APPLICATION OF NATURAL TREATMENT SYSTEMS FOR WASTEWATER POLLUTION CONTROL IN THE EXPANSION AREA OF CALI, COLOMBIA

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ABSTRACT

The aim of the present work is to investigate the possibility to apply natural treatment systems in the future expansion area of Cali, Colombia. This area is planned to be a residential zone; extrapolation of current data predicts a future population of 238,916 inhabitants with an average water demand of 142.8 l/s. Several (conventional) alternatives are already designed for the water management of the area. In this work, alternatives concerning anaerobic facultative and maturation ponds, sub-surface flow constructed wetlands, rock filters and fishponds are considered. The comparison in terms of costs with conventional technologies is performed. Results of the design methodology and cost evaluation confirm the applicability and viability of natural treatment systems in the expansion area of Cali. In particular the alternative that has the best results in terms of area requirements and costs is the one that considers the combination of anaerobic and secondary facultative ponds in series.

KEYWORDS

Constructed wetlands, ecotechnologies, waste stabilisation ponds, wastewater treatment.

INTRODUCTION

Natural treatment systems are largely studied as sustainable and low-maintenance technologies compared with high-end technologies such as activated sludge and membrane filtration. Their application has a strong potential for application in developing countries in which implementation of high-end wastewater treatment is difficult due to the high costs entailed. Moreover natural treatment systems are characterized by the use of natural energies, such as solar and wind energies, and the non-requirement for chemicals resulting in environmental and economic benefits.

The use of natural treatment systems is considered by the SWITCH project of which this work is a part. SWITCH (EU 6th Framework Programme, www.switchurbanwater.eu) develops a new approach in Integrated Urban Water Management, planning new ways for the urban water system of the Cit"y of the Future". The City of Santiago de Cali in Colombia is one of the 10 identified SWITCH Demonstration Cities in which results of the SWITCH research activities are translated into tangible, socially-relevant demonstration activities.

Cali is a 2.1 million inhabitant's city located in the south-west of Colombia in the Cauca Valley, at 958m - 1200m above sea level (Figure 1). The city has a tropical climate with temperatures between 20 and 30 °C and precipitation levels around 1000 mm/year. The future urban expansion area defined in the POT (Land Use Plan) as "Cali-Jamundí" is located in the south of the city and has a surface area of 1653 hectares. Its topography is uniform with a slight descending slope towards the Cauca River (Figure 2). Currently, this area is mostly used for agricultural purposes. Around the area there are several sugar cane culture areas.

