

Article

Simulation of Dynamic Behaviour of a Biological Wastewater Treatment Plant in South East Queensland, Australia using Bio-Win Software

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Abstract. Wastewater treatment is the process of removing pollutants from liquid waste using physical, chemical and biological methods by converting it into an acceptable final effluent before discharging into a water body or reuse, and to safely dispose of solids generated during the treatment process. Limited parameters in Wastewater Treatment Plant (WWTP) are usually measured due to the significant cost and time involved with them.

The mathematical modelling is increasingly becoming a well-established technique among researchers as well as practicing engineers to study the behaviour of wastewater treatment process as it provides more accurate predictions within the limited time frame at a reduced cost. Therefore, this technique can be used to study the engineering design of modern water resource recovery facilities that experience in increasing demands on control of effluent quality. The research work presented here is focused on studying the dynamic (time dependent) behaviours of the wastewater treatment plant in south east Queensland, Australia using the mathematical modelling technique implemented using Bio-Win software. The model developed has been calibrated and validated based on the measured data from the WWTP. The main benefit of this research work is that the developed and validated model can be used to study the non-measured important parameters of the WWTP.

Keywords: Wastewater treatment process, mathematical model, bio-win, dynamic behaviour of wastewater treatment plant.

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1. Introduction

Wastewater treatment is the process of removing pollutants from liquid waste using physical, chemical and biological methods by converting it into an acceptable final effluent before discharging into a water body or reuse, and to safely dispose of solids generated during the process. The physical methods include particle settling due to gravity and filtration and the chemical methods consist of aggregate formation, which aids the settling of solids and pathogens, and chemical disinfection. The biological method uses the activities of bacteria to digest organic matter. Anaerobic bacteria produce methane gas when they degrade organic matter and the methane gas is an excellent energy source. Wastewater contains valuable resources that can be recovered for secondary uses if treated properly. It is therefore very important to study the operation performance and efficiency and investigate the possibilities of upgrading existing wastewater treatment plants in order to satisfy the future requirements [1].

There were several researches conducted to improve the efficiency of wastewater treatment processes in WWTPs due to the significant increase of amounts of waste material entering into the waste streams of every urban and rural areas creating unmanageable environmental and health problems. For instance, Sundara Kumar and Ratnakanth Babu [2] evaluated the performance efficiency of a sewage treatment plant based on a biological treatment method. Results of this method were very useful to identification of the operational and maintenance problems and resulted in plant upgrading to satisfy the future hydraulic and organic loadings. Mo and Zang [3] reviewed the available resource recovery methods of municipal wastewater treatment plants from a comprehensive literature review and found that there is a need to evaluate the applications of the resource recovery methods in wastewater treatment plants from a life cycle perspective in addition to the technology improvements. Bye et al. [4] studied wastewater treatment process linking several regions in Canada using a model based analysis that is used to plan the treatment process across the regions. Outcomes of this study concluded that the behaviour of the wastewater treatment plant impacts on the plants in the other regions as well due to the fact that all the plants are linked together. Oleyblo et al. [5] researched on the activated sludge model that was validated based on full-scale wastewater treatment plant data. Outcomes of this research work resulted in recommendations such as ability to study the various operational units incorporated into the wastewater treatment plant and then select the most appropriate model in order to reduce or eliminate the cost of building additional component(s). Raafat et al. [6] studied application of a hybrid system to upgrade existing wastewater treatment plant in Balaks, Egypt and concluded that moving bed bio film reactor (MBBR) could be a preferable option for this study since a minimum number of aerators would be required and the media used is locally manufactured, thus the operating cost could be narrowed.

The mathematical modelling is increasingly becoming a popular technique amongst researchers as well as among the practicing engineers to study the time dependent (dynamic) behaviour of the wastewater treatment process due to the fact that this technique provides more accurate predictions within the limited time frame and at a reduced cost. Therefore, this technique can be used to study the engineering design of modern water resource recovery facilities that experience in increasing demands on effluent quality. The mathematical model includes a number of mathematical equations that describe reactions and reaction rates of biological, chemical, and physical phenomena of various unit processes [7]. Dercoet et al. [8] demonstrated some possibilities for applying simulation programs to study operation of WWTP. The simulation calculations were performed based on the conditions at the plant in Slovakia and concluded that calibrated activated sludge model can be used to predict the influence of changes in wastewater composition and operational parameters on the effluent wastewater quality and the related operational costs. Spagni et al. [9] evaluated the applicability of the anaerobic digestion model to a Submerged Anaerobic Membrane Bio-Reactor (SAMBR) by simulating industrial wastewater composed of Cheese whey and sucrose. Findings of this evaluation confirmed that the biological processes involved in SAMBR could be modelled using very few parameters modified. The Bio-Win software developed by the EnviroSim organization is widely used for several researches to develop the mathematical model in order to design, upgrade, and optimize wastewater treatment plants of all types [10]. The model developed using this software can simulate the combination of biological, chemical, and physical processes. For instance, Liwarska-Bizukojc et al. [11] has calibrated the mathematical model developed using the Bio-Win software based on the proactive data obtained from the wastewater treatment plant. Secondly, several sensitivity analyses were conducted by changing the parameters in this model in order to improve its accuracy and it was noticed that the analysis results were comparable very well with the proactive data. Eldyasti et al. [12] used the Bio-Win software in order to examine the compositions of a landfill leachate. Outcomes of this

examination concluded that the Bio-Win software has an ability to capture most of the performance parameters with higher accuracy. Liwarska-Bizukojs et al. [13] performed a sensitivity analysis to verify the activated sludge model developed using the Bio-Win software and they concluded that sensitivity analysis was a very important tool when determining many analysis parameters. Friesen [14] conducted a rigorous study to identify Phosphorus at Cargill Foods Beef processing facility in High River, Alberta, Canada. In this study, a mathematical model was developed for Cargill Foods Wastewater Plant using the Bio-Win software. This mathematical model was then used to determine characteristics of wastewater and examine adaptability of the current wastewater plant design in order to remove phosphate biologically.

Liwarska-Bizukojs et al. [15] carried out a study of calibration of a complex activated sludge model to determine its predictability and to improve the effectiveness of nutrients removal in the full-scale plant using the Bio-Win software and one of the conclusions of this study was that the software is very suitable for such a study as it can simulate the WWTP more accurately. Venkatapathi [16] used the Bio-Win software to model and simulate the city of Loveland wastewater treatment plant with the objective of identifying the best treatment process for the existing wastewater treatment plant's new effluent. He concluded that the efficiency of city of Loveland waste water treatment plant can be improved by upgrading the existing activated sludge process to either anaerobic, anoxic, oxic (A2O) process or 5 stage Bardenpho process. Rosinski [17] simulated the Oakville Southwest wastewater treatment plant in Ontario using the Bio-Win software to investigate the effect of primary treatment optimization on the energy balance of the wastewater treatment process which comprises of a conventional activated sludge process and anaerobic digestion. Outcomes of this simulation indicated that improvements to primary sedimentary tank enhanced the efficiency of the overall treatment process. Knapp [18] studied the performance and process control strategies at the Falkenburg Road Advanced Wastewater Treatment Plant in Hillsborough County, Florida. In his study, the Bio-Win software has been used to model and simulate the WWTP to observe relationships between sludge age, Mixed Liquor Suspended Solids (MLSS) concentration, influent loading, and effluent nitrogen concentrations. Findings of this study recommended to practicing engineers and researchers several ways improving the operational performance and efficiency such as chemical addition for phosphorus removal and automation of aeration control using online analysers. Lei et al. [19] conducted a comparison study using the Bio-Win modelling and proved that the Bio-Win software was an effective tool to compare different secondary treatment processes. Based on the literature above, it is clear that mathematical modelling using Bio-Win software can be used to study the behaviour of a wastewater treatment plant successfully and then study the non-measured parameters using the model which can be validated based on the measured parameters.

The research work proposed here in this paper is focused on the Wastewater Treatment Plant (WWTP) located in south east Queensland, Australia; the Loganhome WWTP. The section below describes the operation of the Loganhome WWTP.

Wastewater Treatment Plant in Logan City Council

Loganholme WWTP is situated between the City of Brisbane to the north and Gold Coast to the south. Its current dry weather capacity is 51 ML/ day while the wet weather capacity is around three times higher than the dry weather capacity. It has around 64 suburbs and average population is around 287,517. The Loganholme Waste Water Treatment Plant (WWTP) primarily receives domestic sewage and some trade wastes as well [20]. The influent entering into the plant is physically as well as biologically treated and the final effluent disinfected before discharging into the Logan River as shown in the flow chart in Fig. 1 below [21].

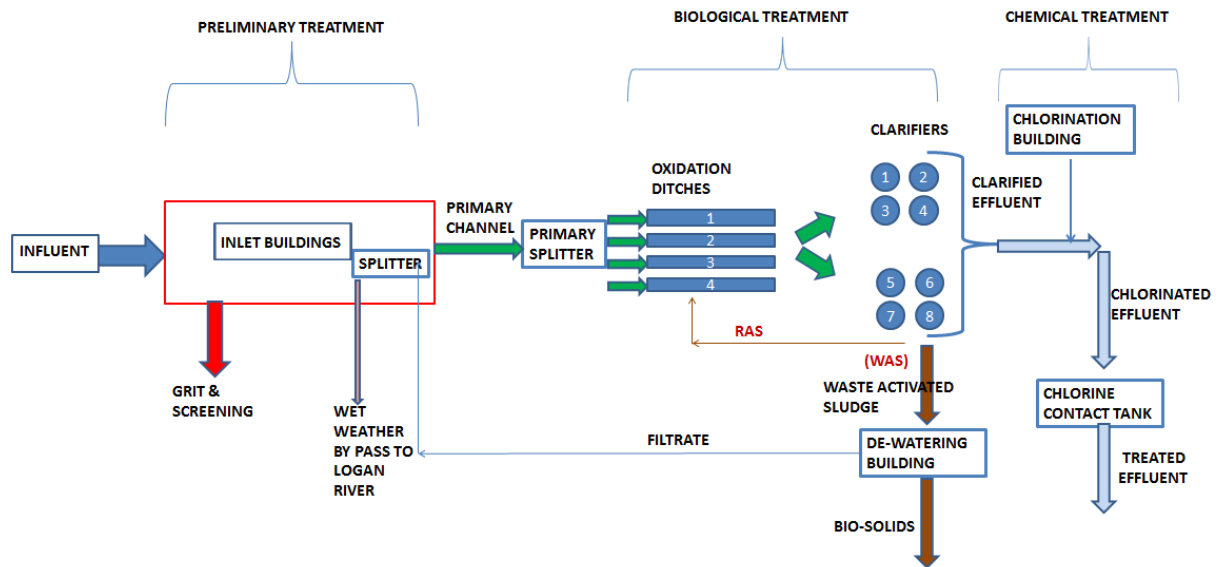


Fig. 1. Flow chart of Loganholme Wastewater Treatment Plant.

