OPTIMIZATION AND MODELING OF A HYBRID SYSTEM FOR EFFICIENT WASTEWATER TREATMENT WITH A FOCUS ON WETLAND PERFORMANCE ENHANCEMENT

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This project focuses on optimizing an existing design and simulating a Subsurface Horizontal Flow Constructed Wetland, integrated into a hybrid treatment system, to enhance wastewater treatment efficiency while optimizing land use. The goal is to improve pollutant removal, including nitrogen and phosphorus, using innovative media like Red Tezontle.

Background

Global pig production has risen significantly due to population growth and demand, leading to environmental challenges. At García Farm, in Mexico, daily cleaning of pig stables generates approximately 1,000 liters of slurry, prompting the integration of a geomembrane tubular biodigester for anaerobic digestion, producing leachate known as biol. [1]

In response, the Universidad del Valle de Atemajac (UNIVA) proposed a hybrid treatment system to purify this as shown below. While efficient, the hybrid system requires excessive space at full scale, necessitating design optimization to reduce its footprint.

Filtration	Activated Sludge	Constructed Wetland	Filtration	Maturation Pond
Gravel, tezontle, fine sand, and activated carbon	1. Aeration 2. Settler Biologically degrade organic matter and nutrients	Subsurface Horizontal Flow throw Tezontle and Gravel.	Volcanic tezontle: removes suspended solids, nutrients, organic compounds.	Polishes effluent

Figure 1. Hybrid System for Biological Treatment for Liquid Waste Generated in Livestock Processes.[1] Own Elaboration.

Objectives

1. To optimize and simulate a subsurface flow wetland for leachate treatment, enhancing efficiency and reducing land use using SubWet 2.0.
2. To scale up the design, ensuring consistent pollutant removal efficiency from lab to field application.

Methodology

01 Literature Review → 02 Identify Software Options → 03 Data Collection → 04 Wetland Design → 05 Simulation SubWet 2.0 → 06 Optimization Process → 07 Simulation vs. Real Data → 08 Anaylisis and Discussion

Wetland Design

Table 1. Wetland Parameters Design and Dimensions. Own Elaboration.

Parameter	Influent (mg/L) [1]	(1)	(2)	(3)	(4)	Q	d	Cin	Cout	k	A
BOD	3546,2	5% [5]	75% [2]	17%	97%	0,9 [1]	0,6 [11]	709,2	106,4	0,3 [5]	9,49
COD	8015,0	5% [6]	65% [6]	18%	88%	0,9 [1]	0,6 [11]	2404,5	961,8	0,2 [5]	6,87
Grease and Oil	14,4	20% [2]	45% [5]	20%	85%	0,9 [1]	0,6 [11]	5,0	2,2	0,07 [12]	18,16
Total N	807	10% [5]	40% [7]	23%	73%	0,9 [1]	0,6 [11]	403,5	217,9	0,08 [13]	11,55
Total P	11,41	5% [6]	20% [2]	30%	55%	0,9 [1]	0,6 [11]	8,6	5,1	0,055 [13]	13,93
S. Solids	320	10% [7]	15% [5]	15%	40%	0,9 [1]	0,6 [11]	240,0	192,0	0,15 [12]	2,23
							Stimated Area Wetland (m2) =				18

