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WASTEWATER TREATMENT SYSTEMS AND THE IMPLEMENTATION OF CONSTRUCTED WETLANDS IN ATITLÁN LAKE BASIN, GUATEMALA

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Abstract

High population growth and an augmented tourist industry in the Atitlán basin have lead to increases in the amount of wastewater discharged into the lake. The polluted wastewater has a negative effect on the lake's and streams' ecosystem in the basin. Drinking water that is taken from the lake or the streams is highly polluted as a result of the wastewater mismanagement. There are seven centralised treatment plants in different communities in the basin but they function poorly or are completely out of function due to lack of economic resources, skill and competence, political problems, and natural catastrophes. In order to improve the wastewater management in the basin, an inexpensive system with swift installation is proposed and designed for small communities. The system includes a septic tank followed by a constructed horizontal subsurface flow wetland. The design of the system considers the topography, climate, economic limitations, land limitation due to agriculture, and culture within the basin.

Key words – Atitlán Lake, Guatemala, wastewater management, subsurface flow wetland, decentralised systems

Introduction

Lake Atitlán, situated in Guatemala's highlands has a surface area of 125 km^2. There are 15 municipalities within the catchment of a total surface area of 548 km^2. The catchment has approximately 196,000 inhabitants of which 92 % are aborigine of Mayan descent. Atitlán Lake receives polluted, untreated, wastewater from the communities within the basin. Due to the economic limitations in Atitlán region, one feasible option to treat the waste water is a constructed wetland system. The system has many advantages that makes it a suitable solution to solve the present problem. It is a technique that involves low cost construction, operation and maintenance. It is easy and cheap to implement and requires only low skilled operators. Normally the disadvantage of a constructed wetland is the requirement of a large area. However, due to the reasonable land prices in the Atitlán Lake basin this factor no longer serves as an obstacle. A local non-governmental organization (*Pro-Lago*) is intending to implement the system to treat grey and domestic wastewater for small communities with a maximum of 50 households. The system has primary treatment consisting of a septic tank and secondary treatment consisting of a constructed horizontal subsurface flow wetland. The system is to be tested in a pilot project in a small community in upper basin. This article is an excerpt from the master thesis developed by the authors at the department of Water and Environmental Engineering of Lund University (LTH), Sweden.

The system is intended to treat septage from septic tank for grey and domestic wastewater for small communities up to 50 households. The design parameters and analysis is based on BOD loading, size of community and hydraulic conductivities. Local materials and resources are used for construction.

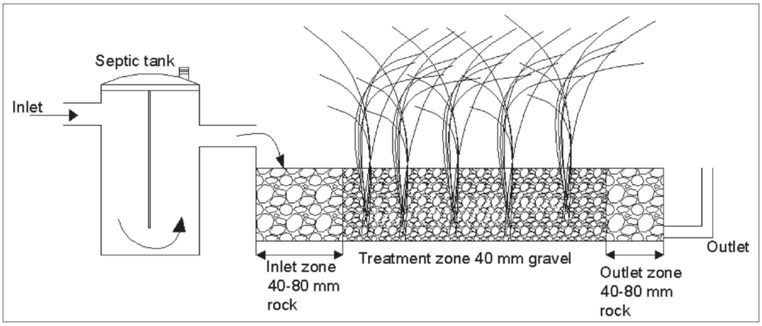

Figure 1. *The treatment system including the septic tank and the constructed horizontal subsurface flow wetland.*

The treatment system

Main idea

The main idea is to develop a relatively simple and economic solution for the treatment of wastewater from small communities in the rural area of the Atitlán basin. The treated wastewater shall fulfil the local wastewater discharge limit of 30 mg BOD/l. The system is designed to treat grey or domestic wastewater with BOD values up to 100 and 300 mg/l, respectively. The design of the channelised wetland is to be made with a predefined cross-section.

The system is to be run in a pilot project in a small community in the upper basin named Argueta. If this project is successful, the system will be applied in other communities. These communities should not have more than 50 households connected to the sewer system with an average of 6 people per house and the water consumption for respective community is 30 l/person/day. Neither industries nor commercial activities are considered in these communities.

System description

The system has both primary and secondary treatment. The primary treatment consists of a prefabricated septic tank. In the particular cases where the households already have a septic tank the centralised septic tank is use as a secondary septic tank. The size of the tank depends on the number of households connected to the system. The secondary treatment consist of a wetland. Figure 1 shows the treatment system.