The purpose of the preliminary treatment is to remove screenings and grit from incoming sewage before they damage or clog pumps or sewage lines of wastewater treatment system. The biological treatment facilities at the WWTP include four oxidation ditches which function to reduce ammonia and nitrate to acceptable low levels. There are eight clarifiers that provide solids – liquid separation to mixed liquor received from the oxidation ditches. Mixed liquor from oxidation ditches 1 and 2 are sent to clarifiers 1 - 4 and mixed liquor from oxidation ditches 3 and 4 are sent to clarifiers 5 - 8. Settled solids at the clarifiers are either returned back to the oxidation ditches via the RAS (Return Activated Sludge) pumping stations or wasted to the dewatering facility as WAS (Waste Activated Sludge). The clarified effluent enters to the chlorination building and then chlorinated effluent passes through the chlorine contact tank where sufficient contact time is maintained to inactivate micro-organisms in the treated effluent. Treated effluent is discharged to the Logan River or transferred to the site to re-use within the WWTP. The dewatering unit at the WWTP is designed to remove any excess water from sludge to produce a bio-solid prior to being transferred out of the WWTP for re-use. All filtrate water produced as a part of the process is discharged back to the head of the plant via the inlet splitter box.

2. Methodology

In the research work presented in this paper, firstly a rigorous mathematical model has been developed using Bio-Win software and validated based on the available measured data obtained from the Loganholme WWTP and then studied the plant behaviour including non-measured important parameters of the WWTP using the validated mathematical model. The sections below present the development, calibration and validation of the mathematical model and the extraction of the non-measured parameters.

The Mathematical Model Development

The Bio-Win software has been used to develop the mathematical model in the research work presented in this paper due to the fact that according to the literature highlighted above, this software has been widely used to study the dynamic (time-dependent) behaviour of the WWTP and is becoming very established in the industry and research projects.

Figure 2 below shows the mathematical model developed using Bio-Win software in this research work based on the flowchart presented in Fig. 1 earlier. This model has an ability to provide the time dependent (dynamic) behaviour of each treatment component and the whole WWTP.

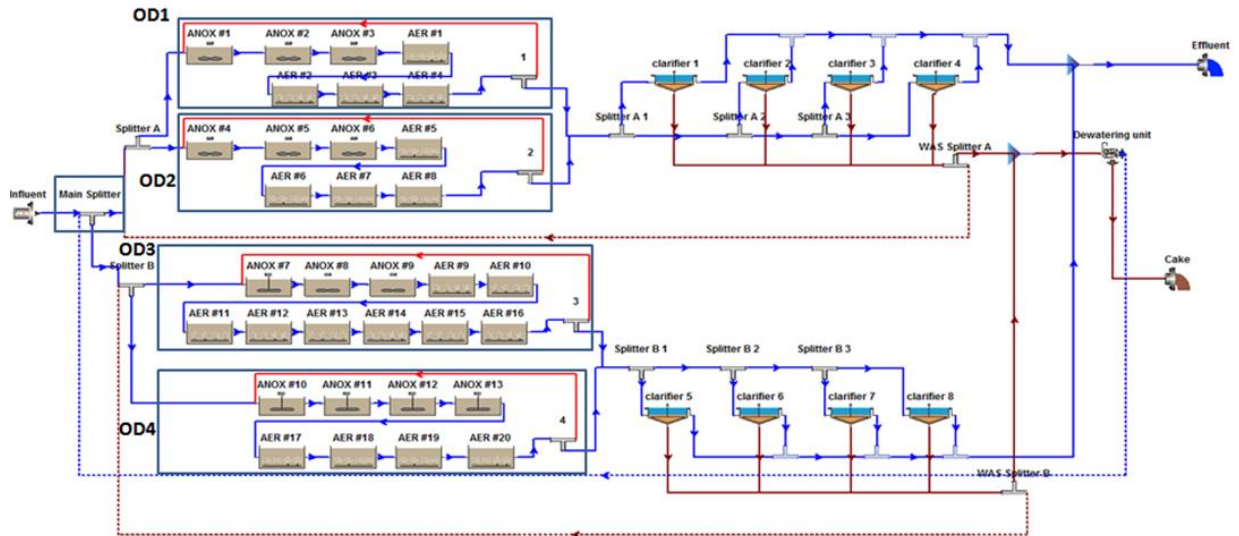


Fig. 2. Mathematical model developed using Bio-Win software.

As indicated in Fig. 2 above, the wastewater initially comes into the system and then divided into two flows using the Main Splitter based on the volume of the treatment components. The volumes of the oxidation ditches are tabulated in Table 1. These Oxidation ditches include anoxic (indicated in the figure above as ANOX) and aerobic (indicated in the figure above as AER) zones and these zones have been modelled separately as shown in Fig. 2. The appropriate dissolved Oxygen concentrations obtained from the WWTP are assigned for these zones. Figure 3 shows the overviews of the Oxidation ditches. The alpha factor value (Oxygen transfer coefficient for Mixed Liquor) has been used as 0.6 to better represent the diffused aeration while the Beta factor (Oxygen saturation coefficient for Mixed Liquor) has been used as 0.8 due to the fact that some trade wastes are entering into the wastewater system. Aerobic/anoxic DO half saturation switch was adjusted from the default of 0.05 to 0.25, which allows more anoxic activity to occur in the presence of oxygen [10]. The Splitters 1 to 4 indicated in Fig. 2 are used to collect the outputs from the Oxidation ditches and these outputs are then divided into the clarifiers based on their volumes using the Splitters A1 to A3 and Splitters B1 to B3. The volumes of the clarifiers are tabulated in Table 2 below. There are 8 ideal clarifiers used to model the plant clarifiers 1, 2, 3, 4, 5, 6, 7 and 8 with sludge blanket height (Fraction of settler height) of 0.14, 0.14, 0.14, 0.14, 0.11, 0.11, 0.11 and 0.11 respectively. The percentage removal of clarifiers has been used as 99.9% as recommended by the WWTP operational staff. The sludge component extracted from the clarifiers are then supplied into the WAS splitter A and B. A portion of this sludge (RAS) is then returned to the Oxidation ditches where it mixes with incoming screened influent in order to enhance the microbial reactions. The RAS recirculation ratio for the oxidation ditches 1 and 2 is 130% of Influent flow while that in the oxidation ditches 3 and 4 is 150% of influent flow. The remaining sludge component (WAS) is supplied to the dewatering unit in order to remove the excess water (Filtrate) which is then supplied back into the system as indicated in Fig. 2 above. The solid component/Bio solid (CAKE) component from the dewatering unit is taken away and then re-used as a soil conditioner. The final effluent of the clarifiers is then disinfected and discharged to the Logan River. The information above summarises operation of the mathematical model developed.

Table 1. Properties of oxidation ditches.

Oxidation Ditch	Volume (ML)	Depth (m)	With (m)	No of Diffuser zones (Aerobic Zones)	No of Anoxic zones
1	8.5	3.1	7.5	4	3
2	8.5	3.1	7.5	4	3
3	8.5	4	8	8	3
4	8.5	4	8	4	4

Table 2. Volume of Clarifiers.

Clarifier No	Volume (ML)
1	2.414
2	2.414
3	3.055
4	3.055
5	6.286
6	6.286
7	6.286
8	6.286

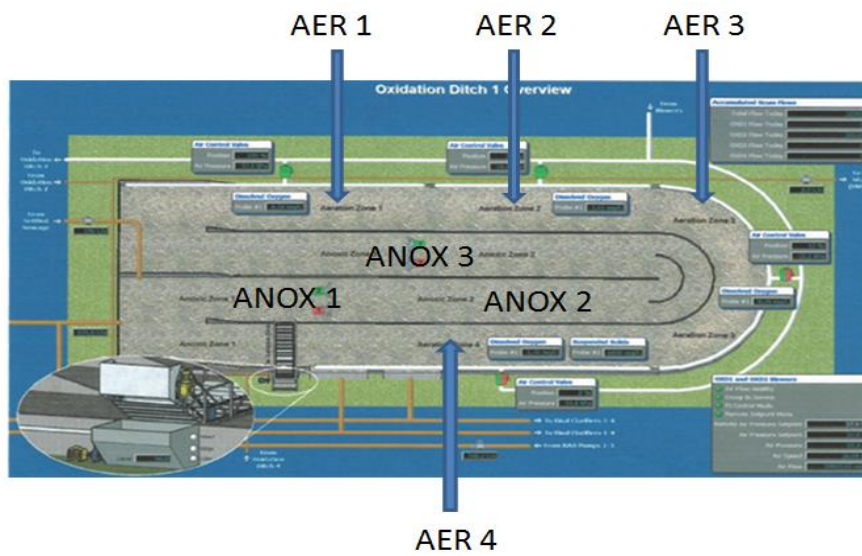


Fig. 3. (a) Overview of the Oxidation Ditch 01 (showing different aeration and anoxic zones).

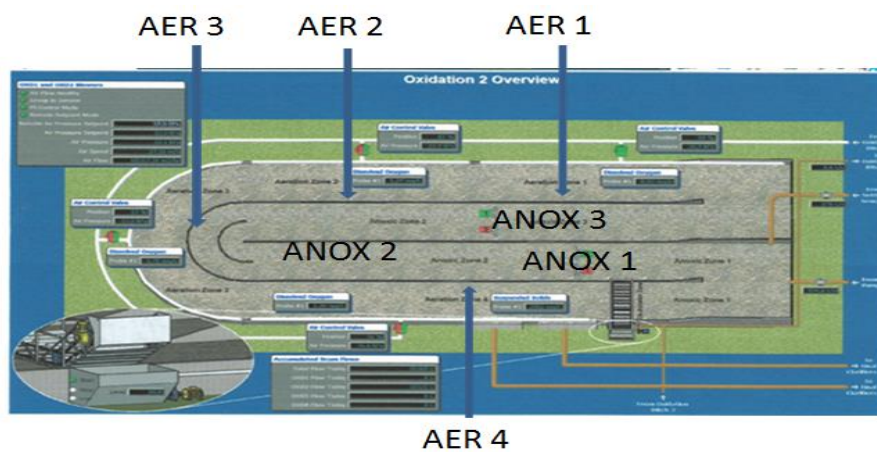


Fig. 3. (b) Overview of the Oxidation Ditch 02 (showing different aeration and anoxic zones).

