DOI: https://doi.org/10.31686/ijier.vol4.iss11.5

Removal of wastes and Re-use of Treated water from Maturation Waste Stabilization Ponds (MWSPs)

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Abstract

This paper presents the results from a study conducted in Tanzania to develop a dynamic mathematical model, tool for the environmental pollution control. This led to Modelling Nitrogen Transformation, Removal and Re-use of Treated water from Maturation Ponds for agriculture and agriculture. The study was conducted at the wastewater treatment system located in Mabogini Moshi in Kilimanjaro Region, North Eastern Tanzania.

Introduction

This paper presents the results from a study conducted in Tanzania to develop a dynamic mathematical model, tool for the environmental pollution control. This led to Modelling Nitrogen Transformation, Removal and Re-use of Treated water from Maturation Ponds for agriculture and agriculture. The study was conducted at the wastewater treatment system located in Mabogini Moshi in Kilimanjaro Region, North Eastern Tanzania.

Nitrogen (N) is a key element in the aquatic media, soils, aquaculture and agriculture as an important management variable in the ecosystems. Excessive concentrations of nitrogen can cause detrimental effects to the quality of receiving water bodies; for example, lakes, rivers, springs, ponds and streams. This can result in growth of algal blooms which in turn decrease light penetration, photosynthesis and productivity. It can also cause loss of dissolved oxygen and eutrophication of receiving water bodies (Chale, 1987 and Paredes *et al.*, 2007). Furthermore, nitrogen can be toxic to aquatic species and human beings. Nitrogen nutrients are mainly accrued from domestic and municipal wastewater, urban run-off, agricultural and mining drainage and industrial inlets (Hammer, 1990; Sekiranda and Kiwanuka, 1998). Nitrogen compounds such as excessive ammonia and nitrates are among the toxic pollutants of wastewater which contaminate both surface and ground water bodies. A good example of a polluted receiving water body is Lake Victoria in North West Tanzania. The lake was until a few years ago heavily infested with water hyacinth (*Eichhornia crassipes*). Excessive nutrients in water bodies can be controlled through wastewater treatment by using waste stabilization ponds as well as wetlands to get clean water for re-use in the ecosystems.

Waste Stabilization Ponds (WSPs)

Waste Stabilization Ponds are one of the most effective non-conventional methods of wastewater treatment and especially in hot climates (Kayombo† *et al.*, 2000). This is due to their high efficiency in destroying pathogenic bacteria and the ova of intestinal parasites which are responsible for high level of human mortality and morbidity where domestic wastewater is not properly disposed off. The natural processes of stabilizing organic waste by bacterial oxidation, both anaerobic and aerobic to produce oxygen by algae in the pond through photosynthesis are fundamental in the treatment of wastewater by WSPs. The reasonably good quality of water from the stabilization ponds and constructed wetland outlet with some nutrients is an advantage for application in aquaculture, agriculture and forestation (Mbwette *et al.*, 2001). One potential use of treated wastewater is for aquaculture and particularly for Fish production (Yohana, 2009). Treated water re-use in aquaculture had received scientific attention in order to conserve water, provided that land is available for pond construction at reasonable cost, recycles nutrients to produce fish and also for safeguarding human health (Edwards, 1992).

Waste Stabilization Ponds (WSPs) wastewater treatment processes

Waste stabilization pond treatment processes are classified into Anaerobic, Facultative and Maturation ponds. WSPs utilize algae, bacteria and solar radiation as natural processes in breaking down the solids and conditioning the untreated wastewater as summarized in Figure 1.

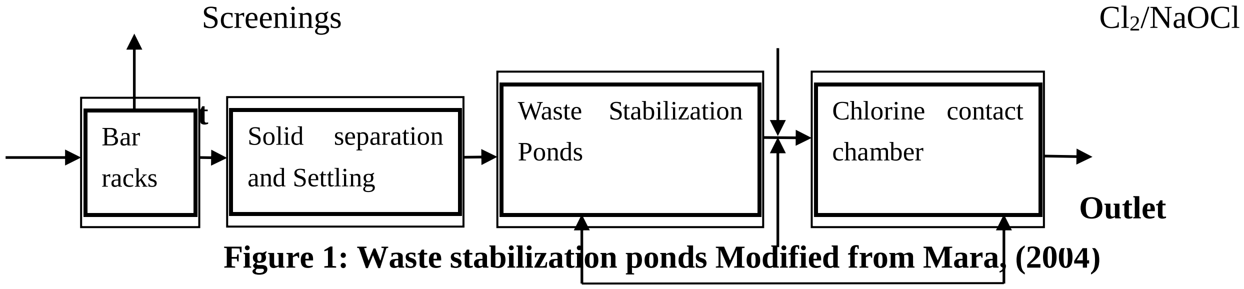


Figure 1: Waste stabilization ponds Modified from Mara, (2004)

(Source: Author, 2016)

The major problems with the operations of WSPs are the growth of algae and the nuisance from odours due to the production of methane (CH_4) and hydrogen sulphide (H_2S) gases. These problems can be mitigated by maintaining a minimum of 1 m up to 1.8 m water depth, limiting hydraulic loading time to two days and using rock filters or micro-strainers in WSPs.

Nitrogen Transformation Processes in WSPs

WSPs are wastewater treatment technologies whose application started in the 1960s and now it's nearly five decades, equivalent to 50 years of use. WSPs are large shallow basins in which raw sewage is treated by entirely natural process by both algae and bacteria (Kayombo† *et al.*, 1998). WSPs are most effective non-conventional method of domestic, industrial and agricultural wastewater treatment in developing countries especially in hot climates as well as in temperate countries. WSPs are classified into three types namely: (i) Anaerobic (ii) Facultative (iii) Maturation ponds in series (Mara and Cairncross, 1989).

Anaerobic WSPs are usually 2-5 m deep. They receive wastewater inlet that is high in organic matter loads greater than 100 g BOD/m^3.day which is equivalent to more than 3000 kg/ha.day for a depth of 3 m (Kayombo†, 2001). Anaerobic ponds do not contain dissolved oxygen or algae and Biochemical Oxygen Demand (BOD) removal is achieved by sedimentation of solids and anaerobic digestion in the resulting sludge. The anaerobic digestion process is more intense at temperatures above 15 $^{\circ}$C. The anaerobic bacteria are sensitive to pH<6.2 which entails the acidic wastewater to be neutralized prior treatment in anaerobic ponds. Anaerobic ponds can achieve about 40% removal of BOD at 10 $^{\circ}$C and more than 60% at 20 $^{\circ}$C with a short retention time of about 2-3 days which leads to facultative WSPs.

Facultative WSPs that are usually 1-2 m deep and are of two types' i.e. primary facultative ponds and secondary facultative ponds. Primary facultative ponds receive raw wastewater inlet and secondary facultative ponds receive particle-free wastewater. Secondary facultative ponds may receive particle-free wastewater from anaerobic ponds, septic tanks, primary facultative ponds and shallow sewerage systems. The processes of oxidation of organic matter by aerobic bacteria occur in primary and secondary facultative ponds. It is estimated that about 30% of the inlet BOD leaves the primary facultative pond in the form of methane gas (Marais, 1970). A high proportion of the BOD that does not leave the pond as methane ends up in algae. This process requires more wastewater retention time of 2-3 weeks. About 70% to 90% of the BOD in the final outlet from a series of WSPs is related to the amount of naturally growing algae in the pond. Secondary facultative ponds receive particle-free sewage (anaerobic outlet) and remaining non-settleable BOD is oxidized by heterotrophic bacteria *Pseudomonas, Flavobacterium, Archromobacter and Alcaligenes Spp.* (Marais, 1970 and Kayombo† *et al.*, 2003). Motile algae *Chlamydomonas* and *Euglena* pre-dominate the turbid water in facultative ponds. Oxygen required for oxidation of BOD is accrued from photosynthetic activity of micro-algae that grow naturally in the facultative ponds.