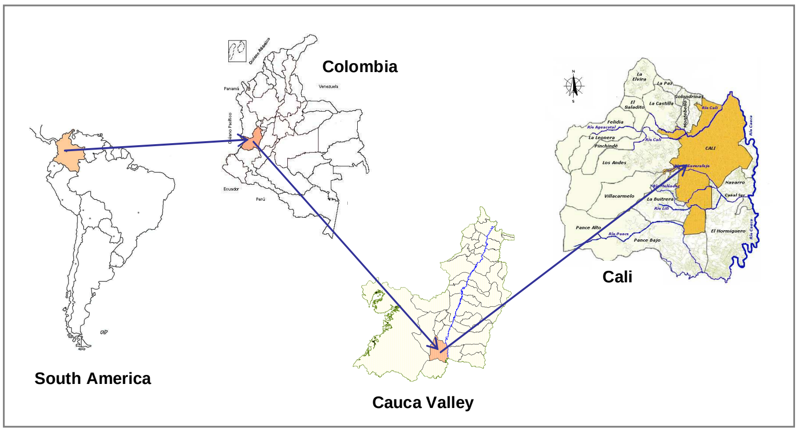

Figure 1. Localisation of Cali within South-America and within Colombia

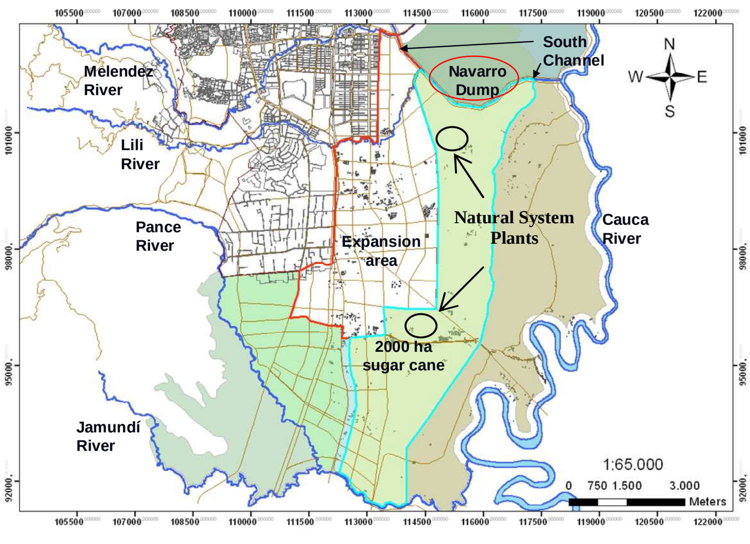

Figure 2. Expansion area localisation with suggested locations for 2 new wastewater treatment plants.

The future urban expansion area of Cali represents an opportunity to implement a wide range of suggested alternatives and new concepts oriented towards sustainable wastewater management. Experiences with natural systems already exist in the Cauca Valley region, such as the anaerobic and facultative ponds in the Cauca Valley municipalities of Guacari, La Unión, Roldanillo and Toro, with BOD_5 removals between 80 and 85%. Other experiences with natural treatment already developed in the area are the full-scale study case in the municipality of Cali (in the rural community of La Voragine) and the pilot-scale case in the municipality of Ginebra (Madera et al., 2003).

The expansion area of Cali will be developed according to the economic status of its inhabitants using the figure of social stratum. The inhabitants of the area belong to strata 3, 4, 5 and 6 that correspond to the middle and upper economical classes. For the estimation of population of the expansion area, density data of Cali from the years 1999 to 2007 were considered; an increase of population density was not found. Population density of the expansion area has been estimated with the average values of other "comunas" of Cali considering the population distribution in strata. Total population of the expansion area of Cali is estimated in a value of 238,916 inhabitants.

To estimate the wastewater production of the expansion area, data of drinking water consumption of the city of Cali have been used. The average water demand is estimated as 142.8 l/s, then considering a return coefficient of 0.8 and estimating a 10% infiltration into sewer pipes, the production of wastewater for the expansion area of Cali has been estimated to be 30,000 m^3/d. For practical and topographical reasons, this flow is equally divided over two treatment plants with a design flow for each plant of 173.6 l/s. The suggested locations of these two plants can be found in Figure 2.

NATURAL TREATMENT SYSTEM DESIGN

For designing the natural treatment systems, several alternatives have been considered, i.e. anaerobic ponds, facultative ponds, maturation ponds, rock filters, sub-surface horizontal-flow constructed wetlands, and fishponds. Design methodologies presented by Mara (1987, 2001, 2003, 2006, 2007), Kadlec and Knight (1996) and Reed et al. (1994) have been implemented. Moreover studies already present in the area have been considered (Peña, 2002; Peña, 2008; Madera et al., 2003).

Two treatments plants have been planned to treat the total wastewater flow estimated in a value of 30,000 m^3/d. Three alternatives have been implemented: (A) primary facultative ponds, (B) anaerobic and secondary facultative ponds in series and (C) anaerobic ponds and sub-surface flow constructed wetlands in series. For each of these three alternatives, the additional implementation of rock filters, maturation ponds and fishponds has also been considered. Detailed system schemes are presented in Figures 3, 4 and 5.