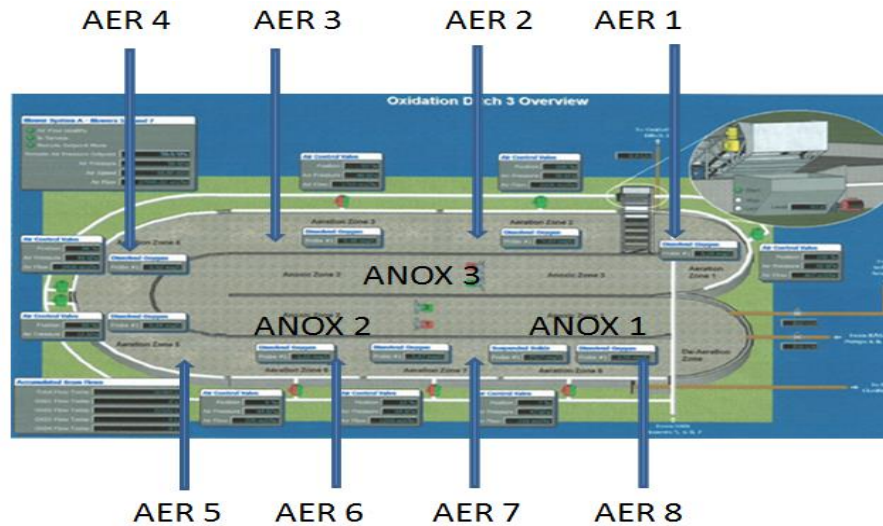


Fig. 3. (c) Overview of the Oxidation Ditch 03 (showing different aeration and anoxic zones).

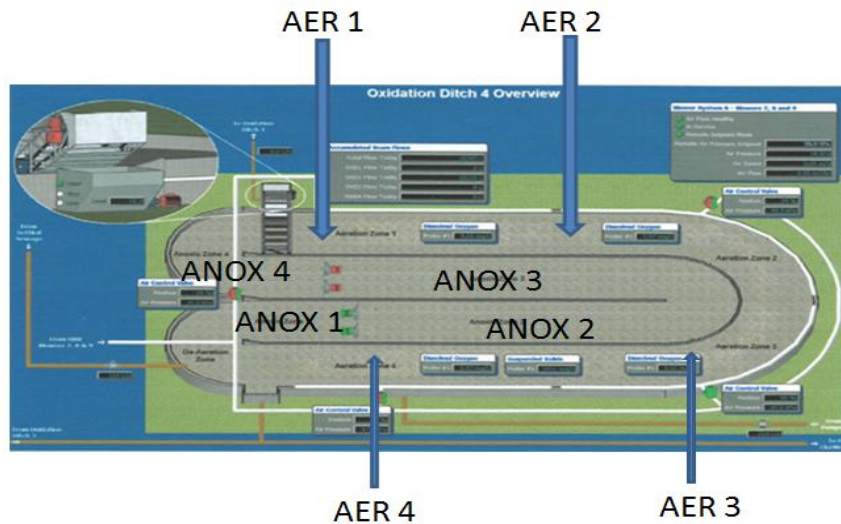


Fig. 3. (d) Overview of the Oxidation Ditch 04 (showing different aeration and anoxic zones).

In this research work, the measured data from 1st of January 2014 to 30th August 2015 has been used due to the fact that it is noticed that this data represents the closest period beginning of the research work with the most recent upgrades incorporated into the WWTP.

All measured data were statistically elaborated by standard methods using Microsoft excel functions. The confidence intervals were calculated at the significance level of 95%. The sample size for the influent flow rate was varying from 20 to 30 per month. The sample sizes of the parameters such as total COD, total Kjeldahl, total P, Total suspended solids and nitrate N vary from 3 to 5 per month. Median values of the measured data have been calculated based on the monthly basis and these values have then been incorporated into the mathematical model as a time dependent basis. This enabled to improve accuracy of the inputs while reducing the computational demand involved with the analysis. Table 3 below shows the main analysis inputs calculated based on the procedure described above and then the time dependent analysis has been performed for the 10 months period using the general Activated Sludge/Anaerobic Digestion Model (ASDM) which is referred to as the Bio-Win ASDM [22]. The Standard deviation (SD) for the influent parameters for each month have been calculated and tabulated in Table 4 below.

Table 3. Input data calculated for the mathematical model.

Time	Flow (ML/d)	Total COD (mg COD/L)	Total Kjeldahl Nitrogen (mg N/L)	Total P (mg P/L)	Nitrate N (mg N/L)	Alkalinity (mmol/L)	ISS Influent (mg ISS/L)
Nov-14	37.89	740	61.0	10.00	0.20	6.0	40.00
Dec-14	39.79	570	63.40	6.90	0.30	6.0	54.00
Jan-15	40.39	490	51.25	6.35	0.20	6.0	39.75
Feb-15	39.69	395	52.35	6.80	0.55	6.0	34.50
Mar-15	46.37	590	54.60	7.10	0.50	6.0	48.75
Apr-15	45.51	550	45.10	5.50	0.60	6.0	42.00
May-15	48.20	430	47.30	7.85	0.60	6.0	43.50
Jun-15	43.26	755	60.40	10.30	0.60	6.0	50.00
Jul-15	42.82	560	61.00	9.90	3.00	6.0	37.05
Aug-15	43.08	775	63.15	11.25	4.30	6.0	59.25

Table 4. Variation of Standard Deviation (SD) for the influent parameters.

Parameter	Variation of SD for the 10 months	
	Min	Max
Influent flow rate	1.43	50.93
Total COD	27.5	424.61
Total Kjeldahl N	2.51	24.97
Total P	0.86	2.66
Inert Suspended Solids	12.69	67.01
Nitrate N	0.15	2.82

As indicated in Table 3 above, the influent flow in the period of March 2015 to May 2015 is higher compared to the other months due to the fact that during this period, the database of the WWTP is recorded a significant rain fall occurred and hence this rainwater mixed with the influent. After this period, it is also noticed that there is slight increment of influent flow due to the human population and their activity growth.

The ISS (Inert Suspended Solids) in the Table 3 above is calculated by subtracting VSS (Volatile Suspended Solids) from TSS (Total Suspended solids). The VSS is not measured regularly in the WWTP so that it is used as 85% of TSS in the analysis as per the plant's operational staff's confirmation.

3. Results and Discussion

3.1. Model Calibration

In this research, waste water fractions and the kinetic parameters were determined based on the measured (prototype) data combined with the sensitivity analysis. The sensitivity analysis allowed the identification of the most important parameters which are needed to be adjusted during model calibration [23]. The influent wastewater fractions for the COD influent are tabulated in Table 5 below.

Table 5. Wastewater fractions for the COD influent element of the Bio Win model.

Fraction	Units	Calculated Value
Fbs - Readily biodegradable COD	g COD/g COD total	0.210
Fac - Acetate	g COD/g rbCOD	0.46
Fxsp- Non -colloidal slowly biodegradable COD	g COD/ g slowly biodegradable COD	0.750
Fus - Soluble unbiodegradable COD	g COD/g COD total	0.050
Fup - Particulate unbiodegradable COD	g COD/g COD total	0.130
Fna - Ammonia	g NH ₃ -N/g TKN	0.680
Fnox - Particulate organic N	g N/g organic N	0.500
Fnus - Soluble unbiodegradable TKN	g N/g TKN	0.020
FupN- N:COD ratio for unbiodegradable particulate COD	g N/g COD	0.350
Fpo4 - Phosphate	g PO ₄ -P/ g TP	0.780
FupP - P:COD ratio for unbiodegradable particulate COD	g P/g COD	0.011

There are many kinetic and stoichiometric parameters included in the Bio-Win Activated Sludge model and they are categorized based on the group of microorganisms such as OHOs, AOB, NOB, AAO, PAOs involved with the biological wastewater treatment process. The typical microbial processes occurring in the activated sludge system are as follows:

1. Growth and decay of ordinary heterotrophic organisms(OHOs)
2. Growth and decay of Methylophils;
3. Hydrolysis, adsorption, ammonification and assimilative denitrification;
4. Growth and decay of Ammonia Oxidizing Biomass (AOB);
5. Growth and decay of Nitrite Oxidizing Biomass (NOB);
6. Growth and decay of Anaerobic Ammonia Oxidizers (AAO), and;
7. Growth and decay of Phosphorus Accumulating Organisms (PAOs).

In the kinetic parameters, there are two additional categories; pH parameter and switching functions included [22]. Several previous studies have identified that the stoichiometric and kinetic parameters do not change dramatically for different systems treating municipal wastewater and default values can be used directly [24].

There are several sensitivity analyses have been conducted in order to identify the values for the parameters such as AOB Maximum specific growth rate, NOB maximum specific growth rate, OHOs maximum specific growth rate and Aerobic /Anoxic DO half saturation constant and noticed that it is necessary to make small adjustments on certain parameters in the model until results extracted from the model compare well with the proactive/measured data. During this analysis process, default values provided by Bio-Win software and engineering knowledge and experience have been used for the model calibration. The final calibrated kinetic parameters are shown in Table 6 below.

Table 6. Calibrated kinetic parameters.

Parameter	Calibrated value
AOB Maximum Specific Growth Rate	0.9
NOB Maximum Specific Growth Rate	0.7
OHOs Maximum Specific Growth Rate	3.2
Aerobic /Anoxic DO half saturation constant	0.25

The calibration of the Bio-Win model has been performed using a plant measured data obtained in January 2014 to October 2014 and then the model has been validated using the plant measured data from November 2014 to August 2015.

