Efficiency of Modified Constructed Wetland System using Helianthus annuus L. in Removing Nitrogen, Phosphorous, and Ammonia in a Milkfish Farm Wastewater in Iloilo City, Philippines

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August 16, 2020

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***Abstract*—** Water is important for all living organisms and is the fundamental element in all processes such as energy production, food production, or environmental management. Water demand is very high and will keep increasing due to the continuous growth of the number of populations. When the population grows, environmental problems continue to rise and It is also due to harmful human acts that drain natural resources and destroy the environment. When nutrients that cause eutrophication are mixed with bodies of water, it can be harmful to aquatic animals. These nutrients can also cause harm to human health through various diseases. Groundwater being exposed to excessive nitrate can resort to it being undrinkable. The primary objective of this thesis paper is to be able to analyze the efficiency of a modified constructed wetland system using Helianthus annuus L. in the removal of Nitrogen, Phosphorous, and Ammonia from septic tank effluents with the use of HF-VF Baffle Hybrid Flow Constructed Wetland. This research will also investigate if the water quality parameter passed to DENR Administrative Order 2016-08 (DAO 2016-08). The removal results were obtained using SubWet Software modeling, the following efficiency removal rate was obtained: 99.89%, 92.61%, 97.10%, 97.70%, 55.37%, 95.07% for BOD5, COD, TSS, TP, N, NH4, respectively. Results of having a hybrid horizontal and vertical flow wetland are effective in the removal of Nitrogen, Phosphorus and Ammonia in the wastewater coming from the fish farm and suggested that the most active sites for nitrification and denitrification were separated spatially in a wetland

I. INTRODUCTION

Nitrogen, Phosphorus, and Ammonia are some of the most important nutrients for living things. However, too much of these nutrients can cause various water quality problems such as eutrophication. When these nutrients are mixed with bodies of water, it can be harmful to aquatic animals. These nutrients can also cause harm to human health through various diseases. Groundwater being exposed to excessive nitrate can resort to it being undrinkable.

The removal of these nutrients has been a long time problem for our natural waters. Nitrogen and phosphorus are commonly removed biologically through activated sludge. Activated sludge systems require a long detention time and a large sedimentation surface, because of that, it takes a very large system to function. More than that, removing these nutrients from effluent requires a post-treatment process which makes it costly.

Studies show that the flower, Canna x Generalis, when used in a constructed wetland can help in rectifying Nitrogen and Phosphorous contaminants (Ojoawo, 2015). This is possible because Canna x Generalis is a herbaceous plant. The characteristics of Canna x Generalis that makes it efficient in treating wastewater are also possessed by Sunflowers. Helianthus annuus, or more commonly known as Sunflowers, are herbaceous and easily thrive. They are easy to grow and are economical because they can be reused as ornamental plants.

The proposed treatment facility will be located in a twenty-hectare organic fish farm just outside the city limits of Dumangas, Western Visayas, Philippines. Dumangas is well known as one of the best bangus production areas in the country. The total area is 20.248 hectares which are equivalent to 50 acres.

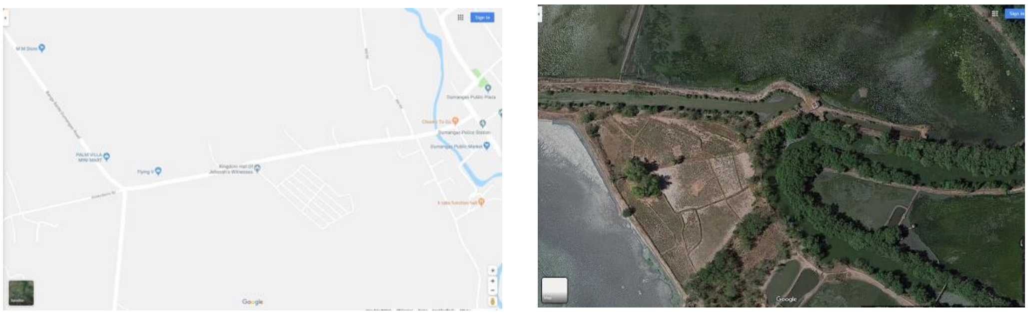

Figure 1: (a) Street View of the Site; (b) Satellite View of the Site

A river is located beside the fish farm, which is classified as Class A. This is an advantage because, in farms that are classified as Class B and Class C, water has to travel secondary ways to the property. The land is near the river and has many canals in conjunction with a series of sluice gates used for filling and discharging of pond water. Water levels are controlled by using the ocean high tide and low tide. The water supply is brackish water, which is a mixture of river water and ocean water. The farmland is at a lower elevation, which is important during the dry season. The farm has several freshwater wells.

Some standards are needed to be complied before discharging wastewater effluent into natural bodies of water. The study aims to provide a solution to water contamination and eutrophication. There are several harmful effects of eutrophication. It can cause harm to both human health and aquatic life. One of the most significant effects of eutrophication is the formation of algal blooms. When algal blooms take place in bodies of water, it can result in blocking sunlight from reaching the water. When aquatic plants are deprived of sunlight, they are also being deprived of undergoing photosynthesis. Photosynthesis is important to aquatic plants because it is a source of oxygen to various aquatic plants (What is Eutrophication? – Definition, Causes & Effects, 2015). When the quality of water is poor, it can lead to a shortage of clean water, which is necessary for human health. The study also aims to avoid wasting the plant used in constructing the wetland, the sunflower can be reused in several ways. The most common way of reducing Nitrogen, Phosphorus, and Ammonia in wastewater is through Activated Sludge Treatment although it is proven to be less economical because it requires a large system to function.

