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Technology selection for pollution control and wastewater impact reduction in Buga, Colombia

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Abstract

The water and sanitation sector is beginning to recognise the importance of selecting sustainable wastewater management practices and technologies. This recognition is related to the limited impact of much of the investment made in pollution control from wastewater in Colombia, and in other Latin American countries. Important problems to achieve sustainable solutions include: lack of holistic vision; insufficiently working with a water basin perspective; inadequate norms and regulations; focus on "end of the pipe" solutions aimed at the construction of wastewater treatments plants, poor community involvement and institutions working in isolation.

As part of its work to contribute to resolving this situation, Cinara Institute of the Universidad del Valle, of Cali, Colombia, is developing a conceptual model for technology selection for pollution control from municipal wastewater. Initially the study has considered communities with less than 30.000 inhabitants. Now the possibility of involving cities of larger size has been stimulated with the participation of the Cinara Institute in the "Sustainable Water Management Improves Tomorrow's Cities Health" SWITCH Project. In this context and with the support of the environmental authority of the region (CVC) and local institutions, a project was carried out to choose the best technology for Buga, a town of approximately 100,000 inhabitants located in the geographical valley of the Cauca river, the second most important river in Colombia.

This case illustrates the complexity to achieve adequate institutional collaboration and community involvement in technology selection. The case shows several possibilities to find the best technology considering different scenarios, including different environmental objectives, reuse possibilities in agriculture of wastewater treated effluent and the protection of a natural wetland. This case will contribute to adapting the current conceptual model to larger cities.

Keywords: Pollution control, technology selection, sustainable solutions, treatment, municipal wastewater

1 Introduction

Buga is located in the center of the Valle del Cauca Department in Colombia, with 97262 inhabitants in 2005 (DANE, 2005), and an important industrial sector, discharges wastewater in the main hydric resources: Cauca river, Guadalajara river and El Conchal wetland. This situation has produced changes in the water quality and depreciates its ecological value.

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As part of the strategies aimed at providing a solution to this issue, the CINARA Institute at Universidad del Valle in Cali, Colombia, and water supply and sanitation institutions assembled a team that has been working on the development of a conceptual approach to the selection of technology for pollution control due to municipal wastewater. Initially the study has only considered small communities (less than 30,000 inhabitants). Now the project is involving the development of methodologies that allow considering applications for municipalities with larger numbers of people. Within this context and with the support of the regional environmental authority (CVC), in 2007, a technology selection project was started for pollution control due to wastewater in Buga, a Colombian municipality of approximately 100,000 inhabitants.

Various analyses have led to the conclusion that the proper selection of technology solutions for municipal wastewater treatment is one of the mechanisms with the highest impact on the protection of water sources. Decision making for technology is generally accompanied by methodological tools. These tools can be classified into several categories: descriptive documents, checklists, selection matrices, algorithms and methods that include computer programs. Authors such as Metcalf & Eddy (1995), von Sperling (2005) Yang & Kao (1996) and WEF & ASCE (1998) discuss descriptive and general technology selection variables, including terms as wide-ranging as environmental impact and treatment objectives. A more elaborate method, with a medium level of complexity, is decision trees, which have been used by Helmer & Hespanhol (1999), Reid (1982), UNEP (1998). Some selection models incorporate multi-criteria analysis: PROSAB, SANEX (Loetscher, 1997), WAWTTAR, and PROSEL and Guerrero (2003). These models have a higher degree of complexity and involve a larger number of factors and variables, as well as allowing for selection from a greater number of alternatives.

The experience of technology selection for the Buga City, in Colombia, it has been executed in the context of the development of the new conceptual model for technology selection. It has compiled the experiences of different authors mentioned and characterization the technological offer as well as the factors identified in the revision of selection tools. This model’s chief aims are to prioritise investment and environmental objectives, but it also considers technical, socio cultural, institutional, economic and financial aspects. This model also looks for to involve cleaner production principles applied for pollution prevention and control, considering the concepts involved in 3 steps Strategic Approach (Nhapi, 2005): 1) prevention and minimization, 2) treatment for reuse, and 3) planned discharge with stimulation of self purification capacity.

