

Sludge Mass Fractions	14-day Sludge Age System (Actual Plant values)	Balanced UCT System (7.8 days)	Percentage Difference
Anaerobic (f_{xana})	0.092	0.092	0%
Anoxic (f_{xanx})	0.123	0.186	34%
Aerobic (f_{xaer})	0.785	0.722	-9%

Table 6-3 : Sludge mass fractions of the Balanced UCT system and 14-day sludge age system

- The total oxygen requirements of the balanced UCT system are 6.8% lower than the 14-day sludge age system, and the active fraction with respect to VSS and TSS of the balanced UCT system is 16% and 20% higher than the 14-day sludge age system.
- The sludge waste flow per day of the balanced UCT system is 15% higher than the 14-day sludge age system.
- The total average oxygen utilisation rate (carbonaceous oxygen demand plus nitrification oxygen demand less oxygen recovery via denitrification) of the Balanced UCT system is 57% higher than the 14-day sludge age system mainly because the aerobic reactor of the Balanced UCT system is smaller.

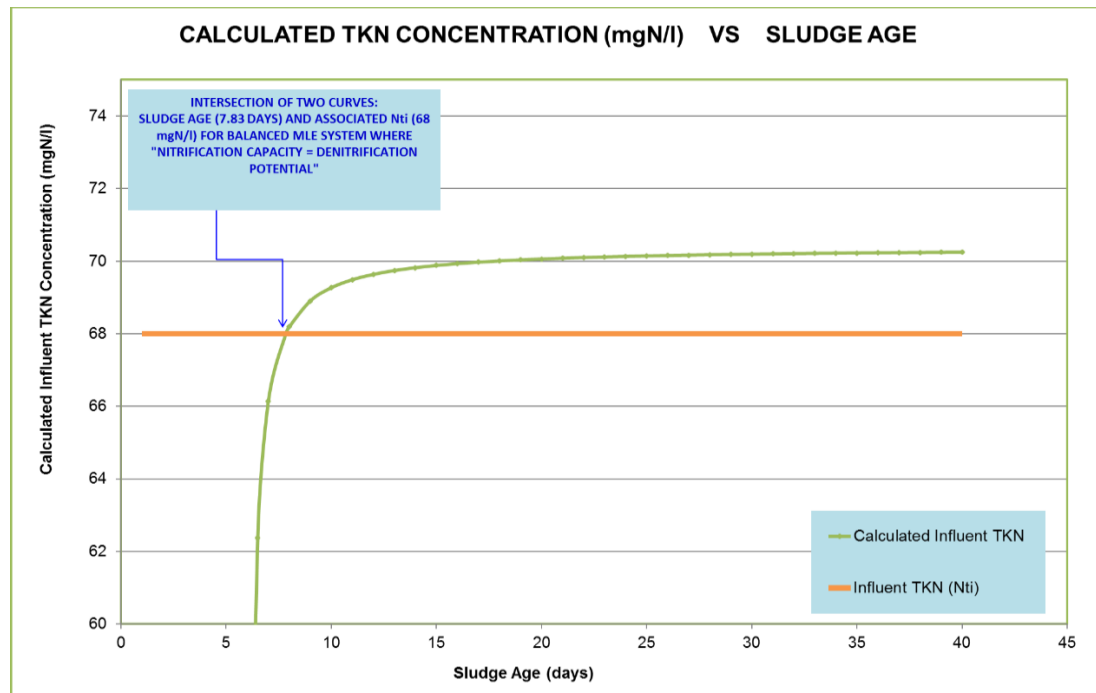


Figure 6-4 : Old Lane – Balanced Sludge Age for UCT Process Configuration

6.2.6 Minimum TKN/COD Ratio for the New Lane (5-stage Bardenpho system)

As presented above, the design procedure of the balanced MLE sludge age system as set out by Ekama (2016) could be applied with slight changes to a UCT process configuration (i.e., Old Lane), but this principle cannot be adopted for the 5-Stage Bardenpho process configuration of the New Lane. However, for the 5-Stage Bardenpho process configuration, there is a minimum influent TKN/COD ratio at which the system can theoretically achieve complete denitrification (zero nitrate effluent concentration) at an optimal a recycle ratio. For this specific scenario, the effective nitrification capacity is equal to the actual nitrification capacity, at which the system can achieve a theoretical nitrate concentration of 0 mgN/l for the optimal a-recycle ratio. A nitrification and denitrification system is governed by the μ_{am20} value, which fixes the sludge age to ensure complete nitrification at a maximum unaerated mass fraction (f_{xm}), thereafter, specific wastewater characteristics, namely the TKN/COD ratio and RBCOD fraction govern the effluent nitrate concentration that can be achieved.

For purposes of this dissertation as discussed in **Section 6.2.1** above, a sludge age of 18 days and anoxic mass fraction of 0.338 (0.197 for primary anoxic and 0.141 for secondary anoxic) was selected for all steady-state and dynamic-state simulations to model the actual reactor volume of the New Lane. An iteration was undertaken for the New Lane where the aforementioned sludge age, mass fractions and RBCOD fraction were fixed at a minimum wastewater temperature of 16°C. Following the iteration, it was found that a minimum TKN/COD ratio of 0.025 will result in a zero-nitrate effluent concentration. A TKN/COD ratio between 0.025 and 0.08 will increase the nitrate effluent concentration from 0 mgN/l to 5 mgN/l, and a TKN/COD ratio between 0.08 and 0.11 will increase the nitrate effluent concentration from 5 mgN/l to 20 mgN/l. For a 4-stage Bardenpho system which does not incorporate an anaerobic zone, theoretically, it is possible to achieve a zero-nitrate effluent concentration when the influent TKN/COD concentration ratio is quite low (<0.09 mgN/mgCOD) for normal municipal wastewater at 14°C (Henze *et al.*, 2008).

6.3 Model Results and Differences

This section aims to summarise the output results of the four steady-state models for both the Old Lane (ADWF of 17.25 Ml/day), the New Lane (ADWF of 43.50 Ml/day) and the Combined Sludge Lane where the aforementioned ADWF design capacities are the “uprated” capacities and not the documented design capacities as presented in **Section 3**. This section will further compare the models in terms of their output results and establish the reasons for the difference in significant model outputs where these occur. Due to the extensiveness of the four models, electronic versions of the models have been included in **Annexure J** of this dissertation. The reader is also referred to **Annexure J** should they wish to view any additional input and output information related to the models.

This section will summarise the output results of the four models in the following manner:

- For each major process unit, two tables are provided for convenience
 - The first table (green) provides a summary of the output results as extracted from each model
 - The second table (red) provides a weighting comparison of the model results, where the value in each cell is “the percentage difference between the specific variable of the model being evaluated and the Author’s PWM”. Any major discrepancies (**a percentage variation of 15%**) have been highlighted in a blue font, and the total count of variables out of range has been totalled at the bottom of the table.
- The following scenarios will arise:
- A percentage value of 100% implies that the model being evaluated has the “**same**” output value as the Author’s PWM
 - A percentage value less than 100% implies that the model being evaluated has a “**lower**” output value than the Author’s PWM, and the lower the percentage the bigger the variation. A percentage value of less than 85% has been highlighted in a blue font
 - A percentage value greater than 100% implies that the model being evaluated has a “**higher**” output value than the Author’s PWM, and the higher the percentage the bigger the variation. A percentage value of more than 115% has been highlighted in a blue font

- Where a cell is inputted with “Not prov.” (i.e., not provided), this implies that this information is not calculated or not readily available in the applicable model.

6.3.1 Old Lane UCT System

Table 6-4 below provides a summary of the model output results for the PSTs based on overflow rates of 1.2 m/hr at ADWF and 2.4 m/hr at PDWF and PWWF:

Parameter	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
Total Area Required (ADWF)	m ²	599	599	Not prov.
Total Area Required (PDWF)	m ²	524	Not prov.	Not prov.
Total Area Required (PWWF)	m ²	749	749	749
Weir Loading at PDWF	m ³ /m.hr	9.10	9.10	Not prov.
Weir Loading at PWWF	m ³ /m.hr	13.00	13.10	Not prov.
Typical concentration of Primary Sludge	mg/l	40140	40100	40200

Table 6-4 : PSTs (Old Lane UCT System) – Summary of model results

The existing PST surface area (i.e., as-built area) is 982 m² which is higher than the surface areas calculated from the models presented in **Table 6-4** above.

Table 6-5 provides a weighting comparison of the model output results for the PSTs, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM:

Parameter	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
Total Area Required (ADWF)	m ²	100.00%	100.01%	Not prov.
Total Area Required (PDWF)	m ²	100.00%	Not prov.	Not prov.
Total Area Required (PWWF)	m ²	100.00%	100.04%	100.04%
Weir Loading at PDWF	m ³ /m.hr	100.00%	100.01%	Not prov.
Weir Loading at PWWF	m ³ /m.hr	100.00%	100.78%	Not prov.
Typical concentration of Primary Sludge	mg/l	100.00%	99.90%	100.15%
Total Count out of range (Total parameters evaluated = 6)		0	0	0

Table 6-5 : PSTs (Old Lane UCT System) – Weighting comparison of model results

From the table above, the output results of the three models are very similar. It can be concluded that the Author's PWM, PWSSD and BioWin size a PST in a similar fashion.

Table 6-6 below provides a summary of the model output results for the Old Lane reactor (UCT process configuration) at a 14-day sludge age:

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)		UCTPHO (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	1655	1655	1678	1678	1640	1640	1640	1640
Volume of Anoxic Reactor	V _{anoxic}	m ³	1110	1110	1122	1122	1100	1100	1100	1100
Volume of Aerobic Reactor	V _{aerobic}	m ³	7076	7076	7156	7156	7100	7100	7100	7100
Volume of Reactor	V _{Total}	m ³	9840	9840	9956	9956	9840	9840	9840	9840
s-recycle ratio (dry weather flow)	s	-	1:1	1:1	1:1	1:1	1:1	1:1	1:1	1:1
r-recycle ratio	r	-	1:1	1:1	1:1	1:1	1:1	1:1	1:1	1:1
a-recycle ratio	a	-	4:1	4:1	4:1	4:1	4:1	4:1	4:1	4:1
Sludge Waste Flow	Q _w	Ml/day	0.649	0.619	0.651	0.620	0.649	0.619	0.646	0.615
Denitrification Potential of Primary Anoxic Reactor	DP ₁	(mgNO ₃ -N)/l	21.63	29.74	21.43	29.87	Not prov.	Not prov.	Not prov.	Not prov.
VSS in Reactor	MX _v	kgVSS	33104	31179	33364	31138	33347	32155	34510	32732
TSS in Reactor	MX _T	kgTSS	45064	42939	45574	43107	44807	43548	Not prov.	Not prov.
Active fraction of Sludge w.r.t VSS	f _{av}	-	0.61	0.57	0.61	0.57	0.55	0.50	Not prov.	Not prov.
Active fraction of Sludge w.r.t TSS	f _{at}	-	0.45	0.42	0.45	0.41	0.47	0.43	Not prov.	Not prov.
Total Average OUR	OUR _{Average}	mgO ₂ /l.hr	55.74	55.06	55.58	55.54	54.20	54.00	56.06	56.52
Effluent COD	S _{te}	mgCOD/l	44.000	44.000	44.000	44.000	44.000	44.000	47.300	48.500
Effluent Free and Saline Ammonia (FSA)	N _{ae}	mgN/l	0.592	0.418	0.586	0.415	0.700	0.400	0.607	0.380
Unbiodegradable Soluble Organic Nitrogen	N _{ousi}	mgN/l	1.800	1.800	1.800	1.800	1.950	1.950	1.800	1.800
Effluent TKN	N _{te}	mgN/l	2.392	2.218	2.386	2.215	2.650	2.350	2.407	2.180
Effluent Nitrate	N _{ne}	mgN/l	33.191	26.068	32.710	25.674	29.500	24.500	30.000	25.500
Total Effluent Nitrogen	TotN _{eff}	mgN/l	35.583	28.286	35.096	27.889	32.150	26.850	32.407	27.680
Effluent P (OrthoP + P _{ouse})	P _{te}	mgP/l	0.300	0.300	0.300	0.300	0.550	0.600	0.300	0.300
Effluent P (Organic P)	P _{ouse}	mgP/l	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Effluent Ortho P	P _{se}	mgP/l	0.000	0.000	0.000	0.000	0.210	0.260	0.000	0.000
Alkalinity of effluent	Alk	mg/l as CaCO ₃	47	69	48	70	Not prov.	Not prov.	Not prov.	Not prov.
pH of effluent from reactor	pH	-	Not prov.	Not prov.	Not prov.	Not prov.	6.92	6.92	Not prov.	Not prov.

Table 6-6 : Reactor (Old Lane UCT System) – Summary of model results

It is noted that the volumes provided in **Table 6-6** above for the BioWin and UCTPHO models are inputted by the user based on the existing case study WWTW volumes as these are input parameters to these models.

As previously discussed in **Section 6.1**, these two modelling platforms do not predict the UCT bioreactor volumes which is the case for the Author's PWM and PSWWD models.

Table 6-7 provides a weighting comparison of the model output results for the reactor, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM:

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)		UCTPHO (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	100.0%	100.0%	101.4%	101.4%	99.1%	99.1%	99.1%	99.1%
Volume of Anoxic Reactor	V _{Anoxic}	m ³	100.0%	100.0%	101.1%	101.1%	99.1%	99.1%	99.1%	99.1%
Volume of Aerobic Reactor	V _{aerobic}	m ³	100.0%	100.0%	101.1%	101.1%	100.3%	100.3%	100.3%	100.3%
Volume of Reactor	V _{Total}	m ³	100.0%	100.0%	101.2%	101.2%	100.0%	100.0%	100.0%	100.0%
Sludge Waste Flow	Q _w	Ml/day	100.0%	10.0%	100.3%	100.3%	100.0%	100.1%	99.5%	99.5%
Denitrification Potential of Primary Anoxic Reactor	DP ₁	(mgNO ₃ -N)/ℓ	100.0%	100.0%	99.1%	100.4%	Not prov.	Not prov.	Not prov.	Not prov.
VSS in Reactor	MX _v	kgVSS	100.0%	100.0%	100.8%	99.9%	100.7%	103.1%	104.2%	105.0%
TSS in Reactor	MX _T	kgTSS	100.0%	100.0%	101.1%	100.4%	99.4%	101.4%	Not prov.	Not prov.
Active fraction of Sludge w.r.t VSS	f _{av}		100.0%	100.0%	99.9%	98.8%	89.6%	87.8%	Not prov.	Not prov.
Active fraction of Sludge w.r.t TSS	f _{at}		100.0%	100.0%	99.6%	98.3%	104.3%	103.4%	Not prov.	Not prov.
Total Average OUR	OUR _{Average}	mgO ₂ /ℓ.hr	100.0%	100.0%	99.7%	100.9%	97.2%	98.1%	100.6%	102.6%
Effluent COD	S _{te}	mgCOD/ℓ	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	107.5%	110.2%
Effluent Free and Saline Ammonia (FSA)	N _{ae}	mgN/ℓ	100.0%	100.0%	98.9%	99.4%	118.3%	95.8%	102.5%	91.0%
Unbiodegradable Soluble Organic Nitrogen	N _{ousi}	mgN/ℓ	100.0%	100.0%	100.0%	100.0%	108.3%	108.3%	100.0%	100.0%
Effluent TKN	N _{te}	mgN/ℓ	100.0%	100.0%	99.7%	99.9%	110.8%	106.0%	100.6%	98.3%
Effluent Nitrate	N _{ne}	mgN/ℓ	100.0%	100.0%	98.6%	98.5%	88.9%	94.0%	90.4%	97.8%
Total Effluent Nitrogen	TotN _{eff}	mgN/ℓ	100.0%	100.0%	98.6%	98.6%	90.4%	94.9%	91.1%	97.9%
Effluent P (OrthoP + P _{ouse})	P _{te}	mgP/ℓ	100.0%	100.0%	100.0%	100.0%	183.3%	200.0%	100.0%	100.0%
Effluent P (Organic P)	P _{ouse}	mgP/ℓ	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Effluent Ortho P	P _{se}	mgP/ℓ	-	-	-	-	-	-	-	-

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)		UCTPHO (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Alkalinity of effluent	Alk	mg/l as CaCO ₃	100.0%	100.0%	103.2%	102.3%	Not prov.	Not prov.	Not prov.	Not prov.
Total Count out of range (Total parameters evaluated = 21)			0	0	0	0	2	1	0	0

Table 6-7 : Reactor (Old Lane UCT System) – Weighting comparison of model results

The output results of the four models are very similar except for the following:

- Active fraction with respect to VSS: BioWin predicts a slightly lower value (less than 13% difference) than the other models and this can be attributed to a slightly lower mass of active PAO organisms in the reactor. This is mainly because of the discrepancy in PAO substrate allocation between BioWin and the spreadsheet models. In BioWin, the activated sludge model relies on the kinetics of anaerobic fermentation of fermentable soluble organics (which dictates how much RBCOD is converted to VFAs) and the kinetics of SBCOD hydrolysis (dictating the quantity of SBCOD conversion of RBCOD). The VFAs available anaerobically are the ones that can be sequestered by PAOs allowing for their increased growth in the AS system. Hence, the higher the RBCOD anaerobic fermentation rate, the higher the potential for PAO growth in the AS system. Hence, the PAOs compete with facultative heterotrophic organisms for utilisation of the VFA present in unaerated zones (according to the kinetics of both PAO conversion of VFA to poly-hydroxy-alkanoates (Smolders *et al.*, 1995) and the kinetics of denitrification by OHOs). If all the nitrates are utilised in an anaerobic zone, then the PAOs have no more competition for the substrate. In the steady state spreadsheet models, the allocation of substrate sequestered by PAOs is calculated without the inclusion of anaerobic fermentation kinetics (It is assumed that the RBCOD fermentation rate is rapid enough for all RBCOD to be converted to VFAs). However, in the steady state spreadsheet models, the nitrates recycled back into the anaerobic zone are assumed to be utilised by facultative OHOs much more rapidly than the PAOs could sequester VFAs. Hence the VFAs available to PAOs are the ones present after all the nitrates have been reduced in the anaerobic zone. Because of this discrepancy between the dynamic simulation software model (in BioWin) and the steady state spreadsheet model (i.e., the VFAs being taken up less in the BioWin model due to slower fermentation kinetics), the PAO growth in the BioWin model is less. This has further implications for the model predictions. Firstly, the reactor active fraction of VSS is reduced, because the PAOs have a much lower endogenous death rate than the OHOs (in the death regeneration model the OHO death rate is 0.62/d, while that of PAOs is 0.04/d; Henze *et al.*, 2008). Also, with a lower PAO population, there is less potential for aerobic polyphosphate uptake, resulting in higher effluent Ortho-P concentrations. Also affected to a lesser degree, is the quantity of nutrients taken up in the reactor being less due to less active biomass, resulting in marginally higher effluent FSA (and again the Ortho-P is similarly affected).
- Effluent free and saline ammonia (FSA): The BioWin model is closer in prediction at higher temperatures with the other models but predicts higher values (greater than 15% difference) than the other models at low temperatures. The discrepancies attributed to FSA can be explained for reasons discussed in the above section that compares the active fraction of VSS in the various models.

However, the BioWin effluent FSA is still less than 0.75 mgN/l so in absolute terms the difference is small.

- **Effluent nitrate:** The BioWin model predicts slightly lower values (less than 12% difference) than the other models, attributed to the higher FSA in the effluent as discussed above.
- **Effluent total P:** BioWin predicts the presence of Ortho-P (less than 0.600 mgP/l for minimum and maximum wastewater temperatures) in the effluent, resulting in a higher total P in the effluent. The other models predict a zero Ortho-P in the effluent. The discrepancies attributed to Ortho-P can be explained for reasons discussed in the above section that compares the active fraction of VSS in the various models.

The Author's PWM and PWSSD predict the same outputs, which would be expected as the design of the various process design modules within these models are based on the same design principles developed by the UCT Research Group. BioWin like UCTPHO, use dynamic kinetic equations under constant flow and load conditions for a steady-state simulation, and this will result in slightly different results (differences less than 15%) than the less complex steady-state models included in the Author's PWM and PWSSD model. Apart from the discrepancies in the output variables discussed above, the output results of the four models are very similar. It can be concluded that the Author's PWM, PWSSD, BioWin and UCTPHO model a UCT reactor in a similar fashion.

Table 6-8 below provides a summary of the model output results for the SSTs:

Parameter	Abbr.	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
Area (including 80% Flux rating correction factor)	A	m ²	2089	2089	2089
Recycle Ratio i.t.o ADWF (Dry weather flow conditions)	R _{f ADWF & PDWF}	-	1.00	1.00	1.00
Recycle Ratio i.t.o ADWF (Wet weather flow conditions)	R _{f PWWF}	-	2.24	2.25	Not prov.
ADWF Underflow Concentration	X _{T Underflow}	mgTSS/l	9993	9991	9800
PDWF Underflow Concentration	X _{T Underflow}	mgTSS/l	13738	13734	Not prov.
PWWF Underflow Concentration	X _{T Underflow}	mgTSS/l	10590	10537	Not prov.

Table 6-8 : SSTs (Old Lane UCT System) – Summary of model results

Table 6-9 provides a weighting comparison of the model output results for the SSTs, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM:

Parameter	Abbr.	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
Area (including 80% Flux rating correction factor)	A	m ²	100.00%	100.02%	100.00%
Recycle Ratio i.t.o ADWF (Dry weather flow conditions)	R _{r ADWF & PDWF}	-	100.00%	100.06%	99.86%
Recycle Ratio i.t.o ADWF (Wet weather flow conditions)	R _{r PWWF}	-	100.00%	100.62%	Not prov.
ADWF Underflow Concentration	X _{T Underflow}	mgTSS/l	100.00%	99.98%	98.07%
PDWF Underflow Concentration	X _{T Underflow}	mgTSS/l	100.00%	99.97%	Not prov.
PWWF Underflow Concentration	X _{T Underflow}	mgTSS/l	100.00%	99.50%	Not prov.
Total Count out of range (Total parameters evaluated = 6)			0	0	0

Table 6-9 : SSTs (Old Lane UCT System) – Weighting comparison of model results

From the table above, the output results of the three models are very similar. It can be concluded that the Author's PWM, PWSSD and BioWin size an SST in a similar fashion.

6.3.2 New Lane 5-stage Bardenpho System

Table 6-10 below provides a summary of the model output results for the PSTs based on overflow rates of 1.2 m/hr at ADWF and 2.4 m/hr at PDWF and PWWF:

Parameter	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
Total Area Required (ADWF)	m ²	1510	1510	Not prov.
Total Area Required (PDWF)	m ²	1322	Not prov.	Not prov.
Total Area Required (PWWF)	m ²	1888	1888	1888
Weir Loading at PDWF	m ³ /m.hr	11.6	11.6	Not prov.
Weir Loading at PWWF	m ³ /m.hr	16.6	16.6	Not prov.
Typical concentration of Primary Sludge	mg/l	40180	40200	40950

Table 6-10 : PSTs (New Lane 5-stage Bardenpho System) – Summary of model results

The existing PST surface area (i.e., as-built area) is 2565 m² which is higher than the surface areas calculated from the models presented in **Table 6-10** above.

Table 6-11 provides a weighting comparison of the model output results for the PSTs, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM:

Parameter	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
Total Area Required (ADWF)	m ²	100.00%	100.00%	Not prov.
Total Area Required (PDWF)	m ²	100.00%	Not prov.	Not prov.
Total Area Required (PWWF)	m ²	100.00%	100.00%	100.00%
Weir Loading at PDWF	m ³ /m.hr	100.00%	99.96%	Not prov.
Weir Loading at PWWF	m ³ /m.hr	100.00%	100.13%	Not prov.
Typical concentration of Primary Sludge	mg/l	100.00%	100.05%	101.92%
Total Count out of range (Total parameters evaluated = 6)		0	0	0

Table 6-11 : PSTs (New Lane 5-stage Bardenpho System) – Weighting comparison of model results

From the table above, the output results of the three models are very similar as was the case of the Old Lane.

Table 6-12 below provides a summary of the model output results for the reactor (5-Stage Bardenpho process) at an 18-day sludge age:

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)		UCTPHO (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	5407	5407	Not prov.	Not prov.	5407	5407	5407	5407
Volume of Primary Anoxic Reactor	V _{anoxic (Primary)}	m ³	7160	7160	Not prov.	Not prov.	7160	7160	7160	7160
Volume of Secondary Anoxic Reactor	V _{anoxic (Secondary)}	m ³	5107	5107	Not prov.	Not prov.	5107	5107	5107	5107
Volume of Aerobic Reactor	V _{aerobic}	m ³	16774	16774	Not prov.	Not prov.	16774	16774	16774	16774
Volume of De-aeration Reactor	V _{de-aeration}	m ³	1852	1852	Not prov.	Not prov.	1852	1852	1852	1852
Volume of Reactor	V _{Total}	m ³	36300	36300	Not prov.	Not prov.	36300	36300	36300	36300
s-recycle ratio (dry weather flow)	s	-	0.9:1	0.9:1	Not prov.	Not prov.	0.9:1	0.9:1	0.9:1	0.9:1
a-recycle ratio	a	-	4:1	4:1	Not prov.	Not prov.	4:1	4:1	4:1	4:1
Sludge Waste Flow	Q _w	Ml/day	2.003	1.968	Not prov.	Not prov.	2.003	1.968	2.003	1.969
					Not prov.	Not prov.				
Denitrification Potential of Primary Anoxic Reactor	DP ₁	(mgNO ₃ -N)/l	37.78	52.70	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.
VSS in Reactor	MX _v	kgVSS	109023	106638	Not prov.	Not prov.	109224	105540	115045	108486
TSS in Reactor	MX _T	kgTSS	163350	160571	Not prov.	Not prov.	160623	157240	Not prov.	Not prov.
Active fraction of Sludge w.r.t VSS	f _{av}	-	0.57	0.55	Not prov.	Not prov.	0.53	0.52	Not prov.	Not prov.
Active fraction of Sludge w.r.t TSS	f _{at}	-	0.38	0.36	Not prov.	Not prov.	0.37	0.35	Not prov.	Not prov.

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)		UCTPHO (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Total Average OUR	OUR Average	mgO ₂ /ℓ.hr	58.57	57.20	Not prov.	Not prov.	55.00	53.50	50.86	53.50
Effluent COD	S _{te}	mgCOD/ℓ	44.000	44.000	Not prov.	Not prov.	44.000	44.000	48.003	49.224
Effluent Free and Saline Ammonia (FSA)	N _{ae}	mgN/ℓ	0.607	0.432	Not prov.	Not prov.	0.280	0.130	0.401	0.301
Unbiodegradable Soluble Organic Nitrogen	N _{ousi}	mgN/ℓ	2.033	2.033	Not prov.	Not prov.	2.200	2.180	2.033	2.033
Effluent TKN	N _{te}	mgN/ℓ	2.640	2.466	Not prov.	Not prov.	2.480	2.310	2.534	2.400
Effluent Nitrate	N _{ne}	mgN/ℓ	16.758	8.847	Not prov.	Not prov.	14.550	10.000	14.500	9.500
Total Effluent Nitrogen	TotN _{eff}	mgN/ℓ	19.398	11.313	Not prov.	Not prov.	17.330	12.310	17.034	11.900
Effluent P (OrthoP + P _{ouse})	P _{te}	mgP/ℓ	0.301	0.301	Not prov.	Not prov.	0.810	0.860	0.301	0.301
Effluent P (Organic P)	P _{ouse}	mgP/ℓ	0.301	0.301	Not prov.	Not prov.	0.301	0.301	0.301	0.301
Effluent Ortho P	P _{se}	mgP/ℓ	0.000	0.000	Not prov.	Not prov.	0.509	0.559	0.000	0.000
Alkalinity of effluent	Alk	mg/ℓ as CaCO ₃	106	133	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.
pH of effluent from reactor	pH	-	Not prov.	Not prov.	Not prov.	Not prov.	7.21	7.26	Not prov.	Not prov.

Table 6-12 : Reactor (New Lane 5-stage Bardenpho System) – Summary of model results

It is noted that the volumes provided in **Table 6-12** above for the BioWin and UCTPHO models are inputted by the user based on the existing case study WWTW volumes as these are input parameters to these models. As previously discussed in **Section 6.1**, these two modelling platforms do not predict the Bardenpho bioreactor volumes which is the case for the Author's PWM and PWSSD model. As previously discussed in **Section 6.1.2**, PWSSD does not cater for the 5-stage Bardenpho activated sludge configuration. It is not possible to simulate the Bardenpho bioreactor of the New Lane with one of the available activated sludge configurations (i.e., Johannesburg or UCT), as one would be comparing different process configurations. As a result, the Bardenpho bioreactor of the New Lane was not modelled in the PWSSD programme

Table 6-13 provides a weighting comparison of the model output results for the reactor of the New Lane, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM:

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)		UCTPHO (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	100.0%	100.0%	Not prov.	Not prov.	100.0%	100.0%	100.0%	100.0%
Volume of Primary Anoxic Reactor	V _{anoxic (Primary)}	m ³	100.0%	100.0%	Not prov.	Not prov.	100.0%	100.0%	100.0%	100.0%
Volume of Secondary Anoxic Reactor	V _{anoxic (Secondary)}	m ³	100.0%	100.0%	Not prov.	Not prov.	100.0%	100.0%	100.0%	100.0%
Volume of Aerobic Reactor	V _{aerobic}	m ³	100.0%	100.0%	Not prov.	Not prov.	100.0%	100.0%	100.0%	100.0%
Volume of De-aeration Reactor	V _{de-aeration}	m ³	100.0%	100.0%	Not prov.	Not prov.	100.0%	100.0%	100.0%	100.0%
Volume of Reactor	V _{Total}	m ³	100.0%	100.0%	Not prov.	Not prov.	100.0%	100.0%	100.0%	100.0%
Sludge Waste Flow	Q _w	Ml/day	100.0%	100.0%	Not prov.	Not prov.	100.0%	100.0%	100.0%	100.0%
Denitrification Potential of Primary Anoxic Reactor	DP ₁	(mgNO ₃ -N)/l	100.0%	100.0%	Not prov.	Not prov.	Not Prov.	Not Prov.	Not Prov.	Not Prov.
VSS in Reactor	MX _v	kgVSS	100.0%	100.0%	Not prov.	Not prov.	100.2%	99.0%	105.5%	101.7%
TSS in Reactor	MX _T	kgTSS	100.0%	100.0%	Not prov.	Not prov.	98.3%	97.9%	Not Prov.	Not Prov.
Active fraction of Sludge w.r.t VSS	f _{av}	-	100.0%	100.0%	Not prov.	Not prov.	93.4%	95.0%	Not Prov.	Not Prov.
Active fraction of Sludge w.r.t TSS	f _{at}	-	100.0%	100.0%	Not prov.	Not prov.	97.7%	96.2%	Not Prov.	Not Prov.
Total Average OUR	OUR _{Average}	mgO ₂ /l.hr	100.0%	100.0%	Not prov.	Not prov.	93.9%	93.5%	86.8%	93.5%
					Not prov.	Not prov.				
Effluent COD	S _{ie}	mgCOD/l	100.0%	100.0%	Not prov.	Not prov.	100.0%	100.0%	109.1%	111.9%
Effluent Free and Saline Ammonia (FSA)	N _{ae}	mgN/l	100.0%	100.0%	Not prov.	Not prov.	46.2%	30.1%	66.2%	69.5%
Unbiodegradable Soluble Organic Nitrogen	N _{ousi}	mgN/l	100.0%	100.0%	Not prov.	Not prov.	108.2%	107.2%	100.0%	100.0%
Effluent TKN	N _{te}	mgN/l	100.0%	100.0%	Not prov.	Not prov.	93.9%	93.7%	96.0%	97.3%
Effluent Nitrate	N _{ne}	mgN/l	100.0%	100.0%	Not prov.	Not prov.	86.8%	113.0%	86.5%	107.4%
Total Effluent Nitrogen	TotN _{eff}	mgN/l	100.0%	100.0%	Not prov.	Not prov.	89.3%	108.8%	87.8%	105.2%
					Not prov.	Not prov.				
Effluent P (OrthoP + P _{ouse})	P _{te}	mgP/l	100.0%	100.0%	Not prov.	Not prov.	269.3%	285.9%	100.0%	100.0%
Effluent P (Organic P)	P _{ouse}	mgP/l	100.0%	100.0%	Not prov.	Not prov.	100.1%	100.1%	100.0%	100.0%
Effluent Ortho P	P _{se}	mgP/l	-	-	Not prov.	Not prov.	-	-	-	-

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)		UCTPHO (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Alkalinity of effluent	Alk	mg/l as CaCO ₃	100.0%	100.0%	Not prov.	Not prov.	Not Prov.	Not Prov.	Not Prov.	Not Prov.
Total Count out of range (Total parameters evaluated = 23)			0	0	Not appl.	Not appl.	2	2	1	1

Table 6-13 : Reactor (New Lane 5-stage Bardenpho System) – Weighting comparison of model results

The output results of the three models are very similar with the exception of the following:

- Effluent free and saline ammonia (FSA): This variable is slightly lower (varies between 0.130 and 0.401 mgN/l) for the BioWin and UCTPHO models, with the BioWin model resulting in the lowest FSA values. The difference in the BioWin model is a result of this model assuming a lower endogenous respiration rate and half saturation coefficient for the nitrifiers. However, all models predict an effluent FSA value less than 0.75 mgN/l so in absolute terms the difference is small.
- Effluent total P: BioWin predicts the presence of ortho-P (less than 0.559 mgP/l for minimum and maximum wastewater temperatures) in the effluent, resulting in a higher total P in the effluent. The other models predict a zero ortho-P in the effluent. As previously discussed for the Old Lane, BioWin adopts two different maximum specific growth rates for the PAOs, namely a higher growth rate constant under phosphorous rich conditions which results in a higher uptake of phosphorous, and a lower growth rate constant under phosphorous limited conditions, where phosphorous uptake is limited. This lower growth rate constant has a different stoichiometry (no polyphosphate storage) and is the reason for BioWin producing a non-zero ortho-P in the effluent.

BioWin like UCTPHO, use dynamic kinetic equations under constant flow and load conditions for a steady-state simulation, and this generates different results than the less complex steady-state models included in the Author's PWM. Apart from the discrepancies in the output variables discussed above, the output results of the four models are very similar. It can be concluded that the Author's PWM, BioWin and UCTPHO model the 5-stage Bardenpho reactor in a similar fashion.

Table 6-14 below provides a summary of the model output results for the SSTs:

Parameter	Abbr.	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
Area (including 80% Flux rating correction factor)	A	m ²	4361	4361	4361
Recycle Ratio i.t.o ADWF (Dry weather flow conditions)	R _{r ADWF & PDWF}	-	0.87	0.87	0.87
Recycle Ratio i.t.o ADWF (Wet weather flow conditions)	R _{r PWWF}	-	1.84	1.85	Not prov.
ADWF Underflow Concentration	X _{T Underflow}	mgTSS/l	9683	9679	9390
PDWF Underflow Concentration	X _{T Underflow}	mgTSS/l	13570	13563	Not prov.

Parameter	Abbr.	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
PWWF Underflow Concentration	$X_{T \text{ Underflow}}$	mgTSS/ℓ	10603	10598	Not prov.

Table 6-14 : SSTs (New Lane 5-stage Bardenpho System) – Summary of model results

Table 6-15 provides a weighting comparison of the model output results for the SSTs, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM:

Parameter	Abbr.	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
Area (including 80% Flux rating correction factor)	A	m ²	100.00%	100.01%	100.00%
Recycle Ratio i.t.o ADWF (Dry weather flow conditions)	$R_{r \text{ ADWF \& PDWF}}$	-	100.00%	100.09%	100.20%
Recycle Ratio i.t.o ADWF (Wet weather flow conditions)	$R_{r \text{ PWWF}}$	-	100.00%	100.09%	Not prov.
ADWF Underflow Concentration	$X_{T \text{ Underflow}}$	mgTSS/ℓ	100.00%	99.96%	96.97%
PDWF Underflow Concentration	$X_{T \text{ Underflow}}$	mgTSS/ℓ	100.00%	99.95%	Not prov.
PWWF Underflow Concentration	$X_{T \text{ Underflow}}$	mgTSS/ℓ	100.00%	99.95%	Not prov.
Total Count out of range (Total parameters evaluated = 6)			0	0	0

Table 6-15 : SSTs (New Lane 5-stage Bardenpho System) – Weighting comparison of model results

From the table above, the output results of the three SST models are very similar as was the case for the Old Lane.

6.3.3 Combined Sludge Lane

Table 6-16 below provides a summary of the model output results for the anaerobic digester:

Parameter	Abbr.	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
PS inflow to Anaerobic Digester	Q_w	m ³ /day	427	427	427
TSS incoming	TSS _{in}	mgTSS/ℓ	38565	38728	42000
VSS incoming	VSS _{in}	mgVSS/ℓ	34260	34405	36000
COD incoming	S _{te in}	mgCOD/ℓ	59131	59370	59000
TKN incoming	N _{te in}	mgN/ℓ	2485	2495	2486
TP incoming	P _{te in}	mgP/ℓ	293	295	294
Volume	Vol	m ³	5112	5122	5122

Parameter	Abbr.	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
TSS digested sludge	TSS out	mgTSS/l	15487	15580	17000
VSS digested sludge	VSS out	mgVSS/l	11182	11285	12000
COD digested sludge	S _{te} out	mgCOD/l	19148	19216	21200
Total N digested sludge	N _{te} out	mgN/l	2300	Not Prov.	2400
TP digested sludge	P _{te} out	mgP/l	258	Not Prov.	275
CH ₄ (Gaseous) By-product	CH ₄	mol/l	0.64	0.63	0.63
CH ₄ (Gaseous) By-product	CH ₄	Nm ³ /day	6559	6441	6450
VSS Destruction	VSS dest.	%	67.4%	67.2%	66.7%

Table 6-16 : Anaerobic Digester (Combined Sludge Lane) – Summary of model results

Table 6-17 provides a weighting comparison of the model output results for the anaerobic digester, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM:

Parameter	Abbr.	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
PS inflow to Anaerobic Digester	Q _w	m ³ /day	100.0%	100.0%	100.0%
TSS incoming	TSS _{in}	mgTSS/l	100.0%	100.4%	108.9%
VSS incoming	VSS _{in}	mgVSS/l	100.0%	100.4%	105.1%
COD incoming	S _{te} in	mgCOD/l	100.0%	100.4%	99.8%
TKN incoming	N _{te} in	mgN/l	100.0%	100.4%	100.0%
TP incoming	P _{te} in	mgP/l	100.0%	100.4%	100.2%
Volume	Vol	m ³	100.0%	100.0%	100.0%
TSS digested sludge	TSS out	mgTSS/l	100.0%	100.6%	109.8%
VSS digested sludge	VSS out	mgVSS/l	100.0%	100.9%	107.3%
COD digested sludge	S _{te} out	mgCOD/l	100.0%	100.4%	110.7%
Total N digested sludge	N _{te} out	mgN/l	100.0%	Not Prov.	104.3%
TP digested sludge	P _{te} out	mgP/l	100.0%	Not Prov.	106.6%
CH ₄ (Gaseous) By-product	CH ₄	mol/l	100.0%	98.7%	99.2%
CH ₄ (Gaseous) By-product	CH ₄	Nm ³ /day	100.0%	98.7%	99.2%
VSS Destruction	VSS dest.	M ³ /day	100.0%	99.8%	99.0%

Parameter	Abbr.	Unit	Author's PWM	PSWWD	BioWin (Steady-State @ 16 °C)
Total Count out of range (Total parameters evaluated = 15)			0	0	0

Table 6-17 : Anaerobic Digester (Combined Sludge Lane) – Weighting comparison of model results

The output results of the three models are very similar apart from the following variables:

- TSS, VSS, COD and Total P of Digested Sludge: The TSS, VSS, COD and Total P of the digested sludge exiting the anaerobic digester is slightly higher (less than 11% difference) for the BioWin model.

As previously mentioned for the Old Lane and New Lane, BioWin uses dynamic kinetic equations under constant flow and load conditions for a steady-state simulation, and this will result in slightly different results (less than 11% difference) than the less complex steady-state models included in the Author's PWM and PWSSD model. However, all output results of the three models are very similar and it can be concluded that the Author's PWM, PWSSD and BioWin model an anaerobic digester in a similar fashion.

Table 6-18 below provides a summary of the model output results for the aerobic digester:

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
WAS in	$Q_{w\text{ in}}$	m ³ /day	350.0	326.0	350.0	326.0	350.0	326.0
WAS out	$Q_{w\text{ OUT}}$	m ³ /day	350.0	326.0	350.0	326.0	350.0	326.0
Influent TSS	$X_{T\text{ in}}$	mgTSS/l	35000	35000	35000	35000	34600	33000
Influent VSS	X_{vi}	mgVSS/l	23868	22616	23801	22706	23700	22300
Influent Active fraction of Sludge w.r.t VSS	f_{av}	-	0.578	0.553	0.578	0.553	0.520	0.500
Influent Active fraction of Sludge w.r.t TSS	f_{at}	-	0.394	0.374	0.394	0.374	0.360	0.340
Volume of Aerobic Digester 1	$V_{\text{aerobic digester 1}}$	m ³	2501	2501	2511	2511	2501	2501
Volume of Aerobic Digester 2	$V_{\text{aerobic digester 2}}$	m ³	2501	2501	2511	2511	2501	2501
Total Volume of Aerobic Digesters	$V_{\text{aerobic digester T}}$	m ³	5002	5002	5022	5022	4968	4968
Digested sludge TSS Concentration: Digester 2	X_T	mgTSS/l	31060	30068	29095	28839	25200	24600
Digested sludge VSS Concentration: Digester 2	X_V	mgVSS/l	16821	16239	18717	18294	16700	16240
Digested sludge Active fraction of Sludge w.r.t VSS	f_{av}	-	0.314	0.301	0.393	0.327	0.290	0.280
Digested sludge Active fraction of Sludge w.r.t TSS	f_{at}	-	0.170	0.162	0.253	0.207	0.150	0.140
Digested sludge COD Concentration: Digester 2	S_{ie}	gCOD/l	23.966	22.918	24.120	23.050	24.300	23.785

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Total Digested sludge N Concentration: Digester 2	TotN _{eff}	gN/l	2.387	2.262	2.394	2.253	2.600	2.513
Digested sludge P Concentration (OrthoP + P _{ouse}): Digester 2	P _{te}	gP/l	1.173	1.101	0.598	0.563	1.400	1.400
Total Oxygen Utilisation Rate: Digester 1	OUR _{T1}	mgO ₂ /(l.hr)	45.4	41.0	43.5	39.5	50.0	45.5
Total Oxygen Utilisation Rate: Digester 2	OUR _{T2}	mgO ₂ /(l.hr)	22.6	20.5	29.0	25.1	20.0	18.0

Table 6-18 : Aerobic Digester (Combined Sludge Lane) – Summary of model results

Table 6-19 provides a weighting comparison of the model output results for the aerobic digester, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM:

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
WAS in	Q _{w in}	m ³ /day	100.0%	100.0%	99.9%	100.0%	99.9%	100.0%
WAS out	Q _{w OUT}	m ³ /day	100.0%	100.0%	99.9%	100.0%	99.9%	100.0%
Influent TSS	X _{T in}	mgTSS/l	100.0%	100.0%	100.0%	100.0%	98.9%	94.3%
Influent VSS	X _{vi}	mgVSS/l	100.0%	100.0%	99.7%	100.4%	99.3%	98.6%
Influent Active fraction of Sludge w.r.t VSS	f _{av}	-	100.0%	100.0%	99.9%	99.9%	90.0%	90.4%
Influent Active fraction of Sludge w.r.t TSS	f _{at}	-	100.0%	100.0%	99.9%	99.9%	91.3%	90.8%
Volume of Aerobic Digester 1	V _{aerobic digester 1}	m ³	100.0%	100.0%	100.4%	100.4%	100.0%	100.0%
Volume of Aerobic Digester 2	V _{aerobic digester 2}	m ³	100.0%	100.0%	100.4%	100.4%	100.0%	100.0%
Volume Total of Aerobic Digesters	V _{aerobic digester T}	m ³	100.0%	100.0%	100.4%	100.4%	99.3%	99.3%
Digested sludge TSS Concentration: Digester 2	X _T	mgTSS/l	100.0%	100.0%	93.7%	95.9%	81.1%	81.8%
Digested sludge VSS Concentration: Digester 2	X _V	mgVSS/l	100.0%	100.0%	111.3%	112.7%	99.3%	100.0%
Digested sludge Active fraction of Sludge w.r.t VSS	f _{av}	-	100.0%	100.0%	124.9%	108.6%	92.3%	93.1%
Digested sludge Active fraction of Sludge w.r.t TSS	f _{at}	-	100.0%	100.0%	148.4%	127.6%	88.1%	86.2%
Digested sludge COD Concentration: Digester 2	S _{te}	gCOD/l	100.0%	100.0%	100.6%	100.6%	101.4%	103.8%
Total Digested sludge N Concentration: Digester 2	TotN _{eff}	gN/l	100.0%	100.0%	100.3%	99.6%	108.9%	111.1%

Parameter	Abbr.	Unit	Author's PWM		PSWWD		BioWin (Steady-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Digested sludge P Concentration (OrthoP + Pouse): Digester 2	P _{te}	gP/l	100.0%	100.0%	51.0%	51.1%	119.3%	127.2%
Total Oxygen Utilisation Rate: Digester 1	OUR _{T1}	mgO ₂ /(l.hr)	100.0%	100.0%	95.7%	96.3%	110.2%	110.9%
Total Oxygen Utilisation Rate: Digester 2	OUR _{T2}	mgO ₂ /(l.hr)	100.0%	100.0%	114.3%	107.4%	88.6%	87.9%
Total Count out of range (Total parameters evaluated = 18)			0	0	3	2	2	2

Table 6-19 : Aerobic Digester (Combined Sludge Lane) – Summary of model results

The output results of the three models are similar apart from the following:

- **TSS and VSS of Digested Sludge:** The BioWin model predicts a lower value (less than 20% difference) for the TSS sludge concentration exiting the last (second) digester. The PWSSD model predicts a slightly higher value (less than 13% difference) for the VSS sludge concentration exiting the last (second) digester, and the reason for this difference is discussed below under the “effluent active fraction” variable.
- **Effluent active fractions with respect to VSS and TSS:** The BioWin model predicts slightly lower values (less than 15% difference) for these variables when compared to the Author's PWM. The PWSSD model predicts higher values (greater than 15%) for these variables when compared to the Author's PWM due to the higher VSS value discussed above, attributed to the fact that the reactor of the New Lane was a dummy model using a Johannesburg process configuration which will result in different sludge characteristics. Also, the version of PWSSD adopted for purposes of this dissertation does not incorporate the latest research on the endogenous respiration rates of the polyphosphate accumulating organisms (PAOs) by Vogts and Ekama (2015).
- **Effluent N:** The BioWin model predicts a slightly higher value (less than 12% difference) in the N sludge concentration exiting the last (second) digester. With the aerobic degradation of the waste activated sludge (WAS) biodegradable particulate organics (BPO), there is a resultant release of the nutrients bound to the BPO (N is released as ammonia and P released as Ortho-P). Hence with the BioWin model having a lower predicted effluent VSS (as explained in the sections above), the VSS degradation is higher, resulting in higher quantities of N and P released as FSA and Ortho-P. BioWin also incorporates struvite precipitation, but according to the kinetics of struvite formation, the N and P that could not be utilised for this process are reflected in the effluent. Similarly, according to the kinetics of nitrate formation, the ammonia not converted to nitrates will also reflect in the effluent. There have been various studies to determine the kinetics of nitrification and mineral precipitation in aerobic digesters (Vogts *et al.*, 2015; Ikumi and Harding 2020). From these studies, it was noted that the ammonia released with the degradation of organics in aerobic digesters could get converted to nitrates and if polyphosphate is present, it disintegrated slowly with the death of PAOs. However, the Ortho-P and counter metals (Mg²⁺, K⁺ and Ca²⁺) released with PP degradation only resulted in trace quantities of K-struvite, which required a sufficiently high pH to form, while other minerals such as amorphous

calcium phosphate (ACP) and NH₄-struvite were deemed more likely to form, depending on the extent of nutrient and metal releases into the aqueous phase (Ikumi and Harding, 2020).

- **Effluent P:** The BioWin model predicts a higher value (greater than 15%) in the P sludge concentration exiting the last (second) digester. This can be explained by the reasons given in the above section on effluent N model comparison. Further, the PWSSD model predicts a lower value (50% difference) in the P sludge concentration exiting the last (second) digester, and this is attributed to the fact that the version of PWSSD adopted for the purposes of this dissertation does not incorporate the latest research on the endogenous respiration rates of the polyphosphate accumulating organisms (PAOs) by Vogts⁴¹ and Ekama (2015) as discussed in **Section 6.1.2**.

As previously mentioned for the Old Lane and New Lane, BioWin uses dynamic kinetic equations under constant flow and load conditions for a steady-state simulation, and this generates different results than the less complex steady-state models included in the Author's PWM and PWSSD model. The PWSSD model also results in slightly different output results, as the version of PWSSD adopted for purposes of this dissertation does not incorporate the latest research on the endogenous respiration rates of the poly accumulating organisms (PAOs) by Vogts⁴¹ and Ekama (2015).

6.4 Discussion of Findings

The following findings were established during the development of the steady-state models discussed above:

6.4.1 Comment on the modelling process

The development of a plant-wide model in UCTPHO was not possible as this programme is limited to the bioreactor only and required separate models for the bioreactor of each lane for the case study WWTW. A plant-wide approach was possible with the other three models (i.e., Author's PWM, PWSSD and BioWin), but BioWin was the preferred tool as a single model could replicate the entire case study WWTW. To replicate a plant-wide approach for the case study WWTW, two separate models were required for the Author's PWM and three separate models were required for PWSSD.

The effort to develop the steady-state models in the four programmes differed as follows:

- The UCTPHO model was easy to develop, as the model is limited to the reactor only and required limited input parameters. However, the programme can only be run from a DOS application, which presented numerous challenges associated with launching the programme. Also, run times for the programme were long, approximately 45 minutes for the steady-state design when compared to the other models which were seconds
- The Author's PWM and PWSSD were the most complex to set up, because more than one unit operation sub model was required to represent a plant-wide replica of the case study WWTW, and these packages required more input parameters than UCTPHO

- The BioWin model was simple to set-up but required more input parameters than the Author's PWM and PWSSD, namely additional kinetic and stoichiometric parameters, and wastewater fractions.

In terms of model output results, the following is noted:

- UCTPHO is limited to specific information in a summary output table, and the user is unable to view the calculation procedure.
- BioWin includes an extensive reach of output data, summarised in tabular or graphical format. However, BioWin does not allow the user to view calculations, and as a result there was specific output data that could not be retrieved (e.g., denitrification potential of the reactor). One of the benefits of modelling with BioWin, the user is alerted to modelling errors and system failures (e.g., low pH in reactor resulting in nitrification problems).
- The Author's PWM and PWSSD are based in Microsoft Excel. As a result, the user has access to the full suite of models, calculations and output results. Alert of modelling errors in these models is limited though.

6.4.2 Process capacity of the case study WWTW

It was established that the limiting factor in the overall process capacity for both the Old Lane and New Lane was the process volume of the bioreactor and SST surface area. The process capacity was calculated as follows based on a raw influent COD of 1,060 mgCOD/l, TKN of 85 mgN/l, TP of 11 mgP/l, TSS of 450 mgTSS/l and VSS of 380 mgVSS/l:

- Old Lane: The maximum process capacity of this lane is 17.25 Ml/day ADWF (influent) based on a sludge age of 14 days and the process parameters noted above. The documented design capacity of this lane is 17 Ml/d ADWF at a 1,000 mg/l COD. The theoretical process capacity estimated is 7% higher than the documented process capacity in terms of COD load.
- New Lane: The maximum process capacity of this lane is 43.5 Ml/day ADWF (influent) based on a sludge age of 18 days and the process parameters noted above. The documented design capacity of this lane is 30 Ml/d ADWF at a 1,000 mg/l COD. The theoretical process capacity estimated is 54% higher than the documented process capacity in terms of COD load.
- Specific process parameters selected in the models to estimate the maximum process capacity, namely sludge age and underflow concentration of PSTs were validated against current on-site operations, and there is a close correlation between the input parameters and on-site values.

6.4.3 Comparison of model output results

The modelling results of the four steady-state models were compared where differences were noted for major discrepancies (a percentage variation of 15%):

- PSTs and SSTs: The Author's PWM, PWSSD and BioWin size a PST and SST in a similar fashion, and the three models predicted negligible differences in the output results

- UCT bioreactor (Old Lane): The output results of the four models were very similar except for the following differences:
 - Active Fraction with respect to VSS: BioWin predicts a slightly lower value (less than 13% difference) than the other models and this can be attributed to a slightly lower mass of active PAO organisms in the reactor which is mainly due to the discrepancy in PAO substrate allocation between BioWin and the spreadsheet models. In BioWin, the activated sludge model relies on the kinetics of anaerobic fermentation of fermentable soluble organics and the kinetics of SBCOD hydrolysis. The VFAs available anaerobically are the ones that can be sequestered by PAOs allowing for their increased growth in the AS system. The higher the RBCOD anaerobic fermentation rate, the higher the potential for PAO growth in the AS system. The PAOs compete with facultative heterotrophic organisms for utilisation of the VFA present in unaerated zones, and if all the nitrate is utilised in an anaerobic zone, then the PAOs have no more competition for the substrate. In the steady state spreadsheet models, the allocation of substrate sequestered by PAOs is calculated without the inclusion of anaerobic fermentation kinetics and the nitrates recycled back into the anaerobic zone are assumed to be utilised by facultative OHOs much more rapidly than the PAOs could sequester VFAs. Hence the VFAs available to PAOs are the ones present after all the nitrate has been reduced in the anaerobic zone. Because of this discrepancy between the dynamic simulation software model (i.e., BioWin) and the steady state spreadsheet model, the PAO growth in the BioWin model is less. With a lower PAO population, there is less potential for aerobic polyphosphate uptake, resulting in higher effluent Ortho-P concentrations. Also affected to a lesser degree, is the quantity of nutrients taken up in the reactor being less due to less active biomass, resulting in marginally higher effluent FSA.
 - Effluent FSA, effluent nitrate and total effluent N: The BioWin model differed slightly from the other models, but the difference in values were not significant. The BioWin effluent FSA is still less than 0.75 mgN/l so in absolute terms the difference is small. The BioWin effluent nitrate and Total Effluent N are closer in prediction at higher temperatures with the other models but predict slightly higher values (less than 15% difference) than the other models at low temperatures.
 - Effluent total P: BioWin predicts the presence of ortho-P (less than 0.260 mgP/l for minimum and maximum wastewater temperatures) in the effluent, resulting in a higher total P in the effluent. The other models predict a zero ortho-P in the effluent. The discrepancies attributed to Ortho-P can be explained for reasons discussed in the above section that compares the active fraction of VSS in the various models.
 - In summary, the Author's PWM and PWSSD predict the same outputs, which is expected as the design of the various process design modules within these models are based on the same design principles developed by the UCT Research Group. BioWin and UCTPHO use dynamic kinetic equations under constant flow and load conditions for a steady-state simulation, and this will result in slightly different results (less than 15% difference) than the less complex steady-state models included in the Author's PWM and PWSSD model.

- 5-Stage Bardenpho bioreactor (New Lane): The output results of the three models were very similar except for the following differences:
 - Effluent free and saline ammonia (FSA): This variable is slightly lower (varies between 0.130 and 0.401 mgN/l) for the BioWin and UCTPHO models, with the BioWin model resulting in the lowest FSA values. The difference in the BioWin model is a result of this model assuming a lower endogenous respiration rate and half saturation coefficient for the nitrifiers. However, all models predict an effluent FSA of less than 0.75 mgN/l so in absolute terms the difference is small.
 - Effluent total P: BioWin predicts the presence of ortho-P (less than 0.559 mgP/l for minimum and maximum wastewater temperatures) in the effluent, resulting in a higher total P in the effluent. The other models predict a zero ortho-P in the effluent. This can be explained by the same reason as previously discussed for the effluent total P for the Old Lane.
 - In summary, BioWin like UCTPHO, use dynamic kinetic equations under constant flow and load conditions for a steady-state simulation, and this generates different results than the less complex steady-state models included in the Author's PWM and PWSSD model
- Anaerobic Digester: The three models predicted very similar output results, with the only exception being the BioWin model, predicting a slightly higher value (less than 11% difference) for the TSS, VSS, COD and Total P of the digested sludge exiting the anaerobic digester.
- Aerobic Digester: The three models predicted very similar output results except for the following:
 - The BioWin model predicted a lower TSS (less than 20% difference) and a lower effluent active fraction (less than 15% difference) with respect to VSS and TSS for the sludge concentration exiting the last (second) digester. The BioWin model also predicted higher effluent N (less than 12% difference) and P concentrations (greater than 15% difference) for the sludge concentration exiting the last (second) digester. With the aerobic degradation of the waste activated sludge (WAS) biodegradable particulate organics (BPO), there is a resultant release of the nutrients bound to the BPO (N is released as ammonia and P released as Ortho-P). Hence with the BioWin model having a lower predicted effluent VSS as previously explained, the VSS degradation is higher, resulting in higher quantities of N and P released as FSA and Ortho-P.
 - The PWSSD model predicts a slightly higher value (less than 13% difference) for the VSS sludge concentration exiting the last (second) digester, resulting in a higher (greater than 15% difference) effluent active fraction with respect to VSS and TSS for the sludge concentration exiting the last (second) digester. The PWSSD model predicts a lower value (50% difference) in the P sludge concentration exiting the last (second) digester. These differences are attributed to the fact that the version of PWSSD adopted for the purposes of this dissertation does not incorporate the latest research on the endogenous respiration rates of the poly accumulating organisms (PAOs) (Vogts and Ekama, 2015).

In conclusion, several output variables were compared across all process units, with the Author's PWM and PWSSD almost identical in output results except for the aerobic digester. The output variables of the BioWin and UCTPHO model did differ slightly for some variables when compared to the Author's PWM and PWSSD,

attributed to the fact that these models use dynamic kinetic equations under constant flow and load conditions for a steady-state simulation, and this generates different results than the less complex steady-state models included in the Author's PWM and PWSSD model.

7. DEVELOPMENT OF DYNAMIC-STATE MODELS

The case study WWTW was analysed using two dynamic-state models developed in the following modelling platforms:

- BioWin 5.0 developed by EnviroSim Associates Ltd. BioWin incorporates all process unit modules required to replicate the case study WWTW, and the case study WWTW has been simulated in a single BioWin model to represent the entire plant (Old Lane, New Lane and Combined Sludge Lane) as previously illustrated in **Figure 6-3**
- UCTPHO dynamic-state design developed by the University of Cape Town (2001). The case study WWTW has been simulated in two models to represent the bioreactors only of the case study WWTW as follows:
 - Model One: A dedicated model for the Old Lane UCT bioreactor only
 - Model Two: A dedicated model for the New Lane Bardenpho bioreactor only.

A background description of the above modelling platforms is provided under **Section 6.1**.

This Chapter will discuss the development of the dynamic-state models for the case study WWTW as follows:

- Document design considerations for the dynamic-state design which are discussed in **Section 7.1** below.
- **Section 7.2** discusses the simulation of the models and a comparison of the dynamic-state models in terms of output and results. The output results of the dynamic-state models are also compared to the steady-state design, in particular by comparing it with the output results of the Author's Plant Wide Model (PWM) as presented under **Section 6.3** to establish differences between the steady-state design and dynamic-state design. The comparison of the steady-state and dynamic-state results was added as an ancillary aspect to this section of the report to showcase the extent of expected variations in results and thereby highlight the extent to which the steady-state models are limited in the prediction of system performance variables for dynamic flow and loading. The description of how this comparative study was performed and the expected outputs is given in Section 7.2 below.
- **Section 7.3** presents the findings of the dynamic-state models for the case study WWTW.