The main goal of the researchers in this study is to be able to analyze the efficiency of a modified constructed wetland system using Helianthus annuus L. in the removal of Nitrogen, Phosphorous, and Ammonia from septic tank effluents with the use of HF-VF Baffle Hybrid Flow Constructed Wetland. Specifically, the study addresses the following: (1) Develop a modified constructed wetland for wastewater treatment using Helianthus annuus L. (2) Investigate the amount of Nitrogen, Phosphorous, and Ammonia removed in the constructed wetland effluent to determine the efficiency of Helianthus annuus L. in wastewater treatment

For industries, our study can be beneficial to the advancement of water treatment facilities, specifically constructed wetlands. Industries that have access to sunflowers and are in a location wherein a constructed wetland can be built and sunflowers could grow in can use this study. Our proposed treatment facility can help communities and industries to save money from purchasing expensive facilities such as activated sludge systems

This study can be beneficial to future students and researchers that are striving to enhance the quality of wastewater treatment facilities. As time goes, technologies are being enhanced and the systems used in wastewater treatment should be improved as well for us to experience the best and most efficient way of disposing of wastewater.

II. METHODOLOGY

Identification of Site

The researchers will identify a site. The proposed treatment facility will be located in a twenty-hectares organic fish farm just outside the city limits of Dumangas, Western Visayas, Iloilo City, Philippines

Septic Tank

The septic tank is an underground closed container containing two chambers for primary wastewater treatment that results in the settlement of solids at the bottom. The use of two chambers in the septic tank's purpose is to remove all heavy solids completely where the second chamber removes all remaining solid components left from the first chamber. While designing the two chambers, the flow rate of wastewater going through them is respected to enable the good separation of solids from wastewater.

The volume of the septic tank will be calculated according to the volume flow rate exiting on a daily basis that is exactly 585 m^3/day of wastewater.

Considering the following equations, we have:

V = t * Q = (1day)(585 $\frac{m^3}{day}$) = 585 m^3

V: Volume (m^3)
T: time (days)
Q: Volume flow rate (m^3/day)

Knowing the exiting wastewater volume that is 480m3 during one day, we can calculate the dimensions of the septic tank:

Width = 15m
Length = 30m → the length must be 2 to 3 times the width
Depth = 1.3m
Total Volume

V = L * W * H = 15m * 30m * 1.3m = 585m^3

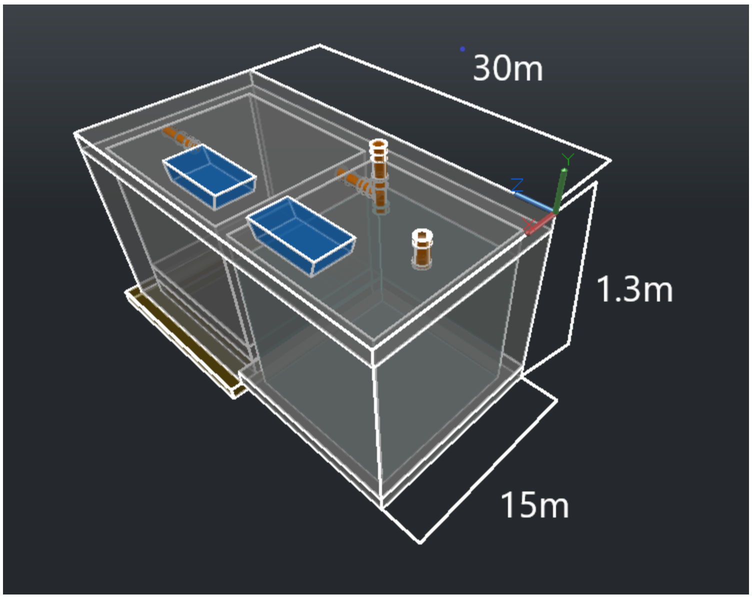

Figure 2: Septic Tank Design

SubWet Software Analysis

SubWet software was developed by the United Nations Environment program to improve the design of constructed wetlands for wastewater treatment to obtain efficient results of the system. The software helps to improve and modeling different scenarios of systems with low performance and the ones containing different contaminants and volumes. The software can be used by professionals as well as individuals who are interested in building constructing wetlands and water sustainability in general. The software demonstrates the proportion of nitrogen, organic matters, phosphorous and other contaminants existing in the wastewater in mg/l and their removal efficiency rates.

Design

After getting the newest version of the software that SubWet 2.0 and choosing the suitable climate of the constructed wetland, which is a warm climate for this project. Multiple inputs need to be inserted first that are selected flow, length, width, slope, depth, hydraulic conductivity, average particular matter percentage, and precipitation factor (PE). **(See Appendix A)**

1) Width, Length, and depth: From previous calculations, we have the width= 15m, length= 30m and depth= 1.3m.

2) Precipitation Factor (PF): This considers both evapotranspiration and precipitation that are 16.7mm/day for this project. It is calculated using the following equations:

$$PF = \frac{(\text{Average precipitation} - \text{ Average evapotranspiration }) + \text{Volume} + 1}{Volume}$$

$$PF = \frac{(16.7 - 16.7) + 585 + 1}{585}$$

$$PF = 1.002$$

3) Selected flow (SF): It represents the flow rate going through the system during the day. The flow rate is 585m$_3$/day that is equivalent to 5.85 liters/day.

4) The average particulate matter percentage (AP):
It is calculated using the following equation:

$$AP = \frac{25 - SF}{8}$$

$$AP = \frac{25 - 5.85}{8}$$

$$AP = 2.3975\ \%$$

5) Slope: To obtain good results, the slope within the wetland should be less than 1%. For this project, we will take the slope to 0.5%.

6) Hydraulic Conductivity: It is the possibility of water going through the system. The hydraulic conductivity will be equal to one of the medium used. As we are using gravel for this constructed wetland, then the hydraulic conductivity is equal to 2592 m/day.

Once all the mentioned parameters are inserted as inputs in the software, the value of flow width and flow length, Recommended Hydraulic Flow, volume, the recommended flow, area, Hydraulic loading, and the number of paths are calculated by the software.