The dynamic analysis results of the model calibration with the statistical evaluations are shown in Figure 4 to Fig. 7. Figure 4 illustrates the comparison of measured and simulated values of effluent BOD under dynamic conditions while Fig. 5 illustrates comparison of measured and simulated values of effluent TSS under dynamic conditions. Figure 6 depicts comparison of measured and simulated values of effluent Total N under dynamic conditions while Fig. 7 depicts Comparison of measured and simulated values of effluent Total P under dynamic conditions. As shown in these figures, the 95% confidence interval of the measured effluent variables such as BOD, TSS, Total N and Total P have been calculated and included for each month. Then the values of effluent variables extracted from the dynamic analysis of the model have been compared with the measured values in the effluent. As shown in Figs. 4 to 7, the model values for BOD, TSS, Total N and Total P are included within the range of confidence interval calculated for their measured values. As highlighted by previous researchers, if output variables extracted from the analyses was included within the confidence interval estimated based on the measured values, the analysis/simulation was successful because there was no significant statistical difference between the analysed and measured value of the tested variable [25]. Based on the information, it can be concluded that the model calibration of the research work presented in this research has been completed successfully.

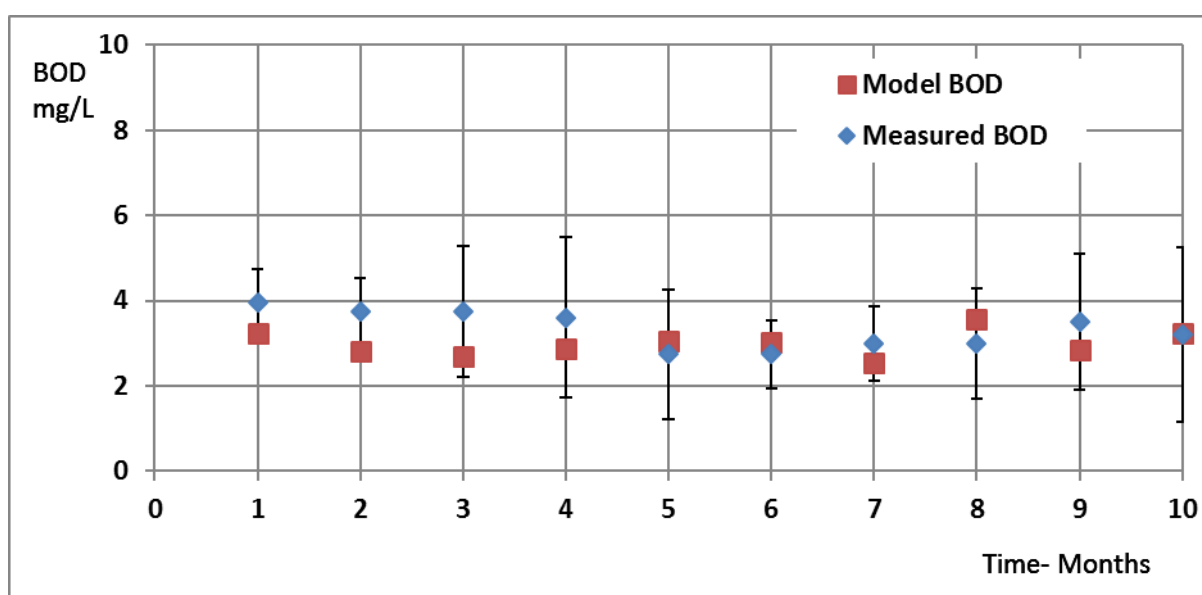


Fig. 4. Comparison of measured and simulated values of effluent BOD under dynamic conditions.

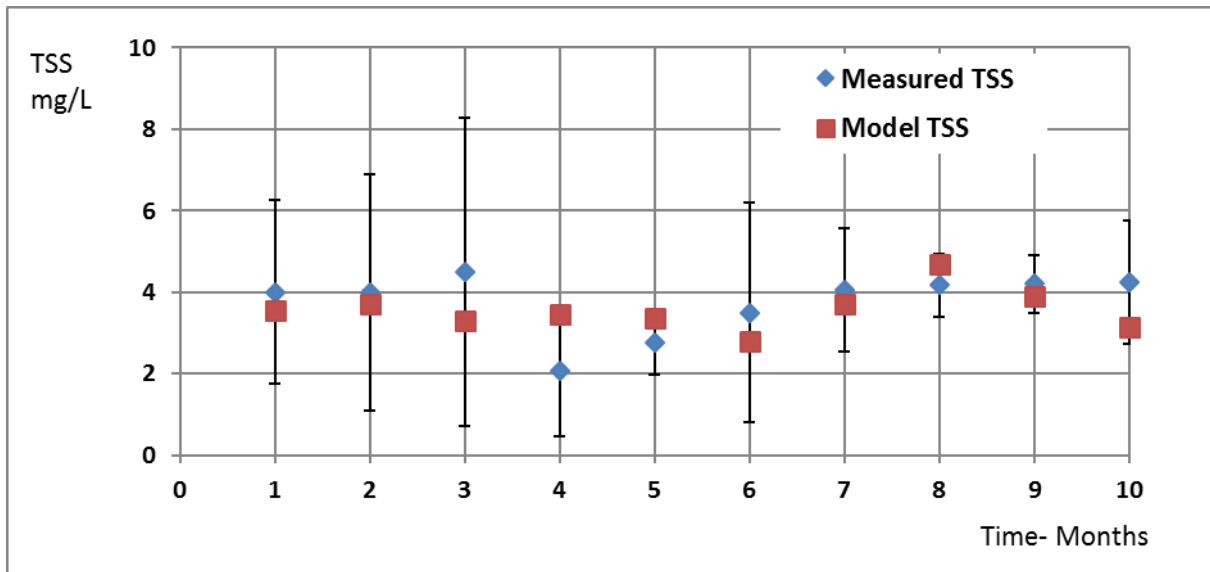


Fig. 5. Comparison of measured and simulated values of effluent TSS under dynamic conditions.

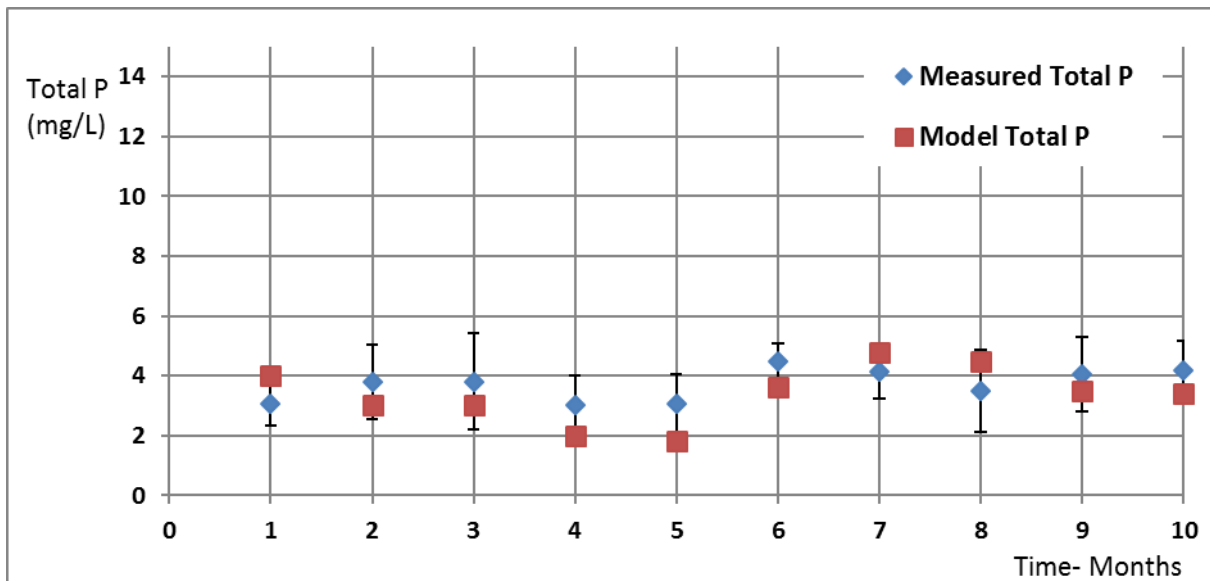


Fig. 6. Comparison of measured and simulated values of effluent Total N under dynamic conditions.

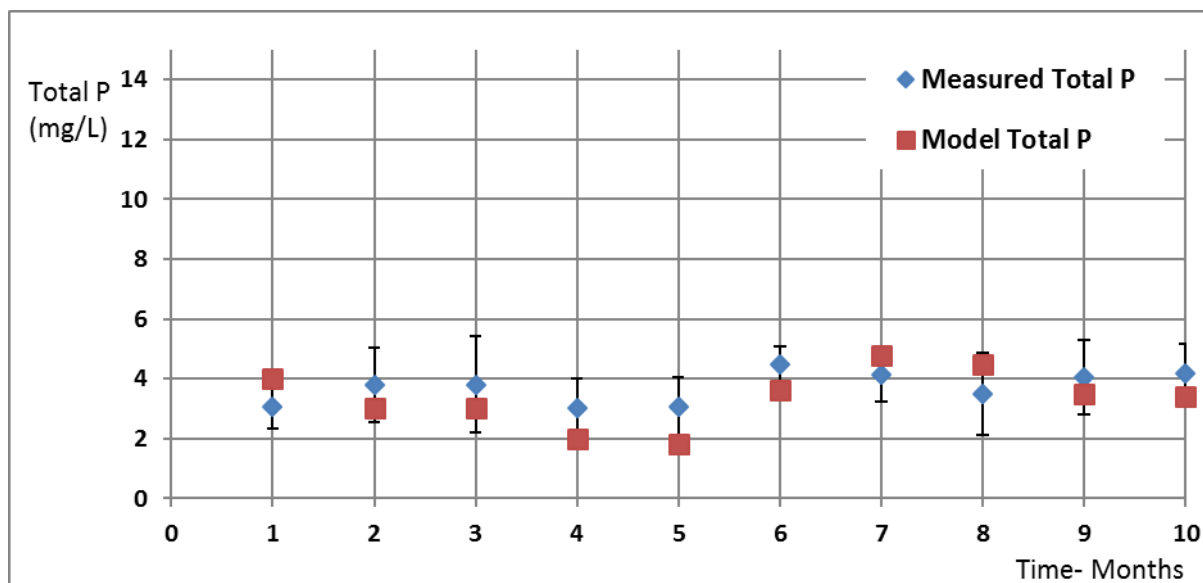


Fig. 7. Comparison of measured and simulated values of effluent Total P under dynamic conditions.