This paper about the Buga case illustrates the impact of considering multiple scenarios based on different environmental objectives. This technology selection process included a first stage in which different criteria work as filters that rule out technologies (preliminary selection) and a hierarchization of sustainable options (multiple criteria). The component of initial investment and operation costs was incorporated in the final phase

2 Study area description

Buga is located in the center of the Valle del Cauca Department in Colombia. The city sits 969 meters above sea level on the flat lands of the Cauca River valley. It is at 3°54´07” northern latitude and 76° 18´14” longitude west of the Greenwich meridian (see Figure 1). It has a warm weather and a mean temperature of 24°C, a rainfall of 1,123 mm/year, and an average relative humidity of 80%. The mean wind speed is 1.46 m/s and the average number of sunlight hours a year is 1,775. In 2005 the urban population of Buga reached 97,262 inhabitants (DANE, 2005).

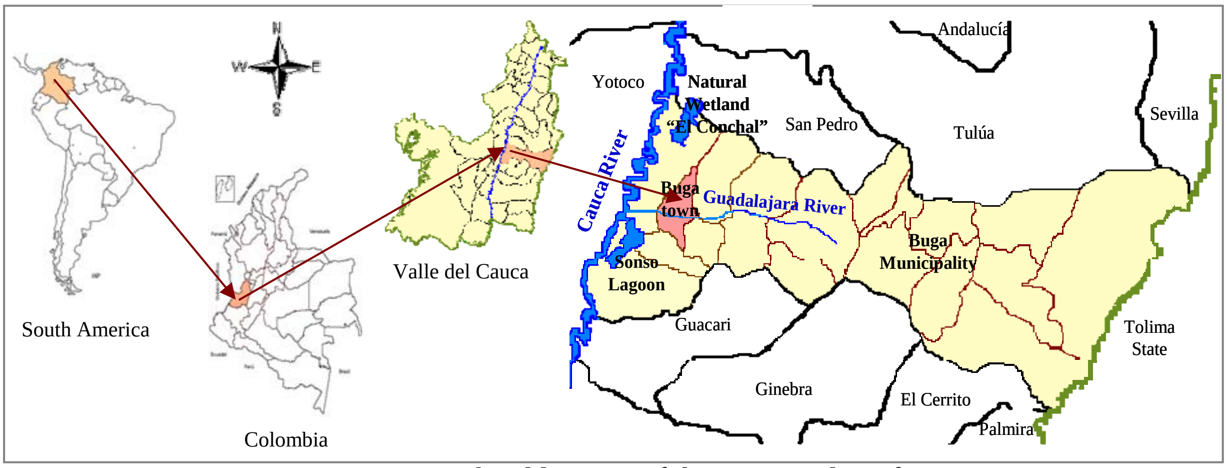

Figure 1: Geographical location of the Municipality of Buga

Water sources in the city of Buga: The Guadalajara River runs through the city from the East to the West. It is the main source of water supply to the city of Buga. Other important sources of surface water are the Cauca River, the Sonso Lagoon, and El Conchal wetlands. The wetlands have experienced changes and a decrease of water and land biodiversity (fauna and flora) and a deterioration of water quality. As a result of construction works to control floods of the Cauca River, preparation of land for farming and livestock production purposes, and wastewater discharges, it is becoming a eutrofied water system (POT, 2000 – 2012; CVC et al., 2007)

Wastewater management in the city of Buga: Buga has a combined water supply system with a 97.4% coverage rate (Aguas de Buga, 2007). It is divided into two sectors, i.e. the northern sector which accounts for 95% and the southern sector which is the area for future expansion. The wastewater discharges in Buga flow through three main collectors: Calle 4ª, San Juanito, and Tiacuante. The sewage system collects wastewater partially treated from 4 food processing companies. With regard to the total load, these discharges represent 18.6% of BOD_5 and 19.0% of TSS. The sewage system discharges flow (75%) untreated into El Conchal wetland, the Guadalajara River, and the Cauca River discharge directly. Last is the final receptor of whole wastewater produced in Buga. In the summer raw wastewater is intensively used for irrigating sugarcane crops. This practice is authorized by the environmental regulation authority (CVC).

3 Methodology

The selection process consisted of the three following stages: diagnosis, selection, and preliminary design. The diagnosis stage included activities such as collecting and compiling information, conducting meetings and workshops with the community and institutions, inspecting and taking a walkthrough of the sewage system facilities, conducting monitoring final effluents, and analyzing information.

The selection process included 2 stages. The first or "preliminary selection" stage was completed on different levels that worked as a filter to rule out technologies that did not meet the sustainability requirements for the city of Buga relate it with impact on health and the environment in a conceptual framework that involved the concepts of sustainability, general system theory and cleaner production (3 Step Strategic Approach). On each level, the following considerations were taken into account: prioritization and feasibility environmental objectives, socio cultural and technological aspects, and sludge management. The second or technology "hierarchization" stage was carried out based on a multiple criteria analysis (see Figure 2). The scores and weights of each variable in the matrix were allocated based on the experience of the work team at Cinara and the participation of national experts.