7) Temperature: We generally take the temperature as the average temperature of the city annually and that is equal to 26.7°C for the city of Iloilo.

8) Porosity: As we used gravel and coarse sand as media for HSSF and VSSF wetlands, thus the sand will be equal to 0.25 for sand and 0.2 for gravel as a fraction or percentage.

III. RESULTS AND DISCUSSION

This last part is about simulating all the data gathered and observing the pollutants removal efficiency with their amounts and mg/l. The graphs represent the efficiency percentage vs. the number of days of the simulation that is 8 days for our case. The table below shows inflow and outflow concentrations of pollutants in the wastewater:

Table 1: Summary of Inflow/ Outflow Contaminants Concentrations

Table 1 Water Quality Parameters (8 days)								
Water Quality Parameter (8 days)	SUMMARY OF THE CHANGE IN PARAMETER VALUES (mg/L)						Total Efficiency Removal	Water Quality Parameter Requirement of Class SB - Fishery
	Influent of	Effluent of	Influent of VCW	Effluent	Influent	Effluent		

	Septic Tank	Septic Tank		of VCW	of HCW	of HCW		Water Class II (mg/L)
BOD5	**180.00**	**54.00**	**54.00**	**14.85**	**14.85**	**0.20**	**99.89**	**30**
COD	**145.16**	**101.61**	**101.61**	**34.14**	**34.14**	**10.73**	**92.61**	**60**
TSS	**14.15**	**7.08**	**7.08**	**3.11**	**3.11**	**0.41**	**97.10**	**70**
Total Phosphorus	**5.65**	**3.50**	**3.50**	**1.25**	**1.25**	**0.13**	**97.70**	**1**
Nitrate	**3.07**	**2.76**	**2.76**	**1.46**	**1.46**	**1.37**	**55.37**	**20**
Ammonia	**2.84**	**2.40**	**2.40**	**0.66**	**0.66**	**0.14**	**95.07**	**0.5**

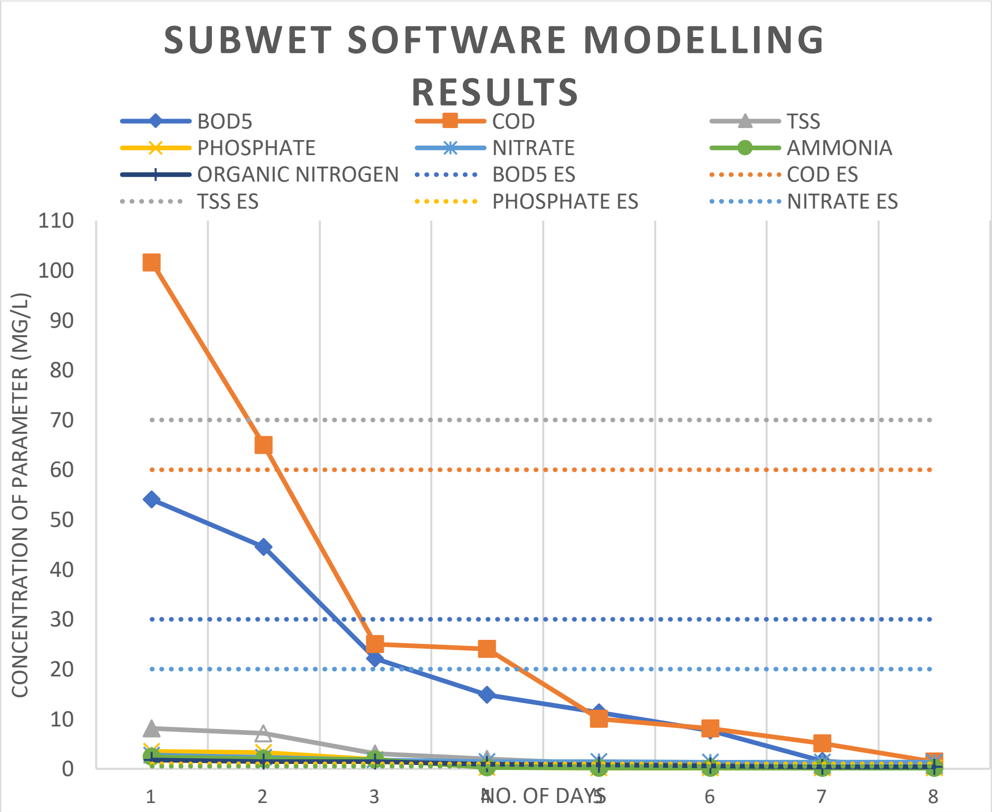

Figure 3: 8 Days SubWet Software Modelling Results

According to studies, BOD removal is dependent on the wastewater flow rate. We can obtain higher BOD removal percentages with a big wastewater flow rate, which is the case for our project, therefore we obtained very satisfactory results leading to prove our hypothesis. Based on the SubWet Software modeling, the following efficiency removal rate was obtained: 99.89%, 92.61%, 97.10%, 97.70%, 55.37%, 95.07% for BOD5, COD, TSS, TP, N, NH4, respectively.

BOD and TSS were similar to each other and were much higher than those of NH4 and TP, thus confirming the low efficiency of the VFW in removing N and P. Dan et al. treated a mixture of domestic and pig farm wastewater using planted VFW and reported comparable removal rate constants for COD and BOD and much higher values for NH4 and TP. Both horizontal and vertical wetlands are efficient in BOD5, TSS, and

COD removal which is why the graph shows a consistent decrease in their concentration in the wastewater. It could be seen that nitrogen, phosphorus, and ammonia did not reach the standard parameters for a Class SB water after being released from the vertical wetland, which is why adding a horizontal wetland was reasonable to have. Due to good oxygen transfer, vertical flow wetlands can nitrify, but denitrification is limited. In order to create a nitrification-denitrification treatment train, this technology was combined with a horizontal flow wetland.