3.2. Model Validation

The time dependent (dynamic) analysis outputs of the calibrated mathematical model have been extracted and compared with the available pro-active (measured) data obtained from the Loganhome WWTP. Based on the availability of the data, two main comparison studies have been conducted such as (1) Outputs from the oxidation ditches and (2) Effluent of the treatment system. These comparison studies enabled to validate the mathematical model developed accurately and hence capture the real behaviours of the prototype (the WWTP). In these comparison studies, there are minor differences observed between variations of the pro-active and the analysis data extracted from the mathematical mode due to the facts listed below. As highlighted by Liwarska-Bizukojc et al. [11], the aim of the comparison between outcomes of the dynamic analysis and the proactive data of the research work presented in this paper is not to compare each value of the individual variable, but to compare the trend of the variable with the time.

- 1). Temporary problems in the aeration system,
- 2). Human and instrument errors involved during the measurements,
- 3). the ambient temperature changes occur during the treatment process affecting bacterial reactions,
- 4). Cleaning the treatment components resulting in adding extra water and chemicals and
- 5). Maintenance of several clarifiers of the WWTP as indicated in the WWTP database

3.2.1. Comparison Study of the oxidation ditches

As stated earlier, there are four oxidation ditches used in the WWTP and their MLSS (Mixed Liquor Suspended Solid) and ammonia nitrogen have been measured and hence they have been used for the comparison study conducted in the research work presented in this paper.

Figures 8(a) to 8(d) below show the comparison of MLSS in the oxidation ditches between the proactive data and the model.

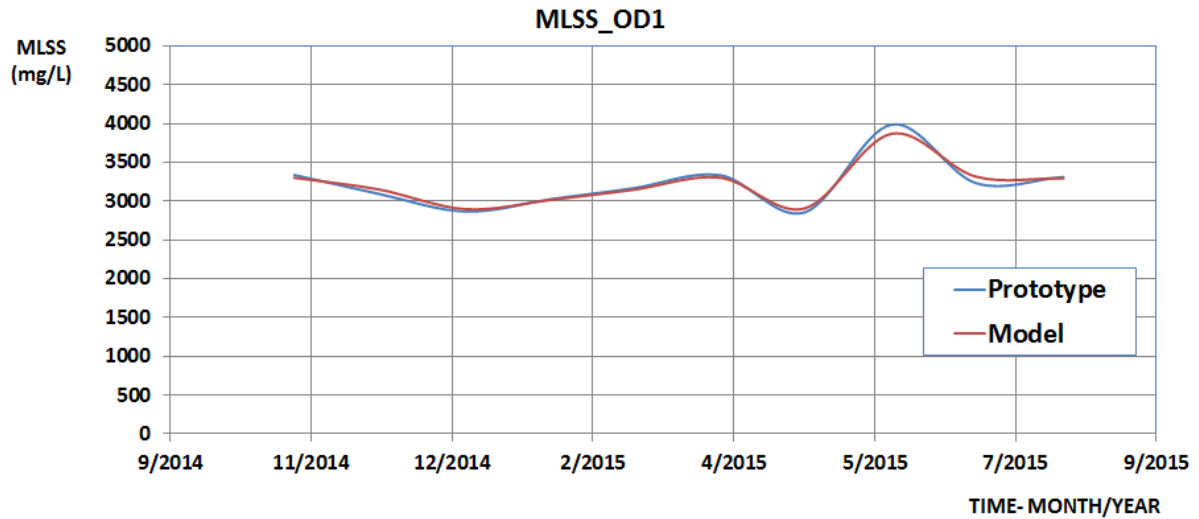


Fig. 8. (a) Variation of MLSS in the oxidation ditch 1 of the proactive data and the model.

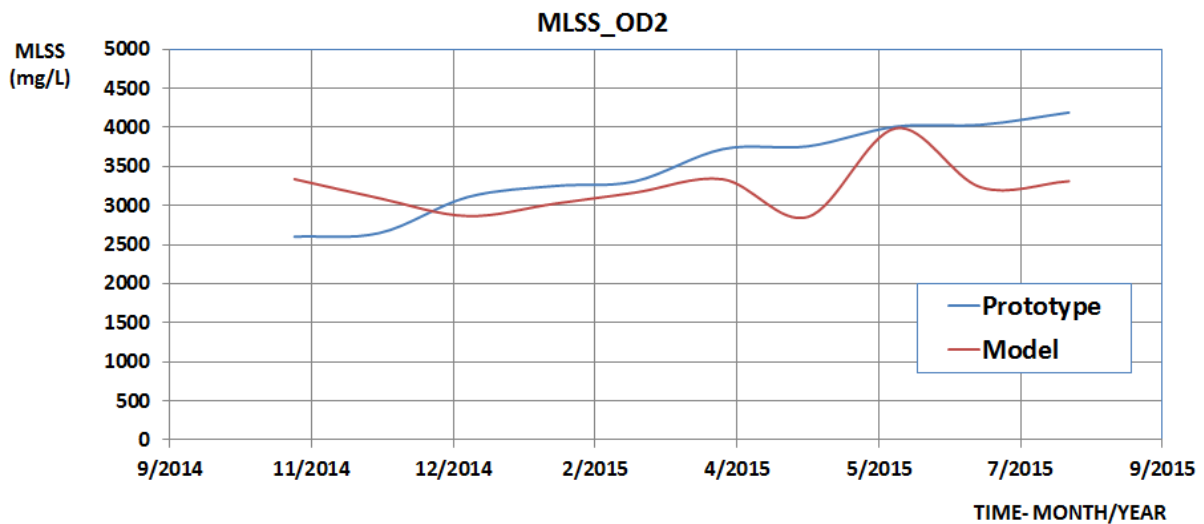


Fig. 8. (b) Variation of MLSS in the oxidation ditch 2 of the proactive data and the model.

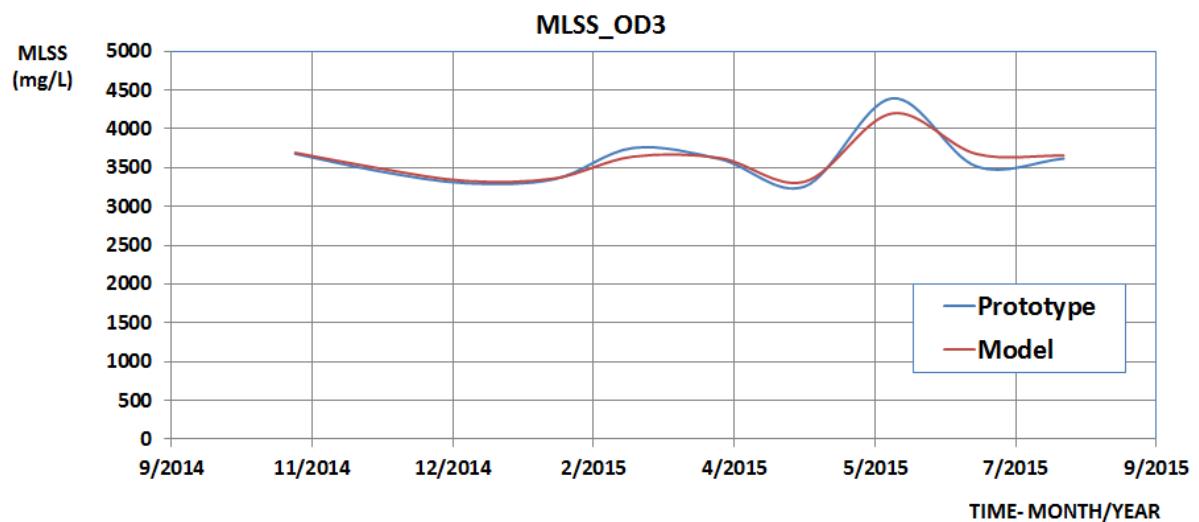


Fig. 8. (c) Variation of MLSS in the oxidation ditch 3 of the proactive data and the model.

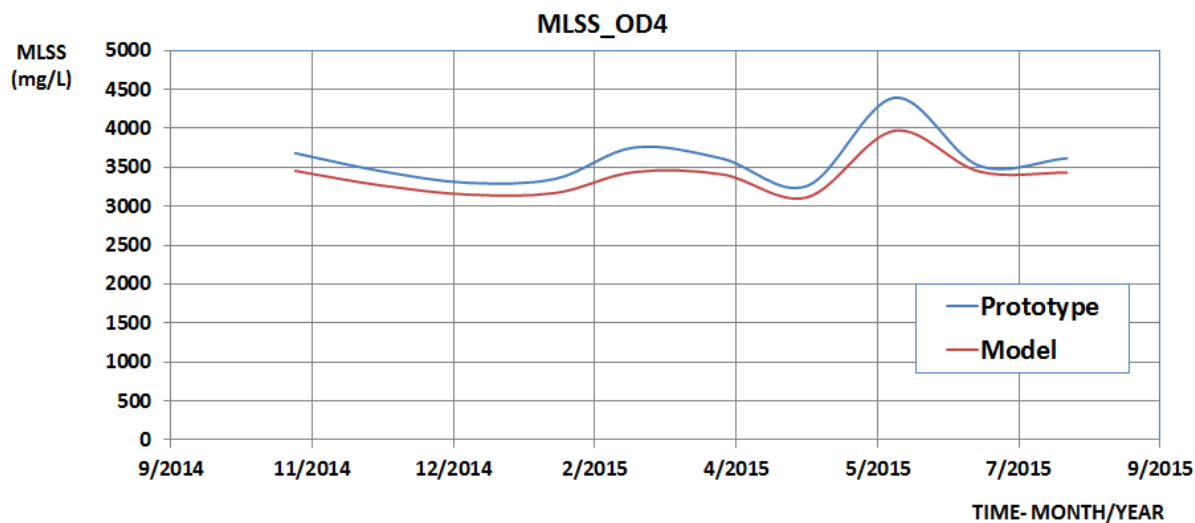


Fig. 8. (d) Variation of MLSS in the oxidation ditch 4 of the proactive data and the model.

According to Figs. 8(a) to 8(d) above, it can be noticed that the analysis and the pro-active data are compared very well as both follow the similar pattern. Further, it is also shown that the variations are below 5000mg/l which is within the acceptable limit as stated by Tchobanoglous et al. [25] It is also noticed that the variations in the Oxidation Ditches 1 and 2 of the prototype and the model are around between 2600 and 4100 while the variations in the Oxidation Ditches 3 and 4 of the prototype and the model are around between 3100 and 4400 due to the fact that the high wastewater amount flows into the Oxidation Ditches 3 and 4 compared to the others according to the arrangement of the systems as described earlier. This concludes that MLSS variation of the Oxidation ditches in the mathematical model is similar to the prototype.