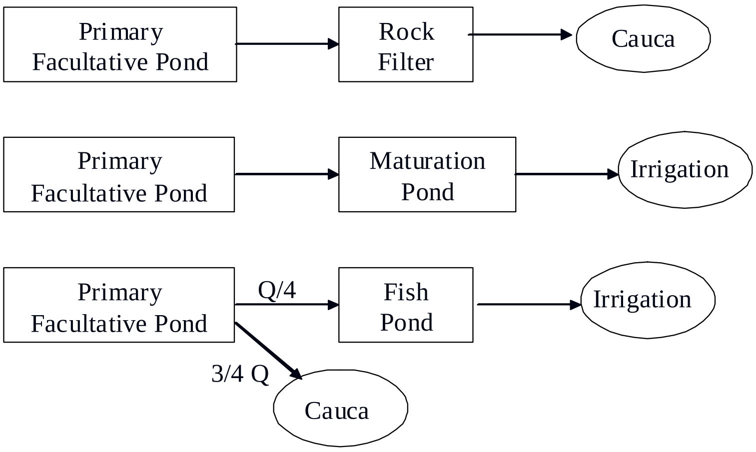

Figure 3. Alternative A

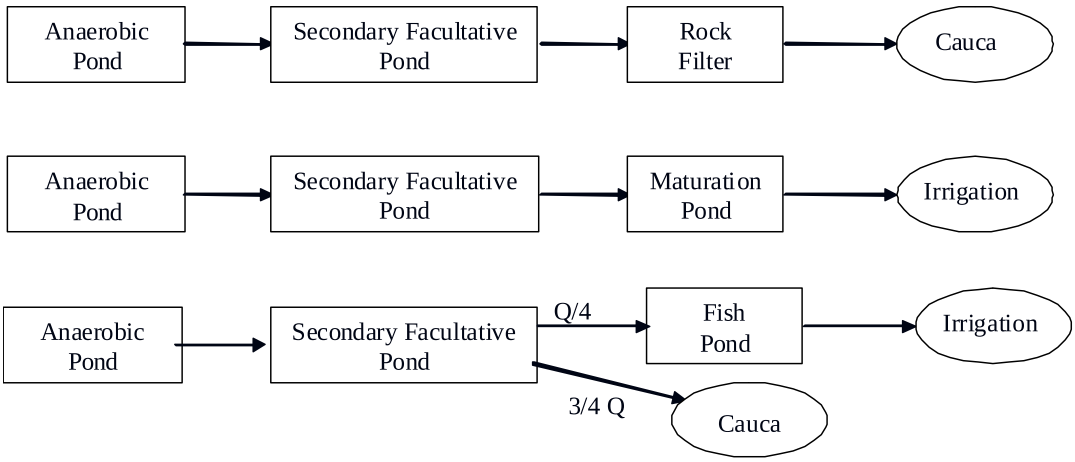

Figure 4. Alternative B

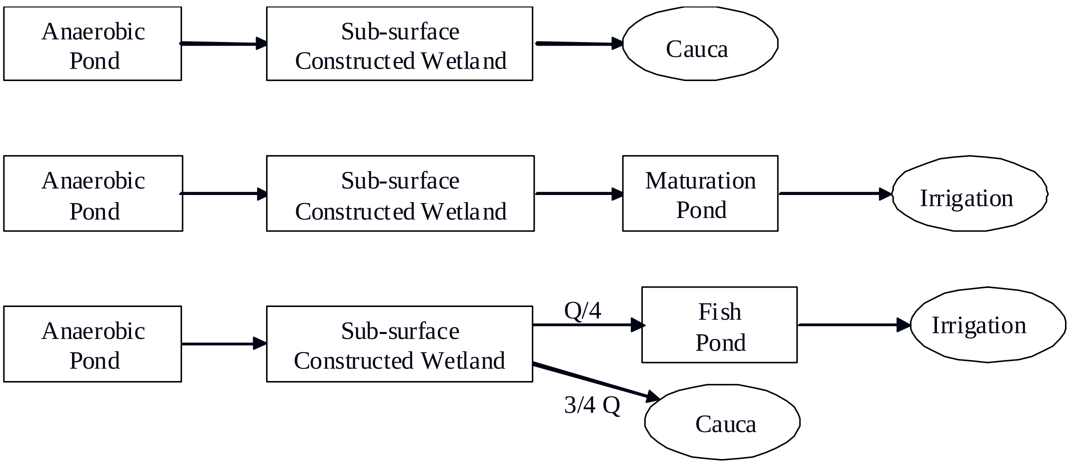

Figure 5. Alternative C

Input data for the design methodology are presented in the following table:

Table 1. Design input data per proposed treatment plant.

Parameter	Value
Influent flow	15,000 m^3/d (Q/2)
Temperature	24 °C
Evaporation	4.8 mm/d
BOD influent	200 mg/l
Total solids influent	188 mg/l
Total Nitrogen influent	51.2 mg/l
Ammonia Influent	18.9 mg/l
Helminthes eggs influent	100 eggs/l
Escherichia coli influent	$5x10^7$ E.coli/100ml
Influent alkalinity	193.6 $mgCaCO_3/l$

Both conventional and high rate anaerobic ponds have been designed. A volumetric BOD loading rate of respectively of 340 and 700 $g/m^3/d$ has been considered. Facultative ponds have been designed with a surface BOD loading rate of 330.5 kg/ha/d. Rock filters are designed for a hydraulic loading rate of 1 $m^3/m^3/d$. Maturation ponds were designed to reach levels recommended by the World Health Organization: < 1 egg/l for Helminthes and 3 log reduction for *Escherichia coli* (for highly mechanised restricted irrigation such as sugar cane cultures).