The NH4 concentration in the effluent is the result of the difference between the rate of its formation, due to organic N mineralization, and the rate of its removal, due to nitrification. The relatively high removal rate of NH4 could be explained by plant uptake and the higher rate of nitrification. This result implies that NH4 uptake by the plant is a minor factor compared to the nitrification process, which is considered the major NH4 removal process.

Filtration occurs by the impaction of particles onto the roots and stems of the sunflowers or onto the soil/gravel particles in surface flow systems. The effect of the VFW on the removal of TSS may be explained by its effect on the sedimentation rate of the suspended particles. In the vertical flow wetland, the system is filled with wastewater for a determined period of time and subsequently drained completely before the next batch of effluent is applied, whereas, in the HFW, the wastewater flows into the media continuously thus keeping it moist all the time. The VFW allowed more solids to be trapped in the pore spaces of the media compared to the HFW, resulting in higher values of TSS removal efficiency

The porosity affects hydraulic performance parameters, according to (Chyan 2013) the hydraulic loading rate (HLR) decreases with decreasing porosity. Hydraulic Conductivity is another factor that affects the hydraulic loading rate. The removal efficiencies of plants are affected by hydraulic retention time

Wetlands are water bodies that are exposed to the atmosphere, this makes it affected by climate, weather, and temperature. The temperature on the location of the wetland affects the performance of the wetland and its removal rate. The biological and physical activities in the wetland system are also greatly affected. The biogeochemical processes which regulate the removal of nutrients in wetlands are dependent on the temperature. This makes the temperature influence the treatment efficiency

The graph shown above represents a simulation of contaminants removal efficiency within the system. This shows the achievement of the targeted goals which is approximately removing all pollutants from the wastewater. It can be seen that the chosen hydraulic retention time which is 8 days is shown on the graph and that is valued between 0 and 100%, this is why we have that particular graph shape

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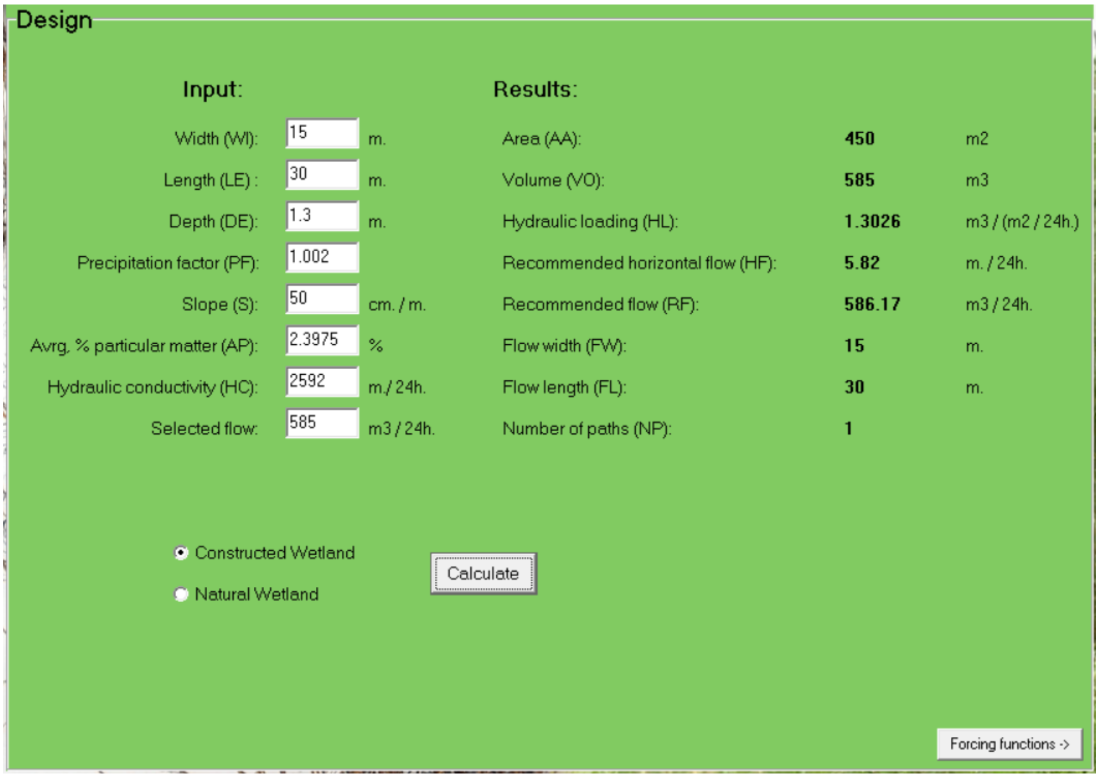
APPENDICES

APPENDIX A.