Primary and secondary treatment

The raw wastewater passes through the septic tank in order to reduce suspended solids and BOD. The wastewater pre-treated in the septic tank passes through the inlet, the treatment and the outlet zone of the wetland. In the inlet and outlet zones which are two and one meters long respectively, the particle media size is in the range of 40 to 80 mm. The gravel media size in the treatment zone is within the range of 30 to 40 mm. In the treatment zone local aquatic plants, Reed species (*Typha dominguenis*), are present. In order to protect the channel from surface run-off, and to keep the geo-membrane in place, a berm built with soil from the area is constructed on each side of the channel. The berm should have a minimum height of 0.15 m. Figure 2 shows the cross-section of the wetland.

Since the wetland is to be constructed along agriculture land, width limitation is one of the design criteria. It is therefore suggested that the wetland is constructed as a channel. The available space for the constructed channel is 1 m wide at the top surface, which means that the lengths has to be selected according to the size requirement. The sides and the bottom of the channel are covered with a geo-membrane that prevents seepage into the groundwater and soil erosion into the wetland. The depth of the bed should be 0.6 m. This depth is commonly used in the construction of SSF wetland (Steiner

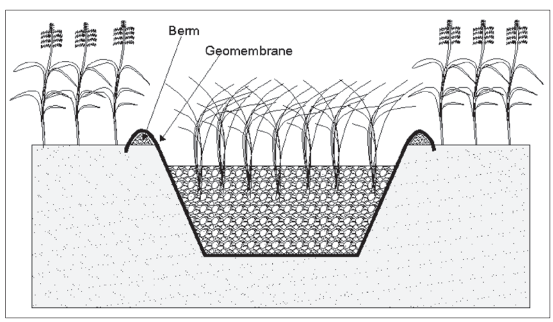

Figure 2. *Cross-section of the wetland constructed as a channel covered with geo-membrane passing through a cornfield. A berm is constructed on each side of the channel.*

G.R. and Freeman, R.J. n.d.). In order to maximize stability it is suggested that the channel slope is constructed with a vertical-horizontal ratio of 1:0.5, which approximately corresponds to 63º.

Septic tank

The raw wastewater is to be treated in a septic tank as primary treatment in order to reduce the amount of suspended solids and BOD coming into the wetland. The volume of the accumulated sludge in the tank and the retention time is used as design parameters. The septic tank should be able to reduce at least 60 % of the incoming BOD in order to reduce the length of the wetland. Based on empirical evidence, the retention time for a septic tank should be at least 24 hours in order to remove 60 to 70 % of the incoming BOD (Crites and Tchobanoglous, 1998). Due to sludge accumulation on the bottom of the tank, the volume of the tank reduces with time. It is therefore recommended that the volume of the tank is at least two times the daily average flow. The expected pump out frequency for this volume is once a year. The septic tank that is to be used for the system is prefabricated and can be bought from different vendors in Guatemala.

Design of subsurface flow wetland based on first order plug flow model

The primary purpose of the system is to remove BOD from the wastewater and BOD is therefore chosen as a critical parameter in the design. The wetland is designed as a channel with a limited width and can therefore be calculated as a plug flow reactor where the wastewater moves as a front in one direction (along the channel). Most similar systems in the US and Europe, whose design is based on kinetics, use a first order plug flow model (EPA 1993). Process kinetics for BOD removal is given by equation (1):

$$\frac{C_e}{C_0} = e^{(-k_T t)} \tag{1}$$

Where:

C_e = BOD concentration in the effluent (mg/l)
C_0 = BOD_5 concentration (mg/l) coming from the septic tank
k_T = rate constant (days^{-1}), at temperature T (ºC)
t = hydraulic residence time (days).

The temperature dependence of the rate constant in equation (1) is given as:

$$k_T = k_{20}\theta^{(T-20°)} \tag{2}$$

Where:

k_{20} = constant rate at 20°C = 1.104
θ = 1.06 (EPA, 1993).

The hydraulic residence time t in equation (1) is defined as:

$$t = \frac{nLA}{Q} \tag{3}$$

Where:

n = effective porosity of the media (%)
L = length of the bed (m)
A = cross-section of the bed (m^2)
Q = average flow through the bed (m^3/day).