The algal concentration in the waste stabilization ponds depends on nutrient loading, temperature and sunlight range of 500-2000 μg chlorophyll-a/litre (Mara *et al.*, 1992; Cooper 1997 and Kayombo† *et al.*, 2003). Due to photosynthetic activities of facultative pond algae, there are diurnal variations in the dissolved oxygen (DO) concentration. The DO concentration in the wastewater gradually rises after sunrise, in response to photosynthetic activity, to a maximum level in the mid-afternoon and then falls to a minimum during the night. At this time, photosynthesis ceases and organisms respiration consume the oxygen (Kayombo† *et al.*, 2002). At the peak of algal photosynthetic activity, carbonate and bicarbonate ions react to provide more carbondioxide (CO_2) for algae, leaving an excess of hydroxyl ions (OH^-) in the wastewater. As a result, the pH of the wastewater can rise to above pH 9 which can kill the faecal coliforms (FC). Thus, the combined effects of changes in temperature, pH, light intensity and carbon dioxide influence photosynthesis, growth of microorganisms and bio-decomposition of organic matter. Thereafter, this influences the process of DO production and utilization in the secondary facultative WSPs which leads to maturation WSPs in series. Maturation WSPs (MWSPs) are 1.0 - 1.5 m deep and they receive the outlet from the facultative ponds (Kayombo†, 2001). MWSPs primary main function is to remove pathogens from the wastewater (Karim *et al.*, 2002). They are also well oxygenated throughout the day which contributes to nutrient removal and a small degree of BOD removal. The principal mechanisms for coliforms bacteria removal and die-off in facultative and maturation ponds increases with time, temperature, high pH>9, high light intensity combined with DO concentration (Kayombo†, 2001 & Mara, 2004). High pH values above 9 occur in MWSPs due to rapid photosynthesis by pond algae which consume CO_2 faster than it can be replaced by bacterial respiration which results in bicarbonate-carbonate ions dissociation equations (1.1) and (1.2):

$$2HCO_3^- \Rightarrow CO_3^{2-} + H_2O + CO_2 \quad (1.1)$$

$$2CO_3^{2-} + 4H_2O \Rightarrow 4OH^- + 2CO_2 + 2H_2O \quad (1.2)$$

The resulting CO_2 is fixed by the algae and then the hydroxyl (OH^-) ions accumulate thereby raising the pH to values above 10. The faecal coliforms bacteria with the exception of *Vibrio cholerae* die very quickly at the pH values higher than 9 (Pearson *et al.*, 1987b). High DO and high light intensity of wavelengths between 425-700 nm can damage faecal coliforms bacteria by being absorbed by the humic substances in the wastewater which is also enhanced at high pH values. Therefore, high light intensity in the sun plays three roles in promoting faecal coliforms bacterial removal in WSPs, increases the pond temperature and provides energy for rapid algal photosynthesis (Mara, 1997). To sum up, anaerobic and facultative ponds are designed for removal of BOD and MWSPs for pathogen removal. But also some pathogen removal in anaerobic and facultative ponds and some BOD removal occur in the MWSPs (Kayombo†, 1987; Mara, 1997; Kiwanuka & Kelderman, 2002). Anaerobic and facultative ponds are needed for BOD removal when the outlet is to be used for restricted crop irrigation and Fish Pond fertilization. This also implies that when weak sewage is to be treated prior to its discharge to surface water bodies. MWSPs are required when the outlet is to be used for unrestricted irrigation. This has to comply with the World Health Organization (WHO, 1989, 2004 and 2006) guidelines of < 1000 faecal coliforms bacteria/100 ml wastewater. Thus, the performance of WSPs may be measured in terms of BOD, nutrients and faecal coliforms bacteria removal.

Nutrients removal in waste stabilization ponds (WSPs)

In anaerobic WSPs, organic nitrogen is hydrolyzed to ammonia (NH_3) which makes the outlet to have higher concentrations of ammonia than in the raw sewage. In facultative and MWSPs, ammonia is incorporated into algal biomass. At higher than pH 9 values, ammonia leaves the pond through volatilization. There is little evidence of nitrification and hence denitrification, unless the wastewater has a high nitrate content (Mara, 1997). This is because the population of nitrifying bacteria is low due to lack of physical attachment sites in the aerobic zone. Total nitrogen and ammonia removal from WSPs can reach 80% and 90%, respectively. Phosphorus removal in WSPs is associated with uptake by algal biomass, precipitation and sedimentation. Mara (1997) suggested that, the best way to remove much of the phosphorus in the wastewater by WSPs is to increase the number of MWSPs. However, both nitrogen and phosphorus nutrients must be removed to prevent eutrophication and toxicity in the receiving water bodies and the end users.

Sampling and Model Development in Maturation Waste Stabilization Ponds (MWSPs)

Sampling and analysis

Grab samples were collected on daily basis for three months between August and April October 2010 at the inlet and outlet of MWSPs The samples were analyzed in water quality laboratory for Biological Oxygen Demand (BOD_5), Total Kjeldahl Nitrogen (TKN), Organic Nitrogen (Org-N), Ammonia Nitrogen (NH_3-N), Nitrate Nitrogen (NO_3-N), Nitrite Nitrogen (NO_2-N), Chlorophyll-a, Nitrogen in the Sediments (N-Sedim), Total Suspended Solids (TSS), Turbidity and the Faecal Coliforms (FC) using Standard Methods of the examination of Water and Wastewater Analysis (APHA, 2005). *In-situ* measurements of pH, Temperature, DO were done using Multi-parameters Portable Spectrophotometer (model 156, 2001).

Ecological Model Development in MWSPs and Mathematical equations

The assumptions behind ecological modelling come from advances in population growth, urbanization and technological development that have had an increasing impact on the environment. Some pollutants are released into ecosystem which may cause species damage or diseases to man. Thus, models are the synthesis of what is known about the ecosystem with reference to the problem under consideration. For instance, Eutrophication, that is excessive Nitrogen and Phosphorus Nutrients in the lake, what components interact, like zooplankton grazes on phytoplankton and which processes can be formulated into mathematical equations for the processes with reference to the problem to solve under the study. Stella II software (STELLA ® 9.1.4) can be utilized to carry on the modelling process and the differential equations for the state variables. The differential equations for the state variables, the nitrogen transformation and removal rates in MWSPs are presented in equations (1.3) to (1.5):

$$d\frac{(Org-N)}{dt} = \frac{Q_i}{V}(Org-N)_i - \frac{Q_e}{V}(Org-N) - r_m - r_s + r_1 + r_2 \quad \text{.....................(1.3)}$$

$$d\frac{(NH_3-N)}{dt} = \frac{Q_i}{V}(NH_3-N)_i - \frac{Q_e}{V}(NH_3-N) - r_1 + r_m + r_v \quad \text{.........................1.4)}$$

$$d\frac{(NO_3-N)}{dt} = \frac{Q_i}{V}(NO_3-N)_i - \frac{Q_e}{V}(NO_3-N) - r_n + r_2 + r_d \quad \text{.........................(1.5)}$$

Where: Q_i = inlet flow rate (m^3/d); Q_e = outlet flow rate in (m^3/d); V= volume of the pond in (m^3); r_m = mineralization rate (mg/l/d); r_s = Sedimentation rate; r_n = nitrification rate (mg/l.d); r_1 = uptake rate of NH_3-N by micro-organisms; (mg/l/d); r_2 = uptake rate of NO_3-N by microorganisms (mg/l/d); r_v = volatilization rate (mg/l/d) and r_d =denitrification rate (mg/l/d).

Development of conceptual diagram of nitrogen transformation and removal in MWSPs

The conceptual diagram Figure 2 indicates N-transformation, material inflows, abbreviated as ("i") and outflows ("e"). The state variables in MWSPs include Organic Nitrogen (Org-N), Ammonia Nitrogen (NH_3-N), Nitrate Nitrogen (NO_3-N), Nitrogen biomass (N-Biomass) and Nitrogen in the sediments

(N-Sedim) following the studies of (Bacca & Arnett, 1976; Fritz *et al.*, 1979; Farrara & Hermann, 1980; USEPA, 1985; Mara, 1997; Jørgensen *et al.*, 1991; Halling-Sørensen, 1995; Mbwette *et al.*, 2001; Kayombo† *et al.*, 2002; Epworth, 2004; Camargo & Mara, 2005).

The processes in the model for inflow and outflow rates of materials in the MWSPs include nitrification, denitrification, ammonia volatilization, uptake of ammonia and nitrates by micro-organisms, sedimentation and regeneration. Ammonia volatilization is the removal of dissolved ammonia gas diffusion and mass transfer from water to the atmosphere at the water-air interface. The aforementioned process depends on wind mixing conditions, high around pH (10.5-11.5) and high temperatures (25-35 in WSPs.