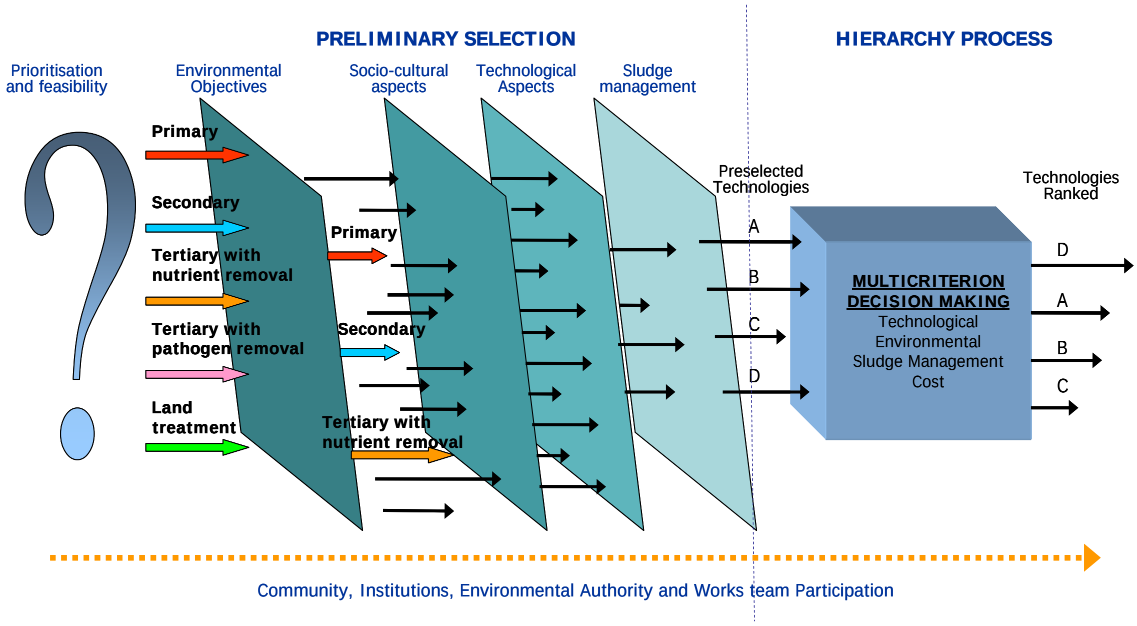

Figure 2: Technology Selection Process Flow Chart

4 Technology Selection

4.1 Preliminary Selection

Prioritization and feasibility: The agreement with the environmental authority (CVC), the Municipal Government, and the Buga water supply and sanitation company (Aguas de Buga) provided the starting points for the preliminary selection process: a) developing a project to build only one wastewater treatment plant because all the wastewater of Buga can be collected at a single location; b) the site of the wastewater treatment plant was previously selected; c) the maximum available area was 25 hectares. The above mentioned assumptions were questioned by the community and some local institutions during the execution of the project. The community believed that pollution control by wastewater was not a priority. To the current users of wastewater, implementing a wastewater treatment system would involve additional costs to continue using water for their crops. The main concern of Aguas de Buga was related with the planning for the southern expansion zone, which could eventually need another wastewater treatment system.

Environmental objectives: Taking into account the water bodies, the water uses and the local, national and international regulations and standards, three different scenarios were suggested for managing wastewater in Buga.

1) A secondary treatment level that involves removing 80% of domestic contaminant loading and discharging the treated effluent into the Cauca River (Ministerio de Salud, 1984).

2) A secondary treatment level that involves removing 80% of the domestic loading and reusing 160 L/s of treated wastewater for agricultural purposes. The national regulations do not address reuse for industrial crops. Therefore, the WHO (2006) standards will be considered (3 log of removal of pathogens or effluent with E. Coli < 10^5 CFU/100 ml).
3) A tertiary treatment level that involves removing nutrients for 45 L/s. Although national regulations forbid discharging wastewater into protected areas such as the wetlands, the work team discussed the possibility of carrying a portion of the effluent flow from the wastewater system to The Conchal wetlands in order to guarantee that there is a minimum quantity of water in the summer season.

In consideration of the above, the minimum necessary treatment level conforms to the proposal in the first scenario. Considering an 80% removal of domestic loading in terms of BOD_5 and TSS, the necessary removal efficiencies of the wastewater treatment system would be 65.1% and 64.9%, respectively. By the end of the design period (30 years) the values of the contaminant loading into the wastewater system would be 7.26 Ton/d of BOD_5 and 5.29 Ton/d of TSS, including the domestic[1] and industrial[2] loading.