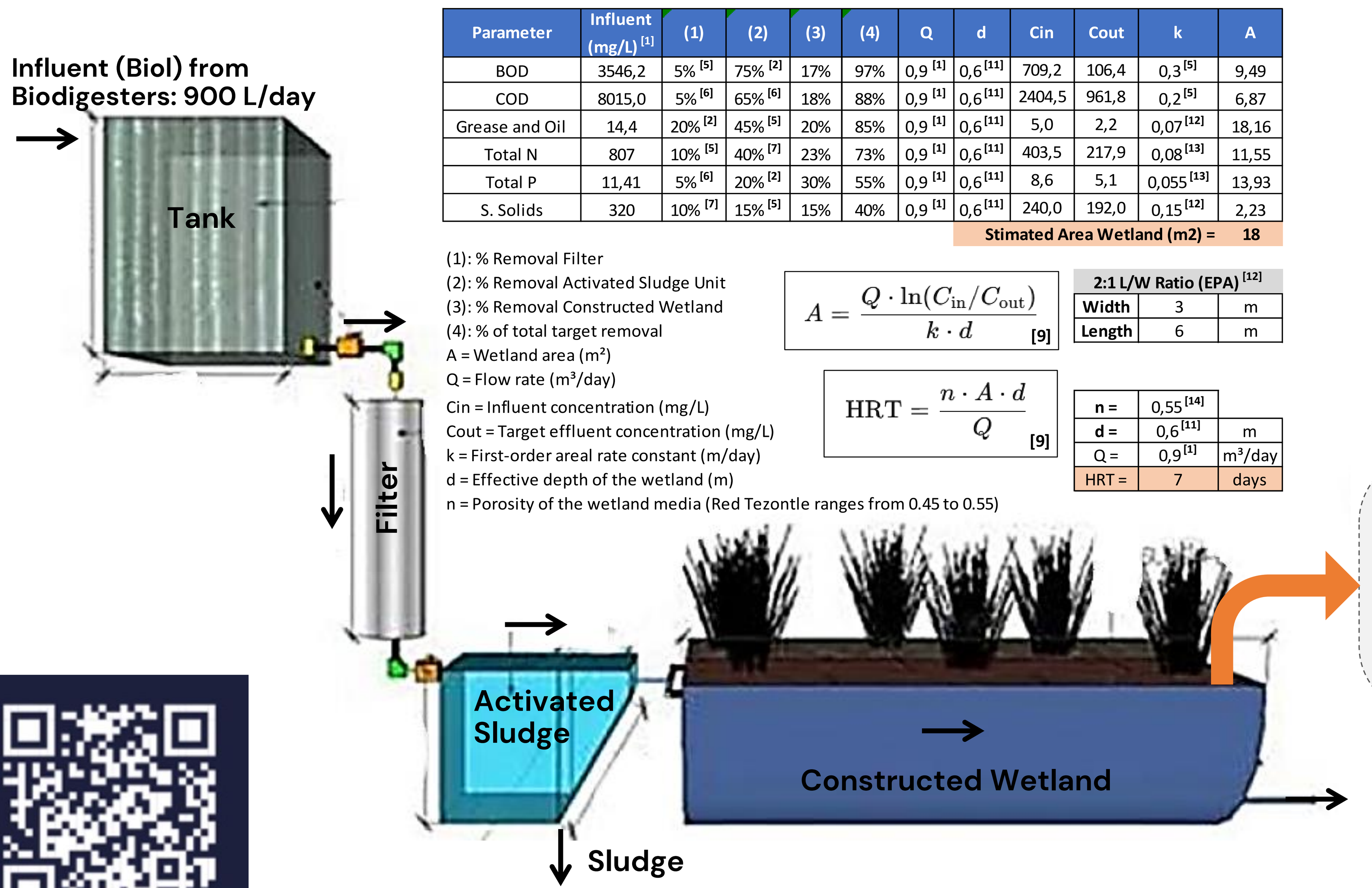
(1): % Removal Filter
(2): % Removal Activated Sludge Unit
(3): % Removal Constructed Wetland
(4): % of total target removal
A = Wetland area (m²)
Q = Flow rate (m³/day)
Cin = Influent concentration (mg/L)
Cout = Target effluent concentration (mg/L)
k = First-order areal rate constant (m/day)
d = Effective depth of the wetland (m)
n = Porosity of the wetland media (Red Tezontle ranges from 0.45 to 0.55)

$$A = \frac{Q \cdot \ln(C_{in}/C_{out})}{k \cdot d} \quad [9]$$

2:1 L/W Ratio (EPA) [12]		
Width	3	m
Length	6	m

$$HRT = \frac{n \cdot A \cdot d}{Q} \quad [9]$$

n =	0,55 [14]	
d =	0,6 [11]	m
Q =	0,9 [1]	m³/day
HRT =	7	days



Red tezontle, a volcanic rock common in Mexico, serves as an effective filter media in constructed wetlands due to its high porosity. [14]

Figure 2. Optimized Hybrid Wastewater Treatment System for Livestock Processes [15]

Simulation with SubWet 2.0 and Results

1. **Input Data:** Width, Length, Precipitation Factor[17], Slope[9], Hydraulic Coductivity[18], Flow
2. **Forcing Functions:** Vol, Porosity[19], Oxygen, DBO, Total N, Total P, Organic Matter [1]
3. **Initial Values** BOD[1], Nitrates, Ammonia, Organic Nitrogen, Total P [1]
4. **Descomposition and Saturation Rates** (Nitrification and Dinitrification) [2, 3, 9]

Nitrate:	5% Total N
Ammonium:	45% Total N
Organic Nitrogen:	50% Total N

[2]

Table 2. Removal Efficiencies SubWet 2.0

Data Sheet for Simulation

Day	eff. BOD5 rem	eff. nit. rem	eff. amm rem	eff. P. rem	eff. o.n. rem	eff. t.n. rem
1	0,03	3,89	1E-8	1E-8	1E-8	1E-8
2	24,81	64,68	1E-8	1E-8	45,18	29,89
3	42,13	78,93	38,56	1E-8	70,24	60,93
4	55,88	86,91	65,72	1E-8	83,85	78,4
5	67,24	91,68	81,07	1E-8	91,23	88,09
6	76,92	94,57	89,58	1E-8	95,24	93,43
7	85,33	96,38	94,26	1E-8	97,42	96,37