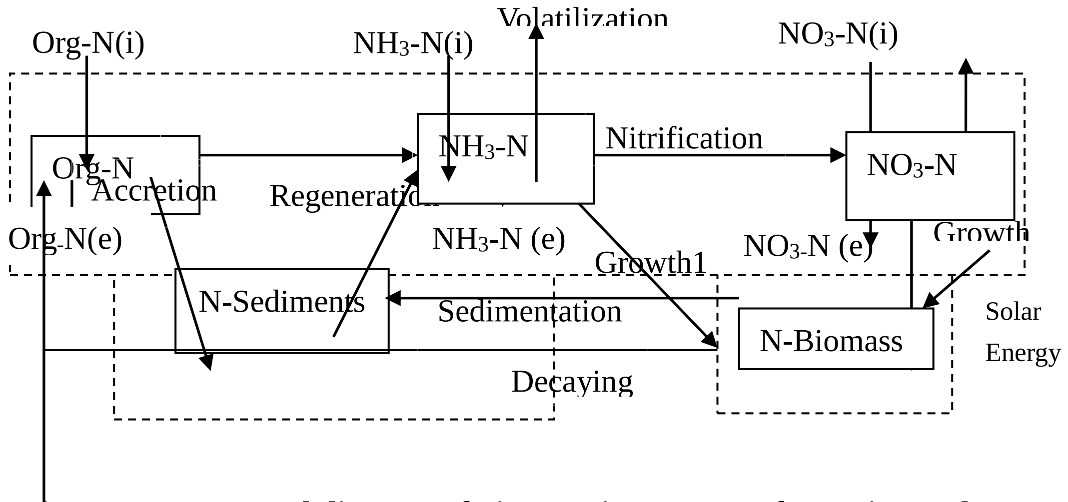


Figure 2: Conceptual diagram of nitrogen inputs, transformation and removal in MWSPs
(Source: Author, 2016)

The boxes represents the state variables, arrows show nitrogen flow pathways and dashed lines indicate three sectors/compartments of the conceptual diagram.The MWSPs ecosystem is divided into three of water column, sediments layer and the biomass or living micro-organisms as indicated by the dashed lines in the conceptual diagram.

The Computer Model of Maturation Waste Stabilization Ponds (MWSPs) is presented in Figure 3.

Model simulations and results from MWSPs

Modelling of nitrogen inputs, transformation and removal in the MWSPs was done by using STELLA II Software (STELLA II ® 9.1.4). The data were processed by using fourth-order Runge-Kutta with four approximations incorporated in the Software that ensures accuracy and precision. STELLA II Software Computer Programme Models contain five main components namely the State Variables, Forcing Functions, Processes, Mathematical Equations and the Reaction Rates.

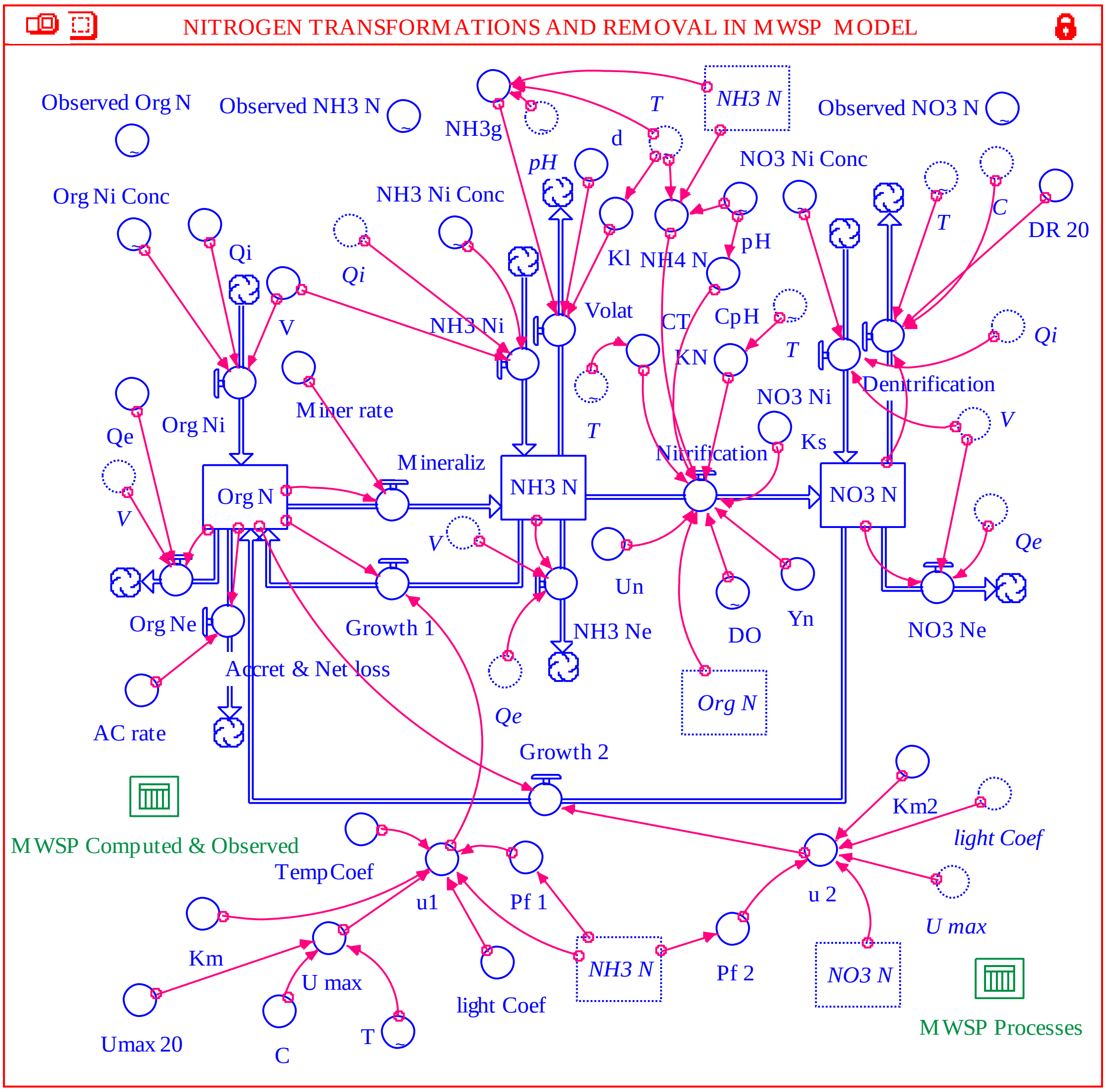
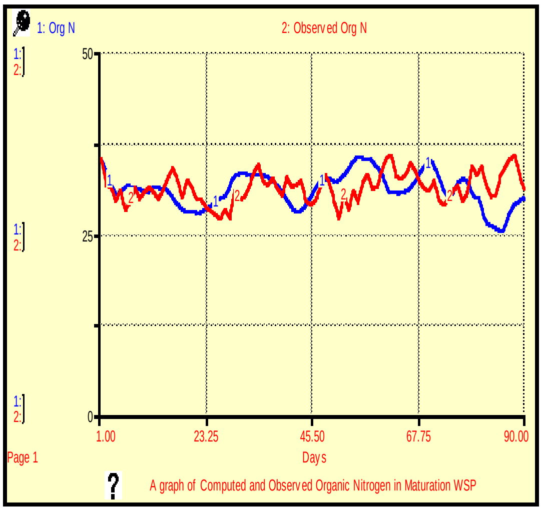


Figure 3: Conceptual Model of Maturation Waste Stabilization Ponds (MWSPs)

(Source: Author, 2016)

The Simulated and Measured/observed value of Org N, NH_3-N, and NO_3-N in MWSPs together with their correlation are as shown Figures 3 (a, b and c).



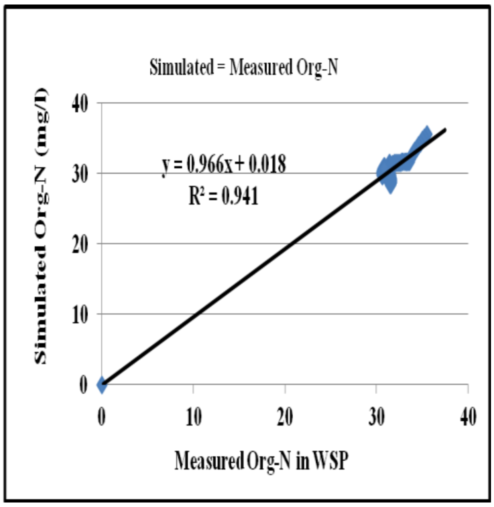


Figure 3 (a): Correlation between Simulated and Measured Org-N in MWSP with R^2 =0.941

Source: This Study

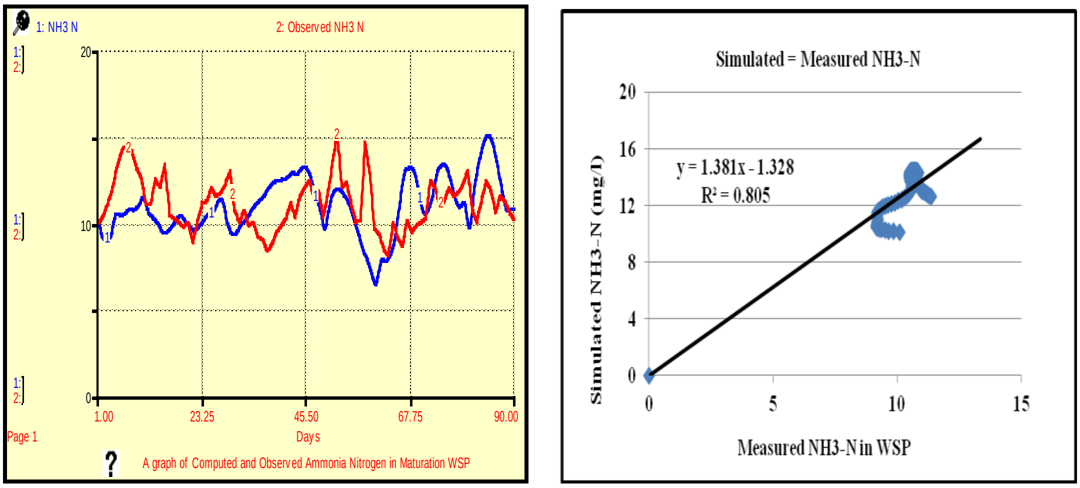


Figure 3 (b): Correlation between Simulated and Measured NH_3-N in MWSP with R^2 = 0.805

Source: This Study

The simulated values of Org-N, NH_3-N and that of NO_3-N in MWSP agree well with the measured values as seen from the correlation regression analysis (R^2) that ranged from 0.805 to 0.941 in Figures 3 (a, b and c).