Based on these requirements a review was conducted of the different technologies available to accomplish the desired treatment level. Out of 24 different technological schemes (see Table 1), the technological schemes were narrowed down to a selection of 15 based on the treatment level of condition 1 (P4, S1, S2, S3, S4, S5, S6, S7, S9, S10, S14, S18, LT1, LT2, and LT3). Technologies that do not achieve a minimum efficiency of 65% were ruled out.

Table 1: Technological schemes for primary and secondary treatment levels and removal efficiencies achieved (sources: von Sperling, 2006, and Galvis et al., 2005)

Technological Schemes		Average Removal Efficiency		
		BOD_5 (%)	TSS (%)	F. Coliforms (log units)
P1	PreT+PS	30-35	55-65	<1
P2	PreT+HRPS	30-35	55-65	<1
P3	**PreT+HRAP**	**50-70**	**50-70**	**1**
S1	PreT+PS+RB +S2	88-95	87-93	1-2
S2	PreT+PS+TF+S2	85-93	87-83	1-2
S3	PreT+FAP+SP	75-85	70-80	1-2
S4	PreT+ASTO+ S2	90-97	87-93	1-2
S5	PreT+PS+AS+S2	85-93	87-93	1-2
S6	PreT+SBR (2 units)	90-97	87-93	1-2
S7	PreT+UASB	60-75	65-80	1-2
S8	PreT+UASB+TF+S2	80-93	87-93	1-2
S9	PreT+HRPS+FWS	80-90	87-93	3-4
S10	PreT+HRPS+FP	75-85	70-80	1-2
S11	PreT+UASB+FP	75-85	70-80	1-2
S12	PreT+UASB+AS	83-93	87-93	1-2
S13	PreT+UASB+FAP	75-85	70-80	1-2
S14	PreT+HRPS+SF	80-90	87-93	3-4
S15	**PreT+HRAP+SF**	**80-90**	**87-93**	**3-4**
S16	PreT+HRAP+FWS	80-90	87-93	3-4
S17	**PreT+HRAP+FP**	**75-85**	**70-80**	**1-2**
S18	PreT+FP (2 series)	75-85	70-80	1-2
LT1	PreT+SP+RI	85-98	>93	4-5
LT2	PreT+SP+SR	90-99	>93	3-5
LT3	PreT+SP+OF	80-90	80-93	2-3

Notes: PreT=Preliminary treatment (thickness screen + Fine screen + grit removal) P=Primary Treatment S=Secondary treatment, LT=Land treatment; SM=Sludge Management; PS=Conventional Primary Sedimentation; HRPS= High Rate Primary Sedimentation; S2=Secondary Sedimentation, HRAP=High Rate Anaerobic Ponds; FP=Facultative Pond; SP=Sedimentation Pond; FWS=Free water Surface Wetland; SF=Subsurface Flow Wetland ; SR=Slow Rate Systems; RI=Rapid Infiltration; OF=Overland Flow Systems; AS=Conventional Activated Sludge; ASTO= Activated sludge with total oxidation; SBR=Sequencing Batch Activated Sludge Reactor; FAP= Facultative Aerated Pond; RB=Rotating Biological Contactor; TF= Trickling Filter; UASB=Upflow Anaerobic Sludge Blanket Reactor

[1] The domestic loading is 5.91Ton/d of BOD_5 and 4.29 Ton/d of TSS. These values were estimated base on a per capita production of 84g of COD/inhabitant/d, 45g of BO D_5/inhabitant/d, and 32 g of TSS/inhabitant/d (information collected from monitoring final discharges in July 2007). Based on the geometric method, the population in 2007 and at the end of the design period (30 years) is 102,114 and 132,006 inhabitants, respectively.

[2] The industrial loading is assumed to be constant in time with values of 1.35 Ton/d of BOD_5 and 1.00 Ton/d of TSS, where the load discharged into the sewage system equals 20% of the total load produced.

Socio cultural Aspects: In Buga there are technical human resources available to manage and operate the necessary technology. There are also adequate resources to supply materials that ensure operation of the wastewater system.

Technological Aspects: This level entailed an assessment of variables such as the amount of wastewater, the size of each technological schemes in terms of the flow rate to be treated (361 L/s at the end of the design period) and the land requirements, including the characteristics of the soil on the premises of the wastewater treatment facility (high water table and high permeability), and power consumption. Having conducted this assessment, 4 technology options were selected: P3, S2, S7 and S10.