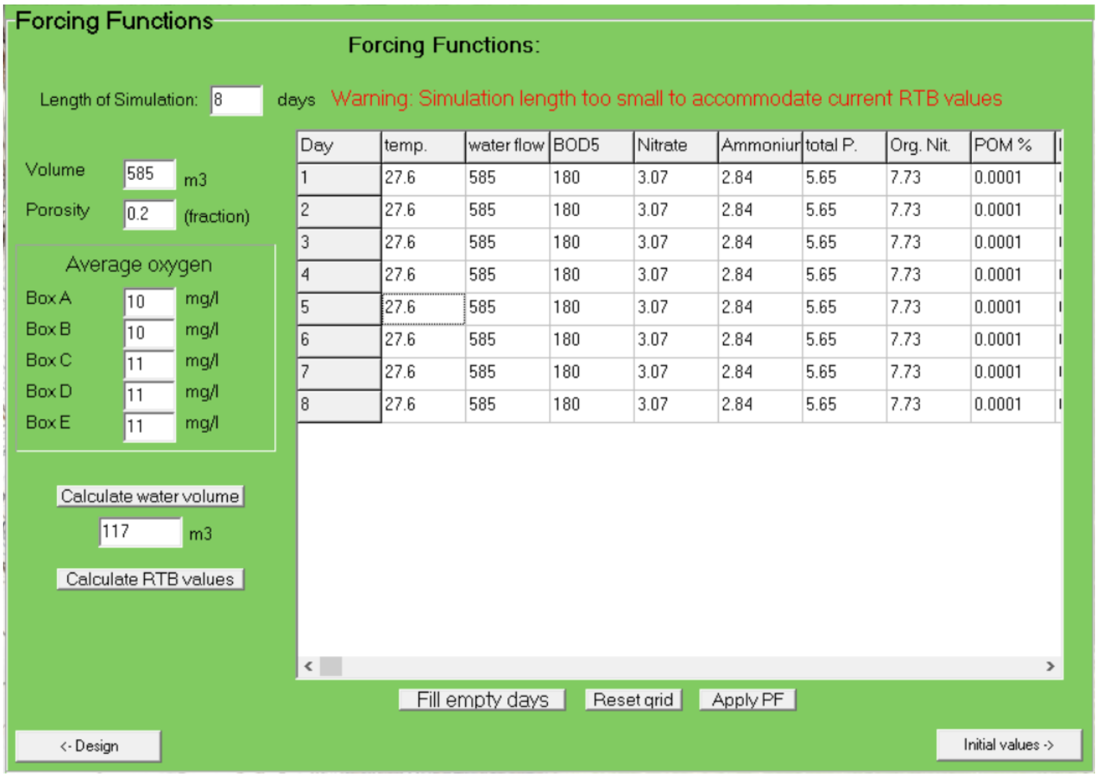
Input:

Width (WI): 15 m.
Length (LE) : 30 m.
Depth (DE): 1.3 m.
Precipitation factor (PF): 1.002
Slope (S): 50 cm. / m.
Avrg. % particular matter (AP): 2.3975 %
Hydraulic conductivity (HC): 2592 m./ 24h.
Selected flow: 585 m3 / 24h.

Results:

Area (AA): **450** m2
Volume (VO): **585** m3
Hydraulic loading (HL): **1.3026** m3 / (m2 / 24h.)
Recommended horizontal flow (HF): **5.82** m. / 24h.
Recommended flow (RF): **586.17** m3 / 24h.
Flow width (FW): **15** m.
Flow length (FL): **30** m.
Number of paths (NP): **1**

● Constructed Wetland
○ Natural Wetland



Forcing Functions:

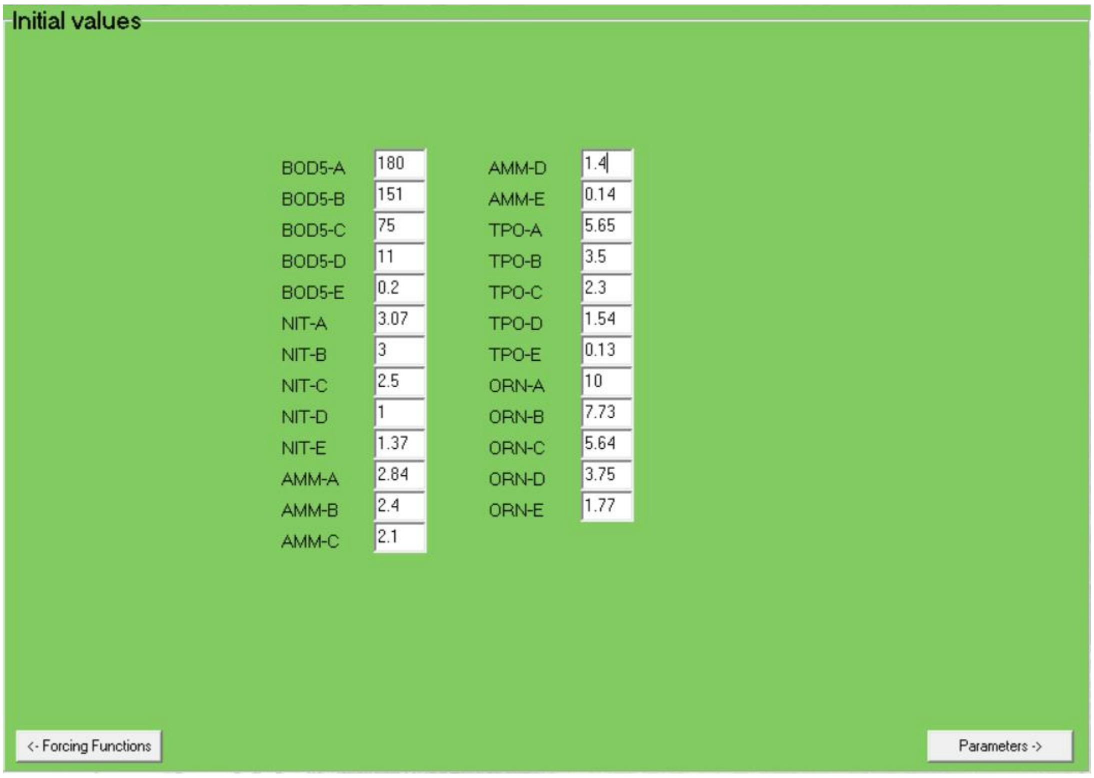
Length of Simulation: 8 days Warning: Simulation length too small to accommodate current RTB values

Volume 585 m3
Porosity 0.2 (fraction)

Average oxygen
Box A 10 mg/l
Box B 10 mg/l
Box C 11 mg/l
Box D 11 mg/l
Box E 11 mg/l