7.1 General considerations for the development of the dynamic-state models

The development of the two dynamic-state models followed the same step-wise approach as the steady-state models previously discussed under **Section 6.2**. The following aspects are specific to the development of the dynamic-state models:

1. The models were firstly structured to replicate the configuration of the case study WWTW as previously presented in **Table 6-2**

2. The BioWin and UCTPHO models developed under the steady-steady design were used as a basis for the dynamic-state design, and included the same wastewater fractions, process design assumptions and process unit assumptions as discussed in **Section 6.2.4**
3. All models were inputted with the same diurnal flow and load patterns as presented in **Sections 4.4 and 5.2** respectively. The diurnal flow and load patterns (COD, TKN, TP, TSS, VSS and ISS) are graphically represented in **Annexure A**. The following is noted:
 - BioWin was modelled for a 24-hour diurnal flow and load pattern based on hourly intervals
 - UCTPHO was modelled for a 24-hour diurnal flow and load pattern based on two-hourly intervals as the UCTPHO model only allows a maximum of a 24-hour diurnal flow and load pattern based on two-hourly intervals (i.e., does not allow a shorter time interval)
 - The average flow of the 24-hour diurnal flow pattern for the two lanes is 17.25 Ml/day for the Old Lane and 43.5 Ml/day for the New Lane. The estimation of these flows was previously discussed under **Section 6.2.1**, and is defined as the maximum ADWF that the Old Lane and New Lane can accommodate which was estimated using the Author's PWM and PWSSD under steady-state conditions
 - The underflow concentration of the PSTs in the models was fixed to 4% TSS as discussed in **Section 4**. The case study plant was operated in the past such that the underflow concentration was 4.29% TSS in 2013, 4.52% TSS in 2014 and 3.84% TSS in 2015
4. As previously discussed in **Section 6.2.1**, the sludge age was selected to best match the actual on-site operational sludge ages as follows:
 - Old Lane: The Old Lane of the case study WWTW is operated on-site at a 14-day sludge age. A design sludge age of 14 days was selected for the purposes of steady-state and dynamic-state modelling which matches the actual operation sludge age
 - New Lane: The New Lane of the case study WWTW is operated on-site at an 18-day sludge age. A design sludge age of 18 days was selected for the purposes of steady-state and dynamic-state modelling which matches the actual operation sludge age
5. This dissertation did not consider the hydraulic capacity of interconnecting pipework and channels between process units of the plant, which could be the limiting constraint in terms of the overall capacity of the plant
6. This dissertation also assumes that the mechanical equipment is not a limiting factor in terms of the overall capacity of the plant. In the analysis presented further in this section, it was found that the following mechanical equipment will limit the process capacity with respect to meeting the effluent quality discharge standards which are also discussed under **Section 9.2**:
 - Mechanical aeration system for the aerobic bioreactor and aerobic digester
 - Recycle pumps (i.e., RAS, a-recycle and r-recycle).

7.2 Model Results and Differences

This section aims to summarise the output results of the two dynamic-state models for both the Old Lane (ADWF of 17.25 Ml/day), the New Lane (ADWF of 43.50 Ml/day) and the Combined Sludge Lane. This section

will compare the models in terms of their output results and establish the reasons for the difference in significant model output where this occurs. The output results of the dynamic-state models will also be compared to the steady-state design, by comparing it with the output results of the Author's PWM to establish differences between the steady-state design and dynamic-state design. Due to the extensiveness of the two dynamic-state models, electronic versions of the models have been included in **Annexure J** of this dissertation. The reader is also referred to **Annexure J** should they wish to view any additional input and output information related to the models.

This section will summarise the output results of the two dynamic-state models in the following manner:

- For each major process unit, two tables are provided for convenience
- The first table (green) provides a summary of the output results as extracted from each model. The output results from BioWin and UCTPHO are in the form of graphs which represents the change in a specific variable over the diurnal period in response to changes in flow and load. An example is illustrated in **Figure 7-1** below, displaying the change in oxygen utilisation rate (OUR) of the Old Lane's UCT bioreactor. Two types of output data were extracted from the output graphs, namely:
 - An average value which represents the average over the 24-hour diurnal pattern
 - A maximum value which represents the maximum value over the 24-hour diurnal pattern
 - It is expected that the output results from the steady-state models should fall between the average value and maximum value of the dynamic-state models
- The second table (red) provides a weighting comparison of the model results, where the value in each cell is "the percentage difference between the specific variable of the model being evaluated and the Author's PWM (steady-state design)". Any major discrepancies (**a percentage variation of 25%**) have been highlighted in a blue font, and the total count of variables out of range has been totalled at the bottom of the table. A percentage variation of 15% was selected for the steady-state models discussed under **Section 6.3**, however 25% was selected for the comparison of the results for the dynamic-state models as the output results of the two dynamic models would include both the average and maximum values over the 24-hour diurnal pattern to illustrate this variation under dynamic flow and load conditions. The maximum value would be substantially higher than the average value and a percentage variation of 25% would sufficiently highlight any major discrepancies between the model results, specifically when compared to the maximum output values of the dynamic models. The following scenarios will arise:
 - A percentage value of 100% implies that the model being evaluated has the "**same**" output value as the Author's PWM (steady-state design)
 - A percentage value less than 100% implies that the model being evaluated has a "**lower**" output value than the Author's PWM (steady-state design), and the lower the percentage the bigger the variation. A percentage value of less than 75% has been highlighted in a blue font
 - A percentage value greater than 100% implies that the model being evaluated has a "**higher**" output value than the Author's PWM (steady-state design), and the higher the percentage the bigger the variation. A percentage value of more than 125% has been highlighted in blue font.

- Where a cell is inputted with “Not prov.” (i.e., not provided), this implies that this information is not calculated or not readily available in the applicable model.

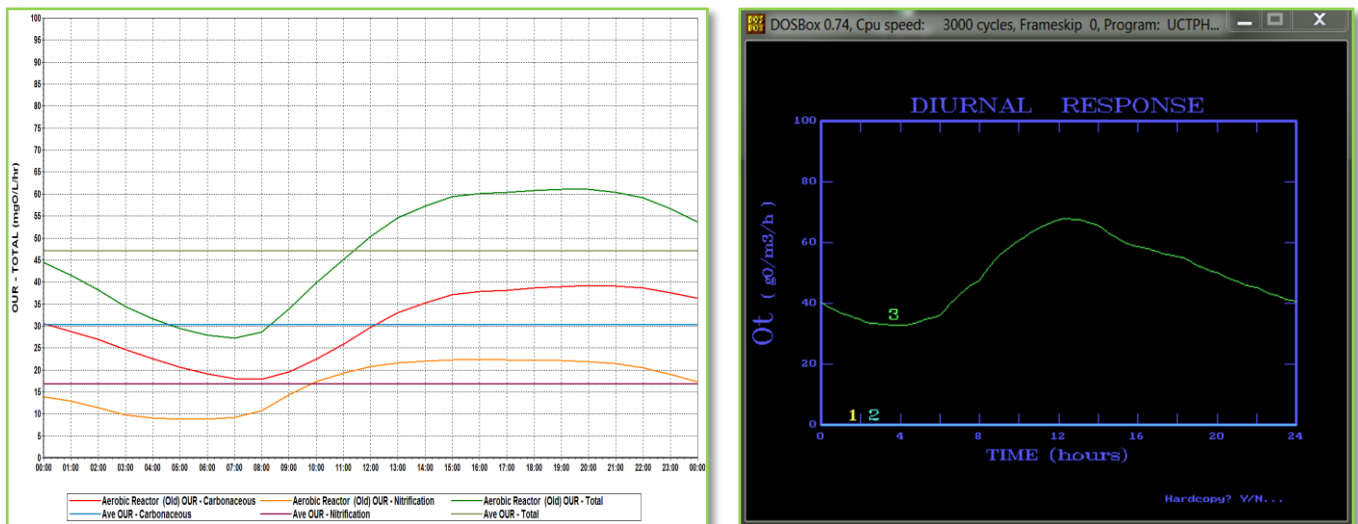


Figure 7-1 : Format of output results for BioWin (left) and UCTPHO (right)

7.2.1 Old Lane UCT System

Table 7-1 below provides a summary of the model output results for the PSTs based on overflow rates of 1.2 m/hr at ADWF and 2.4 m/hr at PDWF and PWWF:

Parameter	Unit	Author's PWM	BioWin – Ave (Dynamic-State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
Total Area Required (ADWF)	m ²	599	Not prov.	Not prov.
Total Area Required (PDWF)	m ²	524	Not prov.	Not prov.
Total Area Required (PWWF)	m ²	749	749	749
Weir Loading at PDWF	m ³ /m.hr	9.1	Not prov.	Not prov.
Weir Loading at PWWF	m ³ /m.hr	13.0	Not prov.	Not prov.
Typical concentration of Primary Sludge	mg/l	40140	36200	40200

Table 7-1 : PSTs (Old Lane UCT System) – Summary of model results

Table 7-2 below provides a weighting comparison of the model output results for the PSTs, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM (steady-state design):

Parameter	Unit	Author's PWM	BioWin – Ave (Dynamic-State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
Total Area Required (ADWF)	m ²	100.0%	Not prov.	Not prov.
Total Area Required (PDWF)	m ²	100.0%	Not prov.	Not prov.
Total Area Required (PWWF)	m ²	100.0%	100.0%	100.0%
Weir Loading at PDWF	m ³ /m.hr	100.0%	Not prov.	Not prov.
Weir Loading at PWWF	m ³ /m.hr	100.0%	Not prov.	Not prov.
Typical concentration of Primary Sludge	mg/l	100.0%	90.2%	100.1%
Total Count out of range (Total parameters evaluated = 6)		0	0	0

Table 7-2 : PSTs (Old Lane UCT System) – Weighting comparison of model results

From the table above, the output results of the steady-state design (Author's PWM) are similar to the maximum value of the BioWin dynamic-state simulation.

Table 7-3 below provides a summary of the model output results for the reactor (UCT process configuration) at a 14-day sludge age. It is noted that the volumes provided in **Table 7-3** below for the BioWin and UCTPHO models are inputted by the user based on the existing case study volumes as these are input parameters to these models. As previously discussed in **Section 6.1**, these two modelling platforms do not predict the UCT bioreactor volumes which is the case for the Author's PWM and PWSSD models.

Table 7-4 provides a weighting comparison of the model output results for the reactor (UCT process configuration), comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM (steady-state design).

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)		UCTPHO – Ave (Dynamic-State)		UCTPHO – Max (Dynamic-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	1655	1655	1640	1640	1640	1640	1640	1640	1640	1640
Volume of Anoxic Reactor	V _{Anoxic}	m ³	1110	1110	1100	1100	1100	1100	1100	1100	1100	1100
Volume of Aerobic Reactor	V _{aerobic}	m ³	7076	7076	7100	7100	7100	7100	7100	7100	7100	7100
Volume of Reactor	V _{Total}	m ³	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840
s-recycle ratio (dry weather flow)	s	-	1:1	1:1	1:1	1:1	1:1	1:1	1:1	1:1	1:1	1:1
r-recycle ratio	r	-	1:1	1:1	1:1	1:1	1:1	1:1	1:1	1:1	1:1	1:1
a-recycle ratio	a	-	4:1	4:1	4:1	4:1	4:1	4:1	4:1	4:1	4:1	4:1
Sludge Waste Flow	Q _w	MI/day	0.649	0.619	0.649	0.619	0.649	0.619	0.649	0.619	0.649	0.619
Denitrification Potential of Primary Anoxic Reactor	DP ₁	(mgNO ₃ -N)/l	21.63	29.74	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.
VSS in Reactor	MX _v	kgVSS	33104	31179	28420	26918	30170	28423	31131	29664	31131	29664
TSS in Reactor	MX _T	kgTSS	45064	42939	41328	40836	44280	41328	Not prov.	Not prov.	Not prov.	Not prov.
Active fraction of Sludge w.r.t VSS	f _{av}	-	0.61	0.57	0.55	0.50	0.61	0.55	Not prov.	Not prov.	Not prov.	Not prov.
Active fraction of Sludge w.r.t TSS	f _{at}	-	0.45	0.42	0.47	0.43	0.52	0.47	Not prov.	Not prov.	Not prov.	Not prov.
Total Average OUR	OUR _{Average}	mgO ₂ /l.hr	55.74	55.06	40.00	42.50	55.00	63.00	59.64	62.67	73.731	77.803
Effluent COD	S _{te}	mgCOD/L	44.000	44.000	44.000	44.000	48.000	48.500	47.000	50.000	48.000	51.000
Effluent Free and Saline Ammonia (FSA)	N _{ae}	mgN/L	0.592	0.418	1.500	1.000	4.000	1.500	0.607	0.302	1.516	1.007
Unbiodegradable Soluble Organic Nitrogen	N _{ousi}	mgN/L	1.800	1.800	3.000	2.000	3.000	2.000	1.800	1.800	1.800	1.800

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)		UCTPHO – Ave (Dynamic-State)		UCTPHO – Max (Dynamic-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Effluent TKN	N _{te}	mgN/L	2.392	2.218	4.500	3.000	7.000	3.500	2.399	2.166	2.822	2.482
Effluent Nitrate	N _{ne}	mgN/L	33.191	26.068	15.000	15.000	18.000	18.000	20.746	19.174	29.044	26.548
Total Effluent Nitrogen	TotN _{eff}	mgN/l	35.583	28.286	19.500	18.000	25.000	21.500	24.591	22.288	33.033	29.426
Effluent P (OrthoP + P _{ouse})	P _{te}	mgP/l	0.300	0.300	1.250	1.250	1.450	1.500	0.301	0.301	0.301	0.301
Effluent P (Organic P)	P _{ouse}	mgP/l	0.300	0.300	0.300	0.250	0.250	0.250	0.301	0.301	0.301	0.301
Effluent Ortho P	P _{se}	mgP/L	0.000	0.000	0.950	1.000	1.200	1.250	0.000	0.000	0.000	0.000
Alkalinity of effluent	Alk	mg/l as CaCO3	47	69	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.

Table 7-3 : Reactor (Old Lane UCT System) – Summary of model results

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)		UCTPHO – Ave (Dynamic-State)		UCTPHO – Max (Dynamic-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	100.0%	100.0%	99.1%	99.1%	99.1%	99.1%	99.1%	99.1%	99.1%	99.1%
Volume of Anoxic Reactor	V _{Anoxic}	m ³	100.0%	100.0%	99.1%	99.1%	99.1%	99.1%	99.1%	99.1%	99.1%	99.1%
Volume of Aerobic Reactor	V _{aerobic}	m ³	100.0%	100.0%	100.3%	100.3%	100.3%	100.3%	100.3%	100.3%	100.3%	100.3%
Volume of Reactor	V _{Total}	m ³	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Sludge Waste Flow	Q _w	MI/day	100.0%	100.0%	100.0%	100.1%	100.0%	100.1%	100.0%	100.1%	100.0%	100.1%
Denitrification Potential of Primary Anoxic Reactor	DP ₁	(mgNO ₃ -N)/l	100.0%	100.0%	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.
VSS in Reactor	MX _v	kgVSS	100.0%	100.0%	85.8%	86.3%	91.1%	91.2%	94.0%	95.1%	94.0%	95.1%

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)		UCTPHO – Ave (Dynamic-State)		UCTPHO – Max (Dynamic-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
TSS in Reactor	MX _T	kgTSS	100.0%	100.0%	91.7%	95.1%	98.3%	96.2%	Not prov.	Not prov.	Not prov.	Not prov.
Active fraction of Sludge w.r.t VSS	f _{av}		100.0%	100.0%	89.6%	87.8%	98.6%	96.6%	Not prov.	Not prov.	Not prov.	Not prov.
Active fraction of Sludge w.r.t TSS	f _{at}		100.0%	100.0%	104.3%	103.4%	114.7%	113.7%	Not prov.	Not prov.	Not prov.	Not prov.
Total Average OUR	OUR Average	mgO ₂ /l.hr	100.0%	100.0%	71.8%	77.2%	98.7%	114.4%	107.0%	113.8%	132.3%	141.3%
Effluent COD	S _{te}	mgCOD/L	100.0%	100.0%	100.0%	100.0%	109.1%	110.2%	106.8%	113.6%	109.1%	115.9%
Effluent Free and Saline Ammonia (FSA)	N _{ae}	mgN/L	100.0%	100.0%	253.5%	239.4%	675.9%	359.1%	102.5%	72.3%	256.2%	241.0%
Unbiodegradable Soluble Organic Nitrogen	N _{ousi}	mgN/L	100.0%	100.0%	166.7%	111.1%	166.7%	111.1%	100.0%	100.0%	100.0%	100.0%
Effluent TKN	N _{te}	mgN/L	100.0%	100.0%	188.1%	135.3%	292.7%	157.8%	100.3%	97.7%	118.0%	111.9%
Effluent Nitrate	N _{ne}	mgN/L	100.0%	100.0%	45.2%	57.5%	54.2%	69.0%	62.5%	73.6%	87.5%	101.8%
Total Effluent Nitrogen	TotN _{eff}	mgN/l	100.0%	100.0%	54.8%	63.6%	70.3%	76.0%	69.1%	78.8%	92.8%	104.0%
Effluent P (OrthoP + P _{ouse})	P _{te}	mgP/l	100.0%	100.0%	316.7%	333.3%	400.0%	416.7%	100.0%	100.0%	100.0%	100.0%
Effluent P (Organic P)	P _{ouse}	mgP/l	100.0%	100.0%	100.0%	83.3%	83.3%	83.3%	100.0%	100.0%	100.0%	100.0%
Effluent Ortho P	P _{se}	mgP/L	-	-	-	-	-	-	-	-	-	-
Alkalinity of effluent	Alk	mg/l as CaCO ₃	100.0%	100.0%	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.
Total Count out of range (Total parameters evaluated = 22)		0	0	0	7	5	6	4	2	1	2	2

Table 7-4 : Reactor (Old Lane UCT System) – Weighting comparison of model results

The output results of the two dynamic models and the Author's PWM (steady-state design) are similar except for the following:

- Oxygen Utilisation Rate: BioWin predicts a lower OUR value (greater than 25% difference) for both the average and maximum scenarios when compared to UCTPHO. The Author's PWM (steady-state design) predicts lower values than UCTPHO (14% difference for the average scenario and greater than 25% difference for the maximum scenario), but when compared to BioWin, the Author's PWM (steady-state design) lies between the average and maximum BioWin values.
- Effluent free and saline ammonia (FSA): The BioWin model predicts higher FSA values (greater than 25% difference) for both the average and maximum scenarios when compared to UCTPHO, whereas the UCTPHO average scenario ties up with the Author's PWM (steady-state design). In the BioWin model, the concentration of ANOs in the reactor significantly impacts the kinetics of nitrate formation, while the Author's PWM assumes that the biomass present is already in substantial quantities, which results in a much more rapid conversion of FSA to nitrates. Due to the lower rate of nitrifier mass formation at dynamic states in the BioWin model, there was a difference in the effluent FSA values when compared to the Author's PWM.
- Unbiodegradable Soluble Organic Nitrogen: BioWin predicts higher values (greater than 50% difference at lower wastewater temperature and less than 15% difference at higher wastewater temperature) than UCTPHO for both the average and maximum scenarios, whereas the Author's PWM (steady-state design) ties up with UCTPHO.
- Effluent nitrate: BioWin predicts lower values (greater than 25% difference) for both the average and maximum scenarios when compared to UCTPHO and the Author's PWM. This is due to the lower rate of nitrifier mass formation adopted by BioWin during the dynamic simulation, resulting in the higher FSA in the effluent as discussed above. UCTPHO correlates with the Author's PWM specifically for the maximum scenario.
- Total effluent N: BioWin will predict values slightly out of range (lower with a difference greater than 25%) to the Author's PWM and UCTPHO due to differences in FSA, unbiodegradable soluble organic nitrogen and effluent nitrate as discussed above, whereas the UCTPHO model ties up with the Author's PWM for the maximum scenario.
- Effluent total P: BioWin predicts the presence of ortho-P (less than 1.250 mgP/l for minimum and maximum wastewater temperatures) in the effluent for both the average and maximum scenarios, resulting in a higher total P in the effluent. The other models predict a zero ortho-P in the effluent where the UCTPHO and the Author's PWM predict the same value for the maximum and average scenario. BioWin adopts two different maximum specific growth rates for the PAOs, namely a higher growth rate constant under phosphorous rich conditions which results in a higher uptake of phosphorous, and a lower growth rate constant under phosphorous limited conditions, where phosphorous uptake is limited. This lower growth rate constant has a different stoichiometry (no polyphosphate storage) and is the reason for BioWin producing a non-zero ortho-P in the effluent. As previously discussed under Section 6.4.3, the PAO growth in the BioWin model is less. With a lower PAO population, there is less potential for aerobic polyphosphate uptake, resulting in higher effluent Ortho-P concentrations.

Apart from the above output variables, the output results of the two dynamic models are similar (less than 25% difference) for both the average and maximum scenarios. The Author's PWM predicts slightly higher values than the BioWin maximum value scenario except for the ammonia, unbiodegradable soluble organic nitrogen and ortho-P variables, whereas with UCTPHO, the Author's PWM predicts somewhere between the average and maximum scenarios. BioWin like UCTPHO, use dynamic kinetic equations under dynamic flow and load conditions, and this will produce different results than the less complex steady-state models included in the Author's PWM which is based on constant flow and load conditions. Apart from the discrepancies in the output variables discussed above, the output results of the two dynamic models are very similar, and not far off range when compared to the steady-state model (Author's PWM).

Table 7-5 below provides a summary of the model output results for the SSTs:

Parameter	Abbr.	Unit	Author's PWM	BioWin – Ave (Dynamic-State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
Area (including 80% Flux rating correction factor)	A	m ²	2089	2089	2089
Recycle Ratio i.t.o ADWF (Dry weather flow conditions)	R _{T ADWF & PDWF}	-	1.00	1.00	1.00
Recycle Ratio i.t.o ADWF (Wet weather flow conditions)	R _{T PWWF}	-	2.24	Not prov.	Not prov.
ADWF Underflow Concentration	X _{T Underflow}	mgTSS/l	9993	8300	9700
PDWF Underflow Concentration	X _{T Underflow}	mgTSS/l	13738	Not prov.	Not prov.
PWWF Underflow Concentration	X _{T Underflow}	mgTSS/l	10590	Not prov.	Not prov.

Table 7-5 : SSTs (Old Lane UCT System) – Summary of model results

Table 7-6 provides a weighting comparison of the model output results for the SSTs, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM (steady-state design):

Parameter	Abbr.	Unit	Author's PWM	BioWin – Ave (Dynamic-State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
Area (including 80% Flux rating correction factor)	A	m ²	100.0%	100.0%	100.0%
Recycle Ratio i.t.o ADWF (Dry weather flow conditions)	R _{r ADWF & PDWF}	-	100.0%	99.9%	99.9%
Recycle Ratio i.t.o ADWF (Wet weather flow conditions)	R _{r PWWF}	-	100.0%	Not prov.	Not prov.
ADWF Underflow Concentration	X _{T Underflow}	mgTSS/l	100.0%	83.1%	97.1%
PDWF Underflow Concentration	X _{T Underflow}	mgTSS/l	100.0%	Not prov.	Not prov.
PWWF Underflow Concentration	X _{T Underflow}	mgTSS/l	100.0%	Not prov.	Not prov.
Total Count out of range (Total parameters evaluated = 6)			0	0	0

Table 7-6 : SSTs (Old Lane UCT System) – Weighting comparison of model results

From the table above, the output results of the steady-state design (Author's PWM) are more in line with the maximum value of the BioWin dynamic-state simulation as was the case with the PSTs.

7.2.2 New Lane 5-stage Bardenpho System

Table 7-7 below provides a summary of the model output results for the PSTs based on overflow rates of 1.2 m/hr at ADWF and 2.4 m/hr at PDWF and PWWF:

Parameter	Unit	Author's PWM	BioWin – Ave (Dynamic-State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
Total Area Required (ADWF)	m ²	1510	Not prov.	Not prov.
Total Area Required (PDWF)	m ²	1322	Not prov.	Not prov.
Total Area Required (PWWF)	m ²	1888	1888	1888
Weir Loading at PDWF	m ³ /m.hr	11.6	Not prov.	Not prov.
Weir Loading at PWWF	m ³ /m.hr	16.6	Not prov.	Not prov.
Typical concentration of Primary Sludge	mg/l	40180	35750	39500

Table 7-7 : PSTs (New Lane 5-stage Bardenpho System) – Summary of model results

Table 7-8 provides a weighting comparison of the model output results for the PSTs, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM (steady-state design):

Parameter	Unit	Author's PWM	BioWin – Ave (Dynamic-State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
Total Area Required (ADWF)	m ²	100.00%	Not prov.	Not prov.
Total Area Required (PDWF)	m ²	100.00%	Not prov.	Not prov.
Total Area Required (PWWF)	m ²	100.00%	100.00%	100.00%
Weir Loading at PDWF	m ³ /m.hr	100.00%	Not prov.	Not prov.
Weir Loading at PWWF	m ³ /m.hr	100.00%	Not prov.	Not prov.
Typical concentration of Primary Sludge	mg/l	100.00%	88.97%	98.31%
Total Count out of range (Total parameters evaluated = 6)		0	0	0

Table 7-8 : PSTs (New Lane 5-stage Bardenpho System) – Weighting comparison of model results

From the table above, the output results of the steady-state design (Author's PWM) are similar to the maximum value of the BioWin dynamic-state simulation.

Table 7-9 below provides a summary of the model output results for the reactor (5-Stage Bardenpho process configuration) at an 18-day sludge age. It is noted that the volumes provided in **Table 7-9** below for the BioWin and UCTPHO models are inputted by the user based on the existing case study volumes as these are input parameters to these models. As previously discussed in **Section 6.1**, these two modelling platforms do not predict the Bardenpho bioreactor volumes which is the case for the Author's PWM and PWSSD models.

Table 7-10 provides a weighting comparison of the model output results for the reactor (5-Stage Bardenpho process configuration), comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM (steady-state design).

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)		UCTPHO – Ave (Dynamic-State)		UCTPHO – Max (Dynamic-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	5407	5407	5407	5407	5407	5407	5407	5407	5407	5407
Volume of Primary Anoxic Reactor	V _{anoxic} (Primary)	m ³	7160	7160	7160	7160	7160	7160	7160	7160	7160	7160
Volume of Secondary Anoxic Reactor	V _{anoxic} (Secondary)	m ³	5107	5107	5107	5107	5107	5107	5107	5107	5107	5107
Volume of Aerobic Reactor	V _{aerobic}	m ³	16774	16774	16774	16774	16774	16774	16774	16774	16774	16774
Volume of De-aeration Reactor	V _{de-aeration}	m ³	1852	1852	1852	1852	1852	1852	1852	1852	1852	1852
Volume of Reactor	V _{Total}	m ³	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300
s-recycle ratio (dry weather flow)	s	-	0.9:1	0.9:1	0.9:1	0.9:1	0.9:1	0.9:1	0.9:1	0.9:1	0.9:1	0.9:1
a-recycle ratio	a	-	4:1	4:1	4:1	4:1	4:1	4:1	4:1	4:1	4:1	4:1
Sludge Waste Flow	Q _w	ML/day	2.003	1.968	2.003	1.968	2.003	1.968	2.003	1.969	2.003	1.969
Denitrification Potential of Primary Anoxic Reactor	DP ₁	(mgNO ₃ -N)/l	37.78	52.70	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.
VSS in Reactor	MX _v	kgVSS	109023	106638	95311	97126	97126	98941	110865	109024	112683	110841
TSS in Reactor	MX _T	kgTSS	163350	160571	137940	139755	136125	141570	Not prov.	Not prov.	Not prov.	Not prov.
Active fraction of Sludge w.r.t VSS	f _{av}	-	0.57	0.55	0.53	0.52	0.61	0.60	Not prov.	Not prov.	Not prov.	Not prov.
Active fraction of Sludge w.r.t TSS	f _{at}	-	0.38	0.36	0.37	0.35	0.43	0.40	Not prov.	Not prov.	Not prov.	Not prov.
Total Average OUR	OUR _{Average}	mgO ₂ /l.hr	58.57	57.20	36.00	40.00	49.00	55.00	48.69	52.45	62.76	68.18
Effluent COD	S _{te}	mgCOD/L	44.000	44.000	51.000	52.000	56.000	57.500	48.848	49.788	53.545	54.485

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)		UCTPHO – Ave (Dynamic-State)		UCTPHO – Max (Dynamic-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Effluent Free and Saline Ammonia (FSA)	N _{ae}	mgN/L	0.607	0.432	2.500	0.750	5.000	0.750	0.502	0.301	2.258	0.501
Unbiodegradable Soluble Organic Nitrogen	N _{ousi}	mgN/L	2.033	2.033	1.000	4.250	3.500	4.350	2.033	2.033	2.033	2.033
Effluent TKN	N _{te}	mgN/L	2.640	2.466	3.500	5.000	8.500	5.100	2.586	2.400	3.491	2.500
Effluent Nitrate	N _{ne}	mgN/L	16.758	8.847	3.750	6.000	4.000	8.000	5.831	2.001	10.933	3.752
Total Effluent Nitrogen	TotN _{eff}	mgN/l	19.398	11.313	7.250	11.000	12.500	13.100	11.122	6.031	17.294	7.539
Effluent P (OrthoP + P _{ouse})	P _{te}	mgP/l	0.301	0.301	1.050	1.200	1.750	2.100	0.635	0.669	1.838	1.838
Effluent P (Organic P)	P _{ouse}	mgP/l	0.301	0.301	0.550	0.550	0.550	0.600	0.301	0.301	0.301	0.301
Effluent Ortho P	P _{se}	mgP/L	0.000	0.000	0.500	0.650	1.200	1.500	0.000	0.000	0.000	0.000
Alkalinity of effluent	Alk	mg/l as CaCO3	151	156	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.

Table 7-9 : Reactor (New Lane 5-stage Bardenpho System) – Summary of model results

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)		UCTPHO – Ave (Dynamic-State)		UCTPHO – Max (Dynamic-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Volume of Primary Anoxic Reactor	V _{anoxic} (Primary)	m ³	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Volume of Secondary Anoxic Reactor	V _{anoxic} (Secondary)	m ³	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Volume of Aerobic Reactor	V _{aerobic}	m ³	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Volume of De-aeration Reactor	V _{de-aeration}	m ³	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Volume of Reactor	V _{Total}	m ³	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Sludge Waste Flow	Q _w	MI/day	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)		UCTPHO – Ave (Dynamic-State)		UCTPHO – Max (Dynamic-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Denitrification Potential of Primary Anoxic Reactor	DP ₁	(mgNO ₃ -N)/l	100.0%	100.0%	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.
VSS in Reactor	MX _v	kgVSS	100.0%	100.0%	87.4%	91.1%	89.1%	92.8%	101.7%	102.2%	103.4%	103.9%
TSS in Reactor	MX _T	kgTSS	100.0%	100.0%	84.4%	87.0%	83.3%	88.2%	Not prov.	Not prov.	Not prov.	Not prov.
Active fraction of Sludge w.r.t VSS	f _{av}	-	100.0%	100.0%	93.4%	95.0%	107.4%	109.2%	Not prov.	Not prov.	Not prov.	Not prov.
Active fraction of Sludge w.r.t TSS	f _{at}	-	100.0%	100.0%	97.7%	96.2%	112.3%	110.7%	Not prov.	Not prov.	Not prov.	Not prov.
Total Average OUR	OUR Average	mgO ₂ /l.hr	100.0%	100.0%	61.5%	69.9%	83.7%	96.2%	83.1%	91.7%	107.1%	119.2%
Effluent COD	S _{te}	mgCOD/L	100.0%	100.0%	115.9%	118.2%	127.3%	130.7%	111.0%	113.2%	121.7%	123.8%
Effluent Free and Saline Ammonia (FSA)	N _{ae}	mgN/L	100.0%	100.0%	412.1%	173.5%	824.1%	173.5%	82.7%	69.5%	372.1%	115.9%
Unbiodegradable Soluble Organic Nitrogen	N _{ousi}	mgN/L	100.0%	100.0%	49.2%	209.0%	172.1%	213.9%	100.0%	100.0%	100.0%	100.0%
Effluent TKN	N _{te}	mgN/L	100.0%	100.0%	132.6%	202.8%	322.0%	206.9%	98.0%	97.3%	132.2%	101.4%
Effluent Nitrate	N _{ne}	mgN/L	100.0%	100.0%	22.4%	67.8%	23.9%	90.4%	34.8%	22.6%	65.2%	42.4%
Total Effluent Nitrogen	TotN _{eff}	mgN/l	100.0%	100.0%	37.4%	97.2%	64.4%	115.8%	57.3%	53.3%	89.2%	66.6%
Effluent P (OrthoP + P _{ouse})	P _{te}	mgP/l	100.0%	100.0%	349.0%	398.9%	581.7%	698.1%	211.1%	222.2%	611.1%	611.1%
Effluent P (Organic P)	P _{ouse}	mgP/l	100.0%	100.0%	182.8%	182.8%	182.8%	199.4%	100.0%	100.0%	100.0%	100.0%
Effluent Ortho P	P _{se}	mgP/L	-	-	-	-	-	-	-	-	-	-
Alkalinity of effluent	Alk	mg/l as CaCO ₃	100.0%	100.0%	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.	Not prov.
Total Count out of range (Total parameters evaluated = 24)		0	0	0	8	7	8	6	3	4	4	3

Table 7-10 : Reactor (New Lane 5-stage Bardenpho System) – Weighting comparison of model results

The output results of the two dynamic models are very similar except for the following:

- Oxygen Utilisation Rate: BioWin predicts a lower OUR value (less than 25% difference) for both the average and maximum scenarios when compared to UCTPHO. The Author's PWM (steady-state design) predicts higher values than BioWin (greater than 25% for average BioWin scenario and less than 25% for maximum BioWin scenario), but when compared to UCTPHO, the Author's PWM (steady-state design) lies between the UCTPHO average and maximum scenarios.
- Effluent free and saline ammonia (FSA): The BioWin model predicts higher FSA values (greater than 25% difference) for both the average and maximum scenarios when compared to UCTPHO, whereas the Author's PWM (steady-state design) lies between the UCTPHO average and maximum scenarios. As previously mentioned for the Old Lane, BioWin assumes a lower initial nitrifier biomass formation than the other models, resulting in the difference in FSA values.
- Unbiodegradable Soluble Organic Nitrogen: BioWin predicts higher values (greater than 25% difference) than UCTPHO for both the average and maximum scenarios, whereas the Author's PWM (steady-state design) ties up with UCTPHO
- Effluent nitrate: BioWin predicts lower values (greater than 25% difference) than UCTPHO for both the average and maximum scenarios at minimum temperature, but at maximum temperature, BioWin predicts higher values (greater than 25% difference) than UCTPHO for the two scenarios. The Author's PWM (steady-state) predicts higher values (greater than 25% difference) than the maximum scenarios for both the BioWin and UCTPHO models
- Total effluent N: BioWin and UCTPHO predict lower values to the Author's PWM due to differences in FSA and effluent nitrate as discussed above, with the exception of the BioWin maximum scenario at high wastewater temperature which predicts a higher value (less than 25% difference) than the Author's PWM.
- Effluent total P: BioWin predicts the presence of ortho-P (less than 1.500 mgP/l for minimum and maximum wastewater temperatures) in the effluent for both the average and maximum scenarios, resulting in a higher total P in the effluent. The other models predict a zero ortho-P in the effluent where the UCTPHO and the Author's PWM predict the same value for the maximum and average scenario. This can be explained by the same reason as previously discussed for the effluent total P for the Old Lane.
- Apart from the above output variables, the output results of the two dynamic models are similar (less than 25% difference) for both the average and maximum scenarios. The Author's PWM predicts values between the average and maximum scenarios of both the BioWin and UCTPHO models, apart from the ammonia, nitrate and ortho-P values. BioWin like UCTPHO, use dynamic kinetic equations under dynamic flow and load conditions, and this will produce different results than the less complex steady-state models included in the Author's PWM which is based on constant flow and load conditions. Apart from the discrepancies in the output variables discussed above (ammonia, nitrate and ortho-P values), the output results of the two dynamic models are very similar, and not far off range when compared to the steady-state model.

Table 7-11 below provides a summary of the model output results for the SSTs:

Parameter	Abbr.	Unit	Author's PWM	BioWin – Ave (Dynamic-State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
Area (including 80% Flux rating correction factor)	A	m ²	4361	4361	4361
Recycle Ratio i.t.o ADWF (Dry weather flow conditions)	R _{r ADWF & PDWF}	-	0.87	0.87	0.87
Recycle Ratio i.t.o ADWF (Wet weather flow conditions)	R _{r PWWF}	-	1.84	Not prov.	Not prov.
ADWF Underflow Concentration	X _{T Underflow}	mgTSS/l	9683	7700	9300
PDWF Underflow Concentration	X _{T Underflow}	mgTSS/l	13570	Not prov.	Not prov.
PWWF Underflow Concentration	X _{T Underflow}	mgTSS/l	10603	Not prov.	Not prov.

Table 7-11 : SSTs (New Lane 5-stage Bardenpho System) – Summary of model results

Table 7-12 provides a weighting comparison of the model output results for the SSTs, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM (steady-state design):

Parameter	Abbr.	Unit	Author's PWM	BioWin – Ave (Dynamic-State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
Area (including 80% Flux rating correction factor)	A	m ²	100.00%	100.00%	100.00%
Recycle Ratio i.t.o ADWF (Dry weather flow conditions)	R _{r ADWF & PDWF}	-	100.00%	100.20%	100.20%
Recycle Ratio i.t.o ADWF (Wet weather flow conditions)	R _{r PWWF}	-	100.00%	Not prov.	Not prov.
ADWF Underflow Concentration	X _{T Underflow}	mgTSS/l	100.00%	79.52%	96.05%
PDWF Underflow Concentration	X _{T Underflow}	mgTSS/l	100.00%	Not prov.	Not prov.
PWWF Underflow Concentration	X _{T Underflow}	mgTSS/l	100.00%	Not prov.	Not prov.
Total Count out of range (Total parameters evaluated = 6)		0	0	0	0

Table 7-12 : SSTs (New Lane 5-stage Bardenpho System) – Weighting comparison of model results

From the table above, the output results of the steady-state design (Author's PWM) is more in line with the maximum value of the BioWin dynamic-state simulation as was the case with the PSTs.

7.2.3 Combined Sludge Lane

Table 7-13 below provides a summary of the model output results for the Anaerobic Digester:

Parameter	Abbr.	Unit	Author's PWM	BioWin – Ave (Dynamic-State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
PS inflow to Anaerobic Digester	Q _w	m ³ /day	427	427	427
TSS incoming	TSS _{in}	mgTSS/l	38565	36000	39000
VSS incoming	VSS _{in}	mgVSS/l	34260	31200	34100
COD incoming	S _{te in}	mgCOD/l	59131	50000	56000
TKN incoming	N _{te in}	mgN/l	2485	2050	2400
TP incoming	P _{te in}	mgP/l	293	260	290
Volume	Vol	m ³	5122	5122	5122
TSS digested sludge	TSS out	mgTSS/l	15487	14750	15000
VSS digested sludge	VSS out	mgVSS/l	11182	10000	10100
COD digested sludge	S _{te out}	mgCOD/l	19148	15700	15800
Total N digested sludge	N _{te out}	mgN/l	2300	2175	2200
TP digested sludge	P _{te out}	mgP/l	258	300	325
pH of Digester	pH	-	Not Prov.	7.70	7.70
CH ₄ (Gaseous) By-product	CH ₄	mol/l	0.64	0.67	0.71
CH ₄ (Gaseous) By-product	CH ₄	Nm ³ /day	6559	6886	7276
VSS Destruction	VSS dest.	%	67.4%	67.9%	70.4%

Table 7-13 : Anaerobic Digester (Combined Sludge Lane) – Summary of model results

Table 7-14 provides a weighting comparison of the model output results for the anaerobic digester, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM (steady-state design):

Parameter	Abbr.	Unit	Author's PWM	BioWin – Ave (Dynamic-State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
PS inflow to Anaerobic Digester	Q _w	m ³ /day	100.0%	100.1%	100.1%
TSS incoming	TSS _{in}	mgTSS/l	100.0%	93.3%	101.1%
VSS incoming	VSS _{in}	mgVSS/l	100.0%	91.1%	99.5%
COD incoming	S _{te in}	mgCOD/l	100.0%	84.6%	94.7%
TKN incoming	N _{te in}	mgN/l	100.0%	82.5%	96.6%
TP incoming	P _{te in}	mgP/l	100.0%	88.6%	98.9%
Volume	Vol	m ³	100.0%	100.0%	100.0%
TSS digested sludge	TSS out	mgTSS/l	100.0%	95.2%	96.9%

Parameter	Abbr.	Unit	Author's PWM	BioWin – Ave (Dynamic- State @ 16 °C)	BioWin – Max (Dynamic-State @ 16 °C)
VSS digested sludge	VSS out	mgVSS/l	100.0%	89.4%	90.3%
COD digested sludge	S _{te} out	mgCOD/l	100.0%	82.0%	82.5%
Total N digested sludge	N _{te} out	mgN/l	100.0%	94.6%	95.6%
TP digested sludge	P _{te} out	mgP/l	100.0%	116.3%	126.0%
pH of Digester	pH		Not prov.	N/appl.	N/appl.
CH ₄ (Gaseous) By-product	CH ₄	mol/l	100.0%	105.5%	111.8%
CH ₄ (Gaseous) By-product	CH ₄	Nm ³ /day	100.0%	104.7%	110.9%
VSS Destruction	VSS dest.	%	100.0%	100.9%	104.5%
Total Count out of range (Total parameters evaluated = 15)			0	0	1

Table 7-14 : Anaerobic Digester (Combined Sludge Lane) – Weighting comparison of model results

The output results of the BioWin and Author's PWM (steady-state design) are very similar except for the following:

- Digested sludge COD: The BioWin model predicts a lower value (less than 20% difference) for both the average and maximum scenarios than the Author's PWM (steady-state design)
- Digested sludge total P: The BioWin model predicts a higher value (16.3% difference for the average scenario and 26% difference for the maximum scenario) for both the average and maximum scenarios than the Author's PWM (steady-state design).

From the table above, there are minor differences between the average and maximum scenarios of the BioWin model. The values predicted by the Author's PWM (steady-state design) are more aligned with the maximum BioWin scenario, except for the variables mentioned above. As previously discussed, the BioWin model uses dynamic kinetic equations under dynamic flow and load conditions, and this generates different results than the less complex steady-state models included in the Author's PWM (steady-state design) which is based on constant flow and load conditions.

Table 7-15 below provides a summary of the model output results for the aerobic digester:

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
WAS in	Q _{w in}	m ³ /day	350	326	350	326	350	326
WAS out	Q _{w out}	m ³ /day	350	326	350	326	350	326
Influent TSS	X _{T in}	mgTSS/l	35000	35000	30000	27500	32000	29000

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)	
			16 °C	24 °C	16 °C	24 °C	16 °C	24 °C
Influent VSS	X_{vi}	mgVSS/l	23868	22616	20000	19000	21000	20000
Influent Active fraction of Sludge w.r.t VSS	f_{av}	-	0.578	0.553	0.536	0.514	0.610	0.584
Influent Active fraction of Sludge w.r.t TSS	f_{at}	-	0.394	0.374	0.398	0.373	0.452	0.422
Volume of Aerobic Digester 1	$V_{aerobic\ digester\ 1}$	m ³	2501	2501	2501	2501	2501	2501
Volume of Aerobic Digester 2	$V_{aerobic\ digester\ 2}$	m ³	2501	2501	2501	2501	2501	2501
Volume Total of Aerobic Digesters	$V_{aerobic\ digester\ T}$	m ³	5002	5002	5002	5002	5002	5002
Digested sludge TSS Concentration: Digester 2	X_T	mgTSS/l	31060	30068	23000	21500	24000	22000
Digested sludge VSS Concentration: Digester 2	X_V	mgVSS/l	16821	16239	15000	14900	15500	14900
Digested sludge Active fraction of Sludge w.r.t VSS	f_{av}	-	0.314	0.301	0.291	0.280	0.331	0.318
Digested sludge Active fraction of Sludge w.r.t TSS	f_{at}	-	0.170	0.162	0.172	0.162	0.195	0.183
Digested sludge COD Concentration: Digester 2	S_{te}	gCOD/L	23.966	22.918	21.200	20.150	21.500	20.850
Total Digested Sludge N Concentration: Digester 2	$TotN_{eff}$	gN/l	2.387	2.262	2.500	2.400	2.500	2.500
Digested sludge P Concentration (OrthoP + P _{ouse}): Digester 2	P_{te}	gP/L	1.173	1.101	1.200	1.200	1.200	1.200
Total Oxygen Utilisation Rate: Digester 1	$OUR_{T\ 1}$	mgO ₂ /(l.hr)	45.4	41.0	52.0	52.0	55.0	54.0
Total Oxygen Utilisation Rate: Digester 2	$OUR_{T\ 2}$	mgO ₂ /(l.hr)	22.6	20.5	20.0	17.5	20.5	18.5

Table 7-15 : Aerobic Digester (Combined Sludge Lane) – Summary of model results

Table 7-16 provides a weighting comparison of the model output results for the aerobic digester, comparing the percentage difference between the specific variable of the model being evaluated with the Author's PWM (steady-state design):

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)	
			16	24	16	24	16	24
WAS in	$Q_{w\ in}$	m ³ /day	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
WAS out	$Q_{w\ out}$	m ³ /day	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Influent TSS	$X_{T\ in}$	mgTSS/l	100.0%	100.0%	85.7%	78.6%	91.4%	82.9%

Parameter	Abbr.	Unit	Author's PWM		BioWin – Ave (Dynamic-State)		BioWin – Max (Dynamic-State)	
			16	24	16	24	16	24
Influent VSS	X_{vi}	mgVSS/l	100.0%	100.0%	83.8%	84.0%	88.0%	88.4%
Influent Active fraction of Sludge w.r.t VSS	f_{av}	-	100.0%	100.0%	92.7%	93.0%	105.5%	105.7%
Influent Active fraction of Sludge w.r.t TSS	f_{at}	-	100.0%	100.0%	101.1%	99.5%	114.7%	112.6%
Volume of Aerobic Digester 1	$V_{aerobic}$ digester 1	m ³	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Volume of Aerobic Digester 2	$V_{aerobic}$ digester 2	m ³	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Volume Total of Aerobic Digesters	$V_{aerobic}$ digester T	m ³	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Digested sludge TSS Concentration: Digester 2	X_T	mgTSS/l	100.0%	100.0%	74.0%	71.5%	77.3%	73.2%
Digested sludge VSS Concentration: Digester 2	X_V	mgVSS/l	100.0%	100.0%	89.2%	91.8%	92.1%	91.8%
Digested sludge Active fraction of Sludge w.r.t VSS	f_{av}	-	100.0%	100.0%	92.7%	93.0%	105.5%	105.7%
Digested sludge Active fraction of Sludge w.r.t TSS	f_{at}	-	100.0%	100.0%	101.1%	99.5%	114.7%	112.6%
Digested sludge COD Concentration: Digester 2	S_{te}	gCOD/L	100.0%	100.0%	88.5%	87.9%	89.7%	91.0%
Total Digested Sludge N Concentration: Digester 2	$TotN_{eff}$	gN/l	100.0%	100.0%	104.7%	106.1%	104.7%	110.5%
Digested sludge P Concentration (OrthoP + P _{ouse}): Digester 2	P_{te}	gP/L	100.0%	100.0%	102.3%	109.0%	102.3%	109.0%
Total Oxygen Utilisation Rate: Digester 1	OUR_{T1}	mgO ₂ /(l.hr)	100.0%	100.0%	114.6%	126.8%	121.2%	131.7%
Total Oxygen Utilisation Rate: Digester 2	OUR_{T2}	mgO ₂ /(l.hr)	100.0%	100.0%	88.6%	85.5%	90.8%	90.4%
Total Count out of range (Total parameters evaluated = 18)			0	0	1	2	0	2

Table 7-16 : Aerobic Digester (Combined Sludge Lane) – Summary of model results

The output results of the BioWin and Author's PWM (steady-state design) are very similar except for the following:

- **Influent VSS and TSS:** BioWin predicts a lower value (less than 25% difference) for both the average and maximum scenario when compared to the Author's PWM (steady-state design) for the influent VSS and TSS
- **Digested sludge TSS in 2nd Digester:** BioWin predicts a lower value (less than 30% difference) for both the average and maximum scenario when compared to the Author's PWM (steady-state design)

- Digested sludge COD Concentration: BioWin predicts slightly lower values (less than 12% difference) for both the average and maximum scenario when compared to the Author's PWM (steady-state design)
- Oxygen utilisation rate in 1st Digester and 2nd Digester: BioWin predicts a higher value (difference greater than 25% but less than 32%) in the 1st digester for both the average and maximum scenario when compared to the Author's PWM (steady-state design) but predicts lower values (less than 15% difference) in the 2nd digester when compared to the Author's PWM (steady-state design).

From the table above, there is a minor difference between the average and maximum scenarios of the BioWin model. The values predicted by the Author's PWM (steady-state design) are more aligned with the maximum BioWin scenario, except for the variables mentioned above. The BioWin model use dynamic kinetic equations under dynamic flow and load conditions, and this generates different results than the less complex steady-state models included in the Author's PWM (steady-state design) which is based on constant flow and load conditions.

7.3 Discussion on Findings

The following findings were established during the development of the dynamic-state models discussed above:

7.3.1 Comment on the modelling process

The development of a plant-wide model in UCTPHO was not possible as this programme is limited to the bioreactor only and required separate models for the bioreactor of each lane (i.e., Old Lane and New Lane of the case study plant). A plant-wide model can easily be developed in BioWin, making BioWin the preferred tool for purposes of dynamic modelling, as a single model could replicate the entire case study WWTW.

The development of the dynamic-state models using the BioWin and UCTPHO modelling software required the same level of input and effort as per the steady-state models discussed in **Section 6.4.1**, except for the input of the diurnal flow and load information. In terms of the diurnal flow, UCTPHO allows a maximum of a 24-hour diurnal flow and load pattern based on two-hourly intervals, and BioWin can cater for one-week influent data limited to one-hourly intervals. In terms of program run times, the BioWin dynamic model took a few minutes to run and balance, whereas the UCTPHO dynamic model was extremely long due to it being operated in a DOS application, taking up to 4 hours for each dynamic simulation run.

In terms of model output results, UCTPHO was limited to specific information in a summary output table and output graphs (see **Figure 7-1** above) with limited output variables, and the user is unable to view the calculation procedure. The model output results of the BioWin model are the same as discussed for the steady-state model in **Section 6.4.1**. BioWin does not allow the user to view calculations, and there was specific output data that could not be retrieved (e.g., denitrification potential of the reactor). One of the benefits of modelling with BioWin, the user is alerted to modelling errors and system failures (e.g., low pH in reactor resulting in nitrification problems).

From each dynamic model, an average value and maximum value were used in the comparison analysis, further summarised below.

7.3.2 Comparison of model output results

The modelling results of the two dynamic-state models and the steady-state design (Author's PWM) were compared where differences were noted for major discrepancies (a percentage variation of 25%):

- PSTs and SSTs: The output results of the steady-state design (Author's PWM) were similar to the maximum value scenario of the BioWin dynamic-state model for both the PSTs and SSTs.
- UCT bioreactor (Old Lane): The output results of the models were very similar except for minor differences as follows:
 - Oxygen Utilisation Rate: BioWin predicts a lower OUR value (greater than 25% difference) for both the average and maximum scenarios when compared to UCTPHO. The Author's PWM (steady-state design) predicts lower values than UCTPHO (14% difference for the average scenario and greater than 25% difference for the maximum scenario), but when compared to BioWin, the Author's PWM (steady-state design) lies between the average and maximum BioWin values.
 - Effluent FSA and effluent unbiodegradable soluble organic nitrogen: The BioWin simulation predicts higher values (average and maximum) than the UCTPHO model, whereas the UCTPHO average appears to correlate more with the steady-state design (Author's PWM). With respect to FSA in the BioWin model, the concentration of ANOs in the reactor significantly impacts the kinetics of nitrate formation, while the Author's PWM assumes that the biomass present is already in substantial quantities, which results in a much more rapid conversion of FSA to nitrates. Due to the lower rate of nitrifier mass formation at dynamic states in the BioWin model, there was a difference in the effluent FSA values when compared to the Author's PWM.
 - Effluent nitrate: BioWin predicts lower values (greater than 25% difference) for both the average and maximum scenarios when compared to UCTPHO and the Author's PWM, whereas the Author's PWM (steady-state design) ties up with UCTPHO. The difference in the BioWin simulation is due to the lower rate of nitrifier mass formation adopted by BioWin during the dynamic simulation, resulting in the higher FSA in the effluent as discussed above.
 - Effluent total P: BioWin predicts the presence of ortho-P (less than 1.250 mgP/l for minimum and maximum wastewater temperatures) in the effluent for both the average and maximum scenarios, resulting in a higher total P in the effluent. The other models predict a zero ortho-P in the effluent where the UCTPHO and the Author's PWM predict the same value for the maximum and average scenario. As previously discussed, BioWin adopts two different maximum specific growth rates for the PAOs, namely a higher growth rate constant under phosphorous rich conditions which results in a higher uptake of phosphorous, and a lower growth rate constant under phosphorous limited conditions, where phosphorous uptake is limited. This lower growth rate constant has a different stoichiometry (no polyphosphate

storage) and is the reason for BioWin producing a non-zero ortho-P in the effluent. The PAO growth in the BioWin model is less resulting in a lower PAO population, hence there is less potential for aerobic polyphosphate uptake, resulting in higher effluent Ortho-P concentrations.

- In summary, the output results of the two dynamic models for the UCT bioreactor (Old Lane) are similar (less than 25% difference) for both the average and maximum scenarios except for the variables listed above. The Author's PWM predicts slightly higher values than the BioWin maximum value scenario except for the ammonia, unbiodegradable soluble organic nitrogen and ortho-P, whereas when compared with UCTPHO, the Author's PWM predicts somewhere between the average and maximum scenarios of UCTPHO. BioWin like UCTPHO, use dynamic kinetic equations under dynamic flow and load conditions, and this will produce different results than the less complex steady-state models included in the Author's PWM which is based on constant flow and load conditions. Apart from the discrepancies in the output variables discussed above, the output results of the two dynamic models are very similar, and not far off range when compared to the steady-state model (Author's PWM).
- 5-Stage Bardenpho bioreactor (New Lane): The output results of the models were very similar except for minor differences as follows:
 - Oxygen Utilisation Rate: BioWin predicts a lower OUR value (less than 25% difference) for both the average and maximum scenarios when compared to UCTPHO. The Author's PWM (steady-state design) predicts higher values than BioWin (greater than 25% for average BioWin scenario and less than 25% for maximum BioWin scenario), but when compared to UCTPHO, the Author's PWM (steady-state design) lies between the UCTPHO average and maximum scenarios
 - Effluent FSA and effluent unbiodegradable soluble organic nitrogen: The BioWin simulation predicts higher values (greater than 25% difference for both average and maximum scenarios) than the UCTPHO model, whereas the Author's PWM (steady-state design) lies between the UCTPHO average and maximum scenarios. As previously mentioned for the Old Lane, BioWin assumes a lower initial nitrifier biomass formation than the other models, resulting in the difference in FSA values.
 - Effluent nitrate: BioWin predicts lower values (greater than 25% difference) than UCTPHO for both the average and maximum scenarios at minimum temperature, but at maximum temperature, BioWin predicts higher values (greater than 25% difference) than UCTPHO for the two scenarios. The Author's PWM (steady-state) predicts higher values (greater than 25% difference) than the maximum scenarios for both the BioWin and UCTPHO models
 - Effluent total P: BioWin predicts the presence of ortho-P (less than 1.500 mgP/l for minimum and maximum wastewater temperatures) in the effluent for both the average and maximum scenarios, resulting in a higher total P in the effluent. The other models predict a zero ortho-P in the effluent where the UCTPHO and the Author's PWM predict the same value for the

maximum and average scenario. As previously discussed for the Old Lane, this difference is due to BioWin adopting two different maximum specific growth rates for the PAOs

- In summary, the output results of the two dynamic models are similar (less than 25% difference) for both the average and maximum scenarios except for the variables listed above. The Author's PWM predicts values between the average and maximum scenarios for both the BioWin and UCTPHO models, except for the ammonia, nitrate and ortho-P variables. BioWin like UCTPHO, use dynamic kinetic equations under dynamic flow and load conditions, and this will produce different results than the less complex steady-state models included in the Author's PWM which is based on constant flow and load conditions. Apart from the discrepancies in the output variables discussed above, the output results of the two dynamic models are very similar, and not far off range when compared to the steady-state model (Author's PWM)
- Anaerobic Digester: The output results of the BioWin dynamic model and steady-state design (Author's PWM) were very similar, except for slight differences in the COD (less than 20% difference) and total P (16.3% difference for the average scenario and 26% difference for the maximum scenario) of the digested sludge. The Author's PWM (steady-state design) correlated more closely with the maximum value of the BioWin dynamic model. There is also a minor difference between the average and maximum scenarios of the BioWin simulation
- Aerobic Digester: There is a minor difference between the average and maximum scenarios of the BioWin simulation. The values predicted by the Author's PWM (steady-state design) are more aligned with the maximum BioWin scenario, except for differences in the digested sludge TSS (less than 30% difference) in the 2nd digester, digested sludge COD concentration (less than 12% difference) and OUR in both the 1st (greater than 25% difference) and 2nd digester (less than 15% difference).

In conclusion, the output results of the two dynamic models were similar (less than 25% difference) for both the average and maximum scenarios and this compared well with the steady-state design (Author's PWM) except for the variables discussed above. It was expected that the steady-state design values would be higher than the dynamic-state average values, and although the majority of output variables were, there were cases where the dynamic models predicted higher average values than the steady-state design. Several output variables were compared across all process units, and the only significant difference appeared in the bioreactor, specifically with respect to the OUR, and N and P concentrations and the aerobic digester (digested sludge TSS and COD concentration). These differences are mainly attributed to the fact that BioWin and UCTPHO use dynamic kinetic equations under dynamic flow and load conditions, and this will produce different results than the less complex steady-state models included in the Author's PWM which are based on constant flow and load conditions.

8. IMPACT OF SIGNIFICANT INFLUENT WASTEWATER CHARACTERISTICS ON SYSTEM PERFORMANCE VARIABLES

The final modelling component of this dissertation entails an evaluation of the impact of specific influent wastewater characteristics on biological nutrient (N and P) removal. The aim of the evaluation is to confirm if the various steady-state and dynamic-state models will behave in a similar fashion with respect to their output and results (i.e., system performance variables) when specific influent wastewater characteristics are varied to their limits.

The selected system performance variables for this evaluation process are those deemed to influence the WWTW capacity and performance as described below:

- In terms of capacity, the output variables considered include process volumes, retention times, surface areas, aeration requirements and sludge wasting volumes.
- In terms of performance, the output variables considered focus on effluent quality and sludge quality.
- If a specific output variable (e.g., the mass of volatile settleable solids in reactor or pH of mixed liquor) has changed significantly which was not expected, this will be identified and discussed.