Fishponds are designed as integrated agricultural-aquacultural alternatives on the basis of a surface loading rate of Total Nitrogen of 4 kgN/ha/d. Partitioning of the influent flow has been necessary to reduce fishpond area requirement.

Constructed wetlands have been designed on the basis of the k-C* model (Rousseau et al., 2004).

RESULTS

Applying the indicated design methodologies yields specifications for each component in terms of required area, volume and hydraulic retention time (HRT). The outcomes of the design exercise are summarized in Tables 2 to 4. It should be noted that these results are referring to one plant (with the second one having equal dimensions).

Table 2. Design parameters – Alternative A

	Area ha	HRT d	Depth m	Length m	Width m
Primary facultative pond	9.08	12.3	2.0	500.0	181.5
Rock Filter	2.43	0.4	0.6	260.0	93.4
Maturation pond	4.34	3.0	1.0	350.0	123.9
Fishpond	22.16	71.3	1.0	800.0	277

Table 3. Design parameters – Alternative B

	Area ha	HRT d	Depth m	Length m	Width m
Conventional anaerobic pond	0.50	1.0	3.0	120.0	41.7
High rate anaerobic pond	0.42	0.75	4.0-2.0	112.5	37.5
Secondary facultative pond	3.97	4.0	1.5	345.0	115.2
Rock Filter	2.47	0.4	0.6	270.0	91.4
Maturation pond	4.41	3.0	1.0	360.0	122.5
Fishpond	23.98	76.7	1.0	840.0	285.4

Table 4. Design parameters – Alternative C

	Area ha	HRT d	Depth m	Length m	Width m
Conventional anaerobic pond	0.50	1.0	3.0	120.0	41.7
High rate anaerobic pond	0.42	0.75	4.0 – 2.0	112.5	37.5
Sub-surface CW	6.44	1.0	0.6	430.0	149.7
Maturation pond	4.38	3.0	1.0	360.0	121.5
Fishpond	32.4	111.9	1.0	950.0	341.1

A comparison of the three alternatives in terms of area requirement and pollutant removal is presented in Table 5 and Figure 6 for the solution that takes into account reuse of the effluent; implementation of maturation ponds was necessary in each scenario in order to reduce pathogens to acceptable levels. The combination of anaerobic and facultative ponds is the best one in terms of area requirement. The cost evaluation that is presented in the next section confirms this conclusion.

Table 5. Comparison of removal efficiencies.

	BOD %	TSS %	Total Nitrogen	Ammonia %	Helminthes %	E. Coli %
Facultative + Maturation Ponds	84.1	82.5	52.4	31.5	99.96	99.91
Anaerobic + Facultative + Maturation Ponds	81.3	93.9	49.4	21.9	99.83	99.96
Anaerobic + CW + Maturation Ponds	95.3	94.3	31.1	40.9	100.00	99.00

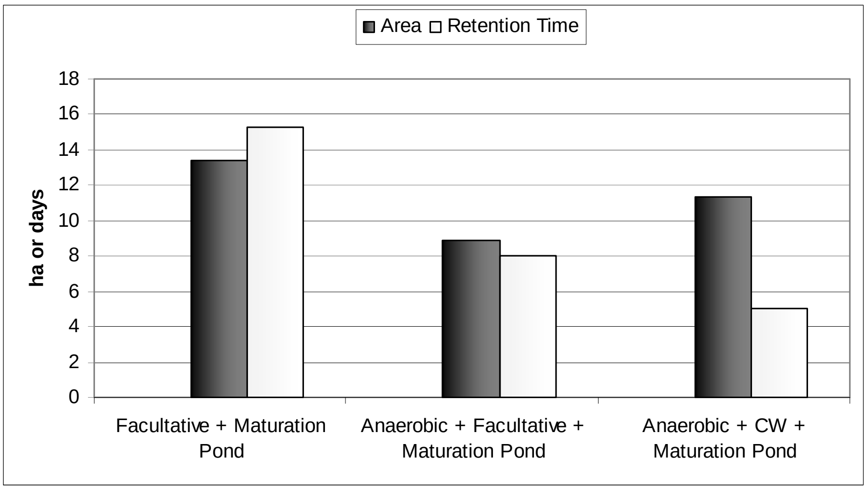

Figure 6. Area requirements (ha) and retention times (days) for the effluent reuse scenario.

