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Preliminary Feasibility of Using Natural Wetland for University Wastewater Treatment: A Case Study

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Abstract

Wetlands contribute to water quality improvement and play an important role in the global carbon cycle. As such, wetlands can sequester carbon and mitigate greenhouse gas emissions. This study utilized a survey as a preliminary investigation of the feasibility of using natural wetlands for university wastewater treatment. A total of 13 natural ponds containing water from rainfall and some discharge from the Rotating Batch Contractor (RBC) in MFU were selected. Of all the 13 ponds, the pond at the stadium was selected as the most suitable, due to the following physical and chemical parameters: slope was<5%, maximum depth was 3.1 m, mean temperature of 24.5°C, dissolved oxygen 6.31 mg/L, pH 7.56, TDS 180 ppt, electrical conductivity 253 μS/cm, and containing 2.35% organic matter. Total cost and carbon emissions were compared between RBC and the proposed natural wetland. Construction, operation and maintenance costs of natural wetland were very low compared with RBC due to no chemical, electricity and skilled staff required. Similarly, the lower electrical consumption of the natural wetland resulted in reduced carbon emissions of 102.9 kg CO_2e per year. This preliminary result can be used to select possible options for university wastewater treatment.

Keywords: Natural wetland; Feasibility; University; Wastewater

Introduction

Wastewater treatment systems have proliferated in recent years as a response to environmental impacts of untreated water disposal from manufacturing and other human activity [1], among the range of approaches, each has its own unique strengths and performance characteristics [2]. Wetlands are defined as areas of land where the water table is either permanently close to the surface, or the land is intermittently or permanently covered by water [3]. Wetlands offer an interesting alternative to technology-intensive treatment systems in certain localities [4]. Moreover, such systems provide critically important ecological habitats [5], and serve as a protective buffer against storms by water storage and flood abatement, and against erosion damage [3]. Moreover, wetlands play a crucial role in the global carbon cycle, sequestering carbon and mitigation the impacts of climate change [6]. A study on balancing carbon sequestration and greenhouse gases emissions in a constructed wetland has showed that wetlands can be regarded as a net CO_2 sink, with net sequestration ranging from 0.27-2.4 $kgm^{-2}y^{-1}$, corresponding to 12-67% of CO_2 fixation of the biomass [7]. Based on this logic, wetland restoration jobs can be considered as green and low-carbon jobs [8].

Educational institutions such as boarding schools or universities are comparable to communities in terms of their high water consumption, averaging from 150-300 liters/capita/day [9]. Wastewater from Mae Fah Luang University typically comprise organic matter, odors and suspended solids, and use similar wastewater treatment systems to those used in the surrounding community. As an institution that prides itself as green university, the university aspires to be a model for communities in terms of wastewater treatment, by reducing energy consumption and eliminating pollution to its barest minimum. In order to investigate the feasibility of alternative methods of wastewater treatment, their economic viability, energy consumption and environmental impacts must first be assessed. Natural wetlands are inexpensive in terms of capital cost, and have a low labour and energy requirement compared with conventional wastewater treatment methods [1, 10-12]. Agencies such as universities should therefore assess the suitability and viability of local water bodies and wetlands as a solution to their institutional wastewater treatment needs.

For this reason, it is important to gain insights into the contributions of wetlands and their environmental benefits, due to their unique ecological roles in nutrient cycling, erosion control and pollution filtration [13]. This study aimed to investigate the physical and chemical characteristics of ponds, costs of land and plant operation analysis and environmental concerns over carbon emissions from plant operation. The study also aimed to assess the overall feasibility of using the ponds as natural wetlands for University wastewater treatment.

Materials and methods

1) Study site

Mae Fah Luang University (MFU) is located in Chiang Rai Province, northern Thailand. The university has area of 7,995,200 m^2 with more than 15,000 people. Four plants of Rotating Biological Contactor (RBC) are used for university wastewater treatment and the wastewater routes are shown in Figure 1. The University was selected for studying the preliminary feasibility of using natural wetland for wastewater treatment as the landscape ponds fill the 2.5% of the university area (excluding forest area).