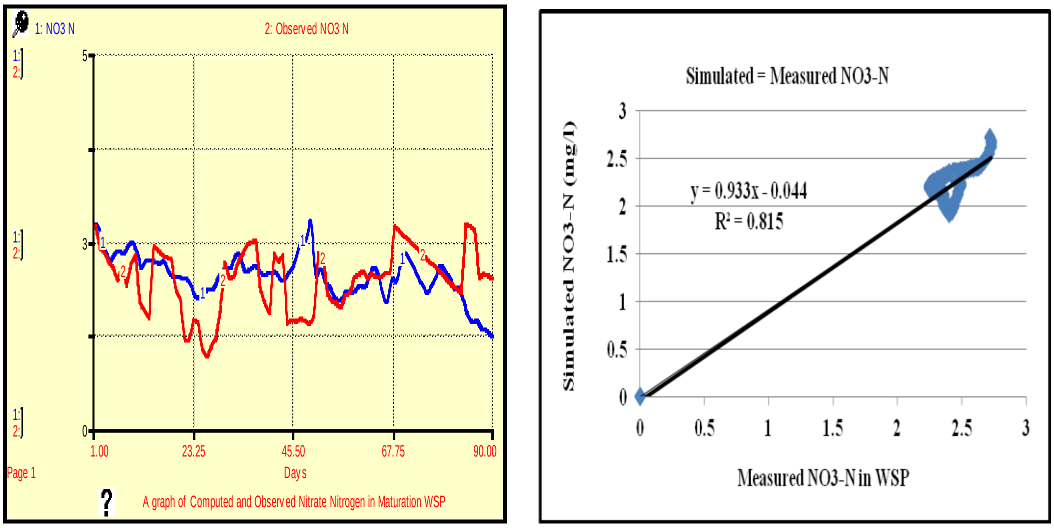


Figure 3 (c): Correlation between Simulated and Measured NO_3-N in MWSP with R^2 = 0.815

Source: This Study

From Figures 3 (a-c), there was good agrrement (R^2) between observed value and simulated value which indicate that the model develped gives nitrogen transformation and removal in MWSPs.

Discussion of Nitrogen Mass Balance in MWSPs

Figure 4 shows mass balance in MWSPs. Accretion and net loss of organic nitrogen to the sediment was the major removal of nitrogen from the pond followed by denitrification. The two processes account for 40.94% (22.37 kg/d) removal of the inflow nitrogen (57.07 kg/d) to the MWSPs. The major processes of nitrogen transformation in MWSPs was found to be uptake of Ammonia Nitrogen by microorganisms (22.07 kg/d). Nitrates uptake in the second route accounted for only (1.87 kg/d).A similar study carried on Primary facultative waste stabilization ponds (Senzia, 1999) indicated that sedimentation was also the major route in permanently removing nitrogen from the pond.

The major mechanisms of nitrogen dynamics in MWSPs were through the uptake of ammonia nitrogen by the algae, accretion and net loss, nitrification, denitrification and mineralization. Ammonia nitrogen uptake by the micro-organisms was the dominant route for nitrogen transformation and accounted for an average of 44.11% in Figure 4. This explains an increased growth of algae in the pond system. Nitrate uptake was not significant in the MWSPs system.

The second route for nitrogen transformation was nitrification that accounted for 18.32% while, mineralization was the third route that transformed 15.10% in MWSP. Thus, the total nitrogen transformed in the pond system accounted for **77.53%**. These results were in accordance with the literature findings of other researchers (Fararra & Avci, 1982; Reed, 1985; Senzia, 1999 and Mara, 2004). The total nitrogen inflows of 106.52 kg/d minus outflows 106.45 kg/d is equal to 0.07 kg/d thus accounting for about 0.1% errors that may be brought about by improper calibration of the field instruments as well as the measurements of the nitrogen compounds by the laboratory instruments/equipments.

On the other hand, the major nitrogen removal routes were found to be through accretion and net loss to the sedimen **19.66kg/d** ification. Accre **36.65kg/d** gen to the se **0.76kg/d** **9.94kg/d** .66% while denitrification removed 8.81% thus tota NH_3-N (i) om MWSPs NO_3-N (i) **.47%**. Volatilization of ammonia gas from the pond system did not account for any nitrogen removal. This might have been due to the low NH_3-N and a near neutral pH 7.69 in the MWSPs system. The removed nitrogen from MWSPs agrees well with observations of Camargo and Mara (2005). The summary of the average flows and mass balance of nitrogen transformed and removed from the MWSPs are presented in Figures 4 and 5, respectively. Nitrogen mass balance in the MWSPs shows that the calculations made by the model follow the mass conservation principle that is *"mass is neither created nor destroyed during the course of a chemical reaction"*. **Mass of Reactants = Mass of Products** (Jørgensen and Fath, 2011). However, in practice there may be more nitrogen outputs due to excretion from the migratory animals visiting the pond. Figure 4 and 5 presents the results of Nitrogen Mass Balance in MWSPs in kg/d and in percentages, respectively.

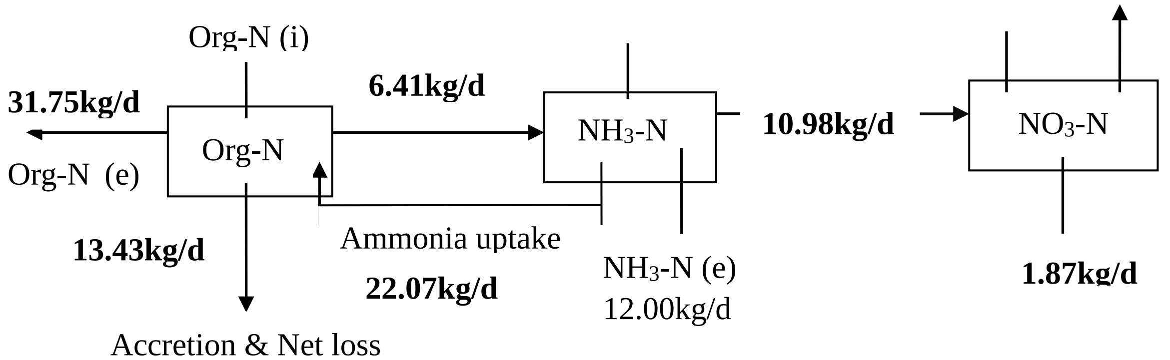


Figure 4: Nitrogen Mass Balance in Maturation Waste Stabilization Ponds (MWSP)

(Source: This study)

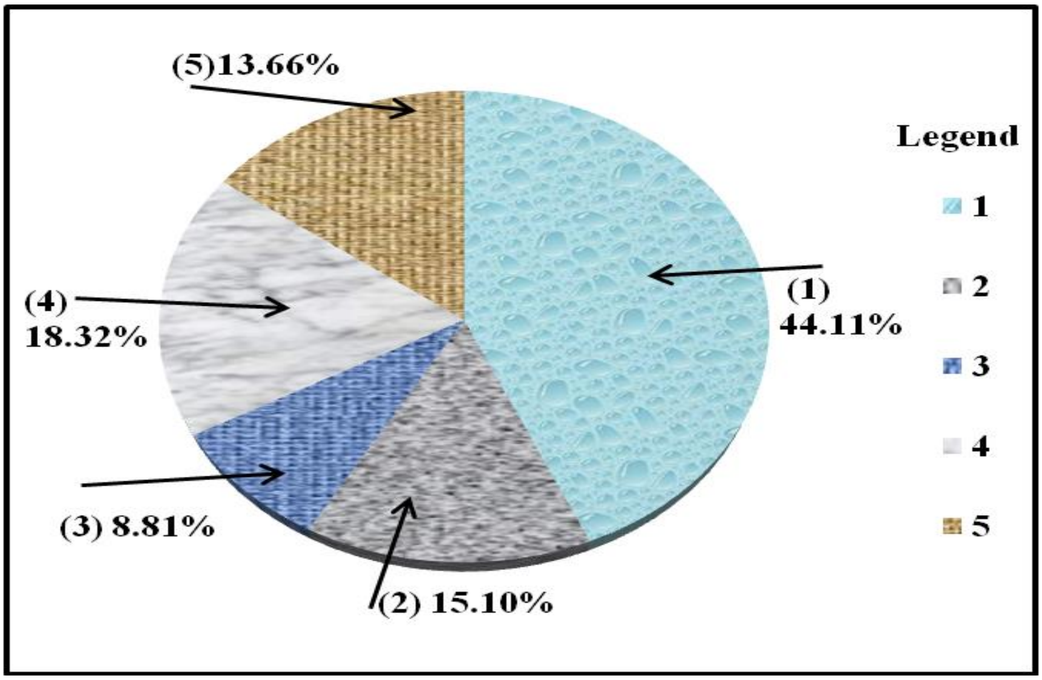


Figure 5: Percentage N-transformation and removal from MWSP

(Source: This study)

In Figure (4.31), the numbers represent the following: (1) Ammonia uptake by micro-organisms, (2) Mineralization of Org-N to NH_3-N, (3) Denitrification of NO_3-N to N_2 gas, (4) Nitrification, (5). Accretion of Nitrogen to the sediments.