Sludge Management: drying beds was considered for anaerobic technologies such as the UASB (S7) and the High Rate Anaerobic Ponds (P3). Technological schemes that include aerobic process: S2 (Trickling Filter) and S10 (primary sedimentation), provided for the use of anaerobic biodigestors before to the drying beds.

4.2 Hierarchization

The multiple criteria analysis included technological aspects necessary area for implementing the technology, complexity of O&M, and flexibility for building on a modular basis); environmental issues (odor generation, location of the site vs. predominant wind direction); sludge management (type of sludge and necessary treatment processes); and investment costs. Investment costs were estimated based on information about similar projects recently executed in the region of the area of study (Cinara -Univalle, 2000; Cinara-Univalle, 2006). The results of the hierarchization of the selected technology options for the three different scenarios are shown in Tables 2, 3 and 4.

Table 2: Results of the hierarchization of the selected technology options

Technological Schemes		Flow (L/s)	BOD_5 (mg/L)		Faecal Coliforms CFU/100ml		Receiving Body	Costs (million US$)	
			influent	effluent	influent	effluent		Initial cost investment	NPV[a]
Technologies considering 80% removal of domestic load (area: 9.6 ha)									
P3	PreT+HRAP+DB	357	330	105	$1.00E^{+07}$	$9.59E^{+05}$	Cauca River	3.37	5.60
Technologies considering 80% removal of domestic load and reuse for agricultural purposes (area: 19.4 ha)									
P3	PreT+HRAP+DB	190	330	105	$1.00E^{+07}$	$9.59E^{+05}$	Cauca River	4.68	7.05
S17	PreT+HRAP+FP+DB	167	105	65	$9.59E^{+05}$	$4.32E^{+04}$	Soil (Crops)		
Technologies considering 80% removal of domestic loading, reuse for agricultural purposes, and recharge of El Conchal wetlands (area: 25 ha)									
P3	PreT+HRAP+DB	145	330	105	$1.00E^{+07}$	$9.59E^{+05}$	Cauca River	7.44	10.88
S17	PreT+HRAP+FP+DB	167	105	65	$9.59E^{+05}$	$4.32E^{+04}$	Soil (Crops)		
S15	PreT+HRAP+SF+DB	45	105	-	-	-	Natural Wetland		

Notes: PreT=Preliminary treatment (thickness screen + Fine screen + grit removal) P=Primary Treatment S=Secondary treatment, HRAP=High Rate Anaerobic Ponds; FP=Facultative Pond; SF=Subsurface Flow Wetland; DB=Sludge Drying Beds
[a] NPV= Net Present Value; estimated using an average discount rate of 13.63% and a 30-year design period

The scores ranged from 1 to 5, whereas: 5 represent a criterion that provides the highest competitive advantages in favor of the technology; 1 represents the criterion where technology does not meet the requirements; and 2, 3 and 4 are intermediate scores. In order of relevance the following weights were assigned to each criterion: NPV costs (0.25), construction-related issues (0.25), odor generation (0.20), sludge management (0.15), complexity of O&M (0.10), and area required (0.05).

5 Conclusions

The limits of the current regulations with regard to preventing contamination, reusing wastewater, encouraging the search for alternatives for "end-of-the-pipe" solutions, and implementing cleaner production policies provide constraints on the selection of different scenarios and technologies. Unlike small communities, the selection of technology in cities like Buga (with more than 100,000 inhabitants), the local capacity to operate and maintain a certain kind of technology becomes less relevant. Having clearly defined scenarios, it is then necessary to analyze the efficiency of each technology for addressing the liquid phase as well as for managing sludge, environmental issues, and initial investment and operation costs. The selection of technology for Buga included an initial phase to rule out technologies (preliminary selection) and hierarchize sustainable treatment options (multiple criteria), and a final phase, in which the cost component was incorporated.

The selection of technology to pollution prevention and control due to municipal wastewater needs to consider treatment objectives to be a priority, thereby taking into account the hydrographic basin as a unit of analysis. It also needs to involve the community and the local institutions in the process of designing different scenarios to be considered. Formulation these scenarios is going to be influenced by aspects such as the current regulations, drainage network configuration, available area for treatment, possibility of reusing treated effluent, and the uncertainty about the estimated behavior of wastewater discharges.

Taking into account the low coverage ratios of pollution control due to municipal wastewater and the diversity of geographical regions which is typical of many Latin American countries, there is not reliable information available about cost models that can be used for supporting decisions in a technology selection process. In this case it was necessary to use the experience from similar projects in the same geographical region.

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