2) Sampling method

During the autumn 2015, the researcher surveyed the location of wetlands in the University and investigated both physical and chemical characteristics of water and soil in the wetlands, including slope, size, depth and volume, measured using length measurement equipment and Google Earth calculation. Chemical parameters were assessed through sampling using the grab method. Temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), total dissolved salt (salinity), and electrical conductivity were measured using WTW 350i/SET multi-parameter (Germany), EUTECH-Salinity and EUTECH-TDS meters. Soil samples were was collected using blades, then classified. Soil organic carbon and organic matter were analyzed using the standard method [14-15] at the Environmental Health laboratory, Mae Fah Luang University.

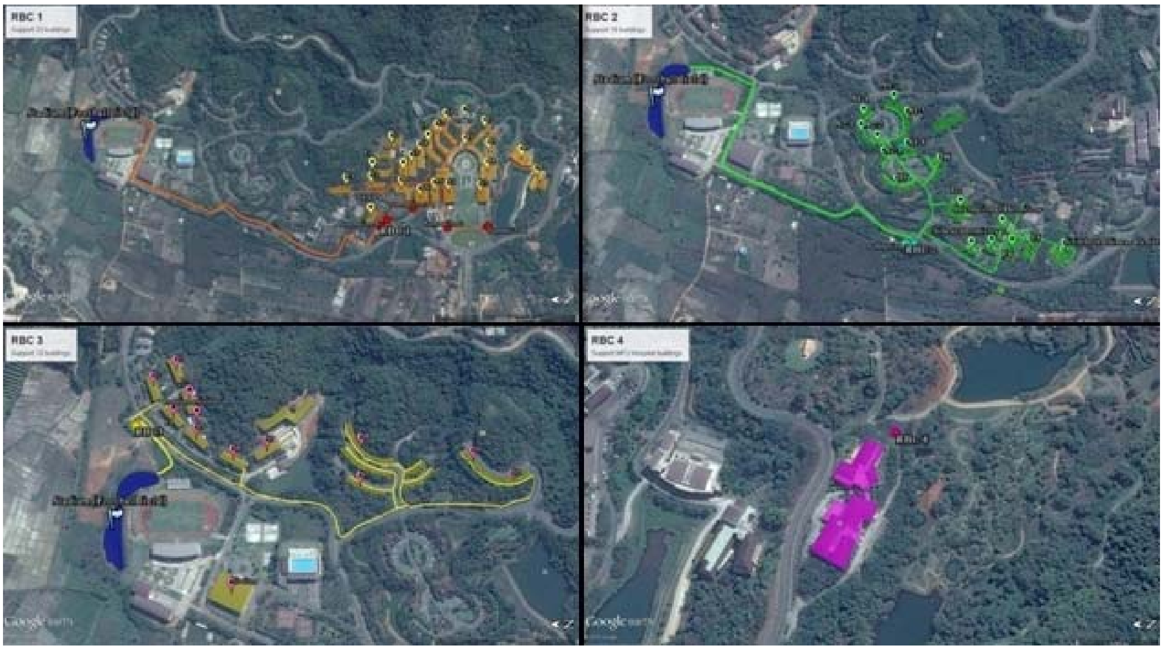

Figure 1 Wastewater pipe routes to four wastewater treatment plants in MFU.