Quality of the MWSP Model Developed

The Observed values were compared to computed modelled state variables as presented in Table 1 which gives correlation between the computer calibrated and measured (R^2) as well as the correlation equations.

Table 1: Correlations between Measured and Computer Modelled State Variables in MWSP

S/No	State Variables	Correlation equations	R^2
1	Organic Nitrogen (**Org-N in MWSP**)	y= 0.966x + 0.018	**0.941**
2	Ammonia Nitrogen (**NH_3-N in MWSP**)	y= 1.381x – 1.328	**0.805**
3	Nitrate Nitrogen (**NO_3-N in MWSP**)	y= 0.933x – 0.044	**0.815**
	TOTAL (R^2)		**0.854 (85%)**

(Source: This Study)

Correlation between the Observed and Measured State Variables gave a good agrrement with the total value regression analysis (R^2) of more than 85%.

Sensitivity Analysis of selected MWSP Model parameter rates and state variables

Sensitivity analysis follows verification (Jørgensen & Fath, 2011). Sensitivity analysis confirm how much the important state variables change if the parameter rates such as mineralization, nitrification, denitrification, sedimentation, uptake rates or forcing functions are changed for instance by 10% (0.1). Table 2 gives the sensitivity analysis of some selected parameter rates and state variables in the developed MWSP.

The results of the sensitivity analysis in MWSP show that Org-N mineralization rate was sensitive to NH_3-N by a value of 5.14 changes, but with negative effects to the other state variables. NH_3-N nitrification rate was sensitivite to NO_3-N by a value of 7.86. NH_3-N and NO_3-N uptake by biota in MWSP was sensitive to Org-N by a value of 6.69 and to NO_3-N by 5.08. The net loss of Org-N to the sediments was sensitive to NH_3-N by a value of 0.09.

Table 2: Sensitivity analysis of some selected parameter rates and some state variables

State Variables / Parameter rates	**Org-N**	**NH_3-N**	**NO_3-N**
Mineralization	29.73	11.07	1.22
	-4.19	5.38	1.33
	-1.41	**5.14**	**-0.9**
Nitrification (U_n)	29.73	11.07	1.22
	33.08	11.97	0.26
	-1.13	**-0.81**	**7.86**
Denitrification	29.73	11.07	1.22
	29.73	11.07	4.44
	0	**0**	**-26.39**
NH_3-N &NO_3-N uptake	29.73	11.07	1.22
	12.8	34.57	0.6
	6.69	-21.23	5.08
Net loss to sediments	29.73	11.07	1.22
	34.35	10.03	1.38
	-1.55	**0.09**	**-1.31**

(Source: This Study)

Nitrification rate, NH_3-N and NO_3-N uptake by biota and Org-N mineralization rate were highly sensitive signify good water quality with enough dissolved oxygen for the micro-organisms activities in MWSP. These parameters are very important for the evaluation and monitoring in order to maximize the performance in the ecosystems.

MWSP Model Validation

The MWSP model was tested (validated) using the independent set of data collected from different ecosystem. There were good agreements between simulated and measured data as they can be seen in Figure 6. The selected state variables for model validation were nitrate nitrogen (NO_3-N) in Maturation Waste Stabilization Pond (MWSP). This NO3-N was randomly selected for model validation to represent the other two state variables in the MWSP since they behave the same way otherwise it could be the repetitions of the same activity.

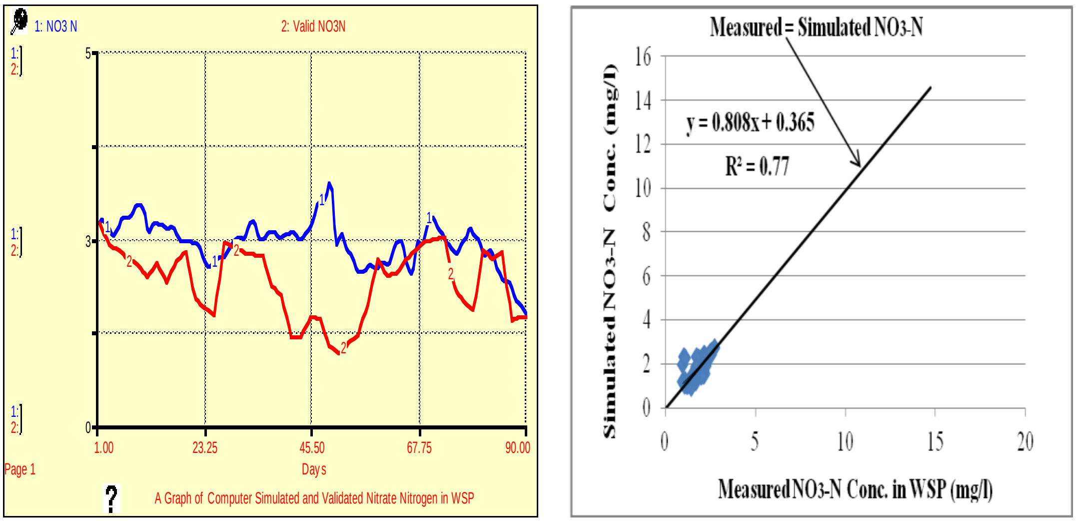


Figure 6: Validated Simulated and Measured NO_3-N Concentration in MWSP
(Source: This Study)

Model application and limitations

The developed MWSP model can be applied for the estimation of nitrogen transformation, removal and re-use in Maturation Waste Stabilization Ponds (MWSPs) in Tropical climatic regions. The treated water may be re-used in the integrated aquaculture and agricultural irrigation for recycling of the nutrients. The model application requires the inflow concentrations of organic nitrogen (Org-N), ammonia nitrogen (NH_3-N) and nitrate nitrogen (NO_3-N) as the major state variables. The temperature, pH, Dissovled Oxygen (DO) and Solar Energy as the external functions as well as volume/area, water depth, inflow and outflow rates are also required. Once this information is available, the knowledge and skills of a computer programme Stella II Software is crucial for integration of the differential equations provided in (**Appendix 1)**. The graphical option menu in Stella Software allows a maximum selection of five (5) variables at a time in choosing any state variables or mathematical equation processes to be simulated by the computer programme. The MWSP model can be used as an Environmental management tool to monitor the performance, productivity and pollution effects in the environment in the hot climatic regions.

Conclusions and Recommendations

Conclusions

1. The MWSP dynamic mathematical model developed achieved a value R^2 of more than 85% which was tested by fitting the simulated and measured values which resulted a good linear correlations as seen in Table 1 and Figures (3 a, b and c), respectively.

(2) The total amount of N-transformed was **77.53%**, while amount of **22.47%** nitrogen was removed from the MWSP ecosystem.

(3) Sensitivity analysis of the MWSP Model for the selected rates and state variables by a change of 10% (0.1), revealed Org-N mineralization rate was by a value of 5.14 to NH_3-N, but with negative effects to the other state variables. NH_3-N nitrification rate was sensitivite to NO_3-N by 7.86. NH_3-N and NO_3-N uptake by biota was sensitive to Org-N by 6.69 and to NO_3-N by 5.08 as the major sensitive parameters. These are important parameters for growth and development in the ecosystem.

(4) The developed MWSP Model can answer the environmental management questions when the forcing functions such as concentration and the forcing functions change.

Recommendations

(i) Other researchers can use the developed dynamic MWSP mathematical Model to solve Environmental pollution problems such as eutrophication and toxic heavy metals and monitor the MWSP ecosystems when the concentration or the forcing functions change;

(ii) This dynamic mathematical model can be used by water engineers to design MWSP in similar climatic conditions as well as the water managers and policy makers for decision making;

(iii) Further research on nitrogen and phosphorus removal levels as well as toxic heavy metals in the re-used outlet should be carried out to safeguard the health of the end users.