The influent wastewater characteristics selected for this evaluation were those characteristics considered highly sensitive to impact on a plant's capacity and performance with respect to nutrient removal. Their selection was based on (i) the intuitive identification of significant parameters via the explicit steady state model equations for calculation of nitrification, denitrification and biological excess P removal (BEPR) processes; and (ii) verification that the parameters selected from (i) are also identified in the sensitivity analysis processes found in the literature (Ikumi, 2020) for nutrient removal AS system models. Hence, the three wastewater characteristics selected for the evaluative process include:

- i. Influent TKN (TKN/COD ratio)
- ii. Maximum specific growth rate of nitrifiers (μ_{Max})
- iii. Readily biodegradable COD (RBCOD).

A varying influent TKN impacts the TKN/COD ratio. The TKN/COD ratio and RBCOD are two wastewater characteristics that can vary significantly during the lifetime of a WWTW, which can impact significantly on the performance of the WWTW with respect to nutrient (N and P) removal. The maximum specific growth rate of nitrifiers (μ_{Max}) is a critical wastewater parameter in the design of activated sludge systems, specifically for BNR systems because of its impact on the design (sizing) and performance of biological N removal systems. It is for these reasons, that these specific influent wastewater characteristics have been selected for this evaluative process and all other parameters (flow rates, load patterns, wastewater characterisation, fractions and design assumptions) were kept constant.

The following modelling platforms were adopted:

- Old Lane: Author's PWM, PWSSD, BioWin (steady-state and dynamic-state) and UCTPHO dynamic model (adopting constant flow and load conditions)
- New Lane: Author's PWM and BioWin (steady-state and dynamic-state)
- Combined Sludge Lane: Author's PWM and BioWin (steady-state and dynamic-state).

PWSSD and UCTPHO were not considered for the New Lane and Combined Sludge Lane due to the following reasons:

- In terms of program run times, UCTPHO can take up to 45 minutes for a steady-state simulation run and 4 hours for each dynamic simulation run. The programme is also unstable when launched through a DOS application
- During the development of the steady-state and dynamic-state models discussed under **Sections 6 and 7**, it was noted that PWSSD does not cater for the 5-stage Bardenpho activated sludge configuration. As a result, it was not possible to simulate the Bardenpho bioreactor of the New Lane with one of the available activated sludge configurations (i.e., Johannesburg or UCT), as one would be comparing different process configurations. As a result, the Bardenpho bioreactor of the New Lane was not modelled in the PWSSD programme. For this reason, it was decided to omit the PWSSD model when evaluating the New Lane and Combined Sludge Lane.

The above exclusions did not influence the findings of the evaluative process as these models were included in the evaluation of the Old Lane, which enabled the Author to confirm the behaviour of these models when the three specific influent wastewater characteristics were varied.

This chapter of the dissertation has been structured as follows:

- **Section 8.1** describes the overall modelling approach and describes the format in which the modelling output and results of the evaluative process will be presented in this dissertation
- **Sections 8.2, 8.3 and 8.4** summarise the output results with regard to system performance, considering the impact for each of the three influent wastewater characteristics listed below:
 - **Section 8.2** discusses the influent TKN (TKN/COD Ratio)
 - **Section 8.3** discusses the maximum specific growth rate of nitrifiers (μ_{Max})
 - **Section 8.4** discusses the readily biodegradable COD (RBCOD)
- **Section 8.5** summarises the findings of the evaluative process.

8.1 General Approach to Study

The overall modelling approach of the evaluative process for each influent wastewater characteristic was consistent in approach for the various modelling programmes using the following step-wise approach:

1. The steady-state and dynamic-state models developed under **Sections 6 and 7** were used as the base models and included the same flow scenarios (i.e., factors for PDWF and PWWF, primary sludge

underflow rates and diurnal load patterns for the dynamic-state design), wastewater fractions, process design assumptions and process unit assumptions

2. Six simulations were undertaken for each influent wastewater characteristic which comprised of three simulations where the wastewater characteristic was decreased incrementally up to a maximum of 50% of the original design value, and a further three simulations where the wastewater characteristic was increased incrementally up to a maximum of 150% of the original design value. This resulted in a total of seven simulations per wastewater characteristic when also considering the first simulation conducted for the design value presented in **Sections 6 and 7**
3. This dissertation did not consider the hydraulic capacity of the plant, which could be the limiting constraint in terms of the overall capacity of the plant
4. This dissertation also assumes that the mechanical equipment is not a limiting factor in terms of the overall capacity of the plant. It was found that the following mechanical equipment will limit the process capacity with respect to meeting the effluent quality discharge standards:
 - Mechanical aeration system for the aerobic bioreactor and aerobic digester
 - Recycle pumps (i.e., RAS, a-recycle and r-recycle).

Sections 8.2, 8.3 and 8.4 present the findings in the following format:

- Firstly, each section provides an overview of the specific wastewater characteristic
- Secondly, each section describes the range over which each wastewater characteristic is varied for purposes of evaluating their impact on system performance.
- Lastly, each section provides a discussion on the modelling results for that specific influent wastewater characteristic. The output variables presented in this section of the dissertation were limited to those that changed significantly during the evaluative process. This has been illustrated graphically where a single graph per parameter captured all models (minimum and maximum temperature) and the associated change in the specific output variable. Also, a summary of the output results for all seven simulations as extracted from each model is presented in a set of tables attached in **Annexure G**, **Annexure H** and **Annexure I**. Each Annexure comprises a dedicated table that has been developed for each influent wastewater characteristic varied.

8.2 Impact of Influent TKN on System Performance

8.2.1 Overview of TKN

The influent TKN comprises free and saline ammonia (FSA) and organically bound nitrogen, where the organic nitrogen is further characterised into biodegradable and unbiodegradable components, each with a soluble and a particulate portion, which in turn has a settleable and non-settleable fraction. Generally, in municipal wastewater, the FSA accounts for a significant portion of the influent TKN, typically between 60 to 80% of the influent TKN (Rossle and Pretorius, 2001; WERF, 2003).

For the case study WWTW, the majority of the particulate TKN (settleable component) will be captured in the PSTs with the primary sludge, where the remaining particulate (non-settleable component), the FSA and soluble organic N will pass through the PSTs to the bioreactor. In the bioreactor, the TKN will be broken down as follows:

- Under aerobic conditions:
 - The FSA is immediately available for nitrification, the biological process where FSA is oxidized to nitrite and nitrate provided the biological and environmental conditions are appropriate
 - The biodegradable organic N (soluble and particulate) will first be converted to FSA by the action of organisms in the bioreactor through the ammonification process before it becomes available for nitrification. In describing and modelling the ammonification of organic N to FSA, it is hypothesized that this is linked to the organic material (COD) biological degradation (Henze *et al.*, 1995). Each of the COD fractions has associated with it an organic N content. When the biodegradable COD is hydrolysed for cell synthesis, the associated organic N is released to the bulk liquid as ammonia, which together with the influent FSA becomes available for nitrification. As the biodegradable COD is virtually completely utilized for all sludge ages greater than 3 days for fully aerobic systems and 6 to 8 days for BNR systems, it can be assumed that the biodegradable organic N is virtually completely ammonified to FSA (Henze *et al.*, 2008).
- Under anoxic conditions:
 - The nitrite and nitrate generated under aerobic conditions (nitrification process) are then available for denitrification, the biological process where nitrate (liquid form) is converted to nitrogen (gas form) and escapes to the atmosphere. The extent of denitrification is dependent on the number of electronic donors available, namely RBCOD and slowly biodegradable organics (SBCOD) where RBCOD is the preferred nutrient in “N only” removal systems, and RBCOD and SBCOD are both used in “N and P combined” removal systems.

Based on the current understanding of BNR systems, varying the influent TKN should have the following impact on the steady-state and dynamic-state models of the case study WWTW:

- Aeration requirements:
 - An increase in influent TKN would imply an increase in FSA, requiring additional oxygen for the nitrification process resulting in an increase in aeration requirements in the bioreactor
 - A decrease in influent TKN will have the opposite effect.
- Effluent nitrate concentration:
 - The influent TKN/COD ratio provides an indication of the magnitude of N removal possible, and generally for municipal wastewater, the TKN/COD ratio lies in the range of 0.07 to 0.13. The nitrification capacity of a system is very sensitive to the influent TKN/COD ratio, and an increase of 0.01 in TKN/COD ratio causes an equal increase of 0.01 in nitrification capacity (i.e., an increase in influent TKN/COD ratio will result in an equal increase in nitrate

- concentration per influent COD). As a result, the denitrification potential would be dependent on the available electron donors in the wastewater organics
- PSTs increase the influent TKN/COD ratio, and as a result, N removal via nitrification and denitrification is always lower with settled wastewater than with raw wastewater
 - If the electron donor (RBCOD and SBCOD) remains constant while increasing the influent TKN, a higher N and P concentration would be expected in the effluent, specifically as a result of a higher nitrate and ortho-P concentration in the effluent. A decrease in TKN will have the opposite effect.
- Changes in effluent pH:
 - Nitrification releases hydrogen ions, which in turn decreases the alkalinity of the mixed liquor in the bioreactor. For every 1 mg of FSA that is nitrified, $2 \times 50/14 = 7.14$ mg Alkalinity (as CaCO_3) is consumed. Assuming the aeration equipment is not a limiting factor, it can be assumed that complete nitrification will occur even at high TKN
 - Denitrification takes up hydrogen ions, which in turn increases the alkalinity of the mixed liquor. For every 1 mg of NO_3 that is denitrified, $1 \times 50/14 = 3.57$ mg of Alkalinity (as CaCO_3) is released
 - Based on the above, decreasing the influent TKN should not have a significant impact on the mixed liquor and effluent alkalinity. However, increasing the influent TKN would result in a significant decrease in alkalinity which impacts negatively on the Maximum specific growth rate of nitrifiers (μ_{Max}) especially when the pH of the mixed liquor is outside the range of 7.2 – 8.0 leading to nitrification problems, which would result in higher FSA levels in the effluent. This aspect is discussed in more detail under **Section 8.3**.
 - Sludge treatment process units:
 - An increase in influent TKN will impact slightly on the sludge treatment facilities resulting in an increase in the N load into the anaerobic and aerobic digester. This will result in slightly higher N concentrations in the digested sludge. For the aerobic digester, a slight increase in aeration requirements is expected. A decrease in influent TKN will have the opposite effect.

8.2.2 Selected parameter ranges

As previously discussed in **Section 8.1**, a total of 7 simulations were undertaken for the influent TKN where this value was varied incrementally between 45 and 130 mgN/l. The selected design influent TKN is 85 mgN/l as discussed in **Section 5.2.1**, and is the value adopted for all steady-state and dynamic-state simulations carried out in **Sections 6** and **7**. The TKN fractions presented in **Section 5.3** remain unchanged.

8.2.3 Discussion on Modelling Results

A summary of the complete output results for all seven simulations where TKN was varied is included in tabular format in **Annexure G** and a graphical format in **Figures 8-1, Figure 8-2 and Figure 8-3** (see overleaf).

The following variables were impacted slightly by varying the influent TKN:

- Anaerobic Digester: An increase in the influent TKN increased the incoming primary sludge N content (higher N content in settleable biodegradable organics), and as a result there was a slight increase in the methane gas production (i.e., an increase in the influent TKN from 85 mgN/l to 130 mgN/l resulted in a 14% increase in methane gas production), specifically in the BioWin model (steady-state and dynamic-state) due to the higher nitrifier biomass that is digested. A decrease in influent TKN had the opposite effect. The Author's PWM remained unchanged
- Aerobic Digester: As the influent TKN increased, the Author's PWM remained unchanged, but there were changes in the BioWin simulations (steady-state and dynamic-state) as follows:
 - There was a slight increase in the aeration requirements (i.e., less than 3% difference as the influent TKN increased from 85 mgN/l to 130 mgN/l)
 - Decrease in active fraction with respect to VSS and TSS of the digested sludge (i.e., less than 15% difference as the influent TKN increased from 85 mgN/l to 130 mgN/l).

The following variables were impacted significantly by a varying influent TKN as indicated in **Figures 8-1, Figure 8-2 and Figure 8-3**:

Liquid stream (Old Lane and New Lane):

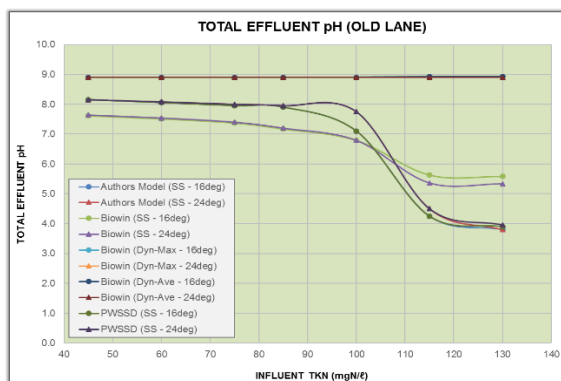
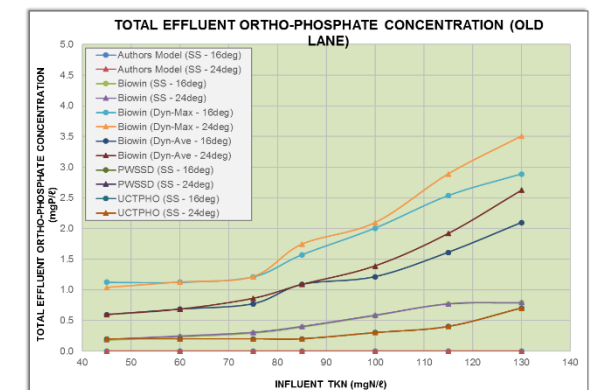
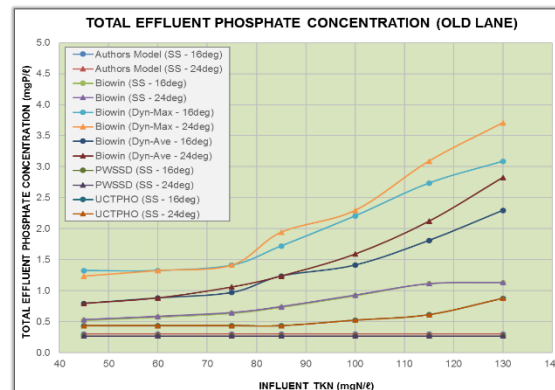
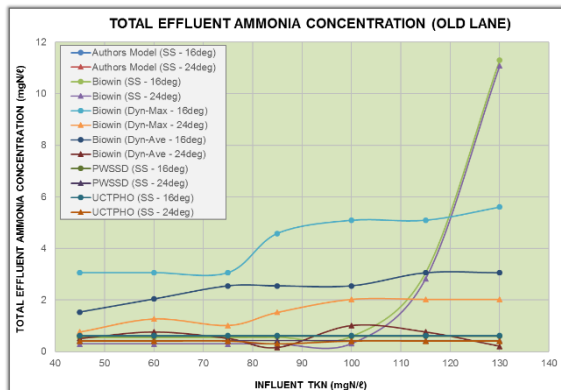
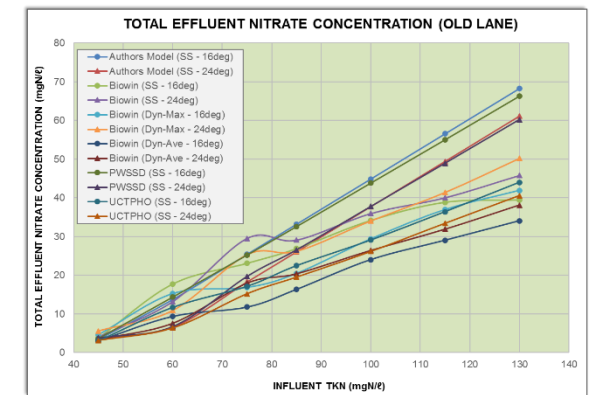
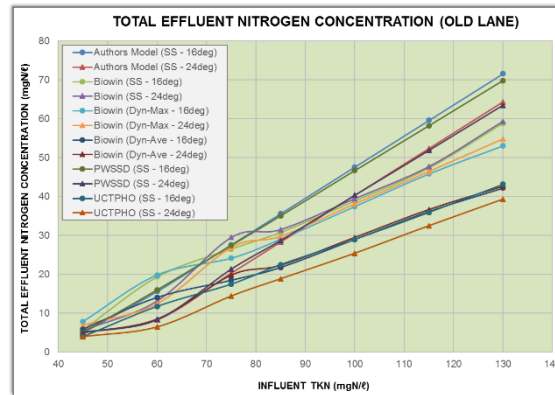
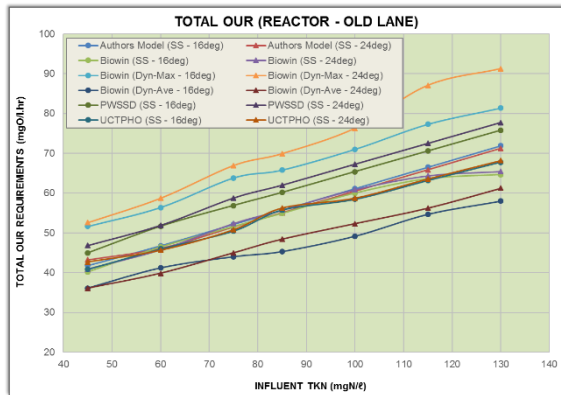
- Bioreactor - Total OUR: As the influent TKN increased, all models increased linearly in terms of total OUR requirements. A decrease in influent TKN had the opposite effect
- Final Effluent - Total effluent nitrate and Total effluent N: As the influent TKN increased beyond 60 mgN/l for the Old Lane and 75 mgN/l for the New Lane, all models increased linearly in terms of these variables
- Final Effluent - Total effluent ammonia: For minimum temperature conditions, as the influent TKN increased beyond 75 mgN/l for the Old Lane and 60 mgN/l for New Lane, the effluent ammonia concentration predicted by the BioWin model increased. For maximum temperature, this occurred in the BioWin model once the influent TKN reached 100 mgN/l for the Old Lane and 115 mgN/l for New Lane. The Author's PWM, PWSSD model and UCTPHO model remained unchanged, predicting low ammonia concentrations in the effluent
- Final Effluent – Total effluent ortho-P and Total effluent P: As the influent TKN increased beyond 75 mgN/l for the Old Lane and 85 mgN/l for New Lane, the effluent Total P and effluent ortho-P increased for all models due to limited amounts of RBCOD and SBCOD available for biological phosphorous removal. For the Old Lane UCT system, when the TKN is greater than 75 mgN/l, nitrate is recycled from the anoxic zone to the anaerobic zone which results in denitrification taking place in the anaerobic zone, thus reducing biological P removal in the anaerobic zone. For a 5-stage Bardenpho system, nitrate is always recycled back to the anaerobic zone even at a low TKN/COD ratio (i.e., less than 0.08). If the influent TKN is increased, more nitrates will be recycled back to the anaerobic zone resulting in denitrification taking place in the anaerobic zone, thus reducing biological P removal in the anaerobic zone
- Final Effluent - Total effluent pH: As the influent TKN increased beyond 85 mgN/l for the Old Lane and 100 mgN/l for the New Lane, the pH in all models started to decrease linearly.

Sludge stream:

- Anaerobic Digester: Incoming total N and Total N in digested sludge: An increase in influent TKN has a negligible impact on the sludge treatment facilities resulting only in an increase in the dissolved N load (nitrate and ammonia) on the anaerobic and aerobic digester resulting in higher N concentrations in the digested sludge.

At higher TKN values, there is a significant band in the graphs below. This band is mainly a result of the difference between the BioWin dynamic model scenarios, namely the average and maximum value scenario. In conclusion, the models appeared to follow the prediction made in **Section 8.2.1** except for the following:

- Apart from the BioWin models, all the other models predicted low ammonia levels in the effluent for those simulations with a high influent TKN. This is a major shortfall in these models as a very high influent TKN would result in a significant decrease in alkalinity in the mixed liquor in the bioreactor, especially if the denitrification capacity is limited as is the case. This impacts negatively on the μ_{Max} leading to nitrification problems, which would result in higher ammonia levels in the effluent as was predicted by the BioWin models.



Figures 8-1 (a-g): Output variables impacted by changes in TKN - Old Lane UCT System

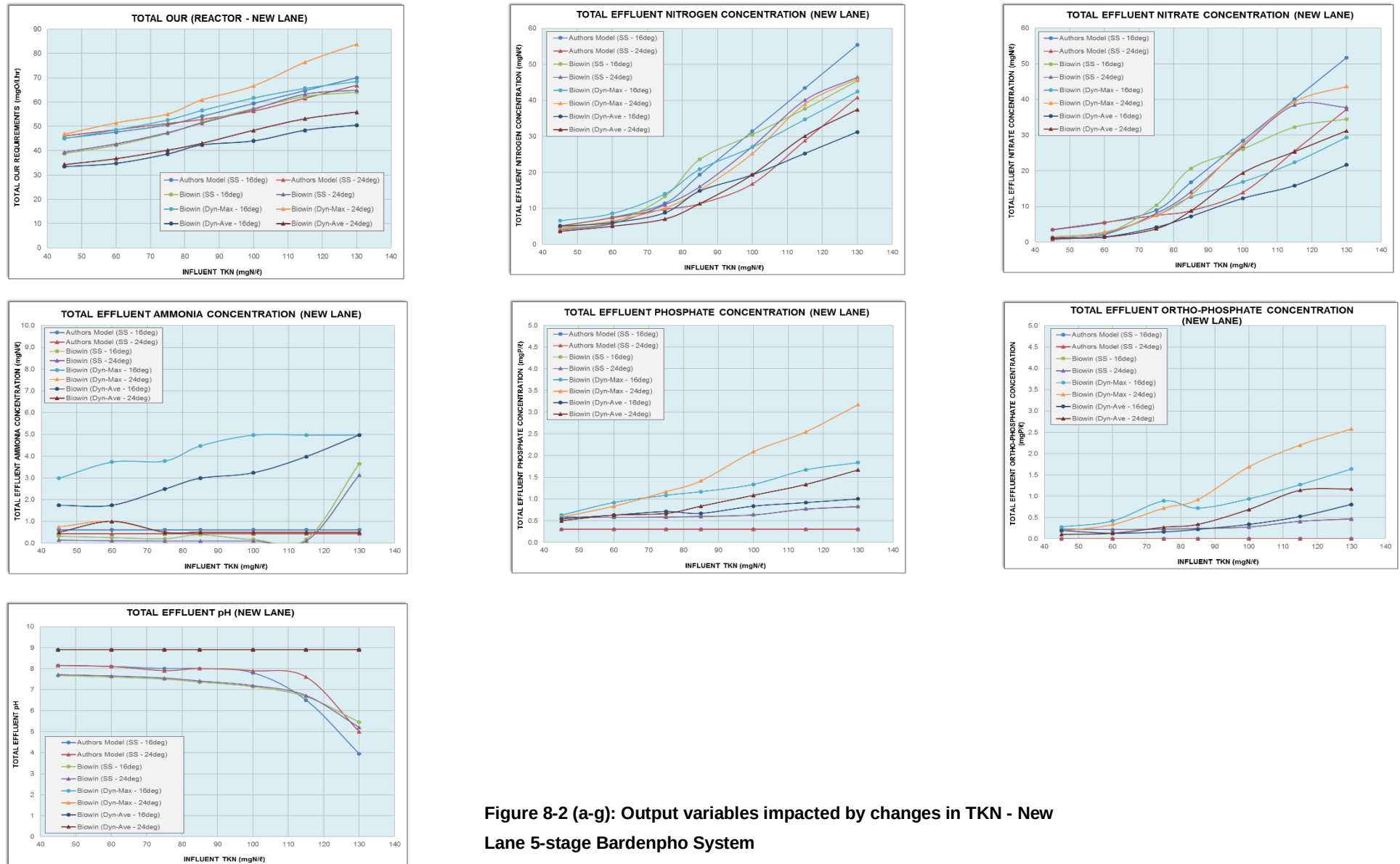


Figure 8-2 (a-g): Output variables impacted by changes in TKN - New Lane 5-stage Bardenpho System

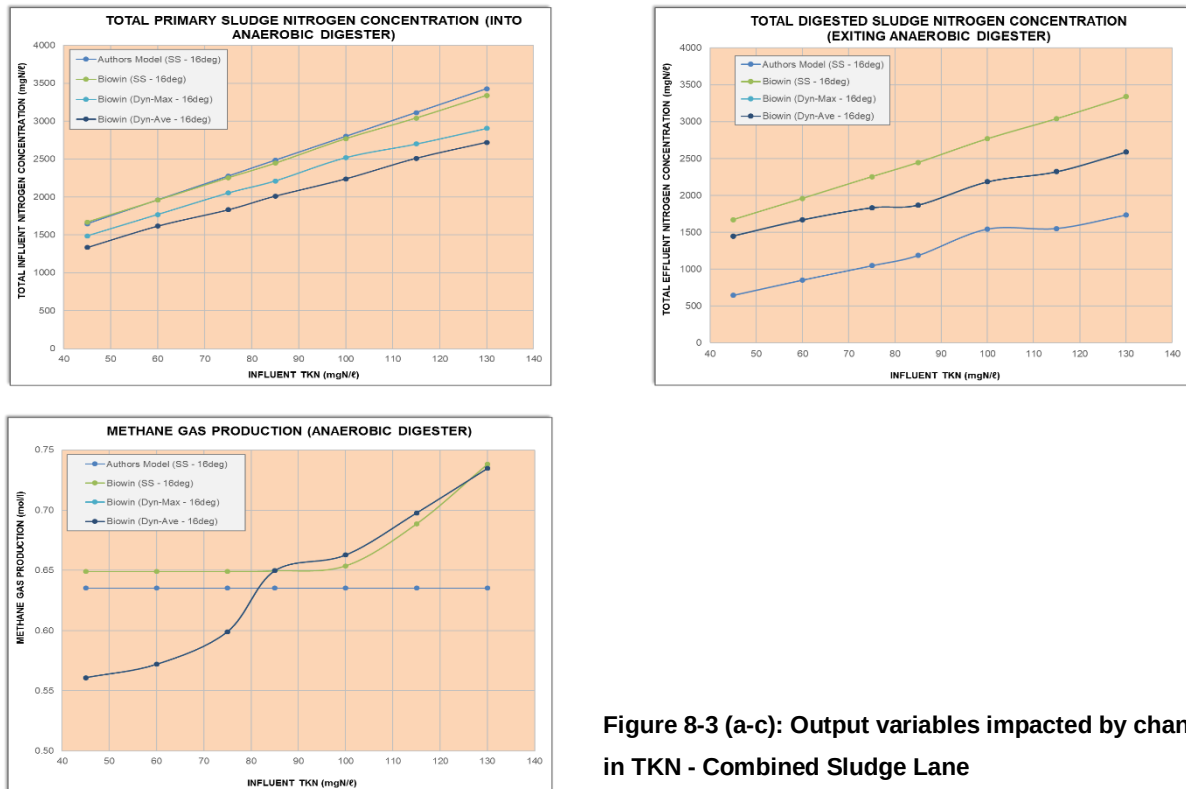


Figure 8-3 (a-c): Output variables impacted by changes in TKN - Combined Sludge Lane

8.3 Impact of maximum specific growth rate of nitrifiers on system performance

8.3.1 Overview of maximum specific growth rate of nitrifiers

In BNR systems which incorporate nitrification and denitrification for the removal of N, the minimum sludge age is based on the specific growth rate of the nitrifiers. The specific growth rate of the nitrifiers is a function of both the maximum specific growth rate (μ_{Max}) and half saturation coefficient (K_n). It has been proven that the minimum sludge age is dominated by the magnitude of μ_{Max} , and only slightly influenced by K_n . The sludge age must be sufficient to prevent the wash-out of the nitrifiers (i.e., exit the system faster than they can grow). For municipal wastewater, μ_{Max} typically varies between 0.30 and 0.75 per day (temperature of 20 °C) and this can result in a minimum sludge age difference of 250% between the two ranges (Henze *et al.*, 2008).

The μ_{Max} has been observed to be specific to the nature of the wastewater and can also vary dependent on the environmental conditions of the wastewater (i.e., pH, temperature and industrial component of the wastewater in terms of metals, elements and organics). As a result, μ_{Max} is usually considered a wastewater characteristic and not a kinetic constant (Henze *et al.*, 2008).

Changes in μ_{Max} do not cause toxicity problems because a high efficiency of nitrification can be achieved even with a low μ_{Max} value provided the sludge age is long enough. However, for a specific sludge age, a decrease in μ_{Max} may cause cessation of nitrification due to nitrifier washout from the system.

When designing a plant, the μ_{Max} should typically be estimated experimentally to ensure optimal design. This estimate can be obtained using batch tests (Still *et al.*, 1985, 1995; Dold *et al.*, 1991) or by running a

completely mixed single reactor at a sludge age of about 8 days, imposing a sequence of aerobic and anoxic periods and measuring the rate of nitrate increase during the aerobic period (van Haandel *et al.*, 1981; WRC, 1984). In practise, this approach is not always adopted, and the approach is to select a low and conservative value for μ_{Max} to ensure nitrification always takes place. If under actual operating conditions, the μ_{Max} is higher, this will imply the sludge age is higher and the reactor volume (unaerated mass fraction) larger than would be required for the N removal system.

The μ_{Max} parameter is extremely sensitive to the pH of the mixed liquor outside the range of 7.2 – 8.0, and optimal nitrification rates typically fall within the aforementioned range. Both the hydrogen (H+) and hydroxyl (OH-) ions act inhibitory when their respective concentrations increase too high. This happens when the pH increases above 8.0 (increasing OH-) or decreases below 7.2 (increasing H+). The pH can fall outside of the aforementioned ranges due to the following:

- Low or high pH in the influent wastewater
- As discussed in **Section 8.2.1** (changes in pH effluent), very high influent TKN would result in a significant decrease in alkalinity specifically if the denitrification capacity is limited (i.e., complete nitrification occurs, but partial denitrification occurs).

The interaction between the biological processes, pH and nitrification is an important consideration for BNR plants, specifically where N removal is imperative. The importance of the selection of μ_{Max} cannot be overstated, if a higher value is selected in design than the actual value during plant operation, even with a safety factor (s_f) of 1.25, the plant is likely to experience nitrification problems resulting in a fluctuating effluent ammonia concentration. As a result, conservative estimates of μ_{Max} (low) and a high safety factor are essential to ensure nitrification and a low effluent ammonia concentration.

Based on the current understanding of BNR systems, varying the influent μ_{Max} only should have the following impact on the steady-state and dynamic-state models of the case study WWTW:

- Aeration requirements:
 - An increase in influent μ_{Max} would imply a slight increase in ammonia removal (i.e., lower FSA effluent value), requiring additional oxygen for the nitrification process resulting in a slight increase in aeration requirements in the bioreactor
 - A decrease in influent μ_{Max} will have the opposite effect.
- Effluent ammonia concentration:
 - A significant increase in influent μ_{Max} would result in a lower ammonia concentration in the effluent, which may increase the effluent nitrate concentration slightly
 - A significant decrease in influent μ_{Max} would cause nitrification problems resulting in an increase in ammonia concentration in the effluent, and an increase in the total nitrogen effluent concentration.

8.3.2 Selected parameter ranges

As previously discussed in **Section 8.1**, a total of 7 simulations were undertaken for the influent μ_{Max} where this value was varied incrementally between 0.225 and 0.675 per day. The selected influent μ_{Max} is 0.450 mgN/l as discussed in **Section 5.2**, and is the value adopted for all steady-state and dynamic-state simulations carried out in **Sections 6** and **7**.

8.3.3 Discussion on Modelling Results

A summary of the complete output results for all seven simulations where μ_{Max} was varied is included in tabular format in **Annexure H** and a graphical format in **Figures 8-4** and **Figures 8-5** (see overleaf).

The following variables were impacted slightly by varying the influent μ_{Max} :

- Bioreactor - Total OUR: As the influent μ_{Max} increased, there was a slight increase in OUR requirements for all the models (i.e., less than 1% change as the μ_{Max} value increased from 0.450 to 0.675)
- Aerobic Digester – N concentration in digested sludge: As the influent μ_{Max} increased, there was a slight decrease for this variable in the BioWin model only (i.e., less than 1% change as the μ_{Max} value increased from 0.450 to 0.675). The Author's PWM remained unchanged.

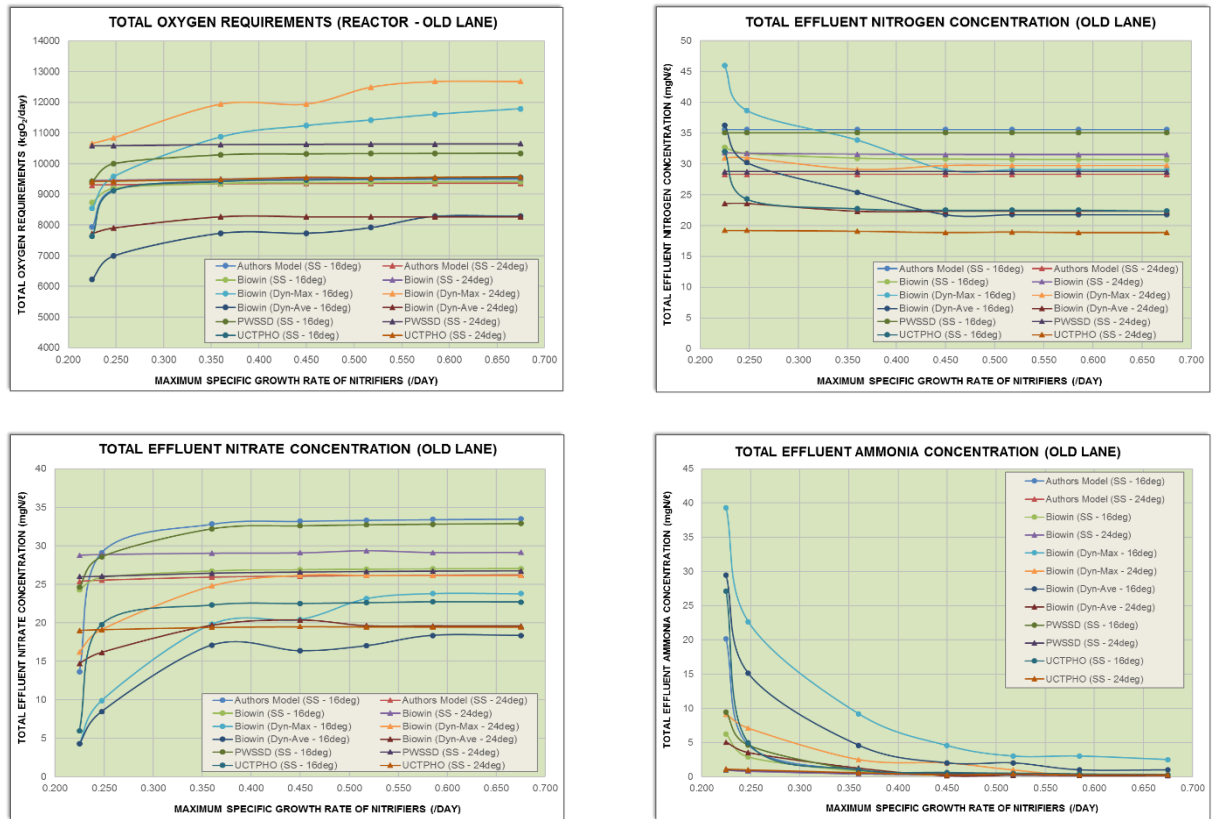
The following variables were impacted significantly by a varying influent μ_{Max} as indicated in **Figures 8-4** and **Figures 8-5** (see overleaf):

Liquid stream (Old Lane and New Lane):

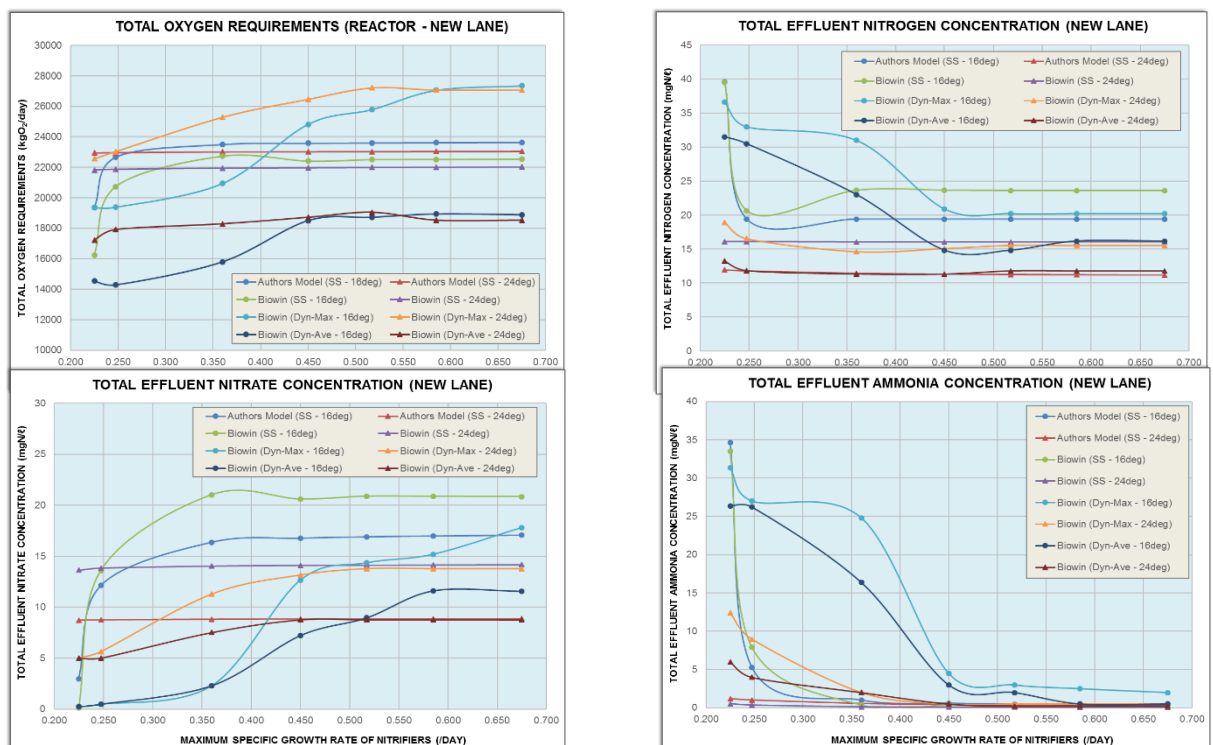
- Final Effluent - Total effluent ammonia and total effluent N:
 - Old Lane: As the influent μ_{Max} decreased below 0.350, the total effluent ammonia and total effluent N concentrations for the BioWin models increased significantly. In terms of the other models, this phenomenon also occurred but at minimum temperature conditions when the μ_{Max} decreased below 0.250
 - New Lane: As the influent μ_{Max} decreased below 0.350, the total effluent ammonia and total effluent N concentrations for the BioWin models increased significantly. In terms of the other models, this phenomenon also occurred but at minimum temperature conditions when the μ_{Max} decreased below 0.275.

In conclusion, the different models (steady-state and dynamic-state) followed the same trend, but nitrification problems occurred at different μ_{Max} values. The BioWin model showed partial nitrification at a higher μ_{Max} threshold value (0.350) than the other models (0.250 and 0.275 for the Old Lane and New Lane respectively) which occurred under minimum temperature conditions only. As previously discussed, the specific growth rate of the nitrifiers is a function of both the maximum specific growth rate (μ_{Max}) and the half saturation coefficient (K_n). The μ_{Max} parameter is extremely sensitive to the pH of the mixed liquor outside the range of 7.2 – 8.0, and when outside this range will lead to nitrification problems. With the exception of BioWin, all other models

adopted in this dissertation do not consider the impact that the pH outside the range of 7.2 – 8.0 would have on the μ_{Max} and the nitrification capacity of the bioreactor.



Figures 8-4 (a-d): Output variables impacted by changes in μ_{Max} - Old Lane UCT System



Figures 8-5 (a-d): Output variables impacted by changes in μ_{Max} - New Lane 5-stage Bardenpho System

8.4 Impact of readily biodegradable COD (RBCOD) on system performance

8.4.1 Overview of Readily Biodegradable COD

The influent COD is characterised into biodegradable and unbiodegradable components, each with a soluble and a particulate portion. The soluble biodegradable component is commonly termed readily biodegradable COD (RBCOD) and is further subdivided into volatile fatty acids (VFA) and fermentable biodegradable COD (F-RBCOD) (Wentzel *et al.*, 1999). This division is critical in biological excess phosphorous removal (BEPR) systems.

In a BEPR system, the level of phosphorous removal is largely dictated by the VFA uptake of the poly accumulating organisms (PAOs) in the anaerobic reactor. The anaerobic reactor typically receives the influent wastewater comprising VFA and F-RBCOD. The OHOs mediate the conversion of F-RBCOD to VFA, which increases the total available VFA for uptake. An increase in VFA uptake will increase the PAO population, which will increase the biological P removal from the system. In the design of a BEPR system, one of the first steps is to calculate the amount of VFA uptake by the PAOs, which involves calculating the split between F-RBCOD converted to VFA for the PAOs and the balance which is not converted but utilised by the OHOs.

In a nitrification, denitrification and biological excess phosphorous removal (NDBEPR) system, the BEPR system is simply combined with the nitrification and denitrification system, as the PAOs and OHOs act essentially independently of each other. The only link between these two groups is the fermentation to VFA of the F-RBCOD in the anaerobic reactor (Wentzel *et al.*, 1990) and its utilisation by the OHOs for denitrification when nitrate and/or dissolved oxygen enters the anaerobic zone.

In a UCT process configuration (Old Lane of the case study WWTW), the system is designed to make practically all the influent RBCOD available to the PAOs in the anaerobic reactor, leaving a limited amount (usually nil) available for denitrification in the anoxic zone. As a result, the electron donors for denitrification are largely limited to the slowly biodegradable COD (SBCOD). It is also important to ensure minimal levels of nitrate and oxygen are present in the r-recycle, if these are present, the OHO's in the anaerobic reactor will utilise the influent RBCOD thereby reducing biological P removal.

The 5-stage Bardenpho process configuration (New Lane of the case study WWTW) caters for a high percentage of N removal due to the high denitrification potential of the primary anoxic zone as a result of the availability of more influent RBCOD and SBCOD in the primary anoxic reactor. For a 5-stage Bardenpho system, nitrate is always recycled (s-recycle) back to the anaerobic zone even at a low TKN/COD ratio (e.g., 0.08) which results in denitrification taking place in the anaerobic zone, enhancing the removal of nitrate and thus reducing biological P removal.

Based on the current understanding of BNR systems, varying the influent RBCOD should have the following impact on the steady-state and dynamic-state models of the case study WWTW:

- Bioreactor:
 - The impact on the Old Lane UCT System and New Lane 5-stage Bardenpho System should be the same as follows:
 - If the influent RBCOD increases, the sludge mass of the system will increase due to an increase in OHO and PAO biomass. In an existing reactor, the volume is fixed, so the sludge age of the system will decrease and the sludge wasting rate will increase to maintain a fixed mass of solids in the reactor. A decrease in RBCOD will have the opposite effect
 - The active fraction with respect to VSS and TSS of the mixed liquor will increase due to the increase in OHOs and PAO biomass. A decrease in RBCOD will have the opposite effect.
- Nitrate and Total N concentration in effluent:
 - Old Lane UCT System: As the RBCOD increases and assuming the PAOs in the anaerobic zone have taken their share of the RBCOD, the electron donors available for denitrification increase, resulting in a lower nitrate and total N concentration in the effluent. A decrease in RBCOD will have the opposite effect
 - New Lane 5-stage Bardenpho System: As the RBCOD increases, the electron donors available for denitrification increases until the denitrification potential is reached, resulting in a lower nitrate and total N concentration in the effluent. A decrease in RBCOD will have the opposite effect.
- Ortho-P and Total P concentration in effluent:
 - Old Lane UCT System: As the RBCOD increases, the VFA uptake will increase resulting in an increase in the PAO biomass which will increase the biological P removal of the system, resulting in a lower ortho-P and total P concentration in the effluent. A decrease in RBCOD would result in the opposite reaction and will also impact the denitrification potential in a NDBEPR system
 - New Lane 5-stage Bardenpho System: As the RBCOD increases, the electron donors available for denitrification increases in the primary anoxic zone, resulting in a lower nitrate and total N concentration in the effluent. This will also result in a lower nitrate concentration being recycled (via the s-recycle) back to the anaerobic zone, limiting denitrification from taking place in the anaerobic zone and thus increasing biological P removal in the anaerobic zone. A decrease in RBCOD will have the opposite effect.
- Sludge treatment process units:
 - An increase in RBCOD will increase the mass of solids wasted from the bioreactor and their active fractions with respect to VSS and TSS, therefore increasing the load on the sludge treatment units
 - Aerobic Digester: The increase in PAOs in the aerobic digester will increase the active fraction with respect to VSS and TSS of the aerobically digested sludge and increase the design volume and OUR of the aerobic digester

- Anaerobic Digester Due to the higher PAO biomass wasted at higher RBCOD fractions, more gas is produced in the anaerobic digester as well as higher N and P concentrations in the dewatering supernatant.

8.4.2 Selected Parameter ranges

As previously discussed in **Section 8.1**, a total of 7 simulations were undertaken for the influent RBCOD where the fraction of this parameter was varied incrementally between 0.040 and 0.300. The selected influent RBCOD fraction is 0.200 as discussed in **Section 5.2**, and is the value adopted for all steady-state and dynamic-state simulations carried out in **Sections 6** and **7**. During the evaluative process, the total incoming COD and biodegradable and unbiodegradable fractions remained unchanged as discussed in **Section 5.3**, but the biodegradable particulate fraction was adjusted to accommodate (balance) the change in RBCOD accordingly.

8.4.3 Discussion on Modelling Results

A summary of the complete output results for all seven simulations where the RBCOD fraction was varied is included in tabular format in **Annexure I** and in a graphical format in **Figures 8-6 and Figure 8-7** (see overleaf).

The following variables were impacted slightly by varying the influent RBCOD:

- Bioreactor (Old Lane and New Lane):
 - An increase in influent RBCOD increased the sludge mass (increase in OHO and PAO biomass) of the system resulting in an increase in reactor VSS and TSS concentration for a specific sludge age. As the RBCOD increased from 0.200 to 0.300, this change was less than 10% for the steady state models and less than 25% for the dynamic models
- Anaerobic Digester: As the influent RBCOD increased, there was an increase in the total N (i.e., this change was less than a 10% increase as the RBCOD increased from 0.200 to 0.300) and total P (i.e., this change was less than a 25% increase as the RBCOD increased from 0.200 to 0.300) of the digested sludge for the BioWin model only, and an increase in VSS destruction predicted in all models. This is due to the higher PAO biomass wasted at higher RBCOD fractions, and as such, more gas is produced in the anaerobic digester as well as higher N and P concentrations in the dewatering supernatant
- Aerobic Digester: As the influent RBCOD increased from 0.200 to 0.300, the models predicted a slight decrease (less than 10% difference) in COD, total N and total P of the digested sludge.

The following variables were impacted significantly by a varying influent RBCOD fraction as indicated in **Figures 8-6 and Figure 8-7** (see overleaf).

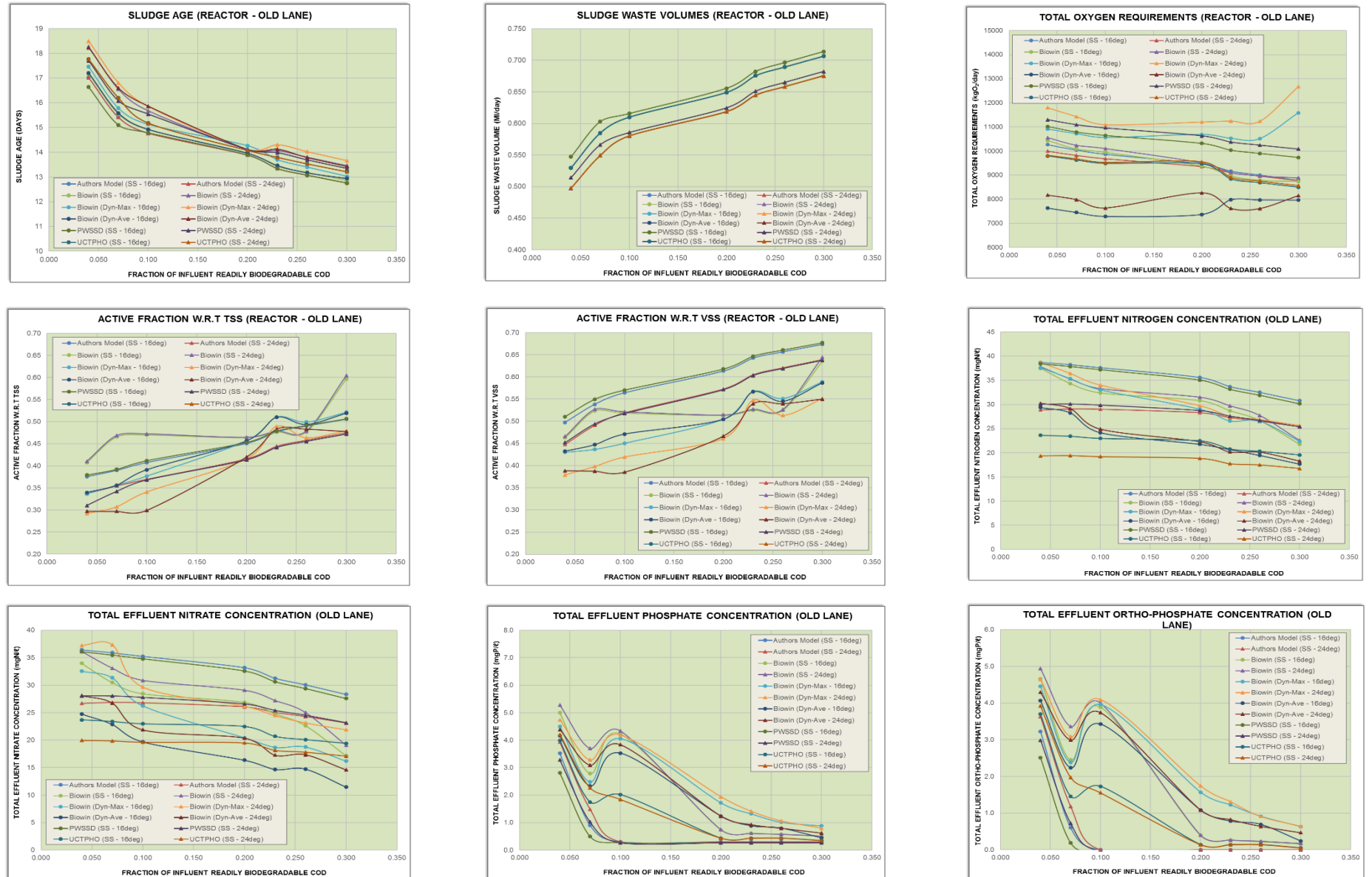
Liquid stream (Old Lane and New Lane):

- Bioreactor:
 - Sludge Age and Waste rate: An increase in influent RBCOD increased the sludge mass (increase in OHO and PAO biomass) of the system resulting in an increase in reactor VSS and TSS concentration for a specific sludge age. However, in an existing reactor, the volume is fixed, to compensate, the sludge age of the system will need to decrease by increasing the sludge wasting rate to maintain a fixed mass of solids in the reactor. The active fraction with respect to VSS and TSS of the mixed liquor increased linearly due to the increase in OHOs and PAO biomass. A decrease in RBCOD had the opposite effect. This was observed in all models (steady-state and dynamic-state)
 - Total OUR: As the influent RBCOD increased, the total OUR requirements decreased slightly for all models (less than 10% difference when the influent RBCOD increased from 0.200 to 0.300)
 - Active fraction with respect to VSS and TSS: As the influent RBCOD increased, these variables increased linearly.
- Final Effluent - Total effluent nitrate and Total effluent N: As the influent RBCOD increased, all models decreased linearly in terms of these variables. A decrease in RBCOD had the opposite effect
- Final Effluent – Total effluent ortho-P and Total effluent P: As the influent RBCOD increased, these variables decreased significantly, with only the unbiodegradable soluble P remaining in the effluent. In terms of the Author's PWM and PWSSD models, all P (except the unbiodegradable soluble portion) was degraded at a threshold RBCOD fraction of 0.100 (both lanes), where for the BioWin and UCTPHO models, this threshold RBCOD fraction was 0.200 (both lanes). A decrease in RBCOD had the opposite effect. BioWin adopts two different maximum specific growth rates for the PAOs, namely a higher growth rate constant under phosphorous rich conditions which results in a higher uptake of phosphorous, and a lower growth rate constant under phosphorous limited conditions, where phosphorous uptake is limited. This lower growth rate constant has a different stoichiometry (no polyphosphate storage) and is the reason for BioWin degrading all P (except the unbiodegradable soluble portion) at a higher RBCOD fraction (i.e., 0.200) when compared to the steady-state models. As previously discussed, the PAO growth in the BioWin model is less resulting in a lower PAO population, hence there is less potential for aerobic polyphosphate uptake, resulting in higher effluent Ortho-P concentrations.

Sludge stream:

- Aerobic Digester:
 - Active fraction with respect to VSS and TSS of digested sludge: An increase in RBCOD will increase the mass of solids wasted from the bioreactor and their active fractions with respect to VSS and TSS, therefore increasing the load on the sludge treatment units. The increase in PAOs in the aerobic digester will increase the active fraction with respect to VSS and TSS of the aerobically digested sludge and increase the design volume of the aerobic digester
 - Total OUR: As the influent RBCOD increased, the aerobic digester OUR increased slightly for all models.

In conclusion, all the models appeared to follow the prediction made in **Section 8.4.1**. The only difference noted in the models is the RBCOD fraction at which complete biological phosphorous removal took place. The Author's PWM and PWSSD models had the same RBCOD fraction, and the BioWin and UCTPHO models had a higher RBCOD fraction at which complete biological phosphorous removal took place.



Figures 8-6 (a-i): Output variables impacted by changes in RBCOD- Old Lane UCT System

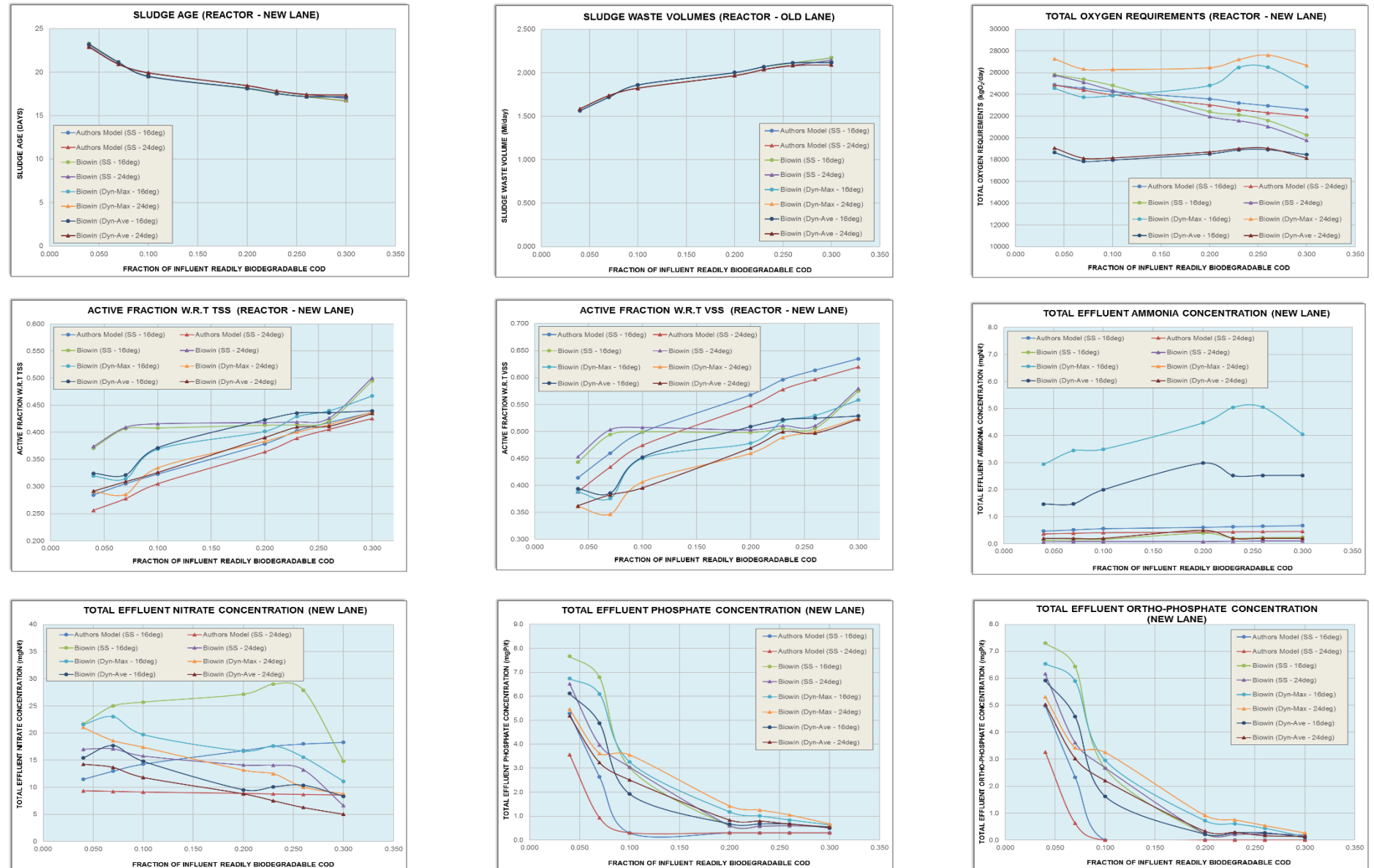


Figure 8-7 (a-i): Output variables impacted by changes in RBCOD - New Lane 5-stage Bardenpho System

8.5 Summary of findings

This chapter entailed evaluating the impact of varying specific influent wastewater characteristics on system performance variables for biological nutrient (N and P) removal, as predicted by the steady-state and dynamic-state models. The wastewater characteristics selected included: i) Influent TKN (TKN/COD Ratio); ii) Maximum specific growth rate of nitrifiers (μ_{Max}); and iii) Readily biodegradable COD (RBCOD). These characteristics were selected as they impact the design (sizing) and performance of a WWTW with respect to nitrogen and phosphorous removal. Their selection was based on the intuitive identification of significant parameters in the explicit steady state model equations for the calculation of nitrification, denitrification and biological excess P removal (BEPR) processes, and these parameters were also identified in the sensitivity analysis processes found in the literature (Ikumi, 2020) for nutrient removal AS system models. All other parameters (flow rates, load patterns, wastewater characterisation, fractions and design assumptions) were kept constant during the evaluative process, which was performed to confirm:

- i. If the models would behave in a similar fashion with respect to their output and results when the above-mentioned influent wastewater characteristics were varied to their limits
- ii. If the models would behave in a similar manner as documented in the research literature. Predictions (see **Sections 8.2.1, 8.3.1 and 8.4.1**) were made on how the models should react to changes in the selected wastewater characteristics based on research literature.

The following conclusions were deduced:

Influent TKN

A varying influent TKN impacts the TKN/COD ratio. The TKN/COD ratio is considered a wastewater characteristic that can vary significantly during the lifetime of a WWTW, which can impact significantly on the performance of the WWTW with respect to nitrogen removal. Varying the influent TKN had the following impacts on the steady-state and dynamic-state models of the case study WWTW:

- Aeration requirements: An increase in TKN resulted in an increase in FSA, requiring additional oxygen for the nitrification process resulting in an increase in aeration requirements in the bioreactor. As the influent TKN increased, all models increased linearly in terms of total OUR requirements. A decrease in influent TKN had the opposite effect
- Effluent ammonia: For minimum temperature conditions, as the influent TKN increased beyond 75 mgN/l for the Old Lane and 60 mgN/l for New Lane, the effluent ammonia concentration predicted by the BioWin model increased. For maximum temperature, this occurred in the BioWin model once the influent TKN reached 100 mgN/l for the Old Lane and 115 mgN/l for New Lane. The Author's PWM, PWSSD model and UCTPHO model remained unchanged when the influent TKN was increased, predicting low ammonia concentrations in the effluent. This is a major deficiency in these models as a very high influent TKN would result in a significant decrease in alkalinity in the mixed liquor in the bioreactor, especially if the denitrification capacity is limited as is the case for the Old and New Lanes.