Figures 9(a) to 9(d) depict the variations of ammonia nitrogen of the oxidation ditches in the prototype and the model.

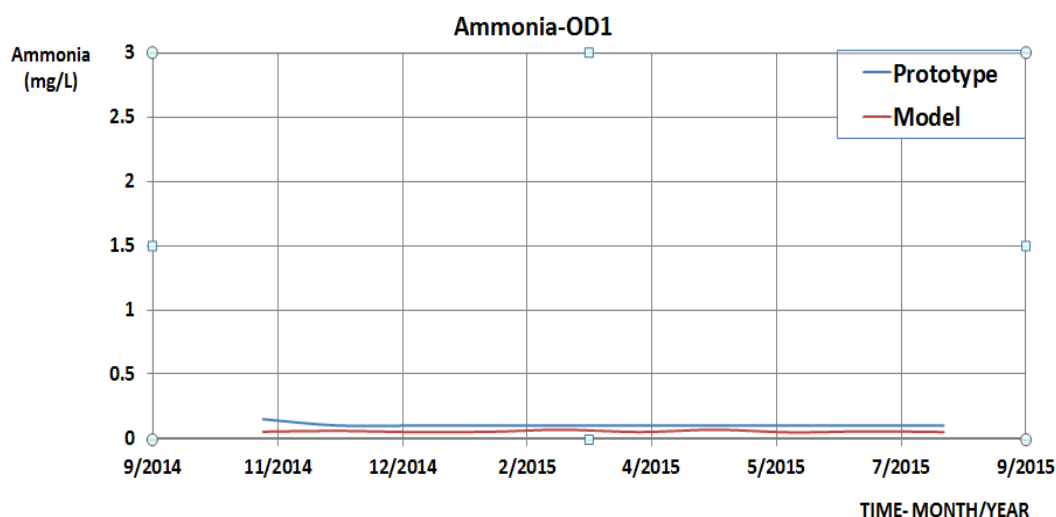


Fig. 9. (a) Variation of ammonia of the oxidation ditch 1 of the pro-active data and the model.

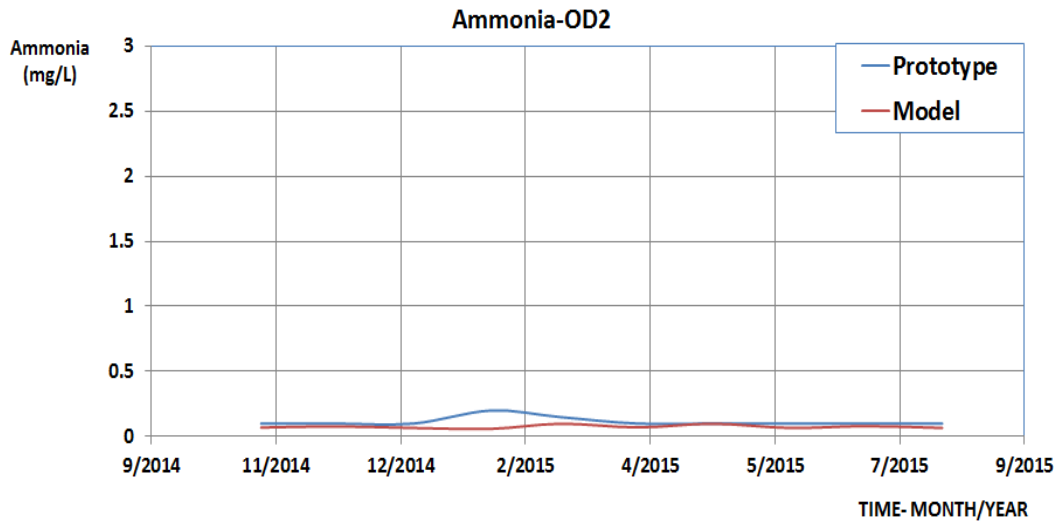


Fig. 9. (b) Variation of ammonia of the oxidation ditch 2 of the pro-active data and the model.

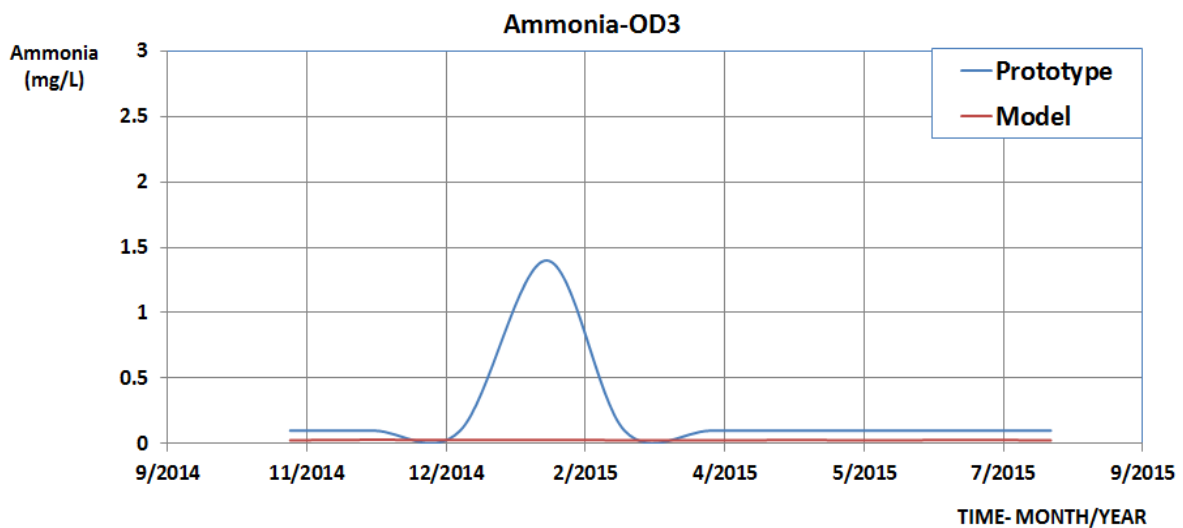


Fig. 9. (c) Variation of ammonia of the oxidation ditch 3 of the pro-active data and the model.

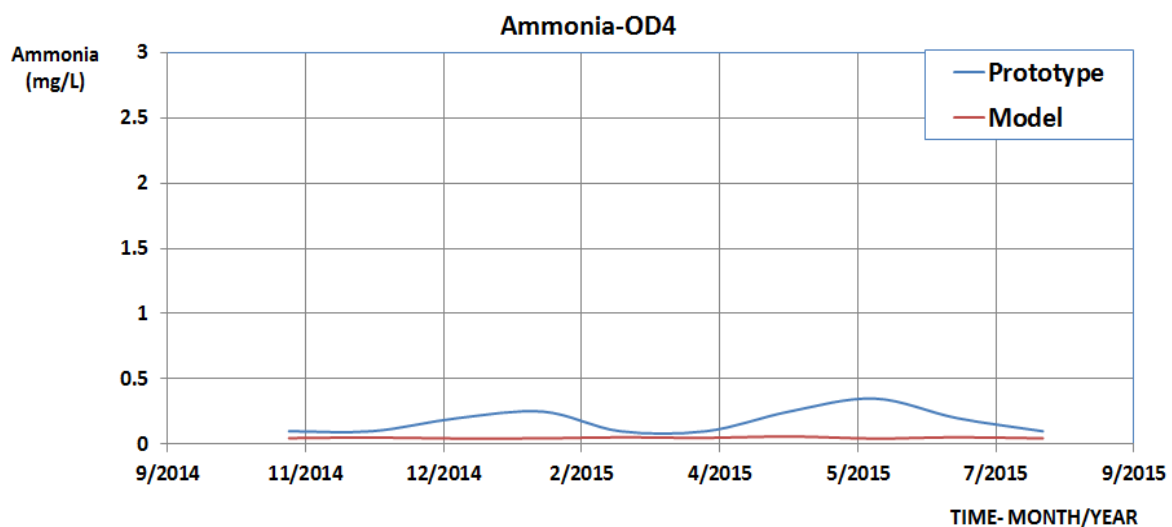


Fig. 9. (d) Variation of ammonia of the oxidation ditch 4 of the pro-active data and the model.

Figure 9 above shows that the variations of Ammonia of the Oxidation Ditches of the measured data and the analysis results extracted from the model. It is clear that these variations are compared very well

highlighting that the WWTP is working effectively during the time frame selected. The unusual ammonia concentration in the oxidation ditch 3 during January could be a temporary problem in the aeration system, an instrumental error or due to temperature changes. Based on the information presented, it can be concluded that the Oxidation Ditches in the model behave similar to the prototype.

3.2.2. Comparison between the effluent of the prototype and the mathematical model

The time dependent comparison study between the analysis outputs and the proactive/measured data of the effluent has been studied. In this comparison study, there are six parameters used such as 1). Influent and effluent flow, 2). Nitrogen(N), 3). Phosphorus(P), 4). Ammonia Nitrogen 5). Biochemical Oxygen Demand (BOD) and 6). Total Suspended Solid (TSS).

Figure 10 shows the comparison between the influent and the effluent flow of the model. As indicated in this figure, the effluent is slightly lower than the influent due to the fact that the solid component included in the influent is removed during the treatment process and the water can be lost/ evaporated during the treatment process. The flow rate during the period of March 2015 to May 2015 is much higher than the other time frame studied and due to the reasons stated earlier. Further, it is clearly indicated from this figure that the pattern/trend of the effluent follows the influent concluding that the model behaviours accurately.

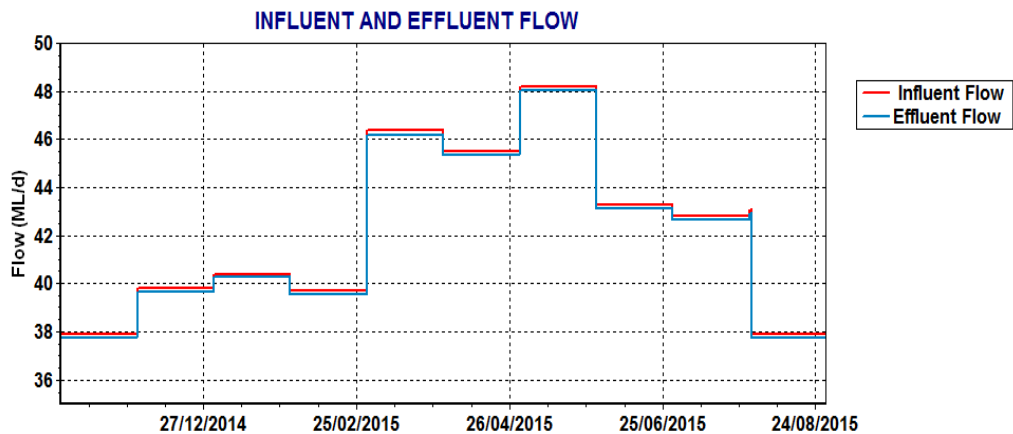


Fig. 10. Variation of influent and effluent flow.