3) Feasibility study

To evaluate the preliminary feasibility of using ponds in university as natural wetlands for wastewater treatment, itis necessary to characterize the physical and chemical parameters, routes of wastewater decomposition, and physical and chemical characteristics of the soil and water in the wetlands under consideration. Costs and carbon emissions in operation were also considered and compared with those of conventional wastewater treatment plant and natural wetlands. Cost analysis of the conventional plant operation was calculated based on actual costs in 2014, while the costs of treatment via natural wetlands was calculated based on estimated costs. Cost estimates were conducted based on the following parameters: land cost, construction, operation and maintenance (OM), as shown in Eq. 1 [16-17]. Operation and maintenance costs (OM) were estimated based on three proxies: electricity consumption, chemical use and staff costs.

$$\text{Total cost} = \text{Land} + \text{Construction} + \text{OM} \qquad \text{(Eq. 1)}$$

Calculation of carbon emissions was based only on electricity use as a proxy, as shown in Eq. 2. The emission factor used was 0.5610 kg CO_2e [18-19].

$$CO_2 \text{ emission} = \text{Activity data} \times \text{emission factor} \qquad \text{(Eq. 2)}$$

To inform decision-making in designing a wastewater treatment system for MFL University, key-wetland characteristics including pollutant loading, cost analysis and carbon emissions were measured to determine the preliminary feasibility of using natural wetlands for wastewater treatment.

Results and Discussion

1) Wastewater characteristics and route pipes

Figure 1 shows the university wastewater routes and plant locations. The Rotating Batch Contractor in MFU has supported wastewater treatment from buildings for 17 years since the university was established. These treatment plants are separated into 4 plants installed in different areas around the university. The Rotating Batch Contractor Plant 1 (RBC 1) supports 23 buildings including the laboratory building, classrooms and office buildings. The Rotating Batch Contractor Plant 2 (RBC 2) supports 16 buildings, most of which are residential. Rotating Batch Contractor Plant 3 (RBC 3) supports 13 buildings. Most of these are also residential except, for the stadium and indoor gym.

The Rotating Batch Contractor Plant 4 (RBC 4) supports the MFU hospital building.

The characteristics of wastewater from the university's activities are summarized in Table 1. Results showed that the influents of RBC system averaged 313.0 m³/day on weekdays, and 260.0 m³/day, at weekends. Effluent levels on weekdays reached 146.0 m³/day and 144.0 m³/day on weekends. Laboratory analysis indicated that BOD, COD and TSS influent concentration of the university were very low, while TDS influent concentrations were at the weak-medium level [9]. The university's wastewater contained high levels of dissolved solids due to on-campus activities. However, BOD, TSS and TDS concentrations in the effluent were within the standard ranges.

2) Physical and chemical characteristics of wetland

The study focused on 13 natural ponds in MFU, fed by rainfall and discharge from the Rotating Batch Contractor (RBC) (Figure 2).

Table 1 Wastewater flow rate and influent and effluent characteristics from RBC*

Items	Influents		Effluents		Discharge Standard [20]
	Weekday	Weekend	Weekday	Weekend	
Flow rate (m³/d)	313.0	260.0	146.0	144.0	
TSS (mg/L)	103.5		18.0		<30
TDS (mg/L)	366.0		324.0		<500
BOD (mg/L)	33.0		1.0		<20
COD (mg/L)	120.0		18.0		-
Total phosphorus (mg/L)	1.2		1.1		-
Total coliform (MPN/100 mL)	676		627		-
E-coli (CFU/100 mL)	406.25×10^{6}		115.25×10^{6}		-

Note: Values presented are the average values of RBC 1, 2 and 3.

Figure 2 Thirteen natural ponds on the MFU campus: (1) MFU Hospital, (2) E2 Reservoir, (3) AV Reservoir, (4) M-square Reservoir, (5) A1-1 (staff dormitory, (6). A1-2 (staff dormitory), (7) A2-1 (staff dormitory), (8) A2-2 (staff dormitory), (9) AD2 (Reservoir), (10) Lamduan Hotline, (11) Lamduan 2, (12). Stadium, and (13) Ruan Rim Num.