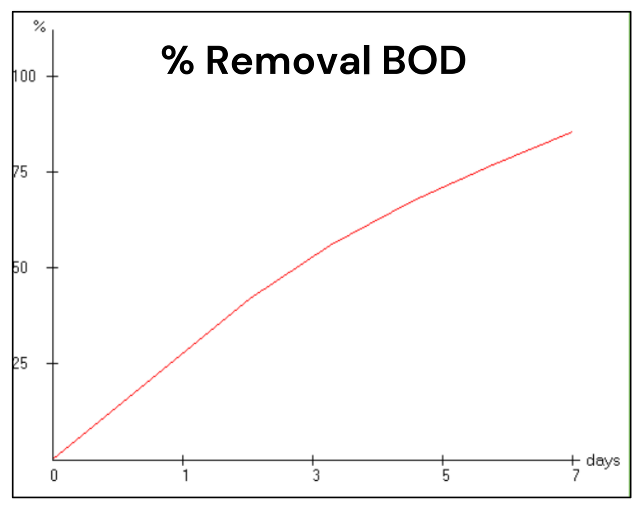


Table 3. Comparison % Removal Hybrid System UNIVA, Calculated Design and Simulation. Own Elaboration

Parameter	% Removal		
	UNIVA[1]	Calculated	SUBWET 2.0
BOD	96,6%	97,0%	85,3%
Total N	73,5%	73,0%	96,4%
Total P	Increased	55,0%	0,0%

Discussion

A subsurface flow constructed wetland was designed to improve the efficiency of a hybrid pig farm wastewater treatment system by consolidating two units into one and eliminating the maturation pond. Based on literature, **an 18 m² wetland with a 7-day retention time was proposed** to meet removal targets for BOD, COD, grease, oils, solids, nitrogen, and phosphorus..

SubWet 2.0 was used to validate the design, confirming a <u>BOD removal efficiency of 85.3% and higher-than-expected total nitrogen removal, 96,4%.</u> However, the wetland was insufficient in removing phosphorus, indicating the need for additional treatment.

While the program offers valuable insights, **limitations** such as the inability to input decimal values reduce precision. Testing different scenarios or obtaining field data is recommended for better system configuration.

By consolidating the wetlands into one and removing the maturation pond, the design optimized space and reduced costs while maintaining high pollutant removal efficiency. Despite the software's limitations, it remains useful for predicting system responses to variable wastewater volumes and optimizing treatment systems.

Red tezontle proved highly effective for BOD and nitrogen removal in the constructed wetland, with its porous structure enhancing filtration and adsorption.

References

[1] Pascoe, Sandra. , et al. (2019). Diseño Y Construcción de un Sistema de Tratamiento Vía Humedal para el Lixiviado de un Biodigestor de Desechos.
[2] Metcalf & Eddy (2014). Wastewater Engineering: Treatment and Resource Recovery.
[3] Vymazal, J. (2010). Constructed Wetlands for Wastewater Treatment. Water.
[4] Wallace, S. D., & Knight, R. L. (2006). Small-Scale Constructed Wetland Treatment Systems: Feasibility, Design Criteria, and O&M Requirements. U.S. EPA.
[5] Tchobanoglous, G., et al. (2003). Wastewater Engineering: Treatment and Reuse.
[6] Henze, M., et al. (2008). Biological Wastewater Treatment: Principles, Modelling, and Design.
[7] Grady Jr, C. P. L., et al. (2011). Biological Wastewater Treatment.
[8] Hammer, D. A. (1996). Creating Freshwater Wetlands. CRC Press.
[9] Kadlec, R. H., & Wallace, S. D. (2009). Treatment Wetlands. CRC Press.
[10] EPA. (1999). Wastewater Technology Fact Sheet: Activated Sludge.
[11] Vymazal, J. (2011). "Plants used in constructed wetlands with horizontal subsurface flow: a review." Hydrobiologia, 674(1), 133-156.
[12] EPA (1999). Manual: Constructed Wetlands Treatment of Municipal Wastewaters. U.S. EPA
[13] Vymazal, J. (2007). Removal of nutrients in various types of constructed wetlands. Science of the Total Environment, 380(1-3), 48-65
[14] Jiménez-Pérez, M. , et al. (2014). "Use of Red Tezontle and Pumice in Constructed Wetlands for Domestic Wastewater Treatment." Ecological Engineering, 70, 72-77
[15] Pascoe, Sandra. , et al. (2020). Biological Treatment for Liquid Waste Generated in Livestock Processes
[16] Bachand, P. A. M., & Horne, A. J. (2000). "Temperature Effects on Ammonification and Nitrification in Constructed Wetlands." Water Science and Technology, 41(3), 145-152. This study discusses the influence of temperature on ammonification processes in wetland systems.
[17] National Meteorological Service (SMN) of Mexico
[18] Pérez, C., & Carrillo, G. (2011). "Hydraulic Conductivity of Soils for Rainwater Harvesting in Mexico." Journal of Environmental Engineering and Science, 10(6), 501-509.
[19] Vázquez, F., & Reyes, E. (2004). "Physical and Chemical Properties of Tezontle." Geofísica Internacional, 43(2), 101-108.

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