Combining equations (1) and (3) gives:

$$\frac{C_e}{C_0} = e^{(-k_T nLA)\ /\ Q} \tag{4}$$

Which can be rearranged as follows:

$$L = \frac{Q\left[\ln\left(\frac{c_0}{c_e}\right)\right]}{k_T nA} \tag{5}$$

Due to the fact that the cross-section area, flow and BOD concentration is assumed constant for a particular community, the length of the wetland can be defined from equation (5).

Dividing the wetland into cells

Since the Atitlán basin has a pronounced topography with steep slopes, the wetland is divided into cells of 10 m length. It gives different configuration alternatives and the cells can be constructed perpendicular to the slope. Wetland division into cells distributes the hydraulic head loss, avoids surface flow and increases flexibility. In order to calculate the maximum flow that can go through the actual cross-section wetland (0.325 m^2), Darcy's equation (6) is used with K = 3500 m^3/m^2/day (assuming 33 % reduction of initial hydraulic conductivity due to media clogging, EPA, 1993).

$$Q = K * A * \frac{dh}{dl} \tag{6}$$

Where:

Q = maximum flow allowed to pass through the wetland (m^3/day)
K = hydraulic conductivity (m^3/m^2/day)
A = cross-section of the channel (m^2)
dh = head loss (m)
dl = length of the cell (m)

The maximum flow in a 10 m cell length (dl), with a head loss of 7 cm (dh), is *7.96 m^3/day* (Q). The maximum head loss (7 cm), is choose in order to ensure that the aquatic plant roots will always reach the water. The

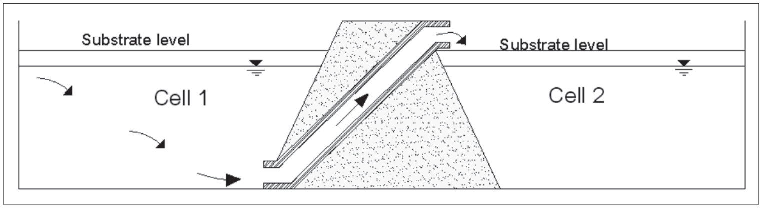

Figure 3. *Two cells connected with a pipe. The wastewater from the upstream cell 1 is collected and discharged at the downstream cell 2.*

number of households that can be connected to one system treating domestic wastewater with this flow (7.96 m^3/day) is 15. According to equation (5) at 18°C, with domestic wastewater from 15 households with BOD concentration 120 mg BOD/l at the influent and 30 mg BOD/l at the effluent, require a length of 40 m wetland, which means a *maximum of 4 cells per system*. If the number of households is more than 15, then another system should be connected in parallel.

Table 1 gives the number of cells for different numbers of household, average and peak flow, and the number of systems that are required. The length of the wetland is calculated according to the first order plug flow model with domestic wastewater at 18°C.

Cell connections

A PVC pipe (or other suitable material) connects two cells as shown in Figure 3. The wastewater flows from the bottom of the upstream cell to the top of the other cell. In that way the hydraulic head is distributed. The connection pipe and the outlet pipe should be able to conduct at least 8 m^3 /day.

Table 1. *Average and peak flow, number of cells and systems for different households calculated according to the first order plug flow.*

Nr. house-holds	Average flow (m^3/day)	Peak flow (m^3/day)	Length of the wetland (m)	Nr. of cells	Nr. of systems
5	1.22	2.43	14	2	1
10	2.44	4.86	27	3	1
15	3.66	7.29	40	4	1
20	4.88	9.72	53	6	2
25	6.10	12.15	67	7	2
30	7.32	14.58	80	8	2
35	8.54	17.01	93	10	3
40	9.76	19.44	106	11	3
45	10.98	21.87	120	12	3
50	12.20	24.30	133	14	4

Configuration alternatives

In the Atitlán basin topography is often the major construction limitation. It is therefore recommended that the cells are connected according to topography. The cells can be connected in parallel or in series. However, it is recommended to connect the cells in parallel, if topography permits, in order to distribute the flow in the system. Be aware that due to difference in water depth along the wetland and the change in hydraulic conductivity, SSF bed slope should be 2% or less (Watson et al n.d.).

Conclusion

The constructed horizontal subsurface flow wetland provides a reliable solution for wastewater treatment in Atitlán Lake basin. The system can be swiftly installed, in a matter of days and can be constructed anywhere in the basin. The high flexibility of the system is an important parameter due to the rough topography of the basin. However the system has not tested yet.

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