E2 reservoir is 253 m long and covers an area of 12,129 m^2; with a storage capacity of 23,000 m^3. Its maximum depth is 3.1 m and the average water temperature is 27.75°C. The MFU Hospital pond has the largest area (43,202 m^2, with storage capacity of 35,000 m^3 and average water temperature of 28.15°C). The AD2 reservoir for staff residences has the largest area (14,445 m^2, depth of 2.6 m, storage capacity of 5,300 m^3, 175 m in length and slope of 4.5%).

In terms of chemical characteristics, measurements found that the E2 reservoir has a pH level of 7.7, DO 6.05 mg/L, TDS 150 mg/L, and electrical conductivity of 206 µS/cm. The MFU hospital reservoir had a pH of 7.8, dissolved oxygen 7.25 mg/L, TDS 90 mg/L, and electrical conductivity of 128.7 µS/cm (see Table 2).

Table 2 summarizes the survey results, which identified the stadium reservoir as the pond with most suitable physical characteristics as a natural wetland for wastewater treatment. The storage capacity of the stadium reservoir for wastewater receiving covers the area approximately 7,222 m^2 with its average depth of 3.1 m (measured from water surface level to the bottom excluding space above water surface), and slope below 5%. The efficiency of pollution removal in such wastewater systems largely depends upon surface area. This pond fits the selection parameters in previous studies to identify water bodies for use in wastewater treatment [5, 13, 21]. Three of the remaining 12 reservoirs (Lamduan, AV and M-square) are also suitable for used as wetland wastewater treatment systems (Table 2). The Lamduan reservoir is appropriate because of the condition of the route of wastewater, depth of pond and slope. The other two large areas and slope can support wastewater but there is a need to build a new route to connect both RBC and natural ponds. With regard to soil texture, results showed that E2, M-square and AD2 are loam while A1-1, Ruan Rim Nam and Lamduan 2are sandy loam, Stadium, A2-2 and A2-1 have sandy clay soils.

3) Preliminary Feasibility Study Results

As noted above, the Stadium Reservoir was the only pond with the appropriate physical characteristics for use as a natural wetland for wastewater treatment. Therefore, the cost of land, construction, operation and maintenance were calculated to determine total cost, in order to compare between RBC and natural wetland. Moreover, carbon emissions of the two systems were also compared based on electricity consumption. Table 3 shows construction cost for the existing RBC treatment system was Baht 189,824,334. Operation and maintenance costs were also high due to the fact that the University uses a rotating biological reactor wastewater treatment system and UV disinfection, incurring high maintenance and repair costs. However, since 2014, costs have been reduced by a change to from UV treatment to chlorination. Nevertheless, the cost of chemicals and requirement for trained professional staff remain important cost factors for operation and maintenance.

The economic analysis showed the total cost of the natural wetland system including cost of land was Baht 5,459,088, while total cost excluding land cost was Baht 42,588. Thus, the total cost of the natural wetland option is very low compared with RBC, due to their cost-effectiveness, and ease of operation and maintenance [22]. Furthermore, carbon emissions of RBC were 4,237.59 kg CO_2e/year, compared to only 102.9 kg CO_2e/year for natural wetland. This gives the natural wetland method a clear advantage in terms of its environmental footprint, comparing with the RBC method currently used.

Table 4 presents the physical and chemical characteristics of the natural wetlands in terms of its suitability for waste water treatment.

Table 2 Physical and chemical characteristics of survey natural wetlands in the university