This impacts negatively on the μ_{Max} leading to nitrification problems, which would result in high ammonia levels in the effluent as was predicted by the BioWin model

- pH: Nitrification decreases alkalinity, while denitrification increases alkalinity but only half the alkalinity is regained through denitrification. It was found that decreasing the influent TKN did not have a significant impact on the mixed liquor and effluent alkalinity. However, increasing the influent TKN resulted in a significant decrease in alkalinity which strongly decreases the μ_{Max} especially when the pH of the mixed liquor is below 7.0. This led to nitrification problems, which resulted in higher FSA levels in the effluent. As discussed under the effluent ammonia variable above, this was demonstrated for the BioWin models, but this was not the case for the other models. In the steady state models, effluent alkalinity can be calculated, and if less than 50 mg/l as CaCO_3 , this can serve as a warning that pH will decrease, and nitrification will become partial
- Effluent nitrate concentration: Influent TKN/COD ratios provide an indication of the magnitude of N removal due to influences on the denitrification potential. If the electron donor (RBCOD and SBCOD) remains constant while increasing the influent TKN, a higher N and P concentration would be expected in the effluent due to elevated levels of effluent nitrate and ortho-P concentration. A decrease in influent TKN has the opposite effect. All models predicted the aforementioned especially when the influent TKN increased beyond 60 mgN/l for the Old Lane and 75 mgN/l for the New Lane
- Total effluent ortho-P and Total effluent P: As the influent TKN increased beyond 75 mgN/l for the Old Lane and 85 mgN/l for New Lane, all models increased in terms of these variables due to limited amounts of RBCOD and SBCOD available for biological phosphorous removal
- Sludge treatment: An increase in influent TKN has a negligible impact on the sludge treatment facilities resulting only in an increase in the dissolved N load (nitrate and ammonia) on the anaerobic and aerobic digester resulting in higher N concentrations in the digested sludge. The following is noted:
 - For the anaerobic digester, as the influent TKN increased, there was a slight increase in the methane gas production (i.e., an increase in the influent TKN from 85 mgN/l to 130 mgN/l resulted in a 14% increase in methane gas production), specifically in the BioWin models (steady-state and dynamic-state) due to the higher nitrifier biomass that is digested. The Author's PWM remained unchanged
 - For the aerobic digester, as the influent TKN increased, there was a slight increase in the aeration requirements (i.e., less than 3% difference as the influent TKN increased from 85 mgN/l to 130 mgN/l) and a decrease in active fraction with respect to VSS and TSS (i.e., less than 15% difference as the influent TKN increased from 85 mgN/l to 130 mgN/l) specifically in the BioWin models (steady-state and dynamic-state).

The various models (steady-state and dynamic-state) appeared to follow the predictions put forth in **Section 8.2.1**. However, with the exception of the BioWin models, all other models adopted in this dissertation do not consider the impact that the pH outside the range of 7.2 – 8.0 would have on the μ_{Max} and the nitrification capacity of the bioreactor. This is a major shortfall in these models.

Maximum specific growth rate of nitrifiers (μ_{Max})

The maximum specific growth rate of nitrifiers (μ_{Max}) is a critical wastewater parameter in the design of activated sludge systems, specifically for BNR systems because of its impact on the design (sizing) and performance of biological N removal systems. Changes in μ_{Max} do not cause toxicity problems because a high efficiency of nitrification can be achieved even with a low μ_{Max} value provided the sludge age is long enough. However, for a specific sludge age, a decrease in μ_{Max} may cause cessation of nitrification due to nitrifier washout from the system. μ_{Max} is extremely sensitive to the pH of the mixed liquor outside the range of 7.2 – 8.0. In practise, the approach is to select a low and conservative value for μ_{Max} to ensure nitrification always takes place. The importance of the selection of μ_{Max} cannot be overstated, if a higher value is selected in design than the actual value during plant operation, even with a safety factor (s_f) of 1.25, the plant is likely to experience nitrification problems resulting in a fluctuating effluent ammonia concentration. As a result, conservative estimates of μ_{Max} (low) and a high safety factor (s_f) are essential to ensure nitrification and a low effluent ammonia concentration. Varying the μ_{Max} had the following impact on the steady-state and dynamic-state models of the case study WWTW:

- Effluent ammonia concentration and Total Effluent N: As the influent μ_{Max} decreased below 0.350, the total effluent ammonia and total effluent N concentrations for the BioWin models increased significantly. In terms of the other models, this phenomenon also occurred but at minimum temperature conditions when the μ_{Max} decreased below 0.250 for the Old Lane and 0.275 for the New Lane.

The different models (steady-state and dynamic-state) followed the same trend but nitrification problems occurred at different μ_{Max} values. The BioWin model showed partial nitrification at a higher μ_{Max} threshold value (0.350 for the Old Lane and New Lane) than the other models (0.250 and 0.275 for the Old Lane and New Lane respectively) which occurred under minimum temperature conditions only.

Readily biodegradable COD (RBCOD)

RBCOD can be considered a wastewater characteristic that can vary significantly during the lifetime of a WWTW, which impacts significantly on the performance of the WWTW with respect to nitrogen and phosphorous removal. In a NDBEPR system, the BEPR system is simply combined with the nitrification and denitrification system, as the PAOs and OHOs act essentially independently of each other. The only link between these two groups is the hydrolysis to VFA of the F-RBCOD in the anaerobic reactor (Wentzel *et al.*, 1990) and its utilisation by the OHOs for denitrification when nitrate and/or dissolved oxygen enters the anaerobic zone.

Varying the influent RBCOD had the following impacts on the steady-state and dynamic-state models of the case study WWTW:

- Bioreactor: An increase in influent RBCOD increased the sludge mass (increase in OHO and PAO biomass) of the system resulting in an increase in reactor VSS and TSS concentration for a specific sludge age. However, in an existing reactor the volume is fixed, to compensate, the sludge age of the system will need to decrease by increasing the sludge wasting rate to maintain a fixed mass of solids

in the reactor. The active fraction with respect to VSS and TSS of the mixed liquor increased linearly due to the increase in OHOs and PAO biomass. A decrease in RBCOD had the opposite effect. This was observed in all models (steady-state and dynamic-state)

- Effluent ortho-P and nitrate concentration: As the RBCOD increases: i) The VFA uptake by the PAOs will increase resulting in an increase in the PAO biomass which will increase the biological P removal of the system, resulting in a lower ortho-P in the effluent; and ii) The electron donors available for denitrification increases, resulting in a lower nitrate concentration in the effluent. A decrease in RBCOD had the opposite effect. This was observed in all models. For the Author's PWM and PWSSD model, all P (except the unbiodegradable soluble portion) was removed at a threshold RBCOD fraction of 0.100 (both lanes), whereas for the BioWin and UCTPHO models, this took place at a 0.200 RBCOD fraction (both lanes). As previously discussed, BioWin adopts two different maximum specific growth rates for the PAOs, namely a higher growth rate constant under phosphorous rich conditions which results in a higher uptake of phosphorous, and a lower growth rate constant under phosphorous limited conditions, where phosphorous uptake is limited. This lower growth rate constant has a different stoichiometry (no polyphosphate storage) and is the main reason for the higher threshold RBCOD fraction
- Sludge treatment: An increase in RBCOD will increase the mass of solids wasted from the bioreactor and their active fractions with respect to VSS and TSS, therefore increasing the load on the sludge treatment units. The increase in PAOs in the aerobic digester increased the active fraction with respect to VSS and TSS of the aerobically digested sludge and increased the design volume of the aerobic digester. As the influent RBCOD increased, the aerobic digester OUR increased slightly for all models. Also due to the higher PAO biomass wasted at higher RBCOD fractions, more gas s produced in the anaerobic digester as well as higher N and P concentrations in the dewatering supernatant.

All the models appeared to follow the prediction made in **Section 8.4.1**. The only difference noted in the models is the RBCOD fraction at which complete P removal took place. The Author's PWM and PWSSD models had the same RBCOD fraction, and the BioWin and UCTPHO models had a higher RBCOD fraction at which complete biological phosphorous removal took place.

In conclusion, substantial changes in the influent TKN, μ_{Max} and RBCOD will impact significantly a WWTW, specifically with respect to N and P removal therefore impacting on effluent quality and sludge quality.

9. CONCLUSIVE DISCUSSION ON FINDINGS

This section provides a conclusive discussion on the findings of key aspects investigated in this dissertation. The findings have been summarised within this section under the following headings which meet the objectives of this dissertation as put forth in **Section 1.2**:

- The importance of wastewater characterisation data in process design modelling
- A comparison of the estimated process capacity and documented process capacity of the case study WWTW. This section will also provide comments on the process configuration of the case study WWTW
- A comparison of the output results for the various models (steady-state and dynamic-state) developed under this dissertation for the case study WWTW
- The impact that a varying influent TKN, μ_{Max} and RBCOD has on an existing WWTW's process capacity and performance
- Lastly, based on the knowledge gained in this dissertation specifically with respect to process modelling, to evaluate the design value offered by steady-state and dynamic-state modelling approaches, and provide some thoughts to further develop and enhance modelling tools from a designer's perspective.

9.1 The importance of wastewater characterisation data in process design modelling

The design life of a WWTW is typically decades, and over time, the wastewater characteristics may change, impacting the plant's process capacity and performance which may result in ineffective process control, inefficient operation and maintenance costs and poor-quality effluent and waste sludge. The characterisation of the influent wastewater is critical for the design and predicting the expected performance of a WWTW. When evaluating an existing plant's wastewater characteristics (flows and concentrations) and the associated wastewater characterization (fractions), the ideal information typically required to undertake an informed evaluation will include:

- An extended history (i.e., at least three years or longer) of grab sample data taken daily or at least every alternative day covering all the key wastewater characteristics where the flow and time at which the sample was collected are also recorded. Key wastewater characteristics should include the total COD, Total Kjeldahl Nitrogen (TKN – filtered and unfiltered), Ammonia, Nitrate/Nitrite, total phosphorous (Total-P – filtered and unfiltered), ortho-phosphates (Ortho-P), total suspended (particulate) solids (TSS), volatile suspended (particulate) solids (VSS), total settleable solids (TSetS), pH and alkalinity. This data should include the influent (raw), settled wastewater (if applicable) and the treated effluent (filtered and unfiltered). The aforementioned data provides a trend of the wastewater characteristics over the data record period, determines the current value of each wastewater characteristic (influent, settled and effluent) and assists with the calculation of the characterisation

(fractions) of the wastewater. The longer the record of such data, the more reliable the data and the easier to select realistic wastewater characteristics for current and future conditions; and

- Recent results of flow-weighted composite samples, non-flow-weighted composite samples over 24-hour intervals, or two-hour concentrations measured over a specific period (preferably a week). This data should cover the key wastewater characteristics discussed above, as well as other characteristics such as the volatile fatty acids, soluble COD (floc filtered COD and/or glass fibre filtered COD) and soluble TKN (glass fibre filtered TKN). Ideally, this data should include the influent (raw), settled wastewater (if applicable) and the treated effluent. Due to the significant costs of such tests, in industry, these tests are typically limited to the influent (raw) and settled wastewater. Such tests should be carried out for at least a week, to give an indication of the weekday loading versus a weekend day loading and should be carried out during the dry weather flow period. The aforementioned data can guide the selection (or verification of the grab sample data) of the wastewater characteristics, the characterisation (fractions) of the wastewater and the selection of the diurnal load patterns (dry weather flow).

In the design industry, the wastewater characterisation can be a complex task for an existing plant mainly due to the following factors:

- Historical sampling data is typically limited because data is collected more for compliance purposes than for WWTW optimisation and control, and there are cases where available data may not be credible
- In some cases, sampling data may be available, but the flow and time at which the grab sample was collected is not recorded, making it difficult to interpret the data
- Important wastewater characteristics (e.g., unbiodegradable particulate COD and the readily biodegradable COD) are typically not measured and so need to be estimated.

When presented with the above limitations, designers are required to make calculated assumptions to fill the gaps in the wastewater characterisation, adopting typical norms as published in the relevant research literature and using sound process engineering judgement. This was the scenario for the case study WWTW as discussed below.

The information made available for evaluating the case study plant's wastewater characteristics (concentrations), the associated wastewater characterization (fractions) and diurnal load patterns were limited to grab sample data over a period of three years, comprising an average of four samples per month. Flow-weighted composite samples, or non-flow-weighted composite samples were not available. As the time of day that the grab sample was taken was not recorded, the grab sample data provided was suitable to inform the selection of the wastewater characteristics and a portion of the wastewater characterization (fractions), but not a complete set for determining the complete wastewater concentrations and diurnal load patterns. As a result, several calculated assumptions were required to inform the wastewater characterisation and diurnal load patterns, namely the selection of historically measured values.

In terms of the wastewater characteristics, the grab sample data was found to be normally distributed for the influent and settled wastewater and treated effluent. As such, normal statistical methods could be applied for the evaluation of the data, where the mean statistical measure guided the selection of wastewater characteristics for the case study WWTW. In terms of verification of the selected design values, the selected wastewater characteristics were compared to historically measured values as published in relevant research literature applicable to municipal wastewater. As the selected design values fell within the ranges expected for typical municipal wastewater, the Author was satisfied that the proposed wastewater characteristics could be adopted as input to the development of the steady-state and dynamic-state models discussed in **Sections 6 and 7**.

The wastewater characterisation for both the influent and settled wastewater was developed using the following information and assumptions: i) Specific wastewater fractions were derived from the measured influent characteristics, settled characteristics and effluent characteristics as previously presented in **Section 5.3.1**; ii) The mass ratios for the unbiodegradable particulate organics (UPO) were assumed to have the same composition and mass ratios as activated sludge biomass as commonly done; and iii) The remaining wastewater fractions were assumed based on historically measured values as published in relevant research literature applicable to municipal wastewater conditions which are presented in **Section 5.3.2**. To verify the wastewater characterisation, the mass ratios, namely the COD/VSS ratio (f_{cv}), TKN/VSS ratio (f_n) and TP/VSS ratio (f_p) were calculated by performing mass balance checks over the PST for both the raw and settled wastewater, and primary sludge flows from the wastewater characterisation block diagrams, and the calculated mass ratios were then checked against historically measured values (Wentzel *et al.*, 2006 and Ekama, 2009). The calculated mass ratios aligned well with the historically measured values with the exception of the calculated influent COD/VSS ratio of the BPO for the raw and settled wastewater streams. It was found that this calculated mass ratio for the BPO is higher than the historically measured values attributed to the low measured TSS and VSS in the influent and settled wastewater. For purposes of the development of the steady-state and dynamic-state models, it was decided to adopt the historically measured influent COD/VSS ratio of the BPO for both the Old Lane and New Lane. If a COD/VSS ratio of 1.550 gCOD/gVSS was selected, one is effectively increasing the VSS concentration of the influent without changing the influent COD concentration. As the models for the activated sludge system and anaerobic digester are COD based, effectively increasing the influent VSS does not affect the sizing, capacity and performance of the aforementioned process units. Apart from the aforementioned COD/VSS mass ratio, the remaining calculated mass ratios aligned well with historically measured values.

By following a mass balance over the PST approach, the characterisation of the primary sludge is done simultaneously with the raw and settled wastewater streams. The characterisation of the primary sludge was derived from the wastewater characterisation of the raw and settled wastewater streams, namely by subtracting the flux of the raw wastewater from the settled wastewater, and then determining the associated concentration of the various portions (biodegradable: particulate and soluble; and unbiodegradable: particulate and soluble) based on the assumed primary sludge underflow rate of 0.775% of ADWF. The mass ratios of the primary sludge were also calculated and were also compared to historically measured values (Wentzel *et al.*, 2006 and Ekama, 2009). The calculated mass ratios aligned well with the historically measured values.

The information made available for evaluating the case study plant's wastewater characteristics (concentrations), the associated wastewater characterization (fractions) and diurnal flow patterns was not ideal. Although the time of day that the grab sample was taken was not recorded, the grab sample data was the only credible information available for this dissertation, and as such, could only be used for determining the wastewater characteristics (concentrations) and some of the associated wastewater characterization (fractions). The balance of the wastewater fractions required for completion of the characterisation needed to be assumed based on relevant research literature. In the design industry, this approach is often followed when undertaking the design of a municipal WWTW due to limited field data, and assumptions are often required using sound process engineering judgement from the designer.

For best practise process control and operation, the following sampling and testing procedures for wastewater characteristics are recommended for municipal WWTW:

- The frequency of grab sample data be extended to daily or at least every alternative day covering all the key wastewater characteristics where the flow and time at which the sample is collected is also recorded in a data retrieval system from which it is easily accessible. Key wastewater characteristics should include the total COD, TKN (filtered and unfiltered), Ammonia, Nitrate/Nitrite, Total-P (filtered and unfiltered), Ortho-P, TSS, VSS, total settleable solids, pH and alkalinity. Daily grab sampling is expensive so consideration should also be given to online measurement
- As a minimum, at least once during the dry season and wet season, a detailed sampling analysis is undertaken comprising either flow-weighted composite samples, or non-flow-weighted composite samples over 24-hour intervals, or two-hour concentrations measured over a 24-hour day which should cover the parameters listed above, as well as other characteristics such as the volatile fatty acids, soluble COD (floc filtered COD and glass fibre filtered COD) and soluble TKN (glass fibre filtered TKN).

Sampling and testing data expanded to include the above will generate reliable wastewater characterisation information that can be used by operators to improve process control and operation; evaluate the plant's reliability level based on the design process capacity; and understand the performance of the biological treatment plant based on influent characteristics.

9.2 Process Capacity of the Case study WWTW

From the steady-state and dynamic-state models previously analysed in **Sections 6** and **7**, it was determined that the limiting factor in the overall process capacity for both the Old Lane and New Lane was the process volume of the bioreactor and SST surface area. The theoretical process capacity was estimated as follows based on an influent COD of 1,060 mgCOD/ℓ, TKN of 85 mgN/ℓ, TP of 11 mgP/ℓ, TSS of 450 mgTSS/ℓ and VSS of 380 mgVSS/ℓ:

- **Old Lane:** The maximum process capacity of this lane is 17.25 Mℓ/day ADWF (influent) based on a sludge age of 14 days and the process parameters noted above. The documented design capacity of this lane is 17 Mℓ/d ADWF at a 1,000 mgCOD/ℓ. The theoretical process capacity estimated is 7% higher than the documented process capacity in terms of COD load
- **New Lane:** The maximum process capacity of this lane is 43.5 Mℓ/day ADWF (influent) based on a sludge age of 18 days and the process parameters noted above. The documented design capacity of this lane is 30 Mℓ/d ADWF at a 1,000 mg/ℓ COD. The theoretical process capacity estimated is 54% higher than the documented process capacity in terms of COD load.

The above estimated theoretical process capacities did not consider the following aspects, which may provide a reason why a lower design capacity was documented for the case study WWTW:

- The evaluation does not consider the hydraulic capacity (i.e., maximum hydraulic flow the WWTW can accommodate via interconnecting pipework, channels and process units) of the plant, and the actual hydraulic capacity (dry and wet weather flows) could be less and would therefore reduce the actual design capacity of the WWTW
- The evaluation does not consider the limitations that mechanical equipment may have on the overall process capacity of the WWTW. The following mechanical design requirements are applicable for the theoretical process capacities estimated for the Old Lane and New Lane:
 - Old Lane – Aerobic reactor – Mechanical aeration system: The theoretical power requirements at the motor (wire power) for maximum temperature conditions is 654 kW, whereas the actual installed power is 390 kW which results in a shortfall of 40%
 - New Lane – Aerobic reactor – Mechanical aeration system: The theoretical power requirements at the motor (wire power) for maximum temperature conditions is 1,526 kW, whereas the actual installed power is 1,190 kW which results in a shortfall of 22%
 - New Lane – Aerobic reactor – Recycle pumps (a, r and RAS): The theoretical recycle flow requirements are much higher than the duty flows that the currently installed pumps can deliver
 - Combined Sludge Lane – DAF units: The theoretical design area for the DAF thickener is much higher than the actual area of the installed units which results in a shortfall of 40%
 - Combined Sludge Lane – Aerobic digester – Mechanical aeration system: The theoretical power requirements at the motor (wire power) for maximum temperature conditions is 360 kW, whereas the actual installed power is 290 kW which results in a shortfall of 20%.

In terms of the total combined capacity, the documented design capacity of the Potsdam WWTW is 47 Mℓ/day (47,000 kgCOD/day) whereas the total theoretical process capacity is estimated as 60.75 Mℓ/day (64,660 kgCOD/day). The total theoretical process capacity is 37.5% higher than the documented process capacity in terms of COD load. In future, should there be a plan to increase the capacity of the WWTW, the existing plant's capacity can be increased by approximately 37.5% by upgrading the plant's overall hydraulic capacity (if required), and the capacity of the mechanical equipment specified above.

In terms of the process configuration of the case study WWTW, the liquid stream is an effective process in meeting the effluent quality standards. The following general comments are noted:

- For a plant of this scale, the incorporation of PSTs into the process is ideal as this reduces the aeration and volume requirements in the bioreactor to between 30% and 40%, depending on the organic content that is captured in the PSTs. This results in a significant saving in electrical costs, as energy requirements for the aeration process typically account for between 40% and 60% of the annual running cost of a WWTW in South Africa, primarily due to the high cost of electrical power
- The existing Water Use License imposes a strict effluent quality standard, especially for phosphorous. This requirement will most likely become stricter in future as the Regulatory Authority (Department of Water and Sanitation) imposes stricter requirements on WWTW, specifically those discharging into sensitive water environments as is the case for the Potsdam WWTW. The Old Lane comprises a UCT process which enhances the biological removal of phosphorous. The New Lane incorporates a 5-stage Bardenpho process which is not typically incorporated at WWTWs requiring a strict phosphorous limit as this process favours nitrogen removal over biological phosphorous removal due to the nitrate return to the anaerobic reactor via under the SST underflow recycle. The reason for selecting this process configuration is unknown, and this process is not considered ideal where stringent effluent phosphorous levels are imposed unless methanol addition to the secondary anoxic reactor is contemplated to ensure a zero nitrate return to the anaerobic reactor (and effluent).

The sludge stream of the Potsdam WWTW is an effective process where the WAS is stabilised and thickened, and the primary sludge is thickened but is not stabilised. The sludge is currently disposed of at the Vissershok landfill site. The following general comments are noted:

- The primary sludge is not stabilised, and as a result, is required to be disposed of at a hazardous landfill site at a significant cost. In future, the City of Cape Town may have to consider the incorporation of anaerobic digestion for primary sludge stabilisation as this will present a cheaper disposal option (e.g., land application etc.) when compared to the current disposal option. The anaerobic digestion process has a further advantage of the potential production of energy from biogas generation. The N and P content of anaerobically digested primary sludge dewatering supernatant may be low enough to be returned to the influent without adversely affecting effluent N and P concentrations (Ekama, 2017)
- The aerobic digestion of WAS is suitable for the current plant, as this is a simple process for stabilisation of concentrated WAS (which is usually rich in nitrogen and phosphorous) from a NDBEPR system (Vogts *et al.*, 2014). However, the following concerns are noted:
 - The aerobic digestion process operates purely as an aerobic digester, and not as an anoxic-aerobic digester. Aerobic digestion will allow for complete nitrification, and as the nitrate generated cannot be denitrified, one loses the advantage of the recovery of alkalinity loss and also the reduction in oxygen demand which occurs in an anoxic-aerobic digester. The City of Cape Town should investigate operating this process unit as an anoxic-aerobic digester, by using an intermittent aeration cycle (i.e., 3 hours on and 3 hours off). This process will ensure

almost complete nitrification and denitrification, allowing for low ammonia and nitrate concentrations in the supernatant

- Aerobic digestion of WAS consumes significant energy which is a concern due to the high cost of electricity and the above-inflation increases in electricity prices in South Africa. Globally, there is a focus on conserving energy with energy efficiency in the wastewater treatment field becoming increasingly important. In future, the City of Cape Town should investigate alternative options for the stabilisation of WAS. An option may include the anaerobic digestion (e.g., mesophilic, thermophilic and thermal hydrolysis etc.) of a mixture of primary sludge and WAS which is becoming a popular solution. This option has disadvantages specifically around the anaerobic digestion of WAS due to the slow hydrolysis rate of the WAS biodegradable organics, and the high nitrogen and phosphorous content of the dewatering supernatant which cannot be returned to the influent without significantly increasing effluent N and P concentrations from the NDBEPR system (Ekama, 2017). As a result, the dewatering supernatant from an anaerobic digestion process treating primary sludge and WAS will require side-line N and P removal technologies before returning to the influent stream. Alternatively, to avoid a high N and P containing dewatering supernatant, lime can be dosed to an anoxic-aerobic digester (Vogts *et al.*, 2014), but then energy is consumed rather than recovered as in the case of the anaerobic digestion system. Both options have merit, and the selection of either will be dependent on the main driver of the WWTW, which could be energy conservation which will promote anaerobic digestion, or a high-standard effluent quality which will favour the anoxic-aerobic digester system. Ekama (2017) goes so far as stating that there is little merit in anaerobic digestion of NDBEPR WAS unless the phosphorous is recovered for re-use because the energy generated is very low and the nitrogen and phosphorous concentrations in the dewatering supernatant very high.

9.3 Comparison of Modelling results

9.3.1 Steady-State Models

A comparison of the model output results of the steady-state models was carried out in **Section 6**, namely for the Author's PWM, PWSSD, BioWin and UCTPHO. Several output variables were compared across all process units for both the liquid and sludge streams, and the following was concluded:

- PSTs and SSTs: The Author's PWM, PWSSD and BioWin size a PST and SST in a similar fashion, and the three models predicted negligible differences in the output results
- UCT bioreactor (Old Lane): The output results of the four models were very similar except for the following differences:
 - Active Fraction with respect to VSS: BioWin predicts a slightly lower value (less than 13% difference) than the other models and this can be attributed to a slightly lower mass of active PAO organisms in the reactor which is mainly due to the discrepancy in PAO substrate

allocation between BioWin and the spreadsheet models. In BioWin, the activated sludge model relies on the kinetics of anaerobic fermentation of fermentable soluble organics and the kinetics of SBCOD hydrolysis. The VFAs available anaerobically are the ones that can be sequestered by PAOs allowing for their increased growth in the AS system. The higher the RBCOD anaerobic fermentation rate, the higher the potential for PAO growth in the AS system. The PAOs compete with facultative heterotrophic organisms for utilisation of the VFA present in unaerated zones, and if all the nitrate is utilised in an anaerobic zone, then the PAOs have no more competition for the substrate. In the steady state spreadsheet models, the allocation of substrate sequestered by PAOs is calculated without the inclusion of anaerobic fermentation kinetics and the nitrates recycled back into the anaerobic zone are assumed to be utilised by facultative OHOs much more rapidly than the PAOs could sequester VFAs. Hence the VFAs available to PAOs are the ones present after all the nitrate has been reduced in the anaerobic zone. Because of this discrepancy between the dynamic simulation software model (i.e., BioWin) and the steady state spreadsheet model (i.e., the VFAs being taken up less in the BioWin model due to slower fermentation kinetics), the PAO growth in the BioWin model is less. With a lower PAO population, there is less potential for aerobic polyphosphate uptake, resulting in higher effluent Ortho-P concentrations. Also affected to a lesser degree, is the quantity of nutrients taken up in the reactor being less due to less active biomass, resulting in marginally higher effluent FSA.

- Effluent FSA, effluent nitrate and total effluent N: The BioWin model differed slightly from the other models, but the difference (less than 15% difference) in values were not significant. The BioWin effluent FSA is still less than 0.75 mgN/l so in absolute terms the difference is small
- Effluent total P: BioWin predicts the presence of ortho-P (less than 0.260 mgP/l for minimum and maximum wastewater temperatures) in the effluent, resulting in a higher total P in the effluent. The other models predict a zero ortho-P in the effluent. The discrepancies attributed to Ortho-P can be explained for reasons discussed in the above section that compares the active fraction of VSS in the various models.
- In summary, the Author's PWM and PWSSD predict the same outputs, which would be expected as the design of the various process design modules within these models are based on the same design principles developed by the UCT Research Group. BioWin and UCTPHO use dynamic kinetic equations under constant flow and load conditions for a steady-state simulation, and this will result in slightly different results (less than 15% difference) than the less complex steady-state models included in the Author's PWM and PWSSD model
- 5-Stage Bardenpho bioreactor (New Lane): The output results of the four models were very similar except for the following differences:
 - Effluent free and saline ammonia (FSA): This variable is slightly lower (varies between 0.130 and 0.401 mgN/l) for the BioWin and UCTPHO models, with the BioWin model resulting in the lowest FSA values. The difference in the BioWin model is a result of this model assuming a lower endogenous respiration rate and half saturation coefficient for the nitrifiers. However,

- all models predict an effluent FSA of less than 0.75 mgN/l so in absolute terms the difference is small
- Effluent total P: BioWin predicts the presence of ortho-P (less than 0.559 mgP/l for minimum and maximum wastewater temperatures) in the effluent, resulting in a higher total P in the effluent. The other models predict a zero ortho-P in the effluent. As previously discussed for the Old Lane, the reason for this difference is that BioWin adopts two different maximum specific growth rates for the PAOs
 - In summary, BioWin like UCTPHO, use dynamic kinetic equations under constant flow and load conditions for a steady-state simulation, and this generates different results than the less complex steady-state models included in the Author's PWM and PWSSD model.
 - Anaerobic Digester: The three models predicted very similar output results, with the only exception being the BioWin model, predicting a slightly higher value (less than 11% difference) for the TSS, VSS, COD and Total P of the digested sludge exiting the anaerobic digester. As previously mentioned, BioWin use dynamic kinetic equations under constant flow and load conditions for a steady-state simulation, and this will generate different results (less than 11% difference) than the less complex steady-state models
 - Aerobic Digester: The three models (Author's PWM, PWSSD and BioWin) predicted very similar output results except for the following:
 - The BioWin model predicted a lower TSS (less than 20% difference) and a lower effluent active fraction (less than 15% difference) with respect to VSS and TSS for the sludge concentration exiting the last (second) digester. The BioWin model also predicted higher effluent N (less than 12% difference) and P concentrations (greater than 15% difference) for the sludge concentration exiting the last (second) digester. With the aerobic degradation of the waste activated sludge (WAS) biodegradable particulate organics (BPO), there is a resultant release of the nutrients bound to the BPO (N is released as ammonia and P released as Ortho-P). Hence with the BioWin model having a lower predicted effluent VSS as previously explained, the VSS degradation is higher, resulting in higher quantities of N and P released as FSA and Ortho-P.
 - The PWSSD model predicts a slightly higher value (less than 13% difference) for the VSS sludge concentration exiting the last (second) digester, resulting in a higher (greater than 15% difference) effluent active fraction with respect to VSS and TSS for the sludge concentration exiting the last (second) digester. The PWSSD model predicts a lower value (50% difference) in the P sludge concentration exiting the last (second) digester. These differences are attributed to the fact that the version of PWSSD adopted for the purposes of this dissertation does not incorporate the latest research on the endogenous respiration rates of the poly accumulating organisms (PAOs) (Vogts and Ekama, 2015).

In terms of the steady-state models, several output variables were compared across all process units, with the Author's PWM and PWSSD generating the same output results except for the aerobic digester. The output variables of the BioWin and UCTPHO models were similar to the other two models but did differ for some variables, attributed to the fact that these models use dynamic kinetic equations under constant flow and load

conditions for a steady-state simulation, and this generates different results than the less complex steady-state models included in the Author's PWM and PWSSD model.

9.3.2 Dynamic-State Models

A comparison of the model output and results of the dynamic-state models (BioWin and UCTPHO) was carried out in **Section 7**, where the average and maximum values over the diurnal period were compared. The results of these models were also compared to the Author model (steady-state design) as presented in **Section 6**. Several output variables were compared across all process units for both the liquid and sludge streams, and the following was concluded:

- PSTs and SSTs: The output results of the steady-state design (Author's PWM) were similar to the maximum value scenario of the BioWin dynamic-state model for both the PSTs and SSTs
- UCT bioreactor (Old Lane): The output results of the models were very similar except for minor differences as follows:
 - Oxygen Utilisation Rate: BioWin predicts a lower OUR value (greater than 25% difference) for both the average and maximum scenarios when compared to UCTPHO. The Author's PWM (steady-state design) predicts lower values than UCTPHO (14% difference for the average scenario and greater than 25% difference for the maximum scenario), but when compared to BioWin, the Author's PWM (steady-state design) lies between the average and maximum BioWin values
 - Effluent FSA and effluent unbiodegradable soluble organic nitrogen: The BioWin simulation predicts higher values (average and maximum) than the UCTPHO model, whereas the UCTPHO average appears to correlate more with the steady-state design (Author's PWM). With respect to FSA in the BioWin model, the concentration of ANOs in the reactor significantly impacts the kinetics of nitrate formation, while the Author's PWM assumes that the biomass present is already in substantial quantities, which results in a much more rapid conversion of FSA to nitrates. Due to the lower rates of nitrifier mass formation at dynamic states in the BioWin model, there was a difference in the effluent FSA values when compared to the Author's PWM.
 - Effluent nitrate: BioWin predicts lower values (greater than 25% difference) for both the average and maximum scenarios when compared to UCTPHO and the Author's PWM, whereas the Author's PWM (steady-state design) ties up with UCTPHO. The difference in the BioWin simulation is due to the lower rate of nitrifier mass formation adopted by BioWin during the dynamic simulation, resulting in the higher FSA in the effluent as discussed above.
 - Effluent total P: BioWin predicts the presence of ortho-P (less than 1.250 mgP/l for minimum and maximum wastewater temperatures) in the effluent for both the average and maximum scenarios, resulting in a higher total P in the effluent. The other models predict a zero ortho-P in the effluent where the UCTPHO and the Author's PWM predict the same value for the maximum and average scenario. As previously discussed for the steady-state models, BioWin adopts two different maximum specific growth rates for the PAOs, namely a higher growth

rate constant under phosphorous rich conditions which results in a higher uptake of phosphorous, and a lower growth rate constant under phosphorous limited conditions, where phosphorous uptake is limited. This lower growth rate constant has a different stoichiometry (no polyphosphate storage) and is the reason for BioWin producing a non-zero ortho-P in the effluent. As the PAO growth in the BioWin model is less resulting in a lower PAO population, there is less potential for aerobic polyphosphate uptake, resulting in higher effluent Ortho-P concentrations.

- In summary, the output results of the two dynamic models for the UCT bioreactor (Old Lane) are similar (less than 25% difference) for both the average and maximum scenarios except for the variables listed above. The Author's PWM predicts slightly higher values than the BioWin maximum value scenario except for the ammonia, unbiodegradable soluble organic nitrogen and ortho-P, whereas when compared with UCTPHO, the Author's PWM predicts somewhere between the average and maximum scenarios of UCTPHO. BioWin like UCTPHO, use dynamic kinetic equations under dynamic flow and load conditions, and this will produce different results than the less complex steady-state models included in the Author's PWM which is based on constant flow and load conditions. Apart from the discrepancies in the output variables discussed above, the output results of the two dynamic models are very similar, and not far off range when compared to the steady-state model
- 5-Stage Bardenpho bioreactor (New Lane): The output results of the models were very similar except for minor differences as follows:
 - Oxygen Utilisation Rate: BioWin predicts a lower OUR value (less than 25% difference) for both the average and maximum scenarios when compared to UCTPHO. The Author's PWM (steady-state design) predicts higher values than BioWin (greater than 25% for average BioWin scenario and less than 25% for maximum BioWin scenario), but when compared to UCTPHO, the Author's PWM (steady-state design) lies between the UCTPHO average and maximum scenarios
 - Effluent FSA and effluent unbiodegradable soluble organic nitrogen: The BioWin simulation predicts higher values (greater than 25% difference for both average and maximum scenarios) than the UCTPHO model, whereas the Author's PWM (steady-state design) lies between the UCTPHO average and maximum scenarios. As previously mentioned for the Old Lane, BioWin assumes a lower initial nitrifier biomass formation than the other models, resulting in the difference in FSA values.
 - Effluent nitrate: BioWin predicts lower values (greater than 25% difference) than UCTPHO for both the average and maximum scenarios at minimum temperature, but at maximum temperature, BioWin predicts higher values (greater than 25% difference) than UCTPHO for the two scenarios. The Author's PWM (steady-state) predicts higher values (greater than 25% difference) than the maximum scenarios for both the BioWin and UCTPHO models
 - Effluent total P: BioWin predicts the presence of ortho-P (less than 1.500 mgP/l for minimum and maximum wastewater temperatures) in the effluent for both the average and maximum scenarios, resulting in a higher total P in the effluent. The other models predict a zero ortho-

P in the effluent where the UCTPHO and the Author's PWM predict the same value for the maximum and average scenario. As previously discussed for the Old Lane, this difference is due to BioWin adopting two different maximum specific growth rates for the PAOs

- In summary, the output results of the two dynamic models are similar (less than 25% difference) for both the average and maximum scenarios except for the variables listed above. The Author's PWM predicts values between the average and maximum scenarios for both the BioWin and UCTPHO models, except for the ammonia, nitrate and ortho-P variables. BioWin like UCTPHO, use dynamic kinetic equations under dynamic flow and load conditions, and this will produce different results than the less complex steady-state models included in the Author's PWM which is based on constant flow and load conditions. Apart from the discrepancies in the output variables discussed above, the output results of the two dynamic models are very similar, and not far off range when compared to the steady-state model
- Anaerobic Digester: The output results of the BioWin dynamic model and steady-state design (Author's PWM) were very similar, except for slight differences in the COD (less than 20% difference) and total P (16.3% difference for the average scenario and 26% difference for the maximum scenario) of the digested sludge. The Author's PWM (steady-state design) correlated more closely with the maximum value of the BioWin dynamic model. There is also a minor difference between the average and maximum scenarios of the BioWin simulation
- Aerobic Digester: There is a minor difference between the average and maximum scenarios of the BioWin simulation. The values predicted by the Author's PWM (steady-state design) are more aligned with the maximum BioWin scenario, except for differences in the digested sludge TSS (less than 30% difference) in the 2nd digester, digested sludge COD concentration (less than 12% difference) and OUR in both the 1st (greater than 25% difference) and 2nd digester (less than 15% difference).

In terms of the dynamic-state models, the output results of the two dynamic models were similar (less than 25% difference) for both the average and maximum scenarios and this compared well with the steady-state design (Author's PWM) except for the variables discussed above. It was expected that the steady-state design values (Author's PWM) would be higher than the dynamic-state average values, and although the majority of output variables were, there were cases where the dynamic models predicted higher average values than the steady-state design. Several output variables were compared across all process units, and the only significant difference appeared in the bioreactor, specifically with respect to the OUR, and N and P concentrations and the aerobic digester (digested sludge TSS and COD concentration). These differences are mainly attributed to the fact that BioWin and UCTPHO use dynamic kinetic equations under dynamic flow and load conditions, and this will produce different results than the less complex steady-state models included in the Author's PWM which are based on constant flow and load conditions.

9.3.3 Closing comment on modelling results

The various steady-state and dynamic-state models correlated well in terms of output results when compared across all process units for both the liquid and sludge streams. In conclusion, the models presented in this

dissertation should give similar output results when modelling the process of a WWTW, apart from the differences summarised above.

9.4 Evaluating the Impact of Specific Wastewater Characteristics

Section 8 presented the results of the impact of varying selected influent wastewater characteristics on the system performance variables for biological nitrogen and phosphorous removal for the steady state and dynamic models. The wastewater characteristics selected included: i) Influent TKN (TKN/COD Ratio); ii) Maximum specific growth rate of nitrifiers (μ_{Max}); and iii) Readily biodegradable COD (RBCOD). These characteristics were selected as they impact the design (sizing) and performance of a WWTW with respect to nitrogen and phosphorous removal. Their selection was based on the intuitive identification of significant parameters in the explicit steady state model equations for the calculation of nitrification, denitrification and biological excess P removal (BEPR) processes. These parameters were also identified in the sensitivity analysis processes found in the literature (Ikumi, 2020) for nutrient removal AS system models. All other parameters (flow rates, load patterns, wastewater characterisation, fractions and design assumptions) were kept constant during the evaluative process, which was used to confirm: i) If the models will behave in a similar fashion with respect to their output and results when the aforementioned influent characteristics were varied to their limits; and ii) If the models would behave in a similar manner as documented in the research literature on the topic. Predictions were made on how the model should react to changes in the selected parameters based on various research papers, and the model results were compared to the predictions made. The following conclusions were deduced from the evaluative process:

9.4.1 Influent TKN

A varying influent TKN impacts the TKN/COD ratio. The TKN/COD ratio is considered a wastewater characteristic that can vary significantly during the lifetime of a WWTW, which can impact significantly on the performance of the WWTW with respect to nitrogen removal. Varying the influent TKN had the following impacts on the steady-state and dynamic-state models of the case study WWTW:

- Aeration requirements: An increase in TKN resulted in an increase in FSA, requiring additional oxygen for the nitrification process resulting in an increase in aeration requirements in the bioreactor. As the influent TKN increased, all models increased linearly in terms of total OUR requirements. A decrease in influent TKN had the opposite effect
- Effluent ammonia: For minimum temperature conditions, as the influent TKN increased beyond 75 mgN/l for the Old Lane and 60 mgN/l for New Lane, the effluent ammonia concentration predicted by the BioWin model increased. For maximum temperature, this occurred in the BioWin model once the influent TKN reached 100 mgN/l for the Old Lane and 115 mgN/l for New Lane. The Author's PWM, PWSSD model and UCTPHO model remained unchanged when the influent TKN was increased and predicted low ammonia concentrations in the effluent. This is a major deficiency in these models as a very high influent TKN would result in a significant decrease in alkalinity in the mixed liquor in the

bioreactor, especially if the denitrification capacity is limited as is the case for the Old and New Lanes. This impacts negatively on the μ_{Max} leading to nitrification problems, which would result in high ammonia levels in the effluent as was predicted by the BioWin model

- pH: Nitrification decreases alkalinity, while denitrification increases alkalinity but only half the alkalinity is regained through denitrification. It was found that decreasing the influent TKN did not have a significant impact on the mixed liquor and effluent alkalinity. However, increasing the influent TKN resulted in a significant decrease in alkalinity which strongly decreases the μ_{Max} especially when the pH of the mixed liquor is below 7.0. This led to nitrification problems, which resulted in higher FSA levels in the effluent. As discussed under the effluent ammonia variable above, this was demonstrated for the BioWin models, but this was not the case for the other models. In the steady state models, effluent alkalinity can be calculated, and if less than 50 mg/l as CaCO_3 , this can serve as a warning that pH will decrease, and nitrification will become partial
- Effluent nitrate concentration: Influent TKN/COD ratios provide an indication of the magnitude of N removal due to influences on the denitrification potential. If the electron donor (RBCOD and SBCOD) remains constant while increasing the influent TKN, a higher N and P concentration would be expected in the effluent due to elevated levels of effluent nitrate and ortho-P concentration. A decrease in influent TKN has the opposite effect. All models predicted the aforementioned especially when the influent TKN increased beyond 60 mgN/l for the Old Lane and 75 mgN/l for the New Lane
- Total effluent ortho-P and Total effluent P: As the influent TKN increased beyond 75 mgN/l for the Old Lane and 85 mgN/l for New Lane, all models increased in terms of these variables due to limited amounts of RBCOD and SBCOD available for biological phosphorous removal. A decrease in influent TKN had the opposite effect
- Sludge treatment: An increase in influent TKN has a negligible impact on the sludge treatment facilities resulting only in an increase in the dissolved N load (nitrate and ammonia) on the anaerobic and aerobic digester resulting in higher N concentrations in the digested sludge. The following is noted:
 - For the anaerobic digester, as the influent TKN increased, there was a slight increase in the methane gas production (i.e., an increase in the influent TKN from 85 mgN/l to 130 mgN/l resulted in a 14% increase in methane gas production), specifically in the BioWin models (steady-state and dynamic-state) due to the higher nitrifier biomass that is digested. The Author's PWM remained unchanged
 - For the aerobic digester, as the influent TKN increased, there was a slight increase in the aeration requirements (i.e., less than 3% difference as the influent TKN increased from 85 mgN/l to 130 mgN/l) and a decrease in active fraction with respect to VSS and TSS (i.e., less than 15% difference as the influent TKN increased from 85 mgN/l to 130 mgN/l) specifically in the BioWin models (steady-state and dynamic-state).

The various models (steady-state and dynamic-state) appeared to follow the predictions put forth. However, with the exception of the BioWin models, all other models adopted in this Dissertation do not consider the impact that the pH outside the range of 7.2 – 8.0 would have on the μ_{Max} and the nitrification capacity of the bioreactor. This is a major shortfall in these models.

9.4.2 Maximum specific growth rate of nitrifiers (μ_{Max})

The maximum specific growth rate of nitrifiers (μ_{Max}) is a critical wastewater parameter in the design of activated sludge systems, specifically for BNR systems because of its impact on the design (sizing) and performance of biological N removal systems. Changes in μ_{Max} do not cause toxicity problems because a high efficiency of nitrification can be achieved even with a low μ_{Max} value provided the sludge age is long enough. However, for a specific sludge age, a decrease in μ_{Max} may cause cessation of nitrification due to nitrifier washout from the system. μ_{Max} is extremely sensitive to the pH of the mixed liquor outside the range of 7.2 – 8.0. In practise, the approach is to select a low and conservative value for μ_{Max} to ensure nitrification always takes place. The importance of the selection of μ_{Max} cannot be overstated, if a higher value is selected in design than the actual value during plant operation, even with a safety factor (s_f) of 1.25, the plant is likely to experience nitrification problems resulting in a fluctuating effluent ammonia concentration. As a result, conservative estimates of μ_{Max} (low) and a high safety factor (s_f) are essential to ensure nitrification and a low effluent ammonia concentration. Varying the μ_{Max} had the following impact on the steady-state and dynamic-state models of the case study WWTW:

- Effluent ammonia concentration and Total Effluent N: As the influent μ_{Max} decreased below 0.350, the total effluent ammonia and total effluent N concentrations for the BioWin models increased significantly. In terms of the other models, this phenomenon also occurred but at minimum temperature conditions when the μ_{Max} decreased below 0.250 for the Old Lane and 0.275 for the New Lane.

The different models (steady-state and dynamic-state) followed the same trend but nitrification problems occurred at different μ_{Max} values. The BioWin model showed partial nitrification at a higher μ_{Max} threshold value (0.350) than the other models (0.250 and 0.275 for the Old Lane and New Lane respectively) which occurred under minimum temperature conditions only.

9.4.3 Readily biodegradable COD (RBCOD)

RBCOD can be considered a wastewater characteristic that can vary significantly during the lifetime of a WWTW, which impacts significantly on the performance of the WWTW with respect to nitrogen and phosphorous removal. In a NDBEPR system, the BEPR system is simply combined with the nitrification and denitrification system, as the PAOs and OHOs act essentially independently of each other. The only link between these two groups is the hydrolysis to VFA of the F-RBCOD in the anaerobic reactor (Wentzel *et al.*, 1990) and its utilisation by the OHOs for denitrification when nitrate and/or dissolved oxygen enters the anaerobic zone.

Varying the influent RBCOD had the following impacts on the steady-state and dynamic-state models of the case study WWTW:

- Bioreactor: An increase in influent RBCOD increased the sludge mass (increase in OHO and PAO biomass) of the system resulting in an increase in reactor VSS and TSS concentration for a specific sludge age. However, in an existing reactor the volume is fixed, to compensate, the sludge age of the system will need to decrease by increasing the sludge wasting rate to maintain a fixed mass of solids

in the reactor. The active fraction with respect to VSS and TSS of the mixed liquor increased linearly due to the increase in OHOs and PAO biomass. A decrease in RBCOD will have the opposite effect. This was observed in all models (steady-state and dynamic-state)

- Effluent ortho-P and nitrate concentration: As the RBCOD increases: i) The VFA uptake by the PAOs will increase resulting in an increase in the PAO biomass which will increase the biological P removal of the system, resulting in a lower ortho-P in the effluent; and ii) The electron donors available for denitrification increases, resulting in a lower nitrate concentration in the effluent. A decrease in RBCOD will have the opposite effect. This was observed in all models. For the Author's PWM and PWSSD model, all P (except the unbiodegradable soluble portion) was removed at a threshold RBCOD fraction of 0.100 (both lanes), whereas for the BioWin and UCTPHO models, this took place at a 0.200 RBCOD fraction (both lanes). BioWin adopts two different maximum specific growth rates for the PAOs, namely a higher growth rate constant under phosphorous rich conditions which results in a higher uptake of phosphorous, and a lower growth rate constant under phosphorous limited conditions, where phosphorous uptake is limited. This lower growth rate constant has a different stoichiometry (no polyphosphate storage) and is the main reason for the higher threshold RBCOD. As the PAO growth in the BioWin model is less resulting in a lower PAO population, there is less potential for aerobic polyphosphate uptake, resulting in higher effluent Ortho-P concentrations.
- Sludge treatment: An increase in RBCOD will increase the mass of solids wasted from the bioreactor and their active fractions with respect to VSS and TSS, therefore increasing the load on the sludge treatment units. The increase in PAOs in the aerobic digester will increase the active fraction with respect to VSS and TSS of the aerobically digested sludge and increase the design volume of the aerobic digester. As the influent RBCOD increased, the aerobic digester OUR increased slightly for all models. Also due to the higher PAO biomass wasted at higher RBCOD fractions, more gas is produced in the anaerobic digester as well as higher N and P concentrations in the dewatering supernatant.

The different models (steady-state and dynamic-state) followed the same trends described above. The only difference noted in the models is the RBCOD fraction at which complete P removal took place. The Author's PWM and PWSSD models had the same RBCOD fraction, and the BioWin and UCTPHO models had a higher RBCOD fraction at which complete biological phosphorous removal took place.

9.4.4 Closing comment

The influent TKN (TKN/COD ratio) and RBCOD are specific wastewater characteristics that can vary during the lifetime of a plant having a strong impact on its N and P removal performance. μ_{Max} is also a critical wastewater parameter with limited knowledge of its variation in wastewater. At sludge ages close to the minimum sludge age for nitrification, this parameter impacts severely on the performance of biological N removal systems. In conclusion, substantial changes in the influent TKN, μ_{Max} and RBCOD will impact significantly on a WWTW, specifically with respect to N and P removal therefore impacting on effluent and sludge quality.

9.5 Closing Comments on Wastewater Process Modelling

From the knowledge gained on the modelling of wastewater processes during this dissertation, the Author offers a closing summary on the value of using steady-state and dynamic-state models and some thoughts to further develop and enhance modelling tools from a designer's perspective.

As discussed in **Section 2.1**, a wastewater treatment plant is complex with many interactions of different processes (biological, chemical and physical) and products taking the form of various phases (aqueous, gas and solid) complicated further by strong variations in influent characteristics, concentrations and flows. To manage these complexities, wastewater process models have been developed over the past 30 years to assist designers, operators and researchers. These models have grown from stand-alone models for individual process units to plant-wide computational steady-state and dynamic models which cater for a broad spectrum of wastewater engineering objectives such as effluent and sludge quality, energy efficient design and nutrient recovery. Steady-state models are powerful in the sense that they comprise simple, explicit, algebraic equations that allow high-level answers to be found easily and quickly with much less input information than dynamic models (Ekama, 2009). These models are usually simple and quick to estimate the design requirements (i.e., volumes, areas, aeration requirements etc.) and operation requirements (e.g., wasting rates, dewatering requirements etc.) of a WWTW. In contrast, dynamic models require detailed input formation and sophisticated mathematical solvers (Wu and Ekama, 2014), but are more accurate in predicting effluent quality, system responses to dynamic conditions and the inhibitory effects of pH, temperature and metabolic products. The decision of selecting a steady-state or dynamic-state model is influenced by several factors, such as available information and influent data, user competency and modelling experience, size and complexity of the plant, as well as the detail and accuracy required by the designer. Models in the form of a steady-state or dynamic-state can serve as a valuable design tool as follows:

- Design: For the design of a new plant (i.e., greenfield); designing an upgrade of an existing plant; and options analysis, steady-state models are preferred as they are pre-processors to generate WWTW process unit sizing and layouts for the dynamic models. Steady-state models therefore complement the dynamic models because they generate the starting conditions required to initiate the dynamic simulation (Ekama, 2009)
- Optimisation: For confirming an existing plant's design capacity; evaluating the behaviour and performance trends of an existing plant; or optimising an existing plant in terms of process and operational modifications, dynamic models are preferred because they can simulate effluent quality and system responses to dynamic conditions (flow and load) and the inhibitory effects of low pH, temperature and metabolic products
- Operational and control strategies: For online monitoring and control; troubleshooting of an existing plant; training of operators; and integration with SCADA systems, dynamic models are preferred.

Although steady-state design approaches are still very common, there is a shift towards plant-wide modelling using dynamic mathematical modelling tools which cater for a broad spectrum of wastewater engineering objectives and allows for more time efficient design outcomes. However, these complex dynamic mathematical

modelling tools do require competent and experienced modellers. It is important to note that the accuracy of a wastewater process model output (whether a steady state model or dynamic model) is subject to a number of criteria, with a few important ones cited below:

- Inserting the correct inputs and model parameters, and using reliable plant data (flows, sampling and laboratory analysis data etc.)
- The user must have a thorough technical knowledge of wastewater treatment processes, specifically the biological, chemical, physical processes and reasonable modelling experience. This is required to understand the model configuration; identify and diagnose model errors; and correctly interpret model outputs
- Influent characteristics can vary over a Plant's life-time, so the user should have sufficient experience to incorporate design safety factors on critical aspects of the process.

In a technology evolving environment, computational power is growing, data is becoming prolific, and there is a need to continuously improve design and operation efficiency. As such, there is an expectation that the capacity and requirements of models will evolve accordingly to meet these challenges. In closing, as wastewater process modelling enters a new generation, the following concepts may require future attention by model developers in both the research and commercial sectors:

- A wastewater engineer uses numerous tools or applications for the design of a WWTW, namely for the process design, mechanical design and hydraulic design, which implies repetition and inefficient design. The concept of a holistic design tool which integrates process design, mechanical design and hydraulic design functions (incl., computational fluid dynamics) may be a future design solution
- Building information modelling (BIM) has transformed the design field, and 4D BIM is an emerging design tool which involves the intelligent linking of 3D computer-aided design (CAD) software with time or schedule related information i.e., enables a sequence of events to be depicted visually on a timeline that has been populated by a 3D model. 4D CAD design software could also be linked to wastewater process modelling, using visualization to enhance the process design experience and providing the framework for a digital twin
- The majority of commercial modelling software does not offer functions for costing (i.e., capital costs and operation and maintenance costs) and reporting. Future versions of modelling software will need to include costing and reporting functions to assist designers, thus improving the efficiency of the design process
- In the design of a WWTW, one of the initial design deliverables is the process design, and this is immediately followed by the development of a process and instrumentation diagram (P&ID), process flow diagram (PFD) or Mechanical Flow Diagram (MFD). Currently, none of the commercial modelling software offers this function. Future development should consider interface functions that link modelling simulation software to a P&ID or PFD or MFD thus streamlining the design process
- Plant-wide modelling tools are currently being developed with the capacity to interface with a SCADA system, therefore allowing real-time input for monitoring and control strategies. In future, modelling simulation software may be integrated with a SCADA system, with the simulation model acting as the

artificial brain of the WWTW through the SCADA system. This may allow for the operation and control of the plant to be based on predictions made by the modelling simulation software allowing for more efficient process operation and control

- Traditionally, the primary objective of wastewater treatment plant monitoring was for compliance and metering purposes. Water utilities collect data from supervisory control and data acquisition (SCADA) systems (flow data, online monitoring, energy consumption, equipment run-hours etc.), laboratory information management systems (LIMS) and computerized maintenance management systems. Although this data is beneficial, the data is gathered and stored in a fragmented manner and as such does not provide the useful insight required for process control and operation, evaluating plant performance, plant optimisation, energy consumption minimisation and optimisation of operation and maintenance. Advances in modern control systems and sensor technology (the so-called internet of things) have allowed WWTW to be better controlled and operated, it also means that the data collected on WWTW has increased exponentially. The data science field has exploded with new developments in order to tap into the potential of the large amount of data being produced e.g., data visualisation software for dashboard reporting or advanced machine learning for predictive maintenance analytics. As the Big Data revolution unfolds, we will see smart systems being introduced which allow the automated management, storage and analytics of data in real-time, while also introducing machine learning and artificial intelligence concepts. Other industries such as the energy industry (e.g., renewable power plants) are at the fore of such technologies and are treating their operational data as strategic information to better manage their physical assets and investments. The integration of improved data collection, management and analysis of wastewater plant data will aid Water Utilities to improve efficiency (process control and operation, plant performance, energy consumption and improved operation and maintenance), extending asset life and addressing long-standing asset management challenges and inform better business decision making (guide long term planning and investment strategies). Commercial modelling software developers will need to consider how their systems can be improved to include functionality for data storage, analysis and reporting.

Available wastewater process models, especially commercial wastewater simulation software have provided designers, operators and researchers with a powerful design tool to aid in the process design of a WWTW. These tools are fast evolving to manage prolific data inputs, improve process design modelling efficiency and the capacity to interface with a SCADA system of an actual WWTW for monitoring and control strategies. In future, wastewater process models may not only play a role as a design tool but may also be incorporated into the management, control and operation of a WWTW.

10. CONCLUSION

This dissertation has set out to achieve the following four objectives:

1. Firstly, to determine the existing theoretical process capacity of the case study WWTW based on actual (field data) influent characteristics, and predict the effluent quality characteristics using steady-state and dynamic-state modelling tools
2. Secondly, to compare the output and results of the various models (steady-state and dynamic-state) developed for the existing full-scale WWTW, and establish the reasons for the difference in model output and results where these occur
3. Thirdly, to examine the impact that specific wastewater characteristics have on the process capacity of the various process units and its influence on the overall performance of the WWTW specifically with respect to effluent and sludge quality. The wastewater characteristics selected were those considered most critical to impact biological nitrogen and phosphorous removal
4. Lastly, based on the knowledge gained in this dissertation specifically with respect to process modelling, evaluate the design value offered by steady-state and dynamic-state modelling approaches, and provide some thoughts to further develop and enhance modelling tools from a designer's perspective.

The first three objectives were achieved through the findings presented in **Sections 6, 7 and 8**, and a summary of these findings is further included in **Section 9**. The fourth objective is presented at the end of **Section 9**. This dissertation also established the following secondary objectives:

- Provided a comparison of the output results of the Author's PWM, PWSSD and BioWin, and pointed out differences that should arise in the model's output. Research of this nature is currently limited
- Presented the correlations between different model output variables under varying conditions, which specifically focussed on the variation of influent wastewater characteristics that impact biological nitrogen and phosphorous removal namely the influent TKN (TKN/COD Ratio), the maximum specific growth rate of nitrifiers (μ_{Max}) and readily biodegradable COD (RBCOD)
- Provided concepts that may require the future attention of developers (research and commercial) in the wastewater process modelling field.