Acknowledgement

The author wish to thank all those who helped in accomplishing this research and thank the family, relatives and friends for their understanding and untiring material and moral support.

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Appendix 1

MUWSA MWSPs Mathematical equations written by Computer STELLA Software

NH_3_N(t) = NH_3_N(t - dt) + (NH_3_Ni + Mineraliz - NH_3_Ne - Volat - Nitrification - Growth_1) * dt

INIT NH_3_N = 10.1

INFLOWS:

NH_3_Ni = NH_3_Ni_Conc*(Qi/V)

Mineraliz = Org_N*Miner_rate

OUTFLOWS:

NH_3_Ne = NH_3_N*(Qe/V)

Volat = (Kl/d)*NH_3g

Nitrification = Un/Yn*(NH4_N/(KN+NH_4_N))*(DO/(Ks+DO))*CT*CpH*Org_N

Growth_1 = (u1*Org_N)

INFLOWS:

NO_3_Ni = NO_3_Ni_Conc*(Qi/V)

Nitrification = Un/Yn*(NH_4_N/(KN+NH_4_N))*(DO/(Ks+DO))*CT*CpH*Org_N

OUTFLOWS:

NO_3_Ne = NO_3_N*(Qe/V)

Growth_2 = u_2*Org_N

Denitrification = NO_3_N*DR_20*C^(T-20)

INFLOWS:

Org_Ni = Org_Ni_Conc*(Qi/V)

Growth_2 = u_2*Org_N

Growth_1 = (u1*Org_N)

OUTFLOWS:

Mineraliz = Org_N*Miner_rate

Org_Ne = Org_N*(Qe/V)

Accret&Net_loss = Org_N*AC_rate

CpH = IF(pH<7.2)THEN(1-(0.833*(7.2-pH)))ELSE(1.0)

CT = EXP(0.098*(T-15))

d = 1.5

DR_20 = 0.90

Kl = 0.0566*EXP (0.13*(T-20))

Km = 2

KN = 10^(0.051*T-1.58)

KNO_2 = 0.3

Ks = 1.3

Light_Coeff = 1.0

Miner_rate = 0.15

n = 0.4

NH_3g = NH_3_N/(1+10^(10.5-0.032*T-pH))

NH_4_N = NH_3_N/(1+10^(pH-10.05+0.032*T))

N_Plankton = N_Planktons*1000

Pf_1 = IF(NH_3_N>0)THEN(1)ELSE(0)

Pf_2 = IF(NH_3_N=0)THEN(1)ELSE(0)

Qe = 1000

Qi = 1000

TempCoef = 1

u1 = u_max*(NH_3_N/(Km+NH_3_N))*light_Coef*TempCoef*Pf_1

Umax_20 = 0.8

Un = 0.006

U_max = Umax_20*C^(T-20)

U_max20 = 0.3

V = 3600

Yn = 0.13

DO = GRAPH (time)

(1.00, 2.76), (2.00, 2.37), (3.00, 2.28), (4.00, 2.42), (5.00, 2.79), (6.00, 2.57), (7.00, 2.35), (8.00, 2.76), (9.00, 2.61), (10.0, 2.77), (11.0, 2.59), (12.0, 2.71), (13.0, 2.68), (14.0, 2.58), (15.0, 2.61), (16.0, 2.72), (17.0, 2.55), (18.0, 2.39), (19.0, 2.41), (20.0, 2.51), (21.0, 2.62), (22.0, 2.27), (23.0, 2.31), (24.0, 2.43), (25.0, 2.53), (26.0, 2.36), (27.0, 2.63), (28.0, 2.52), (29.0, 2.64), (30.0, 2.59), (31.0, 2.67), (32.0, 2.78), (33.0, 2.73), (34.0, 2.32), (35.0, 2.35), (36.0, 2.45), (37.0, 2.49), (38.0, 2.46), (39.0, 2.51), (40.0, 2.49), (41.0, 2.48), (42.0, 2.47), (43.0, 2.52), (44.0, 2.62), (45.0, 2.66), (46.0, 2.61), (47.0, 2.67), (48.0, 2.65), (49.0, 2.71), (50.0, 1.21), (51.0, 3.01), (52.0, 1.42), (53.0, 2.01), (54.0, 1.21), (55.0, 1.25), (56.0, 1.29), (57.0, 1.33), (58.0, 1.38), (59.0, 1.42), (60.0, 1.46), (61.0, 1.51), (62.0, 1.55), (63.0, 1.58), (64.0, 1.62), (65.0, 1.66), (66.0, 1.71), (67.0, 1.74), (68.0, 1.78), (69.0, 1.81), (70.0, 1.85), (71.0, 1.89), (72.0, 1.93), (73.0, 1.97), (74.0, 2.02), (75.0, 2.06), (76.0, 2.11), (77.0, 2.14), (78.0, 2.18), (79.0, 2.15), (80.0, 2.12), (81.0, 2.11), (82.0, 2.07), (83.0, 2.09), (84.0, 2.04), (85.0, 2.06), (86.0, 2.02), (87.0, 1.09), (88.0, 1.05), (89.0, 1.01), (90.0, 1.04)

pH = GRAPH(TIME)

(1.00, 7.92), (2.00, 8.25), (3.00, 8.21), (4.00, 8.22), (5.00, 8.15), (6.00, 8.08), (7.00, 8.21), (8.00, 8.12), (9.00, 7.95), (10.0, 7.94), (11.0, 9.92), (12.0, 7.78), (13.0, 7.73), (14.0, 7.85), (15.0, 7.82), (16.0, 7.83), (17.0, 7.88), (18.0, 7.89), (19.0, 7.44), (20.0, 7.45), (21.0, 7.35), (22.0, 7.54), (23.0, 7.51), (24.0, 7.51), (25.0, 7.53), (26.0, 7.79), (27.0, 7.41), (28.0, 7.71), (29.0, 7.68), (30.0, 7.73), (31.0, 7.31), (32.0, 7.94), (33.0, 7.83), (34.0, 7.79), (35.0, 7.29), (36.0, 7.31), (37.0, 7.31), (38.0, 7.94), (39.0, 7.92), (40.0, 7.96), (41.0, 7.93), (42.0, 7.82), (43.0, 7.84), (44.0, 7.75), (45.0, 7.68), (46.0, 7.64), (47.0, 7.74), (48.0, 7.79), (49.0, 7.83), (50.0, 7.88), (51.0, 7.92), (52.0, 7.97), (53.0, 8.01), (54.0, 8.05), (55.0, 8.08), (56.0, 8.13), (57.0, 8.17), (58.0, 8.15), (59.0, 8.49), (60.0, 8.12), (61.0, 8.23), (62.0, 8.17), (63.0, 7.98), (64.0, 7.95), (65.0, 7.92), (66.0, 7.82), (67.0, 7.76), (68.0, 7.72), (69.0, 7.67), (70.0, 7.61), (71.0, 7.56), (72.0, 7.53), (73.0, 7.51), (74.0, 7.55), (75.0, 7.59), (76.0, 7.62), (77.0, 7.66), (78.0, 7.71), (79.0, 7.75), (80.0, 7.78),

(81.0, 7.84), (82.0, 7.89), (83.0, 7.93), (84.0, 7.99), (85.0, 8.06), (86.0, 8.11), (87.0, 7.37), (88.0, 7.35), (89.0, 7.31), (90.0, 7.33)

T = GRAPH (TIME)

(1.00, 27.4), (2.00, 27.5), (3.00, 27.2), (4.00, 27.1), (5.00, 27.2), (6.00, 27.3), (7.00, 27.6), (8.00, 27.7), (9.00, 27.9), (10.0, 26.9), (11.0, 26.8), (12.0, 26.3), (13.0, 25.7), (14.0, 26.6), (15.0, 26.2), (16.0, 26.8), (17.0, 25.9), (18.0, 26.1), (19.0, 26.9), (20.0, 26.3), (21.0, 26.4), (22.0, 25.6), (23.0, 24.6), (24.0, 24.4), (25.0, 24.9), (26.0, 24.3), (27.0, 24.2), (28.0, 25.1), (29.0, 24.5), (30.0, 25.2), (31.0, 24.9), (32.0, 25.2), (33.0, 24.9), (34.0, 23.6), (35.0, 24.1), (36.0, 24.2), (37.0, 24.4), (38.0, 24.1), (39.0, 24.4), (40.0, 25.2), (41.0, 25.1), (42.0, 24.8), (43.0, 24.6), (44.0, 25.1), (45.0, 25.2), (46.0, 26.3), (47.0, 26.8), (48.0, 26.9), (49.0, 29.4), (50.0, 24.1), (51.0, 24.5), (52.0, 25.4), (53.0, 24.1), (54.0, 24.4), (55.0, 24.7), (56.0, 24.9), (57.0, 26.5), (58.0, 24.6), (59.0, 26.3), (60.0, 27.5), (61.0, 26.3), (62.0, 28.9), (63.0, 29.4), (64.0, 28.1), (65.0, 23.6), (66.0, 23.1), (67.0, 27.6), (68.0, 24.1), (69.0, 26.4), (70.0, 27.1), (71.0, 26.1), (72.0, 25.8), (73.0, 24.7), (74.0, 24.9), (75.0, 23.6), (76.0, 24.7), (77.0, 25.1), (78.0, 26.2), (79.0, 25.5), (80.0, 26.3), (81.0, 24.6), (82.0, 26.8), (83.0, 24.5), (84.0, 23.1), (85.0, 22.5), (86.0, 23.5), (87.0, 24.7), (88.0, 24.3), (89.0, 24.3), (90.0, 22.6)