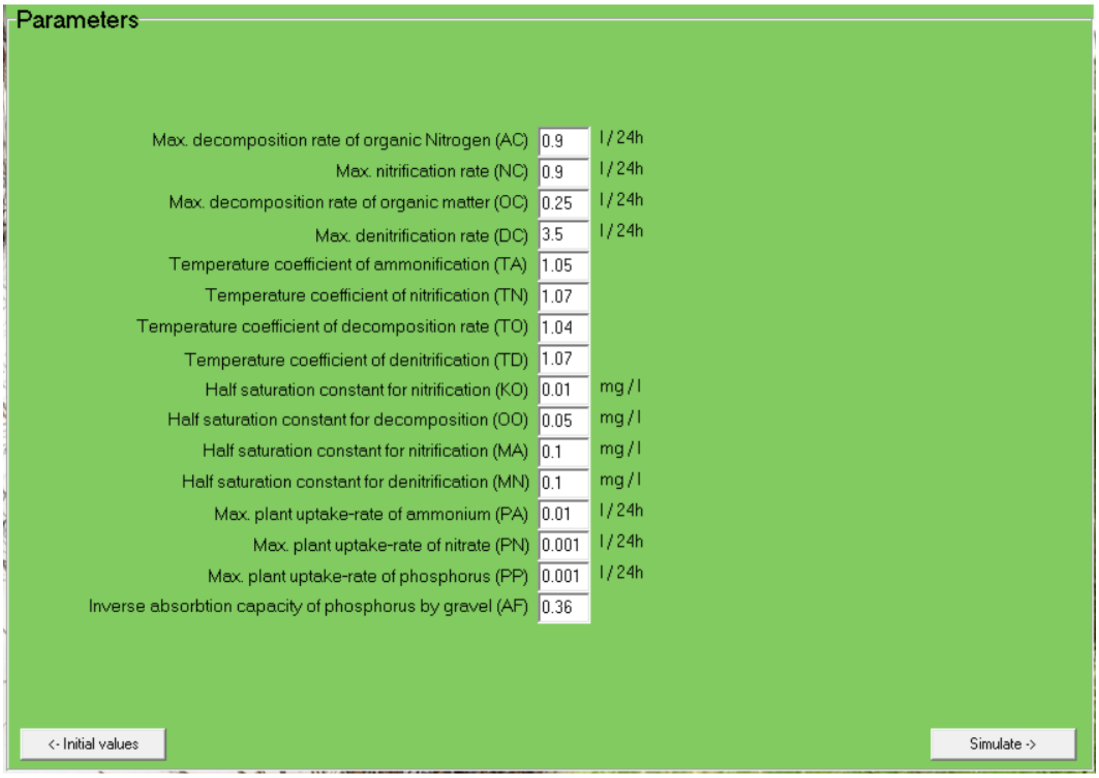
117 m3

Day	temp.	water flow	BOD5	Nitrate	Ammoniur	total P.	Org. Nit.	POM %
1	27.6	585	180	3.07	2.84	5.65	7.73	0.0001
2	27.6	585	180	3.07	2.84	5.65	7.73	0.0001
3	27.6	585	180	3.07	2.84	5.65	7.73	0.0001
4	27.6	585	180	3.07	2.84	5.65	7.73	0.0001
5	27.6	585	180	3.07	2.84	5.65	7.73	0.0001
6	27.6	585	180	3.07	2.84	5.65	7.73	0.0001
7	27.6	585	180	3.07	2.84	5.65	7.73	0.0001
8	27.6	585	180	3.07	2.84	5.65	7.73	0.0001



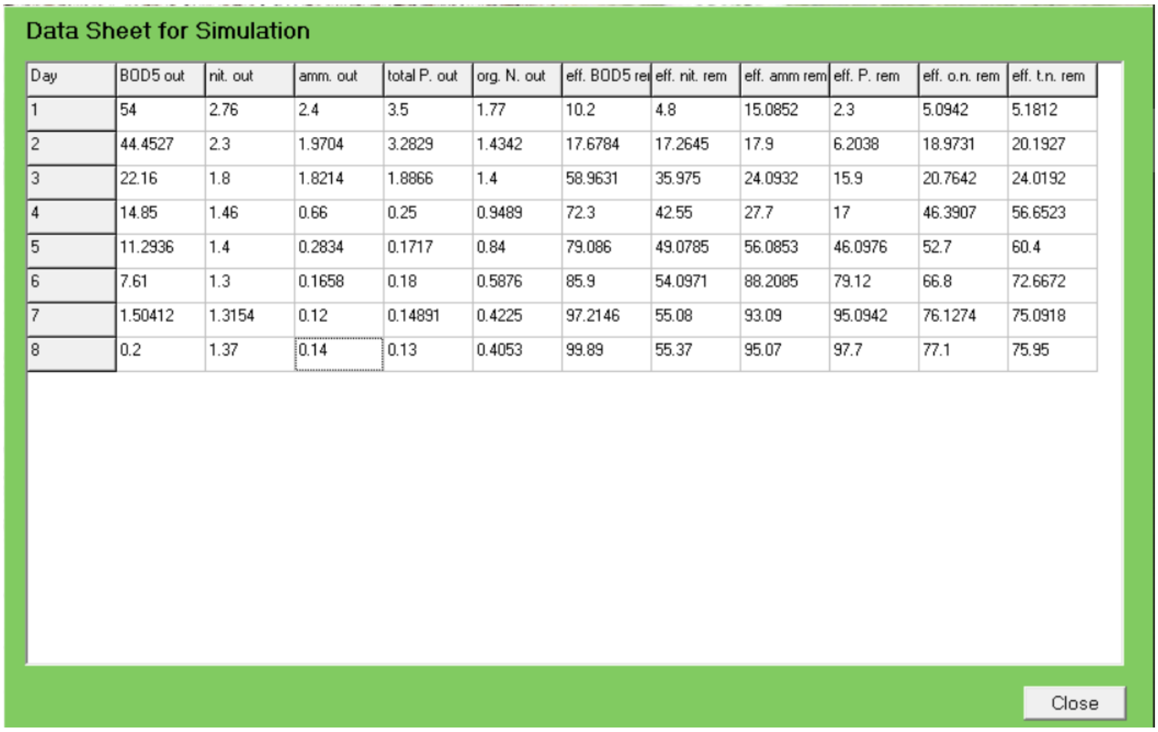
Initial values

BOD5-A	180	AMM-D	1.4
BOD5-B	151	AMM-E	0.14
BOD5-C	75	TPO-A	5.65
BOD5-D	11	TPO-B	3.5
BOD5-E	0.2	TPO-C	2.3
NIT-A	3.07	TPO-D	1.54
NIT-B	3	TPO-E	0.13
NIT-C	2.5	ORN-A	10
NIT-D	1	ORN-B	7.73
NIT-E	1.37	ORN-C	5.64
AMM-A	2.84	ORN-D	3.75
AMM-B	2.4	ORN-E	1.77
AMM-C	2.1		