Wastewater process models have evolved over the last three decades to address the complexities associated with the process design of a WWTW. Today, designers, operators and researchers have access to simulation design software that leverages powerful computational capabilities, and is founded on fundamental biological, chemical, hydraulic and physical process knowledge. At present, predicting the reliability of an operational WWTW is difficult due to the interactions of different processes (biological, chemical and physical) and is further complicated by variations in influent parameters. A future intervention may be the extension of process design simulation software to manage the control and operation of a WWTW, acting as the artificial brain of the SCADA system. This may allow for the operation and control of the WWTW to be based on predictions made by the modelling simulation software allowing for more efficient process operation and control.

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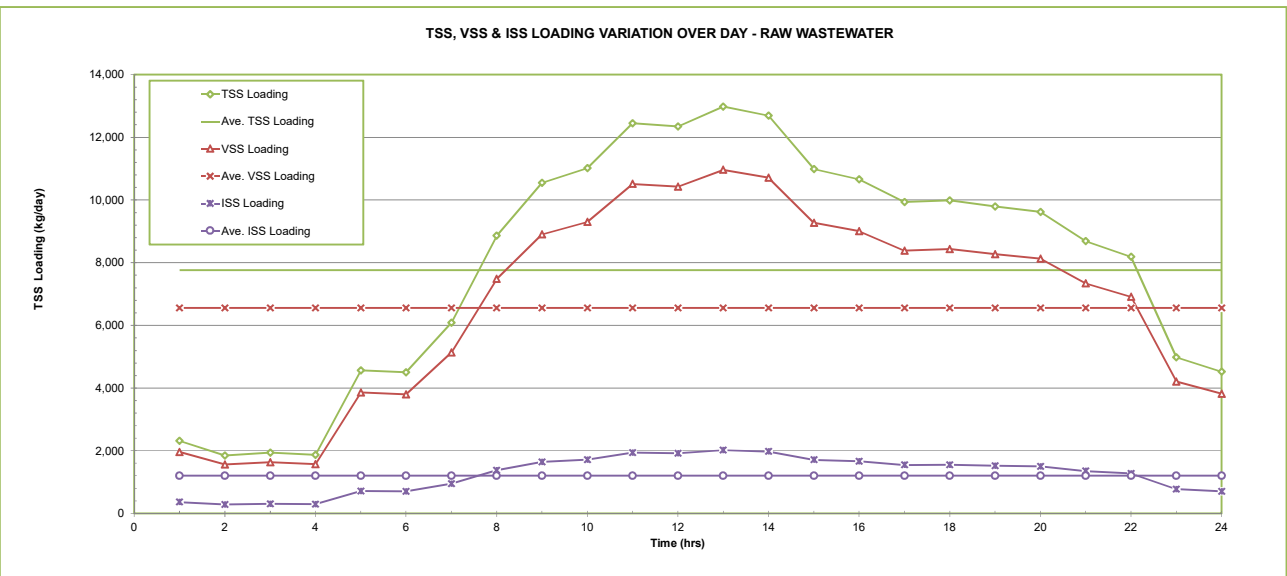
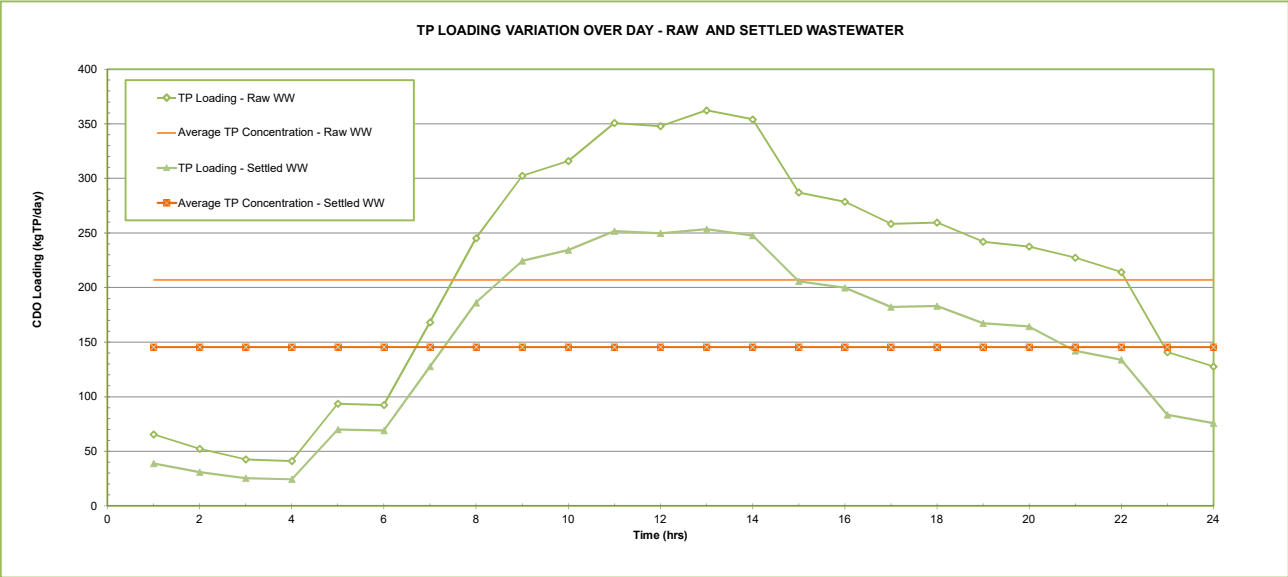
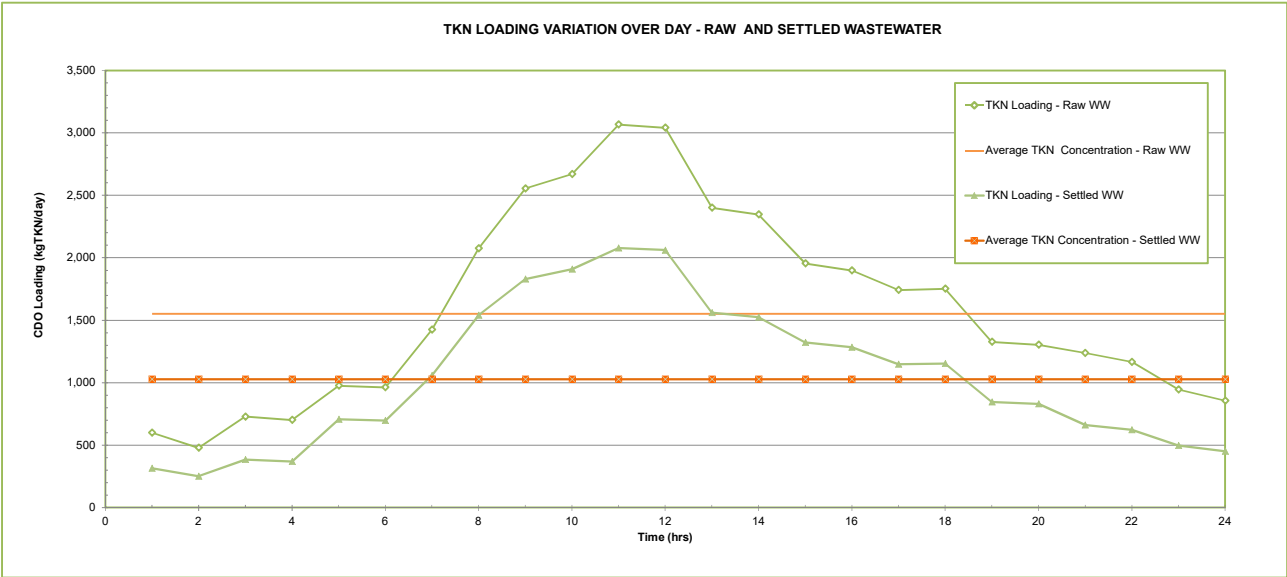
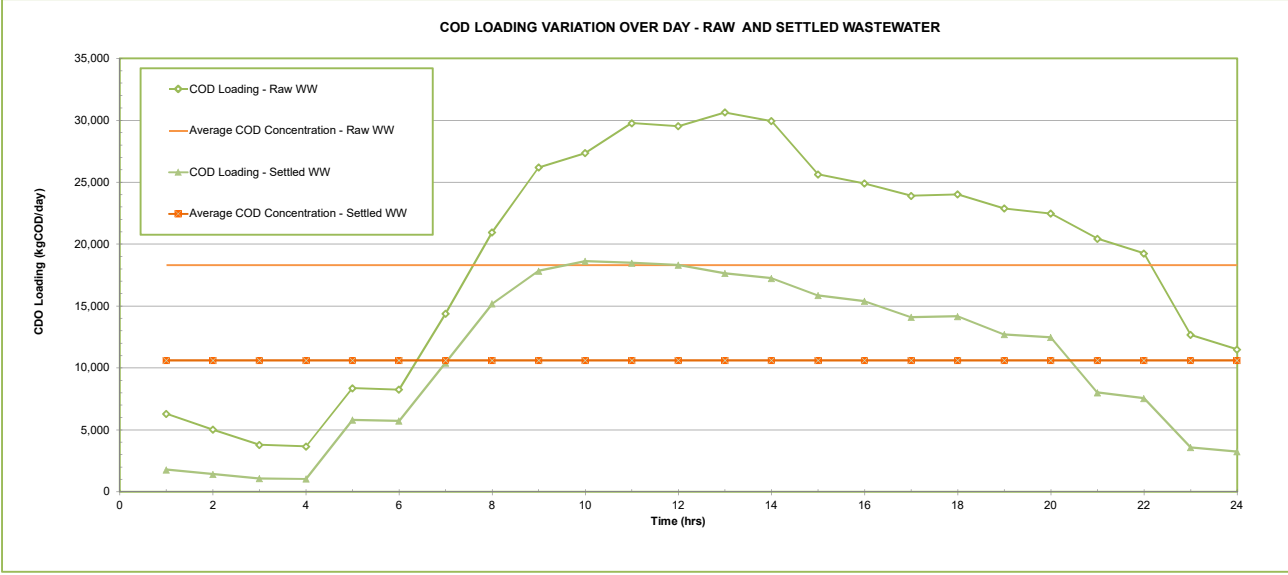
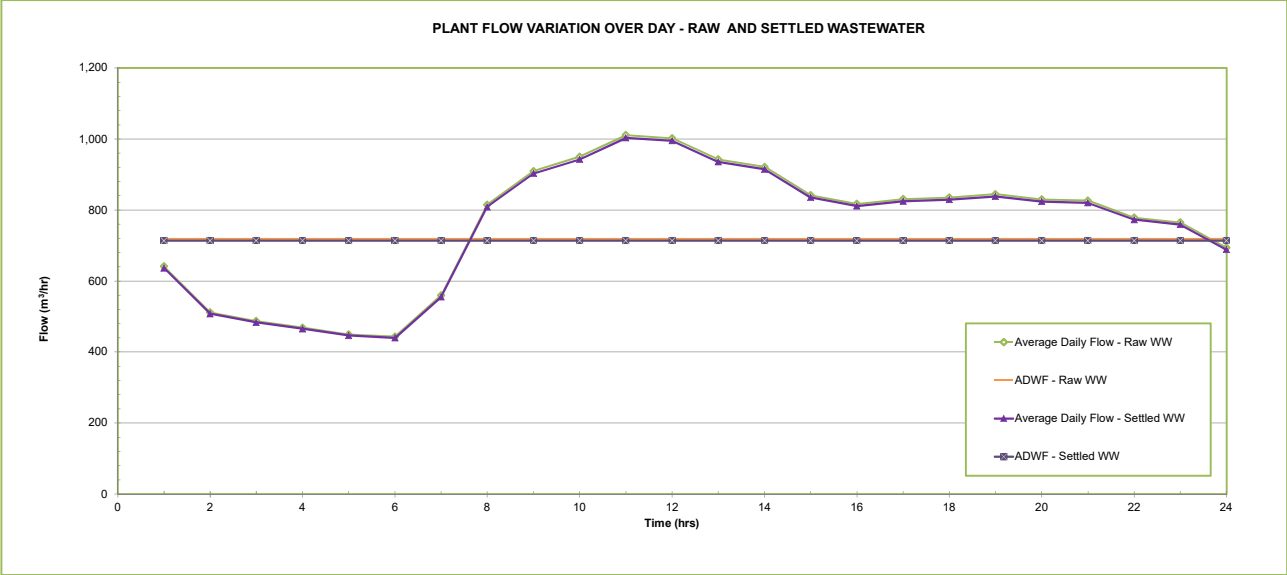
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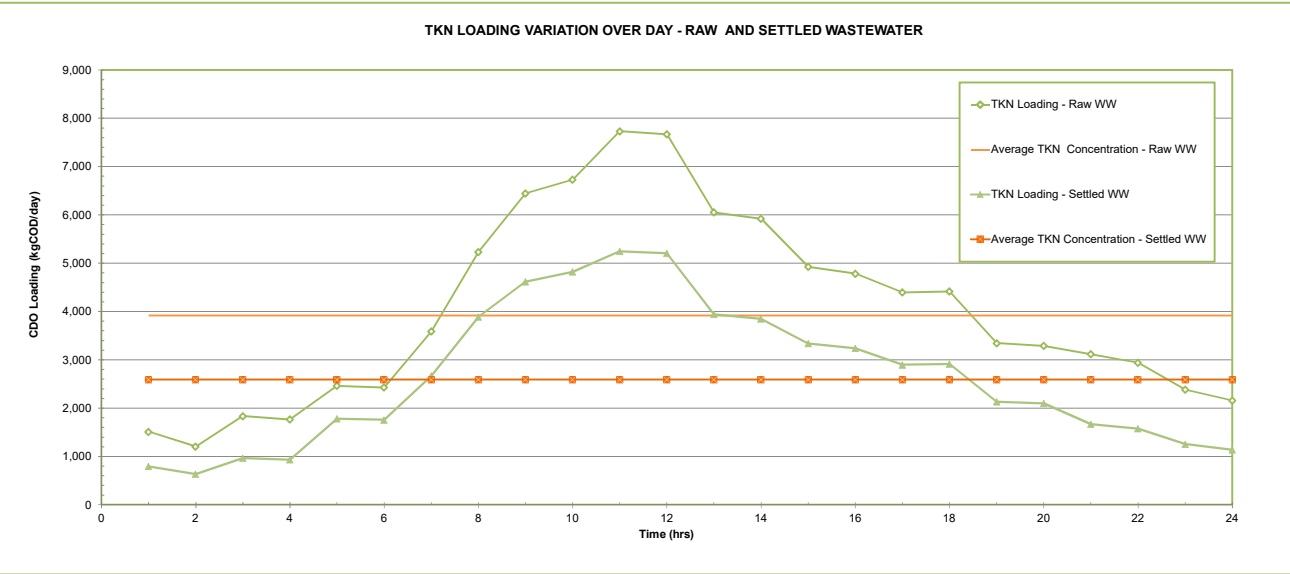
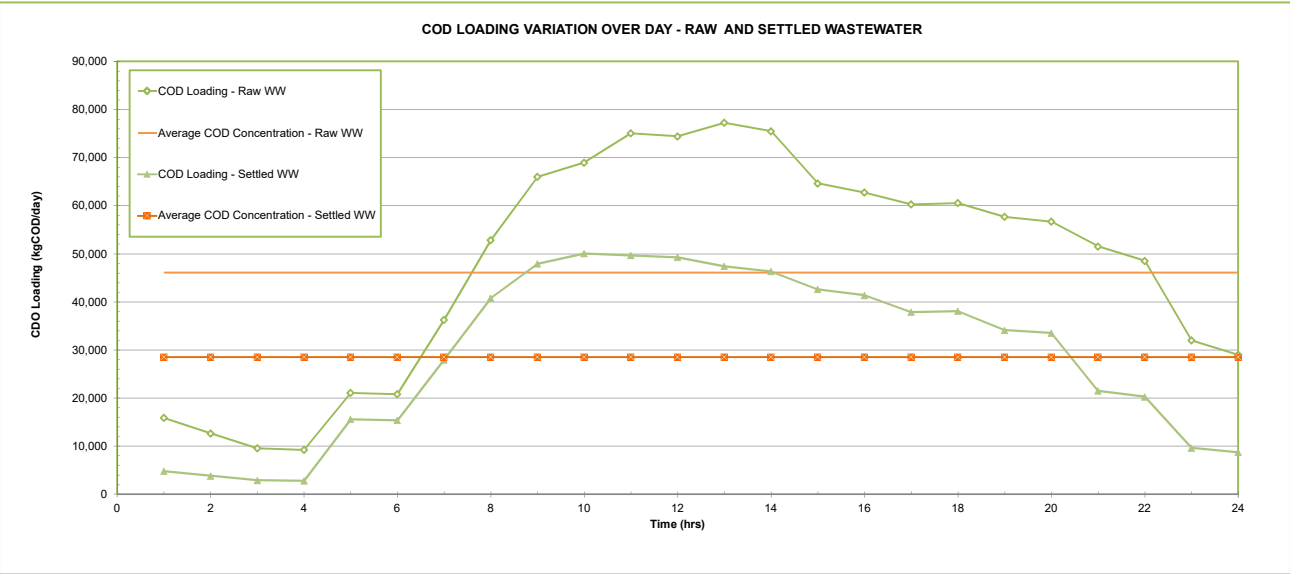
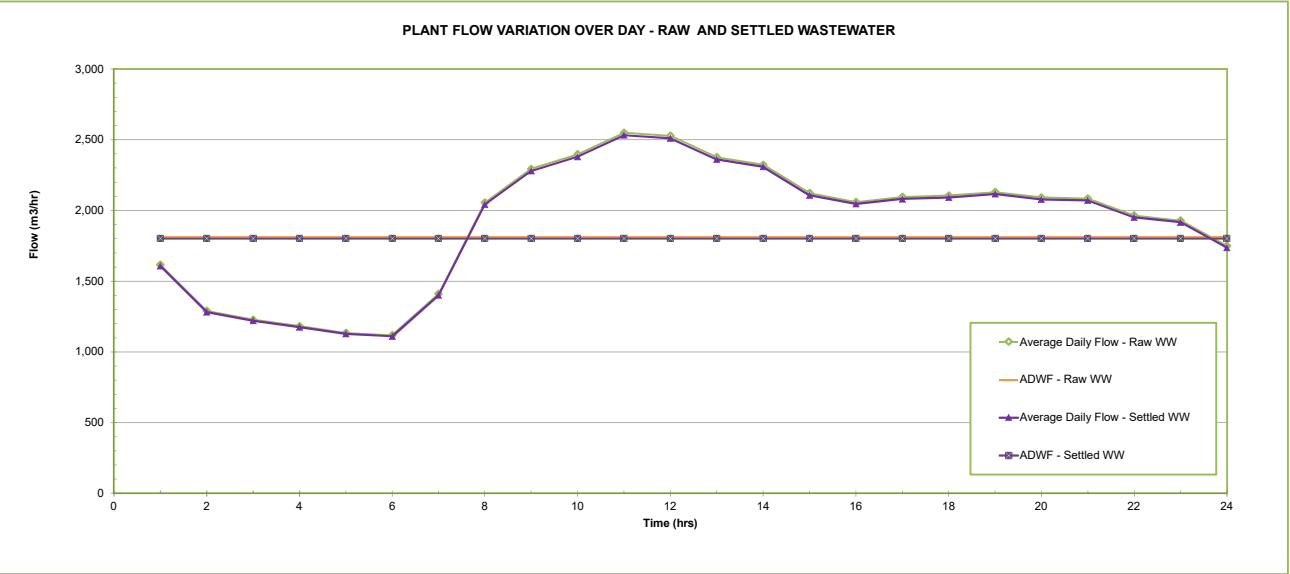
ANNEXURE A

DIURNAL LOAD PATTERN FOR THE INFLUENT WASTEWATER CHARACTERISTICS (RAW AND SETTLED)

ANNEXURE A: DIURNAL LOAD PATTERN FOR THE INFLUENT WASTEWATER CHARACTERISTICS (RAW AND SETTLED): OLD LANE



ANNEXURE A: DIURNAL LOAD PATTERN FOR THE INFLUENT WASTEWATER CHARACTERISTICS (RAW AND SETTLED): NEW LANE



ANNEXURE B

STATISTICAL ANALYSIS OF SETTLED WASTEWATER CHARACTERISTICS (OLD LANE AND NEW LANE) AND EFFLUENT WASTEWATER CHARACTERISTICS

ANNEXURE B:**STATISTICAL ANALYSIS OF SETTLED WASTEWATER CHARACTERISTICS (OLD LANE AND NEW LANE) AND EFFLUENT WASTEWATER CHARACTERISTICS**

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1. Statistical Analysis of settled wastewater characteristics

The settled wastewater data (Old Lane and New Lane) presented in **Section 5.2.1 of this Dissertation** was analysed statistically per wastewater characteristic to confirm if the data was normally distributed; and lastly the normality of the data was checked by assessing the skewness and degree of curvature. The Author has not discussed the aforementioned analysis in detail below and has only documented the findings of the statistical analysis. The reader is referred to **Section 5.2.1 of this Dissertation** for details on the statistical analysis process. The remainder of this section has been structured such that the findings of the statistical analysis for the Old Lane and New Lane are discussed separately below.

1.1 Statistical Analysis of settled wastewater characteristics (Old Lane)

The grab sample data of the Old Lane was firstly analysed for outliers. The three-year data record comprised anomalies, namely some records where the COD, TKN, ammonia, Total-P and ortho-P were not recorded or analysed¹. The data did contain outliers which were omitted from the data set. Outliers omitted from the wastewater characteristics data for the Old Lane were as follows:

- COD where values of more than 1750 mgCOD/ℓ were deemed outliers
- TKN where values of more than 150 mgN/ℓ were deemed outliers
- TSS where values of more than 1000 mgTSS/ℓ were deemed outliers.

The results of the statistical analysis are summarised in **Table 1-1** below:

Row No.	Statistical Parameter	Total COD mgCOD/ℓ	TKN mgN/ℓ	Ammonia mgN/ℓ	Total Phosphorous mgP/ℓ	Ortho-phosphates mgP/ℓ	TSS mgTSS/ℓ
1	Outliers removed	Yes	Yes	No Outliers	No Outliers	No Outliers	Yes
2	Data Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed
3	No. of Samples (excl. Outliers)	180	61	186	61	186	175
4	Mean Value	547	51	38	7.2	5.8	95
5	Minimum Value	268	36	24	4.4	2.8	36
6	Maximum Value	901	73	60	11.4	9.7	236

¹ In this case, the fields were left blank, and this omission did not skew the data analysis.

Row No.	Statistical Parameter	Total COD mgCOD/ℓ	TKN mgN/ℓ	Ammonia mgN/ℓ	Total Phosphorous mgP/ℓ	Ortho-phosphates mgP/ℓ	TSS mgTSS/ℓ
7	Median	542	51	38	6.9	5.8	96
8	Mode	532	52	38	6.2	5.7	97
9	Standard Deviation	114	10	6.0	1.8	1.4	32
10	Coefficient of variation	0.21	0.20	0.16	0.25	0.25	0.33
11	Coefficient of Skewness	0.05 (Symmetrical)	0.17 (Approx. symmetrical)	0.06 (Symmetrical)	0.28 (Approx. symmetrical)	0.19 (Approx. symmetrical)	0.45 (Approx. symmetrical)
12	Coefficient of Kurtosis	3.68 (Peaked curve)	3.01 (Bell curve)	4.08 (Peaked curve)	2.35 (Flat Curve)	2.81 (Flat Curve)	4.12 (Peaked curve)

Table 1-1 : Settled wastewater characteristics (Old Lane) - Summary of statistical analysis

The following conclusions can be drawn from the statistical analysis presented in **Table 1-1** (above) and **Figure 1-1** (below):

- From the probability curves in **Figure 1-1** below for the COD, TKN and Total-P, this specific data could be fitted with a straight line (normal distribution line) on an arithmetical probability curve. As a result, this data can be described as normally distributed. Although not shown in **Figure 1-1**, arithmetical probability curves were also developed for the remaining wastewater characteristics shown in **Table 1-1** which also fitted with a straight line, indicating that this data is also normally distributed
- The normality of the data was also checked by assessing the skewness and degree of curvature of the data. The following was found:
 - The grab sample data was approximately symmetrical as represented by the coefficient of skewness
 - The degree of curvature of the data distribution was mostly peaked as represented by the coefficient of kurtosis, with the exception of the Total-P and Ortho-P which was flatter
 - The symmetry and degree of curvature described above was also confirmed via a Histogram and Bell curve as shown in **Figure 1-1** for the COD, TKN and Total-P. Although not shown in **Figure 1-1**, Histogram and Bell curves were also developed for the remaining wastewater characteristics shown in **Table 1-1** which also confirmed the findings of the coefficients of skewness and kurtosis
- From the above statistical analysis, it can be concluded that the grab sample data for the settled wastewater of the Old Lane is normally distributed. As a result, standard statistical measures can be used to describe the data, or aid in the selection of design values.

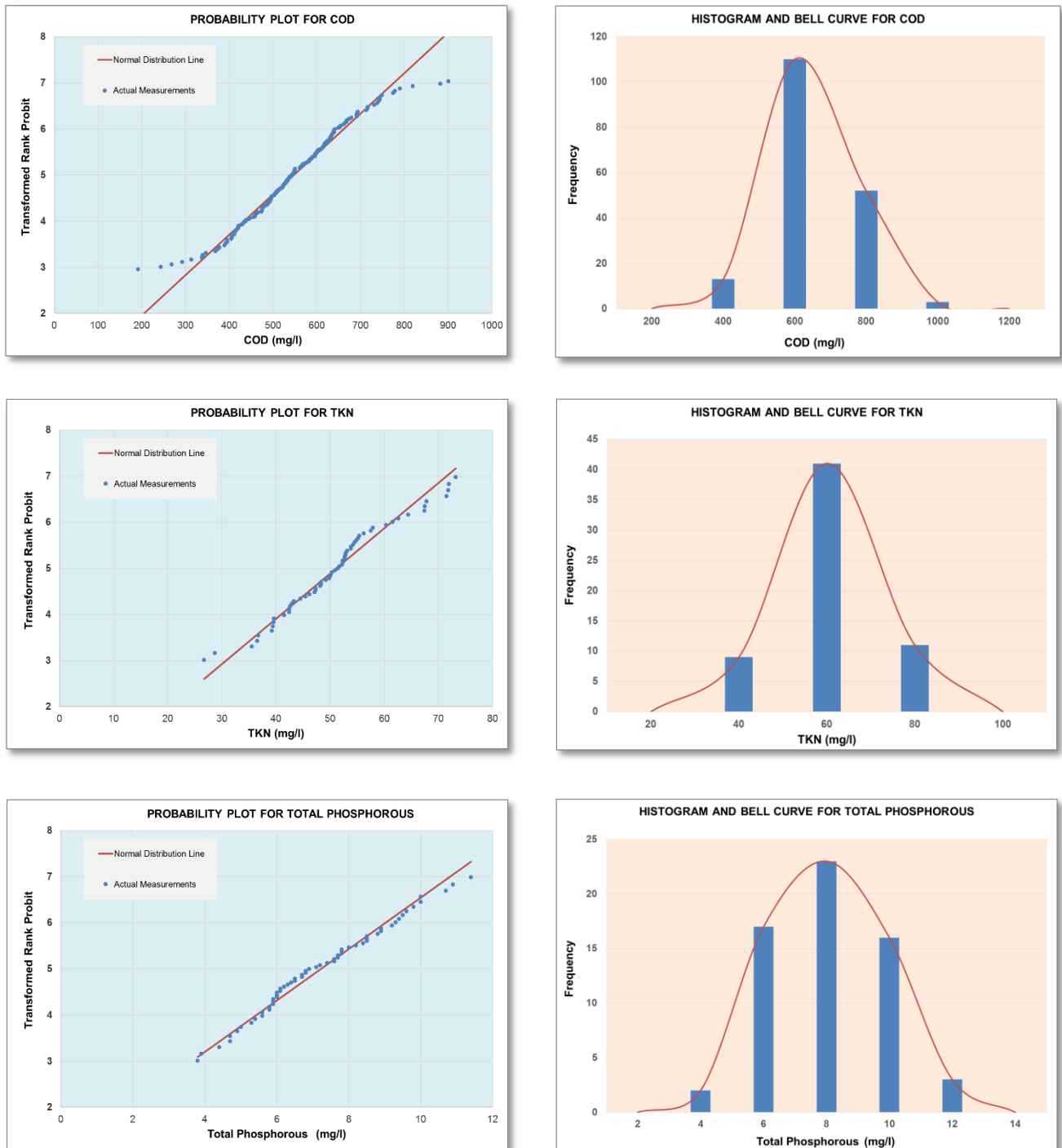


Figure 1-1 : Settled wastewater characteristics (Old Lane) - Probability curve and Histogram & Bell curve

1.2 Statistical Analysis of settled wastewater characteristics (New Lane)

The grab sample data of the New Lane was firstly analysed for outliers. The three-year data record comprised anomalies, namely some records where the COD, TKN, ammonia, Total-P, ortho-P and TSS were not recorded

or analysed². The data did contain outliers which were omitted from the data set. Outliers omitted from the wastewater characteristics data for the New Lane were as follows:

- COD where values of more than 1750 mgCOD/ℓ were deemed outliers
- TKN where values of more than 150 mgN/ℓ were deemed outliers
- Ammonia where values of more than 100 mgN/ℓ were deemed outliers
- Ortho-P where values of more than 25 mgP/ℓ were deemed outliers
- TSS where values of more than 1000 mgTSS/ℓ were deemed outliers.

The results of the statistical analysis are summarised in **Table 1-2** below:

Row No.	Statistical Parameter	Total COD mgCOD/ℓ	TKN mgN/ℓ	Ammonia mgN/ℓ	Total Phosphorous mgP/ℓ	Ortho-phosphates mgP/ℓ	TSS mgTSS/ℓ
1	Outliers removed	Yes	Yes	Yes	No Outliers	Yes	Yes
2	Data Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed
3	No. of Samples (excl. Outliers)	172	61	180	64	181	173
4	Mean Value	582	54	39	7.7	5.9	120
5	Minimum Value	332	42	20	5.1	2.2	44
6	Maximum Value	992	86	57	14.3	10.9	338
7	Median	570	53	38	7.6	5.7	113
8	Mode	547	50	38	7.4	5.3	100
9	Standard Deviation	119	9.2	6.3	1.9	1.5	52
10	Coefficient of variation	0.20	0.17	0.16	0.25	0.25	0.43
11	Coefficient of Skewness	0.67 (Moderate. skewed)	0.85 (Moderate. skewed)	0.25 (Approx. symmetrical)	0.83 (Moderate. skewed)	0.48 (Approx. symmetrical)	1.17 (Highly skewed)
12	Coefficient of Kurtosis	3.64 (Peaked curve)	3.92 (Peaked curve)	3.68 (Peaked curve)	3.72 (Peaked curve)	3.37 (Peaked curve)	5.03 (Peaked curve)

Table 1-2 : Settled wastewater characteristics (New Lane) - Summary of statistical analysis

The following conclusions can be drawn from the statistical analysis presented in **Table 1-2** (above) and **Figure 1-2** (below):

- From the probability curves in **Figure 1-2** for the COD, TKN and Total-P, this specific data could be fitted with a straight line (normal distribution line) on an arithmetical probability curve. As a result, this

² In this case, the fields were left blank, and this omission did not skew the data analysis.

data can be described as normally distributed. Although not shown in and **Figure 1-2**, arithmetical probability curves were also developed for the remaining wastewater characteristics shown in **Table 1-2** which also fitted with a straight line, indicating that this data is also normally distributed

- The normality of the data was also checked by assessing the skewness and degree of curvature of the data. The following was found:
 - The grab sample data varied from approximately skewed to moderately skewed as represented by the coefficient of skewness, except for the TSS which was highly skewed
 - The degree of curvature of the data distribution for all wastewater characteristics were peaked as represented by the coefficient of kurtosis
 - The symmetry and degree of curvature described above was also confirmed via a Histogram and Bell curve as shown in **Figure 1-2** for the COD, TKN and Total-P. Although not shown in **Figure 1-2**, Histogram and Bell curves were also developed for the remaining wastewater characteristics shown in **Table 1-2** which also confirmed the findings of the coefficients of skewness and kurtosis
- From the above statistical analysis, it can be concluded that the grab sample data for the settled wastewater of the New Lane is normally distributed. As a result, standard statistical measures can be used to describe the data, or aid in the selection of design values.

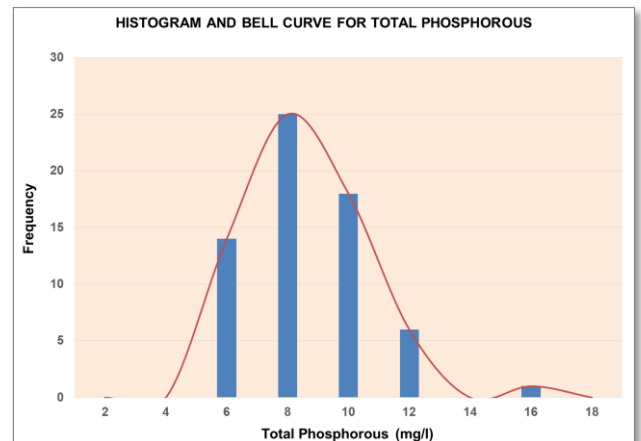
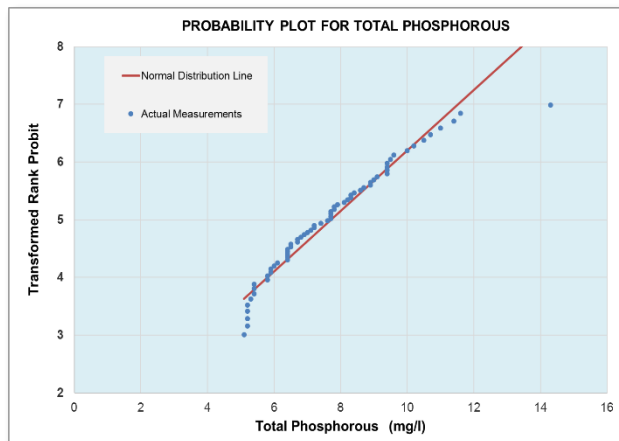
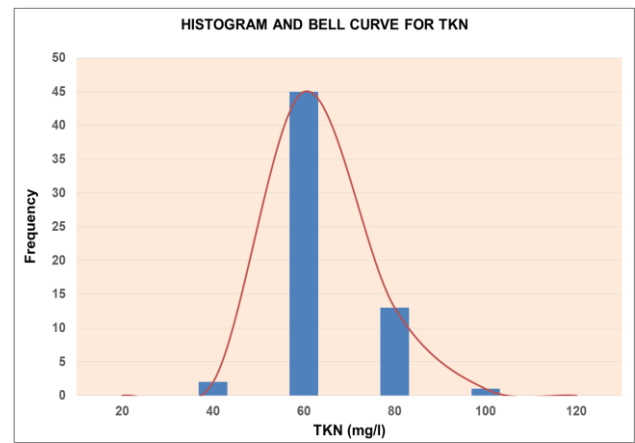
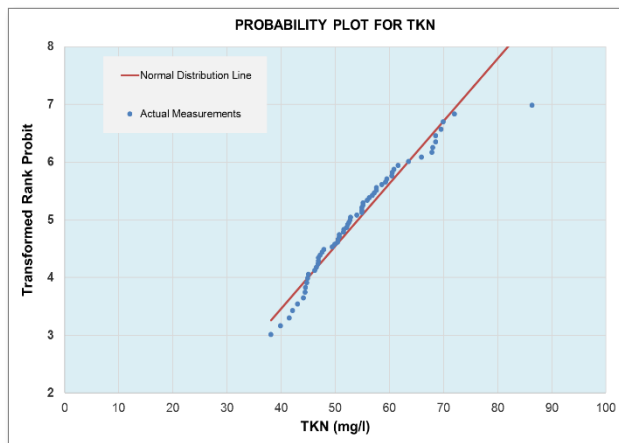
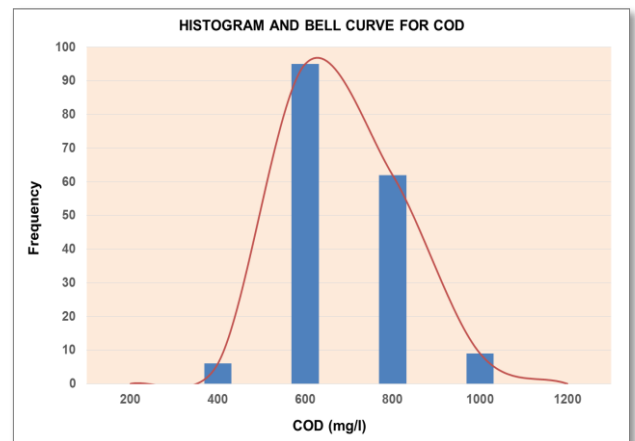
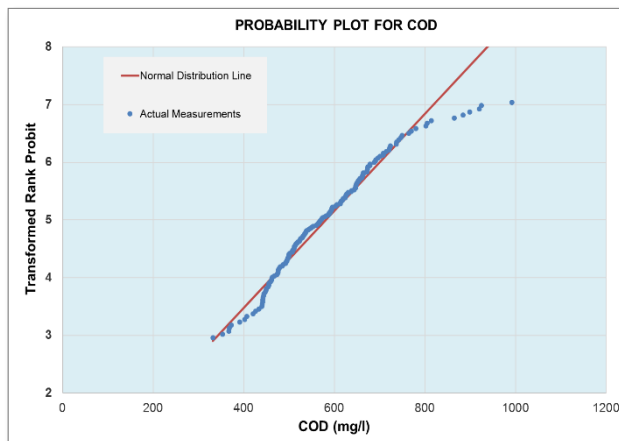


Figure 1-2 : Settled wastewater characteristics (New Lane) - Probability curve and Histogram & Bell curve

2. Statistical Analysis of effluent wastewater characteristics

The effluent characteristics presented in **Section 5.2.1 of this Dissertation** have been derived from a three-year data record of 218 grab samples. The data was analysed statistically per wastewater characteristic to confirm if the data was normally distributed; and lastly the normality of the data was also checked by assessing the skewness and degree of curvature. As with the settled wastewater discussed above, the statistical analysis of the effluent characteristics has not been discussed in detail below. The reader is referred to **Section 5.2.1 of this Dissertation** for details on the statistical analysis process.

The grab sample data was firstly analysed for outliers. The three-year data record did not comprise any significant anomalies, but there were specific effluent characteristics that did contain outliers. These outliers were omitted from the data set. Outliers omitted from the effluent characteristics data were as follows:

- COD where values of more than 100 mgCOD/ℓ were deemed outliers
- TKN where values of more than 12 mgN/ℓ were deemed outliers
- Ammonia where values of more than 10 mgN/ℓ were deemed outliers
- Total-P where values of more than 10 mgP/ℓ were deemed outliers
- Ortho-P where values of more than 10 mgP/ℓ were deemed outliers
- TSS where values of more than 100 mgTSS/ℓ were deemed outliers.

The results of the statistical analysis are summarised in **Table 2-1** and **Figure 2-1** below:

Row No.	Statistical Parameter	Total COD mgCOD/ℓ	TKN mgN/ℓ	Ammonia mgN/ℓ	Nitrate mgN/ℓ	Total-P mgP/ℓ	Ortho-phosphates mgP/ℓ	TSS mgTSS/ℓ
1	Outliers removed	Yes	Yes	Yes	No	Yes	Yes	Yes
2	Data Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed	Yes, Normally Distributed
3	No. of Samples (excl. Outliers)	212	202	213	218	209	209	214
4	Mean Value	44	4.5	1.2	1.5	1.3	1.0	7.3
5	Minimum Value	26	0.5	0.4	0.1	0.1	0.1	1.0
6	Maximum Value	67	10.1	9.3	7.2	3.6	3.6	29.0
7	Median	42	3.7	1.0	2.0	0.8	0.8	5.0
8	Mode	40	3.3	1.1	1.3	0.2	0.2	0.3
9	Standard Deviation	9	1.7	1.0	1.2	0.9	0.8	5.6
10	Coefficient of variation	0.20	0.43	1.04	0.75	0.81	0.81	0.77

Row No.	Statistical Parameter	Total COD mgCOD/ℓ	TKN mgN/ℓ	Ammonia mgN/ℓ	Nitrate mgN/ℓ	Total-P mgP/ℓ	Ortho-phosphates mgP/ℓ	TSS mgTSS/ℓ
11	Coefficient of Skewness	0.54 (Moderate. Skewed)	0.33 (Approx. symmetrical)	1.76 (Highly skewed)	0.78 (Moderate. Skewed)	1.02 (Highly skewed)	1.02 (Highly skewed)	1.56 (Highly skewed)
12	Coefficient of Kurtosis	2.69 (Flat curve)	2.71 (Flat curve)	5.77 (Peaked curve)	2.77 (Flat curve)	3.14 (Peaked curve)	3.14 (Peaked curve)	5.17 (Peaked curve)

Table 2-1 : Effluent wastewater characteristics – Summary of statistical analysis

The following conclusions can be drawn from the statistical analysis presented in **Table 2-1** (above) and **Figure 2-1** (below):

- From the probability curves in **Figure 2-1** for the COD, TKN and Total-P, this specific data could be fitted with a straight line (normal distribution line) on a logarithmic probability curve. As a result, this data can be described as normally distributed. Although not shown in **Figure 2-1**, logarithmic probability curves were also developed for the remaining wastewater characteristics shown in **Table 2-1** which also fitted with a straight line, indicating that this data is also normally distributed
- The normality of the data was also checked by assessing the skewness and degree of curvature of the data. The following was found:
 - The grab sample data was highly skewed as represented by the coefficient of skewness, with the exception of the COD and nitrate which was moderately skewed, and the TKN which was approximately symmetrical. The skewness of the data is expected for effluent quality, as effluent quality can vary dependent on the operation of the plant
 - The degree of curvature of the data distribution was mostly peaked as represented by the coefficient of kurtosis, with the exception of the COD, TKN and nitrate which was flatter
 - The symmetry and degree of curvature described above was also confirmed via a Histogram and Bell curve as shown in **Figure 2-1** for the COD, TKN and Total-P. Although not shown in **Figure 2-1**, Histogram and Bell curves were also developed for the remaining wastewater characteristics shown in **Table 2-1** which also confirmed the findings of the coefficients of skewness and kurtosis
- From the above statistical analysis, it can be concluded that the grab sample data for the effluent wastewater is normally distributed. As a result, standard statistical measures can be used to describe the data, or aid in the selection of design values.

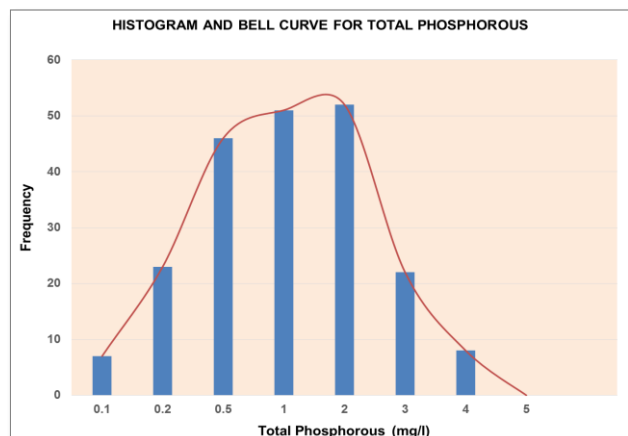
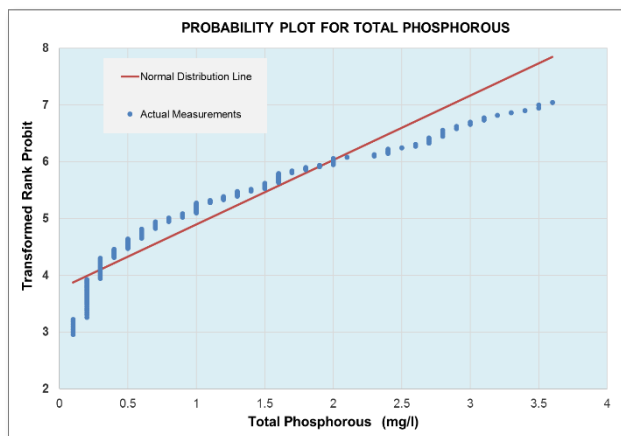
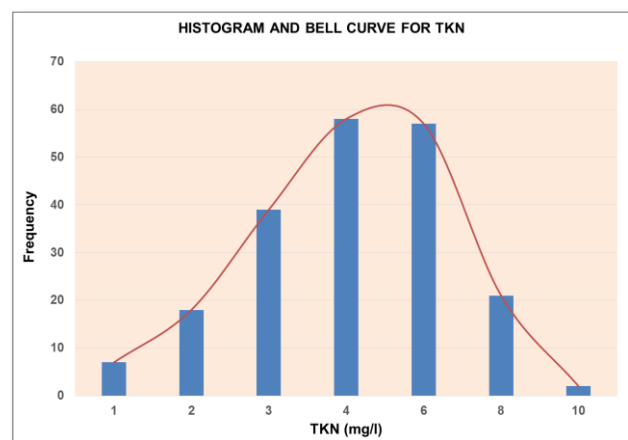
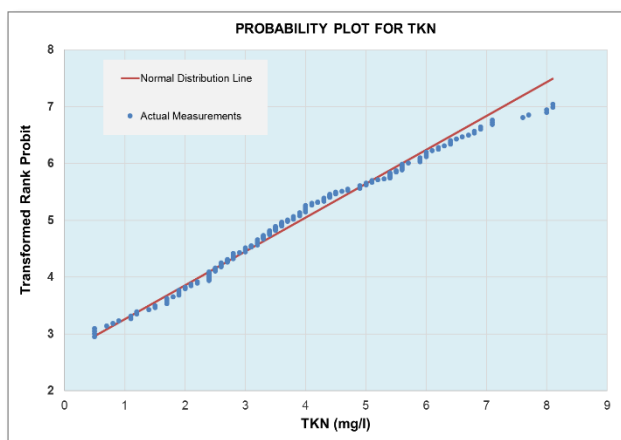
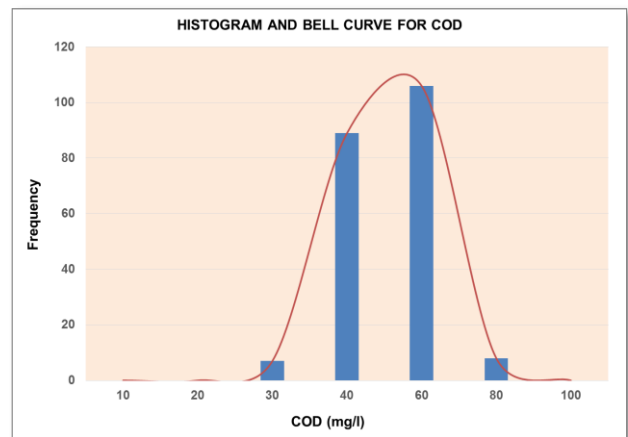
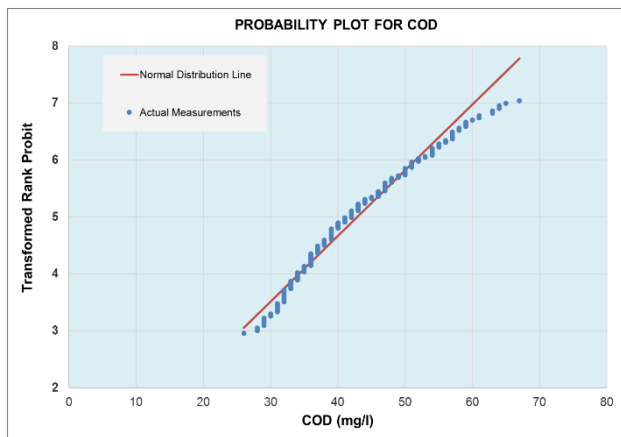
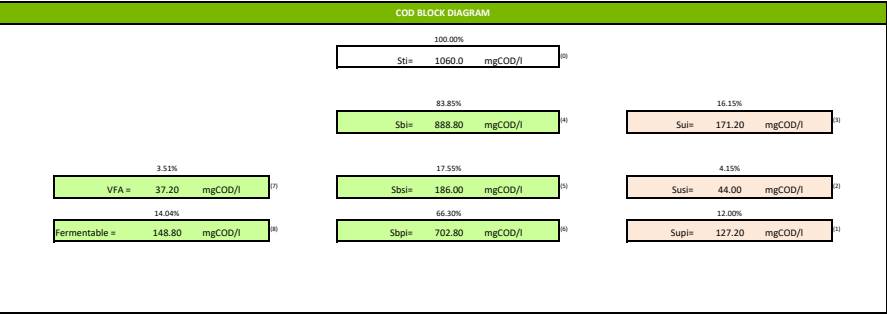


Figure 2-1 : Effluent wastewater characteristics - Probability curve and Histogram & Bell curve

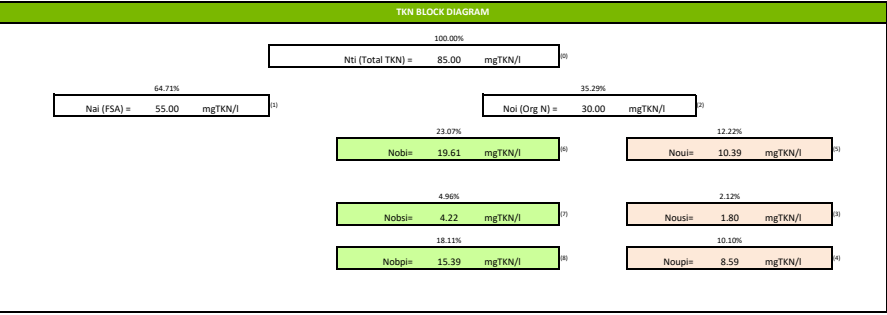
ANNEXURE C

RAW AND SETTLED WASTEWATER CHARACTERISATION

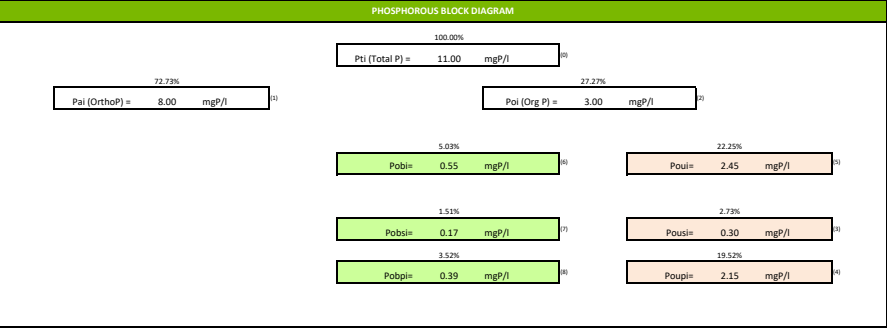
1. OLD LANE : RAW WASTEWATER CHARACTERIZATION FOR THE ACTIVATED SLUDGE SYSTEM



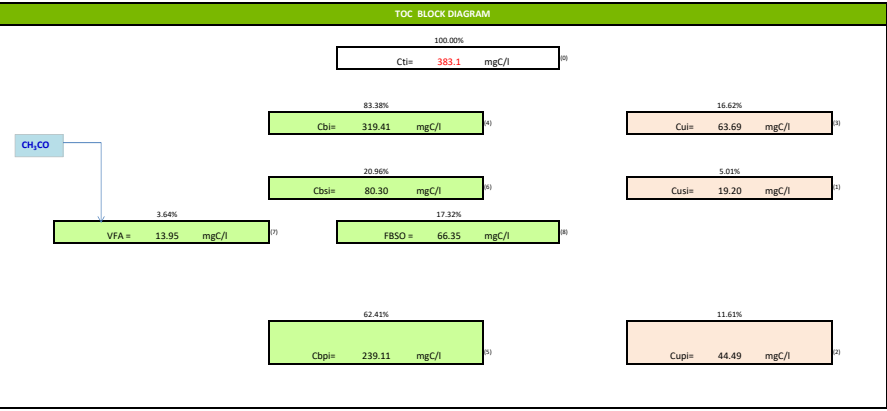
- (R) Total COD as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
(1) Given "Fraction of total influent COD that is unbiodegradable and soluble (f_{su})" OR "Given COD in effluent which is Sui"
(2) Given "Fraction of total influent COD that is unbiodegradable and particulate (f_{sp})"
(3) = Sui + Supi
(4) = Sti - Sui
(5) Given "Fraction of total influent COD that is readily biodegradable (f_{bu})" OR
= COD_{0.45um membrane filtered} - Sui [where COD_{0.45um membrane filtered} is given as 293 mg/l]
(6) = Sbi - Sbsi
(7) = VFA_{0.45um membrane filtered} Or based on "Fraction of readily biodegradable COD that is VFA" (f_{vfa})
(8) = Sbsi - VFA



- (R) Total TKN as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
(1) Given "Fraction of influent TKN that is free and saline ammonia (f_{su})" OR "Given FSA_{0.45um membrane filtered}"
(2) = Nti - Nal
(3) Given "Fraction of influent TKN that unbiodegradable and soluble (f_{su})" OR "Given (TKN-FSA) in effluent which is Nouis"
(4) = Supi x (f_{n}/f_{cv})
(5) = Nouis + Noup
(6) = Noi - Noub
(7) = Nob - Nobpi
(8) Given "Fraction of biodegradable organic TKN that is particulate ($f_{p,tkn}$)"



- (R) Total P as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
(1) Given "Fraction of influent TP that is ortho-phosphate (FSP04)" OR "Given OrthoP_{0.45um membrane filtered}"
(2) = Pti - OrthoP
(3) Given "Fraction of P content of the influent soluble unbiodegradable COD ($f_{p,tkn}$)" OR "Given (TP - OrthoP) in effluent which is Pou"
(4) = Supi x (f_{p}/f_{cv})
(5) = Pou + NPoupi
(6) = Poi - Pou
(7) " = Pobi - Pobi" OR " = P_{0.45um membrane filtered} - OrthoP - Pou" [where P_{0.45um membrane filtered} is given as 14.97 mgN/l]
(8) Given "Fraction of the biodegradable organic influent TP which is particulate (FXBP)"



- (R) Total TOC as provided in Flow Weighted Average Raw and Settled Wastewater Concentrations (Given in table 1.8)
(1) Given TOC in effluent which is Cui
(2) = Supi x (f_{c}/f_{cv})
(3) = Cusi + Cui
(4) = Cti - Cui
(5) = Cti - COD_{0.45um membrane filtered} - Cui
(6) = Cbi - Cbpi
(7) TOC_{uic} =
CH3COOH
C H O N P S
2.0000 4.0000 2.0000 0.0000 0.0000 0.0000
COD 64.0000 gCOD/mol
C Concentration 24 gC/mol
A₂ 8.0000 gC/mol
(8) = Cbsi - VFA

Typical Values (Principle, modelling and design of biological wastewater treatment, published by the International Water Association, 2008)								
Parameter	Abbreviation	Min	Raw Max	Selected Value	Min	Settled Max	Selected Value	Unit
Fraction of readily biodegradable COD that is VFA	f_{re}	0.100	0.400	0.200	0.100	0.400	0.200	mgCOD/mgCOD
Fraction of total influent COD that is readily biodegradable	f_{bu}	0.080	0.250	0.175	0.100	0.350	0.300	mgCOD/mgCOD
Fraction of total influent COD that is soluble unbiodegradable	f_{su}	0.040	0.100	0.042	0.050	0.200	0.071	mgCOD/mgCOD
Fraction of total influent COD that is particulate unbiodegradable	f_{sp}	0.070	0.200	0.120	0.000	0.100	0.050	mgCOD/mgCOD
Fraction of readily biodegradable COD that is Fermentable	f_{fer}	0.600	0.900	0.750	0.600	0.900	0.820	mgCOD/mgCOD
Fraction of influent TKN that is free and saline ammonia	f_{su}	0.600	0.800	0.647	0.700	0.900	0.809	mgN/mgN
Fraction of influent TKN that is unbiodegradable and soluble	$f_{su,tkn}$	0.000	0.040	0.021	0.000	0.050	0.026	mgN/mgN
N content of the particulate unbiodegradable influent COD	$f_{n,tkn}$	0.060	0.080	0.068	0.060	0.080	0.068	mgN/mgCOD
N content of the soluble unbiodegradable influent COD	$f_{n,tkn}$	0.000	0.060	0.021	0.000	0.060	0.026	mgN/mgCOD
Fraction of biodegradable organic TKN that is particulate	$f_{p,tkn}$	0.700	0.850	0.785	0.550	0.700	0.625	
Fraction of influent TP that is ortho-phosphate	f_{p5}	0.700	0.900	0.727	0.750	0.950	0.889	mgP/mgP
P content of the particulate unbiodegradable influent COD	$f_{p,tkn}$	0.010	0.020	0.013	0.010	0.020	0.110	mgP/mgCOD
Fraction of influent TP that is organic unbiodegradable soluble	$f_{p,tkn}$	0.000	0.030	0.027	0.000	0.040	0.033	mgP/mgP
Fraction of unbiodegradable soluble COD which is P	$f_{p,tkn}$	0.000	0.010	0.005	0.000	0.010	0.005	mgP/mgCOD
Fraction of the biodegradable organic influent TP which is particulate	$f_{p,tkn}$	0.600	0.750	0.700	0.500	0.650	0.500	mgP/mgCOD
COD/VSS Ratio of Influent UPO	$f_{u,UPO}$	1.450	1.500	1.481	1.450	1.500	1.481	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content) of Influent UPO	$f_{n,UPO}$	0.102	0.150	0.100	0.131	0.180	0.100	mgN/mgVSS
TP/VSS Ratio (Phosphate Content) of Influent UPO	$f_{p,UPO}$	0.022	0.038	0.025	0.029	0.045	0.025	mgP/mgVSS
TOC/VSS Ratio (Carbon Content) of Influent UPO	$f_{c,UPO}$			0.518			0.518	mgC/mgVSS
COD/VSS Ratio of Influent USO	$f_{u,USO}$			1.493			1.493	mgCOD/mgVSS
TP/VSS Ratio (Phosphate Content) of Influent USO	$f_{p,USO}$			0.000			0.000	mgP/mgVSS
COD/VSS Ratio of Influent FBSO	$f_{u,FBSO}$			1.420			1.420	mgCOD/mgVSS

Flow Weighted Average Raw and Settled Wastewater Concentrations (Given in table 1.8)									
Tests on Wastewater	COD	VFA	TOC	TKN	FSA	TP	OP	TSS	ISS
Units	mg/l	mg/l	mgC/l	mgN/l	mgN/l	mgP/l	mgP/l	mg/l	mg/l
Unfiltered Influent Raw Wastewater	1150	-	383.1	90	-	20	-	665	99.8
Supernatant (Settled Wastewater)	750	-	249.5	70	-	17	-	343	34.3
0.45um membrane filtered	293	50	99.5	63.6	59.6	14.97	14.08	-	-

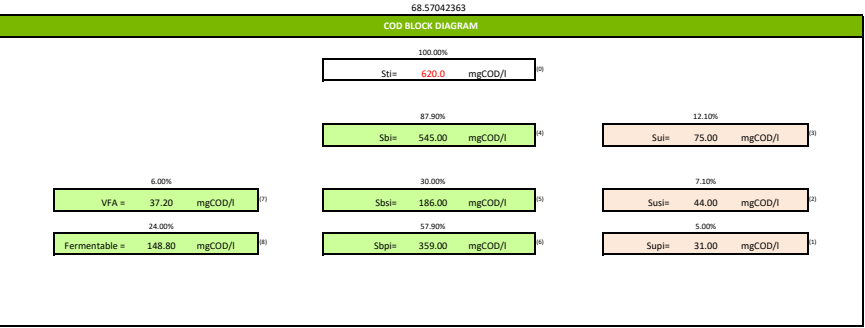
Tests on membrane filtered effluent from AS System operated at 20C (Given in table 1.8)									
Tests on Effluent	COD	VFA	TOC	TKN	FSA	TP	OP	TSS	ISS
Units	mg/l	mg/l	mgC/l	mgN/l	mgN/l	mgP/l	mgP/l	mg/l	mg/l
Raw WW System (Rs = 24 days)	58	0	19.2	1.17	0.17	14.1	14.1	-	-
Settled WW System (Rs = 12 days)	58	0	19.2	1.28	0.28	12.56	12.56	-	-