COST EVALUATION

Costs were analyzed taking into account construction as well as operation and maintenance costs. Four main items have been considered to estimate construction costs: land, excavation, basin sealing and gravel. Costs of El Cerrito Project (2007/2008) in the same department of Cali were used to calculate the construction costs.
Operation and maintenance costs have been estimated taking in account the costs per inhabitant for natural treatment systems as given by the World Health Organization (WHO, 2006), in which O&M costs per year are considered as 5% of the construction costs. O&M costs are estimated with the calculation of the net present value and considering an annual inflation of 5%.
Comparison with two high-end alternatives planned by local institutions is possible. These alternatives consider: (1) pumping the wastewater to the existing wastewater treatment plant of Cañaveralejo (and upgrade from enhanced primary treatment to activated sludge); (2) the construction of a new activated sludge treatment plant near the expansion area (Ww-TP South).
In Figure 7 a comparison between natural and high-end technologies is proposed. Costs in Figure 7 are referring to a situation in which the two natural treatment plants are built in one single stage and the operation and maintenance costs are evaluated with the net present value for a period of 20 years.

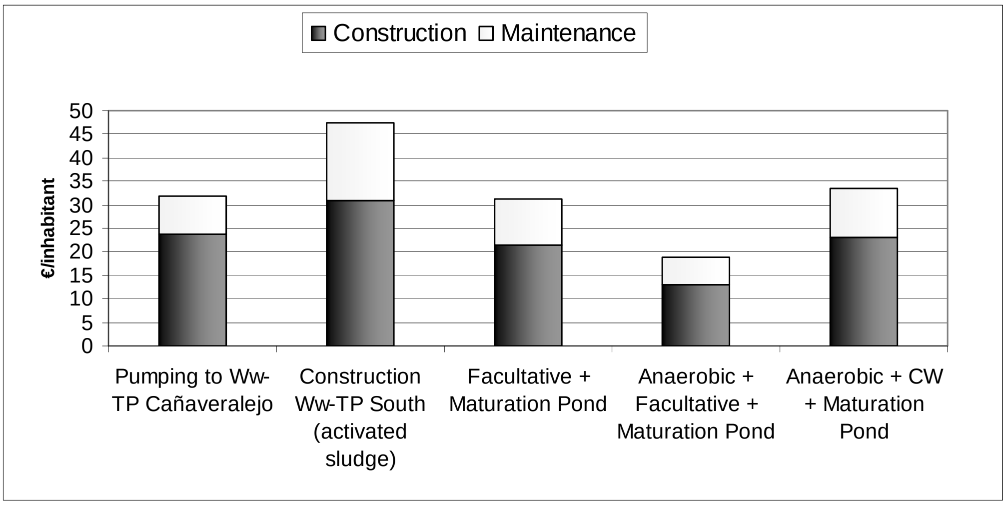

Figure 7. Conventional and natural systems comparison – costs per inhabitant.

All the natural systems have economical benefits when compared with the construction of the new wastewater treatment plant with activated sludge WwTP-South; moreover the effluent of natural system is better and can be used for crop irrigation.
The costs of the alternative that consider using the existing infrastructures (pumping the wastewater to Cañaveralejo treatment plant) do not consider the costs for treatment of the water so the O&M costs have to be increased to consider the treatment. Moreover natural systems are better also in terms of water quality because of the possibility to reuse for crop irrigation.

CONCLUSIONS

Application of natural systems for wastewater treatment in the expansion area of Cali can be satisfactorily applied. They have economical benefits compared to high-end alternatives using activated sludge systems. The effluent of natural systems can be used for irrigation of sugar cane cultures present around the expansion area. Moreover integrated agricultural-aquacultural solutions could be planned and even energy production would be possible with the implementation of high rate anaerobic ponds. Further detailed economical analyses are necessary, in particularly about reuse of effluent and recuperation of biogas. Detailed studies on sugar cane cultures water demand and geological and geotechnical analysis are necessary.

ACKNOWLEDGEMENTS

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