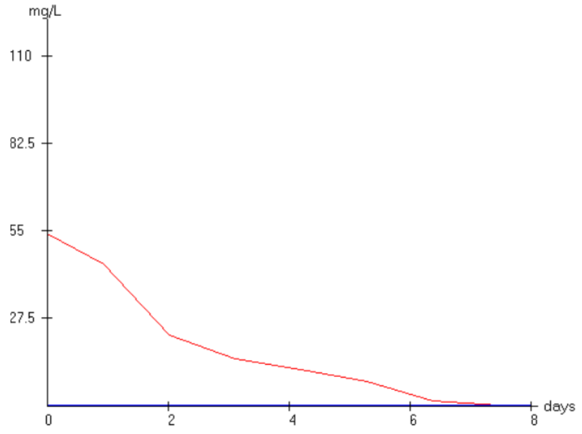
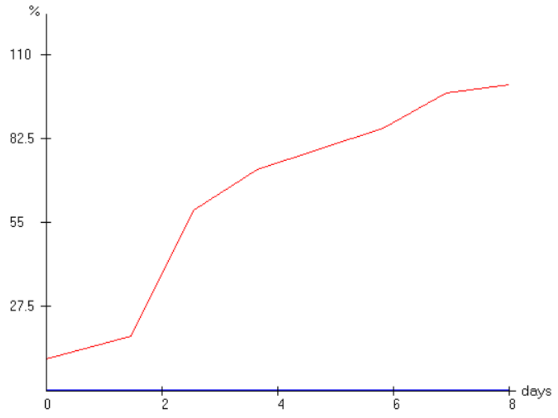
Parameters

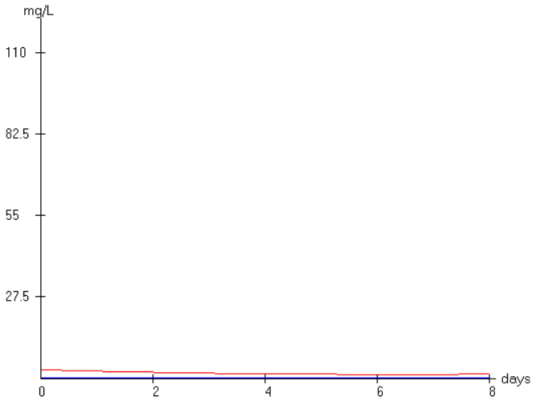
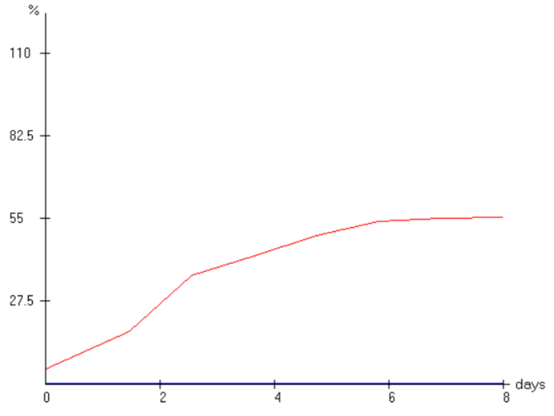
Max. decomposition rate of organic Nitrogen (AC)	0.9	l / 24h
Max. nitrification rate (NC)	0.9	l / 24h
Max. decomposition rate of organic matter (OC)	0.25	l / 24h
Max. denitrification rate (DC)	3.5	l / 24h
Temperature coefficient of ammonification (TA)	1.05	
Temperature coefficient of nitrification (TN)	1.07	
Temperature coefficient of decomposition rate (TO)	1.04	
Temperature coefficient of denitrification (TD)	1.07	
Half saturation constant for nitrification (KO)	0.01	mg / l
Half saturation constant for decomposition (OO)	0.05	mg / l
Half saturation constant for nitrification (MA)	0.1	mg / l
Half saturation constant for denitrification (MN)	0.1	mg / l
Max. plant uptake-rate of ammonium (PA)	0.01	l / 24h
Max. plant uptake-rate of nitrate (PN)	0.001	l / 24h
Max. plant uptake-rate of phosphorus (PP)	0.001	l / 24h
Inverse absorbtion capacity of phosphorus by gravel (AF)	0.36	


Data Sheet for Simulation

Day	BOD5 out	nit. out	amm. out	total P. out	org. N. out	eff. BOD5 re	eff. nit. rem	eff. amm rem	eff. P. rem	eff. o.n. rem	eff. t.n. rem
1	54	2.76	2.4	3.5	1.77	10.2	4.8	15.0852	2.3	5.0942	5.1812
2	44.4527	2.3	1.9704	3.2829	1.4342	17.6784	17.2645	17.9	6.2038	18.9731	20.1927
3	22.16	1.8	1.8214	1.8866	1.4	58.9631	35.975	24.0932	15.9	20.7642	24.0192
4	14.85	1.46	0.66	0.25	0.9489	72.3	42.55	27.7	17	46.3907	56.6523
5	11.2936	1.4	0.2834	0.1717	0.84	79.086	49.0785	56.0853	46.0976	52.7	60.4
6	7.61	1.3	0.1658	0.18	0.5876	85.9	54.0971	88.2085	79.12	66.8	72.6672
7	1.50412	1.3154	0.12	0.14891	0.4225	97.2146	55.08	93.09	95.0942	76.1274	75.0918
8	0.2	1.37	0.14	0.13	0.4053	99.89	55.37	95.07	97.7	77.1	75.95