SUMMARY OF RAW WASTEWATER FRACTIONS						
Parameter	Abbreviation	Concentration Value	Unit	Flux	Unit	Percentage
Total COD	Sti	1060.0	mgCOD/l	18285	kgCOD/day	100.00%
Unbiodegradable COD	Sui	171.20	mgCOD/l	2953	kgCOD/day	16.15%
Unbiodegradable Soluble COD	Susi	44.00	mgCOD/l	759	kgCOD/day	4.15%
Unbiodegradable Particulate COD	Supi	127.20	mgCOD/l	2194	kgCOD/day	12.00%
Biodegradable COD	Sbi	888.80	mgCOD/l	15332	kgCOD/day	83.85%
Biodegradable Soluble COD	Sbsi	186.00	mgCOD/l	3209	kgCOD/day	17.55%
Biodegradable Particulate COD	Sbpi	702.80	mgCOD/l	12123	kgCOD/day	66.30%
Readily biodegradable COD that is VFA	S_{vfa}	37.20	mgCOD/l	642	kgCOD/day	3.51%
Readily biodegradable COD that is Fermentable	S_{ferm}	148.80	mgCOD/l	2567	kgCOD/day	14.04%
Total Kjeldahl Nitrogen	Nti	85.0	mgN/l	1466	kgN/day	100.00%
Free and Saline Ammonia	Nai	55.00	mgN/l	949	kgN/day	64.71%
Organic Nitrogen	Noi	30.00	mgN/l	518	kgN/day	35.29%
Unbiodegradable Organic Nitrogen	Noui	10.39	mgN/l	179	kgN/day	12.22%
Unbiodegradable Soluble Organic Nitrogen	Nousi	1.80	mgN/l	31	kgN/day	2.12%
Unbiodegradable Particulate Organic Nitrogen	Noup	8.59	mgN/l	148	kgN/day	10.10%
Biodegradable Organic Nitrogen	Nobi	19.61	mgN/l	338	kgN/day	23.07%
Biodegradable Soluble Organic Nitrogen	Nobsi	4.22	mgN/l	73	kgN/day	4.96%
Biodegradable Particulate Organic Nitrogen	Nobpi	15.39	mgN/l	266	kgN/day	18.11%
Total Phosphorous	Pti	11.00	mgP/l	190	kgP/day	100.00%
Ortho Phosphate	OrthoP	8.00	mgP/l	138	kgP/day	72.73%
Organic Phosphate	Poi	3.00	mgP/l	52	kgP/day	27.27%
Unbiodegradable Organic Phosphate	Poui	2.45	mgP/l	42	kgP/day	22.25%
Unbiodegradable Soluble Organic Phosphate	Pousi	0.30	mgP/l	5	kgP/day	2.73%
Unbiodegradable Particulate Organic Phosphate	Poupi	2.15	mgP/l	37	kgP/day	19.52%
Biodegradable Organic Phosphate	Pobi	0.55	mgP/l	10	kgP/day	5.03%
Biodegradable Soluble Organic Phosphate	Pobsi	0.17	mgP/l	3	kgP/day	1.51%
Biodegradable Particulate Organic Phosphate	Pobpi	0.39	mgP/l	7	kgP/day	3.52%
Total TOC	Cti	383.1	mgC/l	6608	kgC/day	100.00%
Unbiodegradable TOC	Cui	63.69	mgC/l	1099	kgC/day	16.62%
Unbiodegradable Soluble TOC	Cusi	19.20	mgC/l	331	kgC/day	5.01%
Unbiodegradable Particulate TOC	Cupi	44.49	mgC/l	767	kgC/day	11.61%
Biodegradable TOC	Cbi	319.41	mgC/l	5510	kgC/day	83.38%
Biodegradable Soluble TOC	Cbsi	80.30	mgC/l	1385	kgC/day	20.96%
Biodegradable Soluble VFA TOC	C_{vfa}	13.95	mgC/l	241	kgC/day	3.64%
Biodegradable Soluble FBSO TOC	FBSO	66.35	mgC/l	1145	kgC/day	17.32%
Biodegradable Particulate TOC	Cbp	239.11	mgC/l	4125	kgC/day	62.41%
TSS	X_0	450.00	(mgTSS/L)	7763	kgTSS/day	100.00%
VSS	VSS	380.00	(mgVSS/L)	6555	kgVSS/day	84.44%
ISS	X_{iss}	70.00	(mgISS/L)	1208	kgISS/day	15.56%
Influent Flowrate	Q_0	17.25	Ml/d			

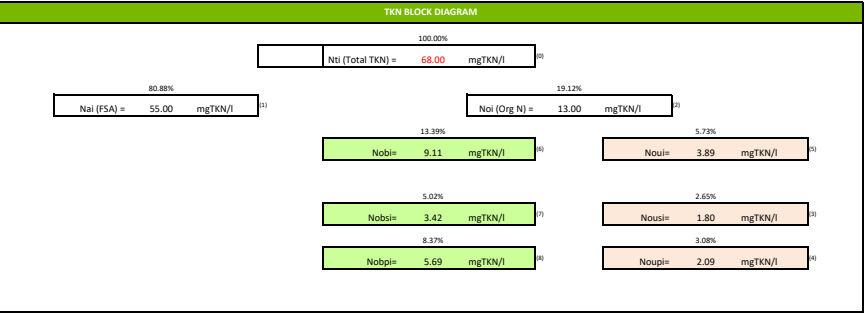
Concentrations and mass ratios of dissolved organics (raw influent)					
Parameter	Abbreviation	SO	USO	VFA	FBSO
COD		230.000	44.000	37.200	148.800
Mass	VSS	171.460	29.471	37.200	104.789
TOC		99.500	19.200	13.950	66.350
Organic Nitrogen		6.016	1.800	0.000	4.216
Organic Phosphate		0.466	0.300	0.000	0.166
COD/VSS Ratio	f _{cv}	1.341	1.493	1.000	1.420
TOC/VSS Ratio (Carbon Content)	f _c	0.580	0.651	0.375	0.633
TKN/VSS Ratio (Nitrogen Content)	f _n	0.035	0.061	0.000	0.040
TP/VSS Ratio (Phosphate Content)	f _p	0.003	0.010	0.000	0.002

Concentrations and mass ratios of Biodegradable Particulate Organics (raw influent)			
Parameter	Abbreviation	BPO Raw	UPO Raw
COD	COD	702.800	127.200
Mass	VSS	294.112	85.888
TOC	TOC	239.110	44.490
Organic Nitrogen	Org N	15.395	8.589
Organic Phosphate	Org P	0.387	2.147
COD/VSS Ratio	f _{cv}	2.390	1.481
TOC/VSS Ratio (Carbon Content)	f _c	0.813	0.518
TKN/VSS Ratio (Nitrogen Content)	f _n	0.052	0.100
TP/VSS Ratio (Phosphate Content)	f _p	0.001	0.025

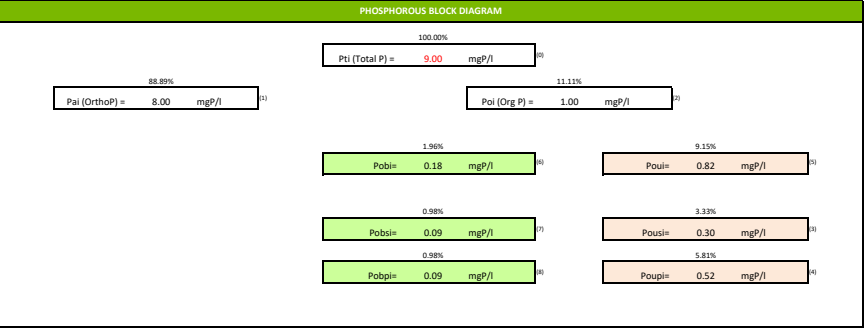
2. OLD LANE : SETTLED WASTEWATER CHARACTERIZATION FOR THE ACTIVATED SLUDGE SYSTEM



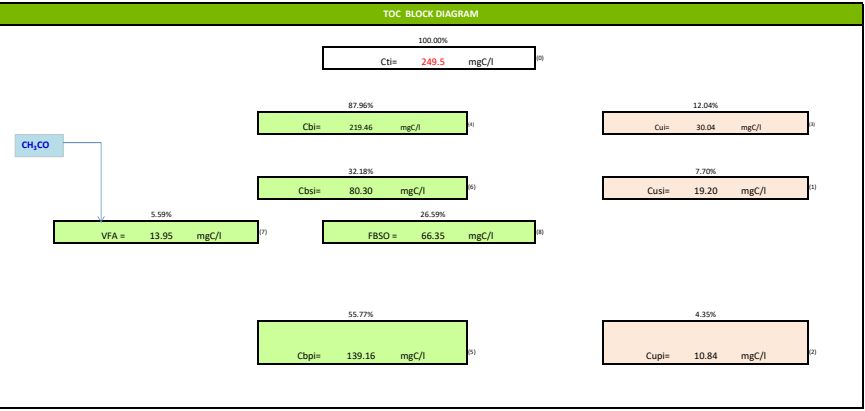
- (0) Total COD as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
- (1) Given "Fraction of total influent COD that is unbiodegradable and soluble (F_{sui})" OR "Given COD in effluent which is Sui"
- (2) Given "Fraction of total influent COD that is unbiodegradable and particulate (F_{sup})"
- (3) = Sui + Supi
- (4) = St - Sui
- (5) Given "Fraction of total influent COD that is readily biodegradable (F_{sbi})" OR
= COD_{0.45um membrane filtered} - Sui [where COD_{0.45um membrane filtered} is given as 293 mg/l]
- (6) = Sbi - Sbsi
- (7) = VFA_{0.45um membrane filtered} OR based on "Fraction of readily biodegradable COD that is VFA" (f_{vfa})
- (8) = Sbsi - VFA



- (0) Total TKN as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
- (1) Given "Fraction of influent TKN that is free and saline ammonia (F_{sal})" OR "Given FSA_{0.45um membrane filtered}"
- (2) = Nti - Nal
- (3) Given "Fraction of influent TKN that unbiodegradable and soluble (F_{noui})" OR "Given (TKN-FSA) in effluent which is Noui"
- (4) = Supi x (fn/fcv)
- (5) = Nousi + Noup
- (6) = Noi - Noui
- (7) = Nobi - Nobpi
- (8) Given "Fraction of biodegradable organic TKN that is particulate (F_{noub})"



- (0) Total P as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
- (1) Given "Fraction of influent TP that is ortho-phosphate (F_{spo4})" OR "Given OrthoP_{0.45um membrane filtered}"
- (2) = Pti - OrthoP
- (3) Given "Fraction of P content of the influent soluble unbiodegradable COD (F_{pui})" OR "Given (TP - OrthoP) in effluent which is Pousi"
- (4) = Supi x (fp/fcv)
- (5) = Pousi + NPoup
- (6) = Poi - Pou
- (7) " = Pobi - Pobpi" OR " = P_{0.45um membrane filtered} - OrthoP - Pousi [where P_{0.45um membrane filtered} is given as 14.97 mgN/l]"
- (8) Given "Fraction of the biodegradable organic influent TP which is particulate (FXBP)"



- (0) Total TOC as provided in Flow Weighted Average Raw and Settled Wastewater Concentrations (Given in table 1.8)
- (1) Given TOC in effluent which is Cui (see tests on Tests on membrane filtered effluent from AS System operated at 20 °C)
- (2) = Supi x (fc/fcv)
- (3) = Cusi + Cupi
- (4) = Cti - Cui
- (5) = Cti - COD_{0.45um membrane filtered} - Cupi
- (6) = Cbi - Cbpi
- (7) TOC_{vfa} = 13.95

CH₃COOH

x	y	z	a	b	
C	H	O	N	P	S
2.0000	4.0000	2.0000	0.0000	0.0000	0.0000

COD	64.0000	gCOD/mol
C Concentration	24.0000	gC/mol
λ_s	8.0000	ge-/mol

- (8) = Cbsi - VFA

Typical Values (Principle, modelling and design of biological wastewater treatment, published by the International Water Association, 2006)								
Parameter	Abbreviation	Min	Raw Max	Selected Value	Min	Settled Max	Selected Value	Unit
Fraction of readily biodegradable COD that is VFA	$F_{sbi/v}$	0.100	0.400	0.200	0.100	0.400	0.200	mgCOD/mgCOD
Fraction of total influent COD that is readily biodegradable	F_{sbi}	0.080	0.250	0.175	0.100	0.350	0.300	mgCOD/mgCOD
Fraction of total influent COD that is soluble unbiodegradable	F_{sui}	0.040	0.100	0.042	0.050	0.200	0.071	mgCOD/mgCOD
Fraction of total influent COD that is particulate unbiodegradable	F_{sup}	0.070	0.200	0.120	0.000	0.100	0.050	mgCOD/mgCOD
Fraction of readily biodegradable COD that is Fermentable	$F_{sbi/f}$	0.600	0.900	0.750	0.600	0.900	0.820	mgCOD/mgCOD
Fraction of influent TKN that is free and saline ammonia	F_{sal}	0.600	0.800	0.647	0.700	0.900	0.809	mgN/mgN
Fraction of influent TKN that is unbiodegradable and soluble	F_{noui}	0.000	0.040	0.021	0.000	0.050	0.026	mgN/mgN
N content of the particulate unbiodegradable influent COD	$F_{sbi/n}$	0.060	0.080	0.068	0.060	0.080	0.068	mgN/mgCOD
N content of the soluble unbiodegradable influent COD	$F_{sui/n}$	0.000	0.060	0.021	0.000	0.060	0.026	mgN/mgCOD
Fraction of biodegradable organic TKN that is particulate	F_{nub}	0.700	0.850	0.785	0.550	0.700	0.625	
Fraction of influent TP that is ortho-phosphate	F_{p15}	0.700	0.900	0.727	0.750	0.950	0.889	mgP/mgP
P content of the particulate unbiodegradable influent COD	$F_{sup/p}$	0.010	0.020	0.013	0.010	0.020	0.110	mgP/mgCOD
Fraction of influent TP that is organic unbiodegradable soluble	F_{pnoi}	0.000	0.030	0.027	0.000	0.040	0.033	mgP/mgP
Fraction of unbiodegradable soluble COD which is P	$f_{sui/p}$	0.000	0.010	0.005	0.000	0.010	0.005	mgP/mgCOD
Fraction of the biodegradable organic influent TP which is particulate	F_{pnb}	0.600	0.750	0.700	0.500	0.650	0.500	mgP/mgCOD
COD/VSS Ratio of influent UPO	$f_{v/uPO}$			1.481			1.481	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content) of influent UPO	f_n			0.100			0.100	mgN/mgVSS
TP/VSS Ratio (Phosphate Content) of influent UPO	f_p			0.025			0.025	mgP/mgVSS
TOC/VSS Ratio (Carbon Content) of influent UPO	f_c			0.518			0.518	mgC/mgVSS
COD/VSS Ratio of influent USO	$f_{v/USO}$			1.493			1.493	mgCOD/mgVSS
TP/VSS Ratio (Phosphate Content) of influent USO	$f_{p/USO}$			0.000			0.000	mgP/mgVSS
COD/VSS Ratio of influent FBSO	$f_{v/FBSO}$			1.420			1.420	mgCOD/mgVSS

Flow Weighted Average Raw and Settled Wastewater Concentrations (Given in table 1.8)								
Tests on Wastewater	COD	VFA	TOC	TKN	FSA	TP	OP	TSS
Units	mg/l	mg/l	mgC/l	mgN/l	mgN/l	mgP/l	mgP/l	mg/l
Unfiltered Influent Raw Wastewater	1150	-	383.1	90	-	20	-	665
Supernatant (Settled Wastewater)	750	-	249.5	70	-	17	-	343
0.45um membrane filtered	293	50	99.5	63.6	59.6	14.97	14.08	-

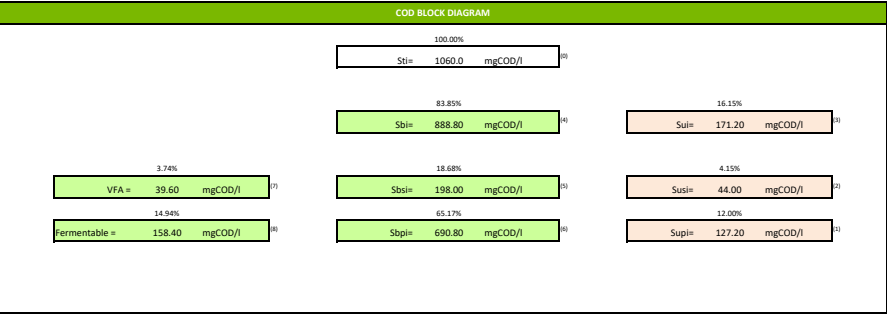
Tests on membrane filtered effluent from AS System operated at 20°C (Given in table 1.8)								
Tests on Effluent	COD	VFA	TOC	TKN	FSA	TP	OP	TSS
Units	mg/l	mg/l	mgC/l	mgN/l	mgN/l	mgP/l	mgP/l	mg/l
Raw WW System (Rs = 24 days)	58	0	19.2	1.17	0.17	14.1	14.1	-
Settled WW System (Rs = 12 days)	58	0	19.2	1.28	0.28	12.56	12.56	-

SUMMARY OF SETTLED WASTEWATER FRACTIONS						
Parameter	Abbreviation	Concentration Value	Unit	Flux	Unit	Percentage
Total COD	Sti	620.0	mgCOD/l	10612	kgCOD/day	100.00%
Unbiodegradable COD	Sui	75.00	mgCOD/l	1284	kgCOD/day	12.10%
Unbiodegradable Soluble COD	Susi	44.00	mgCOD/l	753	kgCOD/day	7.10%
Unbiodegradable Particulate COD	Supi	31.00	mgCOD/l	531	kgCOD/day	5.00%
Biodegradable COD	Sbi	545.00	mgCOD/l	9328	kgCOD/day	87.90%
Biodegradable Soluble COD	Sbsi	186.00	mgCOD/l	3184	kgCOD/day	30.00%
Biodegradable Particulate COD	Sbpi	359.00	mgCOD/l	6145	kgCOD/day	57.90%
Readily biodegradable COD that is VFA	S_{vfa}	37.20	mgCOD/l	6307	kgCOD/day	6.00%
Readily biodegradable COD that is Fermentable	S_{ferm}	148.80	mgCOD/l	2547	kgCOD/day	24.00%
Total Kjeldahl Nitrogen	Nti	68.0	mgN/l	1164	kgN/day	100.00%
Free and Saline Ammonia	Nai	55.00	mgN/l	941	kgN/day	80.88%
Organic Nitrogen	Noi	13.00	mgN/l	223	kgN/day	19.12%
Unbiodegradable Organic Nitrogen	Noui	3.89	mgN/l	67	kgN/day	5.73%
Unbiodegradable Soluble Organic Nitrogen	Nousi	1.80	mgN/l	31	kgN/day	2.65%
Unbiodegradable Particulate Organic Nitrogen	Noup	2.09	mgN/l	36	kgN/day	3.08%
Biodegradable Organic Nitrogen	Nobi	9.11	mgN/l	156	kgN/day	13.39%
Biodegradable Soluble Organic Nitrogen	Nobsi	3.42	mgN/l	58	kgN/day	5.02%
Biodegradable Particulate Organic Nitrogen	Nobpi	5.69	mgN/l	97	kgN/day	8.37%
Total Phosphorous	Pti	9.00	mgP/l	154	kgP/day	100.00%
Ortho Phosphate	OrthoP	8.00	mgP/l	137	kgP/day	88.89%
Organic Phosphate	Poi	1.00	mgP/l	17	kgP/day	11.11%
Unbiodegradable Organic Phosphate	Poui	0.82	mgP/l	14	kgP/day	9.15%
Unbiodegradable Soluble Organic Phosphate	Pousi	0.30	mgP/l	5	kgP/day	3.33%
Unbiodegradable Particulate Organic Phosphate	Poup	0.52	mgP/l	9	kgP/day	5.81%
Biodegradable Organic Phosphate	Pobi	0.18	mgP/l	3	kgP/day	1.96%
Biodegradable Soluble Organic Phosphate	Pobsi	0.09	mgP/l	2	kgP/day	0.98%
Biodegradable Particulate Organic Phosphate	Pobpi	0.09	mgP/l	2	kgP/day	0.98%
Total TOC	Cti	249.5	mgC/l	4271	kgC/day	100.00%
Unbiodegradable TOC	Cui	30.04	mgC/l	514	kgC/day	12.04%
Unbiodegradable Soluble TOC	Cusi	19.20	mgC/l	329	kgC/day	7.70%
Unbiodegradable Particulate TOC	Cupi	10.84	mgC/l	186	kgC/day	4.35%
Biodegradable TOC	Cbi	219.46	mgC/l	3756	kgC/day	87.96%
Biodegradable Soluble TOC	Cbsi	80.30	mgC/l	1374	kgC/day	32.18%
Biodegradable Soluble VFA TOC	C_{vfa}	13.95	mgC/l	239	kgC/day	5.59%
Biodegradable Soluble FBSO TOC	FBSO	66.35	mgC/l	1136	kgC/day	26.59%
Biodegradable Particulate TOC	Cbp	139.16	mgC/l	2382	kgC/day	55.77%
TSS	X_o	140.00	(mgTSS/L)	2396	kgTSS/day	100.00%
VSS	VSS	120.00	(mgVSS/L)	2054	kgVSS/day	85.71%
ISS	X_{iss}	20.00	(mgISS/L)	342	kgISS/day	14.29%
Influent Flowrate	Q_i	17.12	Ml/d			

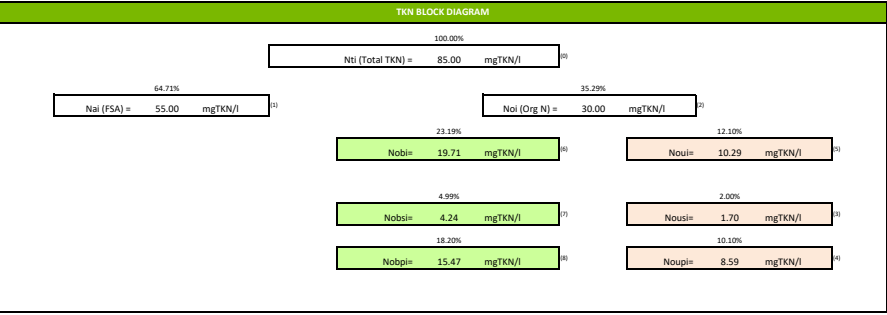
Concentrations and mass ratios of dissolved organics (settled influent)					
Parameter	Abbreviation	SO	USO	VFA	FBSO
COD		230.000	44.000	37.200	148.800
Mass	VSS	171.460	29.471	37.200	104.789
TOC		99.500	19.200	13.950	66.350
Organic Nitrogen		5.215	1.800	0.000	3.415
Organic Phosphate		0.388	0.300	0.000	0.088
COD/VSS Ratio	fcv	1.341	1.493	1.000	1.420
TOC/VSS Ratio (Carbon Content)	fc	0.580	0.651	0.375	0.633
TKN/VSS Ratio (Nitrogen Content)	fn	0.030	0.061	0.000	0.033
TP/VSS Ratio (Phosphate Content)	fp	0.002	0.000	0.000	0.001

Concentrations and mass ratios of Biodegradable Particulate Organics (Settled Influent)							
Parameter	Abbreviation	BPO Raw	BPO Settled	BPO Non-Settled	UPO Raw	UPO Settled	UPO Non-Settled
COD	COD	702.800	350.000	343.800	127.200	31.000	96.200
Mass	VSS	294.112	99.068	195.044	85.888	20.932	64.956
TOC	TOC	239.110	139.157	99.953	44.490	10.843	33.647
Organic Nitrogen	Org N	15.395	5.692	9.703	8.589	2.093	6.496
Organic Phosphate	Org P	0.387	0.088	0.299	2.147	0.523	1.624
COD/VSS Ratio	fcv	2.390	3.624	1.763	1.481	1.481	1.481
TOC/VSS Ratio (Carbon Content)	fc	0.813	1.405	0.512	0.518	0.518	0.518
TKN/VSS Ratio (Nitrogen Content)	fn	0.052	0.057	0.050	0.100	0.100	0.100
TP/VSS Ratio (Phosphate Content)	fp	0.001	0.001	0.002	0.025	0.025	0.025

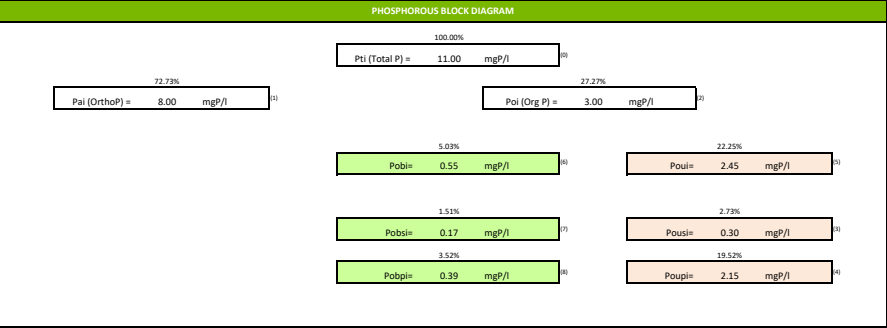
1. NEW LANE : RAW WASTEWATER CHARACTERIZATION FOR THE ACTIVATED SLUDGE SYSTEM



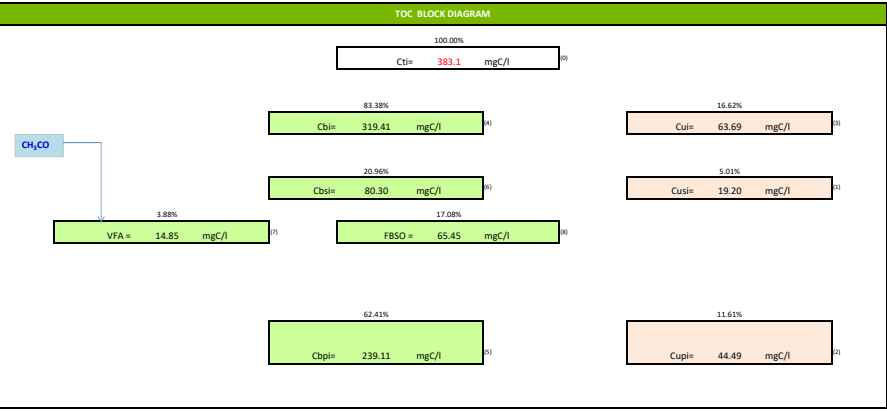
- (1) Total COD as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
Given "Fraction of total influent COD that is unbiodegradable and soluble (f_{su})" OR "Given COD in effluent which is Sui"
- (2) Given "Fraction of total influent COD that is unbiodegradable and particulate (f_{sp})"
= Sui + Supi
- (3) = Sti - Sui
- (4) Given "Fraction of total influent COD that is readily biodegradable (f_{bu})" OR
= COD_{0.45um membrane filtered} - Sui [where COD_{0.45um membrane filtered} is given as 293 mg/l]
= Sbi - Sbsi
- (5) = VFA_{0.45um membrane filtered} Or based on "Fraction of readily biodegradable COD that is VFA" (f_{vfa})
- (6) = Sbsi - VFA



- (1) Total TKN as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
Given "Fraction of influent TKN that is free and saline ammonia (f_{su})" OR "Given FSA_{0.45um membrane filtered}"
= Nti - Nai
- (2) Given "Fraction of influent TKN that unbiodegradable and soluble (f_{su})" OR "Given (TKN-FSA) in effluent which is Nouis"
= Supi x (f_{su}/f_{cv})
- (3) = Nouis + Noup
- (4) = Noi - Nouis
- (5) = Nob - Nobpi
- (6) Given "Fraction of biodegradable organic TKN that is particulate (f_{pbi})"



- (1) Total P as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
Given "Fraction of influent TP that is ortho-phosphate (FSP04)" OR "Given OrthoP_{0.45um membrane filtered}"
= Pti - OrthoP
- (2) Given "Fraction of P content of the influent soluble unbiodegradable COD (f_{pbi})" OR "Given (TP - OrthoP) in effluent which is Pousi"
= Supi x (f_{pbi}/f_{cv})
- (3) = Pousi + NPoupi
- (4) = Poi - Pou
- (5) "Pobi - Pobpi" OR "P_{0.45um membrane filtered} - OrthoP - Pousi" [where P_{0.45um membrane filtered} is given as 14.97 mgN/l]"
- (6) Given "Fraction of the biodegradable organic influent TP which is particulate (FXBP)"



- (1) Total TOC as provided in Flow Weighted Average Raw and Settled Wastewater Concentrations (Given in table 1.8)
Given TOC in effluent which is Cusi
- (2) = Supi x (f_{c}/f_{cv})
- (3) = Cusi + Cupi
- (4) = Cti - Cui
- (5) = Cti - COD_{0.45um membrane filtered} - Cupi
- (6) = Cbi - Cbpi
- (7) TOC_{uvs} = 14.85

CH3COOH						
x	y	z	a	b	S	
C	H	O	N	P	S	
2.0000	4.0000	2.0000	0.0000	0.0000	0.0000	

COD	64.0000	gCOD/mol
C Concentration	24	gC/mol
λ_a	8.0000	ge-/mol

- (8) = Cbsi - VFA

Typical Values (Principle, modelling and design of biological wastewater treatment, published by the International Water Association, 2008)								
Parameter	Abbreviation	Min	Raw Max	Selected Value	Min	Settled Max	Selected Value	Unit
Fraction of readily biodegradable COD that is VFA	f_{re}	0.100	0.400	0.200	0.100	0.400	0.200	mgCOD/mgCOD
Fraction of total influent COD that is readily biodegradable	f_{bu}	0.080	0.250	0.187	0.100	0.350	0.300	mgCOD/mgCOD
Fraction of total influent COD that is soluble unbiodegradable	f_{su}	0.040	0.100	0.042	0.050	0.200	0.067	mgCOD/mgCOD
Fraction of total influent COD that is particulate unbiodegradable	f_{pu}	0.070	0.200	0.120	0.000	0.100	0.050	mgCOD/mgCOD
Fraction of readily biodegradable COD that is Fermentable	f_{fer}	0.600	0.900	0.750	0.600	0.900	0.820	mgCOD/mgCOD
Fraction of influent TKN that is free and saline ammonia	f_{su}	0.600	0.800	0.647	0.700	0.900	0.809	mgN/mgN
Fraction of influent TKN that is unbiodegradable and soluble	f_{suu}	0.000	0.040	0.020	0.000	0.050	0.030	mgN/mgN
N content of the particulate unbiodegradable influent COD	f_{Npu}	0.060	0.080	0.068	0.060	0.080	0.068	mgN/mgCOD
N content of the soluble unbiodegradable influent COD	f_{Nsu}	0.000	0.060	0.021	0.000	0.060	0.026	mgN/mgCOD
Fraction of biodegradable organic TKN that is particulate	f_{pbi}	0.700	0.850	0.785	0.550	0.700	0.625	
Fraction of influent TP that is ortho-phosphate	f_{p5}	0.700	0.900	0.727	0.750	0.950	0.891	mgP/mgP
P content of the particulate unbiodegradable influent COD	f_{pp}	0.010	0.020	0.013	0.010	0.020	0.110	mgP/mgCOD
Fraction of influent TP that is organic unbiodegradable soluble	f_{pou}	0.000	0.030	0.027	0.000	0.040	0.033	mgP/mgP
Fraction of unbiodegradable soluble COD which is P	f_{pbi}	0.000	0.010	0.005	0.000	0.010	0.005	mgP/mgCOD
Fraction of the biodegradable organic influent TP which is particulate	f_{pbi}	0.600	0.750	0.700	0.500	0.650	0.500	mgP/mgCOD
COD/VSS Ratio of Influent UPO	f_{uUPO}	1.450	1.500	1.481	1.450	1.500	1.481	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content) of Influent UPO	f_{uUPO}	0.102	0.150	0.100	0.131	0.180	0.100	mgN/mgVSS
TP/VSS Ratio (Phosphate Content) of Influent UPO	f_{pUPO}	0.022	0.038	0.025	0.029	0.045	0.025	mgP/mgVSS
TOC/VSS Ratio (Carbon Content) of Influent UPO	f_{cUPO}			0.518			0.518	mgC/mgVSS
COD/VSS Ratio of Influent USO	f_{uUSO}			1.493			1.493	mgCOD/mgVSS
TP/VSS Ratio (Phosphate Content) of Influent USO	f_{pUSO}			0.000			0.000	mgP/mgVSS
COD/VSS Ratio of Influent FBSO	f_{uFBSO}			1.420			1.420	mgCOD/mgVSS

Flow Weighted Average Raw and Settled Wastewater Concentrations (Given in table 1.8)									
Tests on Wastewater	COD	VFA	TOC	TKN	FSA	TP	OP	TSS	ISS
Units	mg/l	mg/l	mgC/l	mgN/l	mgN/l	mgP/l	mgP/l	mg/l	mg/l
Unfiltered Influent Raw Wastewater	1150	-	383.1	90	-	20	-	665	99.8
Supernatant (Settled Wastewater)	750	-	249.5	70	-	17	-	343	34.3
0.45um membrane filtered	293	50	99.5	63.6	59.6	14.97	14.08	-	-

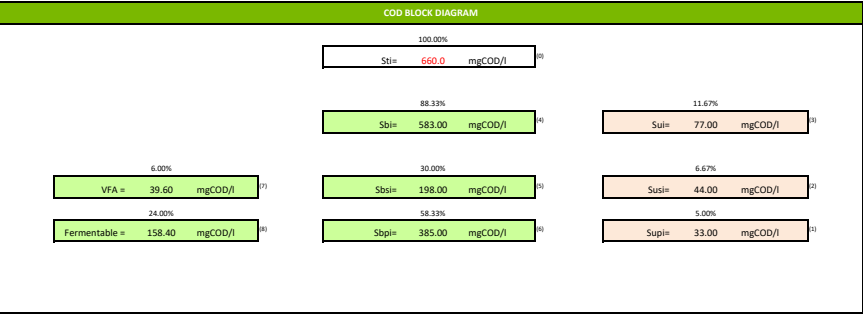
Tests on membrane filtered effluent from AS System operated at 20C (Given in table 1.8)									
Tests on Effluent	COD	VFA	TOC	TKN	FSA	TP	OP	TSS	ISS
Units	mg/l	mg/l	mgC/l	mgN/l	mgN/l	mgP/l	mgP/l	mg/l	mg/l
Raw WW System (Rs = 24 days)	58	0	19.2	1.17	0.17	14.1	14.1	-	-
Settled WW System (Rs = 12 days)	58	0	19.2	1.28	0.28	12.56	12.56	-	-

SUMMARY OF RAW WASTEWATER FRACTIONS						
Parameter	Abbreviation	Concentration Value	Unit	Flux	Unit	Percentage
Total COD	Sti	1060.0	mgCOD/l	46110	kgCOD/day	100.00%
Unbiodegradable COD	Sui	171.20	mgCOD/l	7447	kgCOD/day	16.15%
Unbiodegradable Soluble COD	Susi	44.00	mgCOD/l	1914	kgCOD/day	4.15%
Unbiodegradable Particulate COD	Supi	127.20	mgCOD/l	5533	kgCOD/day	12.00%
Biodegradable COD	Sbi	888.80	mgCOD/l	38663	kgCOD/day	83.85%
Biodegradable Soluble COD	Sbsi	198.00	mgCOD/l	8613	kgCOD/day	18.68%
Biodegradable Particulate COD	Sbpi	690.80	mgCOD/l	30050	kgCOD/day	65.17%
Readily biodegradable COD that is VFA	S _{vfa}	39.60	mgCOD/l	1723	kgCOD/day	3.74%
Readily biodegradable COD that is Fermentable	S _{ferm}	158.40	mgCOD/l	6890	kgCOD/day	14.94%
Total Kjeldahl Nitrogen	Nti	85.0	mgN/l	3697	kgN/day	100.00%
Free and Saline Ammonia	Nai	55.00	mgN/l	2393	kgN/day	64.71%
Organic Nitrogen	Noi	30.00	mgN/l	1305	kgN/day	35.29%
Unbiodegradable Organic Nitrogen	Noui	10.29	mgN/l	448	kgN/day	12.10%
Unbiodegradable Soluble Organic Nitrogen	Nousi	1.70	mgN/l	74	kgN/day	2.00%
Unbiodegradable Particulate Organic Nitrogen	Noup	8.59	mgN/l	374	kgN/day	10.10%
Biodegradable Organic Nitrogen	Nobi	19.71	mgN/l	857	kgN/day	23.19%
Biodegradable Soluble Organic Nitrogen	Nobsi	4.24	mgN/l	184	kgN/day	4.99%
Biodegradable Particulate Organic Nitrogen	Nobpi	15.47	mgN/l	673	kgN/day	18.20%
Total Phosphorous	Pti	11.00	mgP/l	478	kgP/day	100.00%
Ortho Phosphate	OrthoP	8.00	mgP/l	348	kgP/day	72.73%
Organic Phosphate	Poi	3.00	mgP/l	131	kgP/day	27.27%
Unbiodegradable Organic Phosphate	Poui	2.45	mgP/l	106	kgP/day	22.25%
Unbiodegradable Soluble Organic Phosphate	Pousi	0.30	mgP/l	13	kgP/day	2.73%
Unbiodegradable Particulate Organic Phosphate	Poupi	2.15	mgP/l	93	kgP/day	19.52%
Biodegradable Organic Phosphate	Pobi	0.55	mgP/l	24	kgP/day	5.03%
Biodegradable Soluble Organic Phosphate	Pobsi	0.17	mgP/l	7	kgP/day	1.51%
Biodegradable Particulate Organic Phosphate	Pobpi	0.39	mgP/l	17	kgP/day	3.52%
Total TOC	Cti	383.1	mgC/l	16665	kgC/day	100.00%
Unbiodegradable TOC	Cui	63.69	mgC/l	2771	kgC/day	16.62%
Unbiodegradable Soluble TOC	Cusi	19.20	mgC/l	835	kgC/day	5.01%
Unbiodegradable Particulate TOC	Cupi	44.49	mgC/l	1935	kgC/day	11.61%
Biodegradable TOC	Cbi	319.41	mgC/l	13894	kgC/day	83.38%
Biodegradable Soluble TOC	Cbsi	80.30	mgC/l	3493	kgC/day	20.96%
Biodegradable Soluble VFA TOC	C _{vfa}	14.85	mgC/l	646	kgC/day	3.88%
Biodegradable Soluble FBSO TOC	FBSO	65.45	mgC/l	2847	kgC/day	17.08%
Biodegradable Particulate TOC	Cbp	239.11	mgC/l	10401	kgC/day	62.41%
TSS	X _d	450.00	(mgTSS/L)	19575	kgTSS/day	100.00%
VSS	VSS	380.00	(mgVSS/L)	16530	kgVSS/day	84.44%
ISS	X _{iss}	70.00	(mgISS/L)	3045	kgISS/day	15.56%
Influent Flowrate	Q _i	43.50	Ml/d			

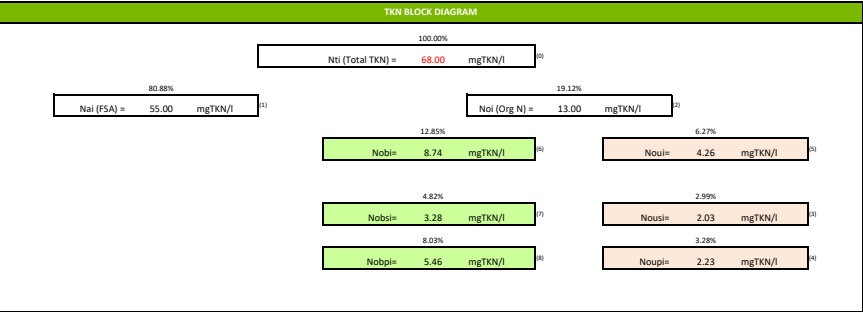
Concentrations and mass ratios of dissolved organics (raw influent)					
Parameter	Abbreviation	SO	USO	VFA	FBSO
COD		242.000	44.000	39.600	158.400
Mass	VSS	180.620	29.471	39.600	111.549
TOC		99.500	19.200	14.850	65.450
Organic Nitrogen		5.938	1.700	0.000	4.238
Organic Phosphate		0.466	0.300	0.000	0.166
COD/VSS Ratio	f _{cv}	1.493	1.493	1.000	1.420
TOC/VSS Ratio (Carbon Content)	f _c	0.551	0.651	0.375	0.587
TKN/VSS Ratio (Nitrogen Content)	f _n	0.033	0.058	0.000	0.038
TP/VSS Ratio (Phosphate Content)	f _p	0.003	0.010	0.000	0.001

Concentrations and mass ratios of Biodegradable Particulate Organics (raw influent)			
Parameter	Abbreviation	BPO Raw	UPO Raw
COD	COD	690.800	127.200
Mass	VSS	294.112	85.888
TOC	TOC	239.110	44.490
Organic Nitrogen	Org N	15.473	8.589
Organic Phosphate	Org P	0.387	2.147
COD/VSS Ratio	f _{cv}	2.349	1.481
TOC/VSS Ratio (Carbon Content)	f _c	0.813	0.518
TKN/VSS Ratio (Nitrogen Content)	f _n	0.053	0.100
TP/VSS Ratio (Phosphate Content)	f _p	0.001	0.025

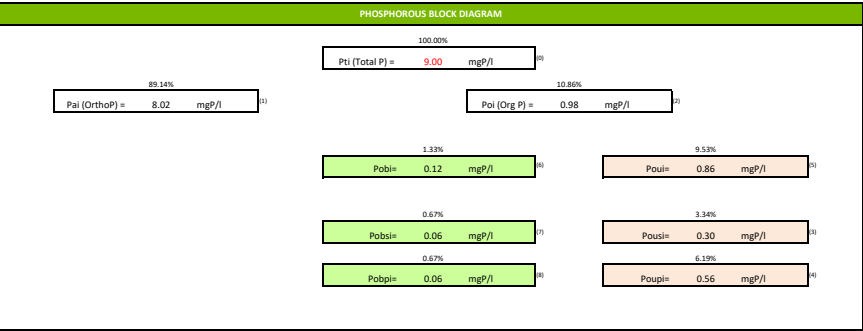
2. NEW LANE : SETTLED WASTEWATER CHARACTERIZATION FOR THE ACTIVATED SLUDGE SYSTEM



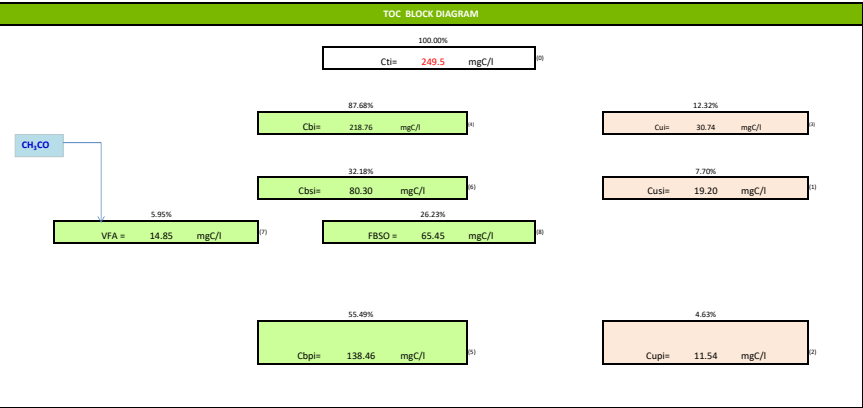
- (8) Total COD as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
(1) Given "Fraction of total influent COD that is unbiodegradable and soluble (F_{sbi})" OR "Given COD in effluent which is Sui"
(2) Given "Fraction of total influent COD that is unbiodegradable and particulate (F_{sp})"
(3) = Sui + Supi
(4) = Sti - Sui
(5) Given "Fraction of total influent COD that is readily biodegradable (F_{bi})" OR
= COD_{0.45um membrane filtered} - Sui⁽¹⁾ [where COD_{0.45um membrane filtered} is given as 293 mg/l]
(6) = Sbi - Sbsi
(7) = VFA_{0.45um membrane filtered} OR based on "Fraction of readily biodegradable COD that is VFA" (f_{vfa})⁽⁸⁾
(8) = Sbsi - VFA



- (8) Total TKN as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
(1) Given "Fraction of influent TKN that is free and saline ammonia (F_{nai})" OR "Given FSA_{0.45um membrane filtered}"
(2) = Nti - Nai
(3) Given "Fraction of influent TKN that unbiodegradable and soluble (F_{noui})" OR "Given (TKN-FSA) in effluent which is Nouis"
(4) = Supi x (fn/fcv)
(5) = Nouis + Noup
(6) = Noi - Noui
(7) = Nobi - Nobpi
(8) Given "Fraction of biodegradable organic TKN that is particulate (F_{noup})"



- (8) Total P as measured from 24 hour composite sample taken on raw WW, averaged as per Simpsons rule
(1) Given "Fraction of influent TP that is ortho-phosphate (F_{sp04})" OR "Given OrthoP_{0.45um membrane filtered}"
(2) = Pti - OrthoP
(3) Given "Fraction of P content of the influent soluble unbiodegradable COD (F_{pbi})" OR "Given (TP - OrthoP) in effluent which is Pousi"
(4) = Supi x (fp/fcv)
(5) = Pousi + NPoup
(6) = Poi - Pou
(7) "s Pobi - Pobpi" OR "s P_{0.45um membrane filtered} - OrthoP - Pousi [where P_{0.45um membrane filtered} is given as 14.97 mgN/l]"
(8) Given "Fraction of the biodegradable organic influent TP which is particulate (FXBP)"



- (8) Total TOC as provided in Flow Weighted Average Raw and Settled Wastewater Concentrations (Given in table 1.8)
(1) Given TOC in effluent which is Cusi (see tests on Tests on membrane filtered effluent from AS System operated at 20 °C)
(2) = Supi x (fc/fcv)
(3) = Cusi + Cupi
(4) = Cti - Cui
(5) = Cti - COD_{0.45um membrane filtered} - Cupi
(6) = Cbi - Cbpi
(7) TOC_{vfa} = 14.85
CH₃COOH

	x	y	z	a	b	
	C	H	O	N	P	S
	2.0000	4.0000	2.0000	0.0000	0.0000	0.0000

	COD		gCOD/mol
	64.0000		
C Concentratio	24	gC/mol	
λ_s	8.0000		ge-/mol

(8) = Cbsi - VFA

Typical Values (Principle, modelling and design of biological wastewater treatment, published by the International Water Association, 2008)								
Parameter	Abbreviation	Min	Raw Max	Selected Value	Min	Settled Max	Selected Value	Unit
Fraction of readily biodegradable COD that is VFA	$F_{bi,vfa}$	0.100	0.400	0.200	0.100	0.400	0.200	mgCOD/mgCOD
Fraction of total influent COD that is readily biodegradable	F_{bi}	0.080	0.250	0.187	0.100	0.350	0.300	mgCOD/mgCOD
Fraction of total influent COD that is soluble unbiodegradable	F_{sbi}	0.040	0.100	0.042	0.050	0.200	0.067	mgCOD/mgCOD
Fraction of total influent COD that is particulate unbiodegradable	F_{up}	0.070	0.200	0.120	0.000	0.100	0.050	mgCOD/mgCOD
Fraction of readily biodegradable COD that is Fermentable	$F_{bi,fer}$	0.600	0.900	0.750	0.600	0.900	0.820	mgCOD/mgCOD
Fraction of influent TKN that is free and saline ammonia	F_{nai}	0.600	0.800	0.647	0.700	0.900	0.809	mgN/mgN
Fraction of influent TKN that is unbiodegradable and soluble	F_{nbi}	0.000	0.040	0.020	0.000	0.050	0.030	mgN/mgN
N content of the particulate unbiodegradable influent COD	$F_{nbi,n}$	0.060	0.080	0.068	0.060	0.080	0.068	mgN/mgCOD
N content of the soluble unbiodegradable influent COD	$F_{sbi,n}$	0.000	0.060	0.021	0.000	0.060	0.026	mgN/mgCOD
Fraction of biodegradable organic TKN that is particulate	F_{nbi}	0.700	0.850	0.785	0.550	0.700	0.625	
Fraction of influent TP that is ortho-phosphate	F_{p04}	0.700	0.900	0.727	0.750	0.950	0.891	mgP/mgP
P content of the particulate unbiodegradable influent COD	$F_{up,p}$	0.010	0.020	0.013	0.010	0.020	0.110	mgP/mgCOD
Fraction of influent TP that is organic unbiodegradable soluble	F_{pbi}	0.000	0.030	0.027	0.000	0.040	0.033	mgP/mgP
Fraction of unbiodegradable soluble COD which is P	$f_{sbi,p}$	0.000	0.010	0.005	0.000	0.010	0.005	mgP/mgCOD
Fraction of the biodegradable organic influent TP which is particulate	F_{pbi}	0.600	0.750	0.700	0.500	0.650	0.500	mgP/mgCOD
COD/VSS Ratio of influent UPO	$f_{v,u}$			1.481			1.481	mgCOD/mgVSS
TKN/VSS Ratio (Nitrogen Content) of influent UPO	f_n			0.100			0.100	mgN/mgVSS
TP/VSS Ratio (Phosphate Content) of influent UPO	f_p			0.025			0.025	mgP/mgVSS
TOC/VSS Ratio (Carbon Content) of influent UPO	f_c			0.518			0.518	mgC/mgVSS
COD/VSS Ratio of influent USO	$f_{v,u}$			1.493			1.493	mgCOD/mgVSS
TP/VSS Ratio (Phosphate Content) of influent USO	$f_{p,u}$			0.000			0.000	mgP/mgVSS
COD/VSS Ratio of influent FBSO	$f_{v,f}$			1.420			1.420	mgCOD/mgVSS

Flow Weighted Average Raw and Settled Wastewater Concentrations (Given in table 1.8)								
Tests on Wastewater	COD	VFA	TOC	TKN	FSA	TP	OP	TSS
Units	mg/l	mg/l	mgC/l	mgN/l	mgN/l	mgP/l	mgP/l	mg/l
Unfiltered Influent Raw Wastewater	1150	-	383.1	90	-	20	-	665
Supernatant (Settled Wastewater)	750	-	249.5	70	-	17	-	343
0.45um membrane filtered	293	50	99.5	63.6	59.6	14.97	14.08	-

Tests on membrane filtered effluent from AS System operated at 20°C (Given in table 1.8)								
Tests on Effluent	COD	VFA	TOC	TKN	FSA	TP	OP	TSS
Units	mg/l	mg/l	mgC/l	mgN/l	mgN/l	mgP/l	mgP/l	mg/l
Raw WW System (Rs = 24 days)	58	0	19.2	1.17	0.17	14.1	14.1	-
Settled WW System (Rs = 12 days)	58	0	19.2	1.28	0.28	12.56	12.56	-

SUMMARY OF SETTLED WASTEWATER FRACTIONS						
Parameter	Abbreviation	Concentration Value	Unit	Flux	Unit	Percentage
Total COD	Sti	660.0	mgCOD/l	28516	kgCOD/day	100.00%
Unbiodegradable COD	Sui	77.00	mgCOD/l	3327	kgCOD/day	11.67%
Unbiodegradable Soluble COD	Susi	44.00	mgCOD/l	1901	kgCOD/day	6.67%
Unbiodegradable Particulate COD	Supi	33.00	mgCOD/l	1426	kgCOD/day	5.00%
Biodegradable COD	Sbi	583.00	mgCOD/l	25189	kgCOD/day	88.33%
Biodegradable Soluble COD	Sbsi	198.00	mgCOD/l	8555	kgCOD/day	30.00%
Biodegradable Particulate COD	Sbpi	385.00	mgCOD/l	16634	kgCOD/day	58.33%
Readily biodegradable COD that is VFA	S_{vfa}	39.60	mgCOD/l	1711	kgCOD/day	6.00%
Readily biodegradable COD that is Fermentable	S_{ferm}	158.40	mgCOD/l	6844	kgCOD/day	24.00%
Total Kjeldahl Nitrogen	Nti	68.0	mgN/l	2938	kgN/day	100.00%
Free and Saline Ammonia	Nai	55.00	mgN/l	2376	kgN/day	80.88%
Organic Nitrogen	Noi	13.00	mgN/l	562	kgN/day	19.12%
Unbiodegradable Organic Nitrogen	Noui	4.26	mgN/l	184	kgN/day	6.27%
Unbiodegradable Soluble Organic Nitrogen	Nouis	2.03	mgN/l	88	kgN/day	2.99%
Unbiodegradable Particulate Organic Nitrogen	Noup	2.23	mgN/l	96	kgN/day	3.28%
Biodegradable Organic Nitrogen	Nobi	8.74	mgN/l	378	kgN/day	12.85%
Biodegradable Soluble Organic Nitrogen	Nobsi	3.28	mgN/l	142	kgN/day	4.82%
Biodegradable Particulate Organic Nitrogen	Nobpi	5.46	mgN/l	236	kgN/day	8.03%
Total Phosphorous	Pti	9.00	mgP/l	389	kgP/day	100.00%
Ortho Phosphate	OrthoP	8.02	mgP/l	347	kgP/day	89.14%
Organic Phosphate	Poi	0.98	mgP/l	42	kgP/day	10.86%
Unbiodegradable Organic Phosphate	Poui	0.86	mgP/l	37	kgP/day	9.53%
Unbiodegradable Soluble Organic Phosphate	Pousi	0.30	mgP/l	13	kgP/day	3.34%
Unbiodegradable Particulate Organic Phosphate	Poup	0.56	mgP/l	24	kgP/day	6.19%
Biodegradable Organic Phosphate	Pobi	0.12	mgP/l	5	kgP/day	1.33%
Biodegradable Soluble Organic Phosphate	Pobsi	0.06	mgP/l	3	kgP/day	0.67%
Biodegradable Particulate Organic Phosphate	Pobpi	0.06	mgP/l	3	kgP/day	0.67%
Total TOC	Cti	249.5	mgC/l	10780	kgC/day	100.00%
Unbiodegradable TOC	Cui	30.74	mgC/l	1328	kgC/day	12.32%
Unbiodegradable Soluble TOC	Cusi	19.20	mgC/l	830	kgC/day	7.70%
Unbiodegradable Particulate TOC	Cupi	11.54	mgC/l	499	kgC/day	4.63%
Biodegradable TOC	Cbi	218.76	mgC/l	9452	kgC/day	87.68%
Biodegradable Soluble TOC	Cbsi	80.30	mgC/l	3469	kgC/day	32.18%
Biodegradable Soluble VFA TOC	C_{vfa}	14.85	mgC/l	642	kgC/day	5.95%
Biodegradable Soluble FBSO TOC	FBSO	65.45	mgC/l	2828	kgC/day	26.23%
Biodegradable Particulate TOC	Cbpi	138.46	mgC/l	5982	kgC/day	55.49%
TSS	X_o	180.00	(mgTSS/L)	7777	kgTSS/day	100.00%
VSS	VSS	140.00	(mgVSS/L)	6049	kgVSS/day	77.78%
ISS	X_{iss}	40.00	(mgISS/L)	1728	kgISS/day	22.22%
Influent Flowrate	Q_i	43.21	Ml/d			

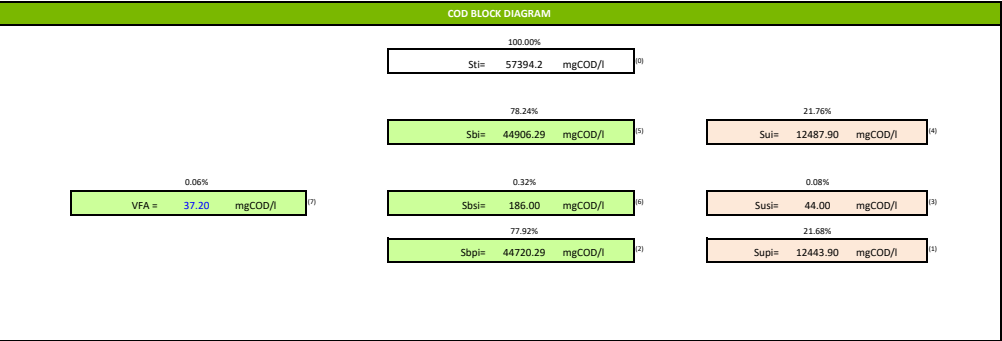
Concentrations and mass ratios of dissolved organics (settled influent)					
Parameter	Abbreviation	SO	USO	VFA	FBSO
COD		242.000	44.000	39.600	158.400
Mass	VSS	180.620	29.471	39.600	111.549
TOC		99.500	19.200	14.850	65.450
Organic Nitrogen		5.310	2.033	0.000	3.277
Organic Phosphate		0.361	0.301	0.000	0.060
COD/VSS Ratio	fcv	1.340	1.493	1.000	1.420
TOC/VSS Ratio (Carbon Content)	fc	0.551	0.651	0.375	0.587
TKN/VSS Ratio (Nitrogen Content)	fn	0.029	0.069	0.000	0.029
TP/VSS Ratio (Phosphate Content)	fp	0.002	0.000	0.000	0.001

Concentrations and mass ratios of Biodegradable Particulate Organics (Settled Influent)							
Parameter	Abbreviation	BPO Raw	BPO Settled	BPO Non -Settled	UPO Raw	UPO Settled	UPO Non -Settled
COD	COD	690.800	385.000	305.800	127.200	33.000	94.200
Mass	Mass	294.112	117.718	176.394	85.888	22.282	63.606
TOC	TOC	239.110	138.458	100.652	44.490	11.542	32.948
Organic Nitrogen	Org N	15.473	5.462	10.012	8.589	2.228	6.361
Organic Phosphate	Org P	0.387	0.060	0.327	2.147	0.557	1.590
COD/VSS Ratio	fcv	2.349	3.271	1.734	1.481	1.481	1.481
TOC/VSS Ratio (Carbon Content)	fc	0.813	1.176	0.571	0.518	0.518	0.518
TKN/VSS Ratio (Nitrogen Content)	fn	0.053	0.046	0.057	0.100	0.100	0.100
TP/VSS Ratio (Phosphate Content)	fp	0.001	0.001	0.002	0.025	0.025	0.025