Org_Ni_Conc = GRAPH (time)

(1.00, 14.2), (2.00, 20.1), (3.00, 15.3), (4.00, 18.4), (5.00, 21.7), (6.00, 21.9), (7.00, 17.7), (8.00, 18.5), (9.00, 17.3), (10.0, 15.4), (11.0, 21.4), (12.0, 21.3), (13.0, 20.4), (14.0, 21.6), (15.0, 19.5), (16.0, 16.9), (17.0, 17.4), (18.0, 16.3), (19.0, 18.4), (20.0, 18.6), (21.0, 19.1), (22.0, 21.2), (23.0, 21.5), (24.0, 21.9), (25.0, 22.3), (26.0, 20.1), (27.0, 21.3), (28.0, 28.2), (29.0, 26.8), (30.0, 25.4), (31.0, 24.1), (32.0, 21.6), (33.0, 23.6), (34.0, 22.5), (35.0, 20.4), (36.0, 19.6), (37.0, 17.1), (38.0, 15.9), (39.0, 13.8), (40.0, 12.5), (41.0, 11.9), (42.0, 14.1), (43.0, 17.6), (44.0, 18.4), (45.0, 19.4), (46.0, 20.2), (47.0, 19.4), (48.0, 19.5), (49.0, 20.1), (50.0, 21.2), (51.0, 22.3), (52.0, 21.1), (53.0, 25.1), (54.0, 25.2), (55.0, 24.4), (56.0, 23.1), (57.0, 27.5), (58.0, 26.6), (59.0, 26.5), (60.0, 26.8), (61.0, 20.1), (62.0, 25.1), (63.0, 22.8), (64.0, 23.6), (65.0, 23.2), (66.0, 21.4), (67.0, 18.5), (68.0, 22.2), (69.0, 20.5), (70.0, 21.8), (71.0, 17.1), (72.0, 14.2), (73.0, 11.4), (74.0, 15.2), (75.0, 21.2), (76.0, 20.7), (77.0, 20.2), (78.0, 15.9), (79.0, 12.5), (80.0, 21.5), (81.0, 8.20), (82.0, 9.40), (83.0, 11.7), (84.0, 10.3), (85.0, 11.1), (86.0, 20.8), (87.0, 21.5), (88.0, 20.4), (89.0, 22.7), (90.0, 20.1)

NH_3_Ni_Conc = GRAPH (time)

(1.00, 32.3), (2.00, 37.1), (3.00, 34.2), (4.00, 41.7), (5.00, 37.7), (6.00, 39.5), (7.00, 41.2), (8.00, 40.4), (9.00, 42.1), (10.0, 43.3), (11.0, 35.8), (12.0, 36.5), (13.0, 34.7), (14.0, 32.9), (15.0, 33.7), (16.0, 35.5), (17.0, 34.7), (18.0, 35.3), (19.0, 32.9), (20.0, 31.6), (21.0, 31.1), (22.0, 32.2), (23.0, 31.9), (24.0, 33.8), (25.0, 33.8), (26.0, 37.1), (27.0, 36.8), (28.0, 30.1), (29.0, 30.8), (30.0, 33.8), (31.0, 36.4), (32.0, 36.7), (33.0, 38.5), (34.0, 37.2), (35.0, 38.3), (36.0, 39.1), (37.0, 41.2), (38.0, 40.3), (39.0, 39.9), (40.0, 40.1), (41.0, 39.5), (42.0, 39.7), (43.0, 37.9), (44.0, 42.3), (45.0, 42.4), (46.0, 41.9), (47.0, 40.1), (48.0, 38.6), (49.0, 36.8), (50.0, 39.1), (51.0, 42.1), (52.0, 40.1), (53.0, 38.2), (54.0, 36.3), (55.0, 33.5), (56.0, 31.4), (57.0, 28.7), (58.0, 25.8), (59.0, 23.2), (60.0, 21.1), (61.0, 31.5), (62.0, 28.4), (63.0, 32.6), (64.0, 34.5), (65.0, 39.1), (66.0, 43.3), (67.0, 47.1), (68.0, 42.2), (69.0, 41.4), (70.0, 37.1), (71.0, 39.3), (72.0, 41.5), (73.0, 44.8), (74.0, 42.6), (75.0, 40.2), (76.0, 38.1), (77.0, 35.7), (78.0, 37.4), (79.0, 39.1), (80.0, 26.2),

(81.0, 43.6), (82.0, 44.8), (83.0, 43.7), (84.0, 40.8), (85.0, 35.4), (86.0, 32.5), (87.0, 30.1), (88.0, 27.3), (89.0, 32.2), (90.0, 29.1)

NO_3_Ni_Conc = GRAPH (time)

(1.00, 0.69), (2.00, 0.45), (3.00, 0.3), (4.00, 0.19), (5.00, 0.615), (6.00, 0.375), (7.00, 0.17), (8.00, 0.375), (9.00, 0.63), (10.0, 0.23), (11.0, 0.45), (12.0, 0.66), (13.0, 0.84), (14.0, 0.34), (15.0, 0.495), (16.0, 0.705), (17.0, 0.525), (18.0, 0.78), (19.0, 0.37), (20.0, 0.585), (21.0, 0.525), (22.0, 0.78), (23.0, 0.26), (24.0, 0.435), (25.0, 0.435), (26.0, 0.735), (27.0, 0.38), (28.0, 0.585), (29.0, 0.855), (30.0, 0.525), (31.0, 0.31), (32.0, 1.43), (33.0, 1.29), (34.0, 0.99), (35.0, 1.26), (36.0, 1.47), (37.0, 1.24), (38.0, 0.9), (39.0, 1.27), (40.0, 1.01), (41.0, 1.64), (42.0, 1.19), (43.0, 1.32), (44.0, 1.50), (45.0, 1.26), (46.0, 1.59), (47.0, 1.24), (48.0, 0.85), (49.0, 1.10), (50.0, 0.71), (51.0, 1.16), (52.0, 0.735), (53.0, 0.45), (54.0, 0.855), (55.0, 0.51), (56.0, 0.63), (57.0, 0.435), (58.0, 0.84), (59.0, 0.525), (60.0, 0.3), (61.0, 0.81), (62.0, 0.52), (63.0, 0.54), (64.0, 0.56), (65.0, 0.93), (66.0, 0.77), (67.0, 0.675), (68.0, 0.83), (69.0, 1.20), (70.0, 0.88), (71.0, 0.735), (72.0, 0.87), (73.0, 1.14), (74.0, 0.86), (75.0, 0.675), (76.0, 0.81), (77.0, 0.79), (78.0, 1.17), (79.0, 0.825), (80.0, 0.585), (81.0, 0.825), (82.0, 0.81), (83.0, 1.05), (84.0, 0.64), (85.0, 0.855), (86.0, 0.645), (87.0, 0.465), (88.0, 0.84), (89.0, 0.49), (90.0, 0.645)

Observed_Org_N = GRAPH (time)