Figure 11 below shows variation of nitrogen (N) of the effluent between the analysis output and the proactive data

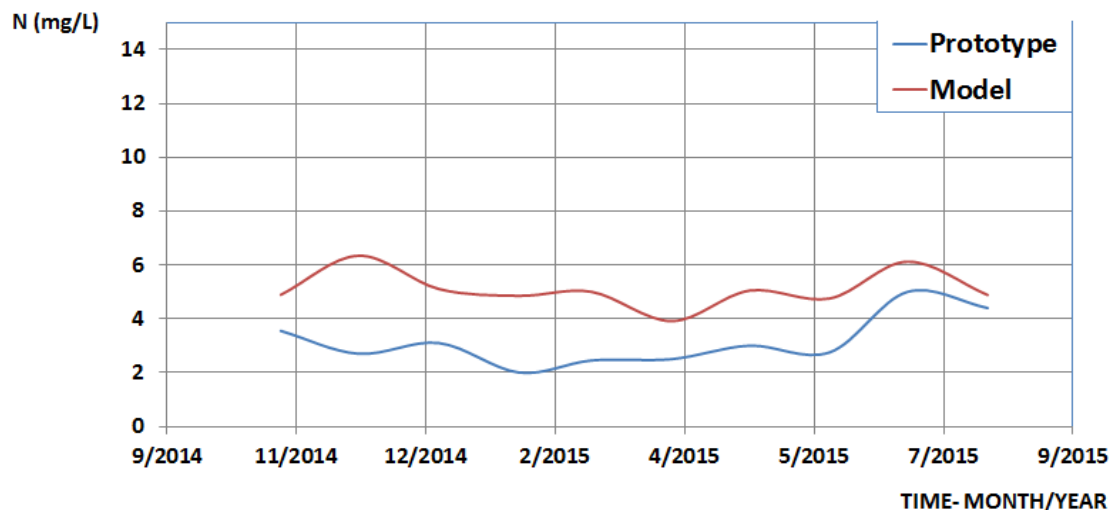


Fig. 11. Variation of nitrogen (N) in the effluent of the prototype and the model.

As indicated in Fig. 11 above, it is noticed that the variations of the prototype and the model are between around 2 and 6mg/L. The 95% confidence interval for the effluent N for each month has been calculated and noticed that it varies between 0.366 and 3.232. According to the literature [26] the maximum value of the Nitrogen for the WWTP studied in this research work needs to be 15mg/L and it is clear that the variations in the figure shown above is less than this value(15mg/L) concluding that the WWTP is efficiently working during the time frame studied. Further, Fig. 11 shows that the Nitrogen variation of the model and the proactive data is compared very well.

Figure 12 below shows variations of the phosphorus (P) of the Effluent in the model and the prototype.

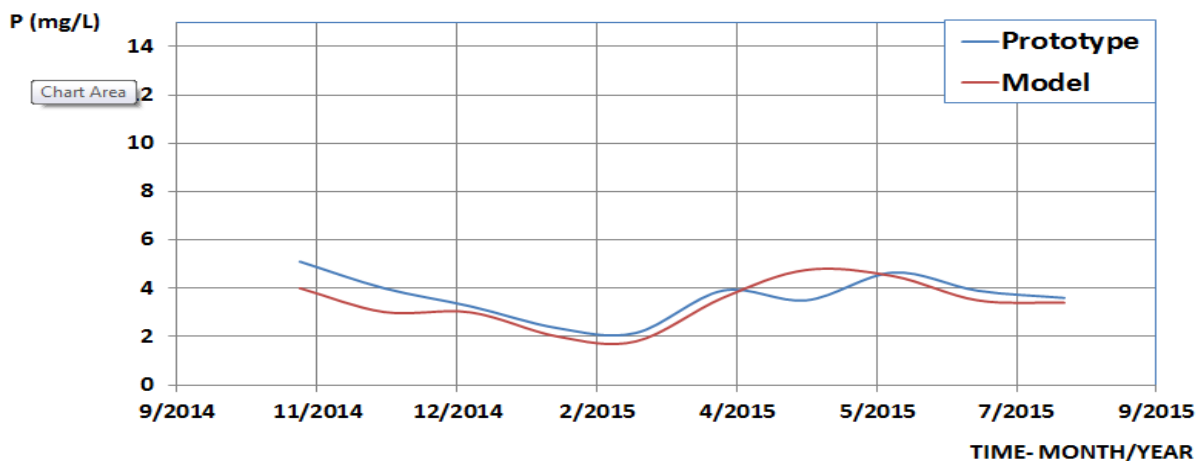


Fig. 12. Variation of phosphorus (P) in the effluent of the prototype and the model.

As shown in Fig. 12 above, it is clear that the variations of the prototype and model is around between 1.8mg/L and 5mg/L and the analysis and the pro-active data are compared very well as both follow the similar pattern. The 95% confidence interval for the effluent P for each month has been calculated and noticed that it varies between 0.464 and 2.350. Based on the literature [24] the variation of the WWTP studied in this research work requires to be less than 15mg/L and it is clear that the variations shown in the figure above is less than this value (15mg/L) highlighting that the WWTP is working efficiently when considering the overall behaviour of the plant during the time frame studied.

Figure 13 below shows variation of Ammonia Nitrogen in the Effluent of the prototype and the model.

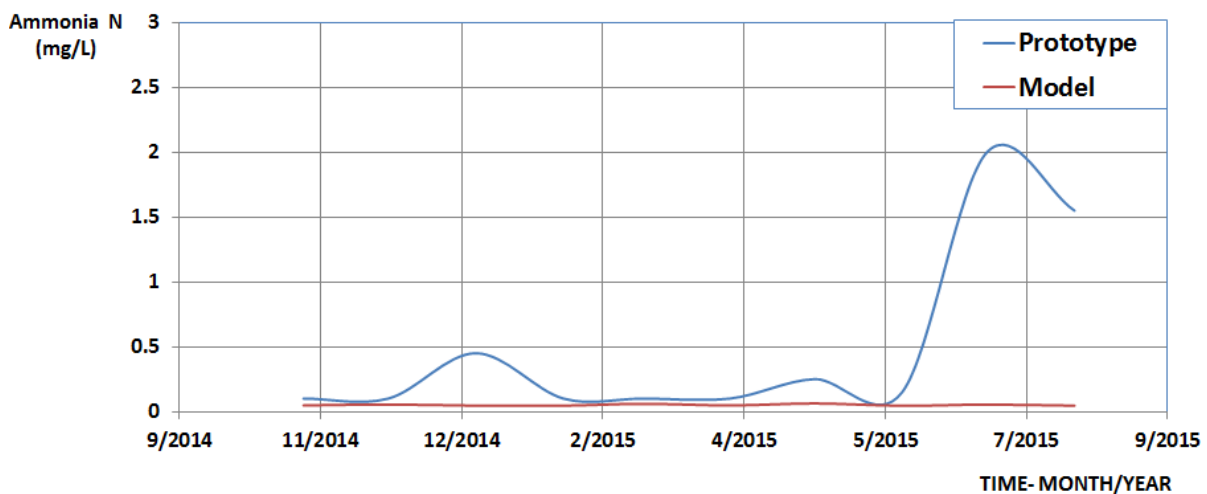


Fig. 13. Variation of ammonia in the effluent of the prototype and the model.

As illustrated in Fig. 13 above, the variations of the prototype and the model are mostly varying between 0.1 and 0.5mg/L except the last two months in the prototype. It can be due to a sudden change in the influent, a problem in the aeration system or an instrumental error. The 95% confidence interval for the effluent Ammonia for each month has been calculated and noticed that it varies between 0 and 0.692 (Except last two months). According to the literature [24] the maximum value for variation of Ammonia of the Effluent for the WWTP studied in this research work is required to be less than 3mg/L. As indicated in the figure above, the variations are less than 3mg/L and they are also compared very well. This concludes that the WWTP is effectively working during that time frame studied.

Figure 14 below shows the BOD variations in the Effluent of the prototype and the model.

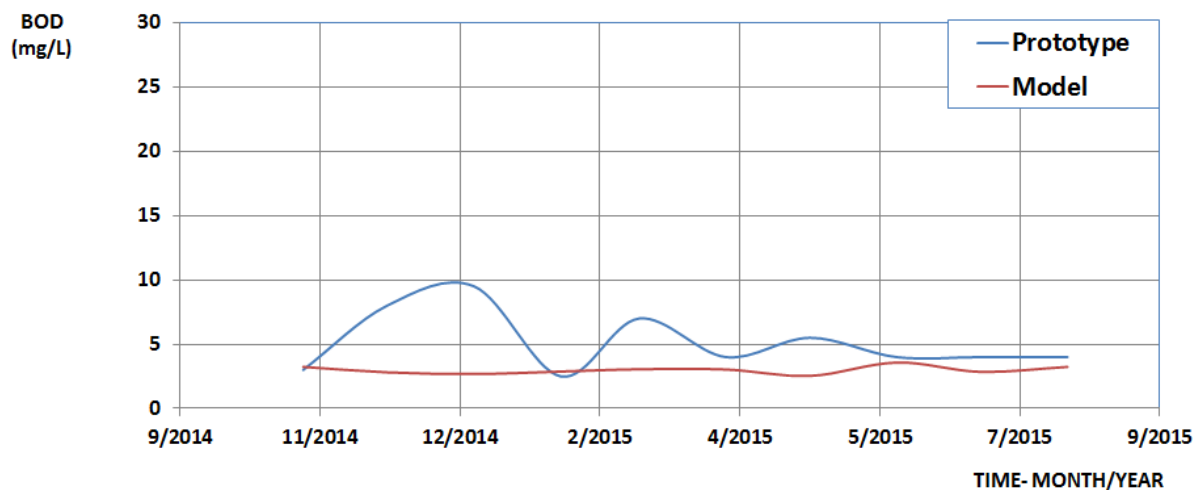


Fig. 14. Variation of BOD in the effluent of the prototype and the model.