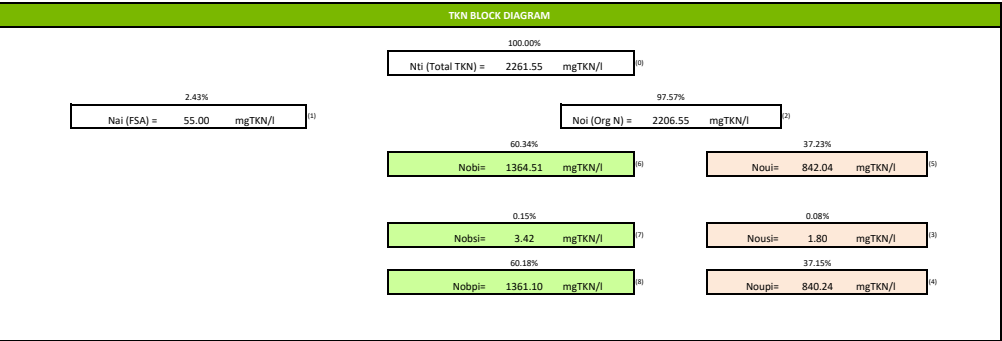
ANNEXURE D

PRIMARY SLUDGE CHARACTERISATION

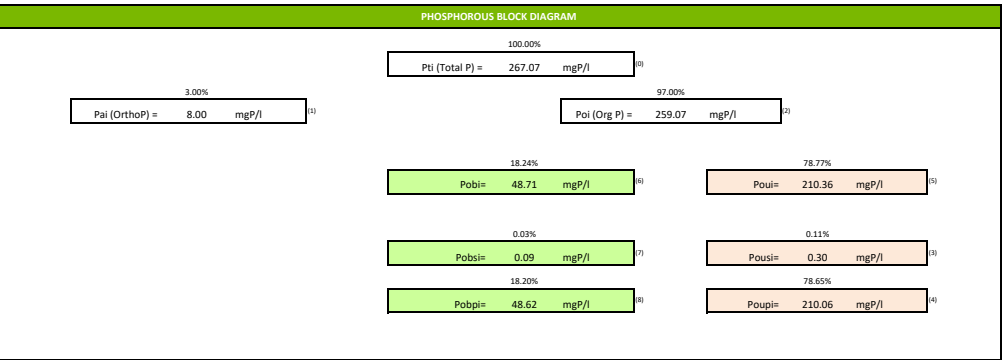
3. OLD LANE : PRIMARY SLUDGE CHARACTERIZATION FOR THE ANAEROBIC DIGESTER



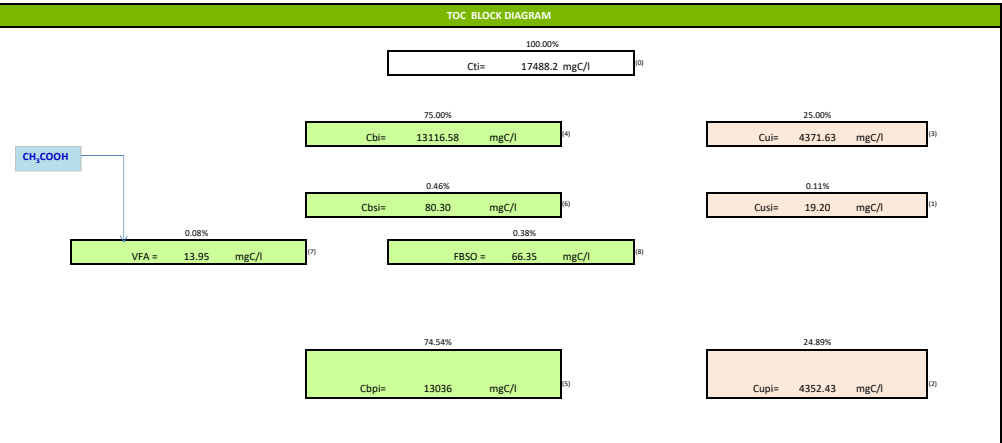
- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See S_i for Primary Sludge.
- ⁽¹⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See S_{bi} for Primary Sludge.
- ⁽²⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See S_{bp} for Primary Sludge.
- ⁽³⁾ COD in effluent which is S_{usi} (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽⁴⁾ = $S_{usi} + S_{upi}$
- ⁽⁵⁾ = $S_{ti} - S_{ui}$
- ⁽⁶⁾ = $S_{bi} - S_{bpi}$
- ⁽⁷⁾ = VFA _{0.45um membrane filtered} Now can determined Fraction of readily biodegradable COD that is VFA ($f_{bio,r}$)



- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See N_i for Primary Sludge.
- ⁽¹⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See N_i for Primary Sludge.
- ⁽²⁾ " = $N_{ti} - N_{ai}$ " OR "Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See N_i for Primary Sludge.
- ⁽³⁾ Given (TKN-FSA) in effluent which is N_{ousi} (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽⁴⁾ = $S_{upi} \times (fn/fcv)$
- ⁽⁵⁾ = $N_{ousi} + N_{oupi}$
- ⁽⁶⁾ = $N_{oi} - N_{oui}$
- ⁽⁷⁾ = TKN _{0.45um membrane filtered} - $N_{ai} - N_{ousi}$
- ⁽⁸⁾ = $N_{bi} - N_{bsi}$



- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See P_i for Primary Sludge.
- ⁽¹⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See P_i for Primary Sludge.
- ⁽²⁾ = $P_{ti} - \text{OrthoP}$ OR Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See P_i for Primary Sludge.
- ⁽³⁾ Given (TP - OrthoP) in effluent which is P_{ousi} (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽⁴⁾ = $S_{upi} \times (fp/fcv)$
- ⁽⁵⁾ = $P_{ousi} + N_{poupi}$
- ⁽⁶⁾ = $P_{oi} - P_{oui}$
- ⁽⁷⁾ = P _{0.45um membrane filtered} - $\text{OrthoP} - P_{ousi}$
- ⁽⁸⁾ = $P_{bi} - P_{bsi}$



- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See C_i for Primary Sludge.
- ⁽¹⁾ Given TOC in effluent which is C_{usi} (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽²⁾ = $S_{upi} \times (fc/fcv)$
- ⁽³⁾ = $C_{usi} + C_{upi}$
- ⁽⁴⁾ = $C_{ti} - C_{ui}$
- ⁽⁵⁾ = $C_{ti} - \text{COD}_{0.45um\ membrane\ filtered} - C_{upi}$
- ⁽⁶⁾ = $C_{bi} - C_{bpi}$
- ⁽⁷⁾ TOC _{VFA} = 13.95

CH3COOH					
x	y	z	a	b	
C	H	O	N	P	S
2.0000	4.0000	2.0000	0.0000	0.0000	0.0000

COD	64.0000	gCOD/mol
C Concentration	24	gC/mol
λ_s	8.0000	ge-/mol

- ⁽⁸⁾ = $C_{bsi} - VFA$

Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge							
Parameter	Abbreviation	Raw WW		Settled WW		Primary Sludge	
Flows							
Parameter	Abbreviation	Value	Unit	Value	Unit	Value	Unit
Flow (Ml/day)	Q	17.25	Ml/day	17.12	Ml/day	0.134	Ml/day
Concentrations and Fluxes							
Parameter	Abbreviation	Raw WW		Settled WW		Primary Sludge	
		Concentration	Flux	Concentration	Flux	Concentration	Flux
		mg/l	kg/day	mg/l	kg/day	mg/l	kg/day
Total COD	Sti	1060.00	18285	620.00	10612	57394	7673
Total Kjedahli Nitrogen	Nti	85.00	1466	68.00	1164	2262	302
Free and Saline Ammonia	Nai	55.00	949	55.00	941	55	7
Organic Nitrogen	Noi	30.00	518	13.00	223	2207	295
Total Phosphorous	Pti	11.00	190	9.00	154	267	36
Ortho Phosphate	OrthoP	8.00	138	8.00	137	8	1
Organic Phosphate	Poi	3.00	52	1.00	17	259	35
Total TOC	Cti	383.10	6608	249.50	4271	17488	2338
TSS	X _o	450.00	7763	140.00	2396	40140	5366
VSS	VSS	380.00	6555	120.00	2054	33668	4501
ISS	X _{ui}	70.00	1208	20.00	342	6472	865
Unbiodegradable Particulate Organics (UPO)	Supi	127.20	2194	31.00	531	12444	1664
Biodegradable Particulate Organics (BPO)	Sbpi	702.80	12123	359.00	6145	44720	5979

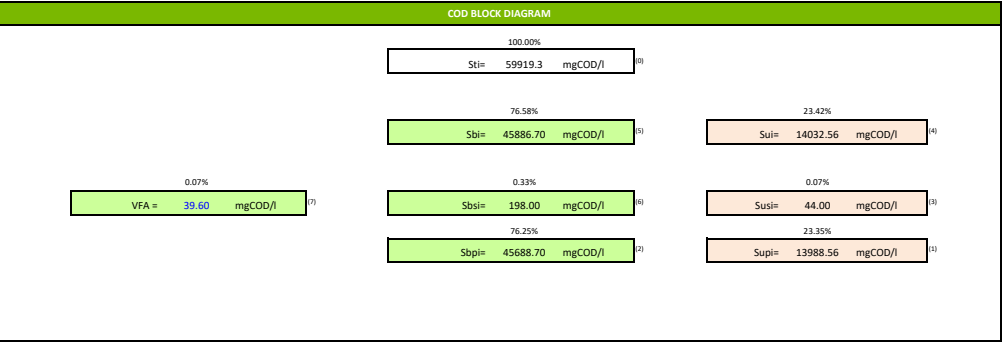
SUMMARY OF PRIMARY SLUDGE WASTEWATER FRACTIONS						
Parameter	Abbreviation	Concentration Value	Unit	Flux	Unit	Percentage
Total COD	Sti	57394.2	mgCOD/l	7673	kgCOD/day	100.00%
Unbiodegradable COD	Sui	12487.90	mgCOD/l	1669	kgCOD/day	21.76%
Unbiodegradable Soluble COD	Susi	44.00	mgCOD/l	6	kgCOD/day	0.08%
Unbiodegradable Particulate COD	Supi	12443.90	mgCOD/l	1664	kgCOD/day	21.68%
Biodegradable COD	Sbi	44906.29	mgCOD/l	6003	kgCOD/day	78.24%
Biodegradable Soluble COD	Sbsi	186.00	mgCOD/l	25	kgCOD/day	0.32%
Biodegradable Particulate COD	Sbpi	44720.29	mgCOD/l	5979	kgCOD/day	77.92%
Readily biodegradable COD that is VFA	S _{VFA}	37.20	mgCOD/l	5	kgCOD/day	0.06%
Total Kjeldahl Nitrogen	Nti	2261.5	mgN/l	302	kgN/day	100.00%
Free and Saline Ammonia	Nai	55.00	mgN/l	7	kgN/day	2.43%
Organic Nitrogen	Noi	2206.55	mgN/l	295	kgN/day	97.57%
Unbiodegradable Organic Nitrogen	Noui	842.04	mgN/l	113	kgN/day	37.23%
Unbiodegradable Soluble Organic Nitrogen	Nousi	1.80	mgN/l	0	kgN/day	0.08%
Unbiodegradable Particulate Organic Nitrogen	Noupi	840.24	mgN/l	112	kgN/day	37.15%
Biodegradable Organic Nitrogen	Nbsi	1364.51	mgN/l	182	kgN/day	60.34%
Biodegradable Soluble Organic Nitrogen	Nbsi	3.42	mgN/l	0	kgN/day	0.15%
Biodegradable Particulate Organic Nitrogen	Nbspi	1361.10	mgN/l	182	kgN/day	60.18%
Total Phosphorous	Pti	267.07	mgP/l	36	kgP/day	100.00%
Ortho Phosphate	OrthoP	8.00	mgP/l	1	kgP/day	3.00%
Organic Phosphate	Poi	259.07	mgP/l	35	kgP/day	97.00%
Unbiodegradable Organic Phosphate	Poui	210.36	mgP/l	28	kgP/day	78.77%
Unbiodegradable Soluble Organic Phosphate	Pousi	0.30	mgP/l	0	kgP/day	0.11%
Unbiodegradable Particulate Organic Phosphate	Poupi	210.06	mgP/l	28	kgP/day	78.65%
Biodegradable Organic Phosphate	Pbsi	48.71	mgP/l	7	kgP/day	18.24%
Biodegradable Soluble Organic Phosphate	Pbsi	0.09	mgP/l	0	kgP/day	0.03%
Biodegradable Particulate Organic Phosphate	Pbspi	48.62	mgP/l	6	kgP/day	18.20%
Total TOC	Cti	17488.2	mgC/l	2338	kgC/day	100.00%
Unbiodegradable TOC	Cui	4371.63	mgC/l	584	kgC/day	25.00%
Unbiodegradable Soluble TOC	Cusi	19.20	mgC/l	3	kgC/day	0.11%
Unbiodegradable Particulate TOC	Cupi	4352.43	mgC/l	582	kgC/day	24.89%
Biodegradable TOC	Cbi	13116.58	mgC/l	1754	kgC/day	75.00%
Biodegradable Soluble TOC	Cbsi	80.30	mgC/l	11	kgC/day	0.46%
Biodegradable Soluble VFA TOC	C _{VFA}	13.95	mgC/l	2	kgC/day	0.08%
Biodegradable Soluble FBSO TOC	FBSO	66.35	mgC/l	9	kgC/day	0.38%
Biodegradable Particulate TOC	Cbpi	13036.28	mgC/l	1743	kgC/day	74.54%
TSS	X _o	40140	(mgTSS/L)	5366	kgTSS/day	100.00%
VSS	VSS	33668	(mgVSS/L)	4501	kgVSS/day	83.88%
ISS	X _{ui}	6472	(mgISS/L)	865	kgISS/day	16.12%
Influent Flowrate	Q _i	0.13	Ml/d			

Concentrations and mass ratios of dissolved organics (settled influent)					
Parameter	Abbreviation	SO	Unbiodegradable Soluble Organics	VFA	Fermentable Biodegradable Soluble Organics
COD of Primary Sludge	COD	230.000	44.000	37.200	148.800
VSS of Primary Sludge	VSS	171.460	29.471	37.200	104.789
TOC of Primary Sludge	TOC	99.500	19.200	13.950	66.350
Organic N Content of Primary Sludge	ORG N	5.215	1.800	0.000	3.415
Organic P Content of Primary Sludge	ORG P	0.388	0.300	0.000	0.088
COD/VSS Ratio of biomass	f _{co}	1.341	1.493	1.000	1.420
TOC/VSS Ratio (Carbon Content) of Biomass	f _c	0.580	0.651	0.375	0.633
TKN/VSS Ratio (Nitrogen Content) of Biomass	f _n	0.030	0.061	0.000	0.033
TP/VSS Ratio (Phosphate Content) of Biomass	f _p	0.002	0.010	0.000	0.001

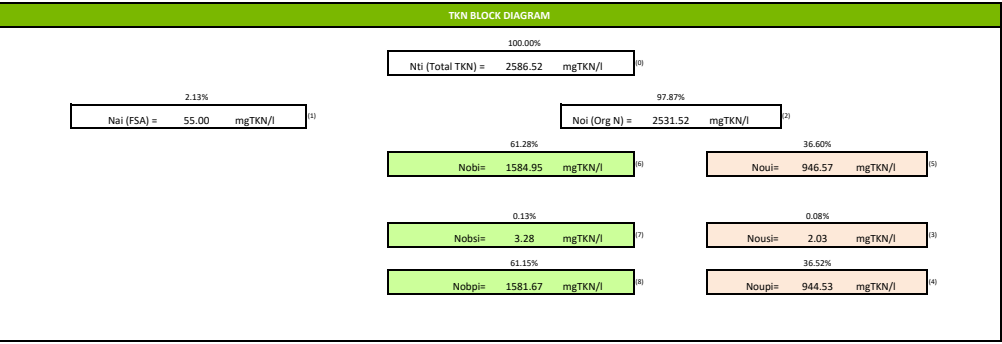
1.493	1.000	1.420
0.061	0.000	0.033
0.010	0.000	0.001

PRIMARY SLUDGE CHARACTERISATION				
Parameter	Abbreviation	Particulate Organics	Unbiodegradable Particulate Organics	Biodegradable Particulate Organics
COD of Primary Sludge	COD	57164	12444	44720
VSS of Primary Sludge	VSS	33497	8402	25095
TOC of Primary Sludge	TOC	17389	4352	13036
Organic N Content of Primary Sludge	ORG N	2201	840	1361
Organic P Content of Primary Sludge	ORG P	259	210	49
COD/VSS Ratio of biomass	f _{co}	1.7066	1.4810	1.7821
TOC/VSS Ratio (Carbon Content) of Biomass	f _c	0.5191	0.5180	0.5195
TKN/VSS Ratio (Nitrogen Content) of Biomass	f _n	0.0657	0.1000	0.0542
TP/VSS Ratio (Phosphate Content) of Biomass	f _p	0.0077	0.0250	0.0019

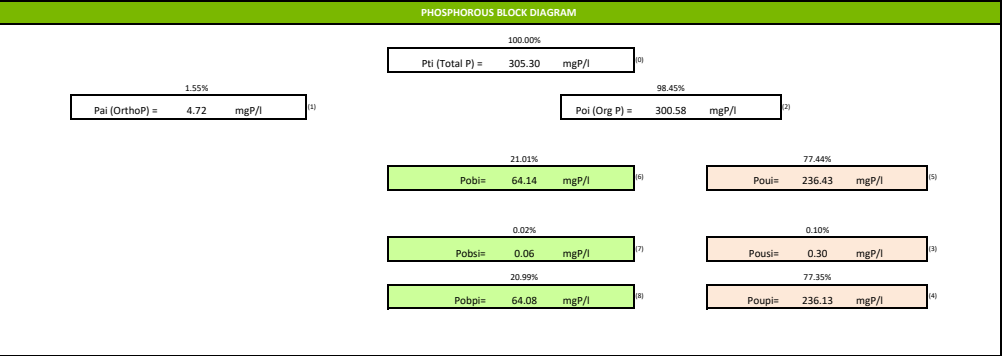
3. NEW LANE : PRIMARY SLUDGE CHARACTERIZATION FOR THE ANAEROBIC DIGESTER



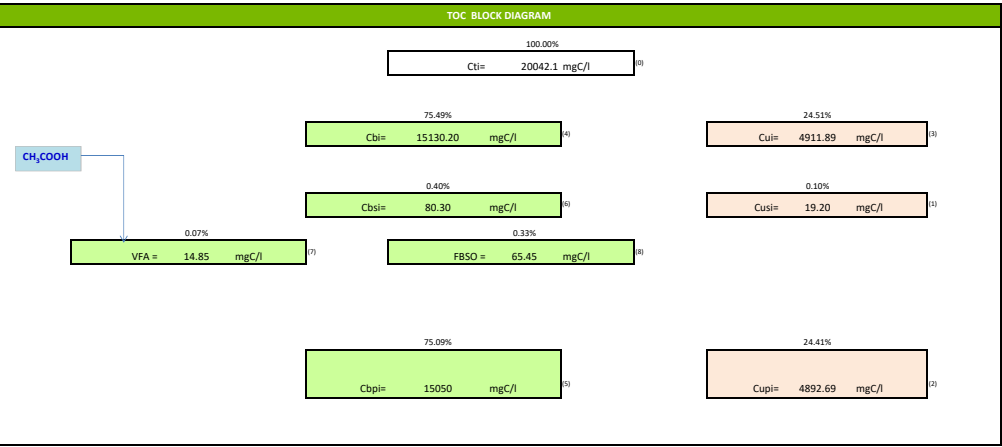
- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See S_i for Primary Sludge.
- ⁽²⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See S_{bi} for Primary Sludge.
- ⁽³⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See S_{bp} for Primary Sludge.
- ⁽⁸⁾ COD in effluent which is S_{usi} (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽⁴⁾ = $S_{usi} + S_{upi}$
- ⁽³⁾ = $S_{ti} - S_{ui}$
- ⁽⁴⁾ = $S_{bi} - S_{bpi}$
- ⁽⁷⁾ = VFA ^{0.45um membrane filtered} Now can determined Fraction of readily biodegradable COD that is VFA (f_{vfa})



- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See N_i for Primary Sludge.
- ⁽¹⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See N_i for Primary Sludge.
- ⁽²⁾ " = $N_{ti} - N_{ai}$ " OR "Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See N_i for Primary Sludge.
- ⁽⁸⁾ Given (TKN-FSA) in effluent which is N_{ousi} (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽⁴⁾ = $S_{upi} \times (fn/fcv)$
- ⁽³⁾ = $N_{ousi} + N_{oup}$
- ⁽⁴⁾ = $N_{oi} - N_{oui}$
- ⁽⁷⁾ = TKN ^{0.45um membrane filtered} - $N_{ai} - N_{ousi}$
- ⁽⁸⁾ = $N_{obi} - N_{obsi}$



- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See P_i for Primary Sludge.
- ⁽¹⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See P_i for Primary Sludge.
- ⁽²⁾ = $P_{ti} - \text{OrthoP}$ OR Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See P_i for Primary Sludge.
- ⁽⁸⁾ Given (TP - OrthoP) in effluent which is P_{ousi} (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽⁴⁾ = $S_{upi} \times (fp/fcv)$
- ⁽³⁾ = $P_{ousi} + N_{poup}$
- ⁽⁴⁾ = $P_{oi} - P_{oui}$
- ⁽⁷⁾ = P ^{0.45um membrane filtered} - $\text{OrthoP} - P_{ousi}$
- ⁽⁸⁾ = $P_{obi} - P_{obsi}$



- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See C_i for Primary Sludge.
- ⁽¹⁾ Given TOC in effluent which is C_{usi} (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽²⁾ = $S_{upi} \times (fc/fcv)$
- ⁽³⁾ = $C_{usi} + C_{upi}$
- ⁽⁴⁾ = $C_{ti} - C_{ui}$
- ⁽³⁾ = $C_{ti} - \text{COD}$ ^{0.45um membrane filtered} - C_{upi}
- ⁽⁴⁾ = $C_{bi} - C_{bpi}$
- ⁽⁷⁾ $\text{TOC}_{VFA} = 14.85$

CH3COOH					
x	y	z	a	b	
C	H	O	N	P	S
2.0000	4.0000	2.0000	0.0000	0.0000	0.0000

COD	64.0000	gCOD/mol
C Concentration	24	gC/mol
λ_s	8.0000	ge-/mol

- ⁽⁸⁾ = $C_{bsi} - VFA$

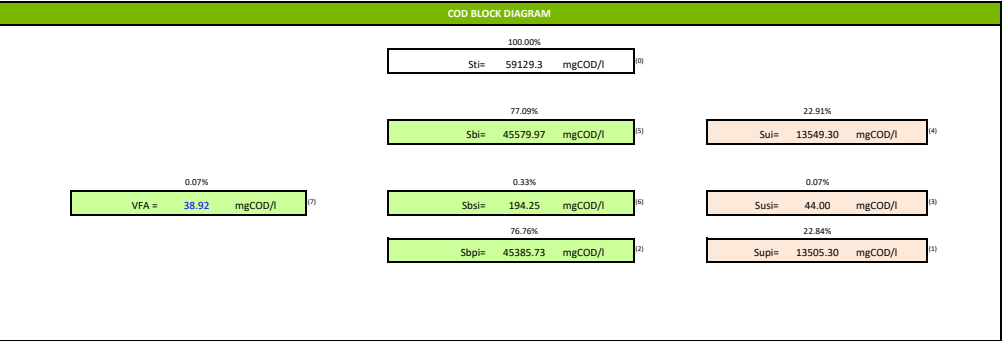
Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge							
Parameter	Abbreviation	Raw WW		Settled WW		Primary Sludge	
Flows							
Parameter	Abbreviation	Value	Unit	Value	Unit	Value	Unit
Flow (Ml/day)	Q	43.50	Ml/day	43.21	Ml/day	0.294	Ml/day
Concentrations and Fluxes							
Parameter	Abbreviation	Raw WW		Settled WW		Primary Sludge	
		Concentration	Flux	Concentration	Flux	Concentration	Flux
		mg/l	kg/day	mg/l	kg/day	mg/l	kg/day
Total COD	Sti	1060.00	46110	660.00	28516	59919	17594
Total Kjedaht Nitrogen	Nti	85.00	3697	68.00	2938	2587	759
Free and Saline Ammonia	Nai	55.00	2393	55.00	2376	55	16
Organic Nitrogen	Noi	30.00	1305	13.00	562	2532	743
Total Phosphorous	Pti	11.00	478	9.00	389	305	90
Ortho Phosphate	OrthoP	8.00	348	8.02	347	5	1
Organic Phosphate	Poi	3.00	131	0.98	42	301	88
Total TOC	Cti	383.10	16665	249.50	10780	20042	5885
TSS	Xo	450.00	19575	180.00	7777	40180	11798
VSS	VSS	380.00	16530	140.00	6049	35696	10481
ISS	Xui	70.00	3045	40.00	1728	4484	1317
Unbiodegradable Particulate Organics (UPO)	Supi	127.20	5533	33.00	1426	13989	4107
Biodegradable Particulate Organics (BPO)	Sbpi	690.80	30050	385.00	16634	45689	13415

SUMMARY OF PRIMARY SLUDGE WASTEWATER FRACTIONS					
Parameter	Abbreviation	Concentration Value	Unit	Flux	Percentage
Total COD	Sti	59919.3	mgCOD/l	17594	kgCOD/day
Unbiodegradable COD	Sui	14032.56	mgCOD/l	4120	kgCOD/day
Unbiodegradable Soluble COD	Susi	44.00	mgCOD/l	13	kgCOD/day
Unbiodegradable Particulate COD	Supi	13988.56	mgCOD/l	4107	kgCOD/day
Biodegradable COD	Sbi	45886.70	mgCOD/l	13473	kgCOD/day
Biodegradable Soluble COD	Sbsi	198.00	mgCOD/l	58	kgCOD/day
Biodegradable Particulate COD	Sbpi	45688.70	mgCOD/l	13415	kgCOD/day
Readily biodegradable COD that is VFA	S _{VFA}	39.60	mgCOD/l	12	kgCOD/day
Total Kjedaht Nitrogen	Nti	2586.5	mgN/l	759	kgN/day
Free and Saline Ammonia	Nai	55.00	mgN/l	16	kgN/day
Organic Nitrogen	Noi	2531.52	mgN/l	743	kgN/day
Unbiodegradable Organic Nitrogen	Noui	946.57	mgN/l	278	kgN/day
Unbiodegradable Soluble Organic Nitrogen	Nousi	2.03	mgN/l	1	kgN/day
Unbiodegradable Particulate Organic Nitrogen	Noup	944.53	mgN/l	277	kgN/day
Biodegradable Organic Nitrogen	Nobi	1584.95	mgN/l	465	kgN/day
Biodegradable Soluble Organic Nitrogen	Nobsi	3.28	mgN/l	1	kgN/day
Biodegradable Particulate Organic Nitrogen	Nobpi	1581.67	mgN/l	464	kgN/day
Total Phosphorous	Pti	305.30	mgP/l	90	kgP/day
Ortho Phosphate	OrthoP	4.72	mgP/l	1	kgP/day
Organic Phosphate	Poi	300.58	mgP/l	88	kgP/day
Unbiodegradable Organic Phosphate	Poui	236.43	mgP/l	69	kgP/day
Unbiodegradable Soluble Organic Phosphate	Pousi	0.30	mgP/l	0	kgP/day
Unbiodegradable Particulate Organic Phosphate	Poup	236.13	mgP/l	69	kgP/day
Biodegradable Organic Phosphate	Pobi	64.14	mgP/l	19	kgP/day
Biodegradable Soluble Organic Phosphate	Pobsi	0.06	mgP/l	0	kgP/day
Biodegradable Particulate Organic Phosphate	Pobpi	64.08	mgP/l	19	kgP/day
Total TOC	Cti	20042.1	mgC/l	5885	kgC/day
Unbiodegradable TOC	Cui	4911.89	mgC/l	1442	kgC/day
Unbiodegradable Soluble TOC	Cusi	19.20	mgC/l	6	kgC/day
Unbiodegradable Particulate TOC	Cupi	4892.69	mgC/l	1437	kgC/day
Biodegradable TOC	Cbi	15130.20	mgC/l	4443	kgC/day
Biodegradable Soluble TOC	Cbsi	80.30	mgC/l	24	kgC/day
Biodegradable Soluble VFA TOC	C _{VFA}	14.85	mgC/l	4	kgC/day
Biodegradable Soluble FBSO TOC	FBSO	65.45	mgC/l	19	kgC/day
Biodegradable Particulate TOC	Cbp	15049.90	mgC/l	4419	kgC/day
TSS	Xo	40180	(mgTSS/L)	11798	kgTSS/day
VSS	Xss	35696	(mgVSS/L)	10481	kgVSS/day
ISS	Xui	4484	(mgISS/L)	1317	kgISS/day
Influent Flowrate	Q _i	0.29	Ml/d		

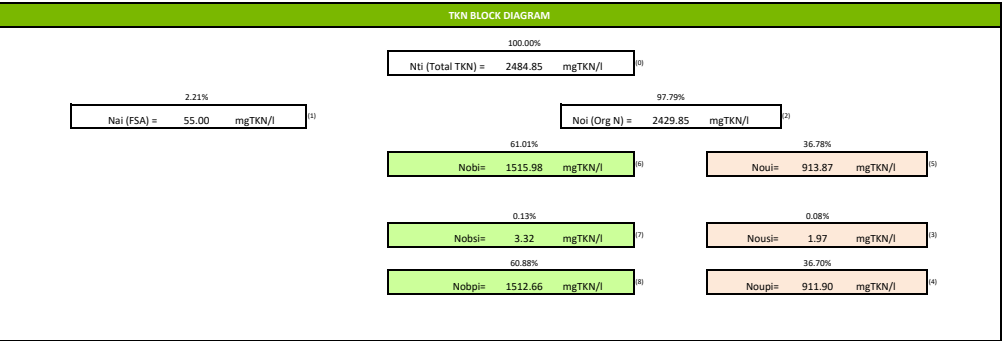
Concentrations and mass ratios of dissolved organics (settled influent)					
Parameter	Abbreviation	SO	Unbiodegradable Soluble Organics	VFA	Fermentable Biodegradable Soluble Organics
COD of Primary Sludge	COD	242.000	44.000	39.600	158.400
VSS of Primary Sludge	VSS	180.620	29.471	39.600	111.549
TOC of Primary Sludge	TOC	99.500	19.200	14.850	65.450
Organic N Content of Primary Sludge	ORG N	5.310	2.033	0.000	3.277
Organic P Content of Primary Sludge	ORG P	0.361	0.301	0.000	0.060
COD/VSS Ratio of biomass	f _{co}	1.340	1.493	1.000	1.420
TOC/VSS Ratio (Carbon Content) of Biomass	f _c	0.551	0.651	0.375	0.587
TKN/VSS Ratio (Nitrogen Content) of Biomass	f _n	0.029	0.069	0.000	0.029
TP/VSS Ratio (Phosphate Content) of Biomass	f _p	0.002	0.010	0.000	0.001

PRIMARY SLUDGE CHARACTERISATION				
Parameter	Abbreviation	Particulate Organics	Unbiodegradable Particulate Organics	Biodegradable Particulate Organics
COD of Primary Sludge	COD	59677	13989	45689
VSS of Primary Sludge	VSS	35515	9445	26070
TOC of Primary Sludge	TOC	19943	4893	15050
Organic N Content of Primary Sludge	ORG N	2526	945	1582
Organic P Content of Primary Sludge	ORG P	300	236	64
COD/VSS Ratio of biomass	f _{co}	1.6803	1.4810	1.7526
TOC/VSS Ratio (Carbon Content) of Biomass	f _c	0.5615	0.5180	0.5773
TKN/VSS Ratio (Nitrogen Content) of Biomass	f _n	0.0711	0.1000	0.0607
TP/VSS Ratio (Phosphate Content) of Biomass	f _p	0.0085	0.0250	0.0025

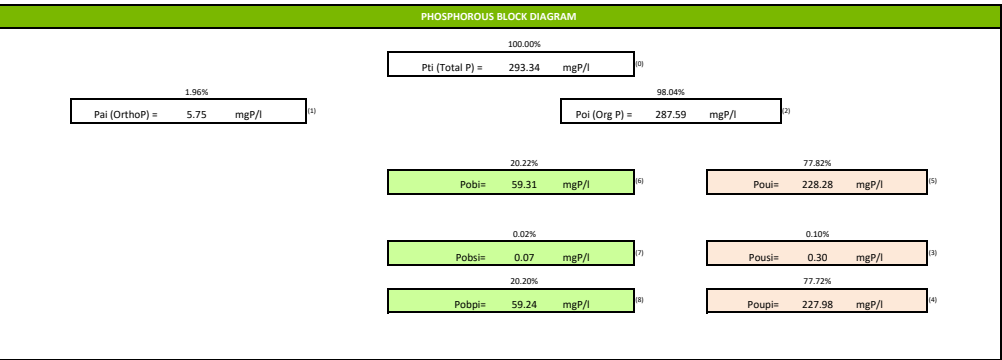
3. COMBINED (OLD LANE AND NEW LANE) : PRIMARY SLUDGE CHARACTERIZATION FOR THE ANAEROBIC DIGESTER



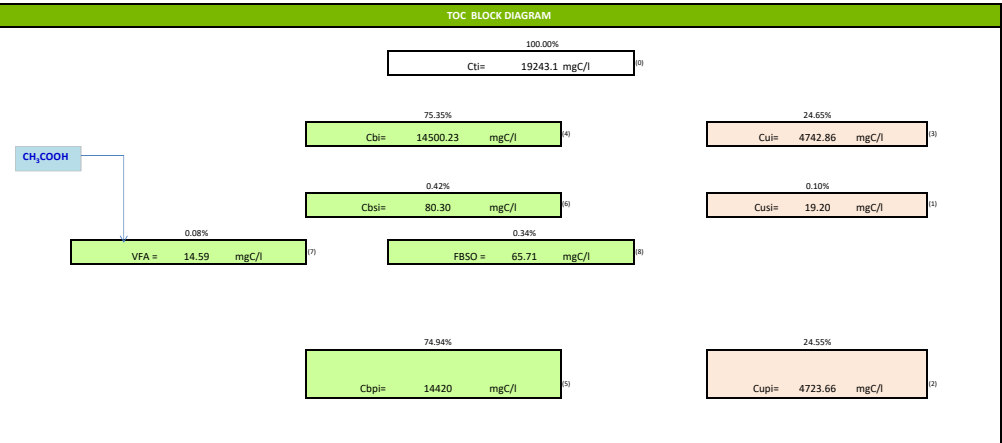
- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See S_i for Primary Sludge.
- ⁽¹⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See S_{bi} for Primary Sludge.
- ⁽²⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See S_{bp} for Primary Sludge.
- ⁽³⁾ COD in effluent which is Susi (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽⁴⁾ = Susi + Supi
- ⁽⁵⁾ = Sti - Sul
- ⁽⁶⁾ = Sbi - Sbpi
- ⁽⁷⁾ = VFA $\times$ 0.45um membrane filtered⁽⁸⁾ Now can determined Fraction of readily biodegradable COD that is VFA ($f_{bi,r}$)



- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See N_i for Primary Sludge.
- ⁽¹⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See N_{bi} for Primary Sludge.
- ⁽²⁾ " = Nti - Nai " OR "Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See N_{bi} for Primary Sludge.
- ⁽³⁾ Given (TKN-FSA) in effluent which is Nousi (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽⁴⁾ = Supi $\times$ (fn/fcv)
- ⁽⁵⁾ = Nousi + Noubpi
- ⁽⁶⁾ = Noi - Noubi
- ⁽⁷⁾ = TKN $\times$ 0.45um membrane filtered⁽⁸⁾ - Nai - Nousi
- ⁽⁸⁾ = Nobi - Nobsi



- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See P_i for Primary Sludge.
- ⁽¹⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See P_{bi} for Primary Sludge.
- ⁽²⁾ = Pti - OrthoP OR Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See P_{bi} for Primary Sludge.
- ⁽³⁾ Given (TP - OrthoP) in effluent which is Pousi (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽⁴⁾ = Supi $\times$ (fp/fcv)
- ⁽⁵⁾ = Pousi + NPoubi
- ⁽⁶⁾ = Poi - Poubi
- ⁽⁷⁾ = P $\times$ 0.45um membrane filtered⁽⁸⁾ - OrthoP - Pousi
- ⁽⁸⁾ = Pobi - Pobsi



- ⁽⁸⁾ Calculated as per Table for "Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge". See C_i for Primary Sludge.
- ⁽¹⁾ Given TOC in effluent which is Cusi (see tests on Tests on membrane filtered effluent from AS System operated at 20°C)
- ⁽²⁾ = Supi $\times$ (fc/fcv)
- ⁽³⁾ = Cusi + Cupi
- ⁽⁴⁾ = Cti - Cui
- ⁽⁵⁾ = Cti - COD $\times$ 0.45um membrane filtered⁽⁸⁾ - Cupi
- ⁽⁶⁾ = Cbi - Cbpi
- ⁽⁷⁾ TOC $\times$ 0.45um membrane filtered⁽⁸⁾

x	y	z	a	b	
C	H	O	N	P	S
2.0000	4.0000	2.0000	0.0000	0.0000	0.0000

COD	64.0000	gCOD/mol
C Concentration	24	gC/mol
λ_s	8.0000	ge-/mol

- ⁽⁸⁾ = Cbsi - VFA

Flows, Concentrations and Fluxes for Raw WW, Settled WW and Primary Sludge							
Parameter	Abbreviation	Raw WW		Settled WW		Primary Sludge	
Flows							
Parameter	Abbreviation	Value	Unit	Value	Unit	Value	Unit
Flow (Ml/day)	Q	60.75	Ml/day	60.32	Ml/day	0.427	Ml/day
Concentrations and Fluxes							
Parameter	Abbreviation	Raw WW		Settled WW		Primary Sludge	
		Concentration	Flux	Concentration	Flux	Concentration	Flux
		mg/l	kg/day	mg/l	kg/day	mg/l	kg/day
Total COD	Sti	1060.00	64395	648.65	39128	59129	25267
Total Kjedahli Nitrogen	Nti	85.00	5164	68.00	4102	2485	1062
Free and Saline Ammonia	Nai	55.00	3341	55.00	3318	55	24
Organic Nitrogen	Noi	30.00	1823	13.00	784	2430	1038
Total Phosphorous	Pti	11.00	668	9.00	543	293	125
Ortho Phosphate	OrthoP	8.00	486	8.02	484	6	2
Organic Phosphate	Poi	3.00	182	0.98	59	288	123
Total TOC	Cti	383.10	23273	249.50	15051	19243	8223
TSS	X _o	450.00	27338	180.00	10858	38565	16479
VSS	VSS	380.00	23085	140.00	8445	34260	14640
ISS	X _{ui}	70.00	4253	40.00	2413	4305	1840
Unbiodegradable Particulate Organics (UPO)	Supi	127.20	7727	32.43	1956	13505	5771
Biodegradable Particulate Organics (BPO)	Sbpi	694.21	42173	377.62	22779	45386	19394
			27338		10173		17164

SUMMARY OF PRIMARY SLUDGE WASTEWATER FRACTIONS					
Parameter	Abbreviation	Concentration Value	Unit	Flux	Percentage
Total COD	Sti	59129.3	mgCOD/l	25267	kgCOD/day
Unbiodegradable COD	Sui	13549.30	mgCOD/l	5790	kgCOD/day
Unbiodegradable Soluble COD	Susi	44.00	mgCOD/l	19	kgCOD/day
Unbiodegradable Particulate COD	Supi	13505.30	mgCOD/l	5771	kgCOD/day
Biodegradable COD	Sbi	45579.97	mgCOD/l	19477	kgCOD/day
Biodegradable Soluble COD	Sbsi	194.25	mgCOD/l	83	kgCOD/day
Biodegradable Particulate COD	Sbpi	45385.73	mgCOD/l	19394	kgCOD/day
Readily biodegradable COD that is VFA	S $\times$ VFA	38.92	mgCOD/l	17	kgCOD/day
Total Kjeldahl Nitrogen	Nti	2484.8	mgN/l	1062	kgN/day
Free and Saline Ammonia	Nai	55.00	mgN/l	24	kgN/day
Organic Nitrogen	Noi	2429.85	mgN/l	1038	kgN/day
Unbiodegradable Organic Nitrogen	Noubi	913.87	mgN/l	391	kgN/day
Unbiodegradable Soluble Organic Nitrogen	Nousi	1.97	mgN/l	1	kgN/day
Unbiodegradable Particulate Organic Nitrogen	Noubpi	911.90	mgN/l	390	kgN/day
Biodegradable Organic Nitrogen	Nobi	1515.98	mgN/l	648	kgN/day
Biodegradable Soluble Organic Nitrogen	Nobsi	3.32	mgN/l	1	kgN/day
Biodegradable Particulate Organic Nitrogen	Nobpi	1512.66	mgN/l	646	kgN/day
Total Phosphorous	Pti	293.34	mgP/l	125	kgP/day
Ortho Phosphate	OrthoP	5.75	mgP/l	2	kgP/day
Organic Phosphate	Poi	287.59	mgP/l	123	kgP/day
Unbiodegradable Organic Phosphate	Poubi	228.28	mgP/l	98	kgP/day
Unbiodegradable Soluble Organic Phosphate	Pousi	0.30	mgP/l	0	kgP/day
Unbiodegradable Particulate Organic Phosphate	Poubpi	227.98	mgP/l	97	kgP/day
Biodegradable Organic Phosphate	Pobi	59.31	mgP/l	25	kgP/day
Biodegradable Soluble Organic Phosphate	Pobsi	0.07	mgP/l	0	kgP/day
Biodegradable Particulate Organic Phosphate	Pobpi	59.24	mgP/l	25	kgP/day
Total TOC	Cti	19243.1	mgC/l	8223	kgC/day
Unbiodegradable TOC	Cui	4742.86	mgC/l	2027	kgC/day
Unbiodegradable Soluble TOC	Cusi	19.20	mgC/l	8	kgC/day
Unbiodegradable Particulate TOC	Cupl	4723.66	mgC/l	2018	kgC/day
Biodegradable TOC	Cbi	14500.23	mgC/l	6196	kgC/day
Biodegradable Soluble TOC	Cbsi	80.30	mgC/l	34	kgC/day
Biodegradable Soluble VFA TOC	C $\times$ VFA	14.59	mgC/l	6	kgC/day
Biodegradable Soluble FBSO TOC	FBSO	65.71	mgC/l	28	kgC/day
Biodegradable Particulate TOC	Cbp	14419.93	mgC/l	6162	kgC/day
TSS	X _o	38565	(mgTSS/L)	16479	kgTSS/day
VSS	X _u	34260	(mgVSS/L)	14640	kgVSS/day
ISS	X _{ui}	4305	(mgISS/L)	1840	kgISS/day
Influent Flowrate	Q _i	0.43	Ml/d		

Concentrations and mass ratios of dissolved organics (settled influent)					
Parameter	Abbreviation	SO	Unbiodegradable Soluble Organics	VFA	Fermentable Biodegradable Soluble Organics
COD of Primary Sludge	COD	238.246	44.000	38.919	155.327
VSS of Primary Sludge	VSS	177.775	29.471	38.919	109.385
TOC of Primary Sludge	TOC	99.500	19.200	14.595	65.705
Organic N Content of Primary Sludge	ORG N	5.283	1.967	0.000	3.316
Organic P Content of Primary Sludge	ORG P	0.369	0.301	0.000	0.068
COD/VSS Ratio of biomass	f _{co}	1.338	1.493	1.000	1.420
TOC/VSS Ratio (Carbon Content) of Biomass	f _c	0.560	0.651	0.375	0.601
TKN/VSS Ratio (Nitrogen Content) of Biomass	f _n	0.030	0.067	0.000	0.030
TP/VSS Ratio (Phosphate Content) of Biomass	f _p	0.002	0.010	0.000	0.001

PRIMARY SLUDGE CHARACTERISATION				
Parameter	Abbreviation	Particulate Organics	Unbiodegradable Particulate Organics	Biodegradable Particulate Organics
COD of Primary Sludge	COD	58891	13505	45386
VSS of Primary Sludge	VSS	34082	9119	24963
TOC of Primary Sludge	TOC	19144	4724	14420
Organic N Content of Primary Sludge	ORG N	2425	912	1513
Organic P Content of Primary Sludge	ORG P	287	228	59
COD/VSS Ratio of biomass	f _{co}	1.7279	1.4810	1.8181
TOC/VSS Ratio (Carbon Content) of Biomass	f _c	0.5617	0.5180	0.5776
TKN/VSS Ratio (Nitrogen Content) of Biomass	f _n	0.0711	0.1000	0.0606
TP/VSS Ratio (Phosphate Content) of Biomass	f _p	0.0084	0.0250	0.0024

ANNEXURE E

SUMMARY OF STOICHIOMETRIC AND KINETIC CONSTANTS

ANNEXURE E: SUMMARY OF STOICHIOMETRIC AND KINETIC CONSTANTS FOR THE ACTIVATED SLUDGE SYSTEM						
Parameter	Abbreviation	Value @ 20 °C	Theta	Value @ T _{MIN}	Value @ T _{MAX}	Unit
STOICHIOMETRIC & KINETIC CONSTANTS: HETEROTROPHS						
Yield Coefficient of Active Organisms of OHOs	Y _H	0.450	1.000	0.450	0.450	mgVSS/mgCOD
Endogenous Respiration Rate of OHOs	b _{HT}	0.240	1.029	0.214	0.269	/day
Endogenous Residue Fraction of OHOs	f _{eh OHOs}	0.200	1.000	0.200	0.200	
Substrate utilisation rate of OHOs	k _{VT}	100.000	1.029	89.195	112.114	l/(mgvss/d)
Organic Nitrogen Degradation Rate of OHOs	K _{rT}	0.015	1.029	0.013	0.017	l/(mgvss/d)
Inorganic Material Content of the OHO active biomass	f _{iOHO}	0.150	1.000	0.150	0.150	mgISS/mgVSS
STOICHIOMETRIC & KINETIC CONSTANTS: NITRIFIERS (AUTOTROPHS)						
Maximum Specific Growth Rate of Nitrifiers	U _{Am20}	0.450	1.123	0.283	0.716	/day
Endogenous Decay/Respiration Rate of Nitrifiers	b _{nT}	0.040	1.029	0.036	0.045	/day
Half Saturation Coefficient of Nitrifiers	K _{nT}	1.000	1.123	0.629	1.590	mgN/L
Yield Coefficient of Nitrifiers	Y _N	0.100	1.000	0.100	0.100	mgCOD/mgN
STOICHIOMETRIC & KINETIC CONSTANTS: DENITRIFICATION RATES						
1 st Denitrification Rate in Primary Anoxic (only for ND systems)	K _{1T}	0.720	1.200	0.347	1.493	mgNO3-N/mgOHOVSS/day
2 nd Denitrification Rate in Primary Anoxic (only for ND systems)	K _{2T}	0.101	1.080	0.074	0.137	mgNO3-N/mgOHOVSS/day
3 rd Denitrification Rate in Secondary Anoxic (only for ND systems)	K _{3T}	0.072	1.029	0.064	0.081	mgNO3-N/mgOHOVSS/day
1 st Denitrification Rate in Primary Anoxic (only for NDBEPR systems)	K _{1T}	0.700	1.200	0.338	1.452	mgNO3-N/mgOHOVSS/day
2 nd Denitrification Rate in Primary Anoxic (only for NDBEPR systems)	K _{2T}	0.255	1.080	0.187	0.347	mgNO3-N/mgOHOVSS/day
3 rd Denitrification Rate in Secondary Anoxic (only for NDBEPR systems)	K _{3T}	0.114	1.029	0.102	0.128	mgNO3-N/mgOHOVSS/day
STOICHIOMETRIC & KINETIC CONSTANTS: POLY-PHOSPHATE ACCUMULATING ORGANISMS						
Yield Coefficient of Poly P Organisms	Y _G	0.450	1.000	0.450	0.450	mgPAOVSS/mgCOD
Endogenous Decay Rate for Poly P Organisms	b _{GT}	0.040	1.029	0.036	0.045	/day
Endogenous Respiration Rate of PAOs (WAS)	b _{GP}	0.040	1.029	0.036	0.045	/day
First Order Rate for Conversion of RBCOD to SCFA	K _{CT}	0.060	1.029	0.054	0.067	l/mgOHOVSS.day
Unbiodegradable Particulate Fraction of Poly-P Organisms	f _g	0.250	1.000	0.250	0.250	mgP/mgPAOVSS
Maximum Fraction of Poly-P Organisms Active Mass	f _{xbgp}	0.380	1.000	0.380	0.380	mgP/mgPAOVSS
Fraction of Heterotrophic Non-Poly P Organisms Active Mass	f _{xbhp}	0.025	1.000	0.025	0.025	mgP/mgAVSS
Inorganic Material Content of the PAO active biomass	f _{i PAO}	n/appl.	n/appl.	1.300	1.300	mgISS/mgVSS
Fraction of Heterotrophic Non-PolyP Organisms Endogenous Mass	f _{xehp}	0.030	1.000	0.030	0.030	mgP/mgAVSS
Fraction of Poly-P Organisms Endogenous Mass	f _{xegp}	0.030	1.000	0.030	0.030	mgP/mgAVSS
Inert Mass	f _{xip}	0.030	1.000	0.030	0.030	mgP/mgISS
Unbiodegradable Particulate Fraction of Heterotrophic Non-Poly P Organisms	f _{eph}	0.200	1.000	0.200	0.200	mgVSS/mgAVSS
Inorganic Material Content of the PAO active biomass	f _{iPAOBM}	0.150	1.000	0.150	0.150	mgISS/mgVSS
P Content of the PAO Cell Mass	f _{XBGpBM}	0.025	1.000	0.025	0.025	mgP/mgPAOVSS
Endogenous Residue Fraction of PAOs (PolyP release rate)	f _{eh PAOs}	0.100	1.000	0.100	0.100	
STOICHIOMETRIC & KINETIC CONSTANTS: PRIMARY SLUDGE						
Monod Hydrolysis Kinetic Constant	K _m	n/appl.	n/appl.	3.34	3.34	gCOD Organics/gCOD Biomass / d
Monod Hydrolysis Kinetic Constant	K _s	n/appl.	n/appl.	3.76	3.76	gCOD/l
Pseudo Acidogen Biomass Yield coefficient	Y _{AD}	n/appl.	n/appl.	0.113	0.113	gCOD Biomass/gCOD Organics
Acidogen Endogenous Respiration Rate	b _{AD}	n/appl.	n/appl.	0.041	0.041	/day
Biomass unbiodegradable fraction	f _{iAD}	n/appl.	n/appl.	0.200	0.200	

ANNEXURE F

AERATION PARAMETERS

ANNEXURE F: AERATION PARAMETERS			
Parameter	Abbreviation	Value	Unit
GENERAL PARAMETERS			
Reactor Operating DO Concentration	C_L	2.500	mgO/l
Standard Conditions: Water Saturated Vapour Pressure	P_{std}	17.510	mmHg
Standard Conditions: Atmospheric Pressure	P_{std}	760.000	mmHg
Standard Conditions: Temperature	T	20.000	degC
DO Saturation in Clean Water at Standard Conditions (20 °C, 1 atm)	C_{S-std}	9.070	mgO/l
SURFACE AERATORS			
Mixed Liquor: Oxygen Transfer Correction Factor, Effect of MLSS	α	0.700	
Mixed Liquor: Effect of Impurities, Salinity-Surface Tension Correction Factor	β	0.900	
Arrhenius constant- used to correct for the effects of temperature	θ	1.024	
Standard Oxygen Transfer rate (Oxygenation Rate) of Aerators provided by Manufacturers (20 °C and 1 atm)	$R_{std \text{ Manufacturer}}$	2.400	kgO/kW.hr
Efficiency of Motor	ϵ_{Motor}	80.00%	%
Efficiency of Gearbox	$\epsilon_{\text{Gearbox}}$	90.00%	%
WASTE ACTIVATED SLUDGE			
Waste Activated Sludge: Oxygen Transfer Correction Factor, Effect of MLSS	α	0.500	
Waste Activated Sludge: Effect of Impurities, Salinity-Surface Tension Correction Factor	β	0.700	

ANNEXURE G

RESULTS – IMPACT OF INFLUENT TKN ON SYSTEM PERFORMANCE

[illegible]

LEGEND:

1. Significant change in parameter
2. Minor change in parameter

ABC

ABC

1. RESULTS – IMPACT ON SYSTEM PERFORMANCE (INFLUENT TKN) - LIQUID STREAM (OLD LANE) : "AUTHORS PWSSM", "BIOWIN", "PWSSD" and "UCTPHO"																																														
Parameter	Abbreviation	Unit	BIOWIN AVE (Dynamic State) (Values only)								PWSSD (Steady State) (Values only)								UCTPHO (Steady State) (Values only)																											
			16	16	16	16	16	16	16	24	24	24	24	24	24	24	24	16	16	16	16	16	16	16	24	24	24	24	24	24	24	16	16	16	16	16	16	24	24	24	24	24	24			
VARYING PARAMETER																																														
Influent TKN	N _i	mgN/l	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00		
1. PRIMARY SETTLING TANKS																																														
Total Area Required (PWWF)	A	m ²	749	749	749	749	749	749	749	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	749	749	749	749	749	749	749	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
Typical concentration of Primary Sludge		mg/l	36500	36500	36500	36500	36750	36500	36500	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	40140	40140	40140	40140	40140	40140	40140	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
2. UCT REACTOR DESIGN																																														
Selected Sludge Age	R _s	days	14.1	14.1	14.0	14.0	14.0	14.0	14.0	14.6	14.6	14.7	14.1	14.7	14.7	14.1	13.9	13.9	13.9	13.9	13.9	13.9	13.9	14.6	14.6	14.6	14.1	14.6	14.6	14.1	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675
Volume of Anoxic Reactor	V _{anoxic}	m ³	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110
Volume of Aerobic Reactor	V _{aerobic}	m ³	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	
Volume of Reactor	V _{Total}	m ³	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840
VSS Concentration: Anaerobic Reactor		mgVSS/l	1639	1639	1688	1688	1688	1688	1688	1788	1788	1788	1639	1788	1788	1639	1833	1833	1833	1833	1833	1833	1833	1711	1711	1711	1711	1711	1711	1711	1961	1950	1934	1999	1901	1888	1881	1846	1847	1841	1903	1805	18	1778		
VSS Concentration: Anoxic Reactor		mgVSS/l	2980	2980	2980	3029	2980	2980	2980	2881	2881	2881	3030	2980	2980	2980	3665	3665	3665	3665	3665	3665	3665	3422	3422	3422	3422	3422	3422	3422	3793	3767	3725	3840	3642	3609	3587	3559	3558	3540	3641	3441	3399	3371		
VSS Concentration: Aerobic Reactor		mgVSS/l	2980	2980	2980	3029	2980	2980	2980	2881	2881	2881	3030	2980	2980	2980	3665	3665	3665	3665	3665	3665	3665	3422	3422	3422	3422	3422	3422	3422	3772	3746	3703	3815	3617	3583	3562	3535	3536	3518	3618	3418	3374	3345		
Mass of Volatile Settleable Solids in Reactor	MX _s	kgVSS	27178	27178	27259	27668	27259	27259	27259	26615	26615	26615	27594	27431	27431	27186	33355	33355	33355	33355	33355	33355	33355	31140	31140	31140	31140	31140	31140	31140	34143	33914	33532	34561	32781	32484	32294	32015	32022	31866	32790	30988	27674	30352		
MLSS Concentration: Anaerobic Reactor		mgTSS/l	2250	2200	2100	2100	2100	2100	2100	2001	2001	2051	2101	2101	2101	2001	2500	2500	2500	2500	2500	2500	2500	2365	2365	2365	2365	2365	2365	2365	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
MLSS Concentration Anoxic Reactor		mgTSS/l	4000	4000	4000	4100	4000	4100	4000	4002	3902	3902	4002	3902	3902	3902	5000	5000	5000	5000	5000	5000	5000	4730	4730	4730	4730	4730	4730	4730	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
MLSS Concentration: Aerobic Reactor		mgTSS/l	4000	4000	4000	4100	4000	4100	4000	4002	3902	3902	4002	3902	3902	3902	5000	5000	5000	5000	5000	5000	5000	4730	4730	4730	4730	4730	4730	4730	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Mass of Total Solids in Reactor	MX _T	kgTSS	36568	36486	36322	37143	36322	37143	36322	36178	35356	35438	36343	35521	35521	35356	45504	45504	45504	45504	45504	45504	45504	43047	43047	43047	43047	43047	43047	43047	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Sludge Waste Flow per day	Q _{sw}	Ml/day	0.649	0.649	0.649	0.649	0.649	0.649	0.649	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.655	0.655	0.655	0.655	0.655	0.655	0.655	0.625	0.625	0.625	0.625	0.625	0.625	0.649	0.649	0.649	0.649	0.649	0.649	0.649	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.619	
MLSS Concentration in of Waste Flow	X _{sw}	mgTSS/l	4000	4000	4000	4100	4000	4100	4000	4002	3902	3902	4002	3902	3902	3902	5000	5000	5000	5000	5000	5000	5000	4730	4730	4730	4730	4730	4730	4730	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Active fraction of Sludge w.r.t VSS	f _{av}		0.52	0.53	0.52	0.50	0.51	0.51	0.51	0.50	0.49	0.48	0.47	0.48	0.47	0.45	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.57	0.57	0.57	0.57	0.57	0.57	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
Active fraction of Sludge w.r.t TSS	f _{st}		0.47	0.48	0.47	0.46	0.46	0.46	0.46	0.45	0.44	0.43	0.42	0.43	0.42	0.41	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.41	0.41	0.41	0.41	0.41	0.41	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
Total Average Oxygen Utilisation Rate (Carbonaceous, Nitrification and Denitrification)	OUR _{Average}	mgO ₂ /l·hr	36.1	41.2	44.0	45.3	49.2	54.7	58.0	36.1	39.9	45.0	48.4	52.3	56.2	61.2	45.0	51.7	56.9	60.2	65.4	70.6	75.8	46.8	51.9	58.8	62.0	67.3	72.5	77.7	40.9	46.0	50.5	55												

[illegible]

LEGEND:

1. Significant change in parameter
2. Minor change in parameter

ABC

ABC

2. RESULTS – IMPACT ON SYSTEM PERFORMANCE (INFLUENT TKN) - LIQUID STREAM (NEW LANE) : "AUTHORS PWSSM" AND "BIOWIN"																
Parameter	Abbreviation	Unit	BIOWIN AVE (Dynamic State) (Values only)													
			16	16	16	16	16	16	16	16	24	24	24	24	24	24
VARYING PARAMETER																
Influent TKN	N _{ti}	mgN/l	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00
1. PRIMARY SETTLING TANKS																
Total Area Required (PWWF)	A	m ²	1888	1888	1888	1888	1888	1888	1888	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Typical concentration of Primary Sludge		mg/l	36500	36500	36500	36500	36500	36500	36500	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
2. 5-STAGE BARDENPHO REACTOR DESIGN																
Selected Sludge Age	R _s	days	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.4	18.4	18.4	18.4	18.4	18.4	18.4
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400
Volume of Primary Anoxic Reactor	V _{anoxic (primary)}	m ³	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150
Volume of Aerobic Reactor	V _{aerobic}	m ³	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800
Volume of Secondary Anoxic Reactor	V _{anoxic (Secondary)}	m ³	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100
Volume of Re-aeration Reactor	V _{aerobic (Reaeration)}	m ³	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850
Volume of Reactor	V _{total}	m ³	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300
VSS Concentration: Anaerobic Reactor		mgVSS/l	2545	2545	2545	2645	2545	2545	2545	2518	2518	2518	2518	2518	2518	2518
VSS Concentration: Primary Anoxic Reactor		mgVSS/l	2545	2545	2545	2645	2545	2545	2545	2518	2518	2518	2518	2518	2518	2518
VSS Concentration: Aerobic Reactor		mgVSS/l	2545	2545	2545	2645	2545	2545	2545	2518	2518	2518	2518	2518	2518	2518
VSS Concentration: Secondary Anoxic Reactor		mgVSS/l	2545	2545	2545	2645	2545	2545	2545	2518	2518	2518	2518	2518	2518	2518
VSS Concentration: Re-aeration Reactor		mgVSS/l	2545	2545	2545	2645	2545	2545	2545	2518	2518	2518	2518	2518	2518	2518
Mass of Volatile Settleable Solids in Reactor	MX _v	kgVSS	92394	92394	92394	96017	92394	92394	92394	91402	91402	91402	91402	91402	91402	91402
MLSS Concentration: Anaerobic Reactor		mgTSS/l	3650	3700	3700	3750	3700	3700	3650	3623	3623	3623	3623	3623	3573	3522
MLSS Concentration: Primary Anoxic Reactor		mgTSS/l	3650	3700	3700	3750	3700	3700	3650	3623	3623	3623	3623	3623	3573	3522
MLSS Concentration: Aerobic Reactor		mgTSS/l	3650	3700	3700	3750	3700	3700	3650	3623	3623	3623	3623	3623	3573	3522
MLSS Concentration: Secondary Anoxic Reactor		mgTSS/l	3650	3700	3700	3750	3700	3700	3650	3623	3623	3623	3623	3623	3573	3522
MLSS Concentration: Re-aeration Reactor		mgTSS/l	3650	3700	3700	3750	3700	3700	3650	3623	3623	3623	3623	3623	3573	3522
Mass of Total Solids in Reactor	MX _T	kgTSS	132495	134310	134310	136125	134310	134310	132495	131519	131519	131519	131519	131519	129692	127865
Sludge Waste Flow per day	Q _{sw}	Ml/day	2.003	2.003	2.003	2.003	2.003	2.003	2.003	1.968	1.968	1.968	1.968	1.968	1.968	1.968
MLSS Concentration in of Waste Flow	X _{sw}	mgTSS/l	3650	3700	3700	3750	3700	3700	3650	3623	3623	3623	3623	3623	3573	3522
Active fraction of Sludge w.r.t VSS	f _{av}		0.522	0.509	0.527	0.509	0.500	0.500	0.494	0.499	0.488	0.478	0.469	0.466	0.465	0.459
Active fraction of Sludge w.r.t TSS	f _{at}		0.437	0.425	0.437	0.423	0.416	0.416	0.410	0.416	0.406	0.397	0.391	0.387	0.385	0.380
Total Average Oxygen Utilisation Rate (Aerobic)	OUR _{average}	mgO ₂ /l.hr	33.5	34.9	38.7	42.4	44.0	48.4	50.5	34.3	36.8	40.2	43.0	48.4	53.1	55.9
Total Average Oxygen Utilisation Rate (Re-aeration)	OUR _{average}	mgO ₂ /l.hr	26.2	29.0	30.1	32.6	33.6	36.1	40.4	25.0	26.3	26.5	30.4	31.2	34.3	35.8
Total O2 flux required	FO _{2b}	kgO ₂ /day	14667	15342	16927	18543	19239	21105	22145	14954	15984	17397	18709	20888	22940	24111
Effluent COD Concentration	S ₂₀	mgCOD/L	47.0	47.0	47.0	47.0	45.1	46.0	46.0	47.0	46.0	46.0	46.0	45.1	46.0	46.0
Effluent Free and Saline Ammonia (FSA) Concentration	N _{sw}	mgN/L	1.739	1.739	2.485	2.981	3.230	3.975	4.969	0.498	0.996	0.498	0.498	0.498	0.498	0.498
Unbiodegradable Soluble Organic Nitrogen	N _{su1}	mgN/L	2.156	2.892	2.110	4.623	3.819	5.408	4.597	1.992	2.629	2.788	2.051	-0.550	4.196	5.731
Effluent TKN Concentration	N ₂₀	mgN/L	3.895	4.632	4.594	7.604	7.049	9.383	9.566	2.490	3.625	3.287	2.549	-0.052	4.694	6.229
Effluent Nitrate Concentration	N ₂₀	mgN/L	1.166	1.432	4.174	7.223	12.260	15.854	21.632	1.141	1.415	3.768	8.762	19.387	25.355	31.178
Total Effluent Nitrogen Concentration	TotN _{eff}	mgN/l	5.061	6.064	8.768	14.827	19.309	25.238	31.199	3.631	5.040	7.055	11.311	19.335	30.049	37.406
Effluent P Concentration (OrthoP + P _{oxid})	P ₂₀	mgP/L	0.543	0.627	0.710	0.669	0.836	0.919	1.003	0.501	0.627	0.669	0.836	1.086	1.337	1.671
Effluent P Concentration (Organic P)	P _{oxid}	mgP/l	0.350	0.500	0.550	0.450	0.500	0.400	0.200	0.400	0.500	0.400	0.500	0.400	0.200	0.500
Effluent Ortho P Concentration	P ₂₀	mgP/l	0.193	0.127	0.160	0.219	0.336	0.519	0.803	0.101	0.127	0.269	0.336	0.686	1.137	1.171
Change in Alkalinity following nitrification & denitrification (effluent)	Alk	mg/l as CaCO3	Not. Prov	Not. Prov	Not. Prov	Not. Prov	Not. Prov	Not. Prov	Not. Prov	Not. Prov	Not. Prov	Not. Prov	Not. Prov	Not. Prov	Not. Prov	Not. Prov
pH of effluent from Reactor	ph		8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90
3. SECONDARY SETTLING TANKS																
Area (including 80% Flux rating correction factor for 1 dimensional fl)	A	m ²	4361	4361	4361	4361	4361	4361	4361	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
S Recycle Ratio I.L.to ADWF (dry weather flow conditions)	R _{s ADWF & PDIWF}		0.870	0.870	0.870	0.870	0.870	0.870	0.870	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
ADWF Underflow Concentration to Reactor (RAS Flow Concentration)	X _{1 Underflow}	mgTSS/l	7800	7700	7700	7900	7750	7750	7750	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.