Location	Physical characteristics					Chemical characteristics								
						Water						Soil		
	Size (m^2)	W (m)	D (m)	Vol. (m^3)	Slope (%)	Temp. (°C)	pH	DO (mg/l)	TDS (ppm)	Salinity (ppt)	Electrical conductivity (µS/cm)	Type	%OC	%OM
MFU Hospital	43,202	Na	Na	35,000	Na	28.15	7.8	7.25	90	0.1	128.7	Clay	1.43	2.46
E2 Reservoir	12,129	253	3.1	23,000	3.6	27.75	7.7	6.05	150	0.1	206	Loam	1.82	3.13
AV Reservoir	3,039	67	3	4,500	4.4	26.7	7.4	9.81	280	0.2	377	Loam	1.27	2.18
M-square Reservoir	8,115	108	3.5	4,000	3.2	27.35	7.6	10.35	210	0.2	290	Loam	1.07	1.85
A1-1 (staff dormitory)	1,089	41.11	3.4	Na	8.2	24.13	7.5	6.86	70	0.1	98	Sandy Loam	2.11	3.64
A1-2 (staff dormitory)	1,213	58.3	1.5	1,800	2.5	27.4	7.51	8.29	70	0.1	101	Clay	1.59	2.74
A2-1 (staff dormitory)	Na	130	2.4	Na	5.5	24.82	7.4	7	100	0.1	126.9	Sandy Clay	2.31	3.97
A2-2 (staff dormitory)	Na	104	1.6	Na	4.6	25.5	7.4	7.28	130	0.1	176.3	Sandy Clay	1.72	2.97
AD2 (Reservoir)	14,445	175	2.6	5,300	4.5	25.5	7.4	6.11	120	0.1	168.7	Loam	1.01	1.74
Lamduan Hotline	729	45	1.7	1,500	3.8	27.02	7.5	8.2	230	0.2	321	Clay Loam	2.37	4.09
Lamduan 2	2,244	31	0.9	4,500	2.9	24.5	7.57	3.69	180	0.1	250	Sandy Loam	2.86	4.93
Stadium	7,222	254	3.1	10,000	3.7	24.5	7.56	6.31	180	0.1	253	Sandy Clay	1.36	2.35
Ruan Rim Num	6,391	158	3.6	15,000	6.8	24.95	7.6	5.51	80	0.1	109.8	Sandy Clay	1.88	3.25

Note: W = Wide, D = Depth, OC= Organic carbon and OM = Organic matter

Table 3 Cost comparison between the operation of RBC and natural wetland in university

Cost (Baht/Year)	RBC	Natural Wetland	
		Case 1: With land cost	Case 2: Without land cost
Land	NA	5,416,500	-
Construction *	189,824,334	-	-
Operation	98,850	-	-
Maintenance	1729	42,588	42,588
Staff (estimated)	1,260,000	-	-
Electricity (10 months)	1,681,426	-	-
Total	192,866,339	5,459,088	42,588
Environmental friendly	**Carbon emissions (kg CO_2e/year, electricity used base)**		
	4,237.59	102.90	

Note: * Construction since 2001

Table 4 Summary of the natural wetland characteristics for wastewater treatment in MFU

Size (m^2)	D (m)	Vol (m^3)	Slope (%)	Temp. (°C)	pH	DO (mg/l)	TDS (ppm)	Salinity (ppt)	Electrical conductivity (µS/cm)	Type	%OC	%OM
7,222	3.1	10,000	3.7	24.5	7.56	6.31	180	0.1	253	Sandy Clay	1.36	2.35

Flow rate	Cost (Baht)		Carbon emission
	Case1: Calculate land cost	Case2: Not calculate land cost	
548.16 m^3/day	5,459,088	42,588	102.9 kg CO_2e/year

Note: W = Wide, D = Depth, OC= Organic carbon and OM = Organic matter

Conclusion

In this study, of all the 13 ponds surveyed, the Stadium reservoir was found to be the most feasible in terms of the composition of the natural wetland. In terms of total cost and eco-friendliness, it was found that natural wetland method offers lower costs and reduced carbon emissions compared to the existing wastewater treatment, which requires chemicals, electricity and skilled staff for operation. Further work is needed to build on this preliminary study, in order to investigate wetland biological characteristic, wetland health assessment, actual treatability and GHG emissions of wetland operation, in order to make a full assessment to inform decision making and recommend improvements to existing ponds or natural wetlands for wastewater treatment at MFU.

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