As indicated in Fig. 14 above, the variations of the prototype and the model are between 3 and 10 mg/L. There is a high value (10mg/L) indicated on December 2014 in the prototype because of a sudden increase in industrial Wastewater or an aeration problem. The 95% confidence interval for the BOD for each month has been calculated and noticed that it varies between 0.795 and 4.444 (except December). According to the Literature [24] the maximum value for these variations of the WWTP studied in this research work needs to be less than 30mg/L and as indicated in the figure above, the variations are less than this value concluding that the WWTP is effectively working during the time frame studied. Further, according to the variations shown in the figure above, it is clear that there is good agreement between the outputs of the analysis model and proactive data.

Figure 15 shows the TSS variations in the Effluent of the prototype and the model. As indicated in this figure, the variations are between around 3 and 6mg/L which is within the acceptable limit (less than 30mg/L) as per the literature [24]. This concludes that during the time frame studied, the WWTP is working effectively. Moreover, the variation of the model is compared very well with the variation of the prototype data. Also, the 95% confidence interval for the TSS for each month has been calculated and noticed that it varies between 0.888 and 2.667.

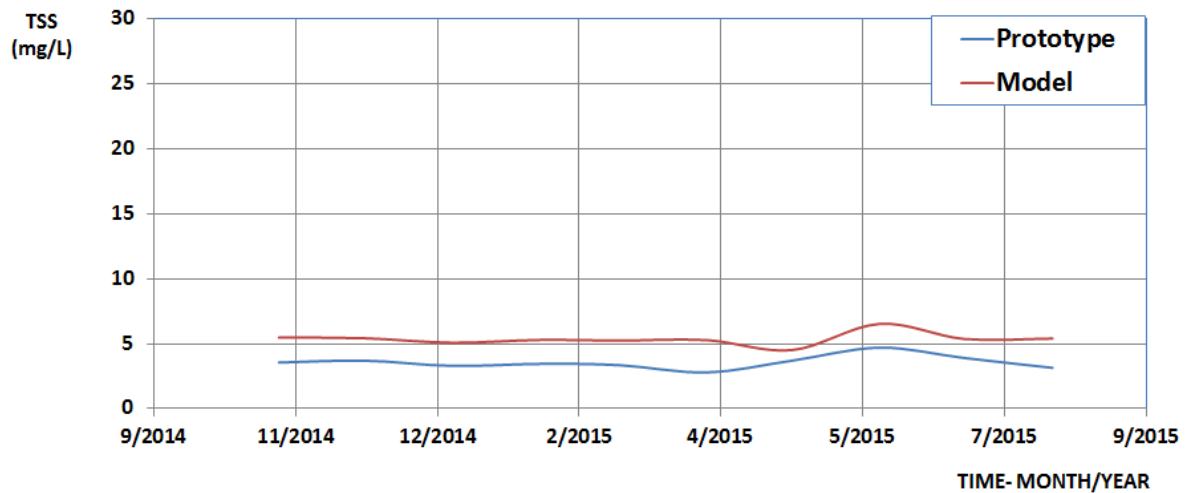


Fig. 15. Variation of TSS in the effluent of the prototype and the model.

Based on the information related to Figs. 8 to 15 above, it is clear that the variations extracted from the model developed are compared very well with the proactive/measured data of the WWTP. This concludes that the mathematical model is validated and hence can be used to simulate the behaviour of the prototype accurately. This validated mathematical model has then been used to study non-measured parameters of the WWTP.

3.3. Study Non-Measured Parameters in the WWTP Using the Validated Mathematical Model

The validated mathematical model has then been used to study non measured parameters of the WWTP. In this section, outcomes of this study have been presented. There are few parameters in the WWTP have been measured as presented earlier due to the cost and time constrains and after validating the mathematical model developed, the non-measured important effluent parameters such as Nitrate; N, Phosphate: P and Volatile Suspended Solid (VSS) can be extracted from the model. Figures 16 and 17 below show variations of Nitrate and Phosphate of the Effluent with the time frame extracted from the model respectively. These variations are very important in order to evaluate the effluent quality. Also these parameters are key components when evaluating the agricultural water quality due to the fact that they impact on yield and quality of crops, facilitate to improve the soil productivity and protection of the environment [27]. Figure 18 depicts variation of VSS of the effluent with the time frame extracted from the model. Wastewater operators are more interested in the VSS because it provides a good indication of how much organic matter is present in wastewater. It is primarily organic matter that can be converted and/or conditioned by the microorganisms. Also, before and after treatment, volatile solids determination may provide an indication of the treatment's effectiveness [28]. Study the non-measured parameters using the validated mathematical model is one of the main benefits in the research work presented in this paper.

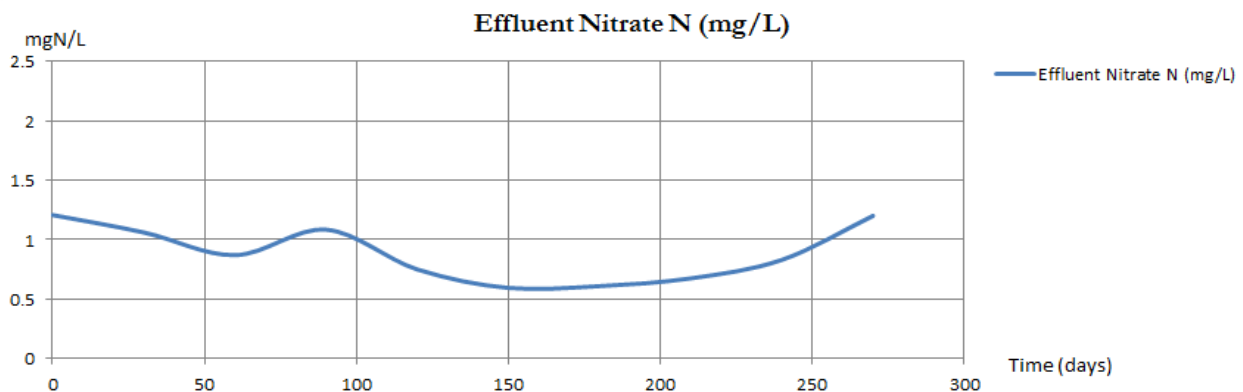


Fig. 16. Variation of nitrate in the effluent.

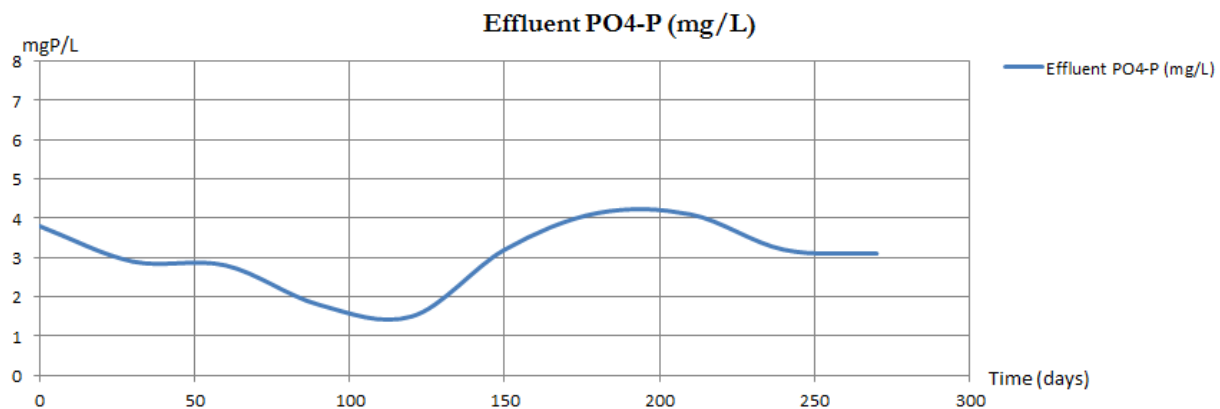


Fig. 17. Variation of phosphate in the effluent.

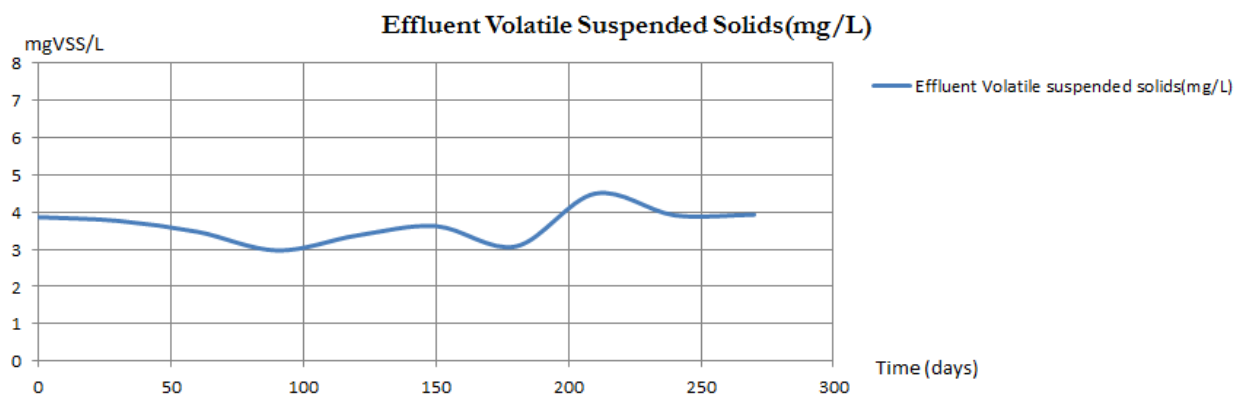


Fig. 18. Variation of VSS in the effluent.

4. Conclusions

In this research, a rigorous mathematical model for the WWTP located in the South East Queensland Australia has been developed using Bio-Win software and studied the time dependent behaviours of the treatment components in the WWTP and the effluent of the whole system. A comparison study between the measured data from the WWTP and the analysis data extracted from the model has been conducted and noticed that the measured and analysis data are compared very well. This research concludes the followings:

- 1) Bio-Win software is an effective tool to study the dynamic behaviour of WWTP;
- 2) The mathematical model developed in this research has been calibrated and validated and hence it can simulate behaviours of the prototype accurately;
- 3) The validated model has then been used to study the non-measured important parameters successfully; and
- 4) The validated model can be used to identify the most suitable way to upgrade the system of the WWTP. The research is being continued in this area.

5. References

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