LEGEND:

1. Significant change in parameter

ABC

2. Minor change in parameter

ABC

3. RESULTS – IMPACT ON SYSTEM PERFORMANCE (INFLUENT TKN) - SLUDGE STREAM : "AUTHORS PWSSM" AND "BIOWIN"																																													
Parameter	Abbreviation	Unit	Author's PWSSM (Steady State) (Values only)														BIOWIN (Steady State) (Values only)														BIOWIN MAX (Dynamic State) (Values only)														
			16	16	16	16	16	16	16	16	24	24	24	24	24	24	24	16	16	16	16	16	16	16	16	24	24	24	24	24	24	24	16	16	16	16	16	16	16	16	24	24	24	24	24
VARYING PARAMETER																																													
Influent TKN	N _{ti}	mgN/l	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00	
1. ANAEROBIC DIGESTER																																													
Primary Sludge inflow to Anaerobic Digester	Q _w	m ³ /day	427	427	427	427	427	427	427	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	428	428	428	428	428	428	428	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	429	429	429	429	429	429	429	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
Total Settleable Solids incoming	TSS _{in}	mgTSS/l	38565	38565	38565	38565	38565	38565	38565	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	42222	42222	42222	42222	42222	42222	42222	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	37252	37252	37252	37444	37252	37252	37252	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
Volatile Settleable Solids incoming	VSS _{in}	mgVSS/l	34260	34260	34260	34260	34260	34260	34260	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	37050	37050	37050	37050	37050	37050	37050	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	33321	33321	33321	33224	33321	33321	33321	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
COD incoming	S _{te in}	mgCOD/l	59131	59131	59131	59131	59131	59131	59131	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	59135	59135	59135	59135	59135	59135	59135	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	53502	53502	53502	53002	53502	53502	53502	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
TKN incoming	N _{te in}	mgN/l	1648	1962	2276	2485	2799	3113	3427	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	1670	1959	2253	2445	2768	3041	3339	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	1486	1769	2052	2212	2519	2699	2906	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
TP incoming	P _{te in}	mgP/l	293	293	293	293	293	293	293	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	300	300	300	300	300	300	300	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	258	258	258	242	258	258	258	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
Volume	Vol	m ³	5122	5122	5122	5122	5122	5122	5122	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	5144	5144	5144	5144	5144	5144	5144	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	5144	5144	5144	5144	5144	5144	5144	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
Total Settleable Solids in effluent	TSS _{out}	mgTSS/l	15487	15487	15487	15487	15487	15487	15487	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	17225	17230	17230	17229	17230	17230	17230	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	14699	14699	14699	14699	14699	14699	14699	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
Volatile Settleable Solids in effluent	VSS _{out}	mgVSS/l	11182	11182	11182	11182	11182	11182	11182	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	11690	11694	11694	11693	11694	11694	11694	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	9962	9962	9962	9962	9962	9962	9962	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
COD in effluent	S _{te out}	mgCOD/l	19148	19148	19148	19148	19148	19148	19148	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	31618	31528	31568	31562	31550	31532	31528	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	21494	21494	21494	21394	21494	21494	21494	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
Total N in effluent	N _{te out}	mgN/l	646	852	1047	1185	1542	1551	1732	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	1670	1959	2253	2445	2768	3041	3339	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	1448	1667	1831	1867	2183	2321	2589	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
TP in effluent	P _{te out}	mgP/l	258	258	258	258	258	258	258	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	377	377	377	377	377	377	377	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	323	323	323	364	364	364	364	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
pH of Digester	pH		7.19	7.19	7.19	7.19	7.19	7.19	7.19	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	7.08	7.08	7.08	7.08	7.08	7.08	7.08	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	7.50	7.50	7.50	7.75	7.50	7.80	7.90	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
CH4 (Gaseous) Bi-product	CH ₄	mol/l	0.64	0.64	0.64	0.64	0.64	0.64	0.64	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	0.65	0.65	0.65	0.65	0.65	0.69	0.74	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	0.56	0.57	0.60	0.65	0.66	0.70	0.73	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
VSS Destruction	VSS _{dest}	%	67.4%	67.4%	67.4%	67.4%	67.4%	67.4%	67.4%	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	68.4%	68.4%	68.4%	68.4%	68.4%	68.4%	68.4%	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	70.1%	70.1%	70.1%	70.0%	70.1%	70.1%	70.1%	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
2. AEROBIC DIGESTER																																													
Sludge Waste Flow per day into Aerobic Digester	Q _{w in}	m ³ /day	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	
Sludge Waste Flow exiting Aerobic Digester	Q _{w out}	m ³ /day	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	
Influent TSS Concentration	X _{ti in}	mgTSS/l	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	34566	34514	34610	34699	34759	34786	34825	33745	33680	33721	33772	33785	33795	33875	28000	28000	28000	28000	28000	28000	28000	27000	27000	27000	28000	27000	27000	27000	
Influent VSS Concentration	X _w	mgVSS/l	23868	23868	23868	23868	23868	23868	23868	22616	22616	22616	22616	22616	22616	22616	23768	23697	23770	23850	23927	24016	24072	23170	23086	23119	23157	23191	23261	23358	19941	19941	19941	19941	19941	19941	19941	19070	19070	19070	19070	19070	19070	19070	
Active fraction of Sludge w.r.t TSS in influent	f _{av}		0.578	0.578	0.578	0.578	0.578	0.578	0.578	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.510	0.507	0.503	0.495	0.499	0.495	0.495	0.523	0.511	0.507	0.499	0.503	0.499	0.499	0.521	0.512	0.505	0.485	0.499	0.499	0.496	0.496	0.487	0.476	0.460	0.469	0.460	0.456	
Active fraction of Sludge w.r.t VSS in influent	f _{at}		0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.432	0.430	0.426	0.419	0.424	0.419	0.419	0.444	0.434	0.430	0.423	0.427	0.423	0.423	0.446	0.437	0.433	0.415	0.426	0.426	0.424	0.422	0.414	0.404	0.391	0.398	0.389	0.385	
Volume of Aerobic Digester 1	V _{aerobic digester 1}	m ³	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501</																						

3. RESULTS – IMPACT ON SYSTEM PERFORMANCE (INFLUENT TKN) - SLUDGE STREAM : "AUTHORS PWSSM" AND "BIOWIN"																		
Parameter	Abbreviation	Unit	BIOWIN AVE (Dynamic State) (Values only)															
			16	16	16	16	16	16	16	16	24	24	24	24	24	24		
VARYING PARAMETER																		
Influent TKN	N _{ti}	mgN/l	45.00	60.00	75.00	85.00	100.00	115.00	130.00	45.00	60.00	75.00	85.00	100.00	115.00	130.00		
1. ANAEROBIC DIGESTER																		
Primary Sludge inflow to Anaerobic Digester	Q _{sw}	m ³ /day	429	429	429	429	429	429	429	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Total Settleable Solids incoming	TSS _{in}	mgTSS/l	34804	34804	34804	35524	34804	34804	34804	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Volatile Settleable Solids incoming	VSS _{in}	mgVSS/l	31025	31025	31025	31074	31025	31025	31025	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
COD incoming	S _{te in}	mgCOD/l	49502	49502	49502	49002	49502	49502	49502	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
TKN incoming	N _{te in}	mgN/l	1334	1616	1831	2011	2239	2510	2721	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
TP incoming	P _{te in}	mgP/l	258	258	258	242	258	258	258	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Volume	V _{ol}	m ³	5144	5144	5144	5144	5144	5144	5144	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Total Settleable Solids in effluent	TSS _{out}	mgTSS/l	14699	14699	14699	14699	14699	14699	14699	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Volatile Settleable Solids in effluent	VSS _{out}	mgVSS/l	9962	9962	9962	9962	9962	9962	9962	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
COD in effluent	S _{te out}	mgCOD/l	21494	21494	21494	21394	21494	21494	21494	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Total N in effluent	N _{te out}	mgN/l	1448	1667	1831	1867	2183	2321	2589	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
TP in effluent	P _{te out}	mgP/l	323	323	323	364	364	364	364	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
pH of Digester	pH		7.50	7.50	7.50	7.75	7.50	7.80	7.90	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
CH4 (Gaseous) Bi-product	CH ₄	mol/l	0.56	0.57	0.60	0.65	0.66	0.70	0.73	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
VSS Destruction	VSS _{dest}	%	67.9%	67.9%	67.9%	67.9%	67.9%	67.9%	67.9%	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
2. AEROBIC DIGESTER																		
Sludge Waste Flow per day into Aerobic Digester	Q _{w in}	m ³ /day	350	350	350	350	350	350	350	350	350	350	350	350	350	350		
Sludge Waste Flow exiting Aerobic Digester	Q _{w OUT}	m ³ /day	350	350	350	350	350	350	350	350	350	350	350	350	350	350		
Influent TSS Concentration	X _{T in}	mgTSS/l	28000	28000	28000	28000	28000	28000	28000	27000	27000	27000	27000	27000	27000	27000		
Influent VSS Concentration	X _{vi}	mgVSS/l	19941	19941	19941	19941	19941	19941	19941	19070	19070	19070	19070	19070	19070	19070		
Active fraction of Sludge w.r.t TSS in influent	f _{av}		0.522	0.513	0.526	0.508	0.503	0.503	0.498	0.499	0.489	0.477	0.469	0.468	0.466	0.458		
Active fraction of Sludge w.r.t VSS in influent	f _{at}		0.445	0.438	0.446	0.431	0.428	0.428	0.422	0.424	0.414	0.404	0.398	0.396	0.394	0.387		
Volume of Aerobic Digester 1	V _{aerobic digester 1}	m ³	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501		
Volume of Aerobic Digester 2	V _{aerobic digester 2}	m ³	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501		
Volume Total of Aerobic Digesters	V _{aerobic digester T}	m ³	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002		
Effluent TSS Concentration: Digester 2	X _T	mgTSS/l	24246	24246	24246	24246	24246	24246	24246	24517	24517	24517	23973	24517	24517	24517		
Effluent VSS Concentration: Digester 2	X _v	mgVSS/l	15873	15873	15873	15873	15873	15873	15873	16002	16002	16002	16002	16002	16002	16002		
Active fraction of Sludge w.r.t VSS in effluent	f _{sv}		0.184	0.182	0.171	0.173	0.171	0.171	0.171	0.177	0.177	0.165	0.150	0.153	0.153	0.127		
Active fraction of Sludge w.r.t TSS in effluent	f _{st}		0.143	0.142	0.134	0.137	0.134	0.134	0.134	0.137	0.137	0.128	0.118	0.118	0.118	0.098		
Effluent COD Concentration: Digester 2	S _{te}	gCOD/L	22.302	16.752	16.752	18.360	16.752	16.752	16.597	16.778	16.778	16.778	17.564	16.673	16.673	16.673		
Total Effluent Nitrogen Concentration: Digester 2	TotN _{eff}	gN/l	1.496	1.545	1.545	1.595	1.545	1.545	1.545	1.455	1.556	1.556	1.505	1.556	1.556	1.556		
Effluent P Concentration (OrthoP + P _{oxide}): Digester 2	P _{te}	gP/L	1.785	1.904	1.904	1.904	1.746	1.746	1.746	1.805	1.805	1.805	1.648	1.727	1.727	1.570		
Total Oxygen Utilisation Rate: Digester 1	OUR _{T 1}	mgO2/(l.hr)	32.9	32.9	32.9	33.8	33.8	34.6	34.6	30.5	30.5	30.5	31.3	31.3	32.1	32.1		
Total Oxygen Utilisation Rate: Digester 2	OUR _{T 2}	mgO2/(l.hr)	12.8	12.8	12.8	12.8	12.0	12.0	10.7	10.8	10.8	10.8	9.9	10.8	10.4	10.4		

LEGEND:

1. Significant change in parameter

2. Minor change in parameter

ABC

ABC

ANNEXURE H

RESULTS – IMPACT OF MAXIMUM SPECIFIC GROWTH RATE OF NITRIFIERS ON SYSTEM PERFORMANCE

1. RESULTS – IMPACT ON SYSTEM PERFORMANCE (MAXIMUM SPECIFIC GROWTH RATE OF NITRIFIERS) - LIQUID STREAM (OLD LANE) : "AUTHORS PWSSM", "BIOWIN", "PWSSD" and "UCTPHO"																																																		
Parameter	Abbreviation	Unit	Author's PWSSM (Steady State) (Values only)												BIOWIN (Steady State) (Values only)												BIOWIN MAX (Dynamic State) (Values only)																							
			16	16	16	16	16	16	16	24	24	24	24	24	24	24	24	16	16	16	16	16	16	16	24	24	24	24	24	24	24	24	16	16	16	16	16	16	24	24	24	24	24	24	24	24				
VARYING PARAMETER																																																		
Maximum Specific Growth Rate of Nitrifiers	UAm20	/day	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675						
1. PRIMARY SETTLING TANKS																																																		
Total Area Required (PWWF)	A	m ²	749	749	749	749	749	749	749	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	749	749	749	749	749	749	749	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	749	749	749	749	749	749	749	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.					
Typical concentration of Primary Sludge		mg/l	40140	40140	40140	40140	40140	40140	40140	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	44000	44000	44000	44000	44000	44000	44000	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	40000	40000	40000	40000	40000	40000	40000	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.					
2. UCT REACTOR DESIGN																																																		
Selected Sludge Age	R _s	days	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.2	14.3	14.3	14.3	14.3	14.3	14.3	14.1	14.1	14.1	14.1	14.1	14.1	14.1						
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	1655	1655	1655	1655	1655	1655	1655	1655	1655	1655	1655	1655	1655	1655	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644					
Volume of Anoxic Reactor	V _{Anoxic}	m ³	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102					
Volume of Aerobic Reactor	V _{aerobic}	m ³	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	7076	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115				
Volume of Reactor	V _{total}	m ³	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9840	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861					
VSS Concentration: Anaerobic Reactor		mgVSS/l	1837	1837	1837	1837	1837	1837	1837	1730	1730	1730	1730	1730	1730	1730	1974	1975	1973	1970	1968	1966	1964	1911	1910	1906	1903	1900	1967	1894	1887	1788	1788	1788	1986	1788	1887	1887	1788	1788	1788	1937	1937	1937	1888	1888				
VSS Concentration: Anoxic Reactor		mgVSS/l	3673	3673	3673	3673	3673	3673	3673	3459	3459	3459	3459	3459	3459	3459	3661	3663	3659	3653	3649	3645	3639	3534	3532	3523	3516	3511	3646	3498	2930	2980	2980	3079	3029	2980	2980	2980	2980	2980	2980	2980	2980	2980	2980					
VSS Concentration: Aerobic Reactor		mgVSS/l	3673	3673	3673	3673	3673	3673	3673	3459	3459	3459	3459	3459	3459	3459	3633	3635	3631	3626	3621	3617	3612	3506	3504	3495	3487	3482	3618	3469	2930	2980	2980	3079	3029	2980	2980	2980	2980	2980	2980	2980	2980	2980	2980	2980				
Mass of Volatile Settleable Solids in Reactor	MX _v	kgVSS	33104	33104	33104	33104	33104	33104	33104	31179	31179	31179	31179	31179	31179	31179	33130	33148	33113	33066	33023	32987	32940	31983	31965	31885	31814	31769	32997	31653	27178	27423	27423	28565	27831	27586	27586	27431	27023	27023	28084	27676	27676	27594	27594					
MLSS Concentration: Anaerobic Reactor		mgTSS/l	2500	2500	2500	2500	2500	2500	2500	2382	2382	2382	2382	2382	2382	2382	2585	2588	2587	2585	2582	2580	2577	2518	2518	2513	2509	2506	2582	2499	2500	2600	2600	2600	2600	2600	2600	2501	2501	2501	2501	2501	2501	2501	2501					
MLSS Concentration Anoxic Reactor		mgTSS/l	5000	5000	5000	5000	5000	5000	5000	4764	4764	4764	4764	4764	4764	4764	4989	4990	4985	4978	4974	4969	4963	4850	4848	4837	4829	4823	4972	4808	4000	4000	4000	4100	4100	4000	4000	4002	4002	4002	4002	4002	4002	4002	4002					
MLSS Concentration: Aerobic Reactor		mgTSS/l	5000	5000	5000	5000	5000	5000	5000	4764	4764	4764	4764	4764	4764	4764	4988	4988	4982	4976	4971	4966	4960	4847	4845	4834	4826	4819	4969	4805	4000	4000	4000	4100	4100	4000	4000	4002	4002	4002	4002	4002	4002	4002	4002					
Mass of Total Solids in Reactor	MX _t	kgTSS	45064	45064	45064	45064	45064	45064	45064	42939	42939	42939	42939	42939	42939	42939	45239	45245	45195	45141	45096	45052	44998	43972	43955	43856	43784	43723	45078	43595	36979	37143	37143	37965	37965	37143	37143	37001	37001	37001	37001	37001	37001	37001	37001					
Sludge Waste Flow per day	Q _w	Ml/day	0.649	0.649	0.649	0.649	0.649	0.649	0.649	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.649	0.649	0.649	0.649	0.649	0.649	0.649	0.619	0.619	0.619	0.619	0.619	0.619	0.649	0.649	0.649	0.649	0.649	0.649	0.619	0.619	0.619	0.619	0.619	0.619	0.619	0.619							
MLSS Concentration in of Waste Flow	X _{Qw}	mgTSS/l	5000	5000	5000	5000	5000	5000	5000	4364	4364	4364	4364	4364	4364	4364	4988	4988	4982	4976	4971	4966	4960	4847	4845	4834	4826	4819	4969	4805	4000	4000	4000	4100	4100	4000	4000	4002	4002	4002	4002	4002	4002	4002						
Active fraction of Sludge w.r.t VSS	f _{av}		0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.52	0.52	0.51	0.50	0.50	0.52	0.52	0.49	0.49	0.48	0.46	0.47	0.47	0.47							
Active fraction of Sludge w.r.t TSS	f _{at}		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46							
Total Average Oxygen Utilisation Rate (Carbonaceous, Nitrification and Denitrification)	OUR _{Average}	mgO ₂ /l.hr	46.7	53.9	55.6	55.7	55.8	55.8	55.9	54.7	54.8	55.0	55.1	55.1	55.1	55.1	51.1	53.8	54.8	54.9	55.0	55.0	55.1	55.3	55.4	55.6	55.7	55.7	55.8	55.8	50.0	56.1	63.7	65.8	66.9	67.9	69.0	62.4	63.5	69.9	69.9	73.1	74.2	74.2	74.2					
Total O2 flux required	F _{Om}	kgO ₂ /day	7935	9145	9436	9465	9476	9482	9488	9295	9308	9340	9351	9356	9360	9363	8728	9193	9349	9376	9388	9399	9409	9442	9457	9494	9																							

1. RESULTS – IMPACT ON SYSTEM PERFORMANCE (MAXIMUM SPECIFIC GROWTH RATE OF NITRIFIERS) - LIQUID STREAM (OLD LANE) : "AUTHORS PWSSM", "BIOWIN", "PWSSD" and "UCTPHO"																																																			
Parameter	Abbreviation	Unit	BIOWIN AVE (Dynamic State) (Values only)												PWSSD (Steady State) (Values only)												UCTPHO (Steady State) (Values only)																								
			16	16	16	16	16	16	16	24	24	24	24	24	24	24	24	16	16	16	16	16	16	16	24	24	24	24	24	24	24	24	16	16	16	16	16	16	24	24	24	24	24	24	24	24					
VARYING PARAMETER																																																			
Maximum Specific Growth Rate of Nitrifiers	U _{am20}	/day	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675
1. PRIMARY SETTLING TANKS																																																			
Total Area Required (PWWF)	A	m ²	749	749	749	749	749	749	749	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	749	749	749	749	749	749	749	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
Typical concentration of Primary Sludge		mg/l	36500	36500	36500	36500	36500	36500	36500	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	40140	40140	40140	40140	40140	40140	40140	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	
2. UCT REACTOR DESIGN																																																			
Selected Sludge Age	R _s	days	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.1	14.1	14.1	14.1	14.1	14.1	14.1	13.9	13.9	13.9	13.9	13.9	13.9	13.9	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0			
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1644	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675	1675			
Volume of Anoxic Reactor	V _{anoxic}	m ³	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1102	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1119	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110	1110				
Volume of Aerobic Reactor	V _{aerobic}	m ³	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7115	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144	7144			
Volume of Reactor	V _{total}	m ³	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9861	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938	9938			
VSS Concentration: Anaerobic Reactor		mgVSS/l	1589	1589	1589	1688	1639	1639	1639	1490	1590	1590	1639	1689	1639	1639	1833	1833	1833	1833	1833	1833	1833	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711	1711			
VSS Concentration: Anoxic Reactor		mgVSS/l	2930	2930	2930	3029	2980	2980	2980	2881	2881	2881	3030	2931	2980	2980	3665	3665	3665	3665	3665	3665	3665	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422			
VSS Concentration: Aerobic Reactor		mgVSS/l	2930	2930	2930	3029	2980	2980	2980	2881	2881	2881	3030	2931	2980	2980	3665	3665	3665	3665	3665	3665	3665	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422	3422		
Mass of Volatile Settleable Solids in Reactor	MX _v	kgVSS	26688	26688	26688	27668	27178	27178	27178	26125	26288	26288	27594	26860	27186	27186	33355	33355	33355	33355	33355	33355	33355	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140	31140			
MLSS Concentration: Anaerobic Reactor		mgTSS/l	2100	2100	2100	2100	2100	2100	2100	2001	2051	2051	2101	2101	2201	2101	2500	2500	2500	2500	2500	2500	2500	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365	2365		
MLSS Concentration Anoxic Reactor		mgTSS/l	4000	4000	4000	4100	4050	4000	4000	4052	4002	4002	4002	4002	3952	4002	5000	5000	5000	5000	5000	5000	5000	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730			
MLSS Concentration: Aerobic Reactor		mgTSS/l	4000	4000	4000	4100	4050	4000	4000	4052	4002	4002	4002	4002	3952	4002	5000	5000	5000	5000	5000	5000	5000	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730	4730			
Mass of Total Solids in Reactor	MX _t	kgTSS	36322	36322	36322	37143	36732	36322	36322	36590	36261	36261	36343	36343	36096	36343	45504	45504	45504	45504	45504	45504	45504	43047	43047	43047	43047	43047	43047	43047	43047	43047	43047	43047	43047																

2. RESULTS – IMPACT ON SYSTEM PERFORMANCE (MAXIMUM SPECIFIC GROWTH RATE OF NITRIFIERS) - LIQUID STREAM (NEW LANE) : "AUTHORS PWSSM" AND "BIOWIN"																		
Parameter	Abbreviation	Unit	BIOWIN AVE (Dynamic State) (Values only)															
			16	16	16	16	16	16	16	24	24	24	24	24	24	24		
VARYING PARAMETER																		
Maximum Specific Growth Rate of Nitrifiers	UAm20	/day	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675		
1. PRIMARY SETTLING TANKS																		
Total Area Required (PWWF)	A	m²	1888	1888	1888	1888	1888	1888	1888	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Typical concentration of Primary Sludge		mg/l	36500	36500	36500	36500	36500	36500	36500	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
2. 5-STAGE BARDENPHO REACTOR DESIGN																		
Selected Sludge Age	Rs	days	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.4	18.4	18.4	18.4	18.4	18.4	18.4		
Volume of Anaerobic Reactor	Vanaerobic	m³	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400		
Volume of Primary Anoxic Reactor	Vanoxic (Primary)	m³	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150		
Volume of Aerobic Reactor	Vaerobic	m³	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800		
Volume of Secondary Anoxic Reactor	Vanoxic (Secondary)	m³	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100		
Volume of Re-aeration Reactor	Vaerobic (Reaeration)	m³	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850		
Volume of Reactor	Vtotal	m³	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300		
VSS Concentration: Anaerobic Reactor		mgVSS/l	2545	2545	2545	2645	2595	2595	2595	2468	2468	2468	2518	2518	2518	2518		
VSS Concentration: Primary Anoxic Reactor		mgVSS/l	2545	2545	2545	2645	2595	2595	2595	2468	2468	2468	2518	2518	2518	2518		
VSS Concentration: Aerobic Reactor		mgVSS/l	2545	2545	2545	2645	2595	2595	2595	2468	2468	2468	2518	2518	2518	2518		
VSS Concentration: Secondary Anoxic Reactor		mgVSS/l	2545	2545	2545	2645	2595	2595	2595	2468	2468	2468	2518	2518	2518	2518		
VSS Concentration: Re-aeration Reactor		mgVSS/l	2545	2545	2545	2645	2645	2645	2645	2468	2468	2468	2518	2518	2518	2518		
Mass of Volatile Settleable Solids in Reactor	MXv	kgVSS	92394	92394	92394	96017	94298	94298	94298	89574	89574	89574	91402	91402	91402	91402		
MLSS Concentration: Anaerobic Reactor		mgTSS/l	3700	3700	3700	3750	3600	3650	3750	3623	3623	3623	3623	3623	3623	3623		
MLSS Concentration: Primary Anoxic Reactor		mgTSS/l	3700	3700	3700	3750	3600	3650	3750	3623	3623	3623	3623	3623	3623	3623		
MLSS Concentration: Aerobic Reactor		mgTSS/l	3700	3700	3700	3750	3600	3650	3750	3623	3623	3623	3623	3623	3623	3623		
MLSS Concentration: Secondary Anoxic Reactor		mgTSS/l	3700	3700	3700	3750	3600	3650	3750	3623	3623	3623	3623	3623	3623	3623		
MLSS Concentration: Re-aeration Reactor		mgTSS/l	3700	3700	3700	3750	3600	3650	3750	3623	3623	3623	3623	3623	3623	3623		
Mass of Total Solids in Reactor	MXt	kgTSS	134310	134310	134310	136125	130680	132495	136125	131519	131519	131519	131519	131519	131519	131519		
Sludge Waste Flow per day	Qw	ML/day	2.003	2.003	2.003	2.003	2.003	2.003	2.003	1.969	1.969	1.969	1.969	1.969	1.969	1.969		
MLSS Concentration in of Waste Flow	XQw	mgTSS/l	3700	3700	3700	3750	3600	3650	3750	3623	3623	3623	3623	3623	3623	3623		
Active fraction of Sludge w.r.t VSS	fav		0.534	0.524	0.523	0.509	0.512	0.503	0.503	0.487	0.487	0.490	0.469	0.475	0.472	0.472		
Active fraction of Sludge w.r.t TSS	fat		0.446	0.438	0.437	0.423	0.425	0.419	0.419	0.404	0.404	0.407	0.391	0.395	0.394	0.394		
Total Average Oxygen Utilisation Rate (Aerobic)	OURAverage	mgO2/l.hr	33.2	32.5	35.9	42.4	42.9	43.5	43.5	39.4	41.0	42.0	43.0	44.1	43.0	43.0		
Total Average Oxygen Utilisation Rate (Re-aeration)	OURAverage	mgO2/l.hr	25.5	27.0	29.9	31.5	31.5	31.5	30.4	30.5	31.5	30.4	30.4	28.3	26.2	26.2		
Total O2 flux required	FOm	kgO2/day	14537	14288	15798	18495	18712	18930	18881	17230	17911	18286	18709	19039	18522	18522		
Effluent COD Concentration	S10	mgCOD/L	47.0	47.0	47.0	47.0	46.0	46.0	49.3	46.0	46.0	46.0	46.0	46.0	46.0	46.0		
Effluent Free and Saline Ammonia (FSA) Concentration	Nae	mgN/L	26.361	26.208	16.366	2.981	1.989	0.497	0.498	5.970	3.981	1.992	0.498	0.249	0.249	0.249		
Unbiodegradable Soluble Organic Nitrogen	Nous	mgN/L	4.901	3.799	4.332	4.623	3.870	4.067	4.107	2.236	2.805	1.809	2.051	2.771	2.771	2.770		
Effluent TKN Concentration	Nte	mgN/L	31.262	30.007	20.697	7.604	5.859	4.564	4.605	8.206	6.786	3.802	2.549	3.020	3.020	3.020		
Effluent Nitrate Concentration	Nno	mgN/L	0.250	0.493	2.303	7.223	8.968	11.611	11.570	5.026	5.022	7.516	8.762	8.759	8.757	8.755		
Total Effluent Nitrogen Concentration	TotNeff	mgN/l	31.512	30.500	23.000	14.827	14.827	16.175	16.175	13.232	11.807	11.317	11.311	11.779	11.777	11.775		
Effluent P Concentration (OrthoP + Pous)	Pte	mgP/l	0.501	0.543	0.585	0.669	0.752	0.836	0.836	0.836	0.836	0.836	0.836	0.836	0.836	0.836		
Effluent P Concentration (Organic P)	Pous	mgP/l	0.400	0.450	0.450	0.450	0.450	0.500	0.400	0.500	0.400	0.500	0.500	0.500	0.400	0.400		
Effluent Ortho P Concentration	Pe	mgP/l	0.101	0.093	0.135	0.219	0.302	0.336	0.436	0.336	0.436	0.336	0.336	0.336	0.436	0.436		
Change in Alkalinity following nitrification & denitrification of effluent from Reactor	Alkph	mg/l as CaCO3	Not Prov. 8.8	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.8	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9		
3. SECONDARY SETTLING TANKS																		
Area (including 80% Flux rating correction factor for 1 di	A	m²	4361	4361	4361	4361	4361	4361	4361	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
S Recycle Ratio i.Lto ADWF (dry weather flow conditions)	Ri,ADWF & PWWF		0.870	0.870	0.870	0.870	0.870	0.870	0.870	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
ADWF Underflow Concentration to Reactor (RAS Flow Concentration)	XrUnderflow	mgTSS/l	8200	7800	7750	7900	7750	7750	7750	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		

LEGEND:

1. Significant change in parameter

2. Minor change in parameter

ABC

ABC

3. RESULTS – IMPACT ON SYSTEM PERFORMANCE (MAXIMUM SPECIFIC GROWTH RATE OF NITRIFIERS) - SLUDGE STREAM : "AUTHORS PWSSM" AND "BIOWIN"

Parameter	Abbreviation	Unit	Author's PWSSM (Steady State) (Values only)								BIOWIN (Steady State) (Values only)								BIOWIN MAX (Dynamic State) (Values only)											
			16	16	16	16	16	16	16	16	24	24	24	24	24	24	24	24	16	16	16	16	16	16	16	16	24	24	24	24
VARYING PARAMETER																														
Maximum Specific Growth Rate of Nitrifiers	UAm20	/day	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675
1. ANAEROBIC DIGESTER																														
Primary Sludge Inflow to Anaerobic Digester	Q _w	m ³ /day	427	427	427	427	427	427	427	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Total Settleable Solids incoming	TSS _{in}	mgTSS/l	38565	38565	38565	38565	38565	38565	38565	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Volatile Settleable Solids incoming	VSS _{in}	mgVSS/l	34260	34260	34260	34260	34260	34260	34260	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
COD incoming	S _{bio in}	mgCOD/l	59131	59131	59131	59131	59131	59131	59131	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
TKN incoming	N _{bio in}	mgN/l	2485	2485	2485	2485	2485	2485	2485	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
TP incoming	P _{bio in}	mgP/l	293	293	293	293	293	293	293	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Volume	Vol	m ³	5122	5122	5122	5122	5122	5122	5122	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Total Settleable Solids in effluent	TSS _{out}	mgTSS/l	15487	15487	15487	15487	15487	15487	15487	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Volatile Settleable Solids in effluent	VSS _{out}	mgVSS/l	11182	11182	11182	11182	11182	11182	11182	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
COD in effluent	S _{bio out}	mgCOD/l	19148	19148	19148	19148	19148	19148	19148	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Total N in effluent	N _{bio out}	mgN/l	2300	2300	2300	2300	2300	2300	2300	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
TP in effluent	P _{bio out}	mgP/l	258	258	258	258	258	258	258	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
pH of Digester	pH		7.19	7.19	7.19	7.19	7.19	7.19	7.19	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
CH ₄ (Gaseous) Bi-product	CH ₄	mol/l	0.64	0.64	0.64	0.64	0.64	0.64	0.64	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
VSS Destruction	VSS _{dest}	%	67.4%	67.4%	67.4%	67.4%	67.4%	67.4%	67.4%	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
2. AEROBIC DIGESTER																														
Sludge Waste Flow per day into Aerobic Digester	Q _{w in}	m ³ /day	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Sludge Waste Flow exiting Aerobic Digester	Q _{w out}	m ³ /day	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Influent TSS Concentration	X _{T in}	mgTSS/l	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000
Influent VSS Concentration	X _{vi}	mgVSS/l	23868	23868	23868	23868	23868	23868	23868	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616	22616
Active fraction of Sludge w.r.t TSS in influent	f _{av}		0.578	0.578	0.578	0.578	0.578	0.578	0.578	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553	
Active fraction of Sludge w.r.t VSS in influent	f _{ai}		0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374	
Volume of Aerobic Digester 1	V _{aerobic digester 1}	m ³	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501
Volume of Aerobic Digester 2	V _{aerobic digester 2}	m ³	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501
Volume Total of Aerobic Digesters	V _{aerobic digester T}	m ³	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002
Effluent TSS Concentration: Digester 2	X _T	mgTSS/l	31060	31060	31060	31060	31060	31060	31060	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068	30068
Effluent VSS Concentration: Digester 2	X _v	mgVSS/l	16821	16821	16821	16821	16821	16821	16821	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239	16239
Active fraction of Sludge w.r.t VSS in effluent	f _{av}		0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	
Active fraction of Sludge w.r.t TSS in effluent	f _{ai}		0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	
Effluent COD Concentration: Digester 2	S _{bio}	gCOD/L	28.378	28.378	28.378	28.378	28.378	28.378	28.378	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	27.195	
Total Effluent Nitrogen Concentration: Digester 2	TotN _{eff}	gN/l	2.387	2.387	2.387	2.387	2.387	2.387	2.387	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	2.262	
Effluent P Concentration (OrthoP + P _{solub}): Digester 2	P _{bio}	gP/L	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	0.884	
Total Oxygen Utilisation Rate: Digester 1	OUR _{T1}	mgO2/(l.hr)	45.4	45.4	45.4	45.4	45.4	45.4	45.4	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	
Total Oxygen Utilisation Rate: Digester 2	OUR _{T2}	mgO2/(l.hr)	22.6	22.6	22.6	22.6	22.6	22.6	22.6	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	

LEGEND:

1. Significant change in parameter

ABC

2. Minor change in parameter

ABC

3. RESULTS – IMPACT ON SYSTEM PERFORMANCE (MAXIMUM SPECIFIC GROWTH RATE OF NITRIFIERS) - SLUDGE STREAM : "AUTHORS PWSSM" AND "BIOWIN"																
Parameter	Abbreviation	Unit	BIOWIN AVE (Dynamic State) (Values only)													
			16	16	16	16	16	16	16	24	24	24	24	24	24	24
VARYING PARAMETER																
Maximum Specific Growth Rate of Nitrifiers	UAm20	/day	0.225	0.248	0.360	0.450	0.518	0.585	0.675	0.225	0.248	0.360	0.450	0.518	0.585	0.675
1. ANAEROBIC DIGESTER																
Primary Sludge inflow to Anaerobic Digester	Q _w	m ³ /day	429	429	429	429	429	429	429	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Total Settleable Solids incoming	TSS _{in}	mgTSS/l	35524	35524	35524	35524	35044	35044	35524	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Volatile Settleable Solids incoming	VSS _{in}	mgVSS/l	30292	30292	31074	31074	31074	31074	31074	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
COD incoming	S _{te in}	mgCOD/l	49002	49002	49002	49002	49002	49002	49002	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
TKN incoming	N _{te in}	mgN/l	2011	2011	2011	2011	2011	2011	2011	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
TP incoming	P _{te in}	mgP/l	242	242	242	242	242	242	242	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Volume	Vol	m ³	5144	5144	5144	5144	5144	5144	5144	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Total Settleable Solids in effluent	TSS _{out}	mgTSS/l	14699	14699	14699	14699	14699	14699	14699	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Volatile Settleable Solids in effluent	VSS _{out}	mgVSS/l	9962	9962	9962	9962	9962	9962	9962	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
COD in effluent	S _{te out}	mgCOD/l	21244	21394	21394	21394	21394	21394	21394	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Total N in effluent	N _{te out}	mgN/l	3791	3791	3791	3624	3624	3624	3624	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
TP in effluent	P _{te out}	mgP/l	364	364	364	364	364	364	364	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
pH of Digester	pH		7.87	7.72	7.72	7.72	7.72	7.72	7.72	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
CH4 (Gaseous) Bi-product	CH ₄	mol/l	0.65	0.65	0.65	0.65	0.65	0.65	0.65	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
VSS Destruction	VSS _{dest}	%	67.1%	67.1%	67.9%	67.9%	67.9%	67.9%	67.9%	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
2. AEROBIC DIGESTER																
Sludge Waste Flow per day into Aerobic Digester	Q _{w in}	m ³ /day	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Sludge Waste Flow exiting Aerobic Digester	Q _{w OUT}	m ³ /day	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Influent TSS Concentration	X _{T in}	mgTSS/l	28500	28000	28000	28000	28000	28000	28000	27000	27000	27000	27000	27000	27000	27000
Influent VSS Concentration	X _{vl}	mgVSS/l	19941	19941	19941	19941	19941	19941	19941	18568	18568	18568	19070	19070	19070	19070
Active fraction of Sludge w.r.t TSS in influent	f _{av}		0.532	0.524	0.523	0.508	0.510	0.506	0.506	0.485	0.485	0.486	0.469	0.473	0.471	0.471
Active fraction of Sludge w.r.t VSS in influent	f _{at}		0.454	0.446	0.445	0.431	0.433	0.430	0.430	0.410	0.410	0.412	0.398	0.401	0.400	0.400
Volume of Aerobic Digester 1	V _{aerobic digester 1}	m ³	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501
Volume of Aerobic Digester 2	V _{aerobic digester 2}	m ³	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501	2501
Volume Total of Aerobic Digesters	V _{aerobic digester T}	m ³	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002	5002
Effluent TSS Concentration: Digester 2	X _T	mgTSS/l	22630	22630	24246	24246	23707	23707	23707	23973	23973	23973	23973	25062	23973	23973
Effluent VSS Concentration: Digester 2	X _v	mgVSS/l	15873	15873	15873	15873	15873	15873	15873	16002	16002	16002	16002	16002	15469	15469
Active fraction of Sludge w.r.t VSS in effluent	f _{av}		0.210	0.210	0.210	0.173	0.173	0.173	0.173	0.165	0.165	0.150	0.150	0.150	0.150	0.150
Active fraction of Sludge w.r.t TSS in effluent	f _{at}		0.167	0.167	0.167	0.137	0.137	0.137	0.137	0.130	0.130	0.118	0.118	0.118	0.118	0.118
Effluent COD Concentration: Digester 2	S _{te}	gCOD/L	16.908	16.773	16.773	18.360	16.700	16.597	16.597	16.778	16.673	16.778	17.564	16.778	16.673	16.673
Total Effluent Nitrogen Concentration: Digester 2	TotN _{eff}	gN/l	1.595	1.595	1.595	1.595	1.595	1.595	1.595	1.556	1.556	1.556	1.505	1.505	1.556	1.556
Effluent P Concentration (OrthoP + P _{total}): Digester 2	P _{te}	gP/L	1.904	1.904	1.904	1.904	1.904	1.904	1.904	1.648	1.648	1.648	1.648	1.648	1.727	1.727
Total Oxygen Utilisation Rate: Digester 1	OUR _{T1}	mgO2/(l.hr)	32.9	32.9	33.8	33.8	33.8	33.8	33.8	32.1	32.1	32.1	31.3	31.3	31.3	31.3
Total Oxygen Utilisation Rate: Digester 2	OUR _{T2}	mgO2/(l.hr)	12.8	12.8	12.8	12.8	12.8	12.8	12.8	10.8	10.8	9.9	9.9	9.9	9.9	9.9

LEGEND:

1. Significant change in parameter

ABC

2. Minor change in parameter

ABC

ANNEXURE I

RESULTS – IMPACT OF READILY BIODEGRADABLE COD ON SYSTEM PERFORMANCE

ParameterAbbreviationUnit			Author's PWSM (Steady State) (Values only)												BIOWIN (Steady State) (Values only)												BIOWIN MAX (Dynamic State) (Values only)																																																																																																																																																																																																																																																																																																															
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LEGEND:

1. Significant change in parameter
2. Minor change in parameter

ABC

ABC

ParameterAbbreviationUnit			BIOWIN AVE (Dynamic State) (Values only)												PWSSD (Steady State) (Values only)												UCTPHO (Steady State) (Values only)																																																																																																																																																																																																																																																																																																												
			1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	1616161616161624242424242424	161616161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LEGEND:

1. Significant change in parameter
2. Minor change in parameter

ABC

ABC

2. RESULTS – IMPACT ON SYSTEM PERFORMANCE (READILY BIODEGRADABLE COD) - LIQUID STREAM (NEW LANE) : "AUTHORS PWSSM" AND "BIOWIN"

[illegible]

LEGEND:

1. Significant change in parameter
2. Minor change in parameter

ABC

ABC

2. RESULTS – IMPACT ON SYSTEM PERFORMANCE (READILY BIODEGRADABLE COD) - LIQUID STREAM (NEW LANE) : "AUTHORS PWSSM" AND "BIOWIN"																
Parameter	Abbreviation	Unit	BIOWIN AVE (Dynamic State) (Values only)													
			16	16	16	16	16	16	16	24	24	24	24	24	24	24
VARYING PARAMETER																
Fraction of total influent COD that is readily biodegradable	f _{sb} 's		0.0400	0.0700	0.1000	0.2000	0.2300	0.2600	0.3000	0.0400	0.0700	0.1000	0.2000	0.2300	0.2600	0.3000
1. PRIMARY SETTLING TANKS																
Total Area Required (PWWF)	A	m ²	1888	1888	1888	1888	1888	1888	1888	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
Typical concentration of Primary Sludge		mg/l	36500	36500	36500	36500	36500	36500	36500	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
2. 5-STAGE BARDENPHO REACTOR DESIGN																
Selected Sludge Age	R _s	days	23.2	21.1	19.5	18.1	17.5	17.2	17.1	22.9	20.9	19.9	18.4	17.8	17.4	17.4
Volume of Anaerobic Reactor	V _{anaerobic}	m ³	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400	5400
Volume of Primary Anoxic Reactor	V _{anoxic (Primary)}	m ³	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150
Volume of Aerobic Reactor	V _{aerobic}	m ³	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800	16800
Volume of Secondary Anoxic Reactor	V _{anoxic (Secondary)}	m ³	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100
Volume of Re-aeration Reactor	V _{aerobic (Reaeration)}	m ³	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850
Volume of Reactor	V _{Total}	m ³	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300	36300
VSS Concentration: Anaerobic Reactor		mgVSS/l	2022	2066	2000	2645	2607	2708	3110	1791	1836	1769	2518	2632	2682	2985
VSS Concentration: Primary Anoxic Reactor		mgVSS/l	2022	2066	2000	2645	2607	2708	3110	1791	1836	1769	2518	2632	2682	2985
VSS Concentration: Aerobic Reactor		mgVSS/l	2022	2066	2000	2645	2607	2708	3110	1791	1836	1769	2518	2632	2682	2985
VSS Concentration: Secondary Anoxic Reactor		mgVSS/l	2022	2066	2000	2645	2607	2708	3110	1791	1836	1769	2518	2632	2682	2985
VSS Concentration: Re-aeration Reactor		mgVSS/l	2022	2066	2000	2645	2607	2708	3110	1791	1836	1769	2518	2632	2682	2985
Mass of Volatile Settleable Solids in Reactor	MX _v	kgVSS	73381	75004	72591	96017	94627	98302	112909	65031	66649	64231	91402	95524	97361	108369
MLSS Concentration: Anaerobic Reactor		mgTSS/l	2800	2800	3000	3750	4000	4000	4700	2771	2816	2771	3623	3876	3976	4528
MLSS Concentration: Primary Anoxic Reactor		mgTSS/l	2800	2800	3000	3750	4000	4000	4700	2771	2816	2771	3623	3876	3976	4528
MLSS Concentration: Aerobic Reactor		mgTSS/l	2800	2800	3000	3750	4000	4000	4700	2771	2816	2771	3623	3876	3976	4528
MLSS Concentration: Secondary Anoxic Reactor		mgTSS/l	2800	2800	3000	3750	4000	4000	4700	2771	2816	2771	3623	3876	3976	4528
MLSS Concentration: Re-aeration Reactor		mgTSS/l	2800	2800	3000	3750	4000	4000	4700	2771	2816	2771	3623	3876	3976	4528
Mass of Total Solids in Reactor	MX _T	kgTSS	101640	101640	108900	136125	145200	145200	170610	100582	102233	100590	131519	140695	144319	164365
Sludge Waste Flow per day	Q _{sw}	ML/day	1.564	1.719	1.861	2.003	2.069	2.114	2.117	1.585	1.737	1.824	1.968	2.038	2.085	2.091
MLSS Concentration in of Waste Flow	X _{sw}	mgTSS/l	2800	2800	3000	3750	4000	4000	4700	2771	2816	2771	3623	3876	3976	4528
Active fraction of Sludge w.r.t VSS	f _{av}		0.394	0.386	0.452	0.509	0.522	0.525	0.529	0.362	0.383	0.395	0.469	0.499	0.497	0.523
Active fraction of Sludge w.r.t TSS	f _{at}		0.324	0.321	0.371	0.423	0.435	0.436	0.439	0.292	0.309	0.326	0.391	0.410	0.412	0.435
Total Average Oxygen Utilisation Rate (Aerobic)	OUR _{Average}	mgO ₂ /l.hr	42.5	40.7	41.0	42.4	43.3	43.4	42.3	44.0	41.8	41.8	43.0	43.8	43.8	41.8
Total Average Oxygen Utilisation Rate (Re-aeration)	OUR _{Average}	mgO ₂ /l.hr	34.0	32.2	32.4	32.6	32.5	32.5	31.5	30.4	28.2	29.3	30.4	30.3	30.8	29.2
Total O ₂ flux required	FO _m	kgO ₂ /day	18661	17854	17965	18543	18912	18930	18467	19072	18128	18152	18709	19020	19042	18133
Effluent COD Concentration	S _{co}	mgCOD/L	45.1	45.1	45.1	47.0	47.0	47.0	47.0	45.1	45.1	45.1	46.0	46.0	47.0	47.0
Effluent Free and Saline Ammonia (FSA) Concentration	N _{ss}	mgN/L	1.468	1.477	1.998	2.981	2.520	2.524	2.529	0.197	0.198	0.200	0.498	0.201	0.201	0.201
Unbiodegradable Soluble Organic Nitrogen	N _{ous}	mgN/L	0.560	-0.326	2.415	5.057	5.799	5.923	6.998	0.695	0.799	1.210	2.051	3.107	2.930	2.754
Effluent TKN Concentration	N _{te}	mgN/L	2.029	1.151	4.413	8.039	8.318	8.446	9.527	0.892	0.997	1.409	2.549	3.308	3.131	2.956
Effluent Nitrate Concentration	N _{no}	mgN/L	15.374	17.685	14.756	9.508	10.046	10.347	8.306	14.218	13.627	11.785	8.762	7.492	6.254	5.014
Total Effluent Nitrogen Concentration	TotN _{eff}	mgN/l	17.403	18.835	19.170	17.547	18.364	18.793	17.833	15.111	14.625	13.194	11.311	10.800	9.385	7.970
Effluent P Concentration (OrthoP + P _{bound})	P _{te}	mgP/L	6.113	4.876	1.922	0.669	0.669	0.669	0.501	5.181	3.229	2.507	0.836	0.794	0.669	0.543
Effluent P Concentration (Organic P)	P _{ous}	mgP/l	0.200	0.300	0.300	0.450	0.400	0.400	0.400	0.150	0.200	0.300	0.500	0.500	0.500	0.400
Effluent Ortho P Concentration	P _{ss}	mgP/l	5.913	4.576	1.622	0.219	0.269	0.269	0.101	5.031	3.029	2.207	0.336	0.294	0.169	0.143
Change in Alkalinity following nitrification & denitrification pH of effluent from Reactor	Alk pH	mg/l as CaCO3	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9	Not Prov. 8.9
3. SECONDARY SETTLING TANKS																
Area (including 80% Flux rating correction factor for 1 dim	A	m ²	4361	4361	4361	4361	4361	4361	4361	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
S Recycle Ratio i.t.o ADWF (dry weather flow conditions)	R _{i,ADWF & PWWF}		0.870	0.870	0.870	0.870	0.870	0.870	0.870	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.
ADWF Underflow Concentration to Reactor (RAS Flow Concentration)	X _{T Underflow}	mgTSS/l	6000	5800	6300	7900	7500	8500	9750	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.

LEGEND:
1. Significant change in parameter
2. Minor change in parameter

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[illegible]

LEGEND:

1. Significant change in parameter

ABC

2. Minor change in parameter

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3. RESULTS – IMPACT ON SYSTEM PERFORMANCE (READILY BIODEGRADABLE COD) - SLUDGE STREAM : "AUTHORS PWSSM" AND "BIOWIN"																		
Parameter	Abbreviation	Unit	BIOWIN AVE (Dynamic State) (Values only)															
			16	16	16	16	16	16	16	16	24	24	24	24	24	24	24	
VARYING PARAMETER																		
Fraction of total influent COD that is readily biodegradable	fsb's		0.040	0.070	0.100	0.200	0.230	0.260	0.300	0.040 0.070 0.100 0.200 0.230 0.260 0.300								
1. ANAEROBIC DIGESTER																		
Primary Sludge inflow to Anaerobic Digester	Q _w	m ³ /day	428	428	428	428	428	428	428	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Total Settleable Solids incoming	TSS _{in}	mgTSS/l	27843	29763	30532	35524	36004	40805	53766	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Volatile Settleable Solids incoming	VSS _{in}	mgVSS/l	23404	24397	26368	31074	33265	37206	49983	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
COD incoming	S _{te in}	mgCOD/l	61003	64003	59002	49002	46002	44002	44002	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
TKN incoming	N _{te in}	mgN/l	2413	2413	2298	2011	1896	1753	1753	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
TP incoming	P _{te in}	mgP/l	258	258	322	242	225	193	193	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Volume	Vol	m ³	5144	5144	5144	5144	5144	5144	5144	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Total Settleable Solids in effluent	TSS _{out}	mgTSS/l	14447	14451	14455	14699	14237	13759	16623	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Volatile Settleable Solids in effluent	VSS _{out}	mgVSS/l	10445	10449	10454	9962	10973	9971	12733	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
COD in effluent	S _{te out}	mgCOD/l	27813	27012	26012	21394	16007	13496	28613	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
Total N in effluent	N _{te out}	mgN/l	4667	4639	4384	3624	3603	3413	3276	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
TP in effluent	P _{te out}	mgP/l	328	327	408	364	323	281	281	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
pH of Digester	pH		7.62	7.62	8.02	7.72	7.92	8.02	7.51	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
CH ₄ (Gaseous) Bi-product	CH ₄	mol/l	0.60	0.57	0.62	0.65	0.67	0.68	0.52	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
VSS Destruction	VSS _{dest}	%	55.4%	57.2%	60.4%	67.9%	67.0%	73.2%	74.5%	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.	n/appl.		
2. AEROBIC DIGESTER																		
Sludge Waste Flow per day into Aerobic Digester	Q _{w in}	m ³ /day	293.9	273.2	332.0	350.1	358.8	359.1	357.2	294	273	332	350	359	359	357		
Sludge Waste Flow exiting Aerobic Digester	Q _{w OUT}	m ³ /day	293.9	273.2	332.0	350.0	358.8	359.1	357.2	294	273	332	350	359	359	357		
Influent TSS Concentration	X _{ti in}	mgTSS/l	22500	20000	22500	28000	29000	30000	35000	21500	19000	21000	27000	29000	29000	34000		
Influent VSS Concentration	X _{vi}	mgVSS/l	14964	14062	15049	19941	19985	20967	23937	15042	13701	14184	19070	20141	20115	22603		
Active fraction of Sludge w.r.t TSS in influent	f _{av}		0.327	0.329	0.376	0.508	0.453	0.450	0.459	0.293	0.307	0.321	0.469	0.426	0.428	0.445		
Active fraction of Sludge w.r.t VSS in influent	f _{at}		0.402	0.399	0.457	0.431	0.533	0.530	0.543	0.367	0.384	0.393	0.398	0.509	0.507	0.529		
Volume of Aerobic Digester 1	V _{aerobic digester 1}	m ³	1480	1772	2052	2501	2711	2852	3033	1480	1772	2052	2501	2711	2852	3033		
Volume of Aerobic Digester 2	V _{aerobic digester 2}	m ³	1480	1772	2052	2501	2711	2852	3033	1480	1772	2052	2501	2711	2852	3033		
Volume Total of Aerobic Digesters	V _{aerobic digester T}	m ³	2605	3428	3975	5052	5426	5741	6186	2605	3428	3975	5052	5426	5741	6186		
Effluent TSS Concentration: Digester 2	X _t	mgTSS/l	17240	17457	17124	24246	24265	24379	28350	17765	15312	16330	23973	24526	24625	28630		
Effluent VSS Concentration: Digester 2	X _v	mgVSS/l	10499	9688	10288	15873	16000	16653	18973	10560	9279	9357	16002	16134	16243	19118		
Active fraction of Sludge w.r.t VSS in effluent	f _{av}		0.072	0.073	0.126	0.173	0.110	0.112	0.192	0.082	0.040	0.123	0.150	0.164	0.159	0.166		
Active fraction of Sludge w.r.t TSS in effluent	f _{at}		0.052	0.056	0.093	0.137	0.087	0.087	0.149	0.058	0.030	0.090	0.118	0.129	0.124	0.128		
Effluent COD Concentration: Digester 2	S _{se}	gCOD/L	15.974	15.209	15.296	18.360	16.714	17.007	17.115	15.872	14.355	14.449	17.564	16.388	17.213	17.115		
Total Effluent Nitrogen Concentration: Digester 2	TotN _{eff}	gN/l	0.998	1.055	1.254	1.595	1.549	1.597	1.696	0.903	0.812	1.064	1.505	1.511	1.609	1.758		
Effluent P Concentration (OrthoP + P _{oase}): Digester 2	P _{te}	gP/L	0.673	0.772	1.258	1.904	1.920	1.925	1.931	0.588	0.686	1.087	1.648	1.747	1.914	1.924		
Total Oxygen Utilisation Rate: Digester 1	OUR _{T 1}	mgO2/(l.hr)	44.9	35.9	35.1	33.8	32.8	32.3	31.6	41.0	34.7	33.3	31.3	30.8	30.3	29.6		
Total Oxygen Utilisation Rate: Digester 2	OUR _{T 2}	mgO2/(l.hr)	16.3	10.8	13.2	12.8	12.7	12.6	12.6	12.7	10.8	10.7	9.9	10.3	10.3	10.3		

LEGEND:

1. Significant change in parameter

ABC

2. Minor change in parameter

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ANNEXURE J

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