APPENDIX B

PARAMETER: **BOD5**	
CONCENTRATION VS TIME	REMOVAL EFFICIENCY VS TIME
	

PARAMETER: **NITRATE**	
CONCENTRATION VS TIME	REMOVAL EFFICIENCY VS TIME
	

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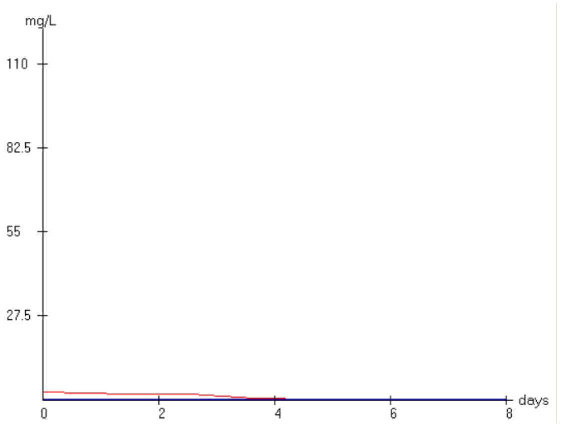

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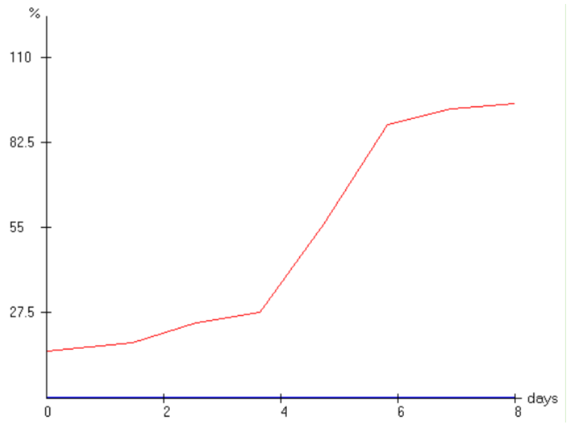

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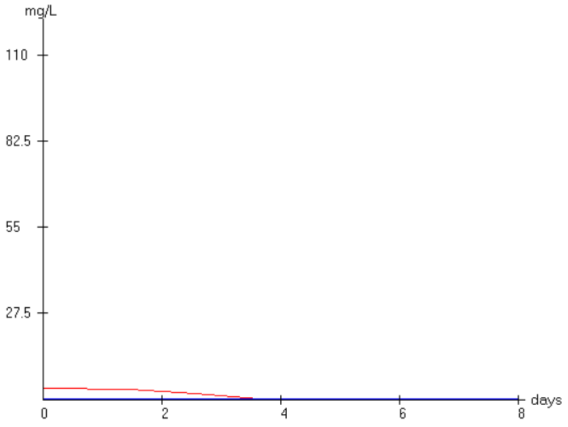

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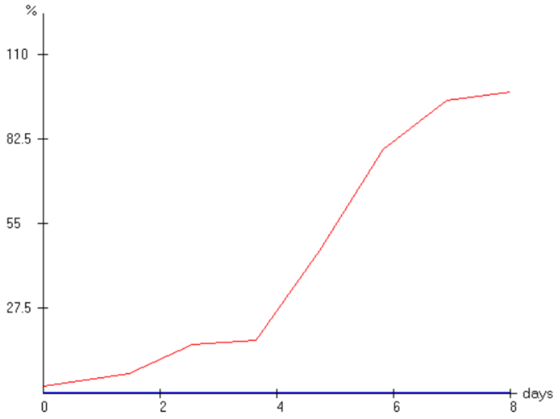

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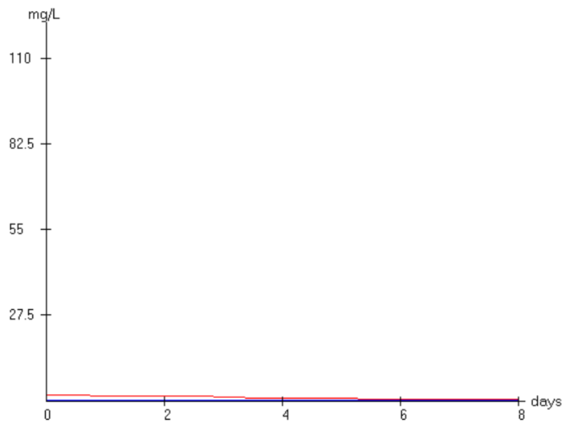
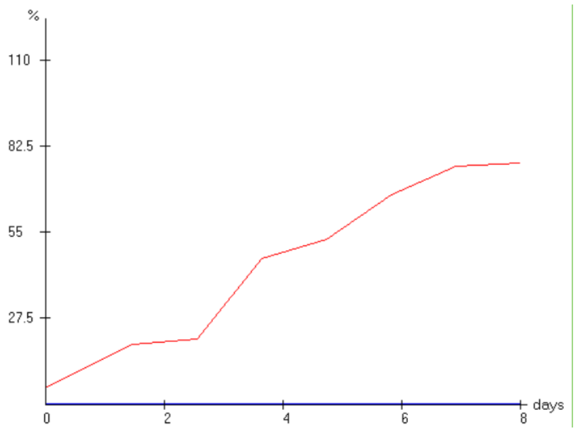
<tr><td>
</td><td>
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REMOVAL EFFICIENCY VS TIME OF TOTAL NITROGEN