(1.00, 35.5), (2.00, 31.7), (3.00, 31.5), (4.00, 29.6), (5.00, 31.1), (6.00, 28.4), (7.00, 29.4), (8.00, 31.5), (9.00, 29.9), (10.0, 30.8), (11.0, 31.5), (12.0, 30.8), (13.0, 29.8), (14.0, 31.2), (15.0, 32.8), (16.0, 34.2), (17.0, 32.4), (18.0, 30.0), (19.0, 32.6), (20.0, 31.5), (21.0, 29.8), (22.0, 29.8), (23.0, 28.6), (24.0, 28.2), (25.0, 27.6), (26.0, 27.1), (27.0, 28.4), (28.0, 27.2), (29.0, 31.1), (30.0, 29.7), (31.0, 30.1), (32.0, 31.4), (33.0, 33.5), (34.0, 34.6), (35.0, 32.3), (36.0, 31.7), (37.0, 32.8), (38.0, 31.3), (39.0, 30.4), (40.0, 32.9), (41.0, 31.5), (42.0, 31.8), (43.0, 32.4), (44.0, 29.6), (45.0, 29.0), (46.0, 29.6), (47.0, 31.4), (48.0, 33.3), (49.0, 32.1), (50.0, 29.4), (51.0, 27.2), (52.0, 30.6), (53.0, 28.4), (54.0, 31.0), (55.0, 29.4), (56.0, 32.2), (57.0, 33.3), (58.0, 31.3), (59.0, 31.6), (60.0, 33.8), (61.0, 35.6), (62.0, 36.0), (63.0, 33.0), (64.0, 32.6), (65.0, 33.2), (66.0, 34.9), (67.0, 33.8), (68.0, 32.2), (69.0, 31.2), (70.0, 31.1), (71.0, 32.4), (72.0, 29.7), (73.0, 29.0), (74.0, 29.8), (75.0, 31.0), (76.0, 31.7), (77.0, 29.5), (78.0, 30.8), (79.0, 34.4), (80.0, 33.1), (81.0, 34.4), (82.0, 31.7), (83.0, 30.2), (84.0, 30.4), (85.0, 33.2), (86.0, 34.4), (87.0, 35.4), (88.0, 36.0), (89.0, 33.2), (90.0, 31.0)

Observed_NH_3_N = GRAPH (time)

(1.00, 10.1), (2.00, 10.6), (3.00, 11.4), (4.00, 12.3), (5.00, 13.6), (6.00, 14.4), (7.00, 14.5), (8.00, 14.2), (9.00, 13.2), (10.0, 12.6), (11.0, 11.1), (12.0, 11.2), (13.0, 12.6), (14.0, 12.1), (15.0, 13.5), (16.0, 10.5), (17.0, 10.3), (18.0, 10.1), (19.0, 9.80), (20.0, 10.1), (21.0, 8.90), (22.0, 10.1), (23.0, 11.2), (24.0, 11.3), (25.0, 12.1), (26.0, 11.6), (27.0, 11.8), (28.0, 12.3), (29.0, 13.1), (30.0, 10.8), (31.0, 10.1), (32.0, 10.8), (33.0, 9.90), (34.0, 10.1), (35.0, 9.20), (36.0, 9.10), (37.0, 8.40), (38.0, 8.80), (39.0, 9.50), (40.0, 9.90), (41.0, 10.3), (42.0, 11.2), (43.0, 10.4), (44.0, 11.6), (45.0, 12.1), (46.0, 12.5), (47.0, 11.5), (48.0, 11.9), (49.0, 10.4), (50.0, 11.7), (51.0, 13.6), (52.0, 15.2), (53.0, 12.1), (54.0, 12.4), (55.0, 11.2), (56.0, 10.1), (57.0, 10.2), (58.0, 14.7), (59.0, 12.9), (60.0, 9.70), (61.0, 9.40), (62.0, 8.50), (63.0, 8.10), (64.0, 10.1), (65.0, 9.20), (66.0, 8.70), (67.0, 10.2), (68.0, 9.50), (69.0, 9.90), (70.0, 10.1), (71.0, 10.3), (72.0, 12.5), (73.0, 12.1), (74.0, 11.2), (75.0, 11.3), (76.0, 12.1), (77.0, 11.6), (78.0, 11.8), (79.0, 12.3), (80.0, 13.1),

(81.0, 10.8), (82.0, 10.1), (83.0, 11.4), (84.0, 12.5), (85.0, 11.9), (86.0, 10.7), (87.0, 11.6), (88.0, 11.3), (89.0, 10.7), (90.0, 10.2)

Observed_NO_3_N = GRAPH (time)

(1.00, 2.72), (2.00, 2.41), (3.00, 2.36), (4.00, 2.23), (5.00, 2.15), (6.00, 1.98), (7.00, 2.17), (8.00, 1.92), (9.00, 2.21), (10.0, 2.32), (11.0, 1.69), (12.0, 1.57), (13.0, 1.48), (14.0, 2.45), (15.0, 2.39), (16.0, 2.32), (17.0, 2.29), (18.0, 2.27), (19.0, 1.86), (20.0, 1.73), (21.0, 1.18), (22.0, 1.18), (23.0, 1.45), (24.0, 1.43), (25.0, 1.05), (26.0, 0.95), (27.0, 1.11), (28.0, 1.21), (29.0, 1.62), (30.0, 2.22), (31.0, 2.01), (32.0, 2.03), (33.0, 2.23), (34.0, 2.34), (35.0, 2.47), (36.0, 2.49), (37.0, 2.53), (38.0, 1.85), (39.0, 1.66), (40.0, 1.54), (41.0, 2.34), (42.0, 2.23), (43.0, 2.32), (44.0, 1.41), (45.0, 1.45), (46.0, 1.43), (47.0, 1.47), (48.0, 1.44), (49.0, 1.39), (50.0, 1.50), (51.0, 2.35), (52.0, 2.27), (53.0, 1.80), (54.0, 1.70), (55.0, 1.67), (56.0, 1.61), (57.0, 1.79), (58.0, 1.81), (59.0, 2.02), (60.0, 2.06), (61.0, 2.11), (62.0, 2.01), (63.0, 2.07), (64.0, 2.02), (65.0, 2.03), (66.0, 2.08), (67.0, 2.09), (68.0, 2.71), (69.0, 2.65), (70.0, 2.58), (71.0, 2.54), (72.0, 2.47), (73.0, 2.42), (74.0, 2.36), (75.0, 2.29), (76.0, 2.22), (77.0, 2.18), (78.0, 2.11), (79.0, 2.05), (80.0, 1.97), (81.0, 1.91), (82.0, 1.86), (83.0, 1.82), (84.0, 2.74), (85.0, 2.71), (86.0, 2.65), (87.0, 2.01), (88.0, 2.07), (89.0, 2.05), (90.0, 1.99)

Observed_N_Planktons = GRAPH (TIME)

(1.00, 387), (5.68, 375), (10.4, 354), (15.1, 381), (19.7, 396), (24.4, 370), (29.1, 391), (33.8, 381), (38.5, 382), (43.2, 376), (47.8, 367), (52.5, 379), (57.2, 354), (61.9, 360), (66.6, 347), (71.3, 341), (75.9, 356), (80.6, 342), (85.3, 337), (90.0, 329)

Observed_NSedim = GRAPH (TIME)

(0.00, 948), (10.0, 949), (20.0, 952), (30.0, 954), (40.0, 967), (50.0, 951), (60.0, 949), (70.0, 947), (80.0, 951), (90.0, 949)

Valid_NO_3N = GRAPH (TIME)

(1.00, 2.72), (2.00, 2.57), (3.00, 2.41), (4.00, 2.38), (5.00, 2.36), (6.00, 2.29), (7.00, 2.23), (8.00, 2.19), (9.00, 2.15), (10.0, 2.06), (11.0, 1.98), (12.0, 2.08), (13.0, 2.17), (14.0, 2.04), (15.0, 1.92), (16.0, 2.06), (17.0, 2.21), (18.0, 2.26), (19.0, 2.32), (20.0, 2.00), (21.0, 1.69), (22.0, 1.63), (23.0, 1.57), (24.0, 1.52), (25.0, 1.48), (26.0, 1.97), (27.0, 2.45), (28.0, 2.42), (29.0, 2.39), (30.0, 2.36), (31.0, 2.32), (32.0, 2.30), (33.0, 2.29), (34.0, 2.28), (35.0, 2.27), (36.0, 2.06), (37.0, 1.86), (38.0, 1.79), (39.0, 1.73), (40.0, 1.45), (41.0, 1.18), (42.0, 1.18), (43.0, 1.18), (44.0, 1.31), (45.0, 1.45), (46.0, 1.44), (47.0, 1.43), (48.0, 1.24), (49.0, 1.05), (50.0, 1.00), (51.0, 0.95), (52.0, 1.03), (53.0, 1.11), (54.0, 1.16), (55.0, 1.21), (56.0, 1.42), (57.0, 1.62), (58.0, 1.92), (59.0, 2.22), (60.0, 2.12), (61.0, 2.01), (62.0, 2.02), (63.0, 2.03), (64.0, 2.13), (65.0, 2.23), (66.0, 2.29), (67.0, 2.34), (68.0, 2.41), (69.0, 2.47), (70.0, 2.48), (71.0, 2.49), (72.0, 2.51), (73.0, 2.53), (74.0, 2.19), (75.0, 1.85), (76.0, 1.75), (77.0, 1.66), (78.0, 1.60), (79.0, 1.54), (80.0, 1.94), (81.0, 2.34), (82.0, 2.29), (83.0, 2.23), (84.0, 2.27), (85.0, 2.32), (86.0, 1.86), (87.0, 1.41), (88.0, 1.43), (89.0, 1.45), (90.0, 1.44)